

Biomechanics of cell growth

Focus on bacteria

ME-480 Lecture 13

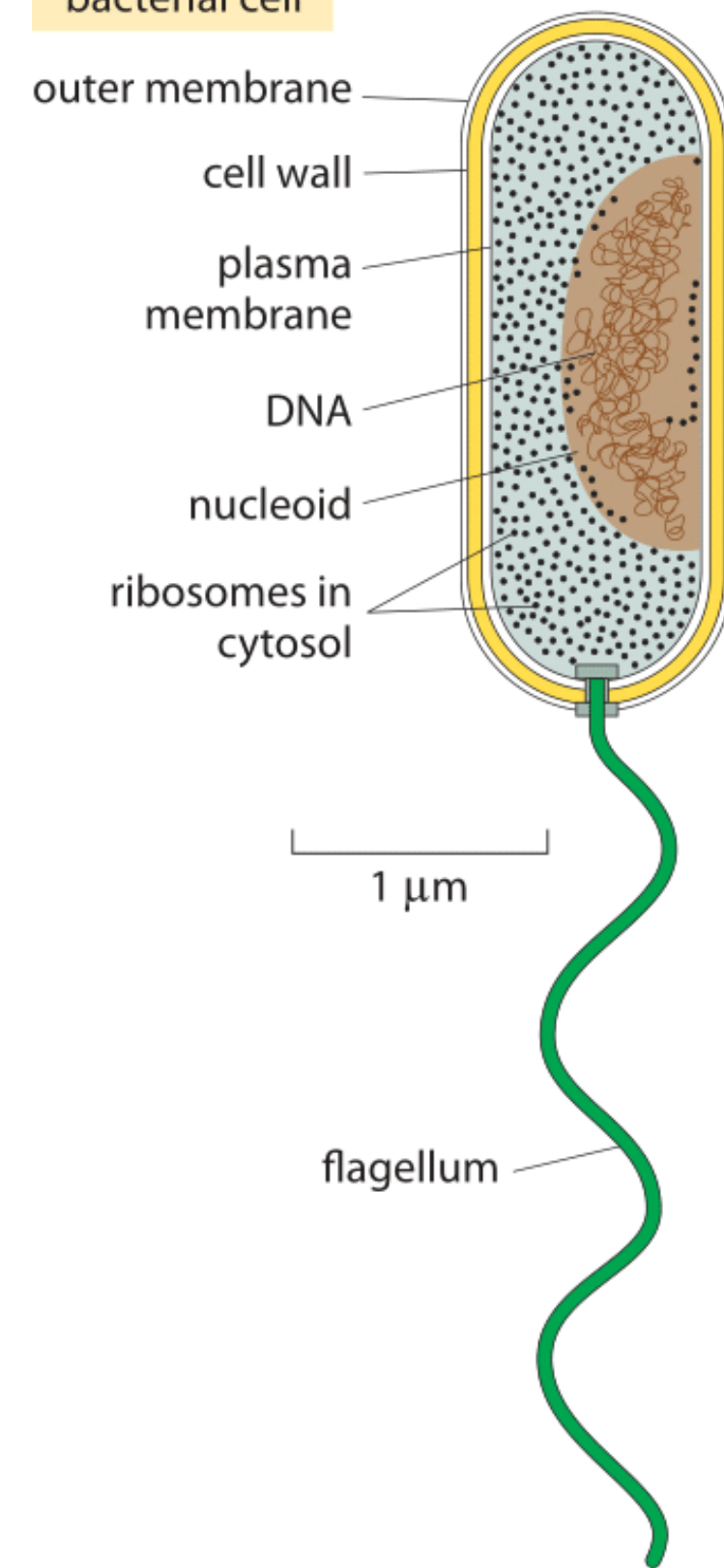
.Cell growth and division

Lecture 7 outline

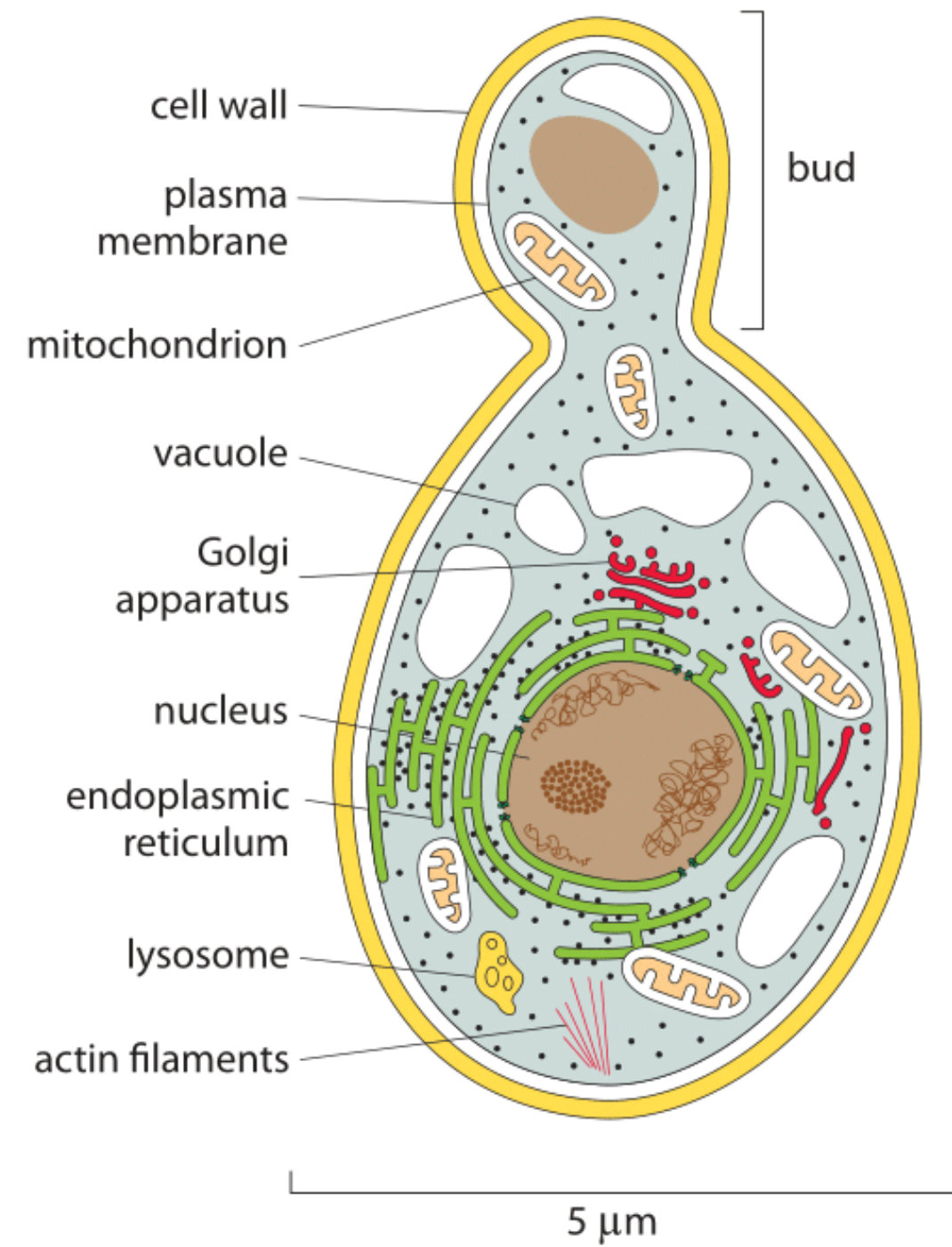
- Mechanics of soft and stiff cell envelopes
- Turgor/osmotic pressure
- Feedback between growth and cell envelope mechanics
- Plants repurpose turgor for rapid movements

Different envelopes and growth strategies

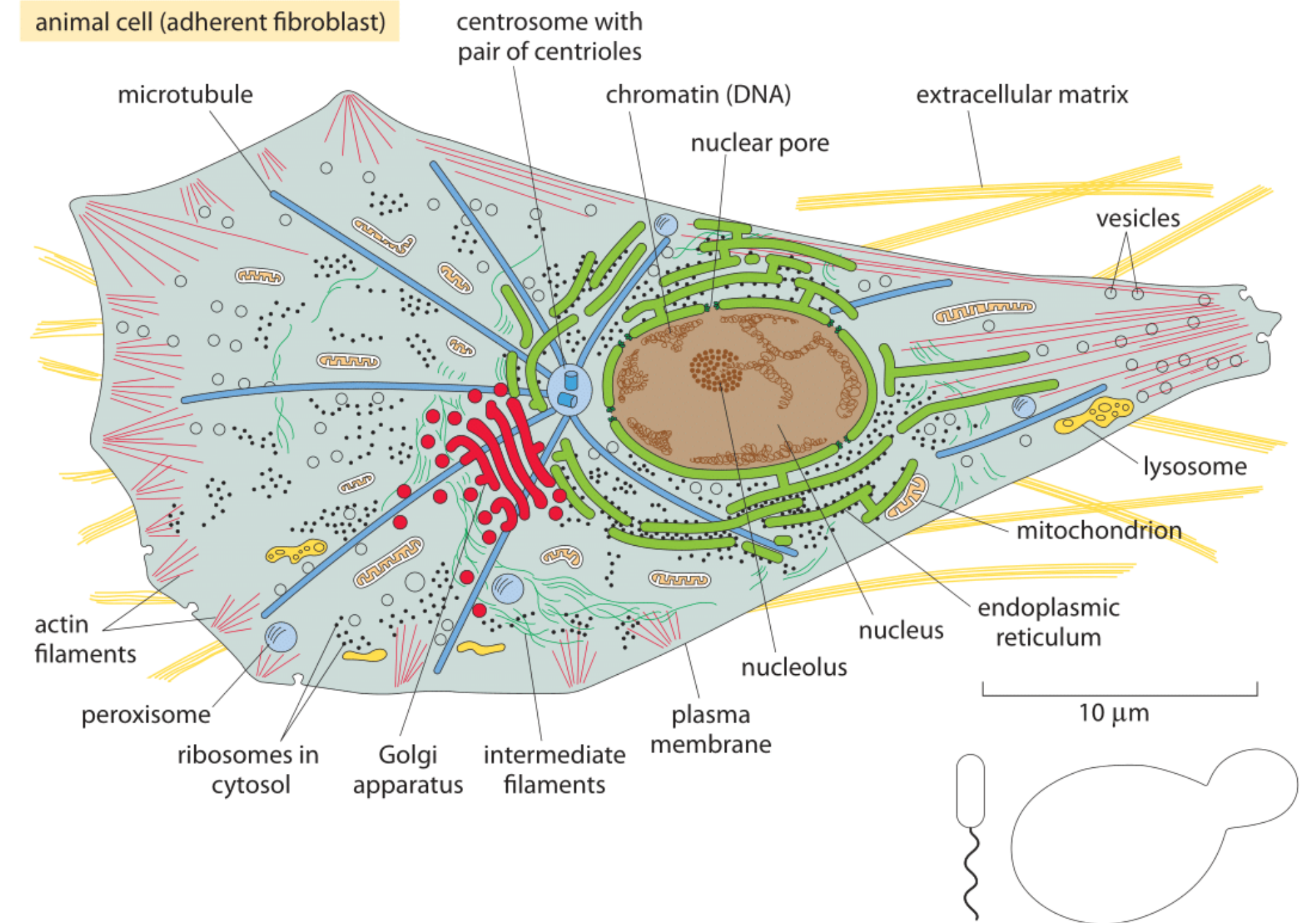
bacterial cell



yeast cell



animal cell (adherent fibroblast)



Growth and division of animal cells



■ Growth and division of animal cells

The membrane bilayer is fluid

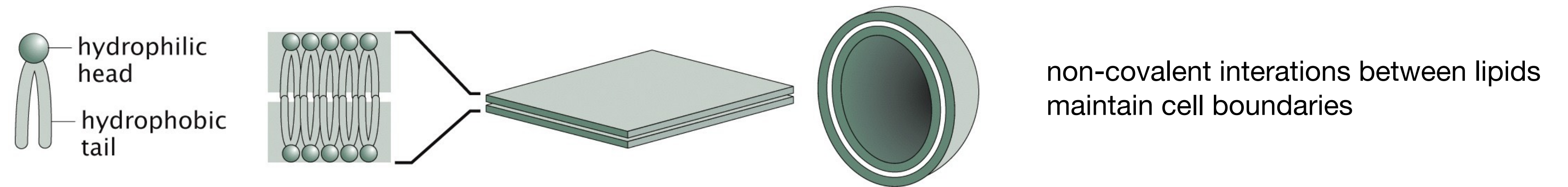


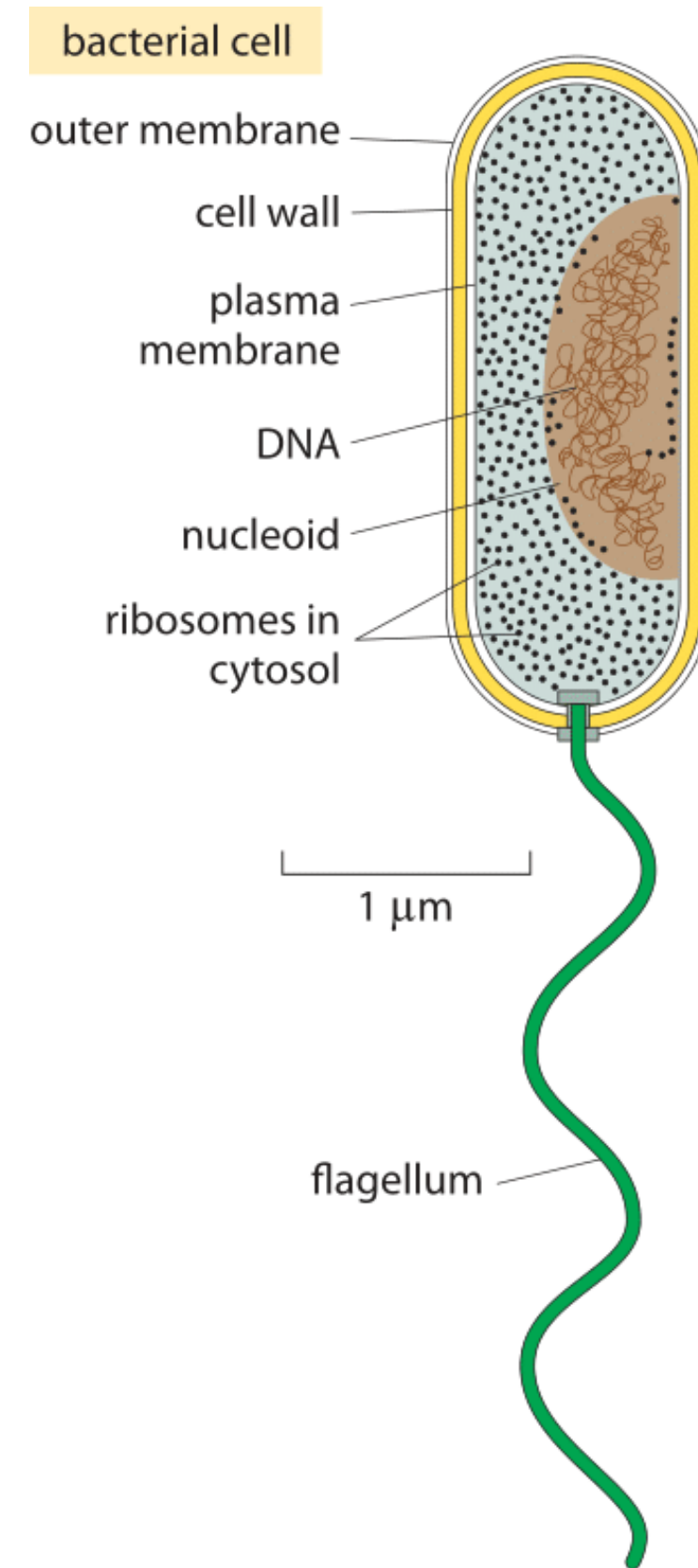
Figure 11.1a Physical Biology of the Cell, 2ed. (© Garland Science 2013)

■ Growing with an elastic cell wall



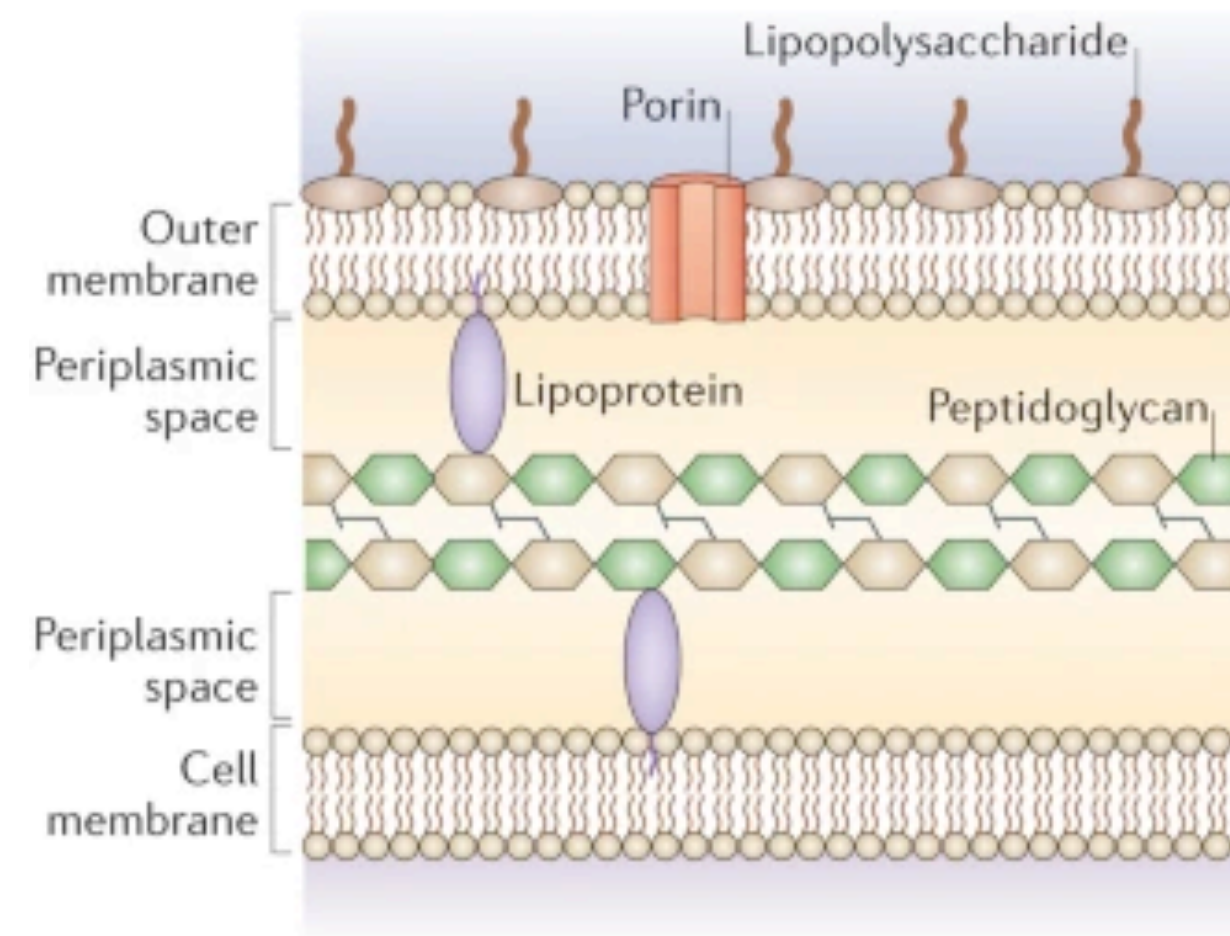
Bacteria, yeast and plants: different but common theme for growth

Bacterial cell wall



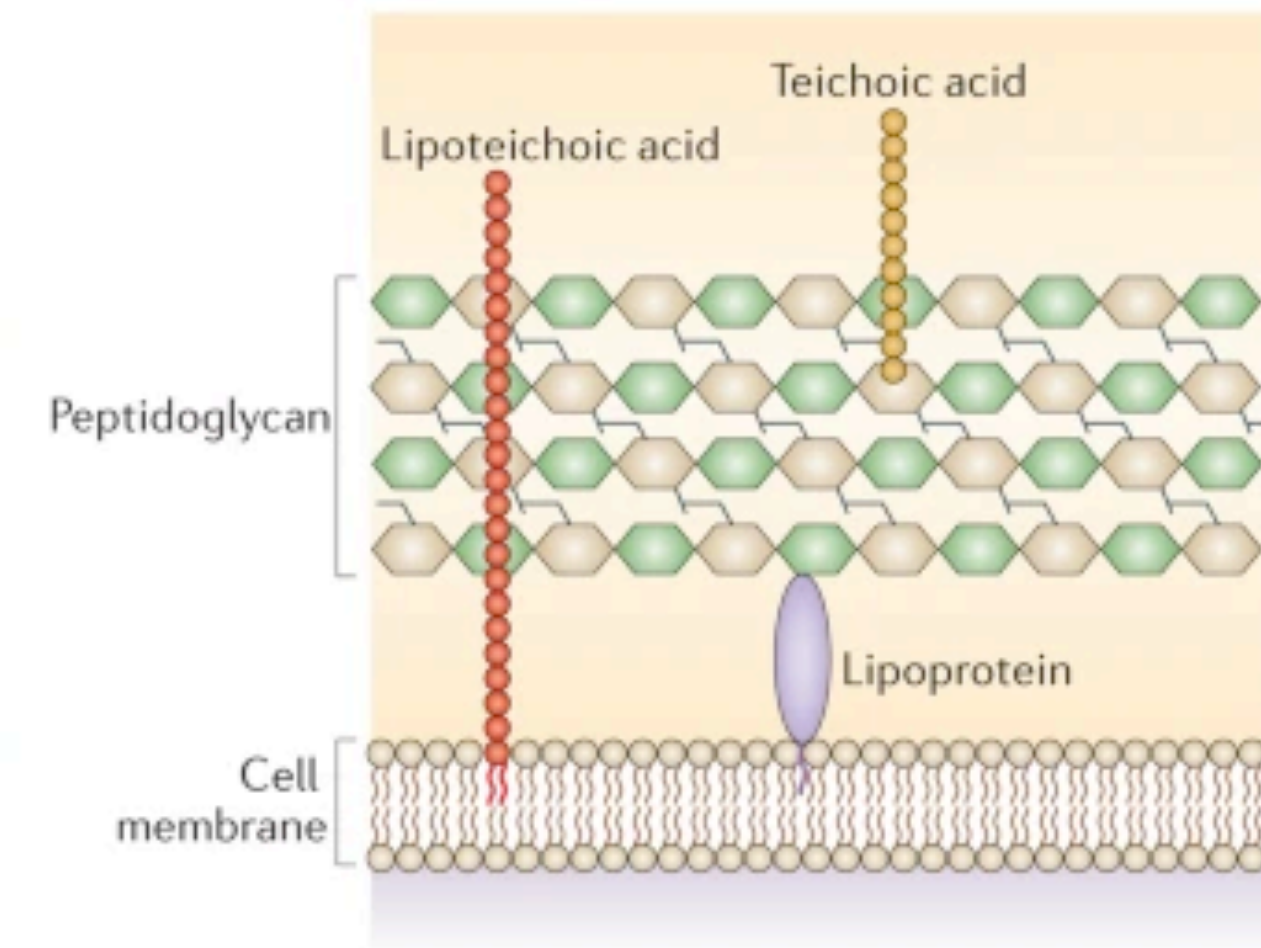
Cell wall architecture

a Gram-negative bacteria



example: *E. coli*

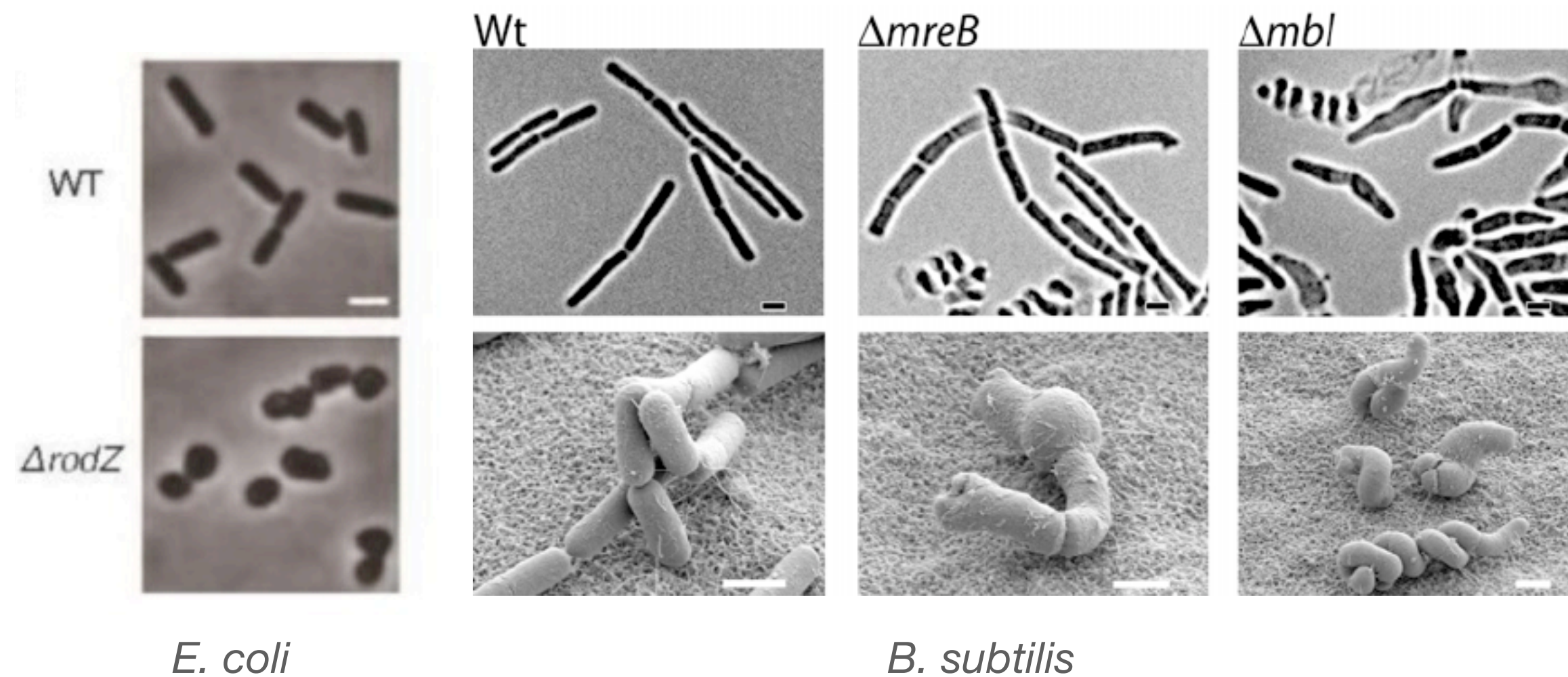
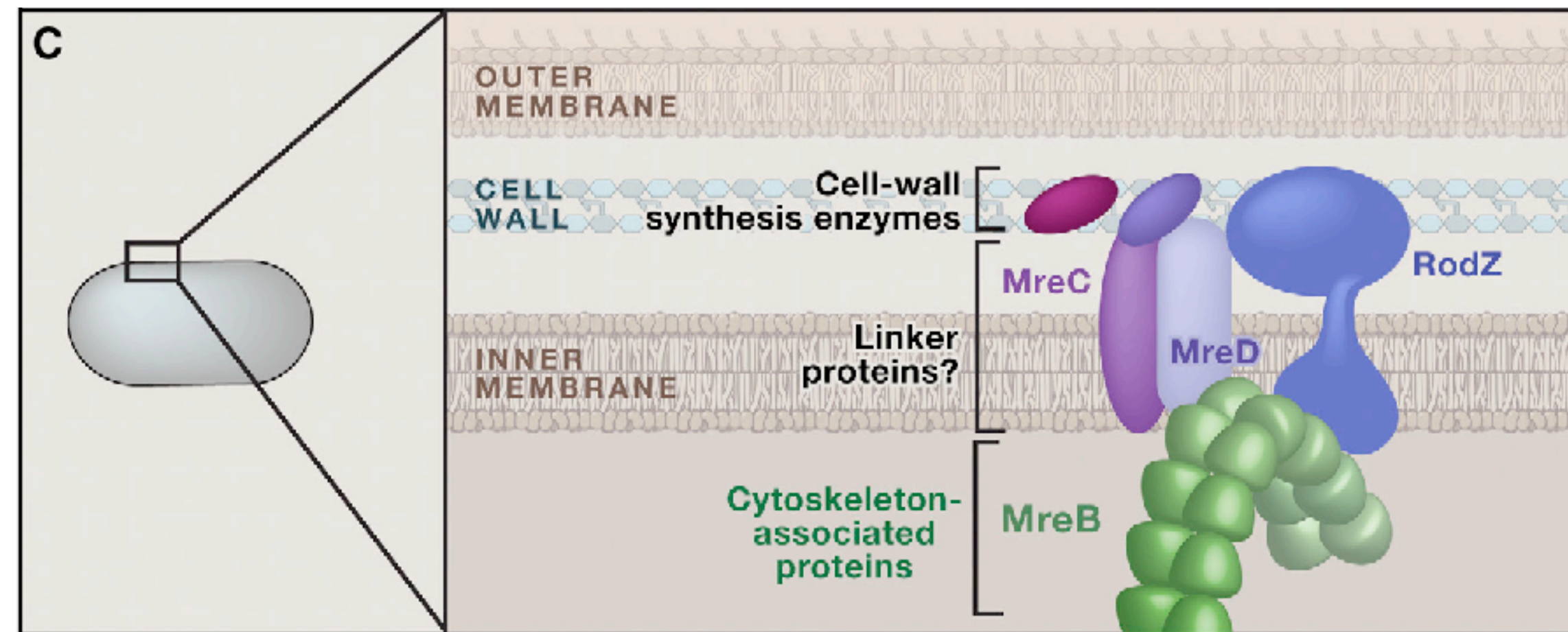
b Gram-positive bacteria



example: *Bacillus subtilis*

Cell wall synthesis: machinery

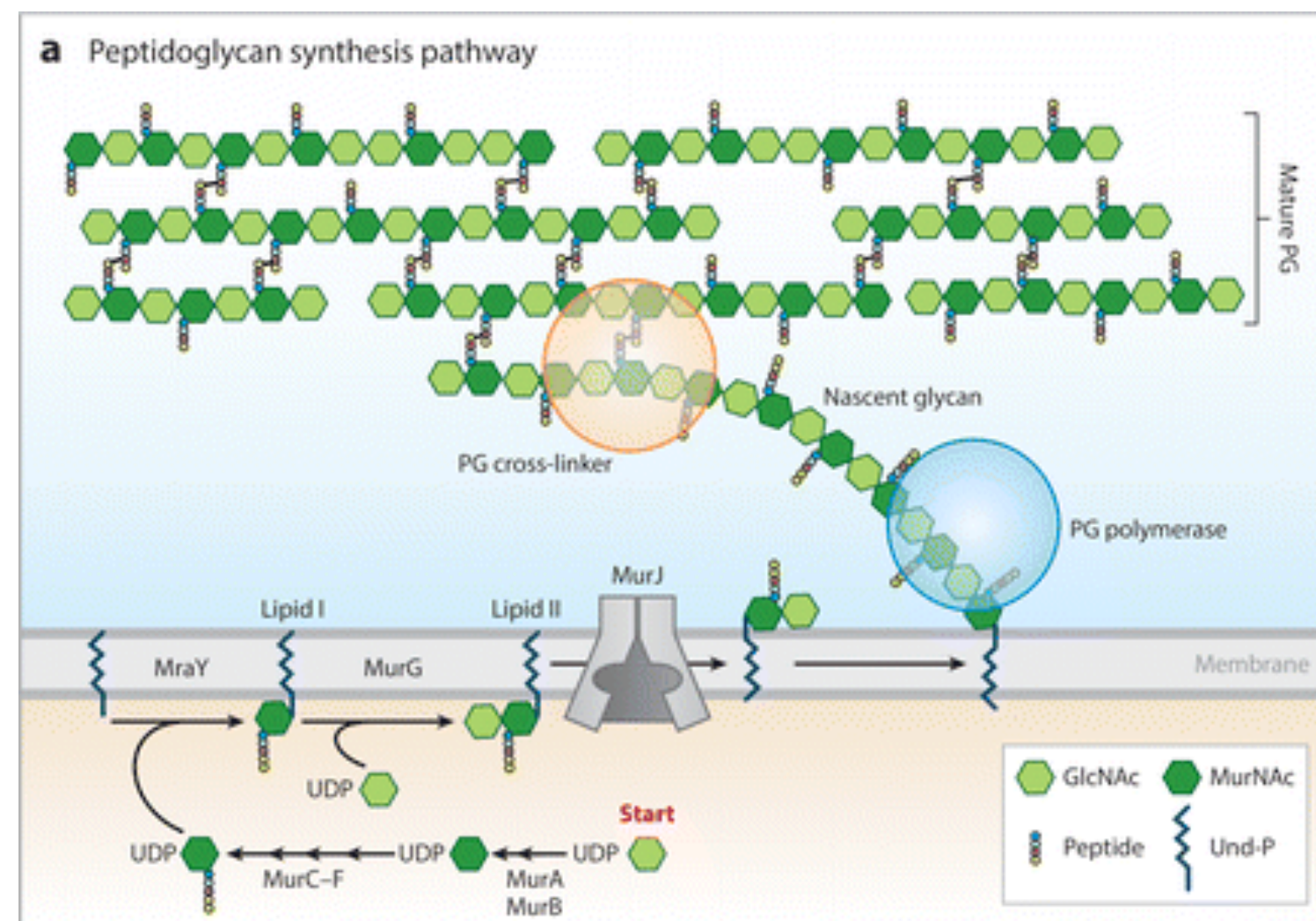
- **PBPs** synthesize and insert peptidoglycan
- **MreB** spatially-guides synthesis
- **RodZ** controls PBP localization



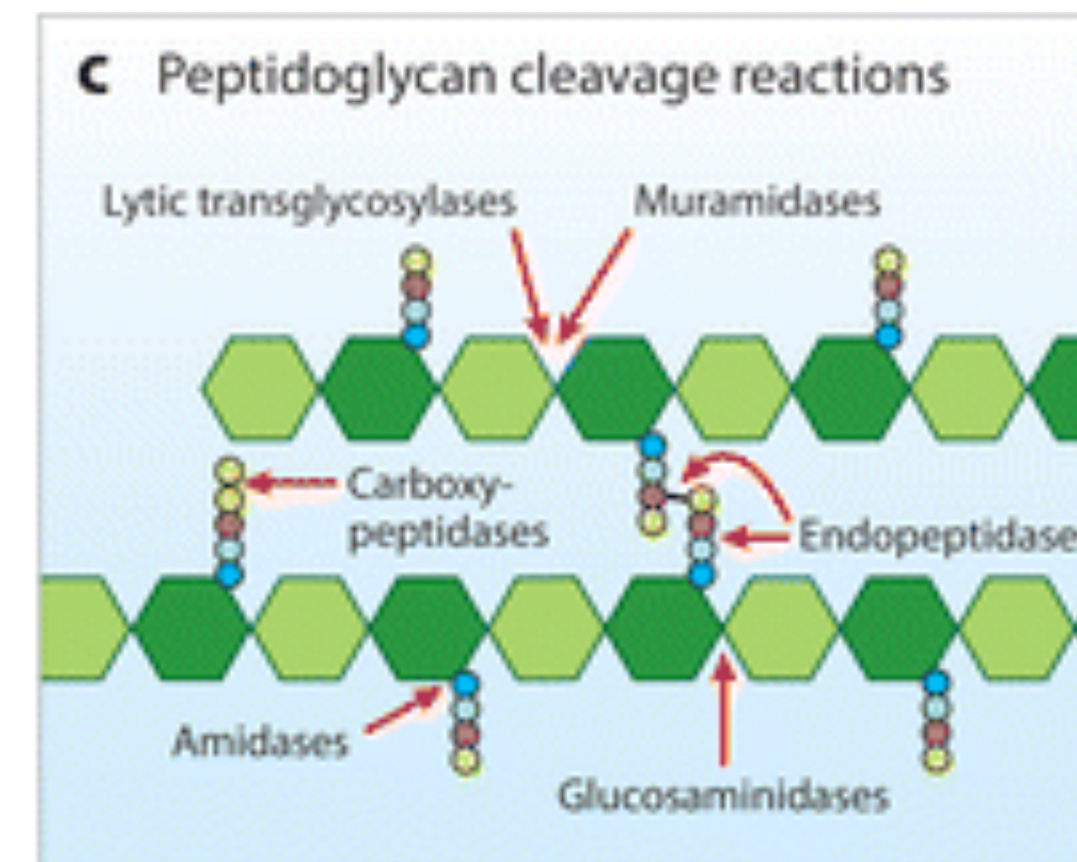
Bacterial cell wall growth

Cell wall growth required cleavage and synthesis of new peptidoglycan

Cell wall growth

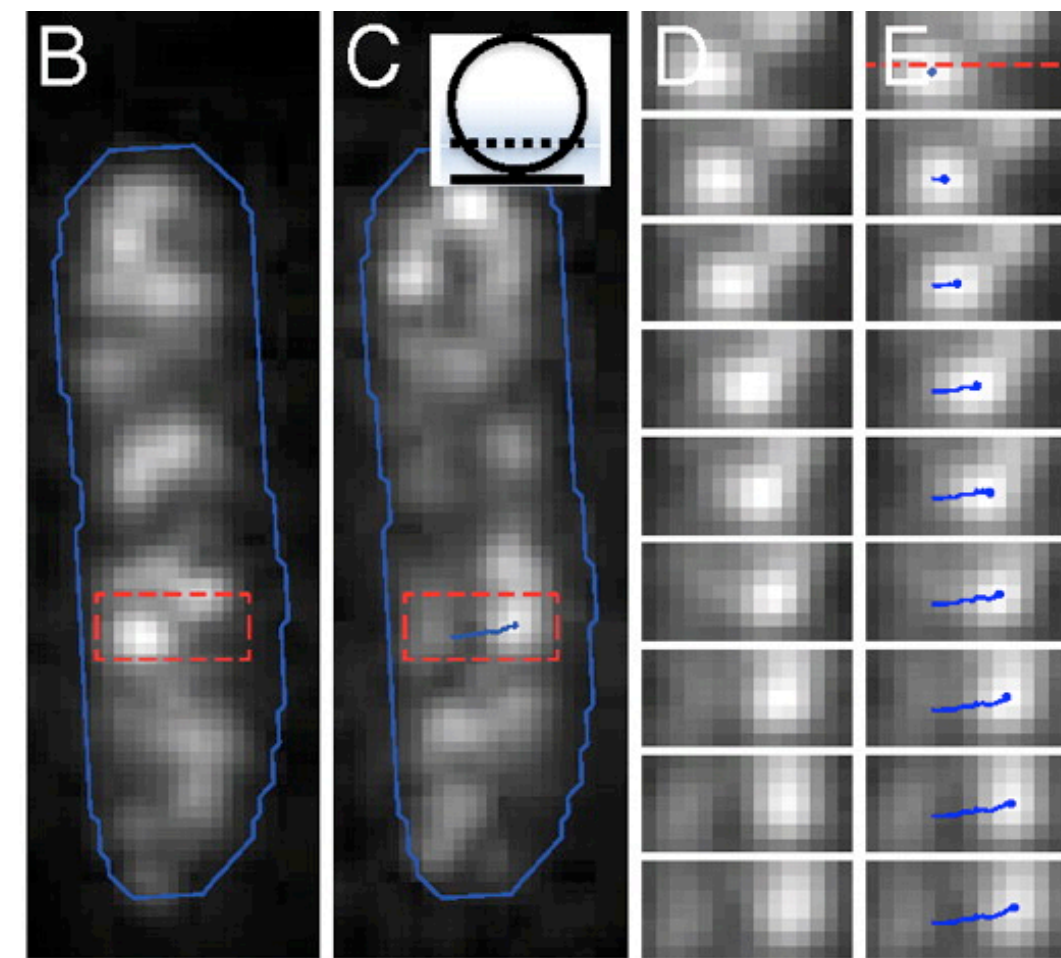
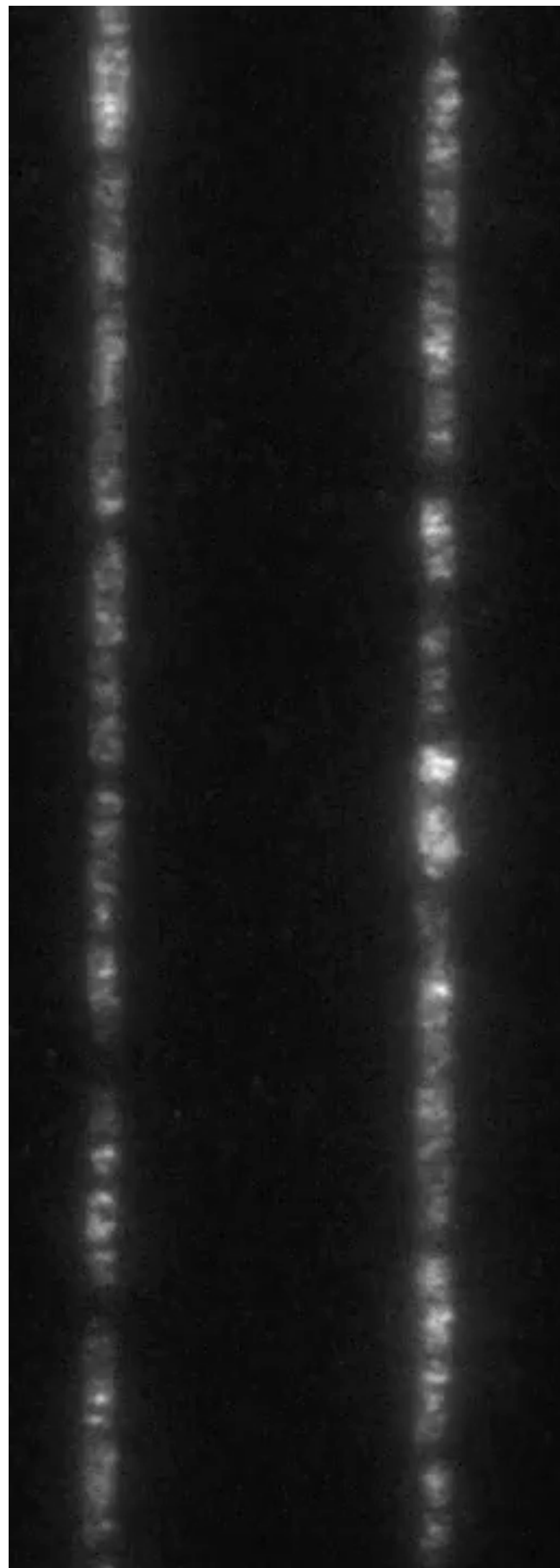


Cell wall cleavage

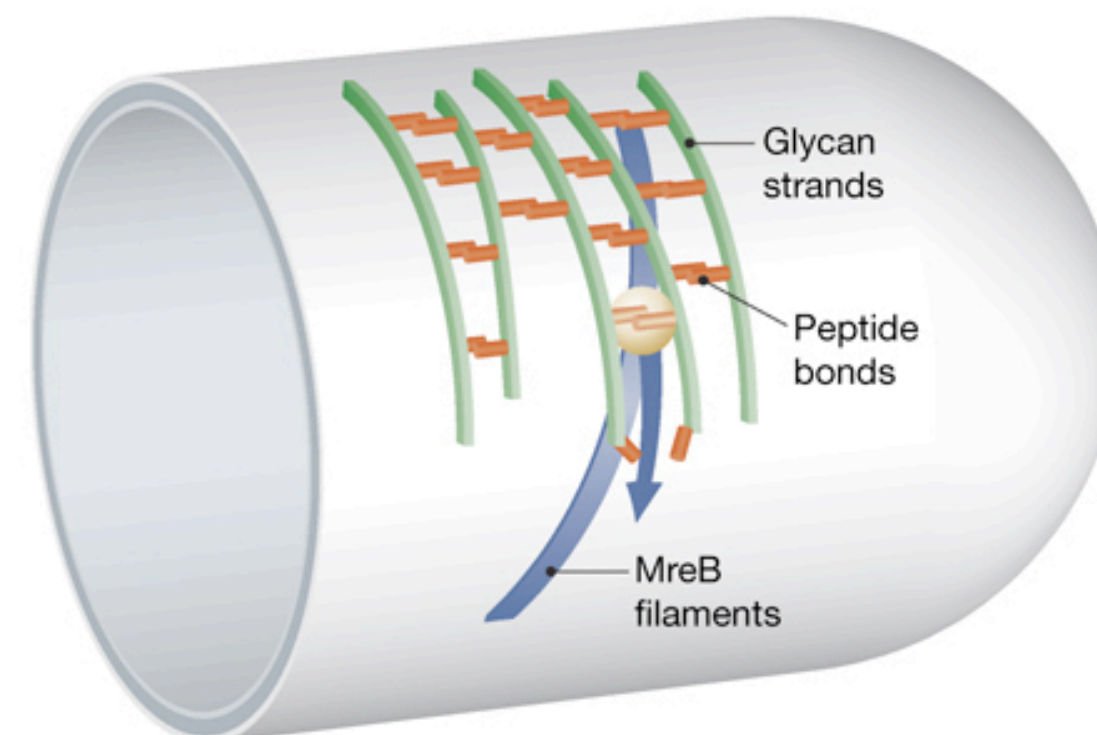


Cell wall patterning by MreB (or Mbl)

Rotation stabilizes morphogenesis

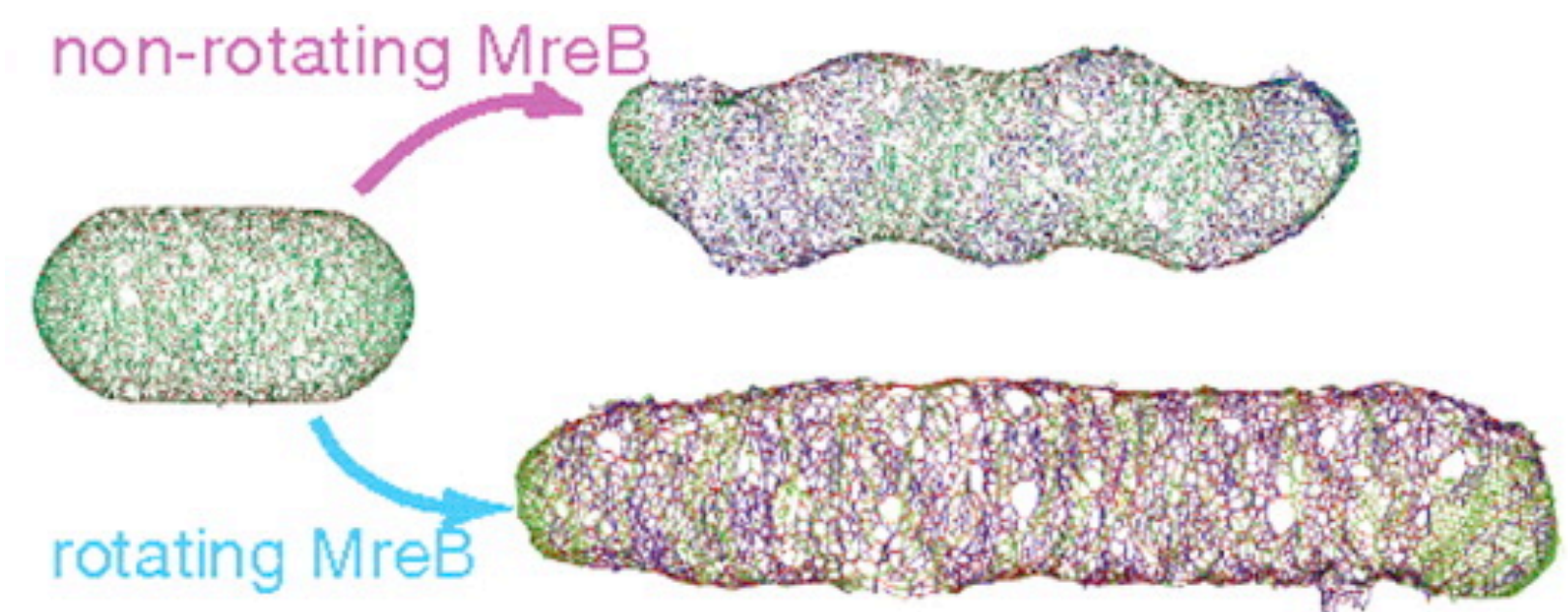


B Spatio-temporal control of PG/WTa insertion

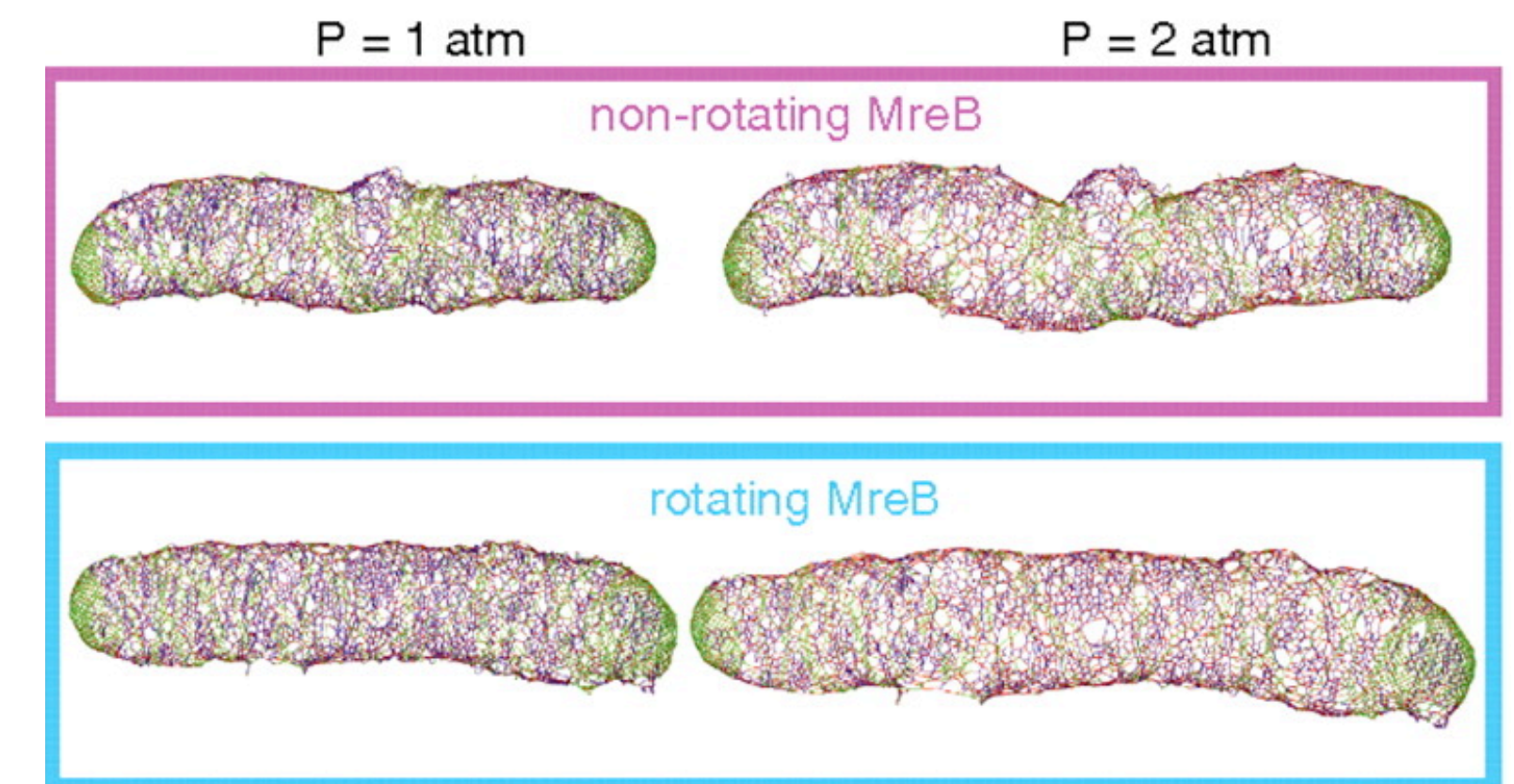


Simulations

Rotation promotes rod-shape

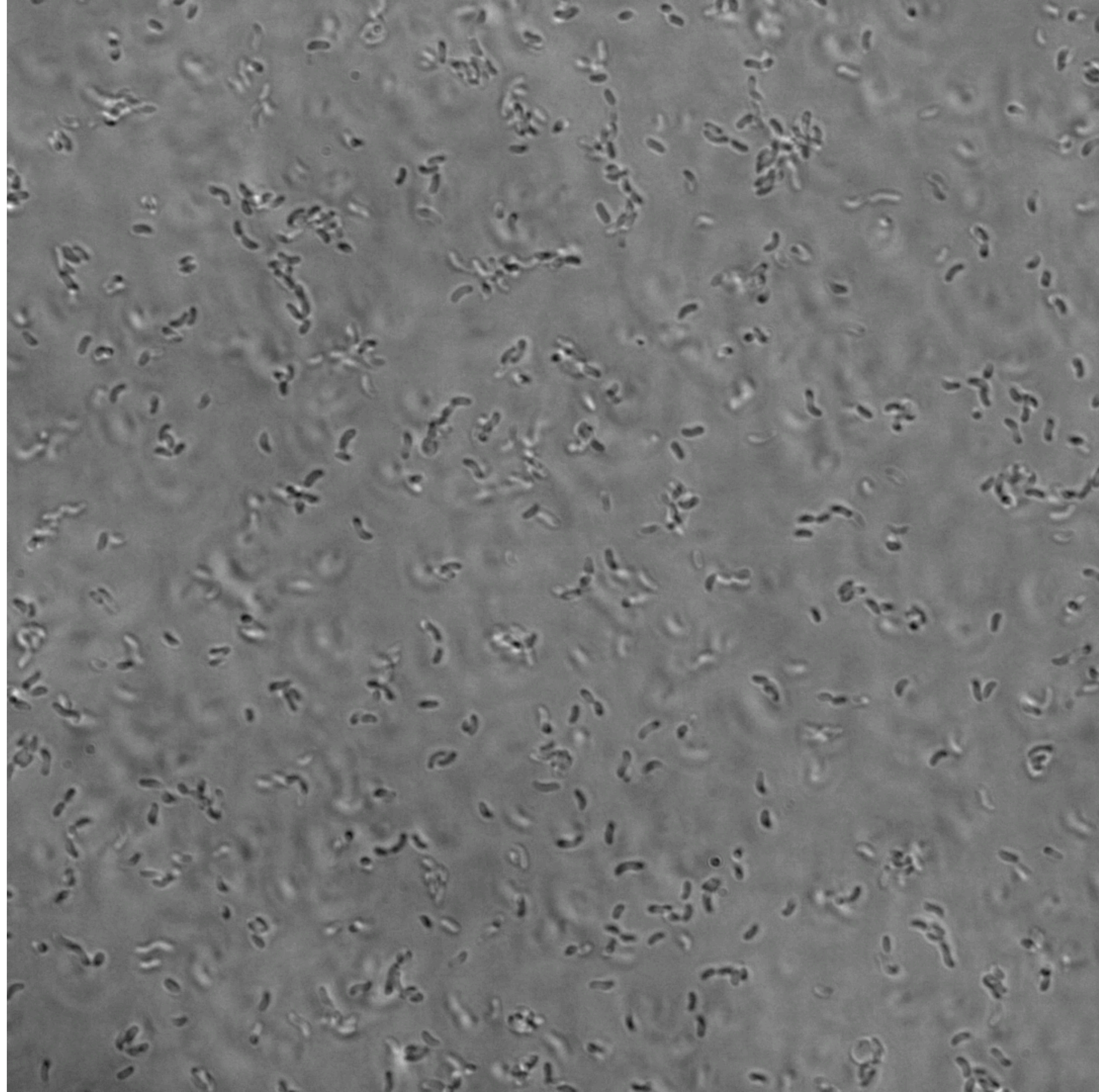


Internal osmotic pressure promotes growth

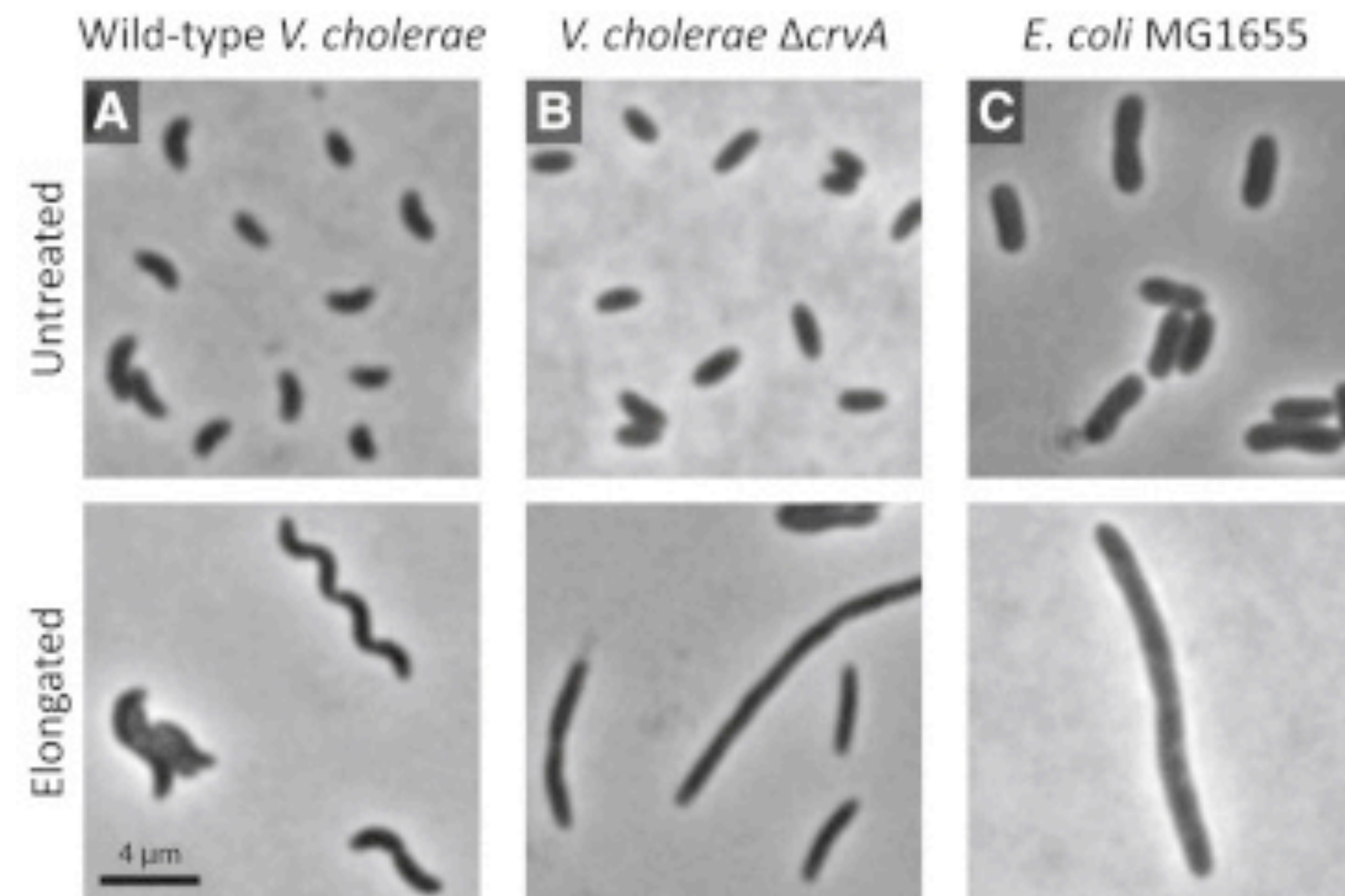


How to grow while maintaining shape?

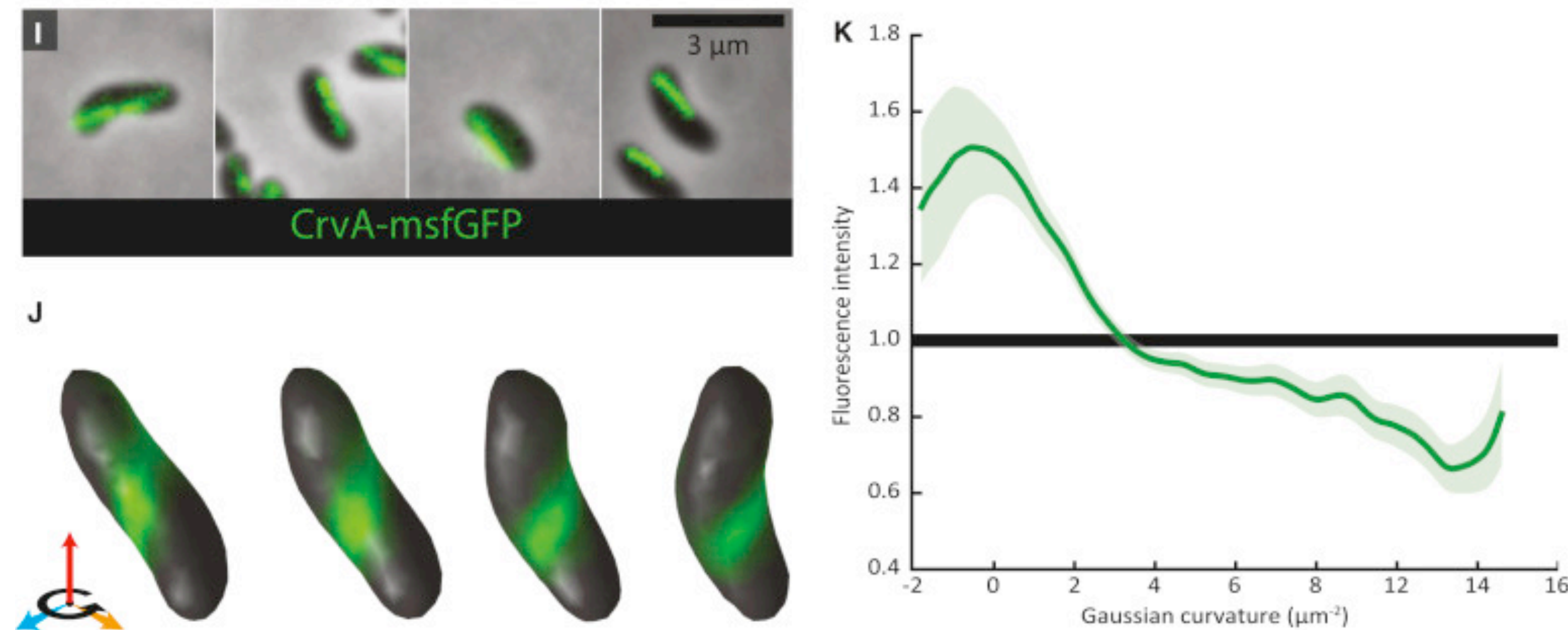
Vibrio cholerae



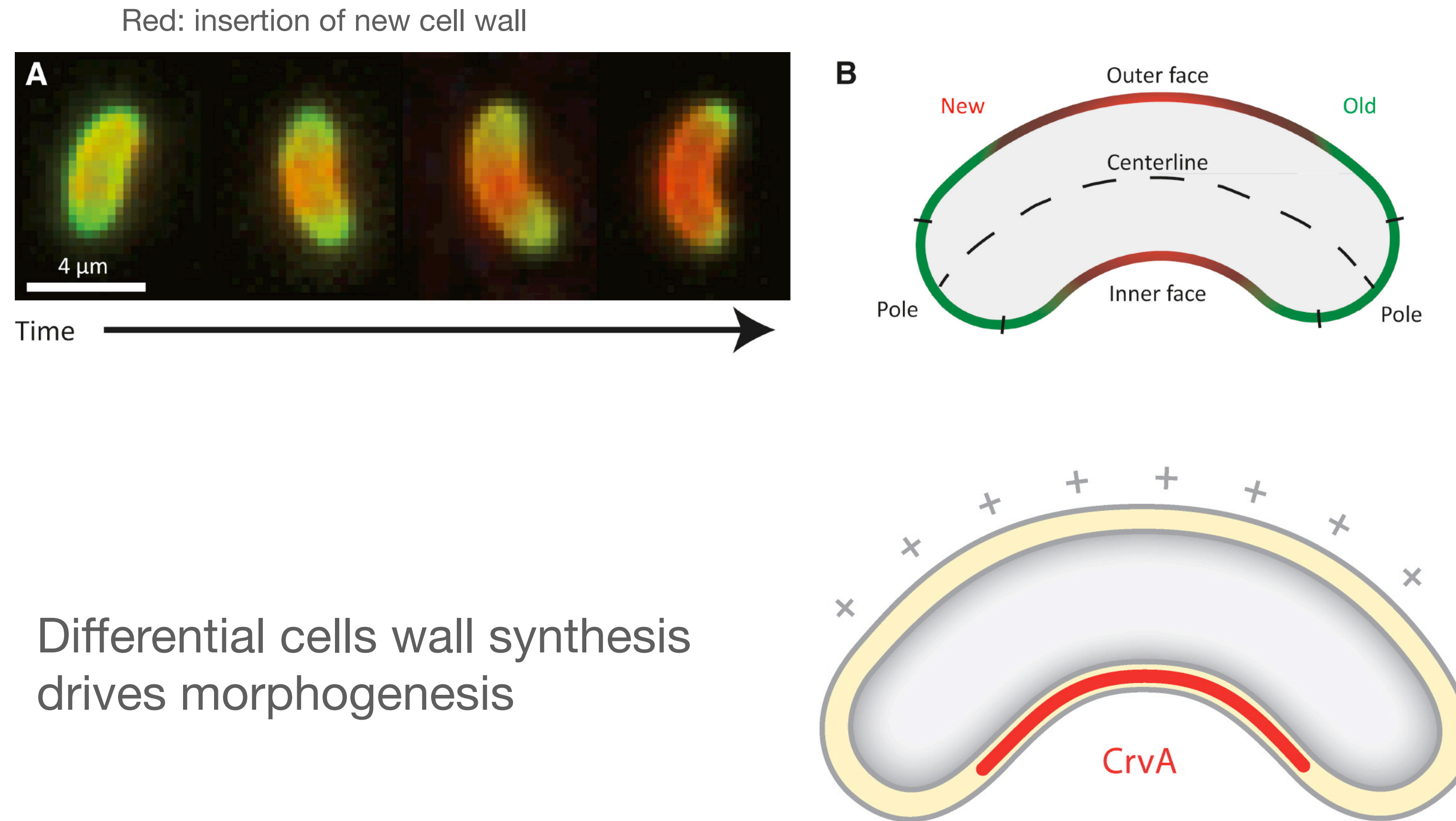
Vibrio's helical shape depends on a single protein CrvA (“curv-A”)



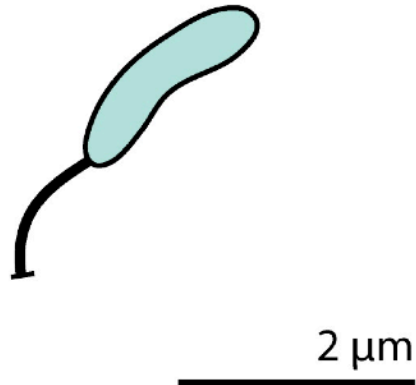
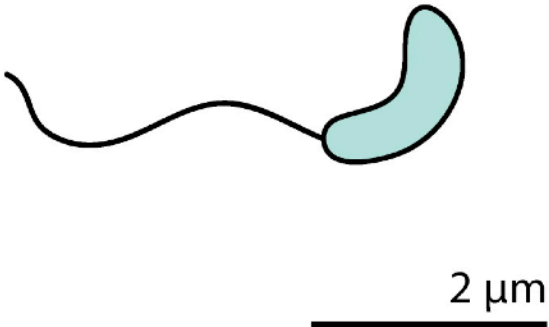
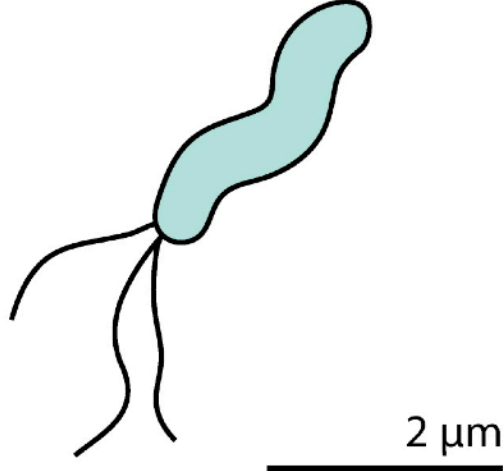
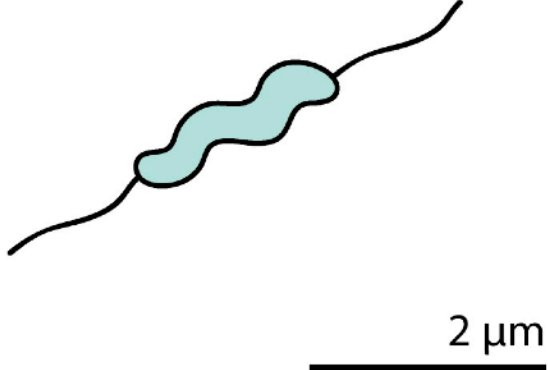
CrvA forms a filament at the inner surface



CrvA patterns new cell wall



Cell wall patterning produces complex morphologies

	<i>Caulobacter crescentus</i>	<i>Vibrio cholerae</i>	<i>Helicobacter pylori</i>	<i>Campylobacter jejuni</i>
				
Natural habitat	Freshwater, soil, seawater	Water reservoirs; transiently colonizes intestine	Human stomach	Intestine of mammals and birds
Significance of cell shape	Survival in flow	Motility and intestinal virulence	Stomach colonization, induction of inflammation	Colonization of chickens, penetration of intestinal crypts, intestinal inflammation

■ Osmotic pressure

Impermeability of membrane to a solute creates a concentration gradients
-> generates a pressure difference across the membrane

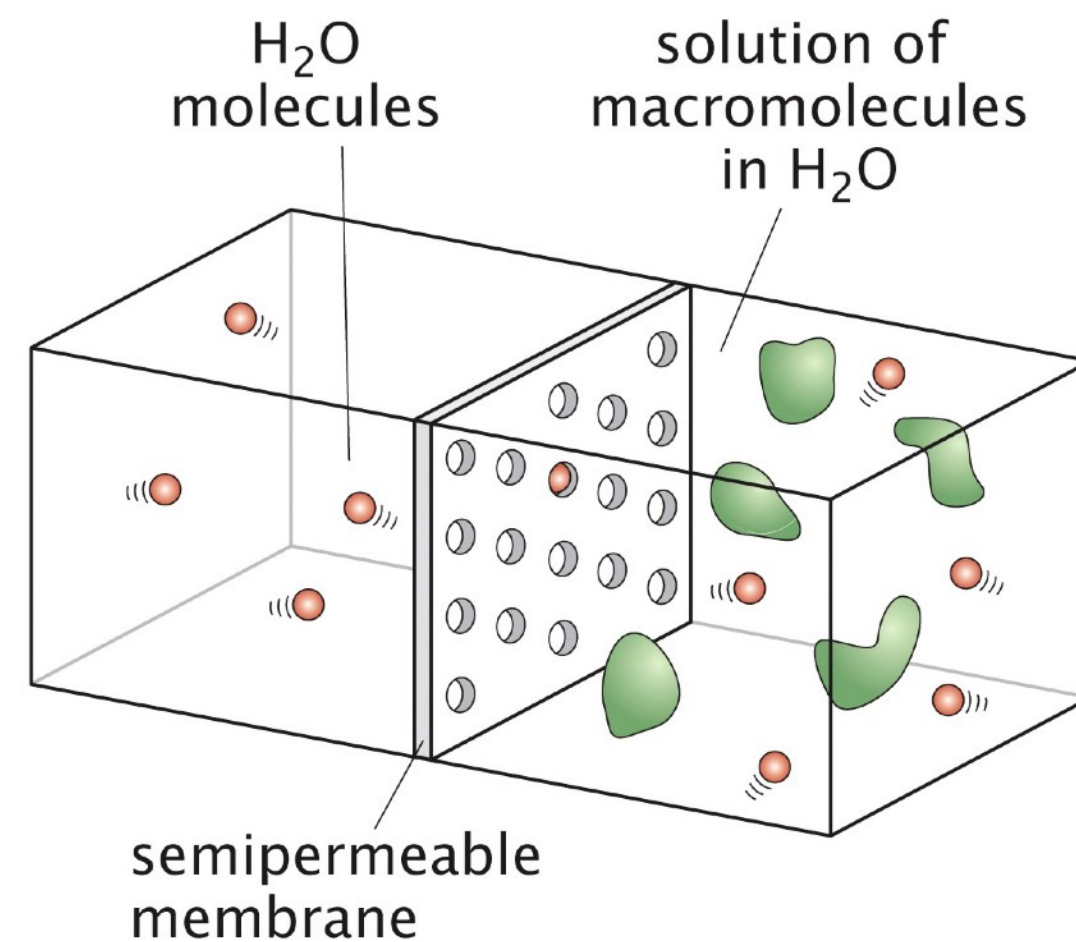
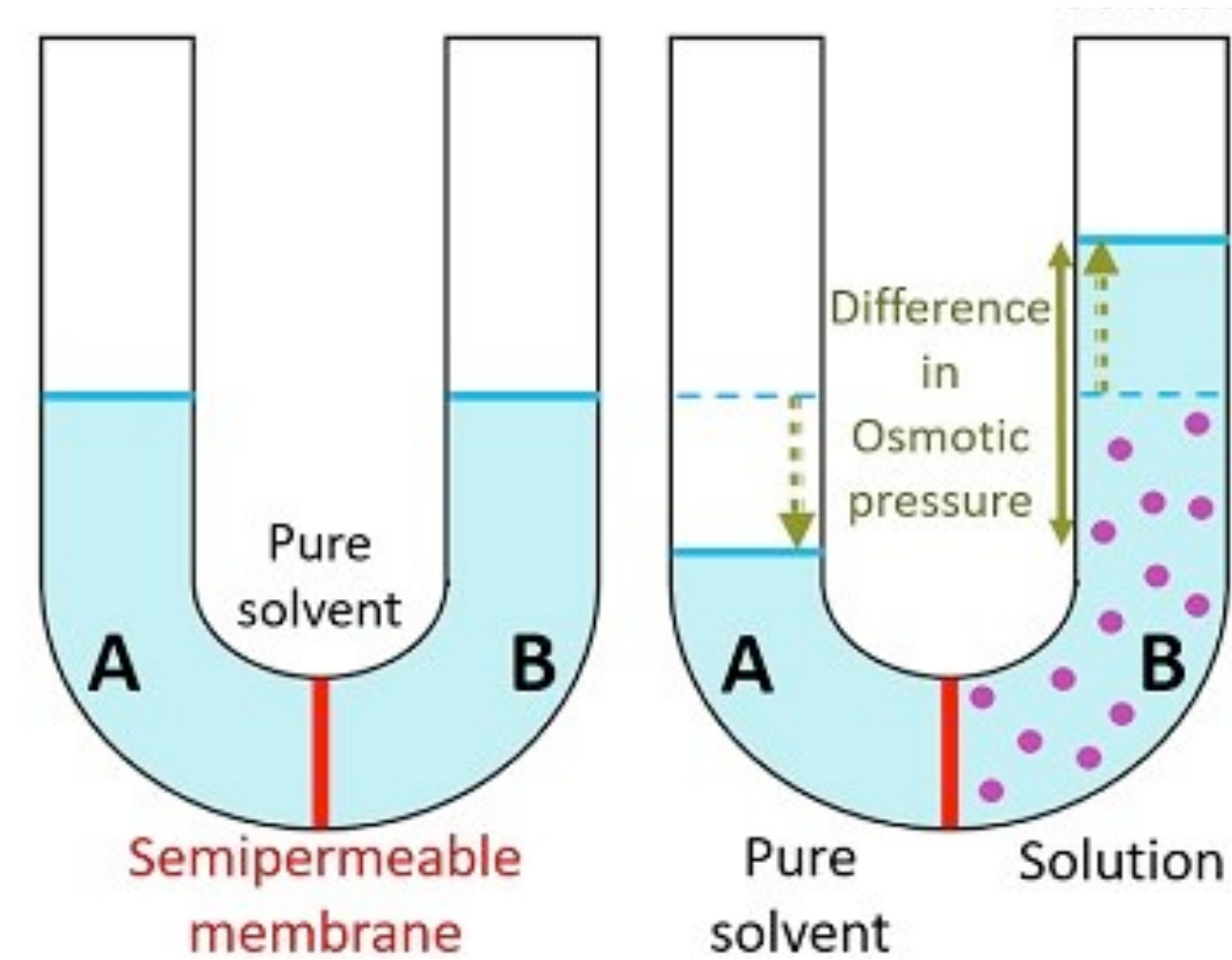


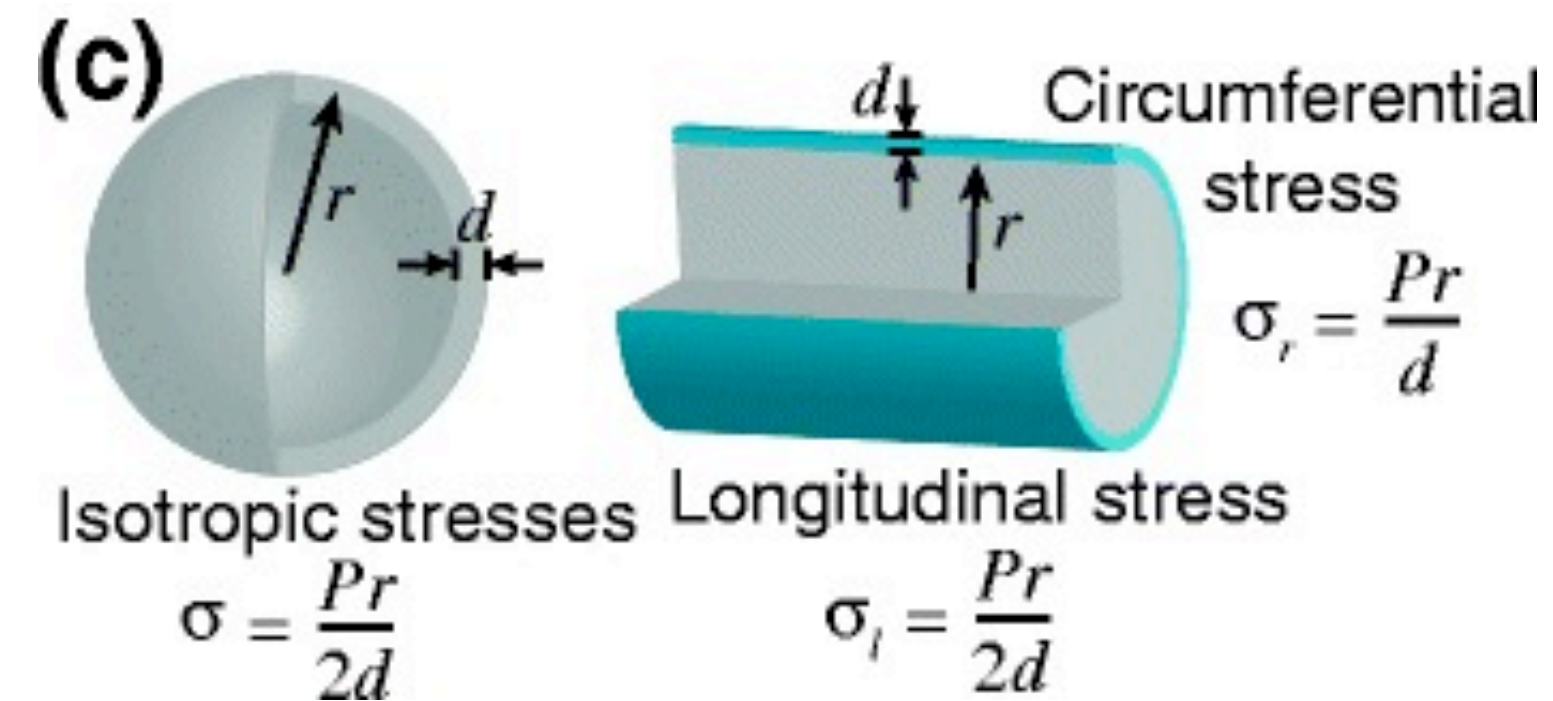
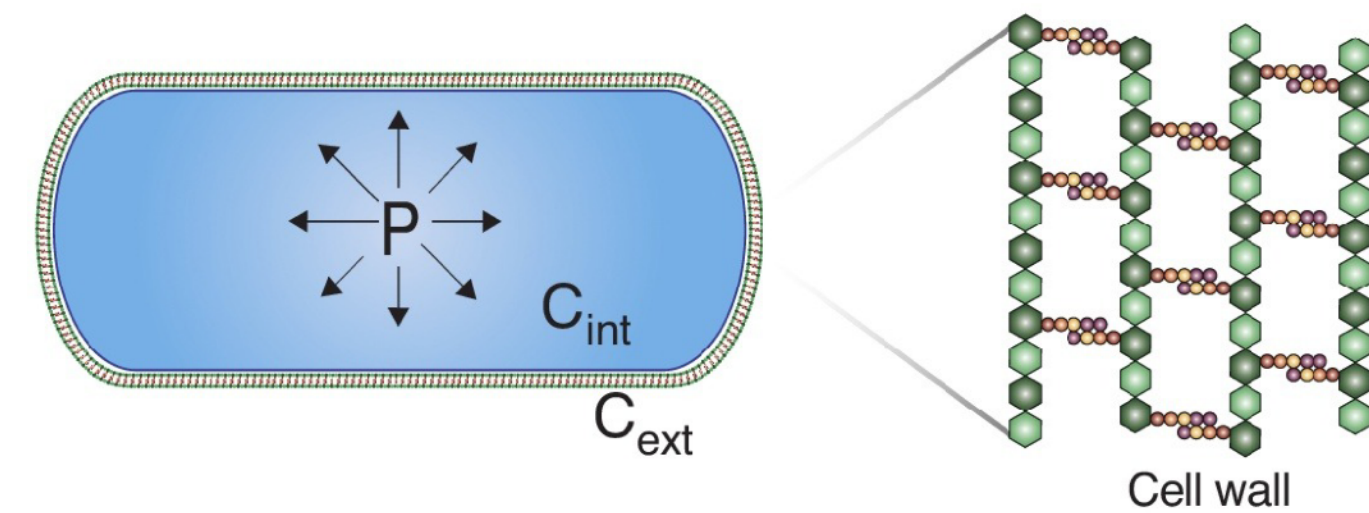
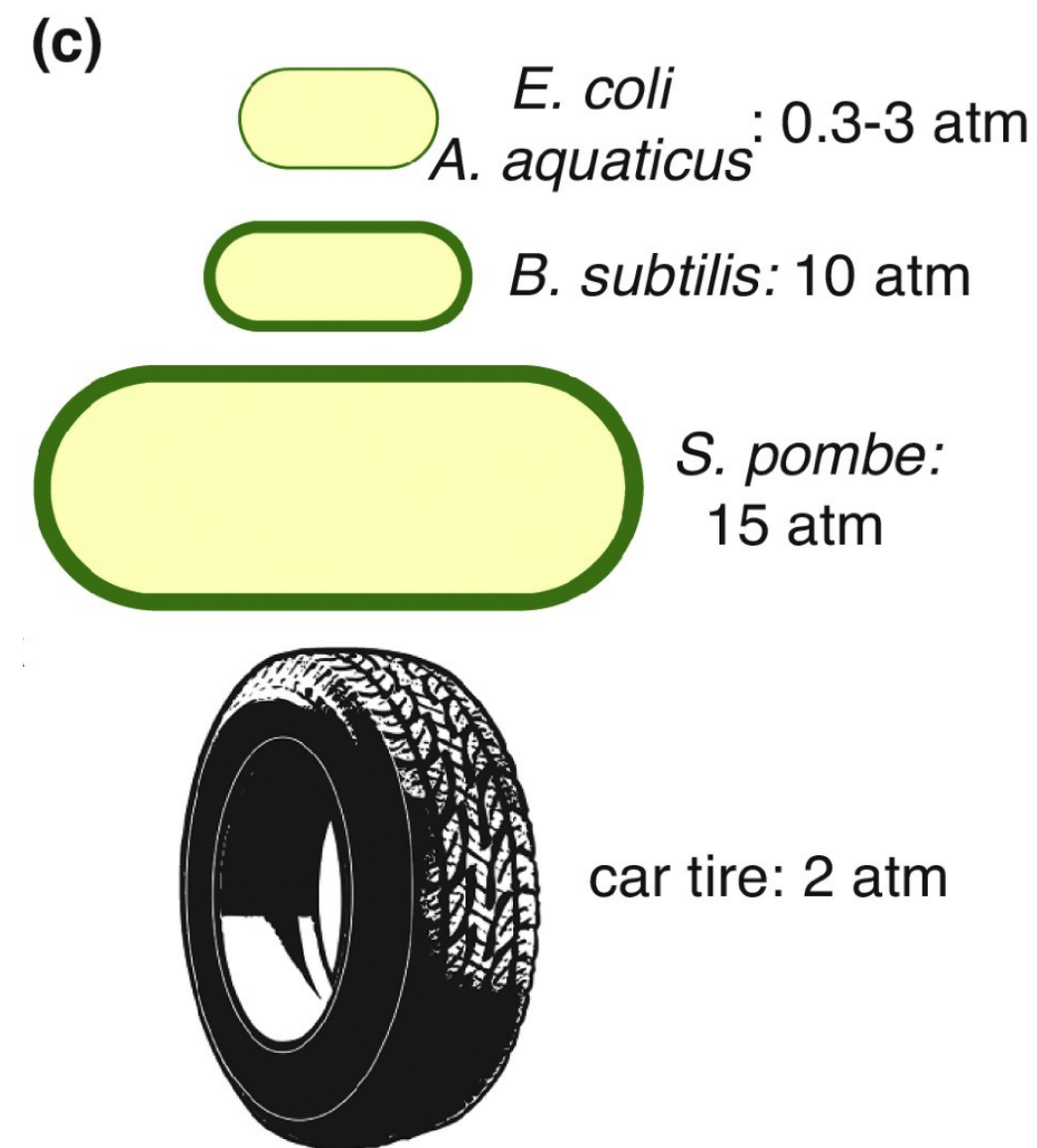
Figure 6.22 Physical Biology of the Cell, 2ed. (© Garland Science 2013)



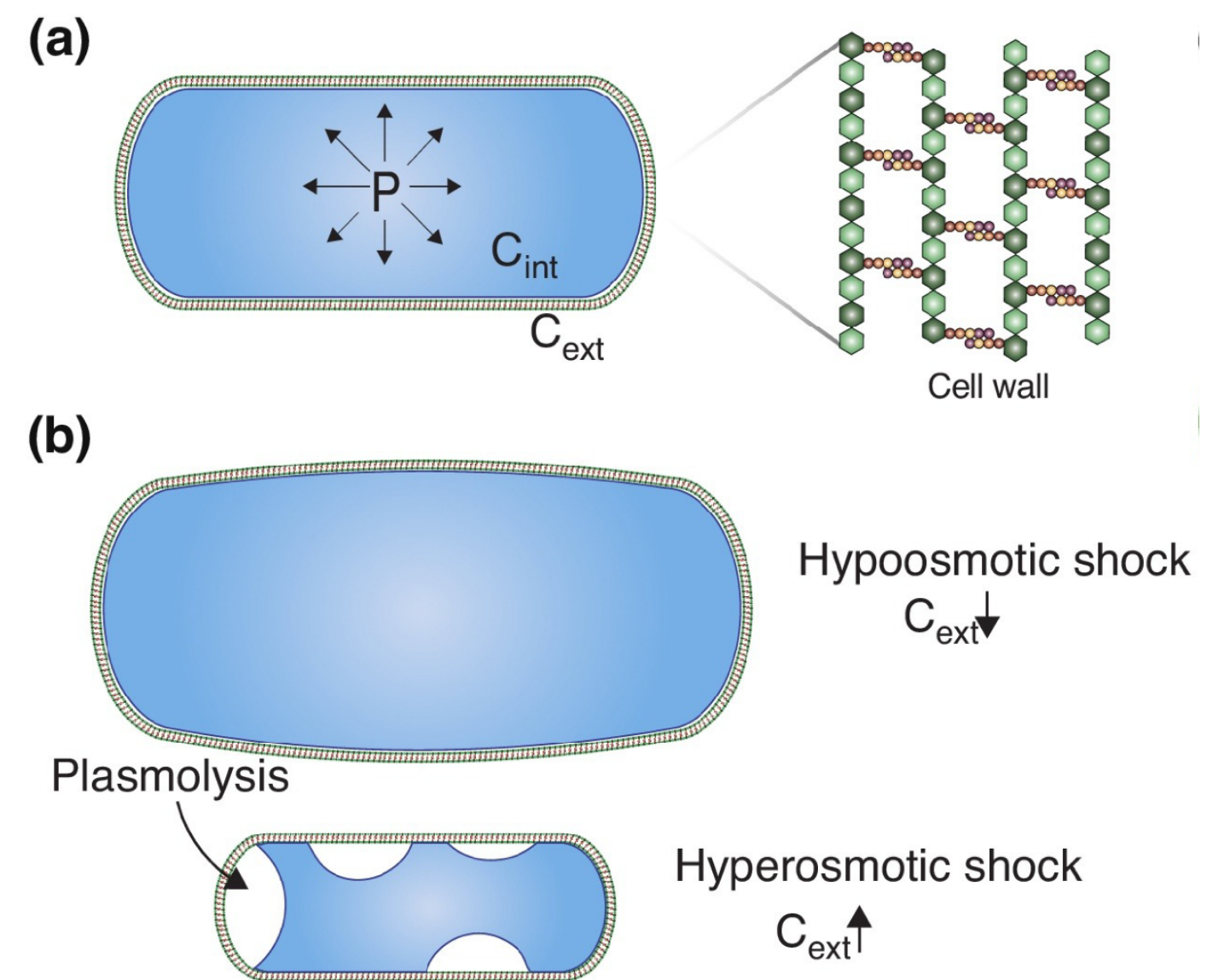
.Calculating osmotic pressure

Ranges of osmotic pressures

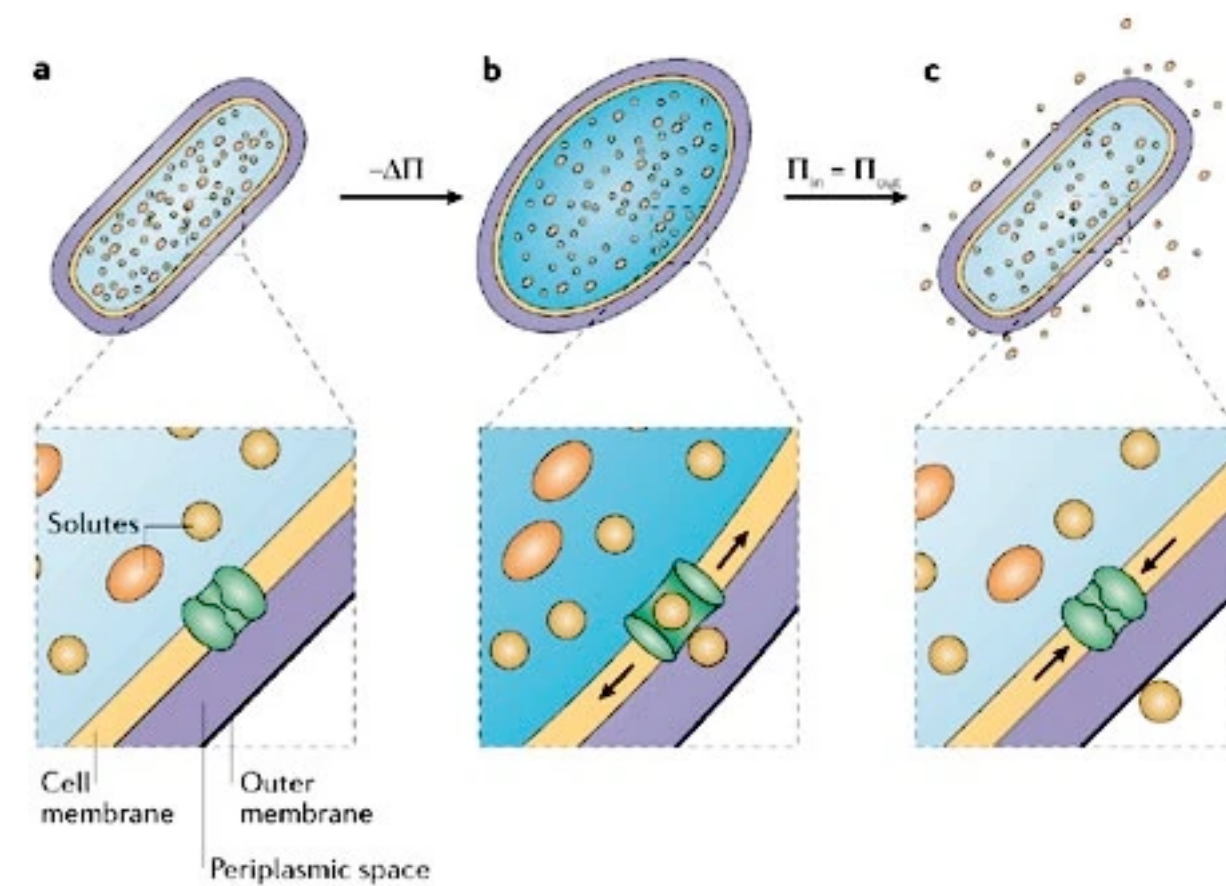
Internal pressure stresses the cell wall



Osmotic shock

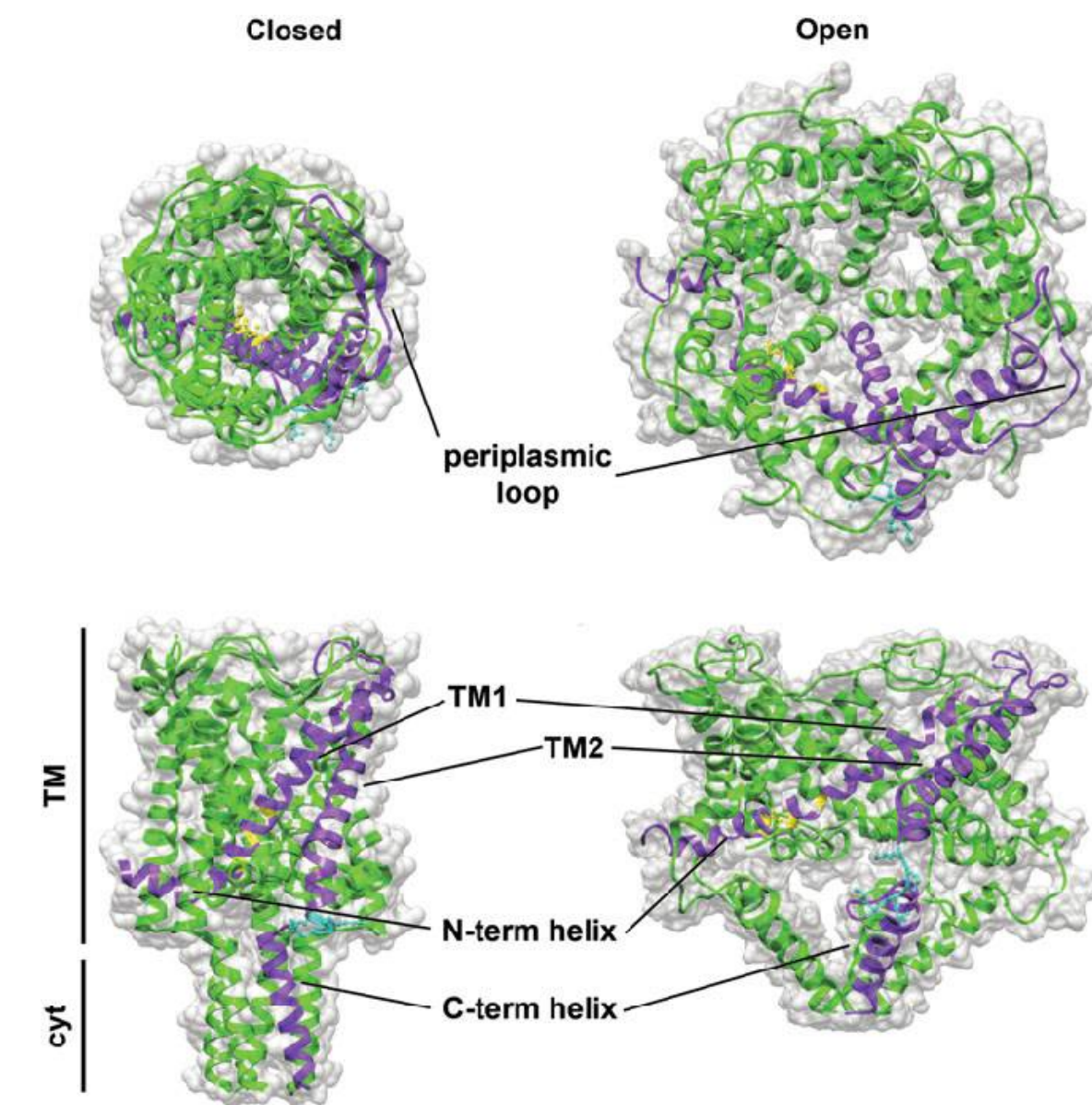


Cells sense and respond to osmotic shock



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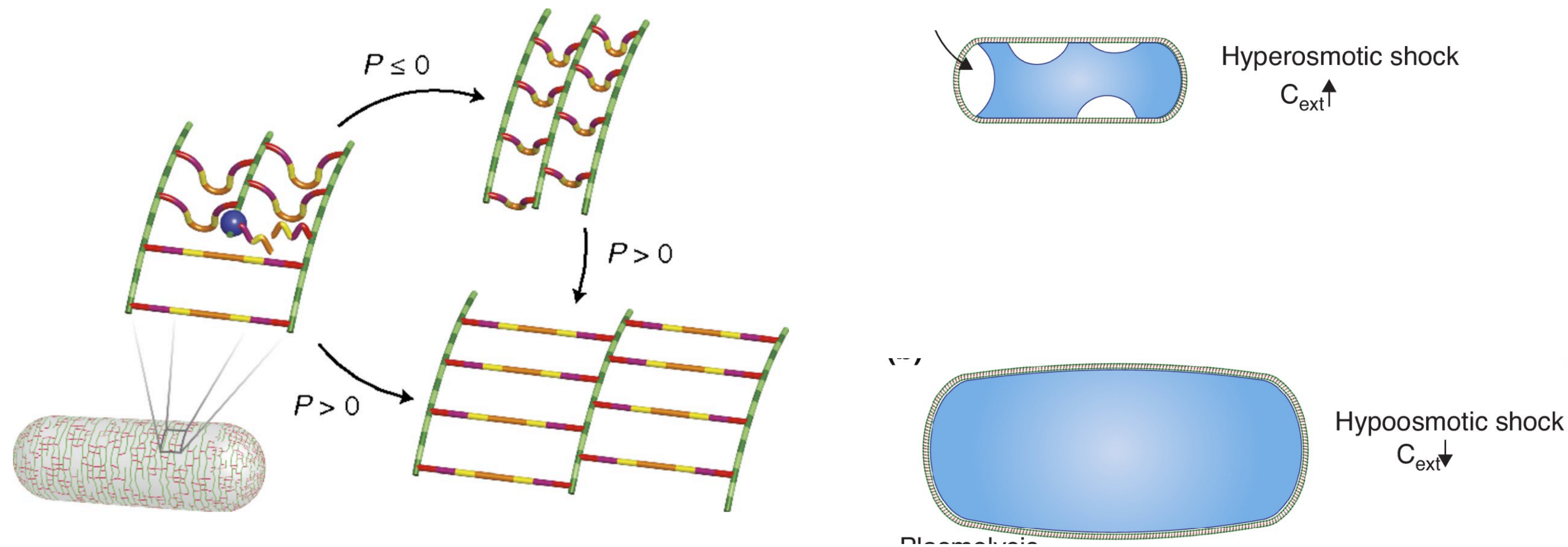
ion channels at the inner membrane help cells resist to osmotic shock
function as mechanosensitive “relief valves”



MScL: a model for ion channel structure and mechanical activation

How does turgor pressure contribute to growth?

Modulating cell wall stress with osmotic shock



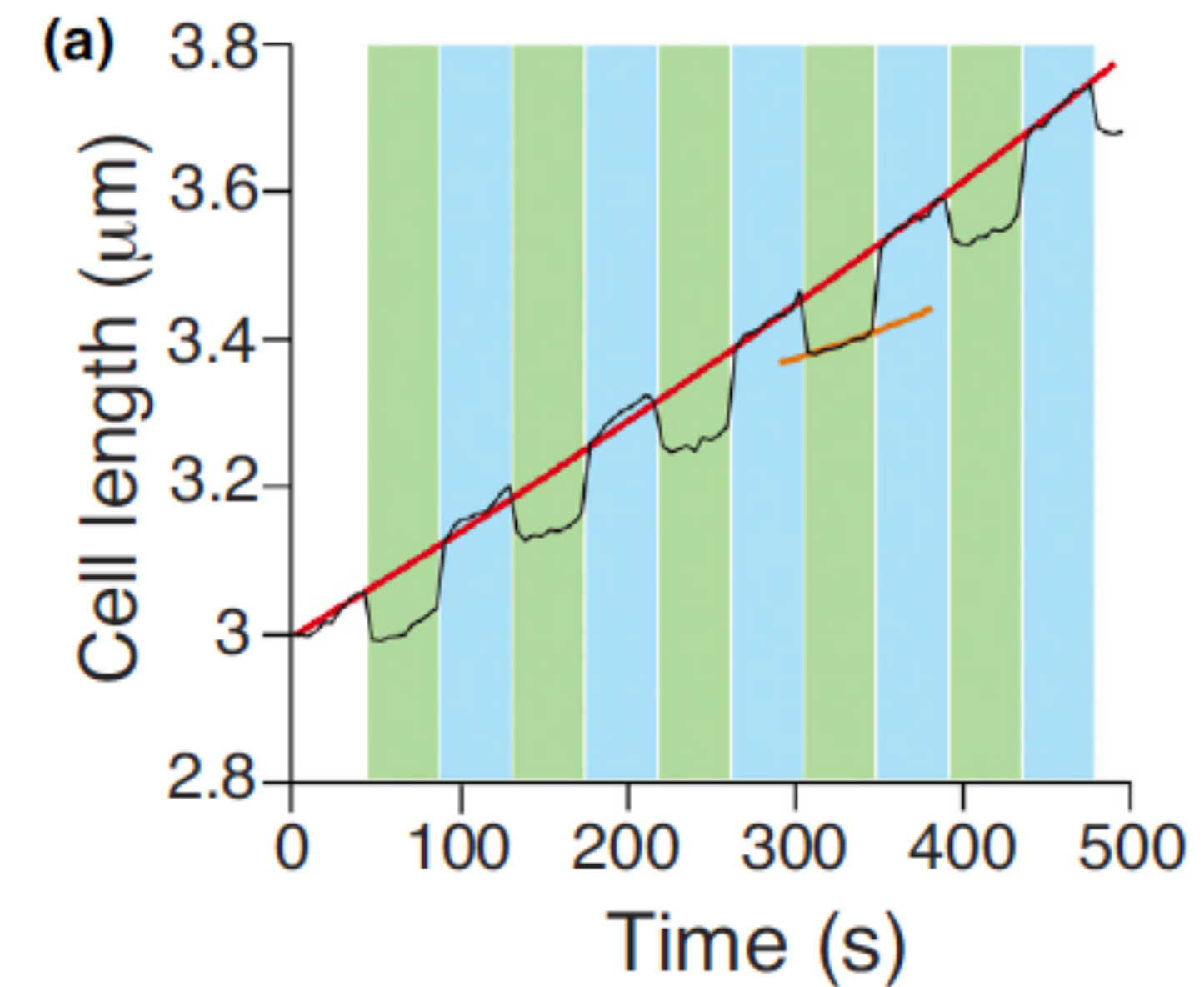
We can use osmotic pressure changes to probe the contributions of cell wall mechanics to growth

Wall stress does not affect *E. coli* growth

Growth during osmotic shocks



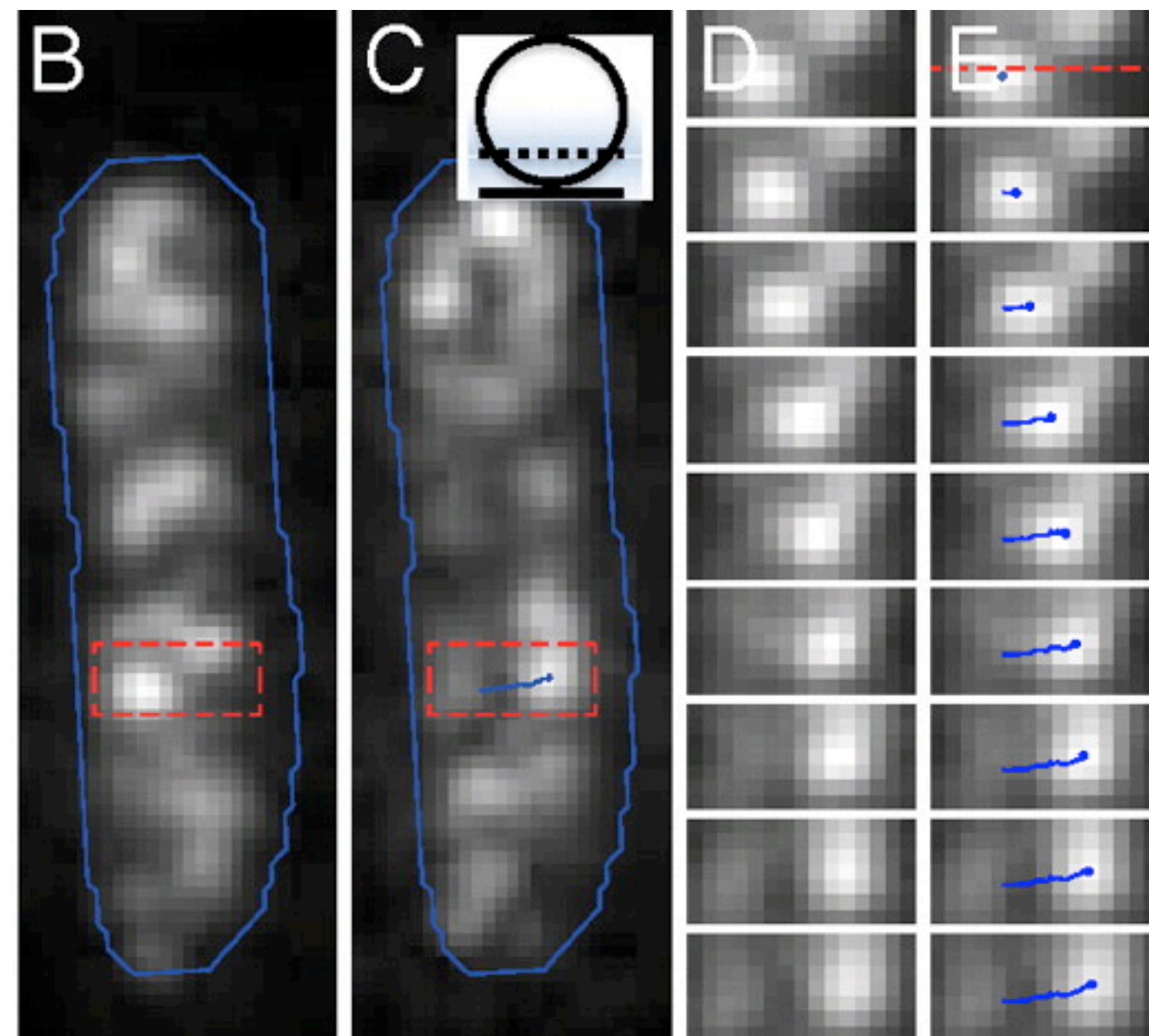
E. coli with a fluorescently-labeled peptidoglycan
Pulses in osmotic pressure for sequential shock
Measure cell length



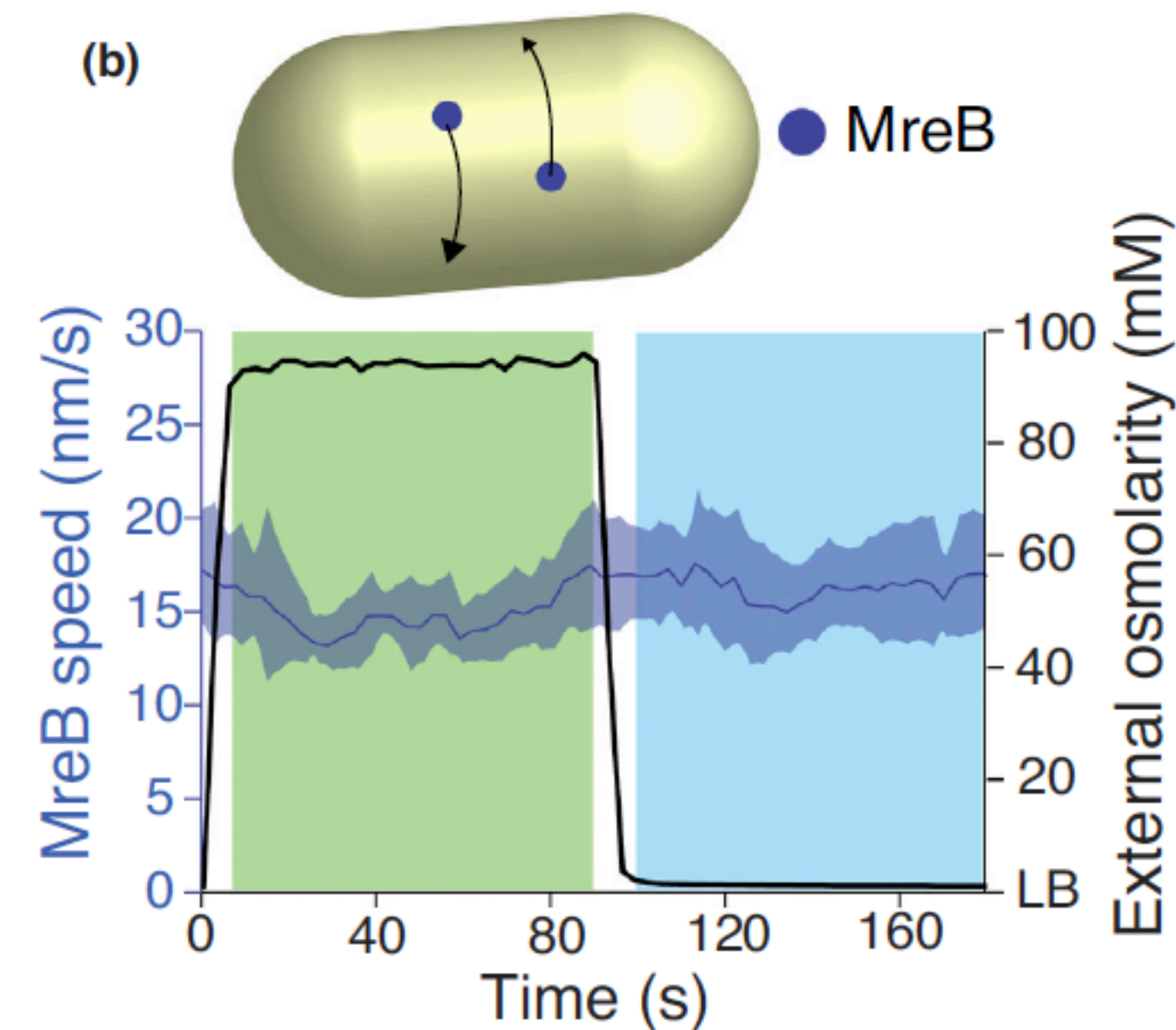
E coli cell wall synthesis machinery

MreB speed is not affected by osmotic shock

Speed



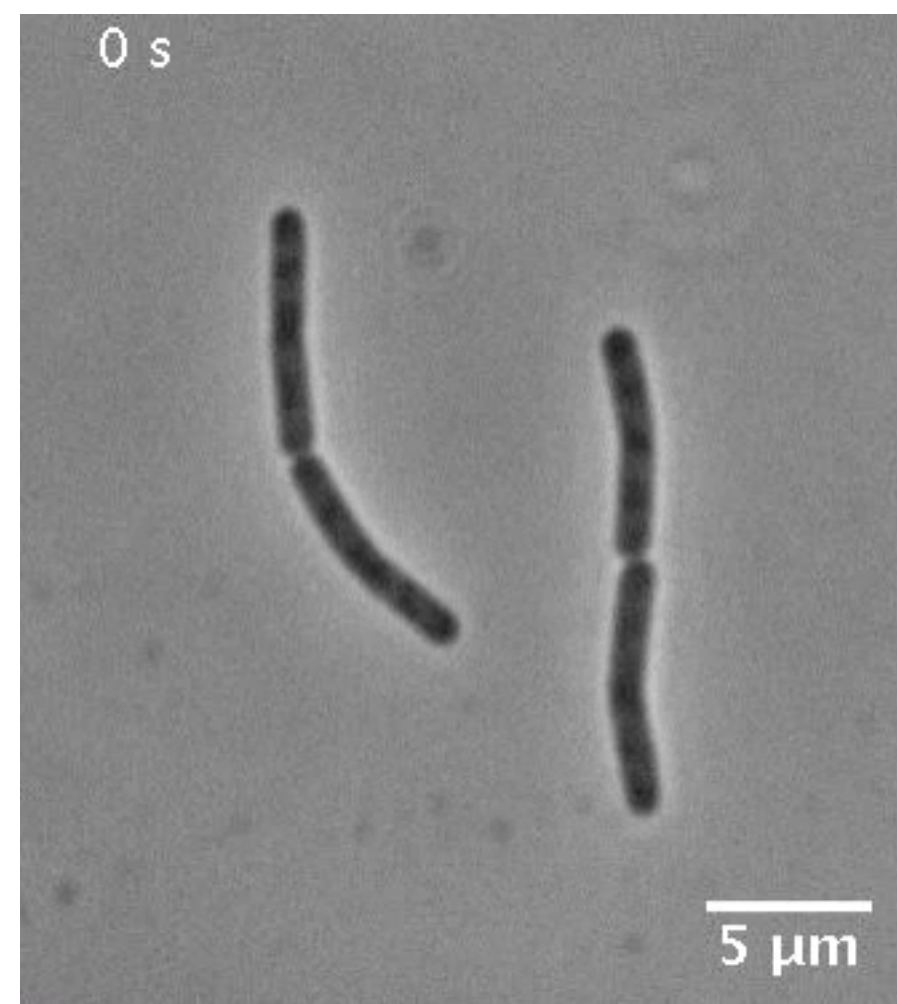
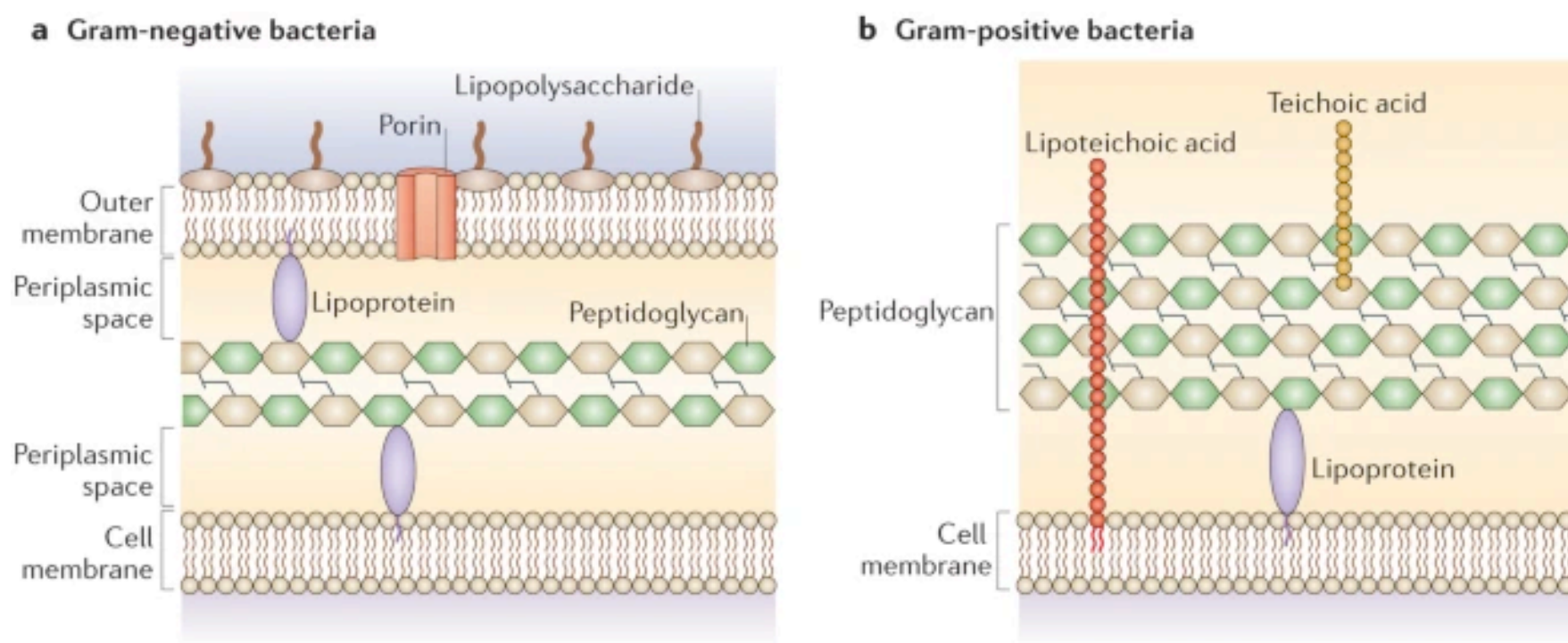
Speed during shock



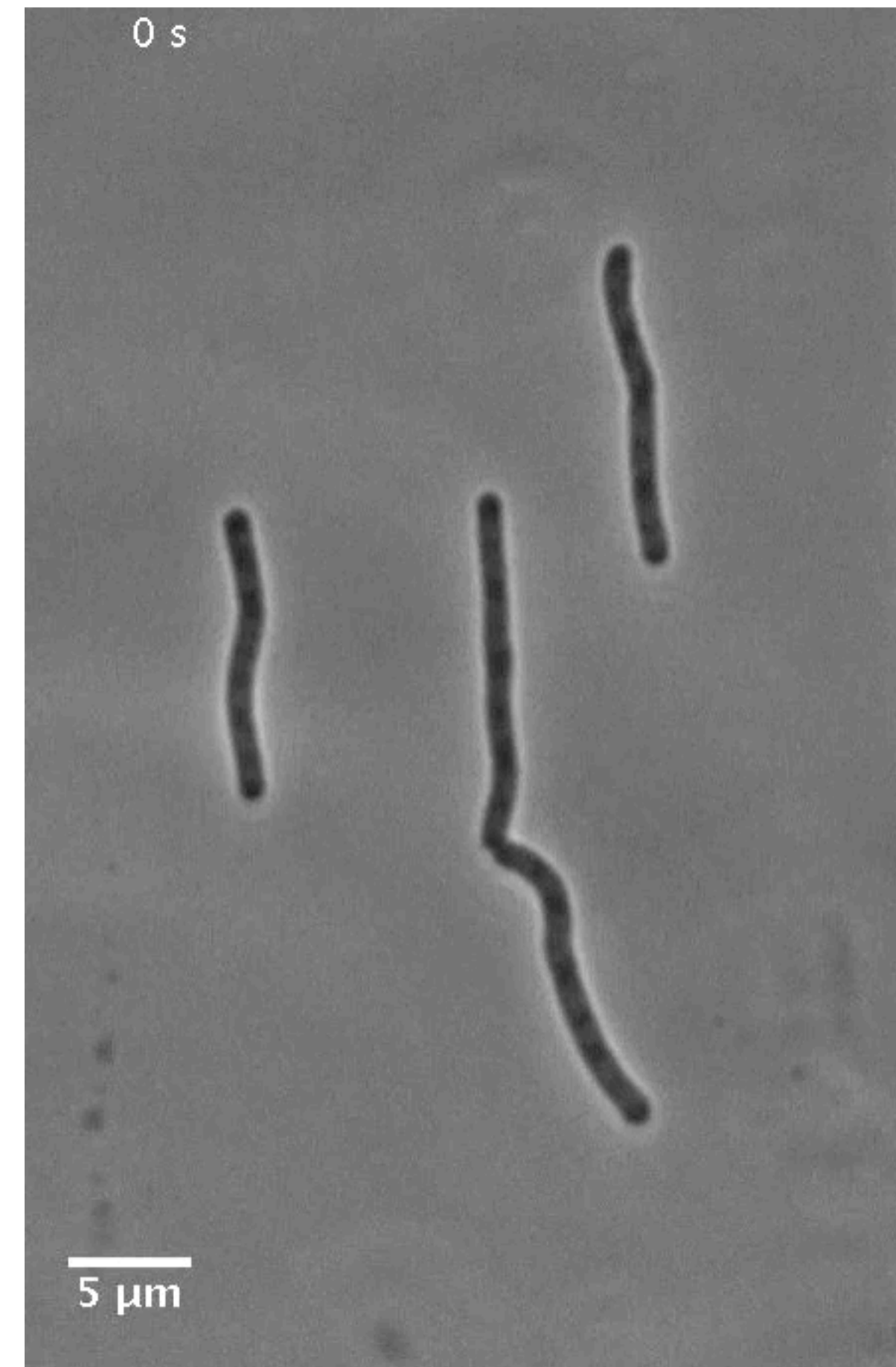
Does *E. coli* coordinate cell growth via a mechanical feedback?... **Not really**

Mechanical feedback in *Bacillus*

Same experiment, other bacterium (“Gram-positive”)



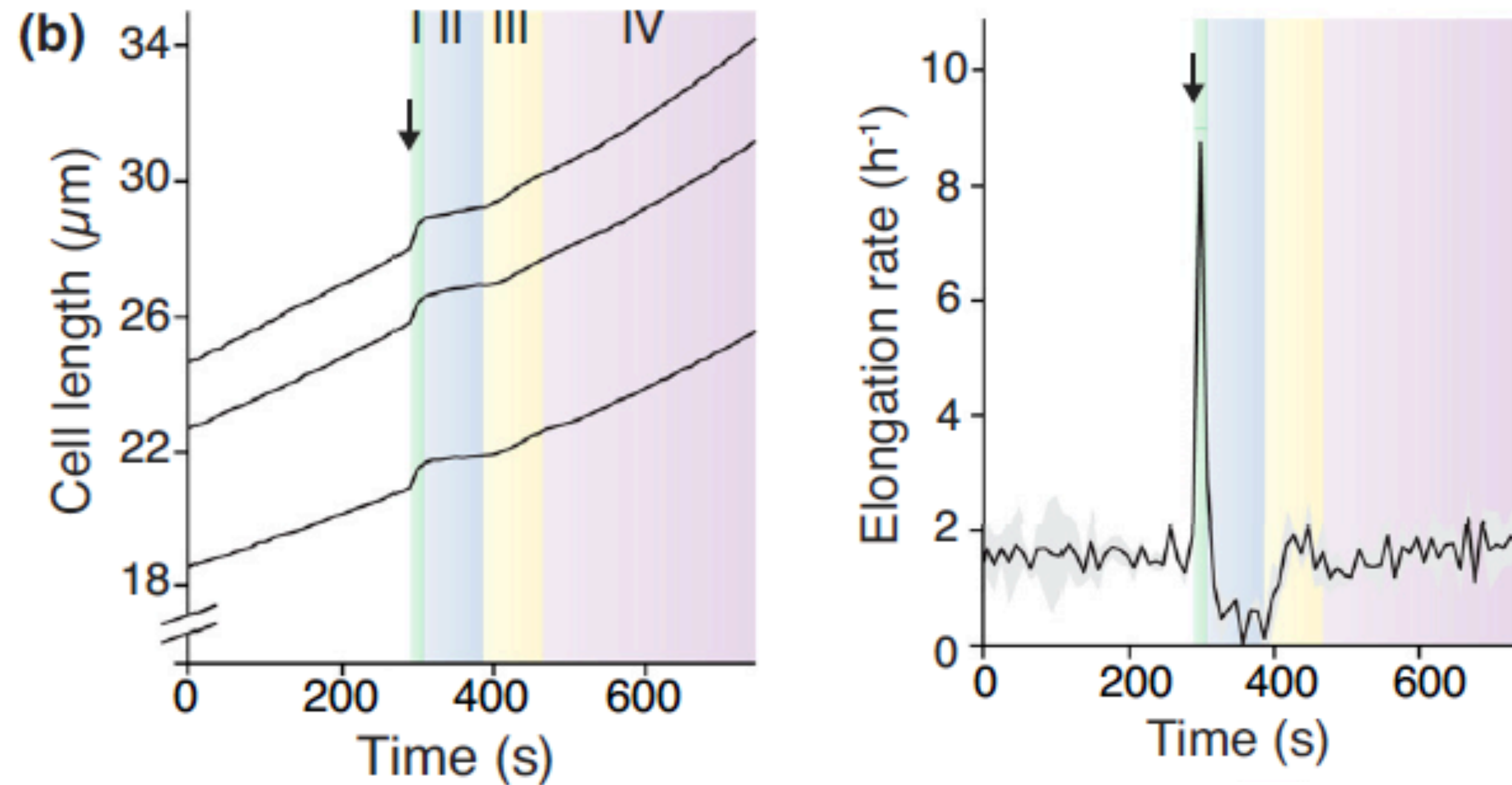
Bacillus: 1 hypoosmotic shock



Bacillus: successive shocks

Does turgor pressure contribute to *Bacillus* growth?

hypoosmotic shock (stretch)



I Osmotic swelling
II Growth inhibition
III Burst in growth
IV Relaxation to steady-state elongation rate

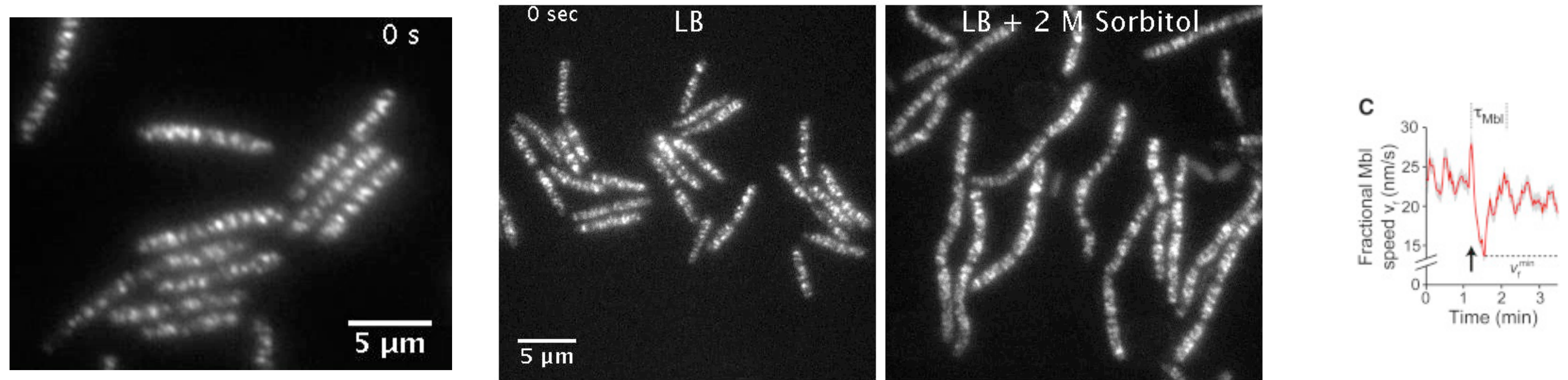
Inhibition followed by growth burst

Yes

Mechanical stress tends to reduce growth

Cell wall synthesis under stress

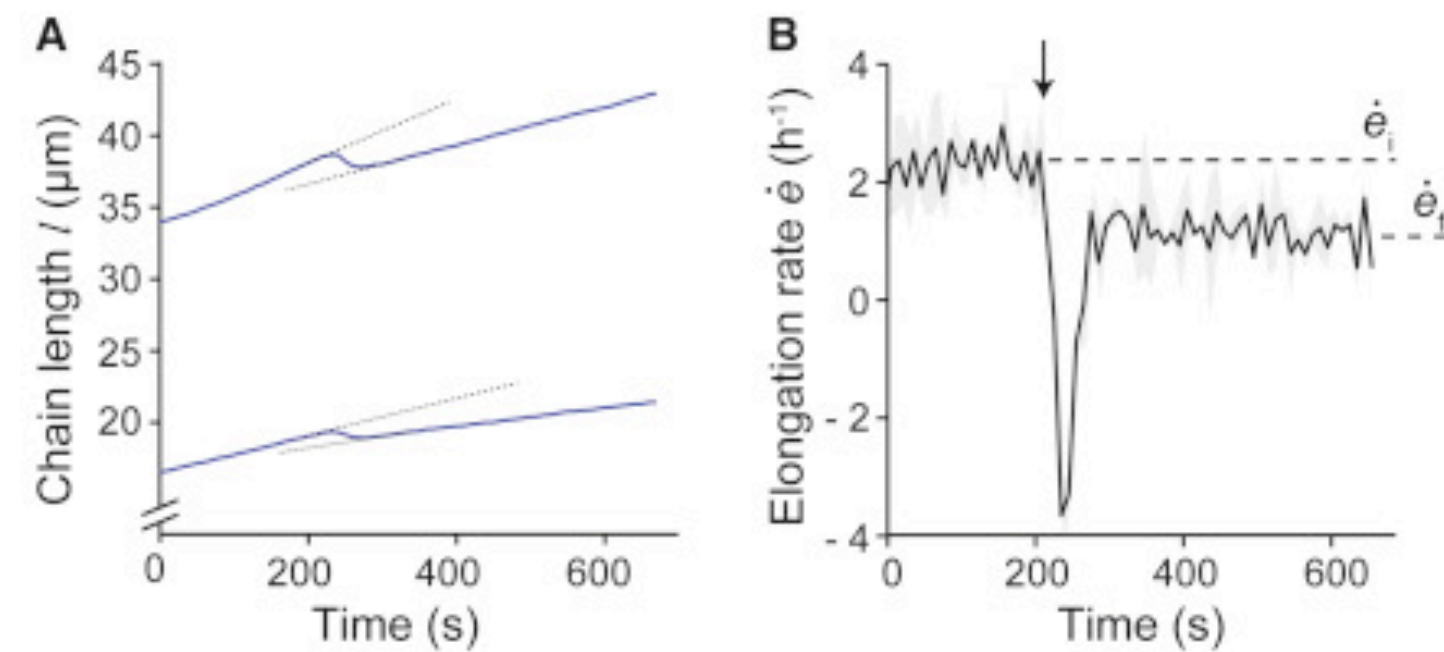
Tracking trajectories of cell wall synthesis protein Mbl



Hypoosmotic shock slows down cell wall synthesis

Growth during cell envelope relaxation

Response to hyperosmotic shock



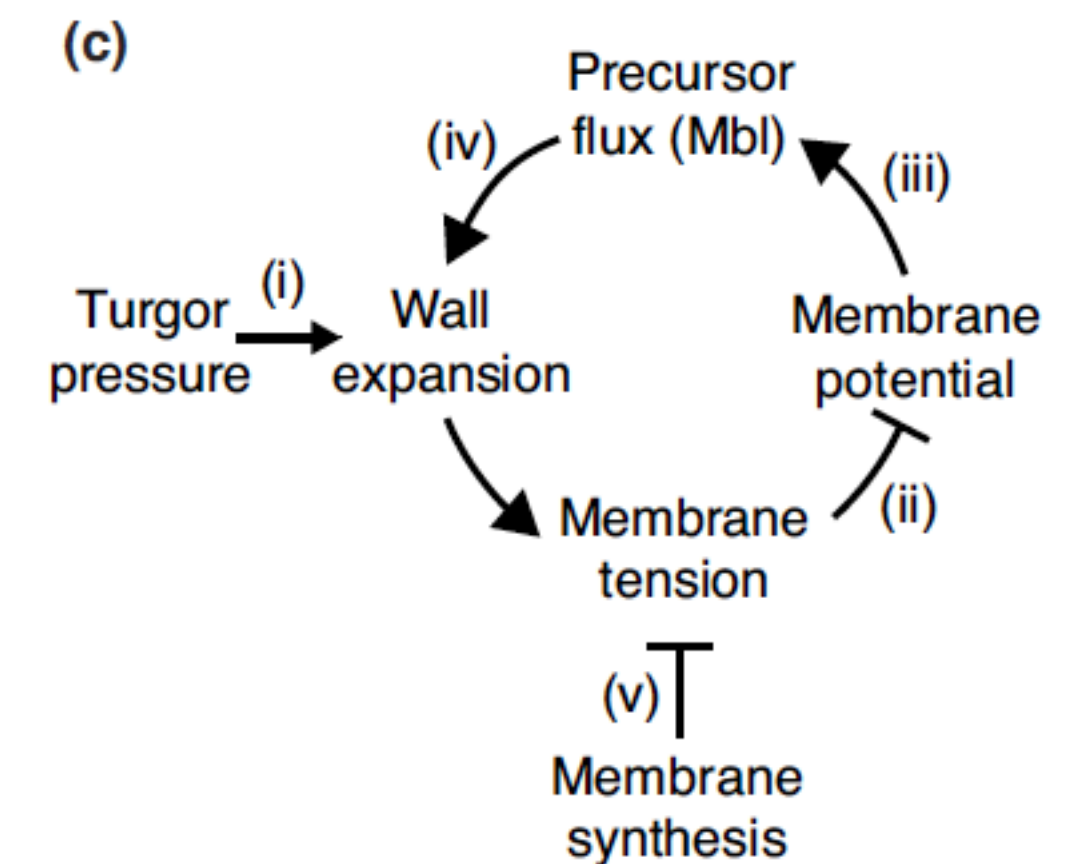
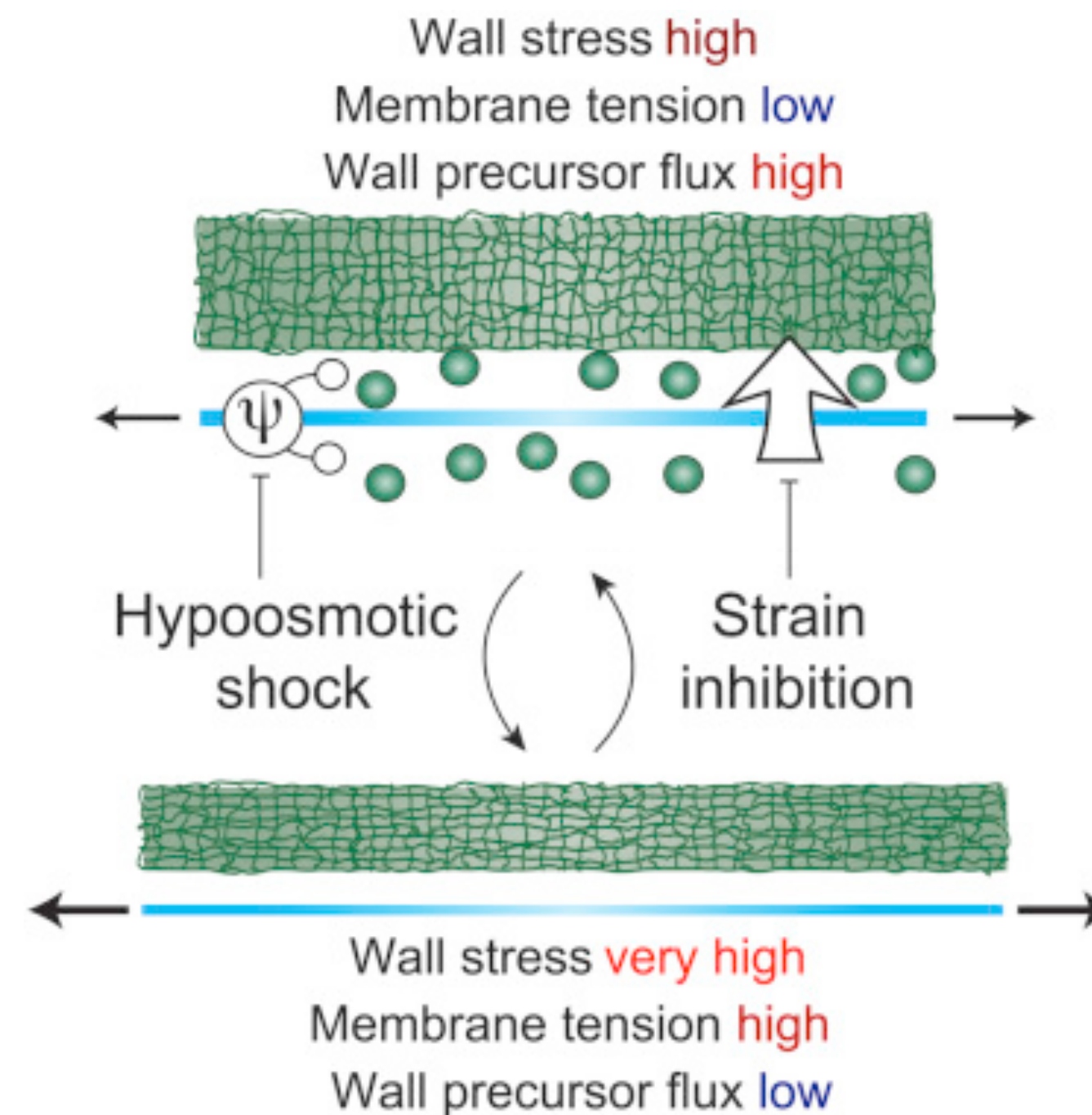
Hyperosmotic shock also slows down cell growth

Mechanisms of tension-dependent growth

Not just mechanics

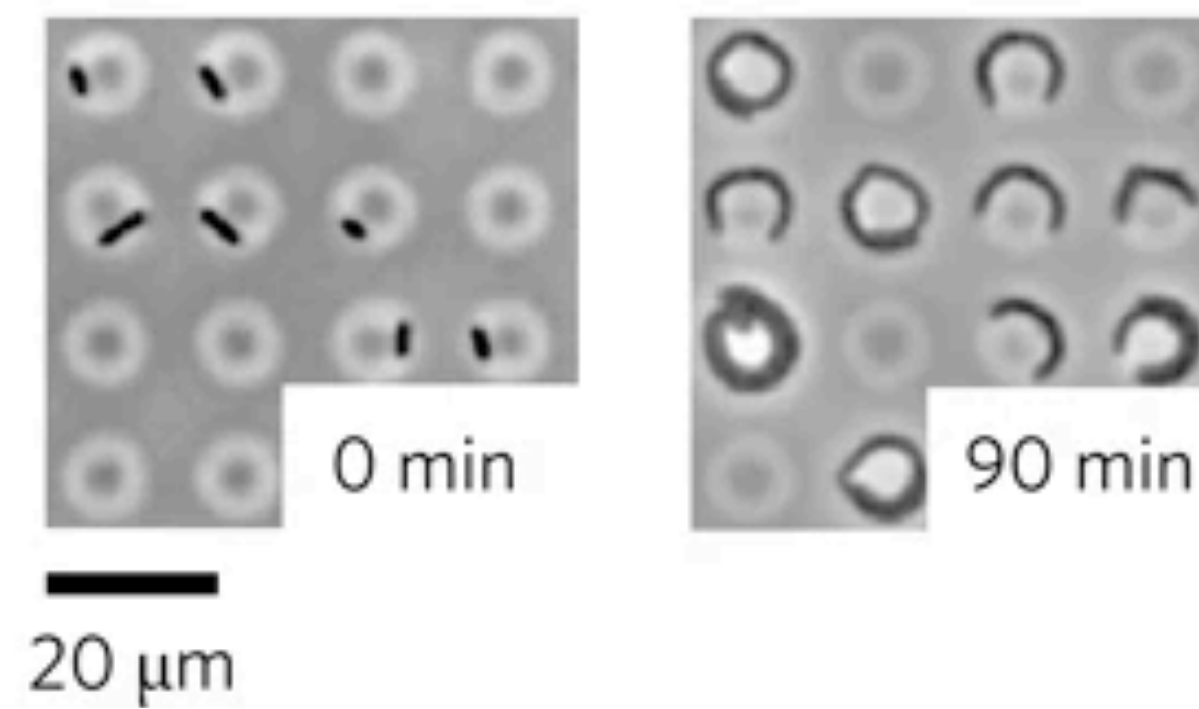
Membrane tension regulates:

- mechanical stress (stretches cell wall)
- electrical potential across membrane (drives synthesis machinery)
- flux of cell wall precursors (stimulates growth)

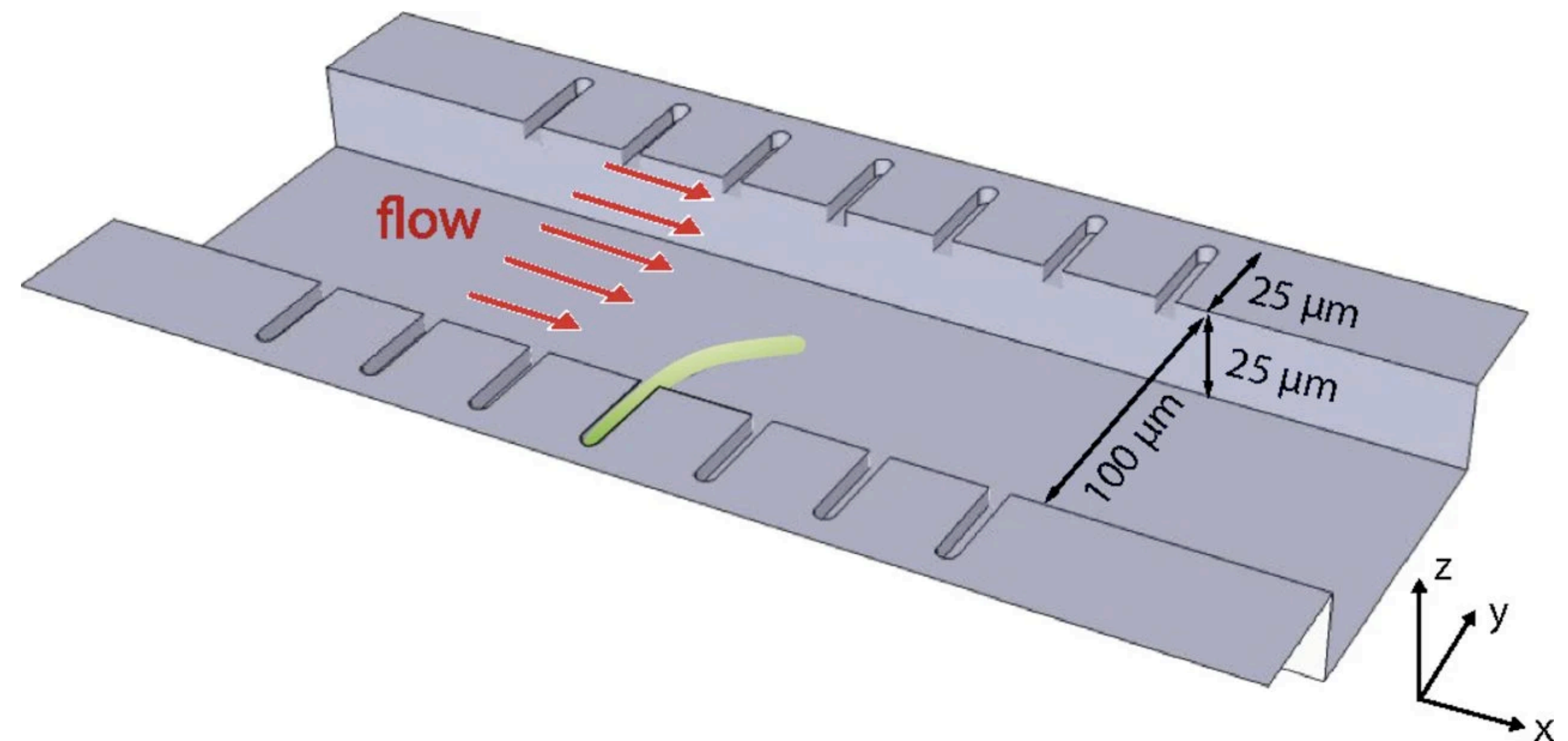


Growth under external force

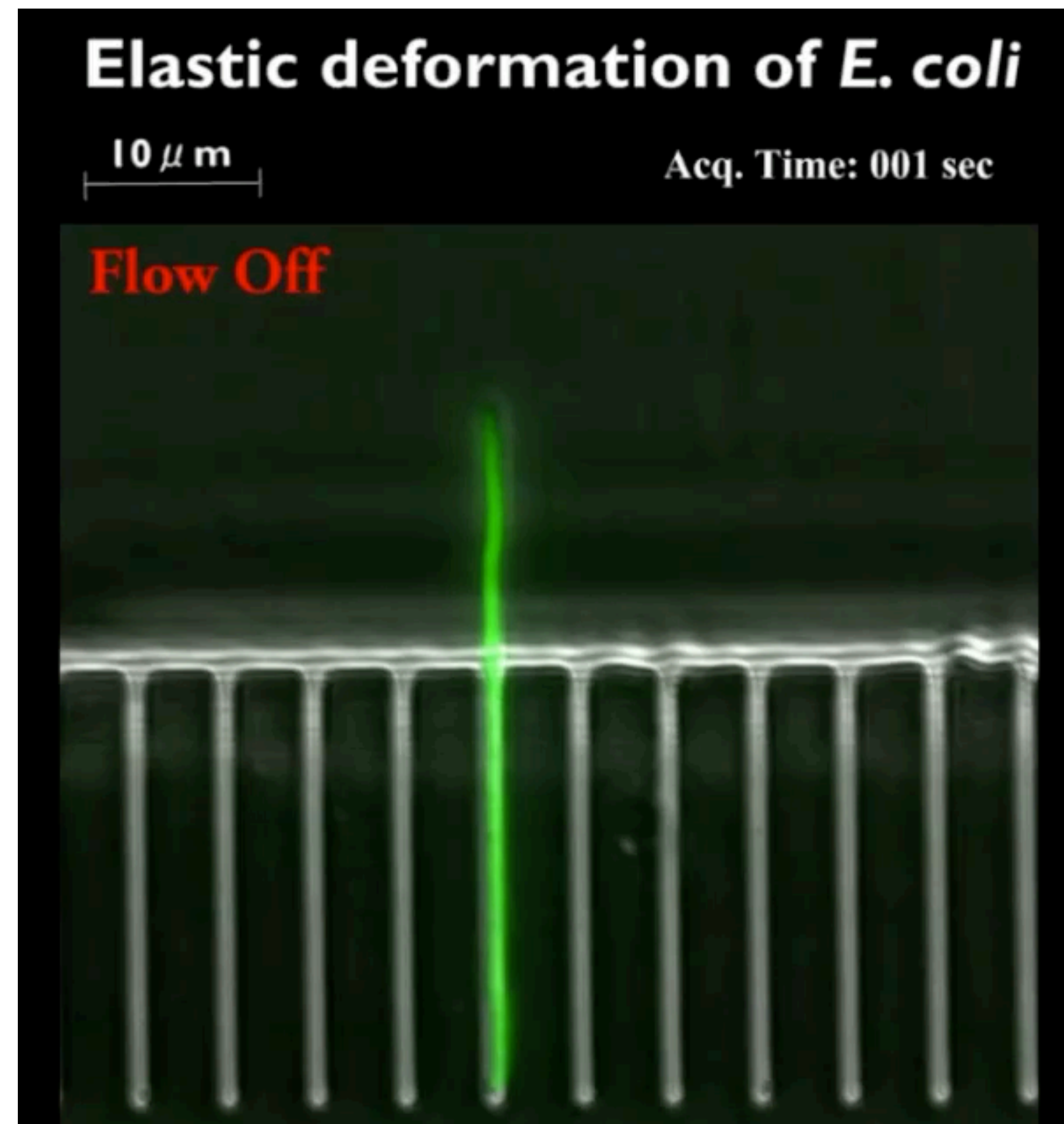
Growth in chambers



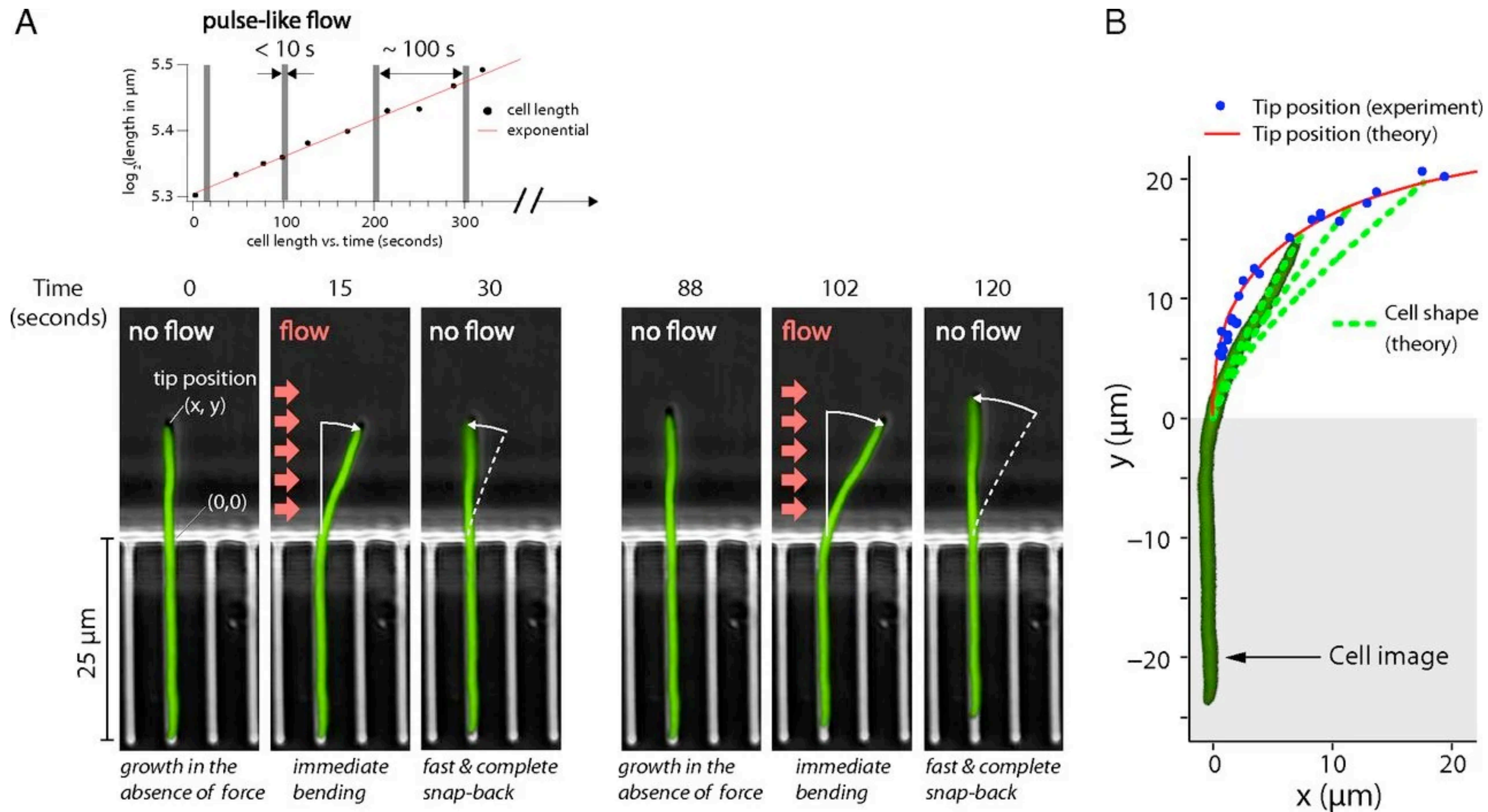
Growth under flow



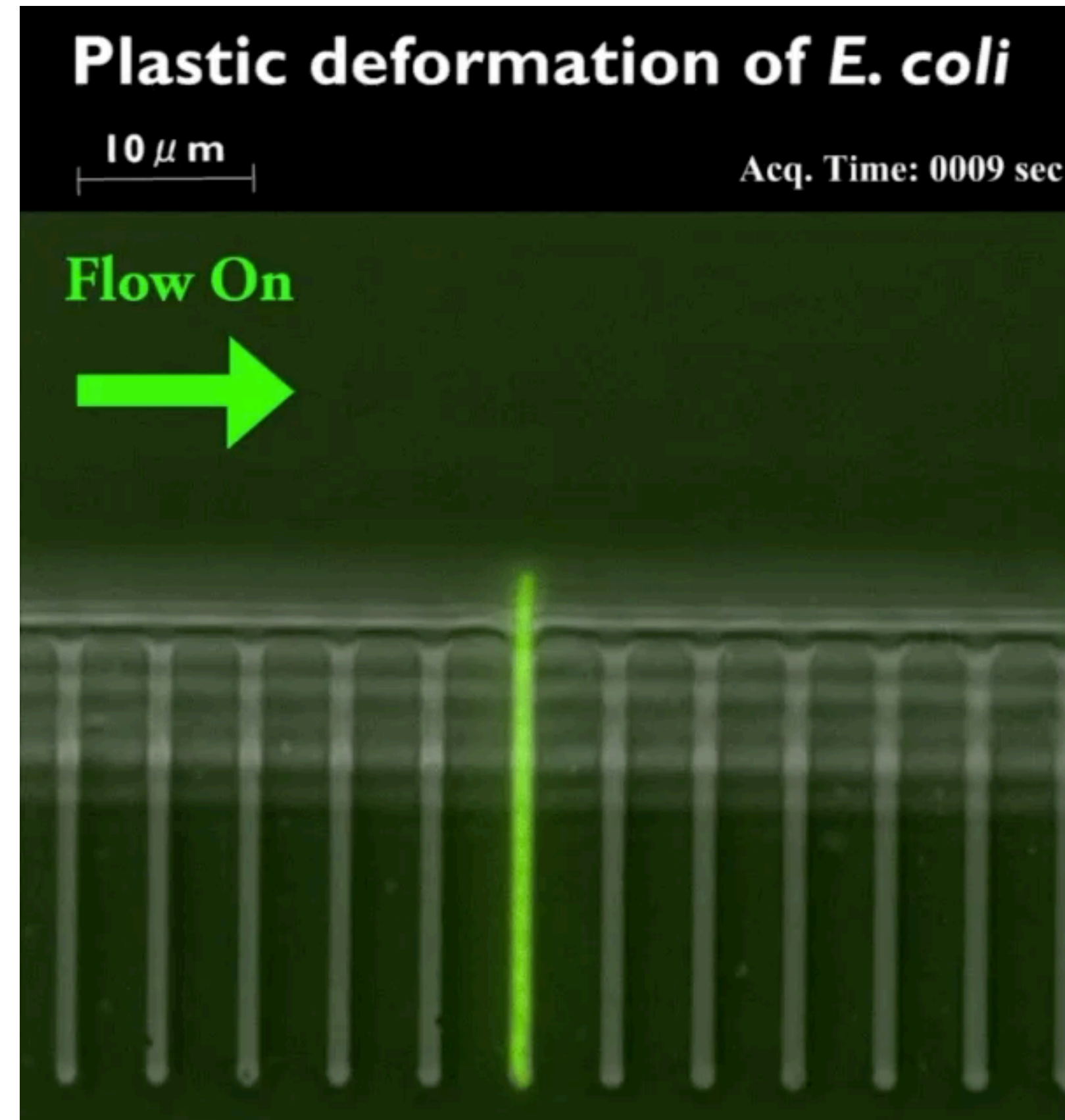
Flow-induced deformations



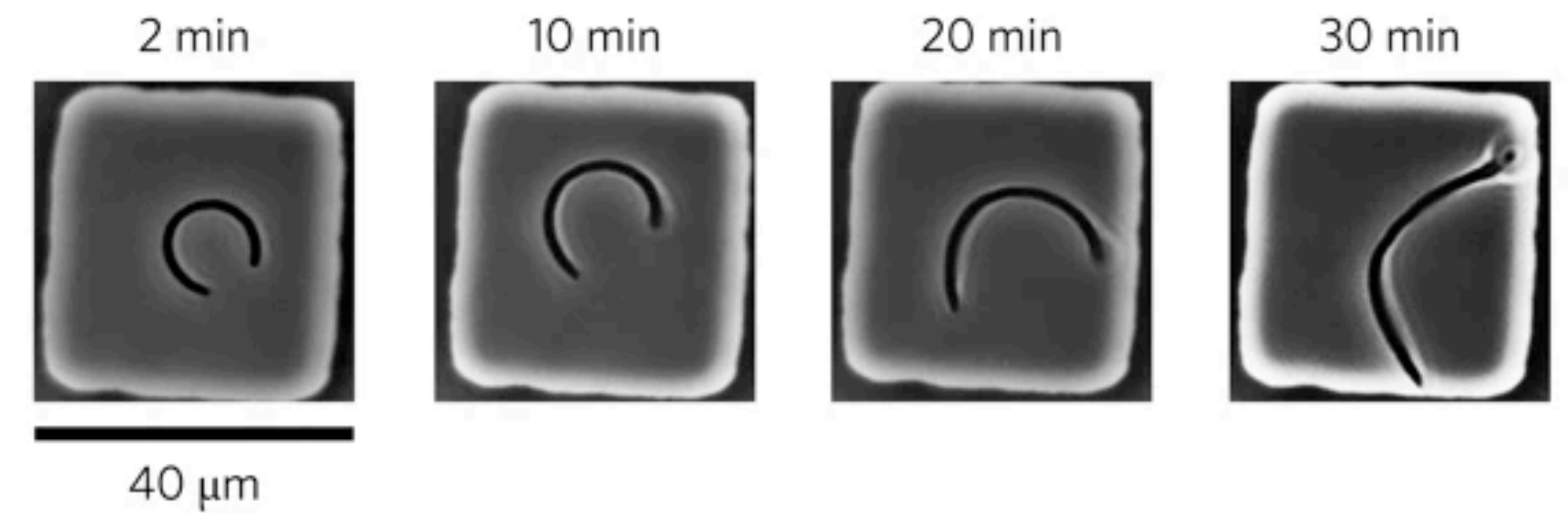
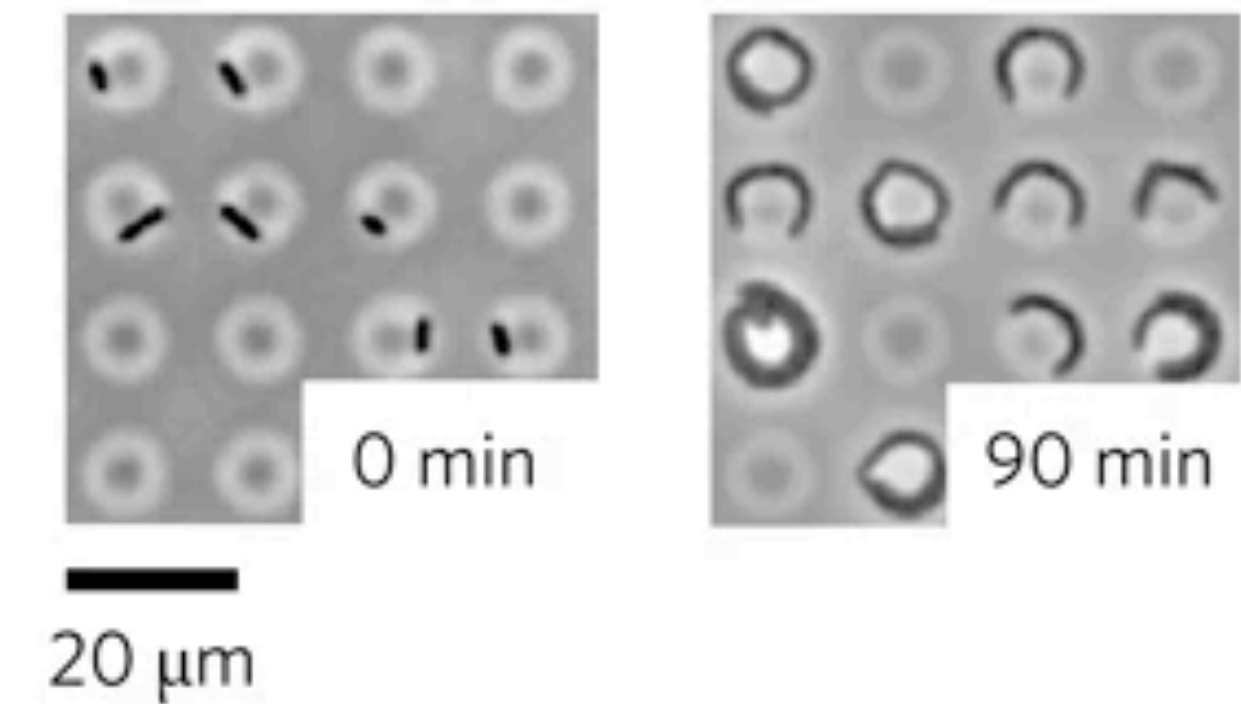
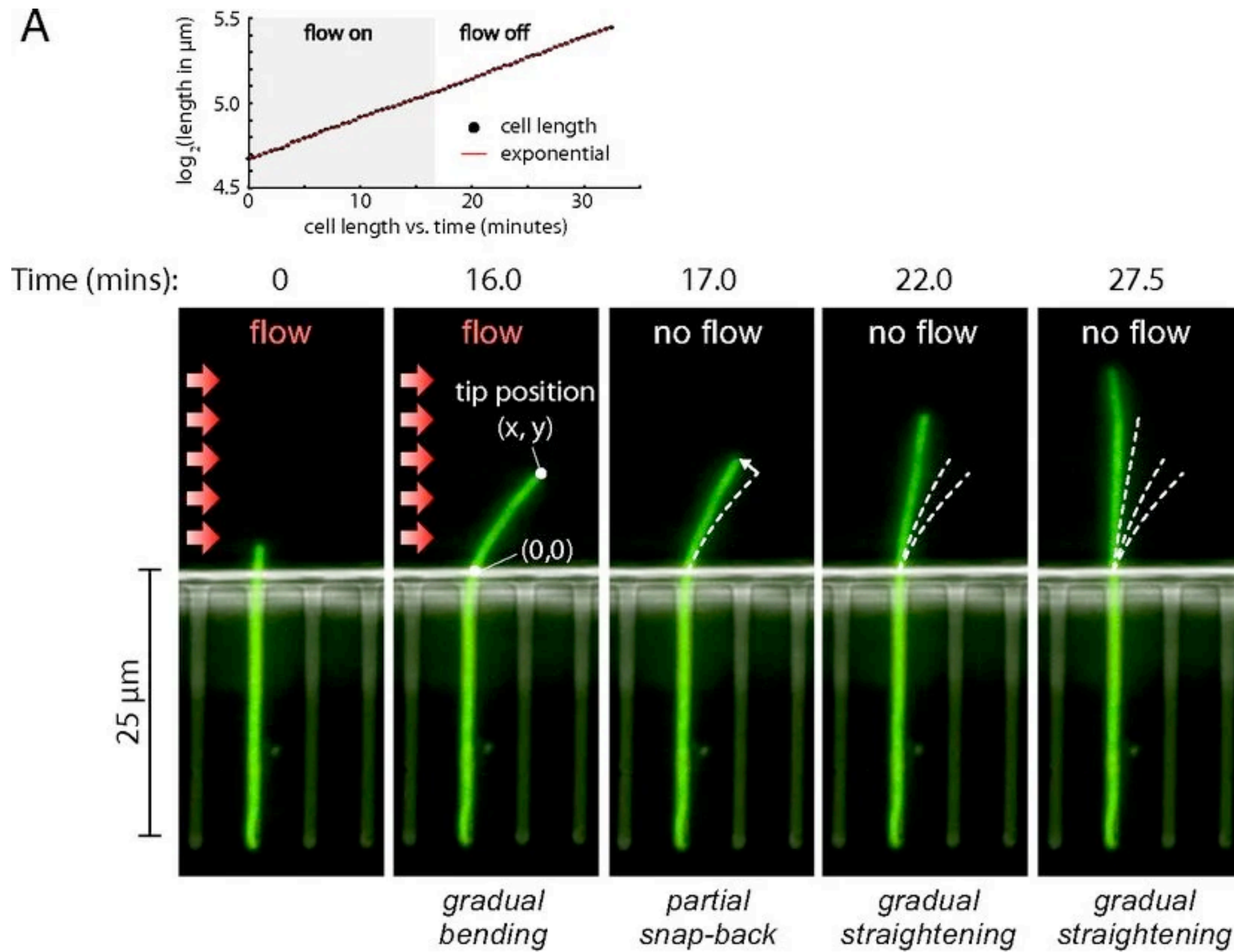
Elastic deformation on short timescale



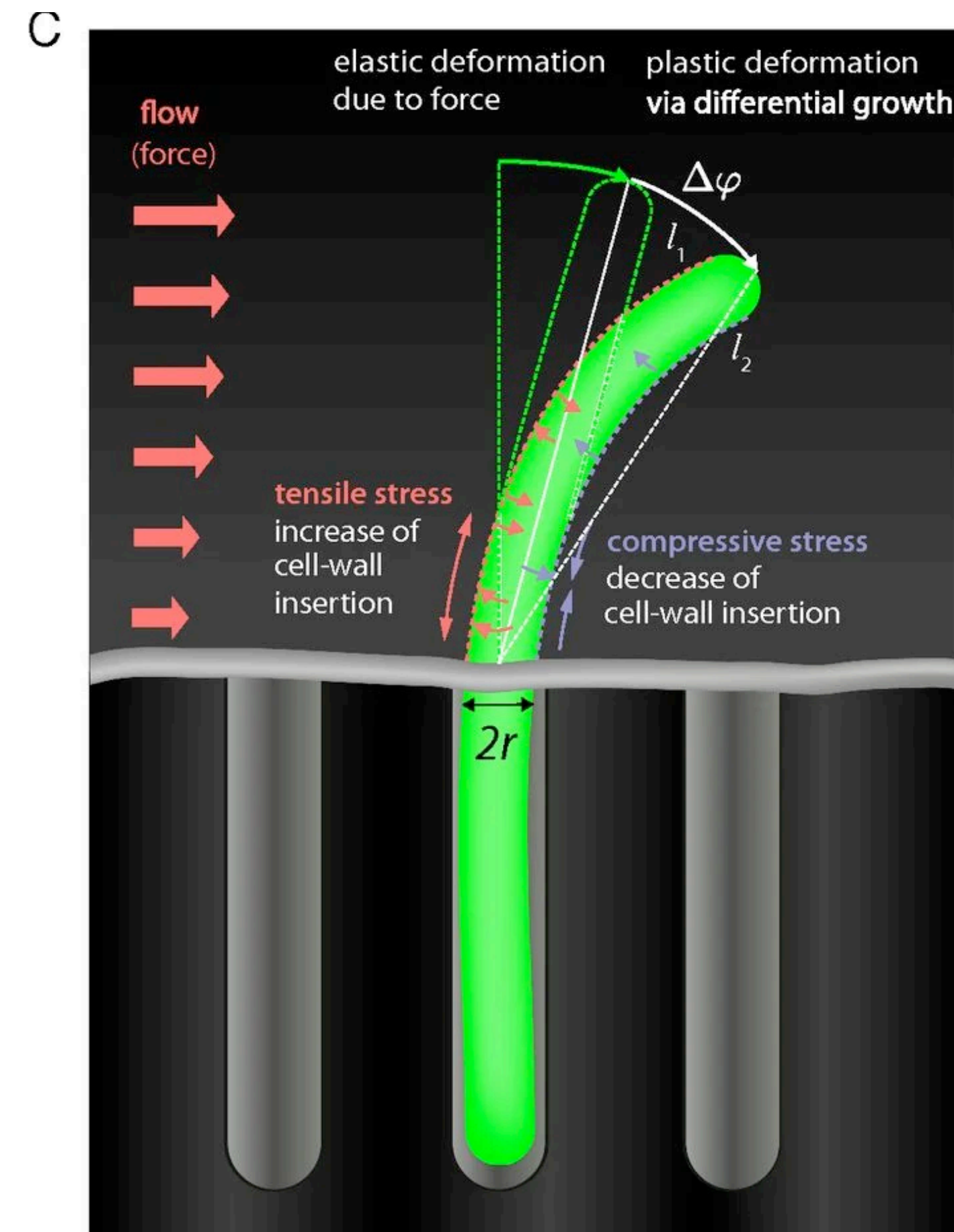
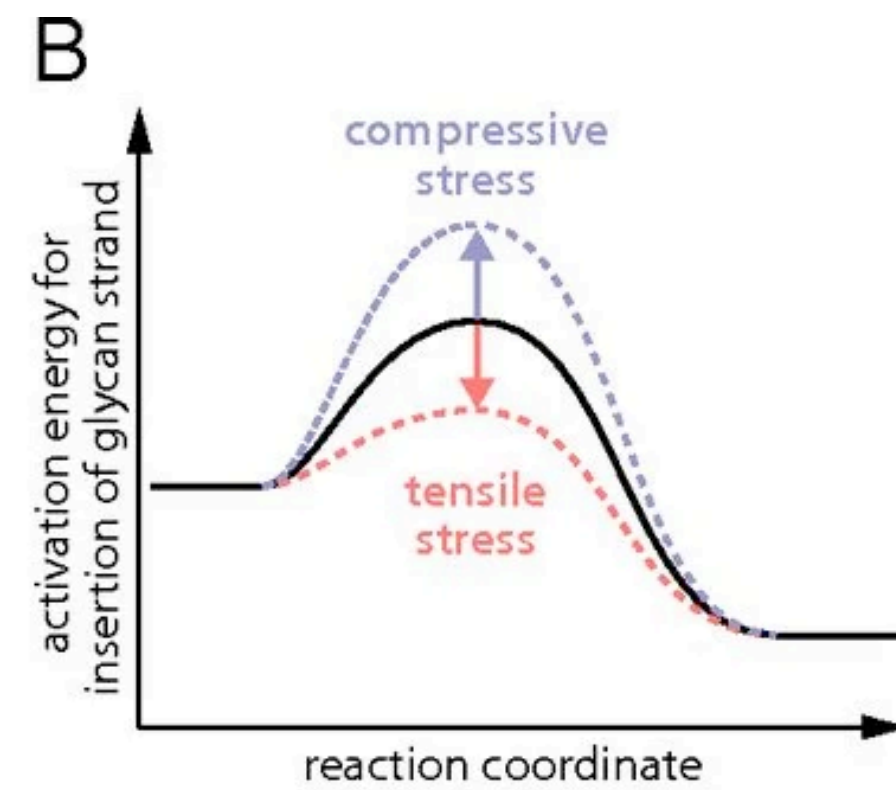
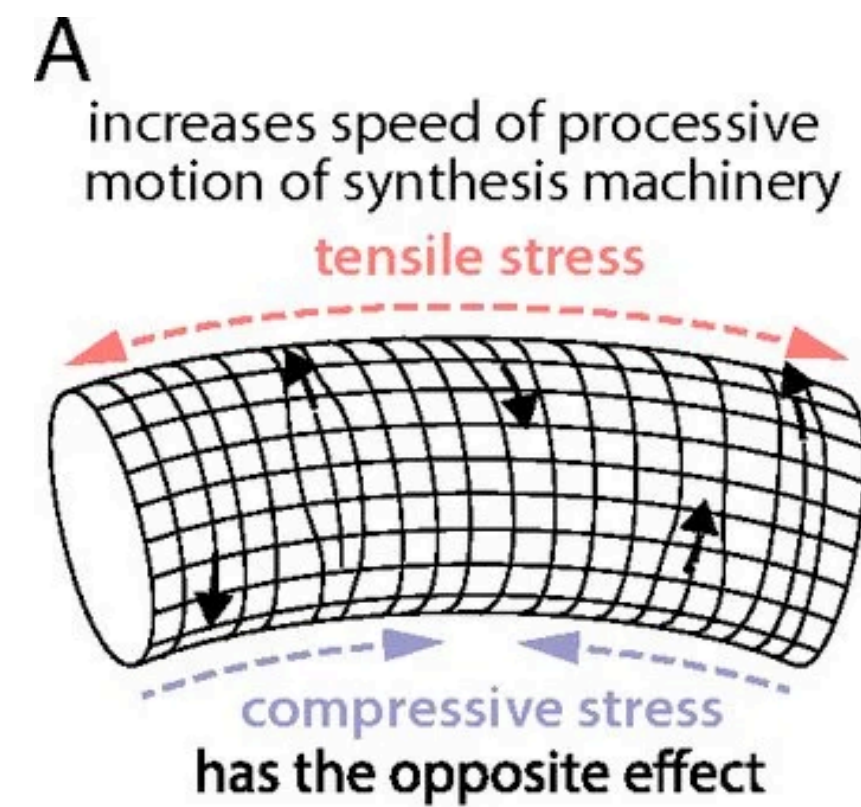
Long timescale deformations



Plastic deformation and recovery

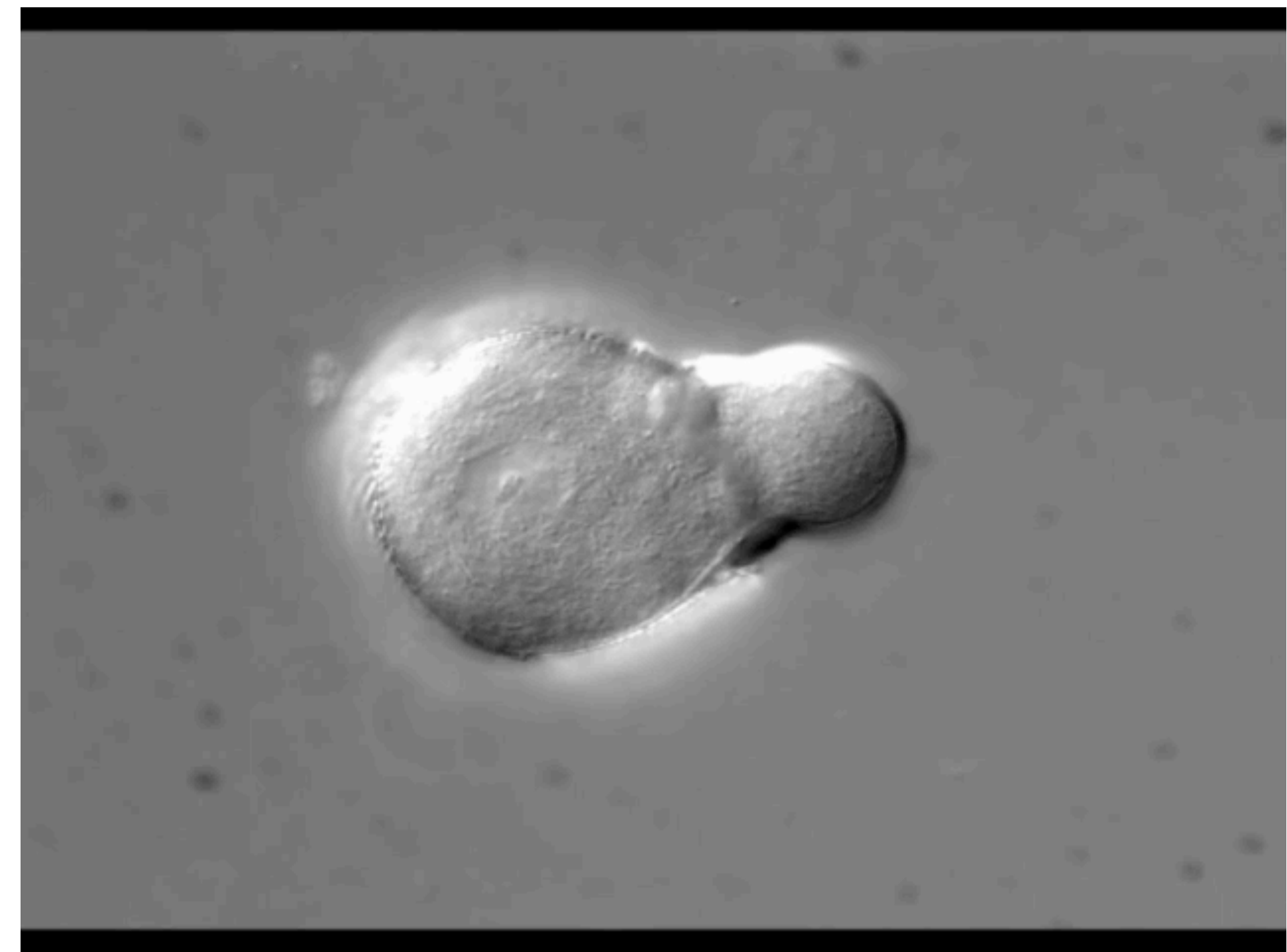
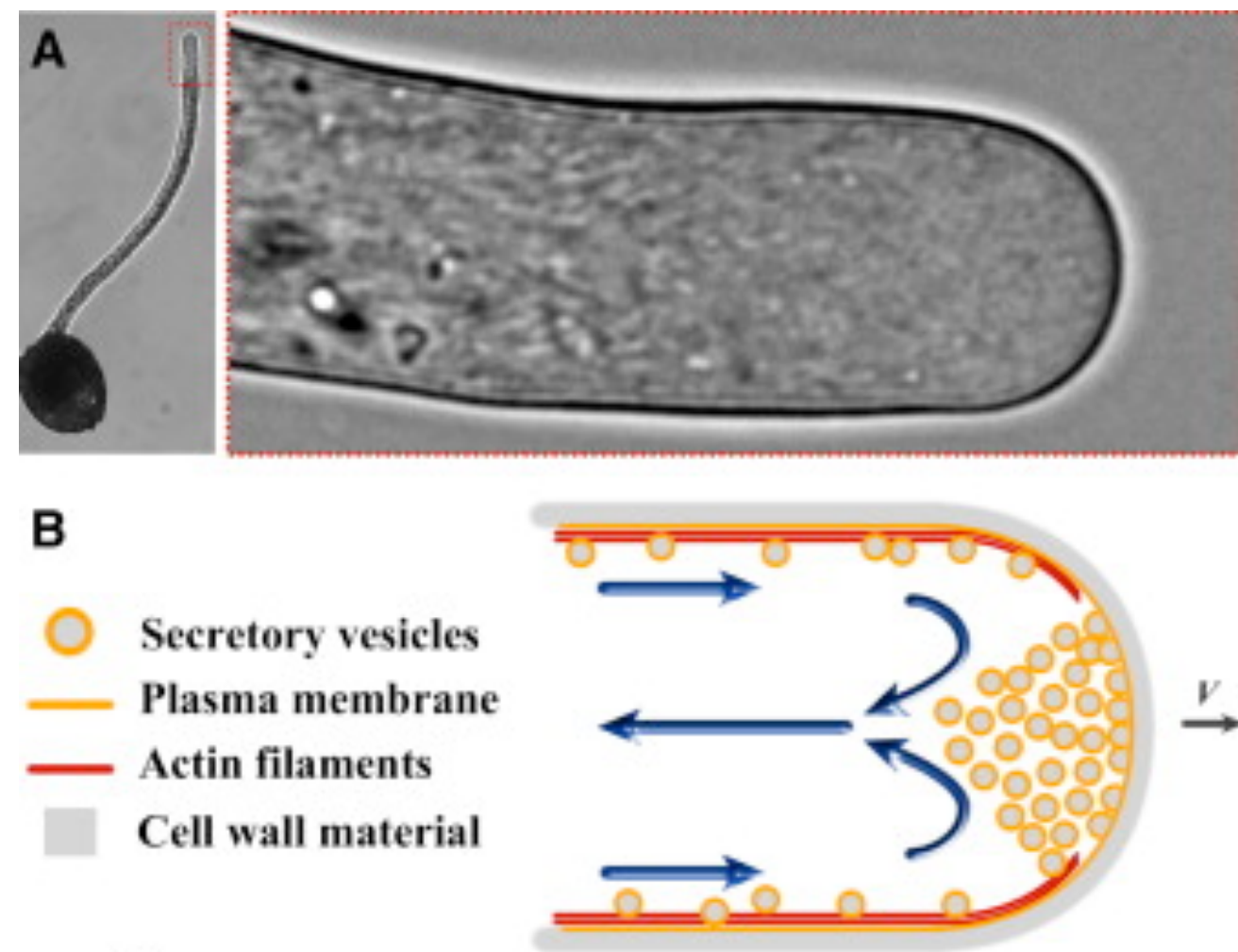


Mechanical feedback in cell wall growth

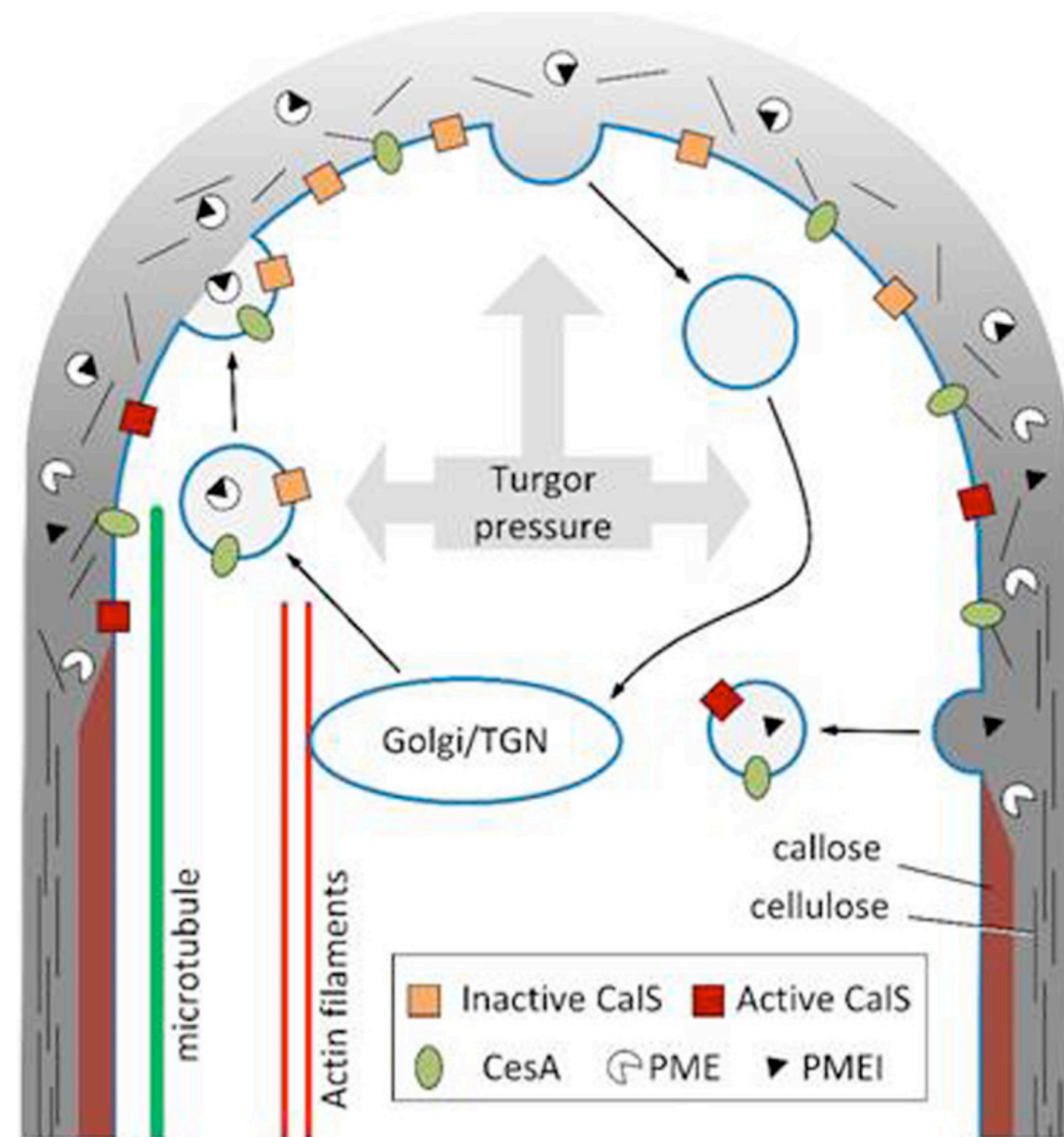


Mechanical feedback regulates plant growth

Turgor pressure stimulates root tip growth



Turgor pressure drive cell wall expansion



Movement in plants

The venus flytrap

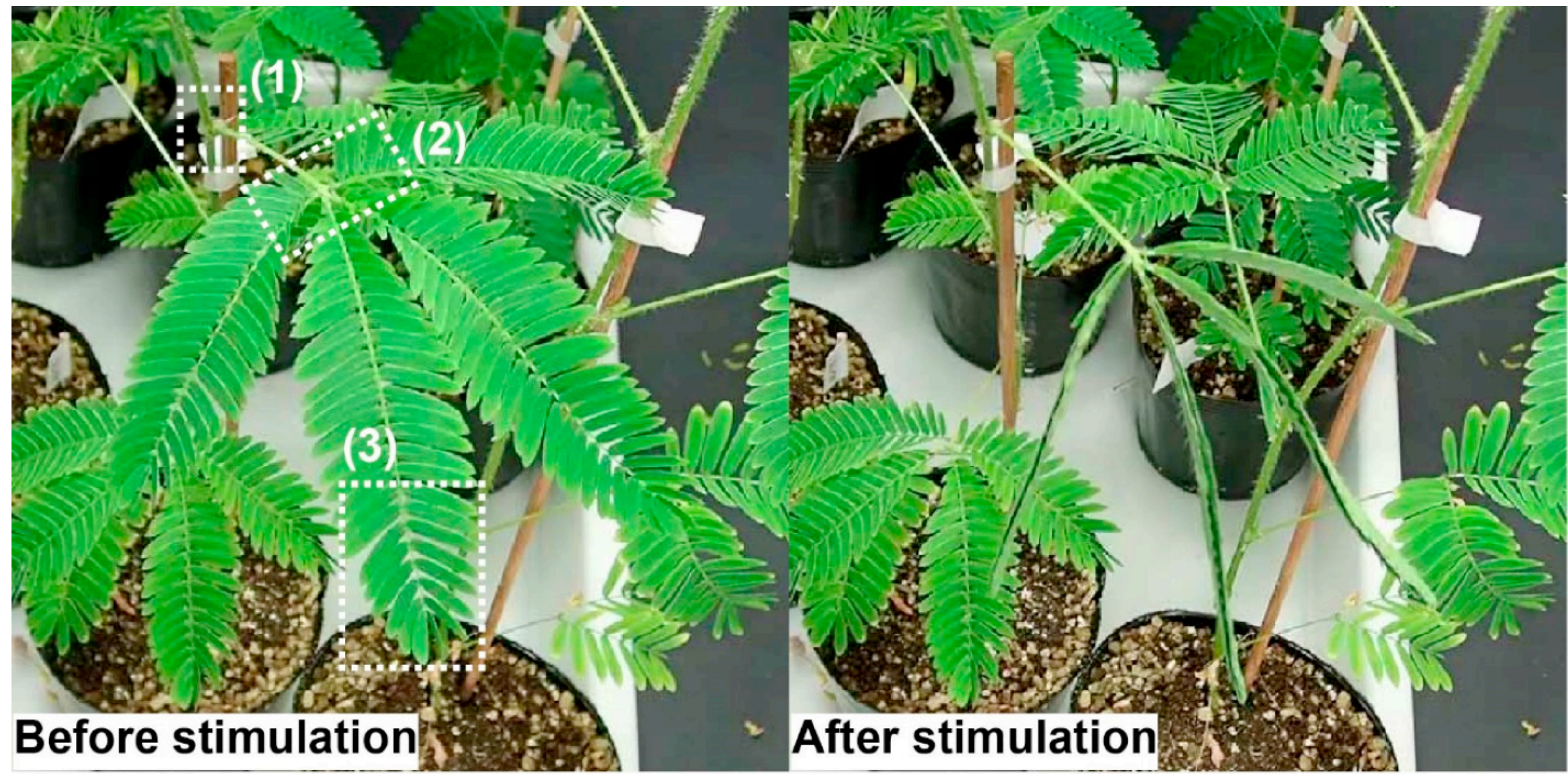


Mimosa pudica



Mimosa pudica

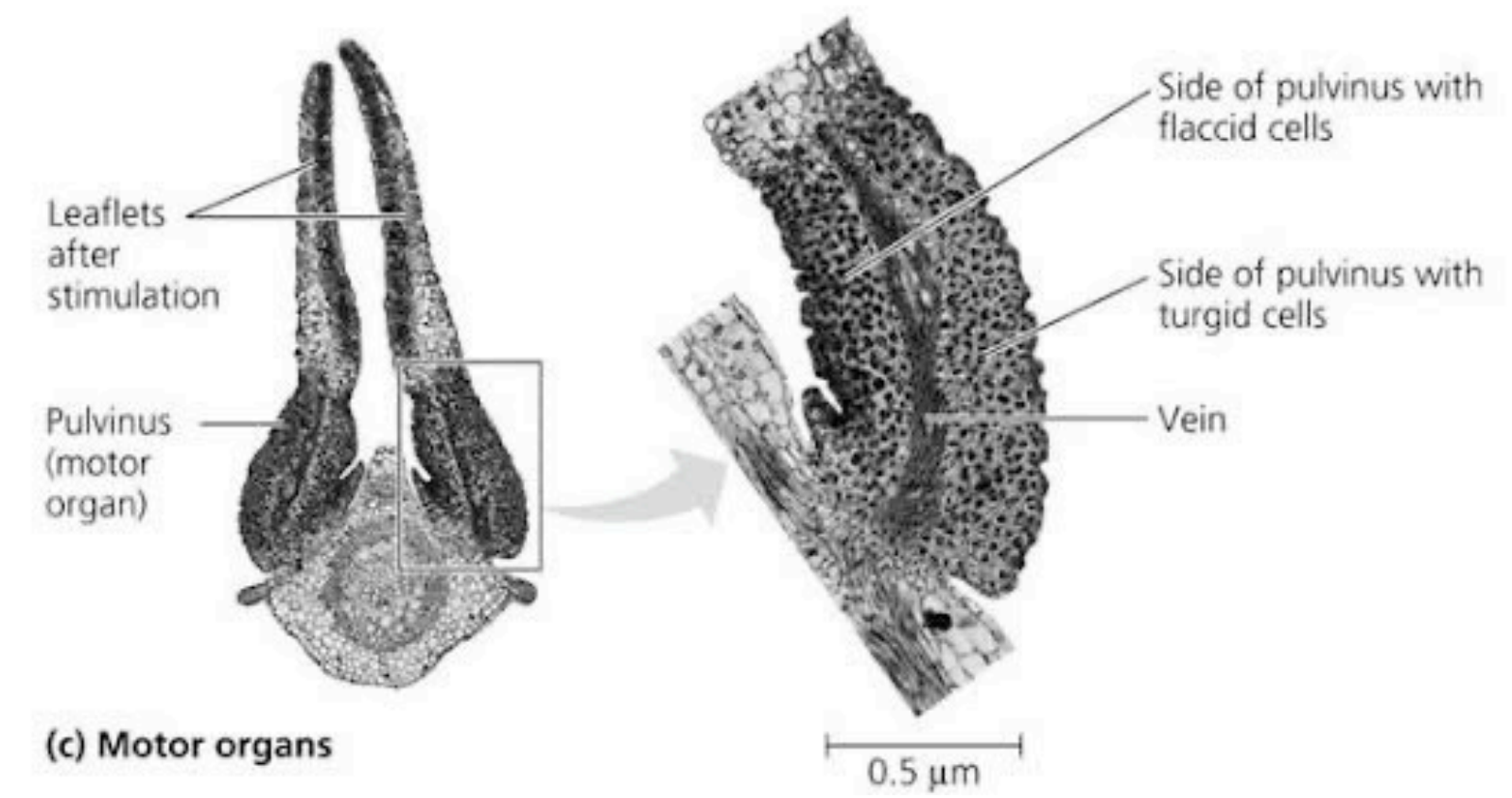
- What is the force driving leaf closure?
- How does it sense touch?



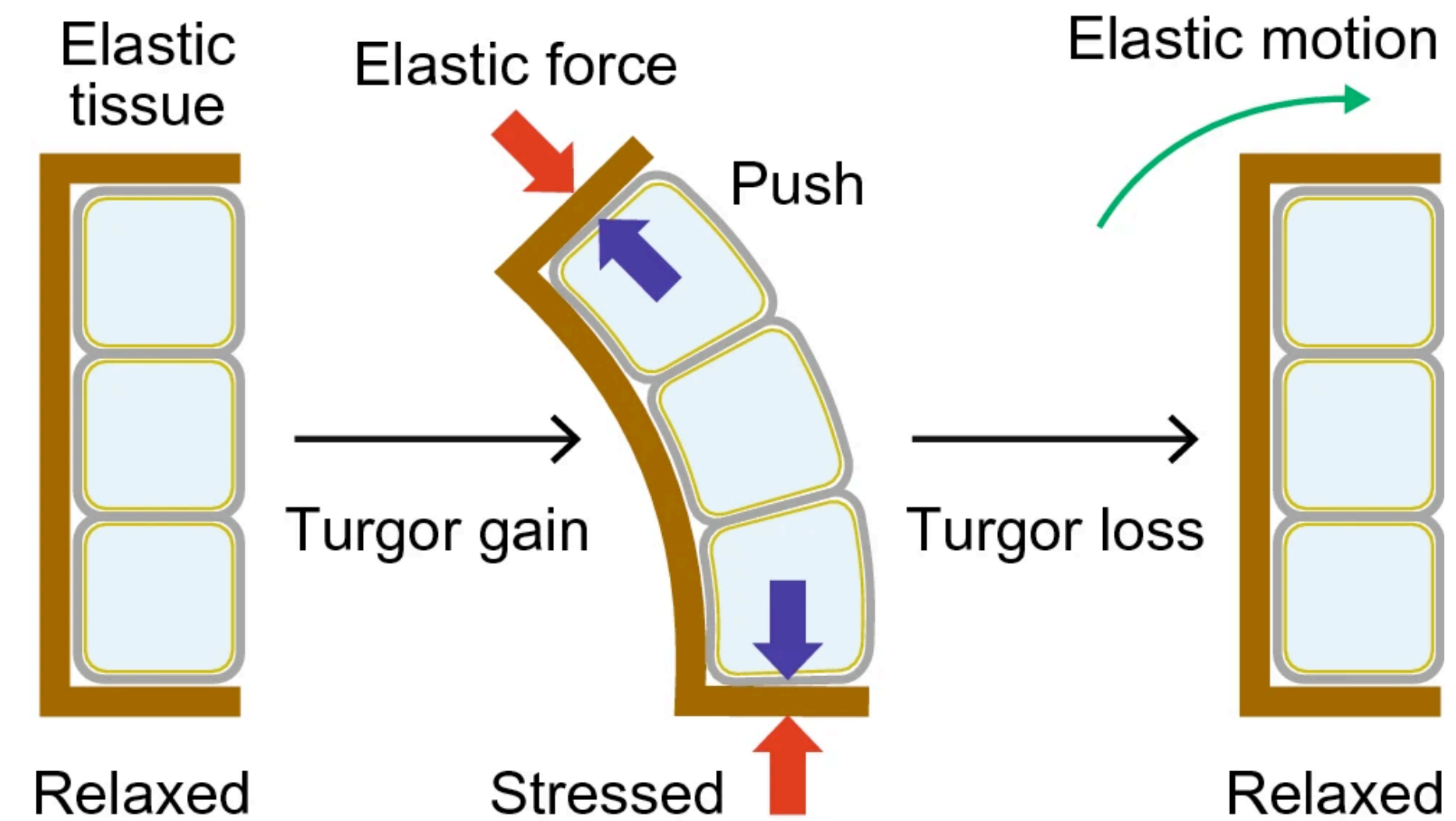
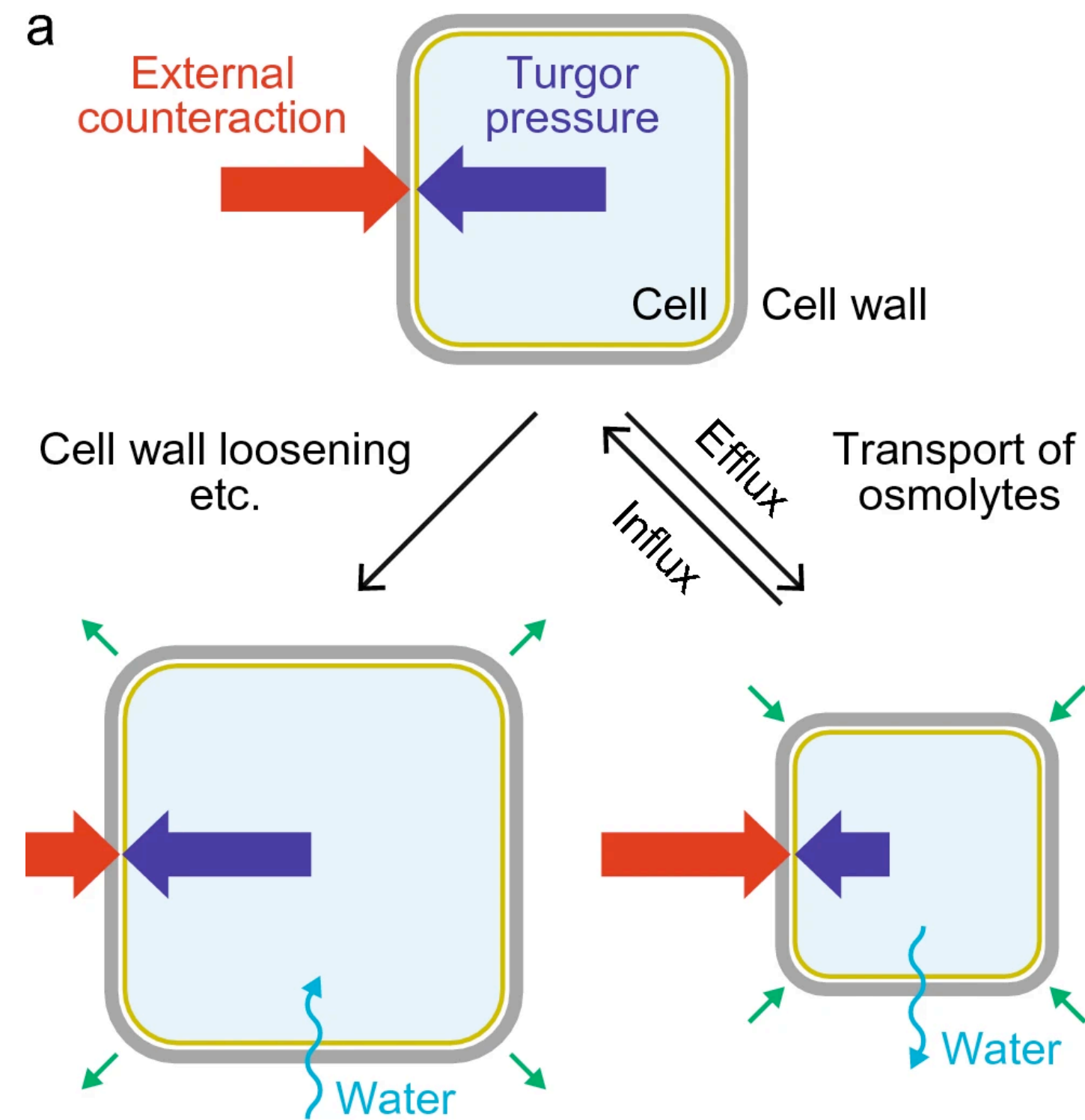


(a) Unstimulated

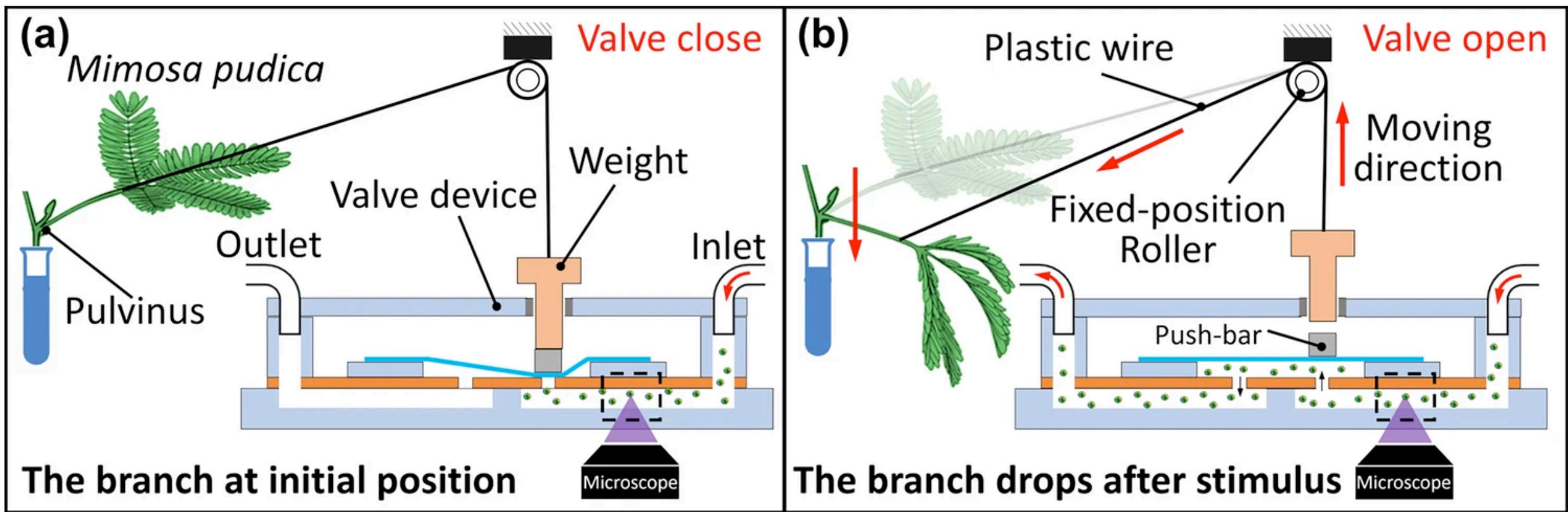
(b) Stimulated



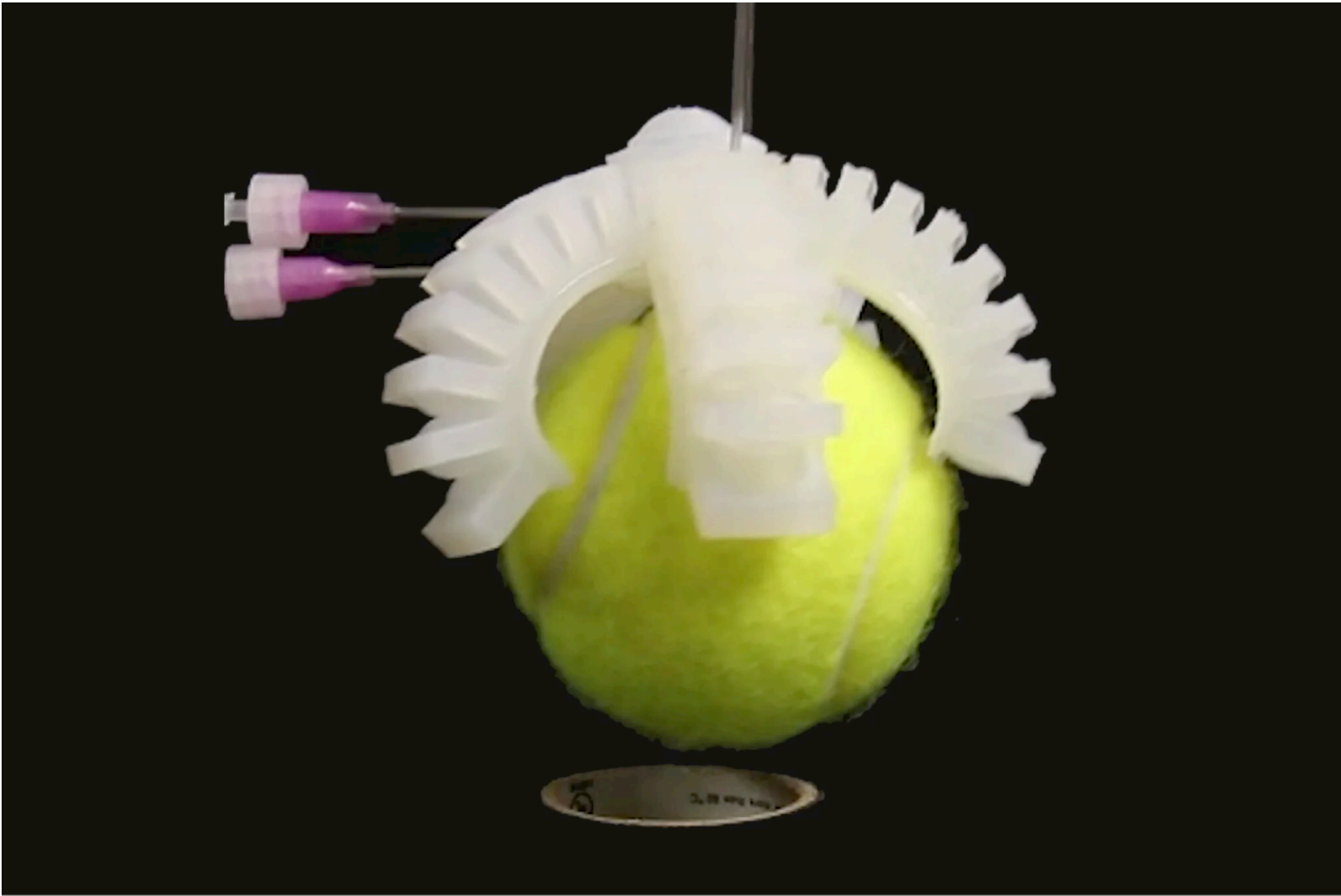
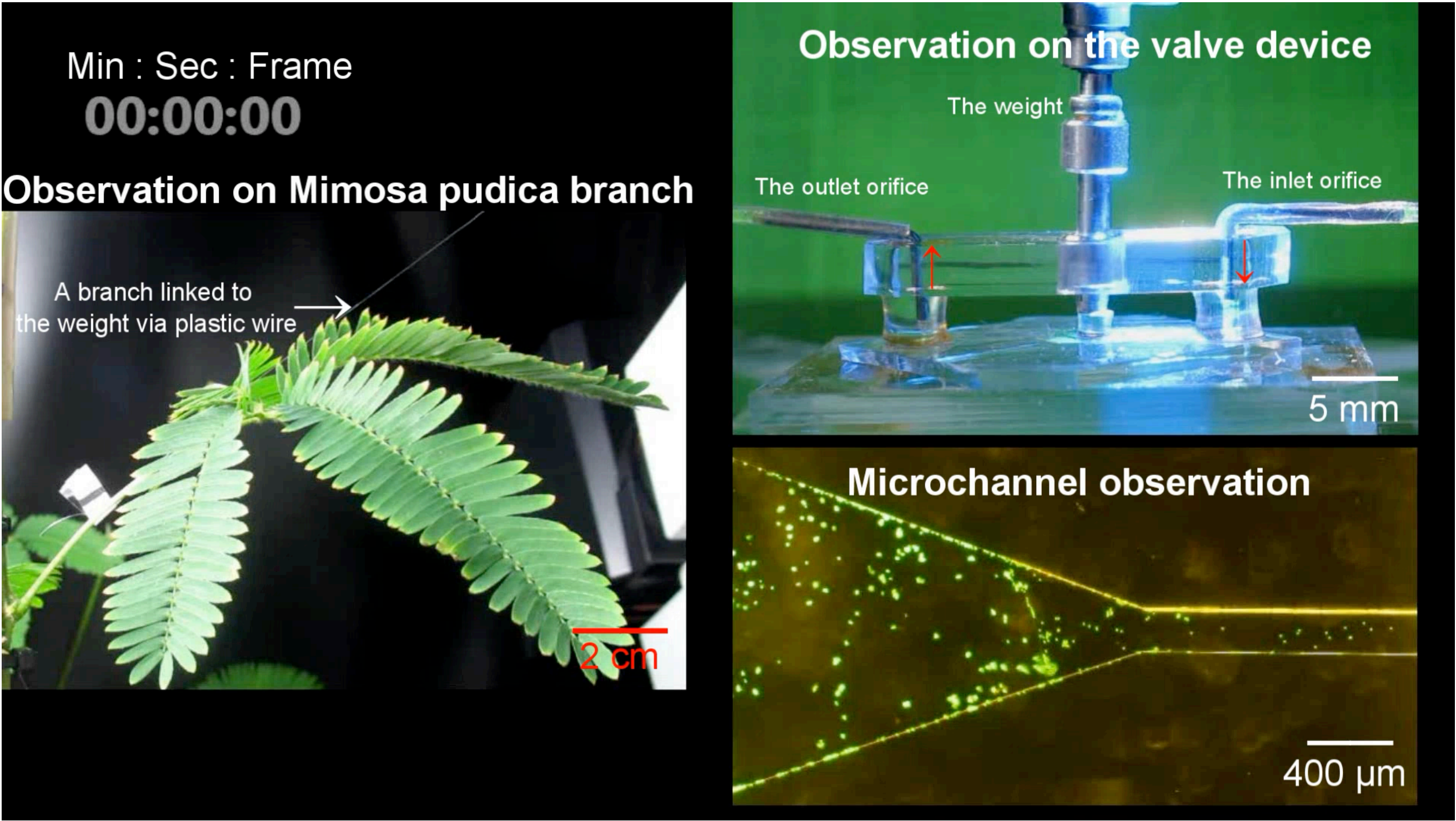
Osmotic swelling can actuate movements



Applications



Plant-inspired actuation: soft robotics

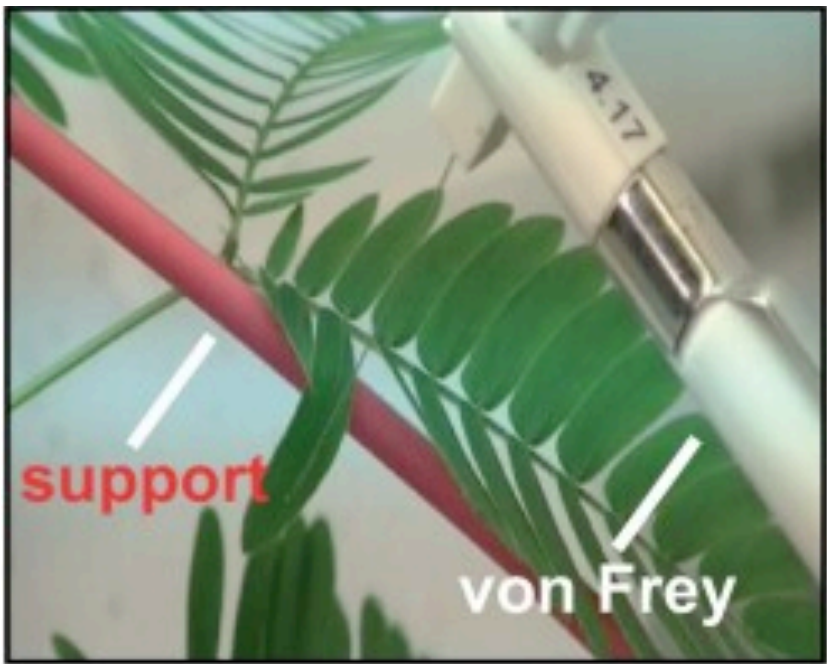


Mechanical stimulation of *Mimosa pudica*

Excitation

Response (score)

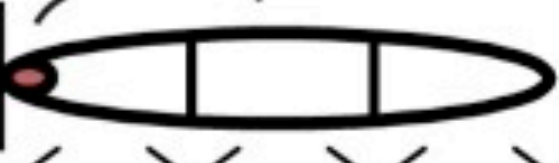
magnitude



Mimosa leaflet

rachis

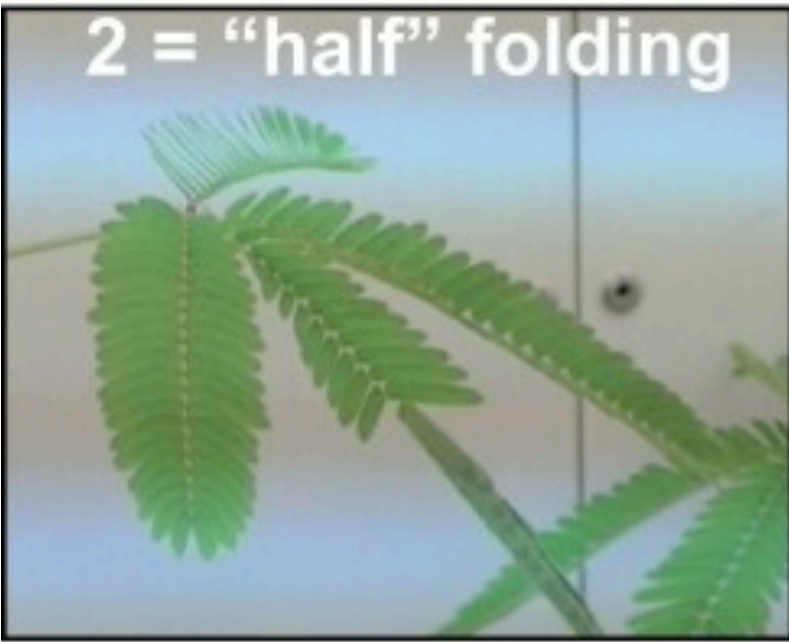
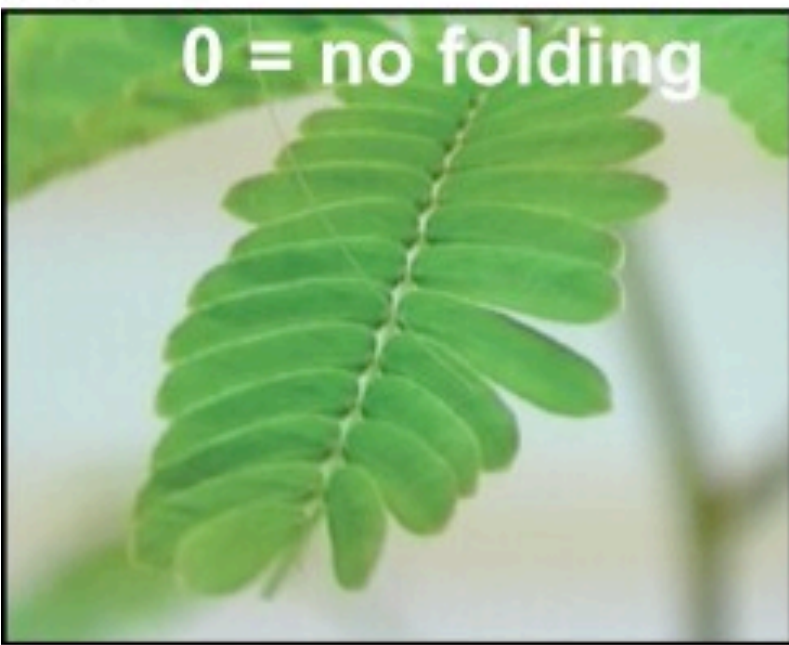
pulvinus



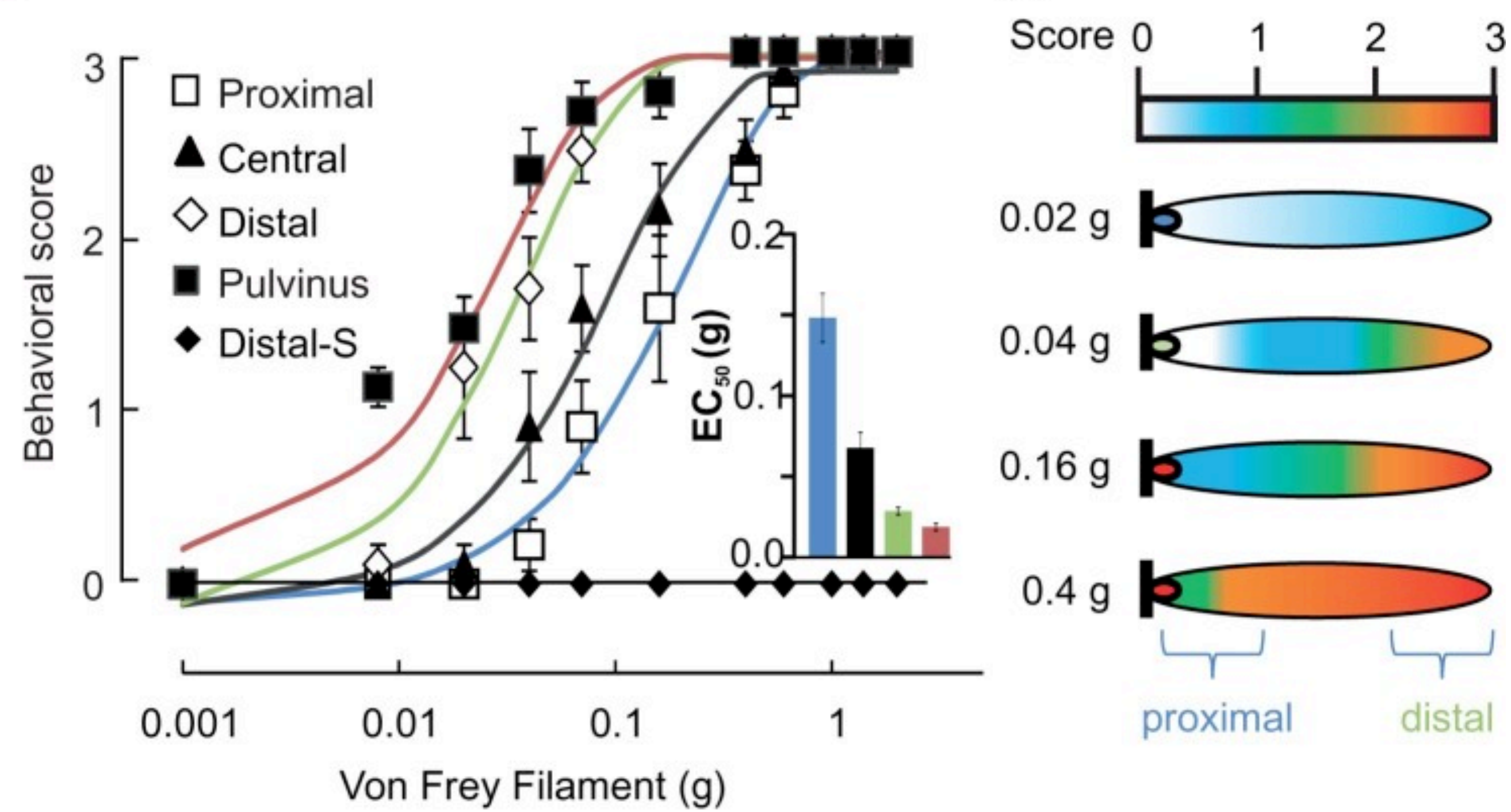
proximal central distal

Stimulation zones

location



Localized sensitivity



Pulvinus organ bending

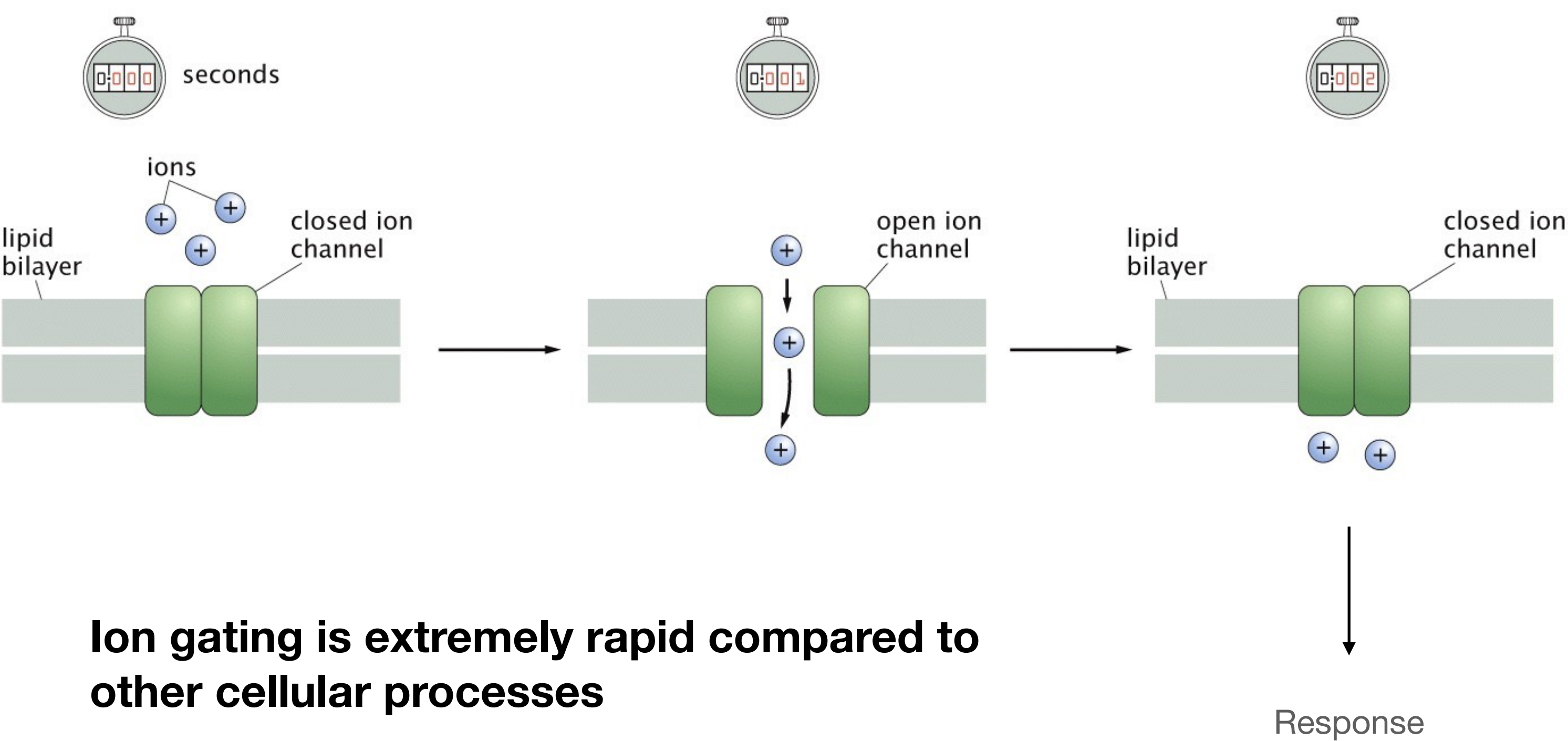


- Pulvini express many mechanosensory proteins
 - They are nodes of deformation during stimulation
- > could they sense mechanical stimulation?

Mechanosensitive ion channels

more on this in 2 weeks!

Gating of ion channels



Ion gating is extremely rapid compared to other cellular processes

mechanosensitivity

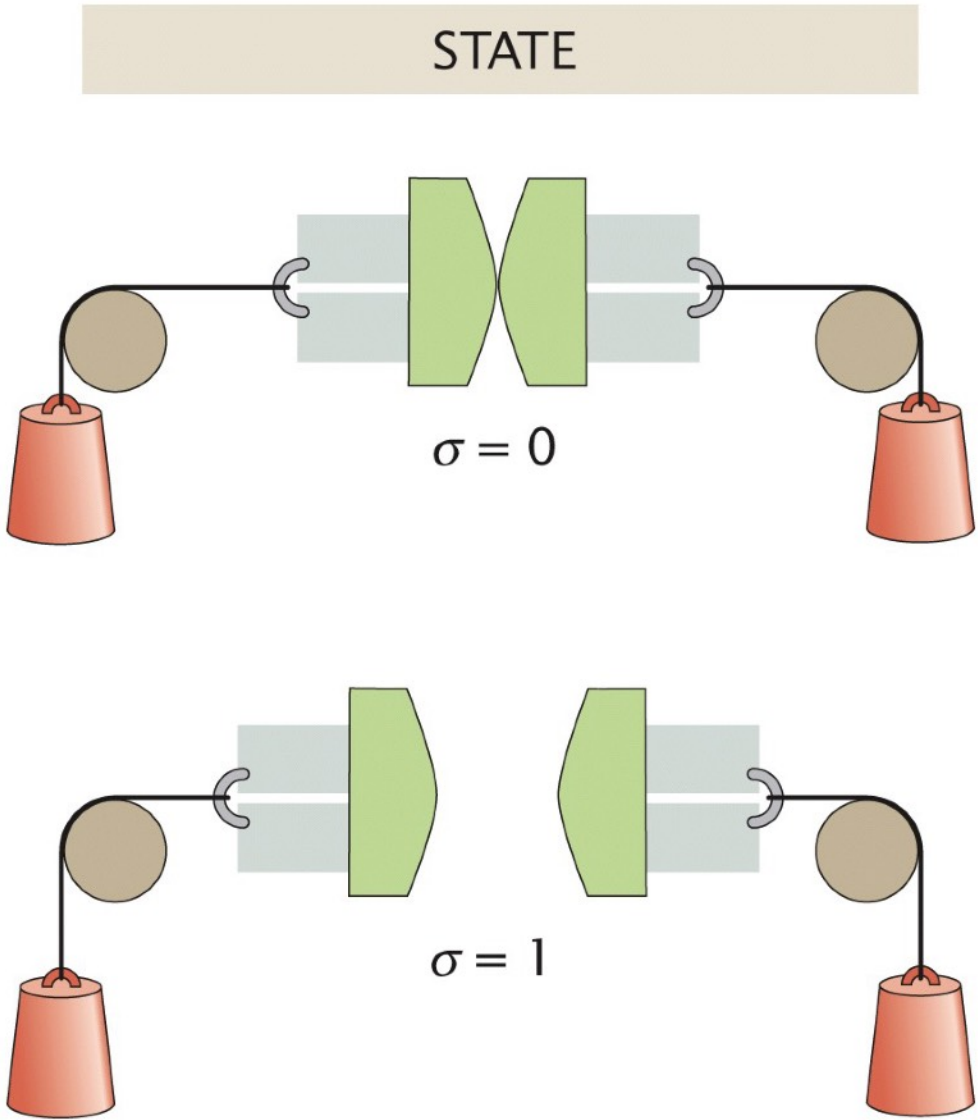
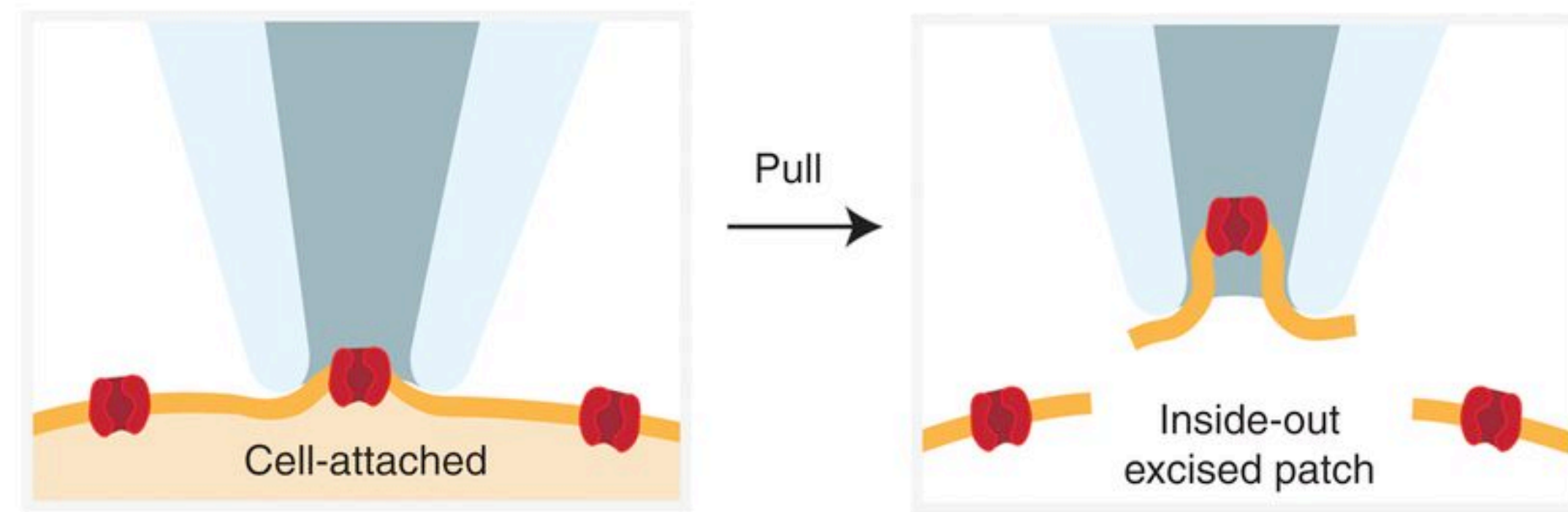


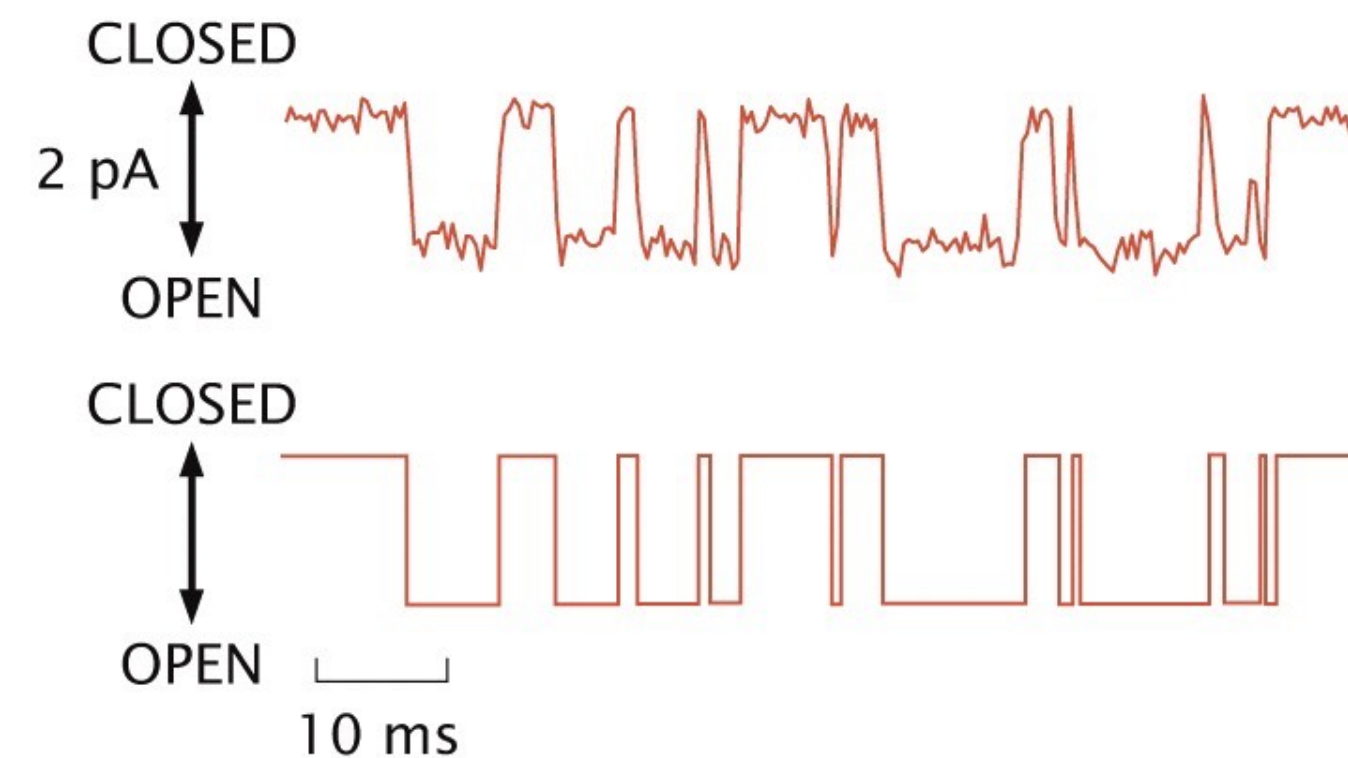
Figure 7.4 Physical Biology of the Cell, 2ed. (© Garland Science 2013)

Measuring mechanosensitivity

patch clamp recording



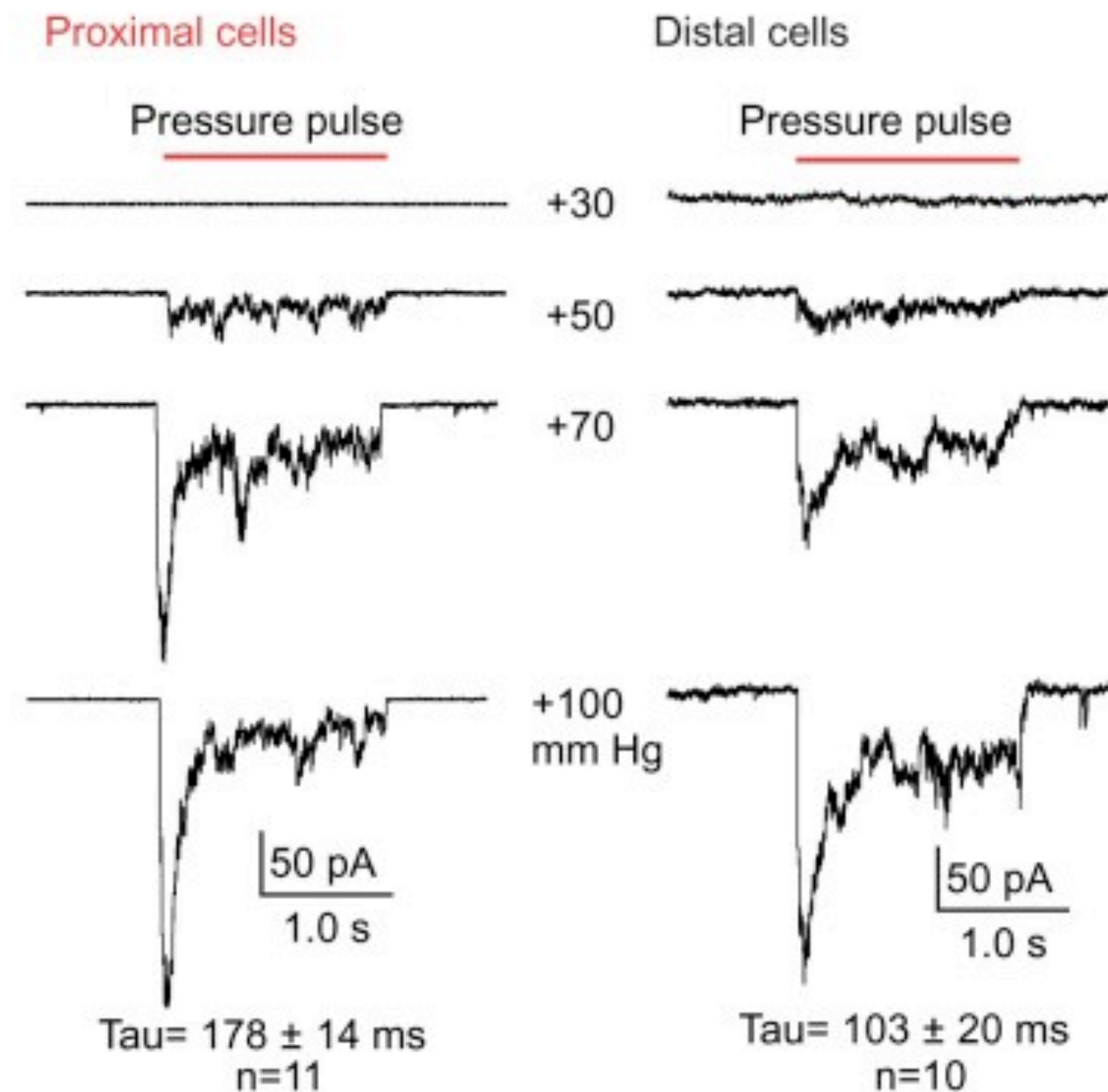
1. Apply pressure
2. Measure electrical current



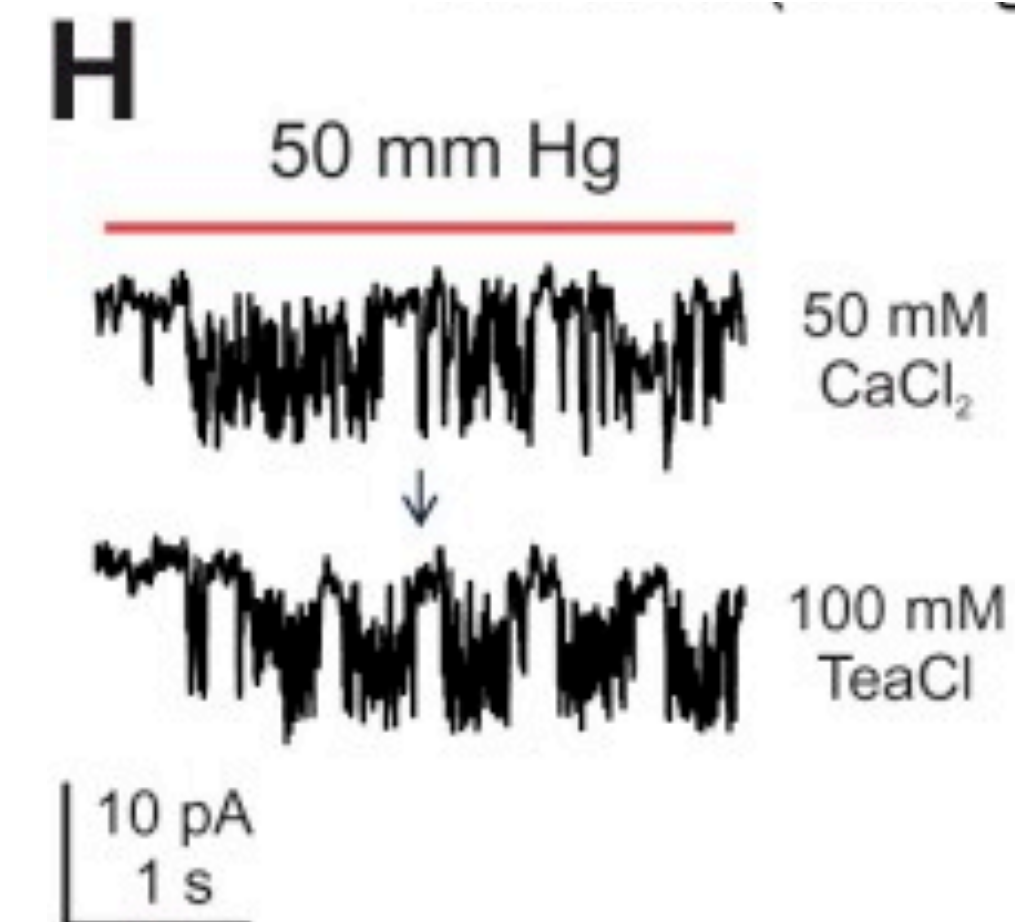
Electrical current measurements

Ionic currents in the pulvinus

patch clamp recording

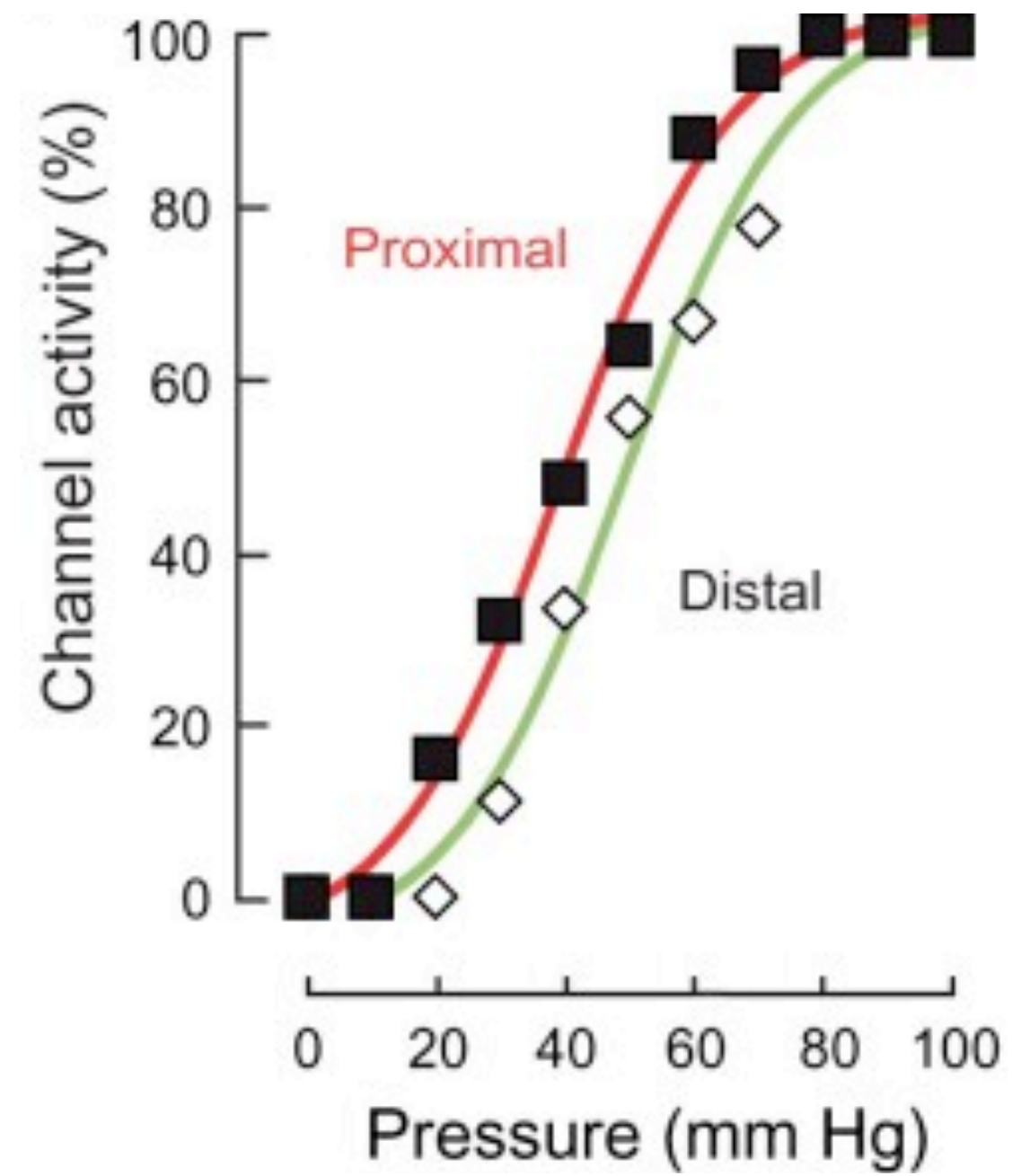


Pressure induces membrane current



Ionic current is calcium-independent

Sensitivity to pressure



Sensitivity to pressure

Lecture 8 summary

- Bacteria, plants and yeast need to deal with mechanics of envelope in order to grow
- patterning cell wall requires degradation of elastic material
- Turgor/osmotic pressure promote patterning of cell wall at the right location
- Feedback between growth and cell envelope mechanics
- Plants re-use mechanics of growth for rapid movements.