From Genes to Growth and Form

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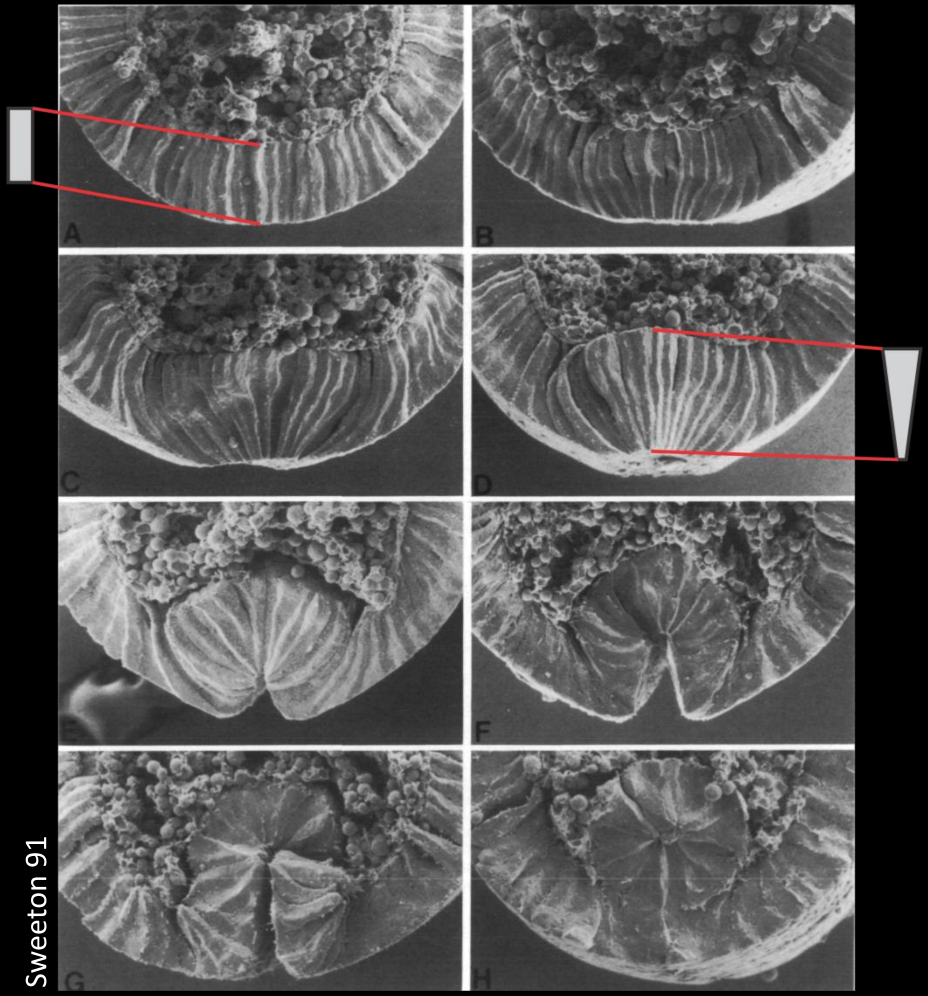
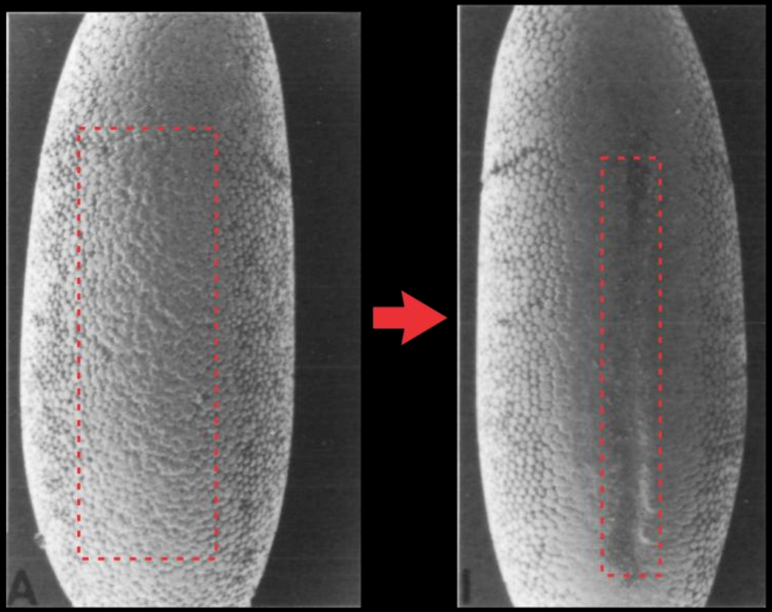
KITP, August 2016

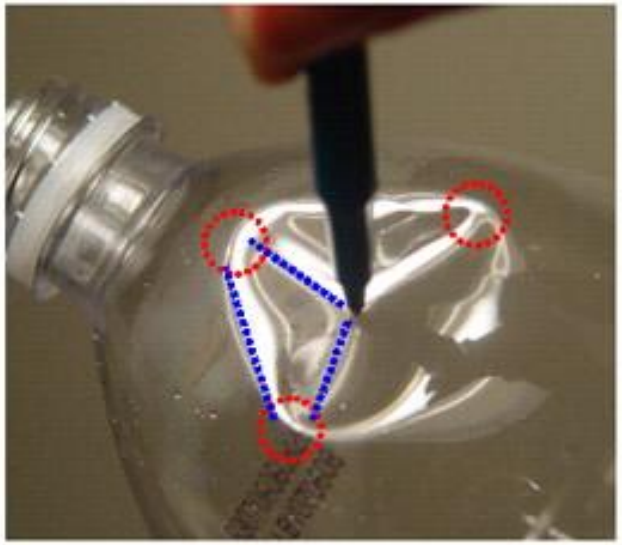
Gastrulation (Ventral Furrow)

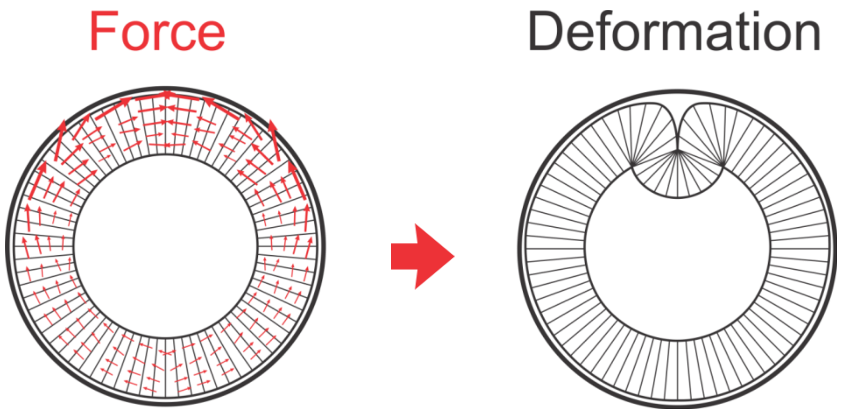


Sweeton 91

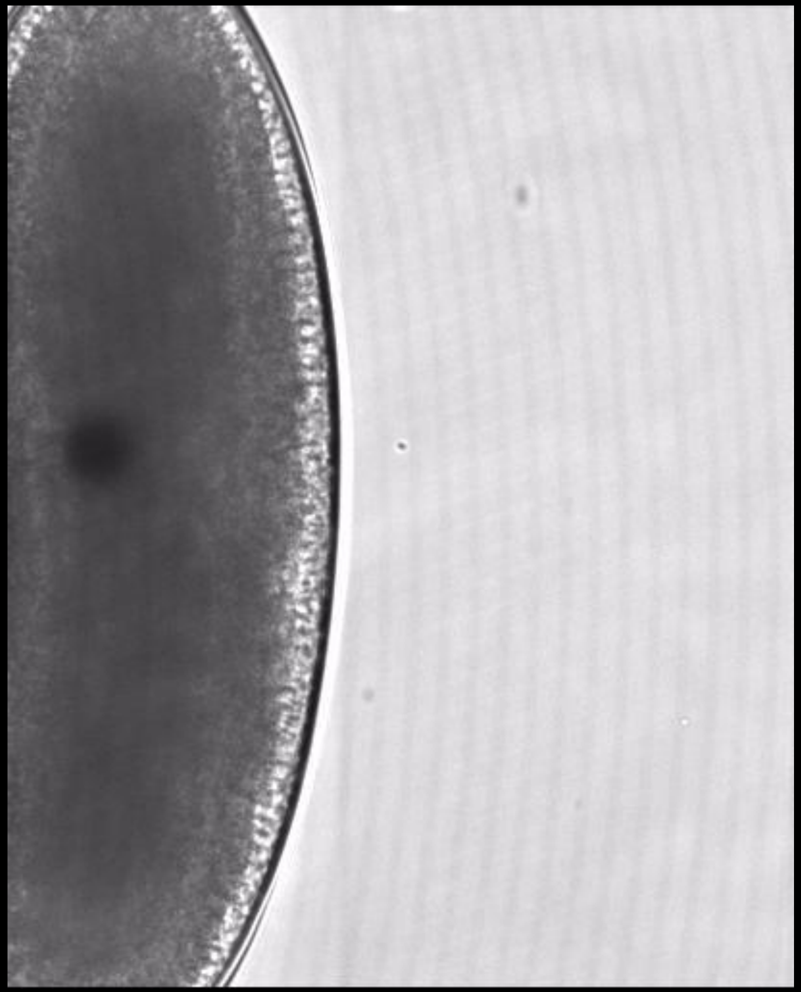


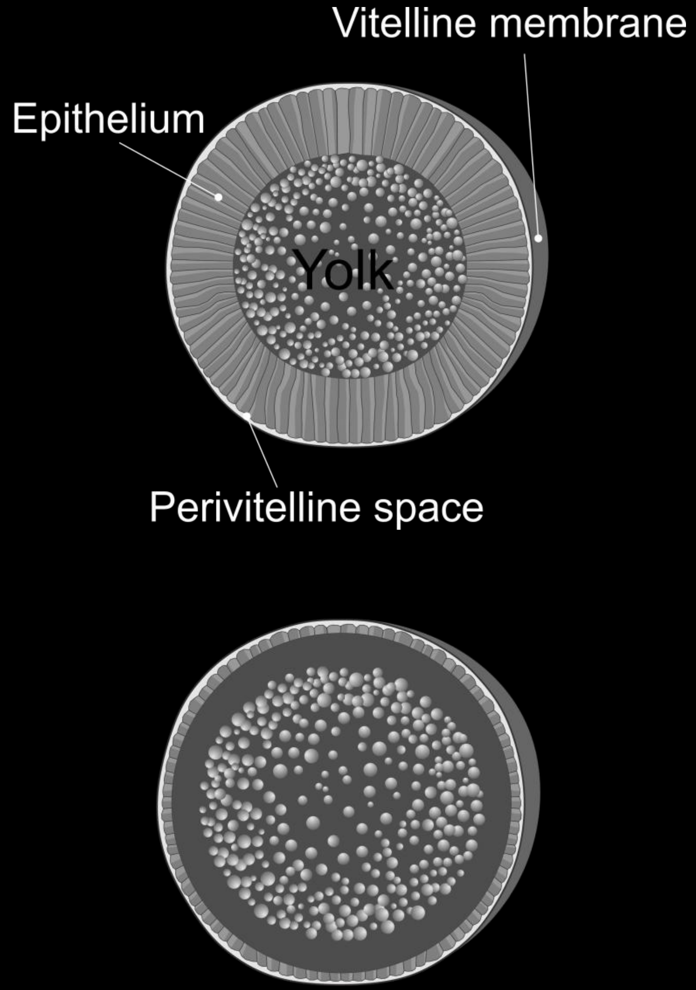
Dynamics = passive response + active forcing



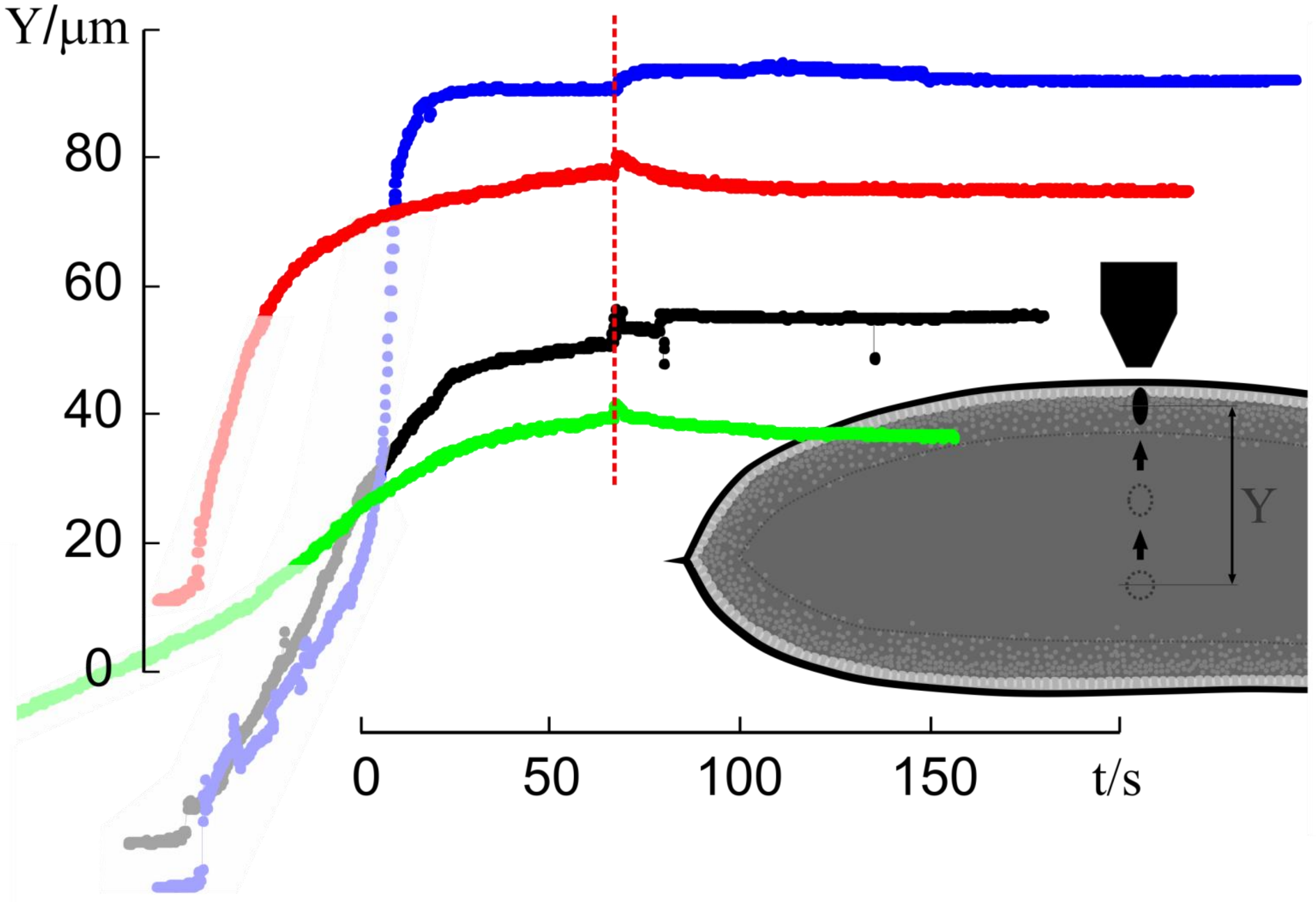


Ferrofluids: measuring tissue properties

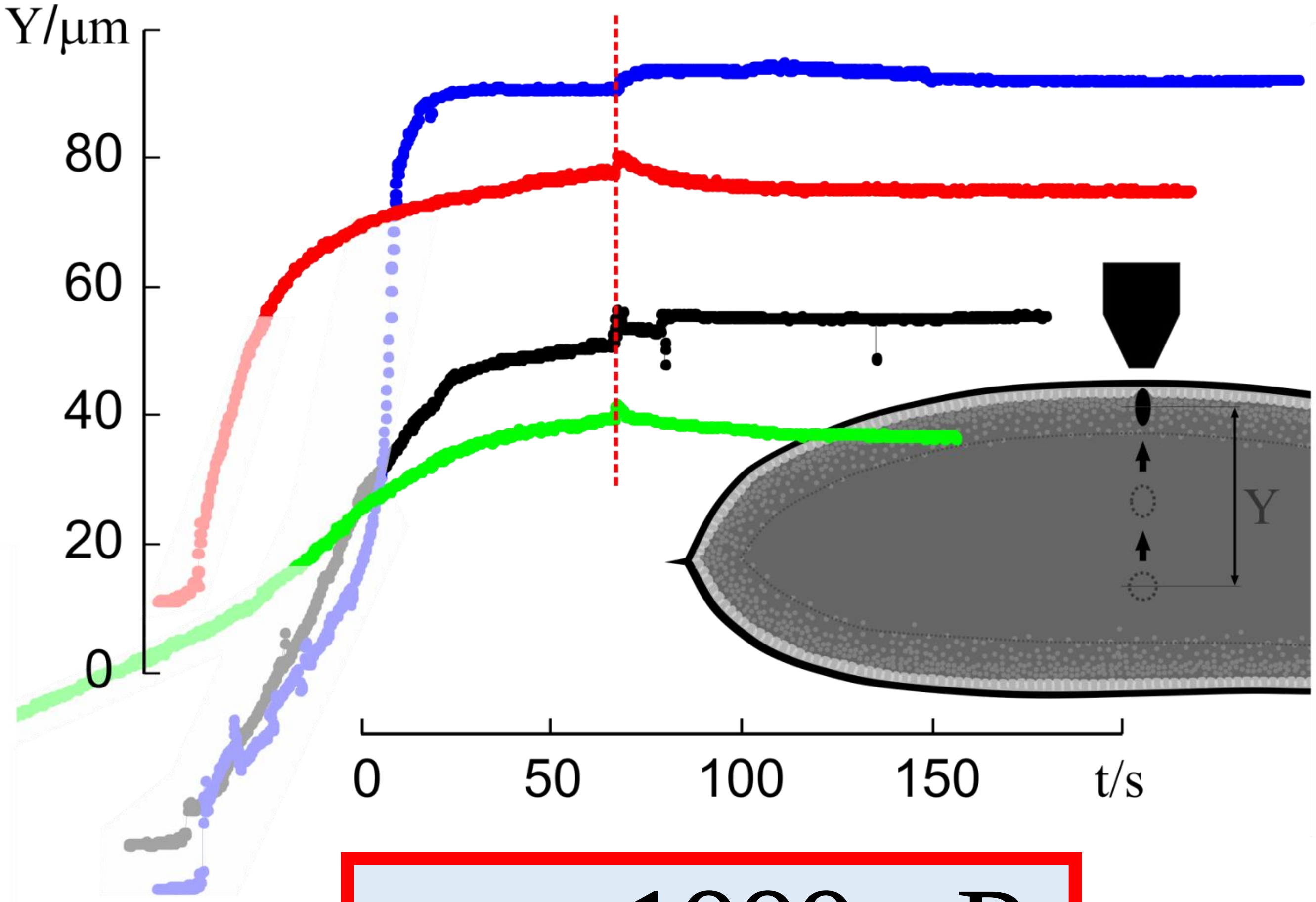




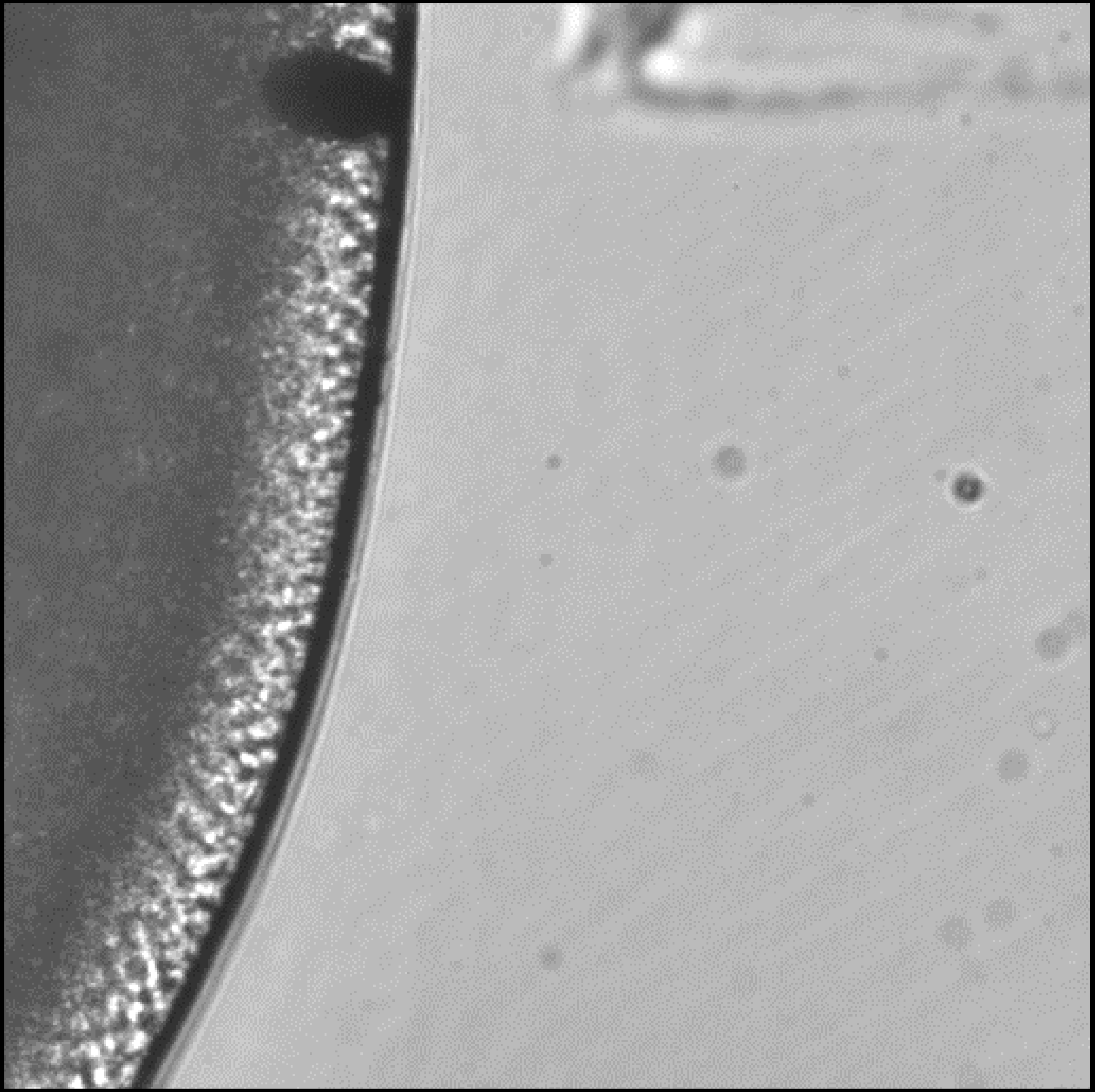
Viscous interior

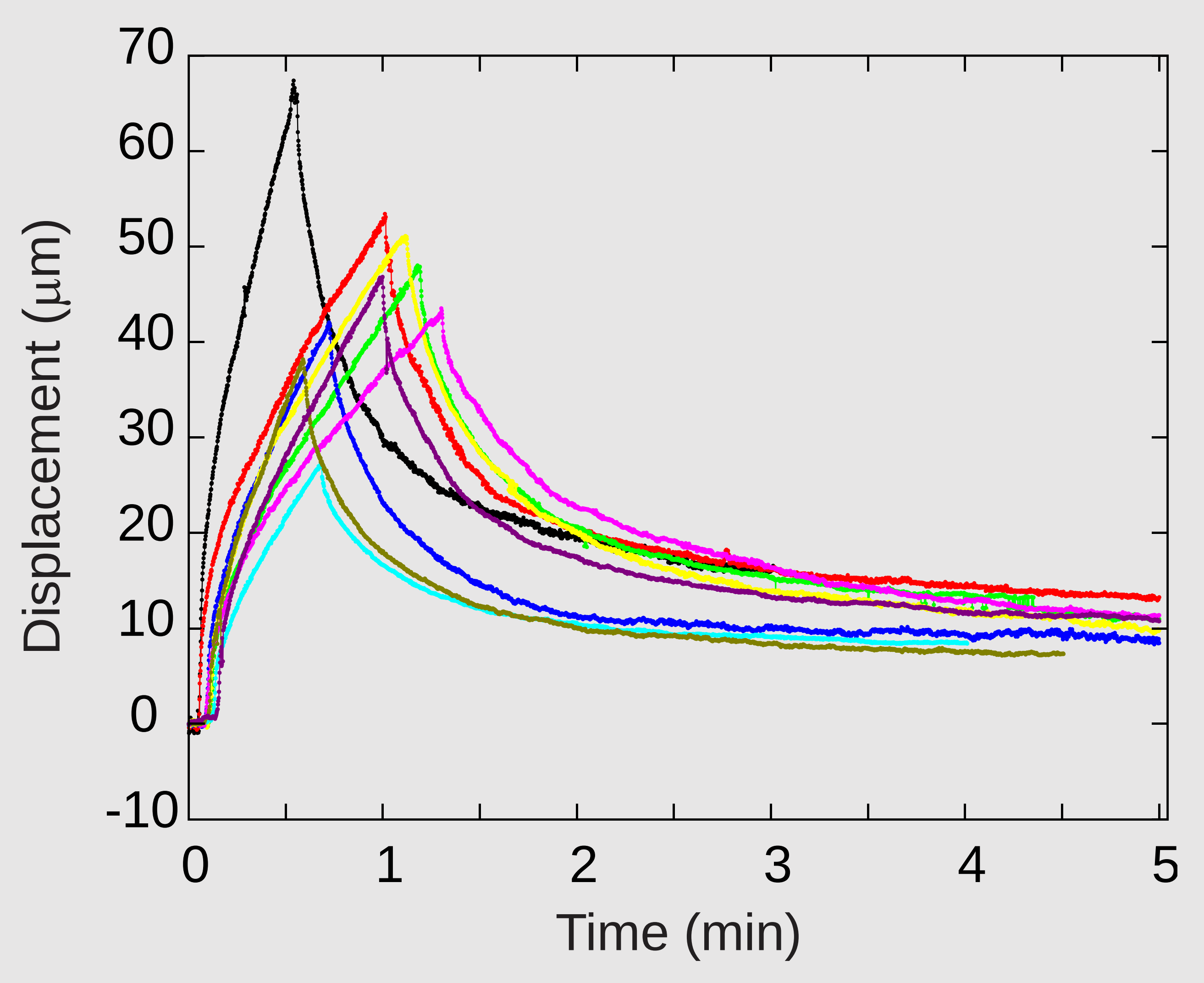


Viscous interior

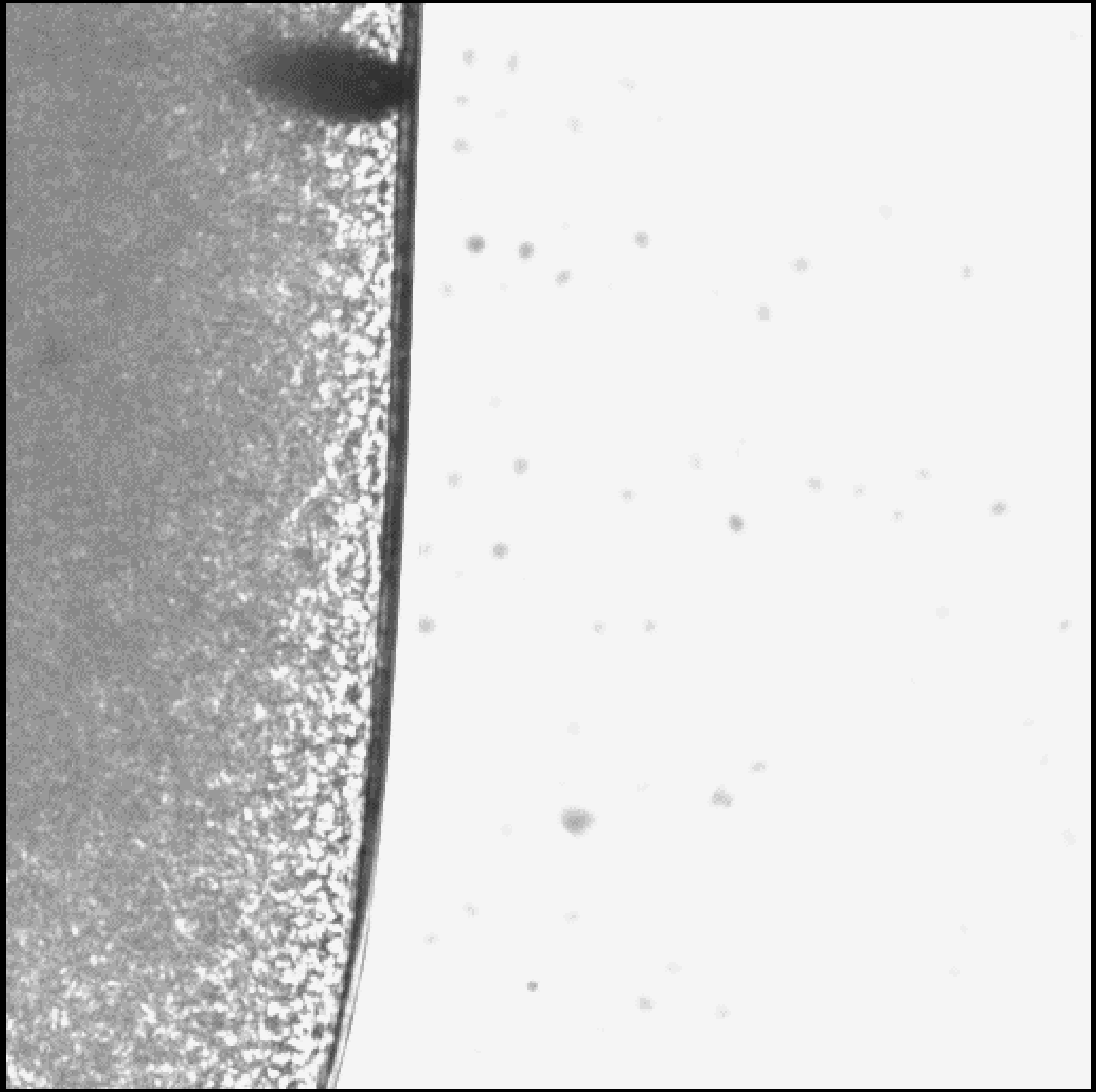


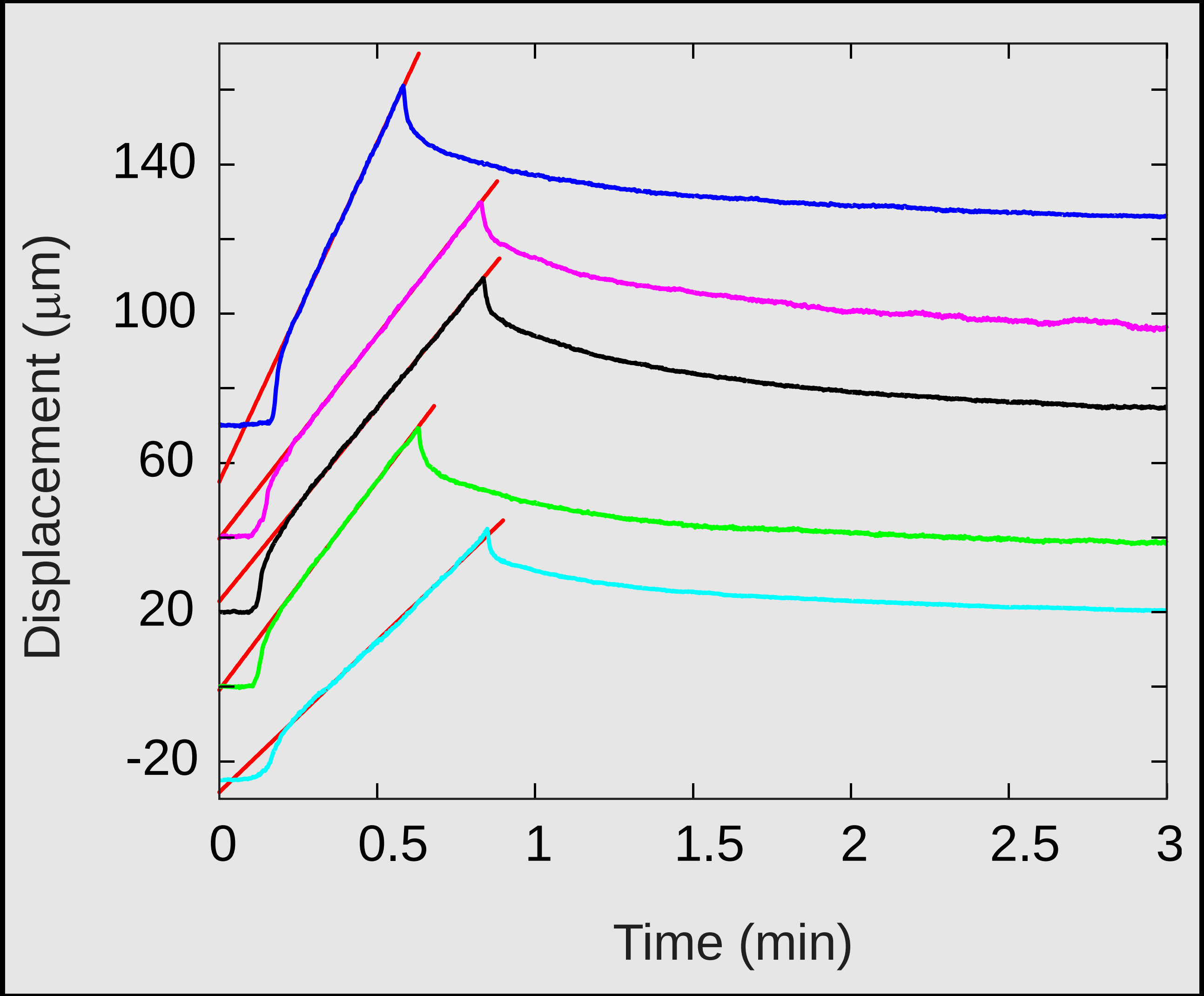
$$\eta = 1000 \text{ cP}$$

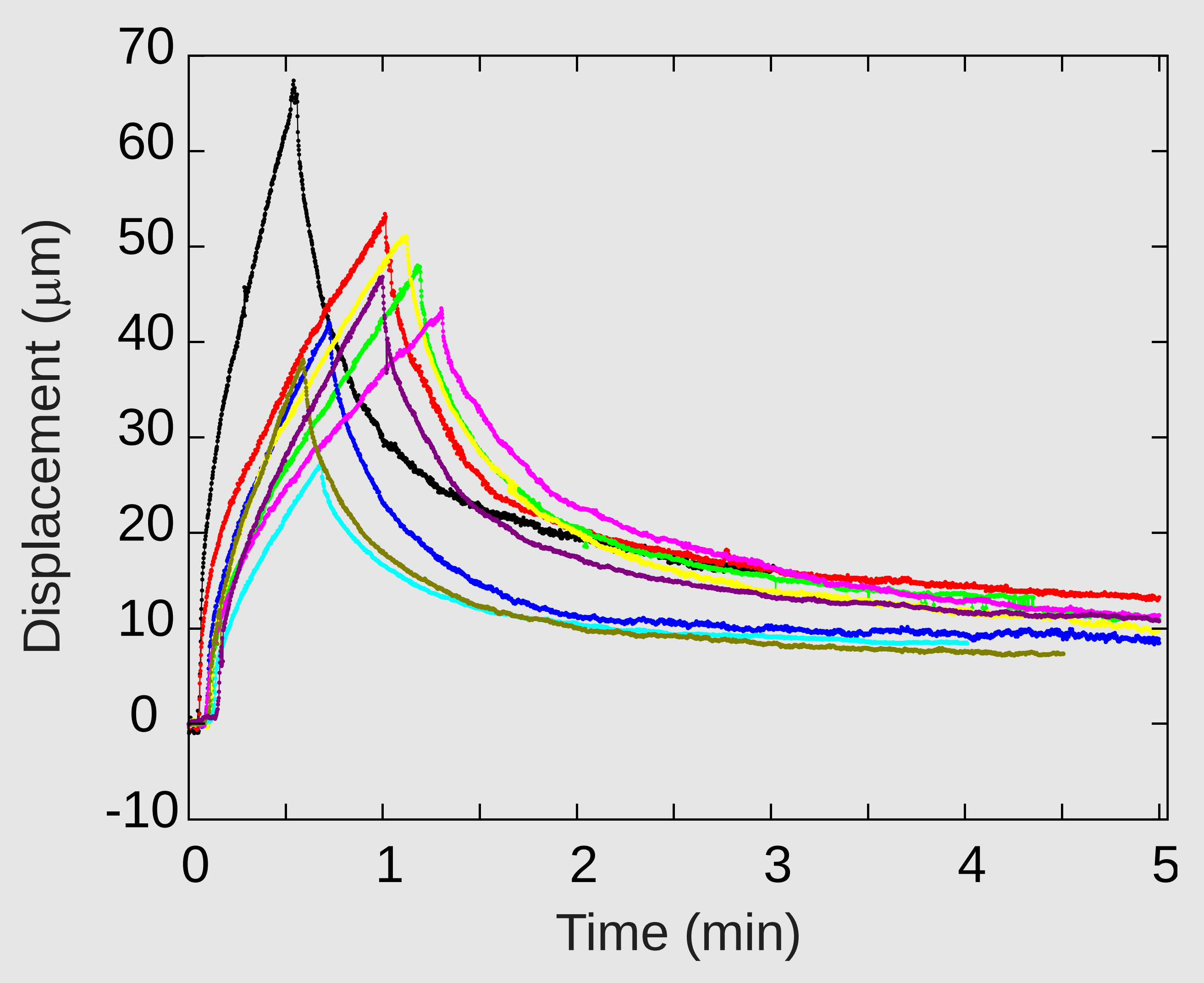



Displacement (μm)
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
Time (min)

Control: constant force

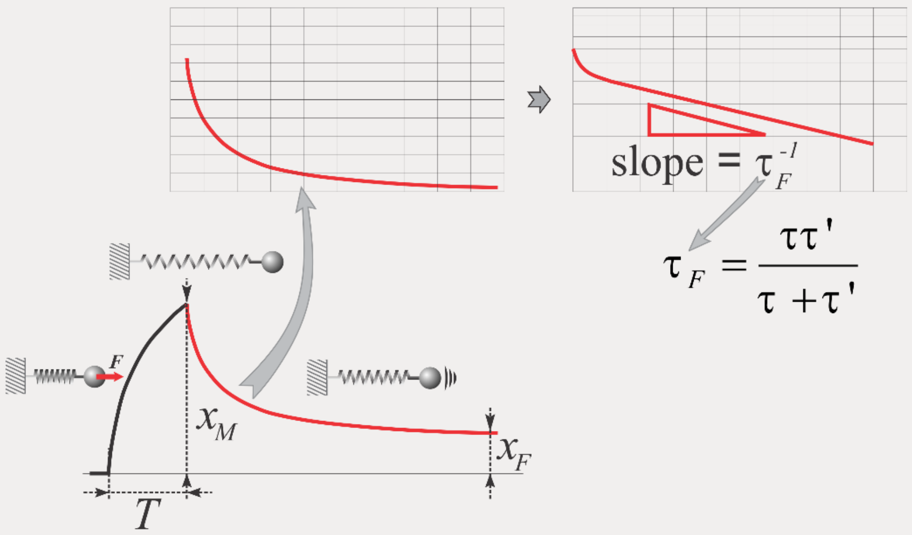






70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
Displacement (μm)
Time (min)

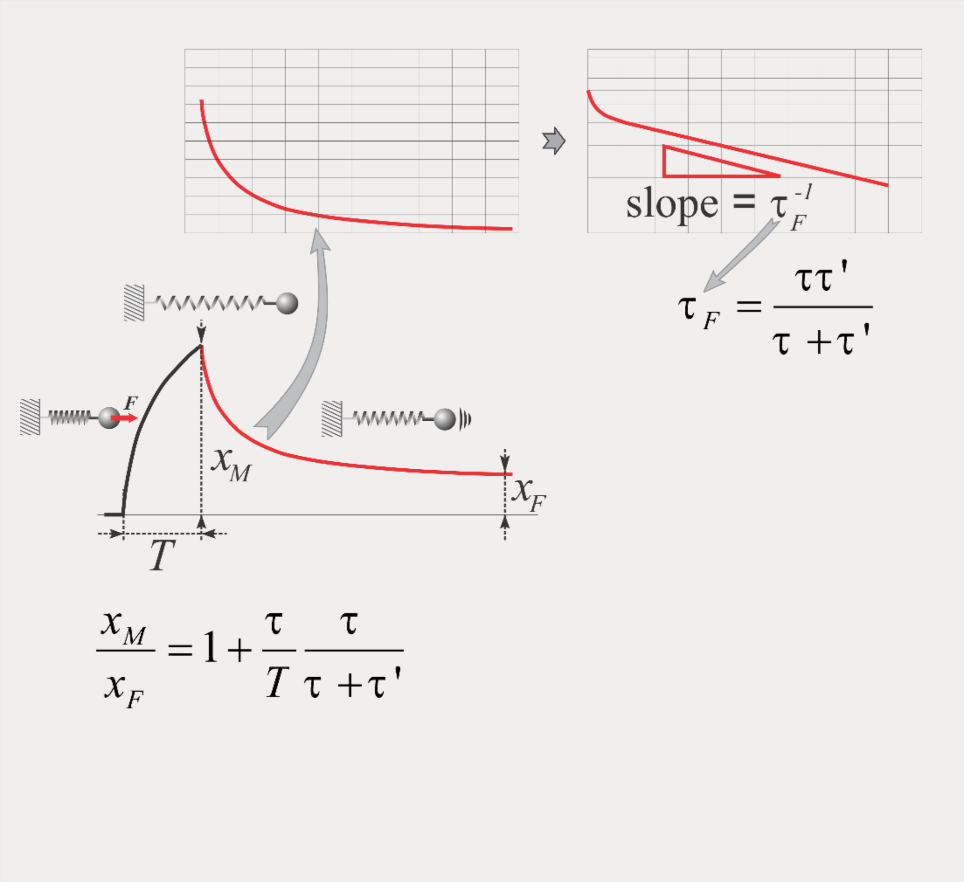
Recoil curves: analysis



$$\tau_F = \frac{\tau\tau'}{\tau+\tau'}$$

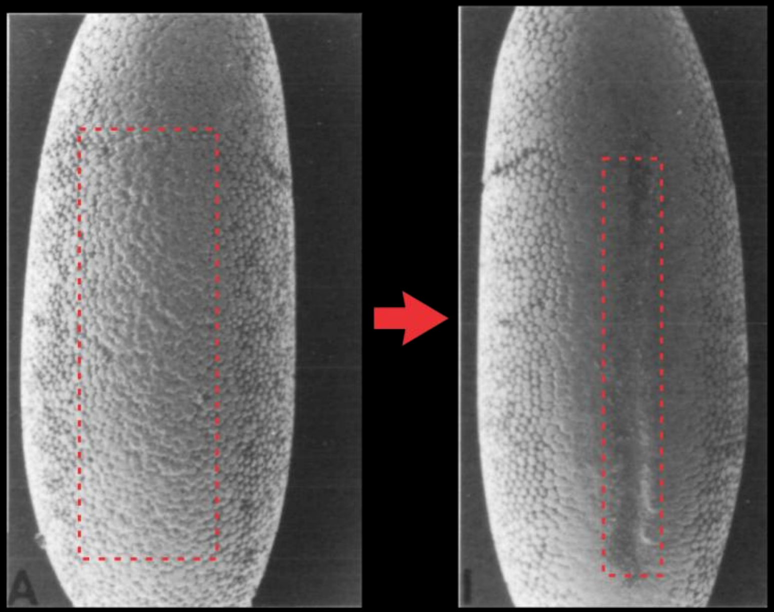
$$\frac{x_M}{x_F} = 1 + \frac{\tau}{T}\frac{\tau}{\tau+\tau'}$$

Recoil curves: analysis



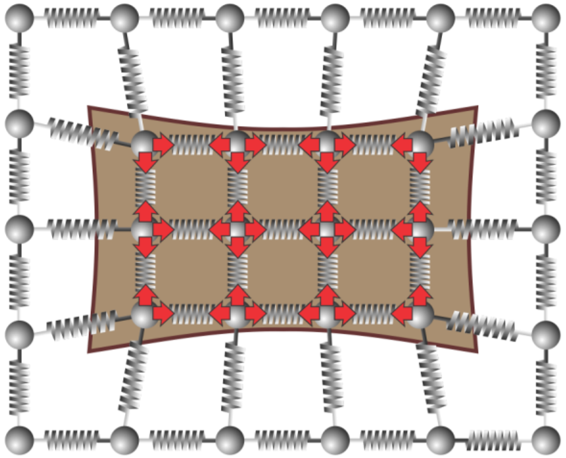
τ = 3.7 min

Gastrulation (Ventral Furrow)



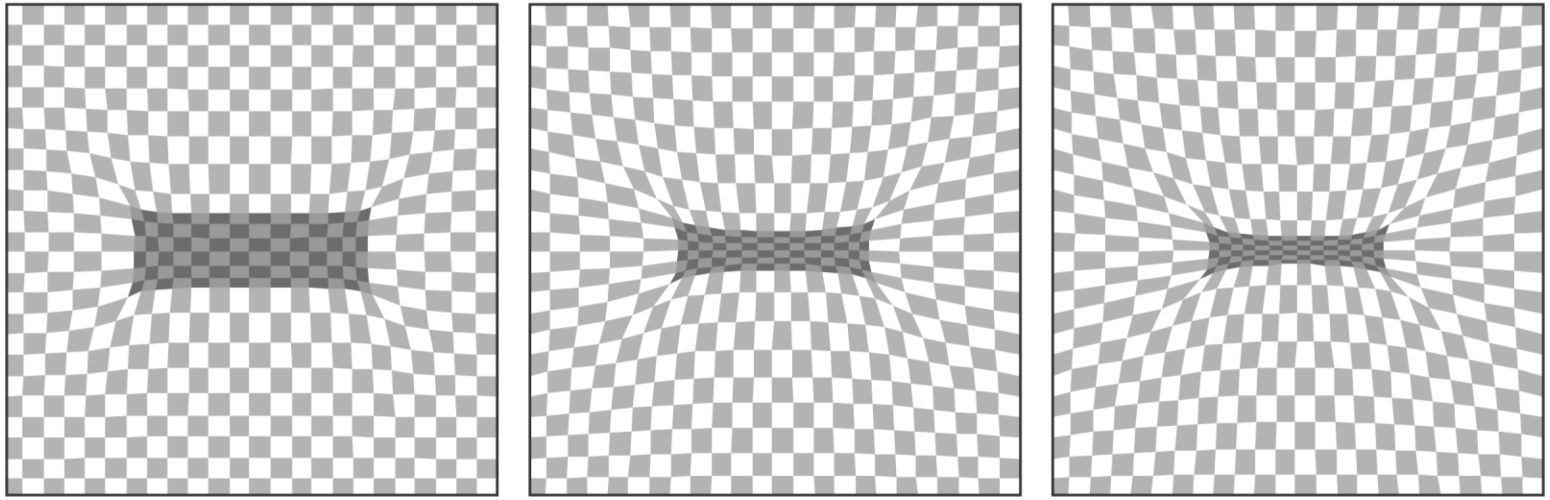
Sweeton 91

Implications for the dynamics



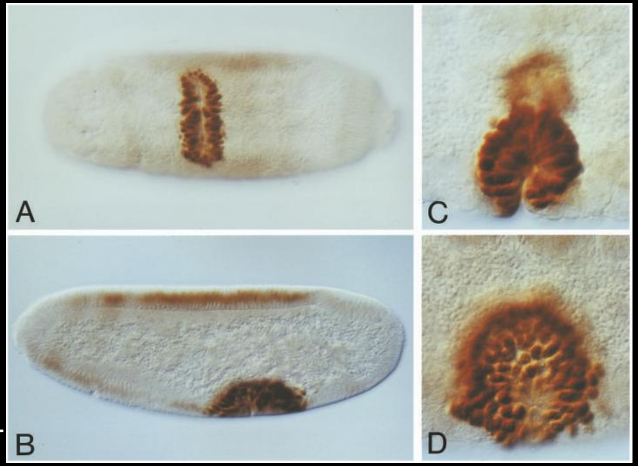
$$\eta\,\partial_t \mathbf{u} = \frac{E}{2(1+\sigma)}\nabla^2\mathbf{u} + \frac{E}{2(1+\sigma)(1-2\sigma)}\nabla\nabla\cdot\mathbf{u} + \nabla\cdot\mu$$

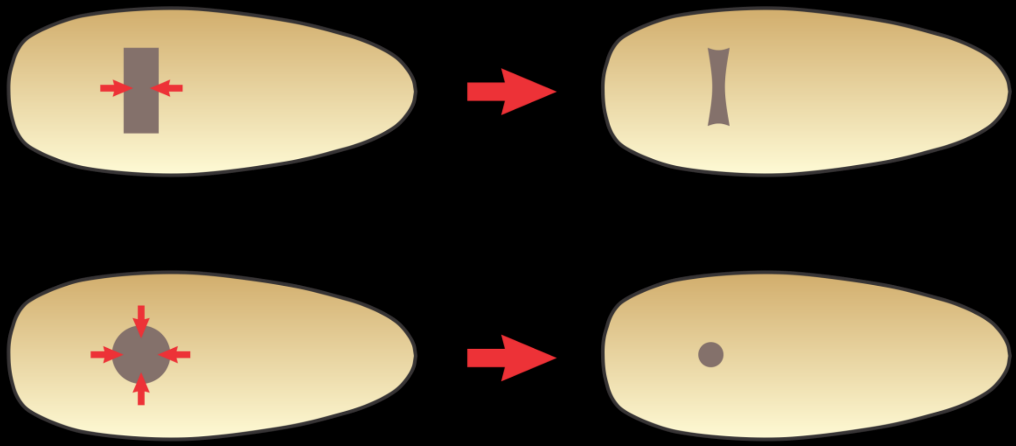
$$\mu = \mathbf{I}\mu_0$$



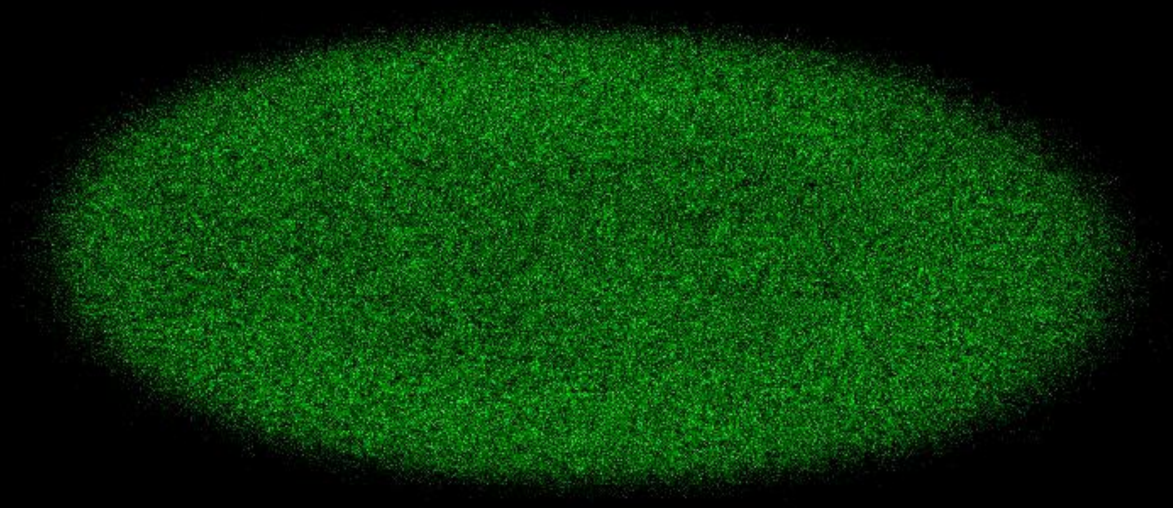
Implications for the dynamics

Leptin and Roth 94



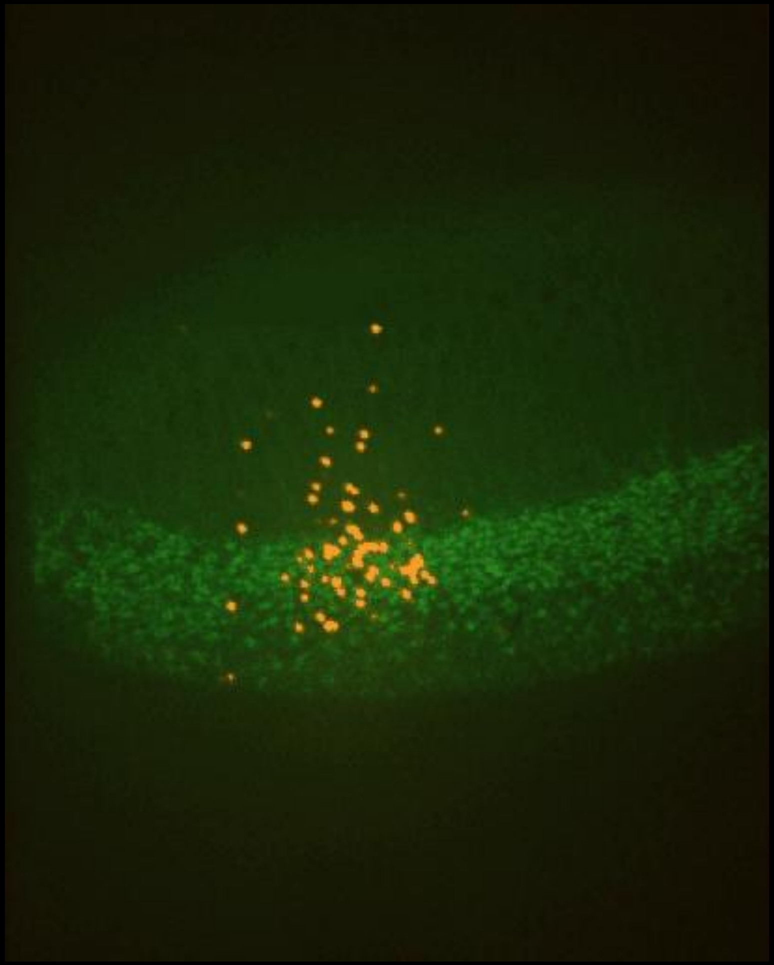


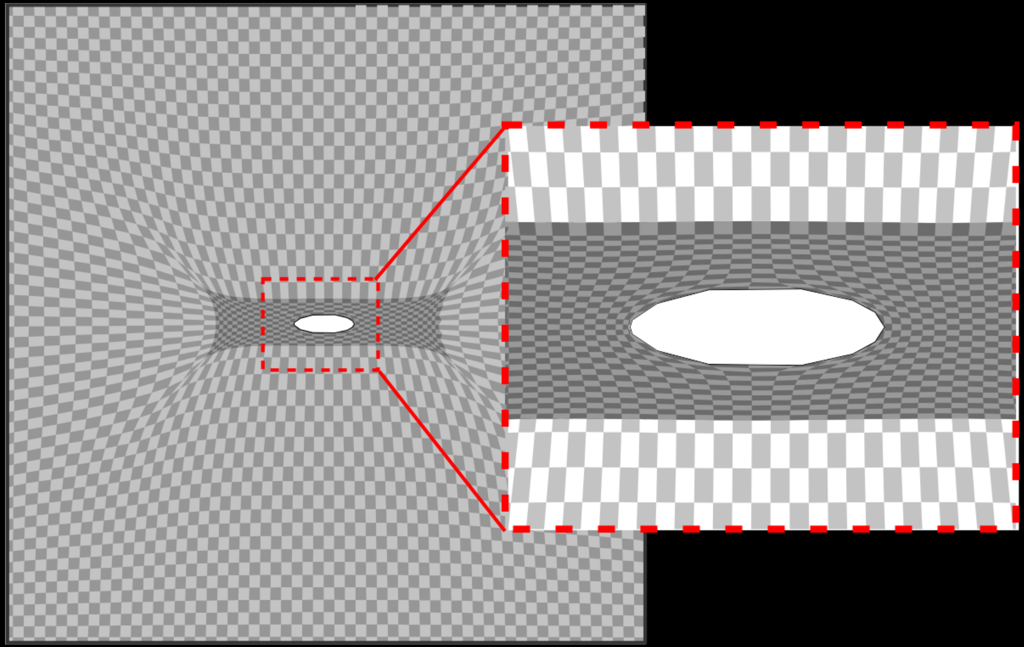
Implications for the dynamics



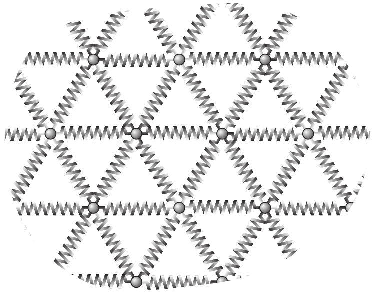
Courtesy: Michael Swan

Implications for the dynamics

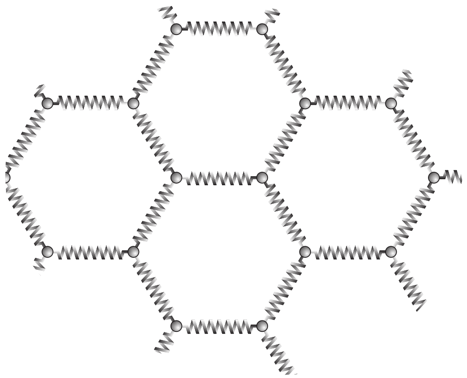




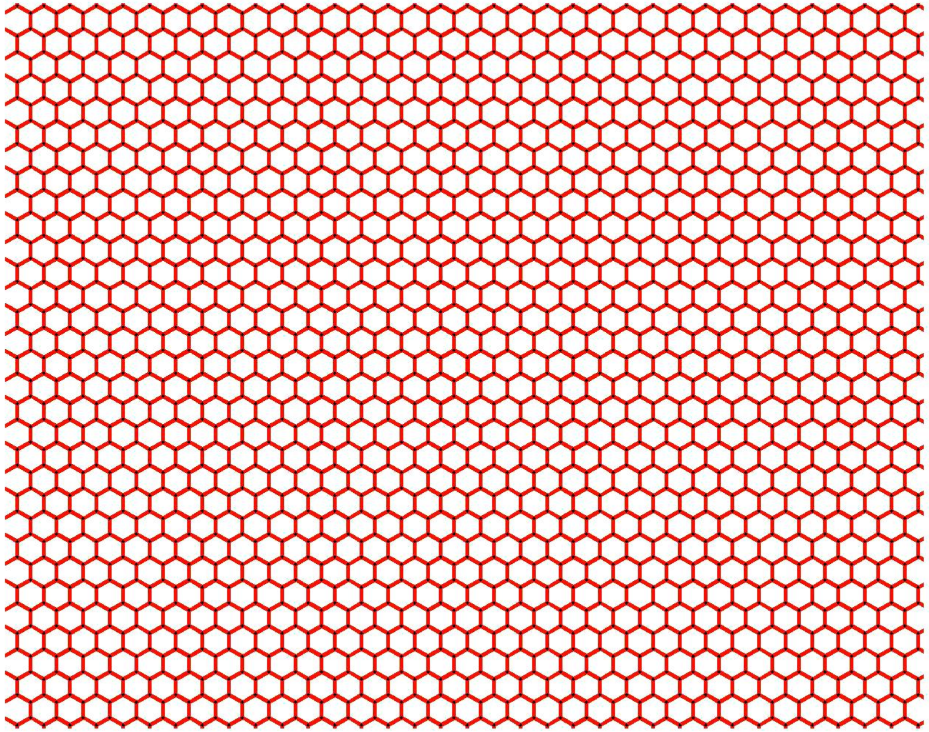
Stiff versus floppy



Stiff



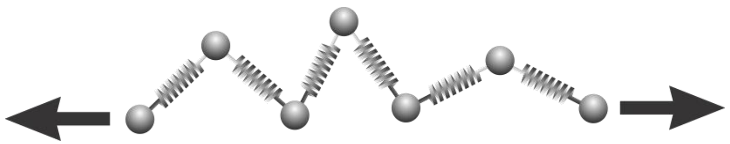
Floppy



How to test if network is floppy?

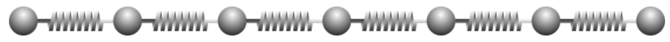
Pull twice.

Pull once: weak recoil

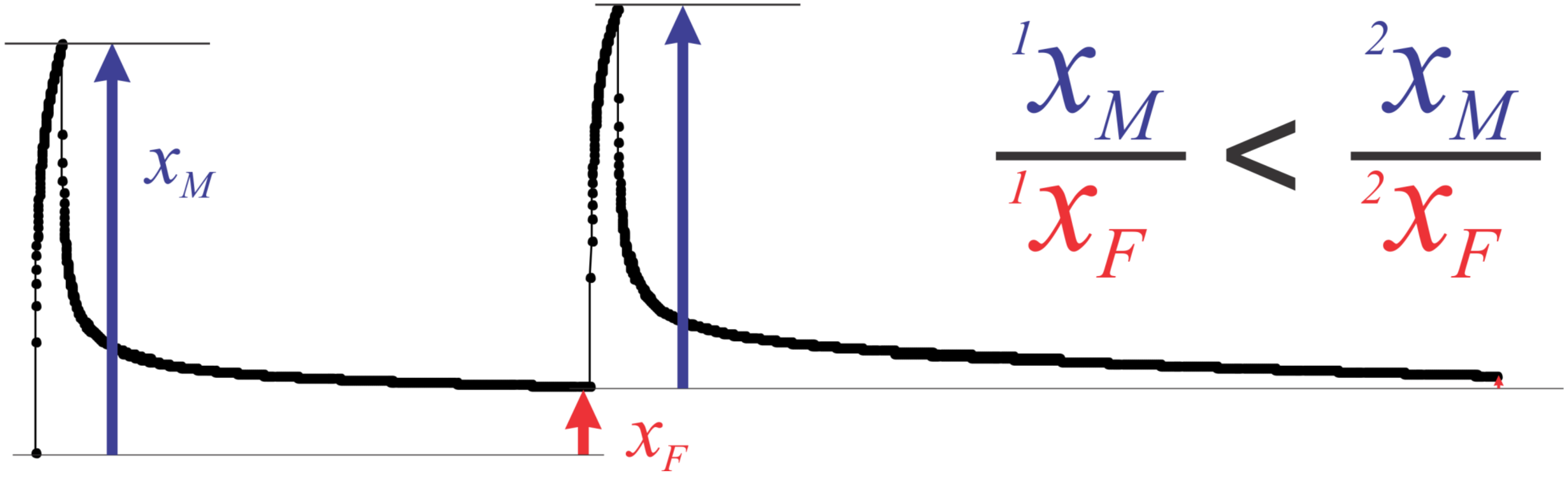


Floppy

Pull again: stronger recoil



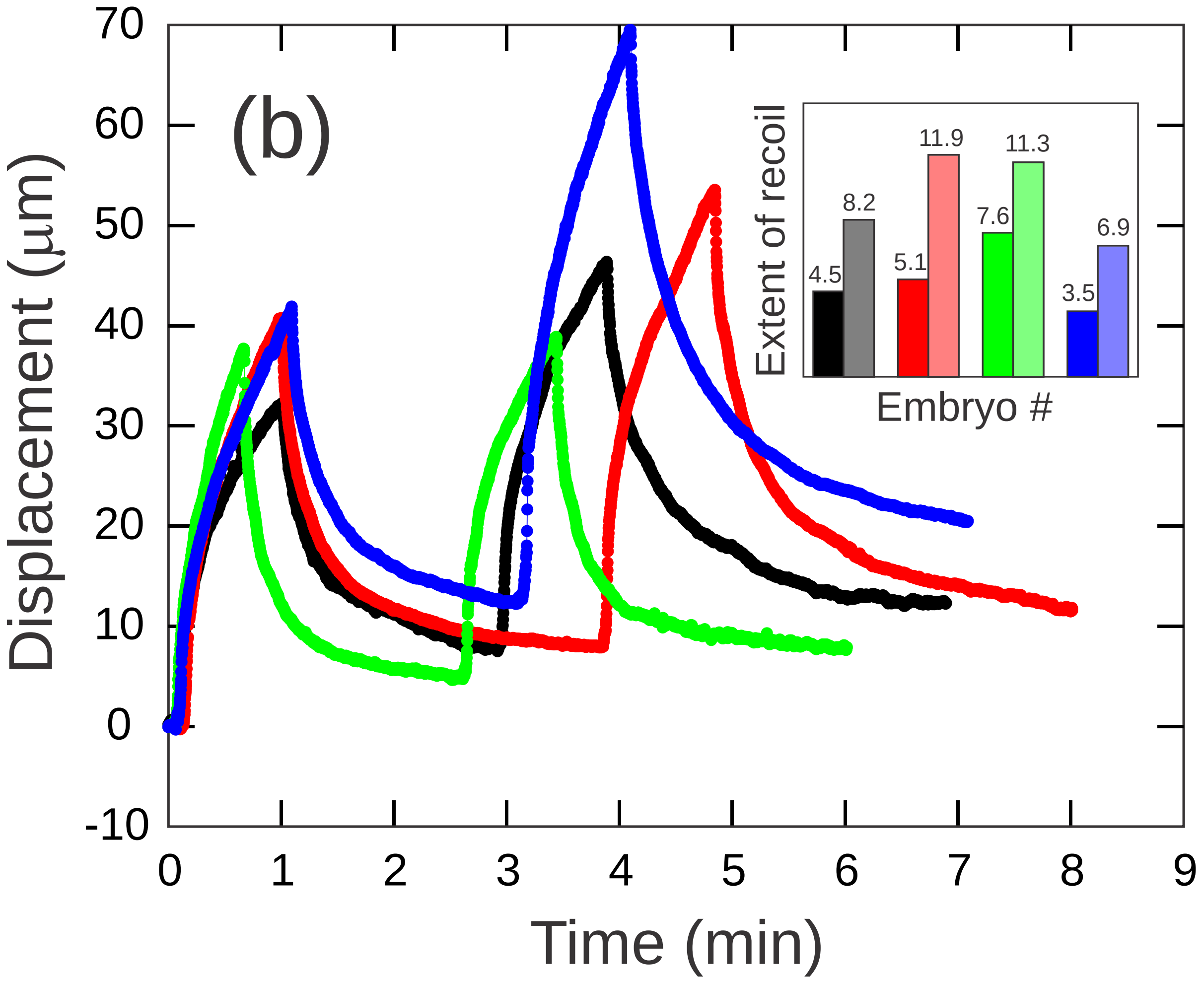
Not floppy



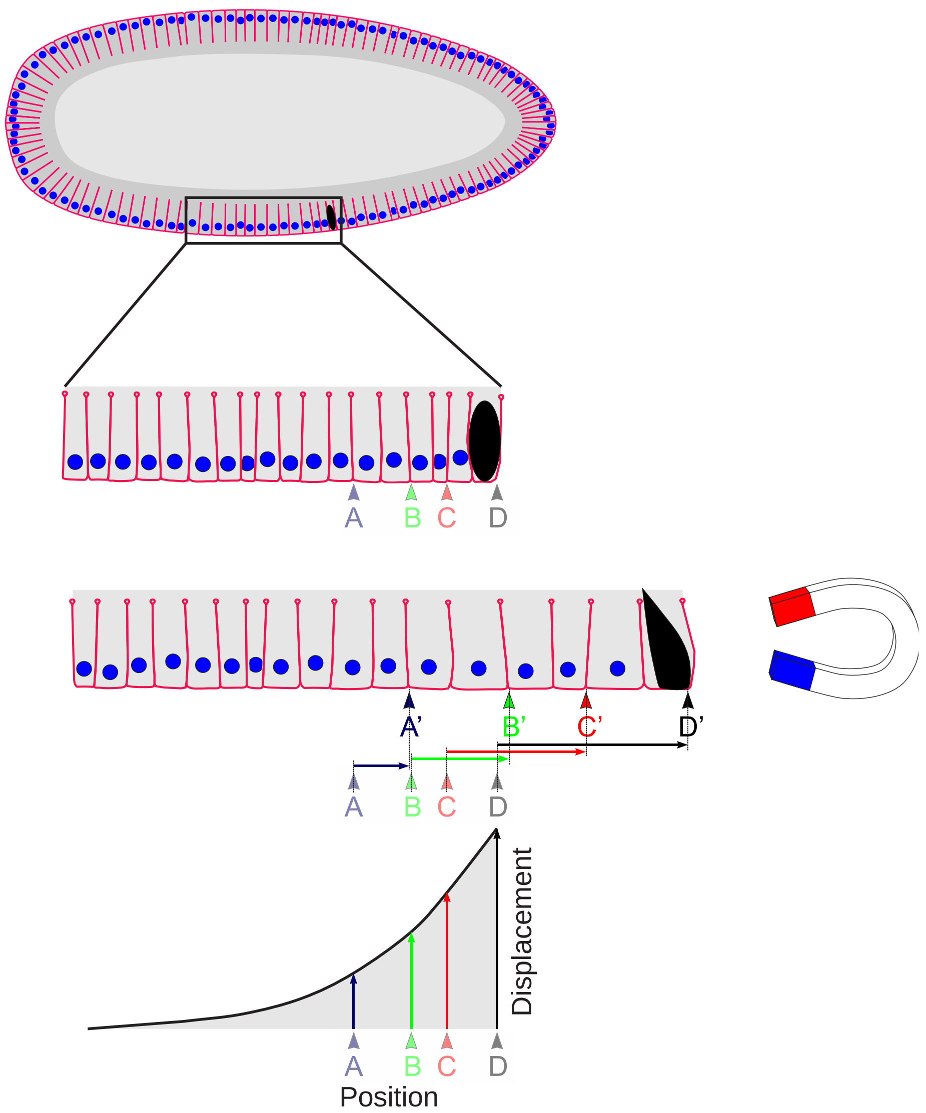
$$\frac{{}^{1}x_M}{{}^{1}x_F} < \frac{{}^{2}x_M}{{}^{2}x_F}$$

Proof of principle simulation

Fly epithelium as a floppy network



Geometry of the experiment



Linear elasticity: quantitative analysis

$$\eta \, \partial_t \mathbf{u} = \frac{E}{2(1+\sigma)} \nabla^2 \mathbf{u} + \frac{E}{2(1+\sigma)(1-2\sigma)} \nabla \nabla \cdot \mathbf{u} + \mathbf{f}$$

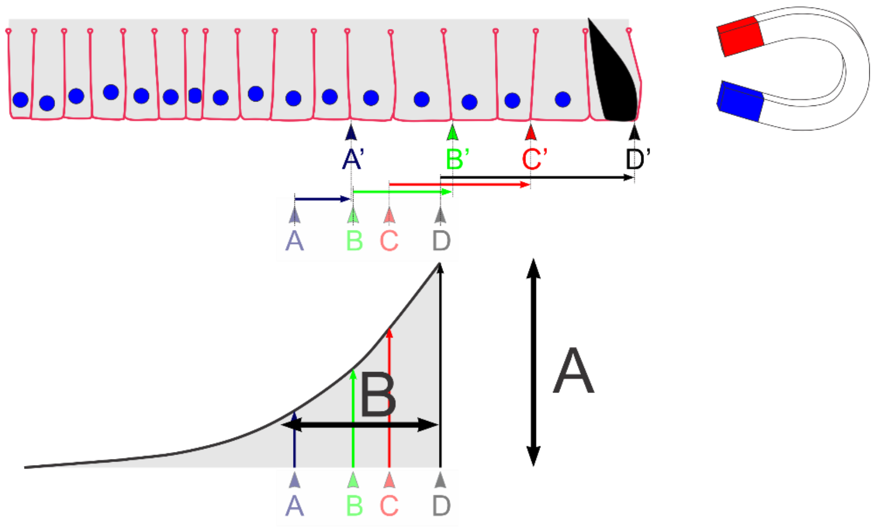
$$u_x(\mathbf{r}=0) = \frac{A(1+\sigma)}{4\pi E} \log\left[1 + \frac{8E\pi^2}{(1+\sigma)\eta\xi^2} t\right]$$

$$\sigma_u \sim \sqrt{t}$$

Linear elasticity: scaling analysis

$$\eta \partial_t \mathbf{u} = \frac{E}{2(1+\sigma)} \nabla^2 \mathbf{u} + \frac{E}{2(1+\sigma)(1-2\sigma)} \nabla \nabla \cdot \mathbf{u} + \mathbf{f}$$

$$\partial_t \int d\mathbf{r}\, u_x = const \qquad \int d\mathbf{r}\, u_x \sim t$$



$$A \sim t^{\alpha}$$

$$B \sim t^{\beta}$$

$$AB^2 \sim t^{\alpha} t^{2\beta} \sim t$$

$$\alpha + 2\beta = 1$$

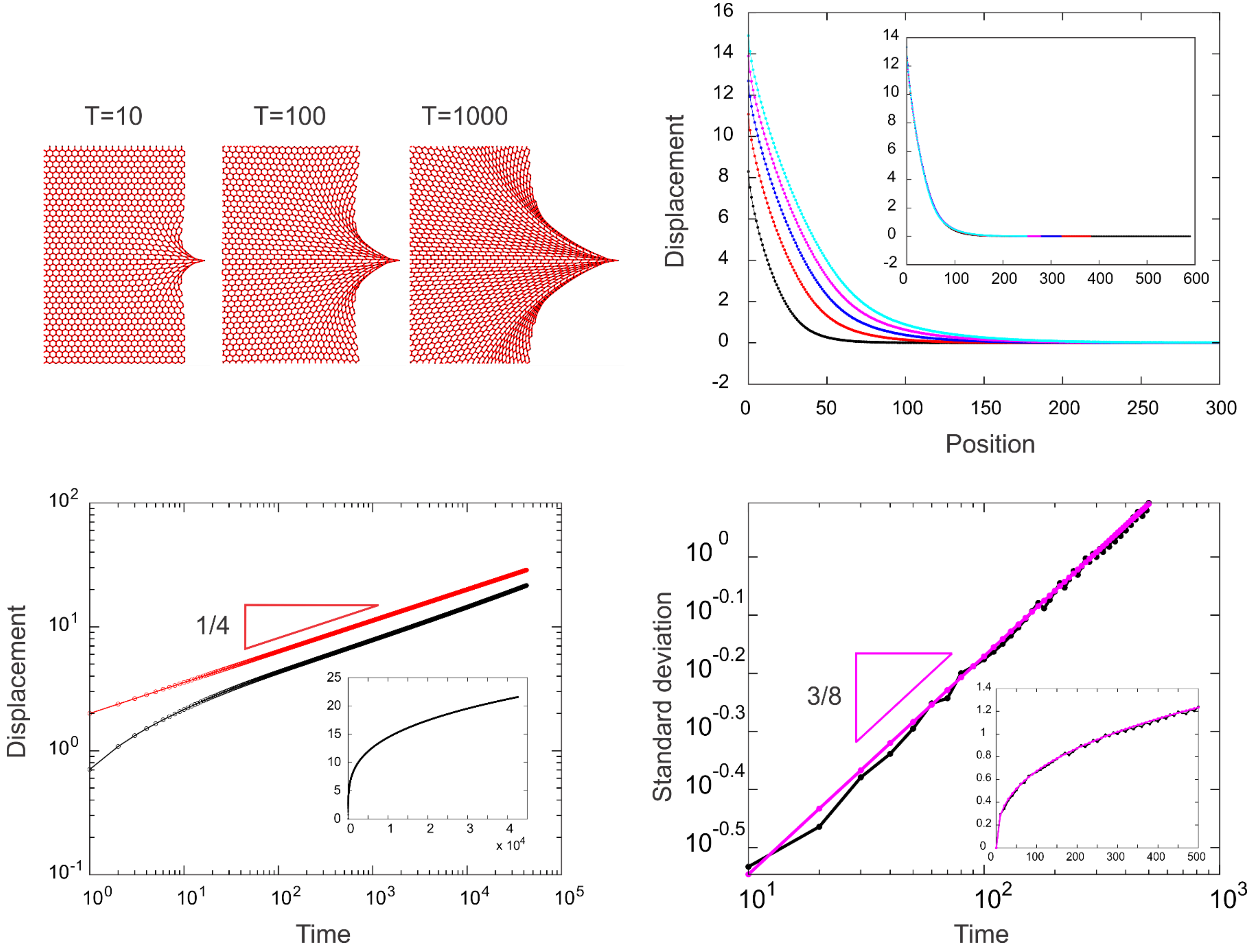
$$u_x \sim t^{\alpha} g\left(\frac{x}{t^{\beta}}, \frac{y}{t^{\beta}}\right)$$

$$\alpha - 1 = -2\beta + \alpha$$

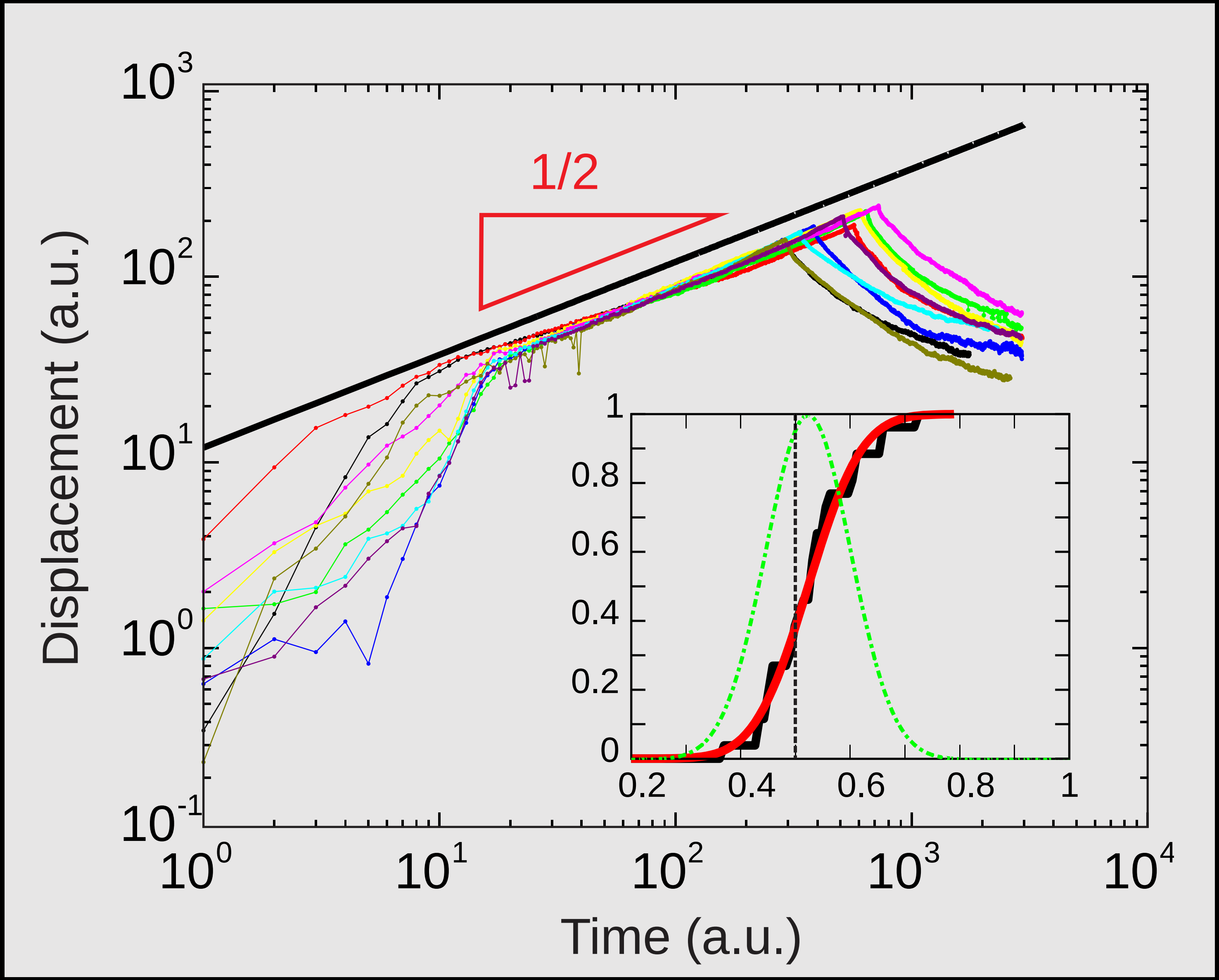
$$\alpha = 0 \qquad \beta = \frac{1}{2}$$

Scaling: nonlinear case

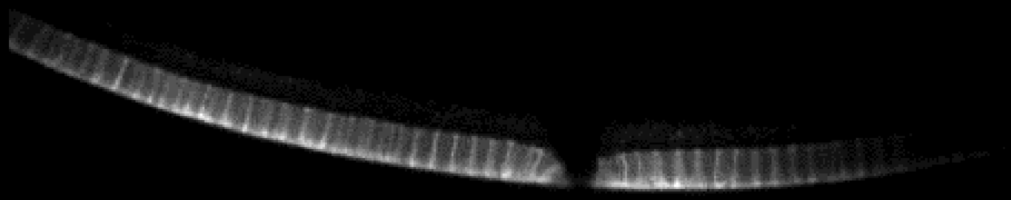
$$E \sim [\nabla \cdot \mathbf{u}]^2$$

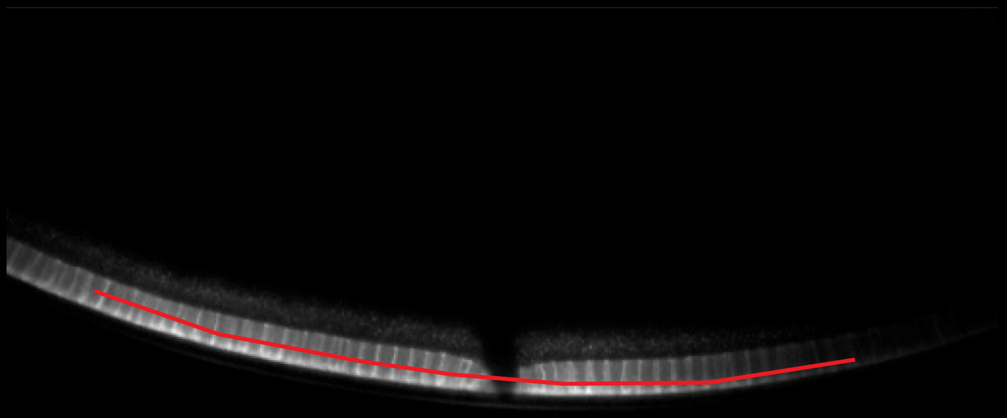


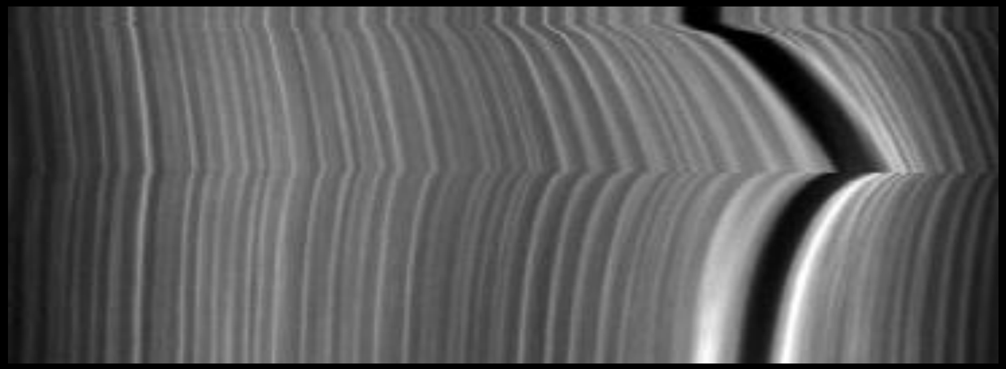
Data: power law behavior



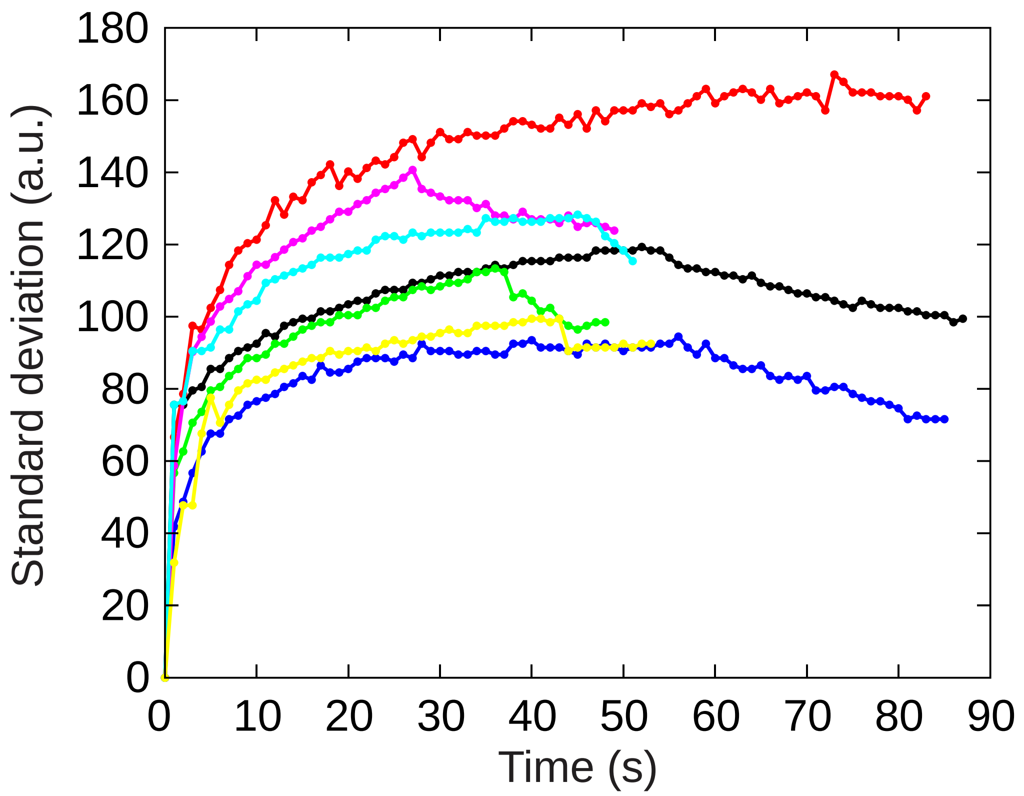
Following deformation imaging labeled membranes

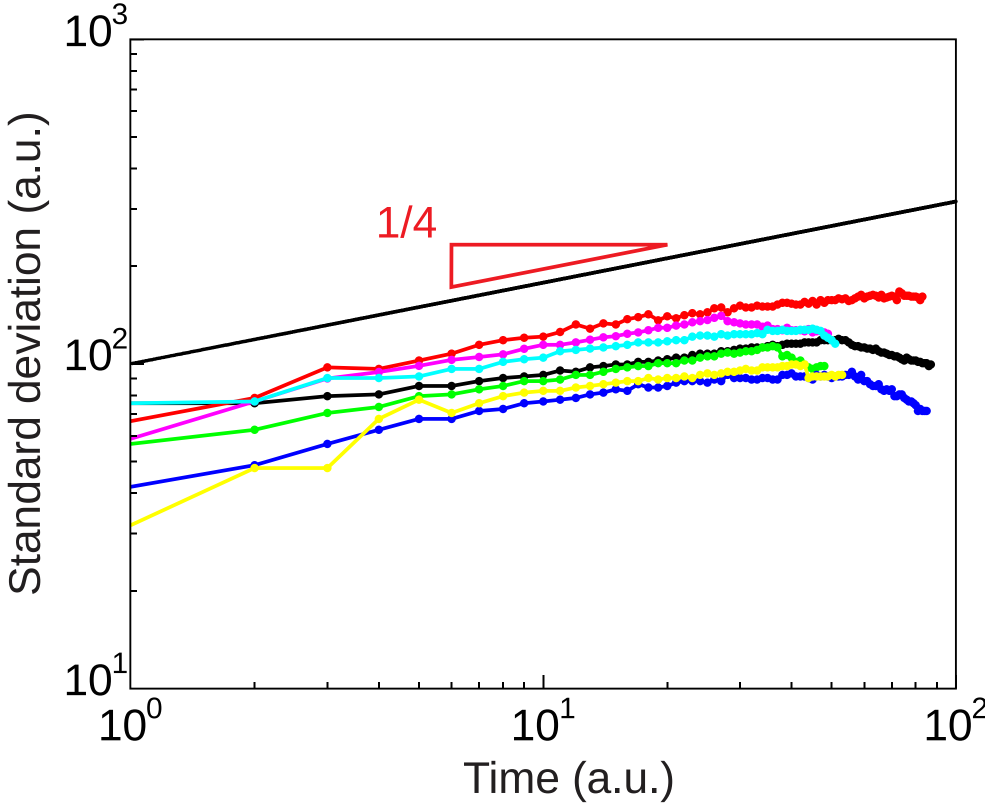




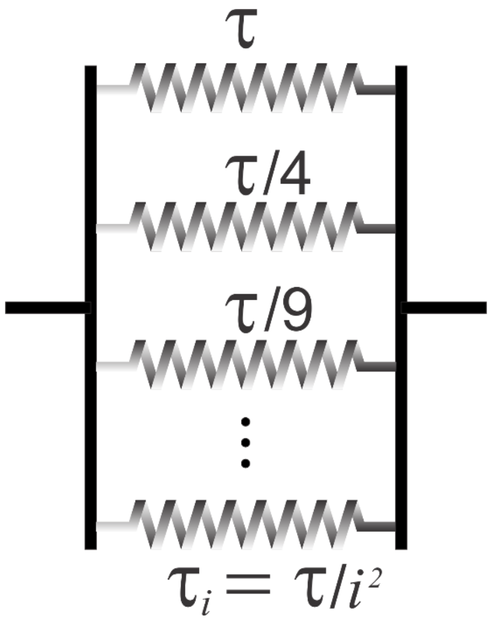


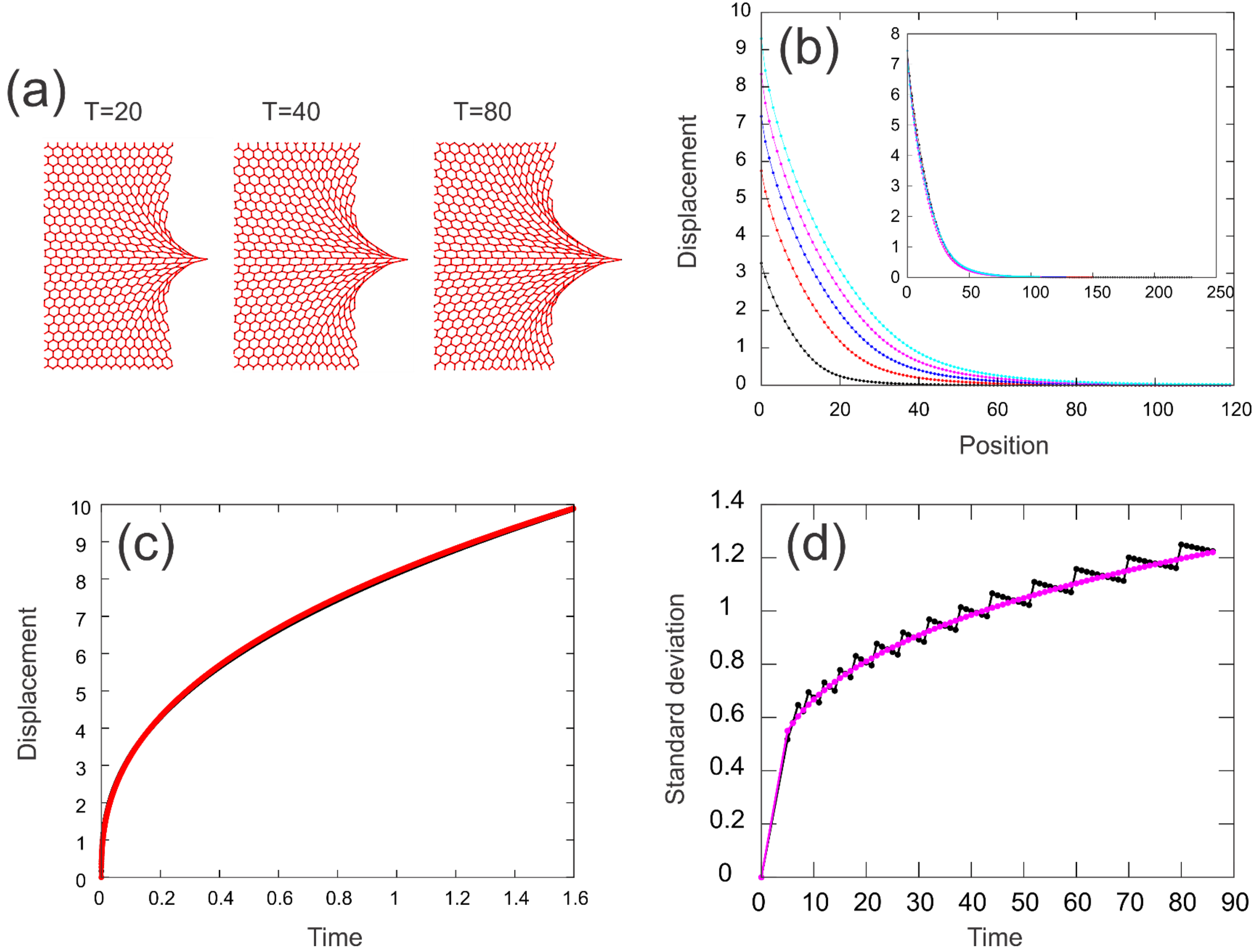
Growth of domain size: experiment



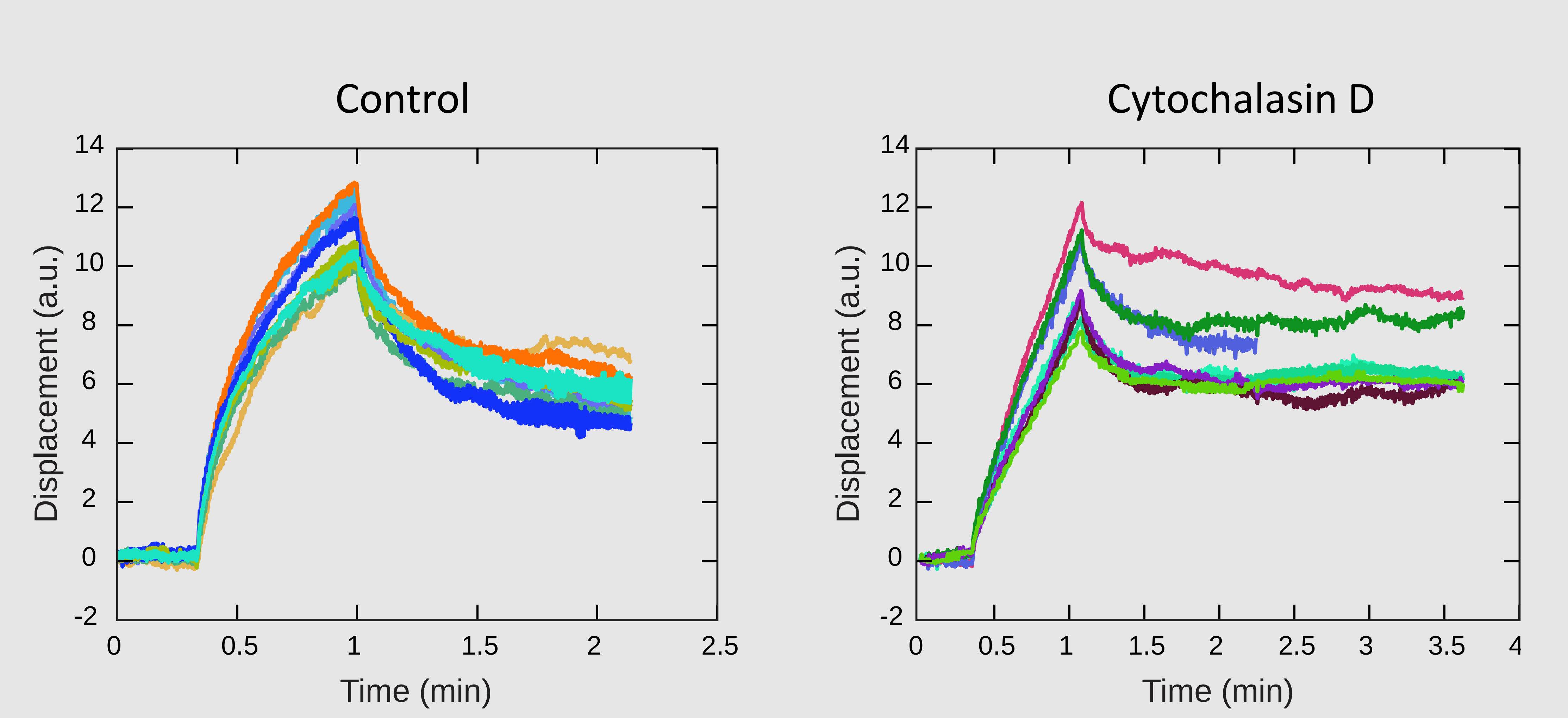


Capturing the individual values of the exponents





Where does elasticity reside?



Out of plane deformation: adiabatic?