The mechanics of cell growth

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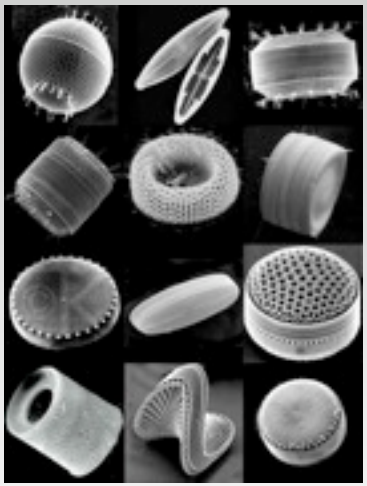
Outline

- Introduction: an atlas of shape
- Fission yeast: Minc et al. 2009–
- Plant cells (*Arabidopsis*): Hamant et al. 2008–

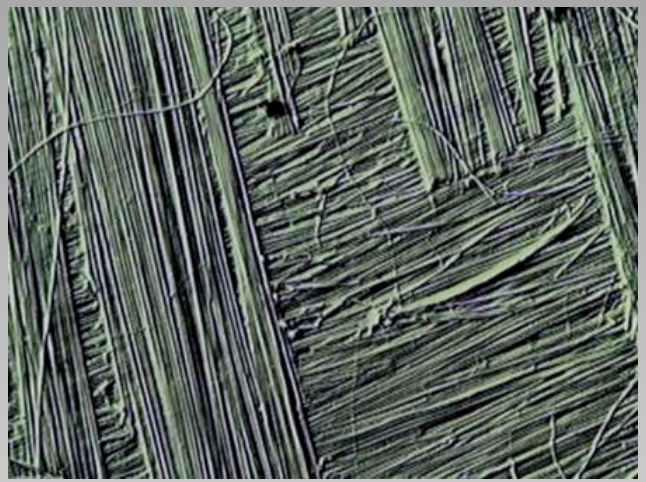
Introduction

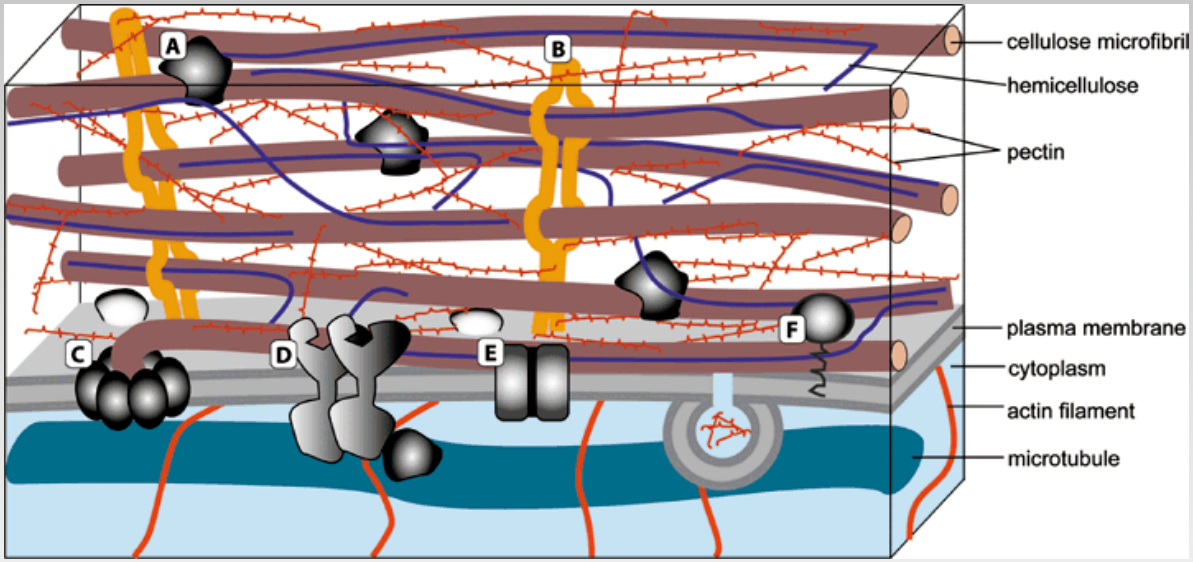
★Non walled cells

★Walled cells - A stiff casing
- Bacteria *peptidoglycan*
- Archea *various polymers (aminoacids + sugars)*
- Fungi *chitin*
- Plants and green algae *cellulose*
- Diatoms (not relevant here) *silica*



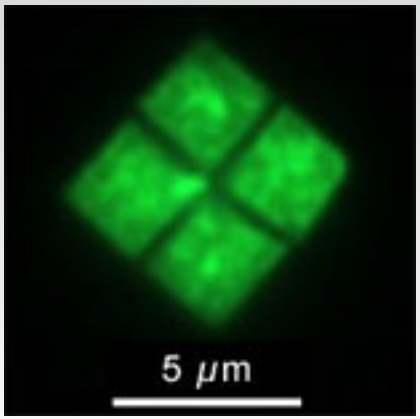
Introduction



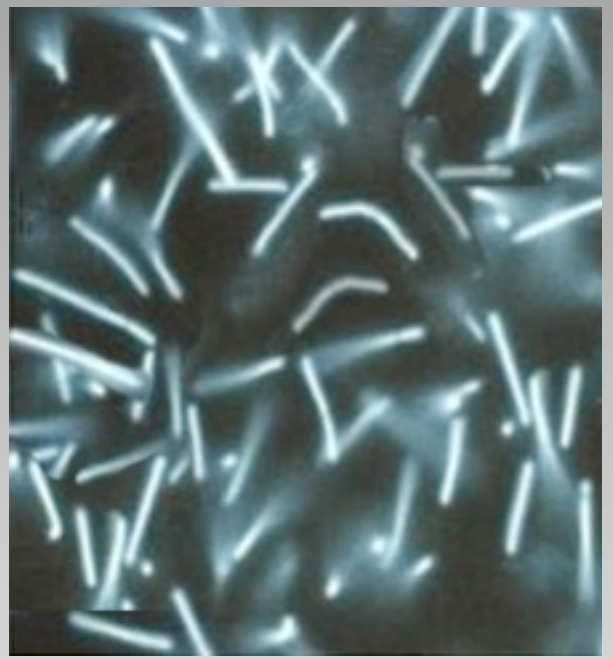


Introduction

Halobacteria

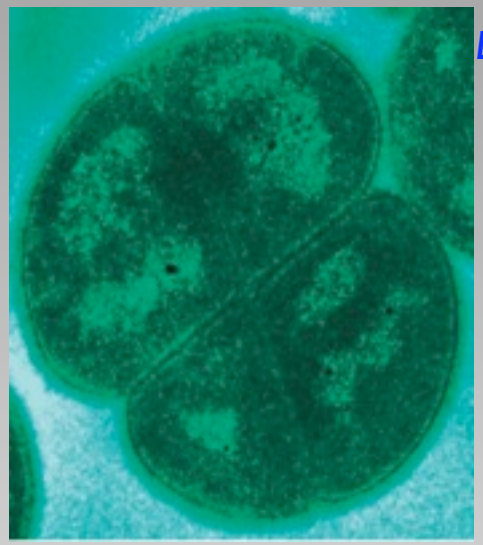


Haloquadra walsbyi



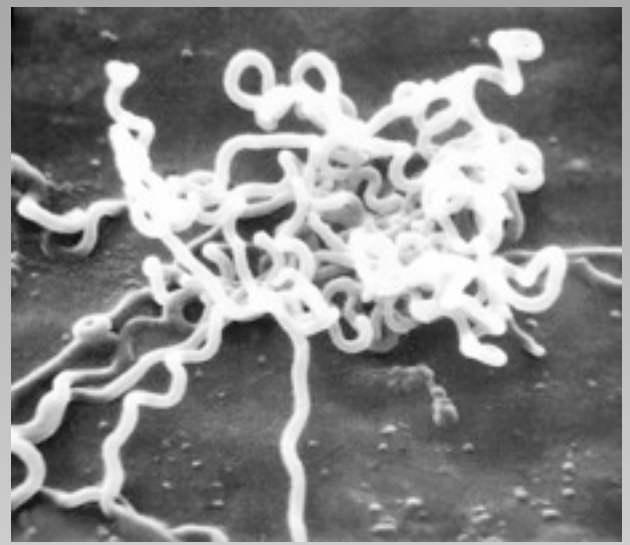
Methanopyrus kandleri

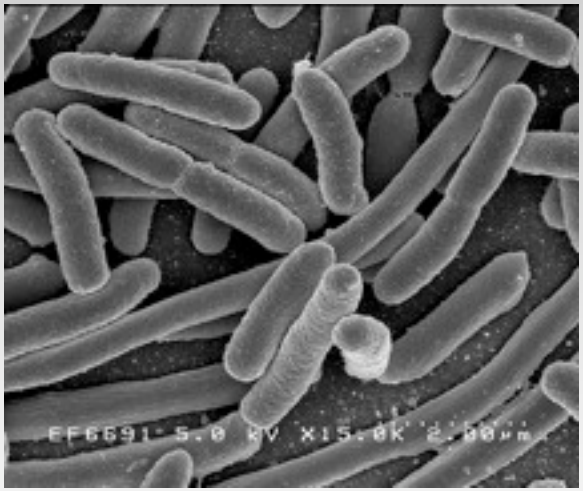
Introduction



Deinococcus radiodurans

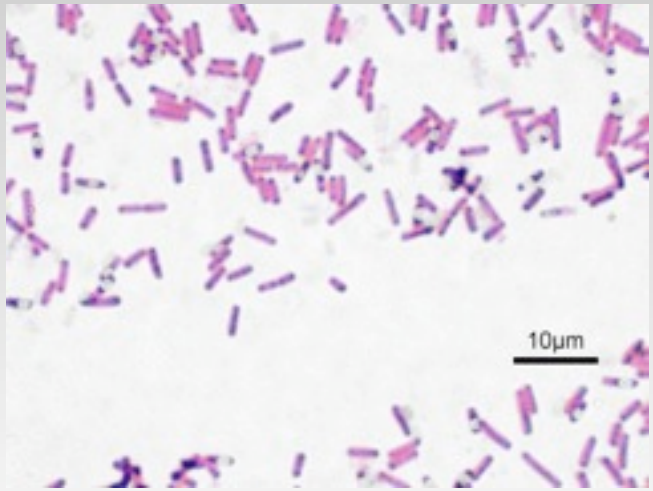
Treponema pallidum



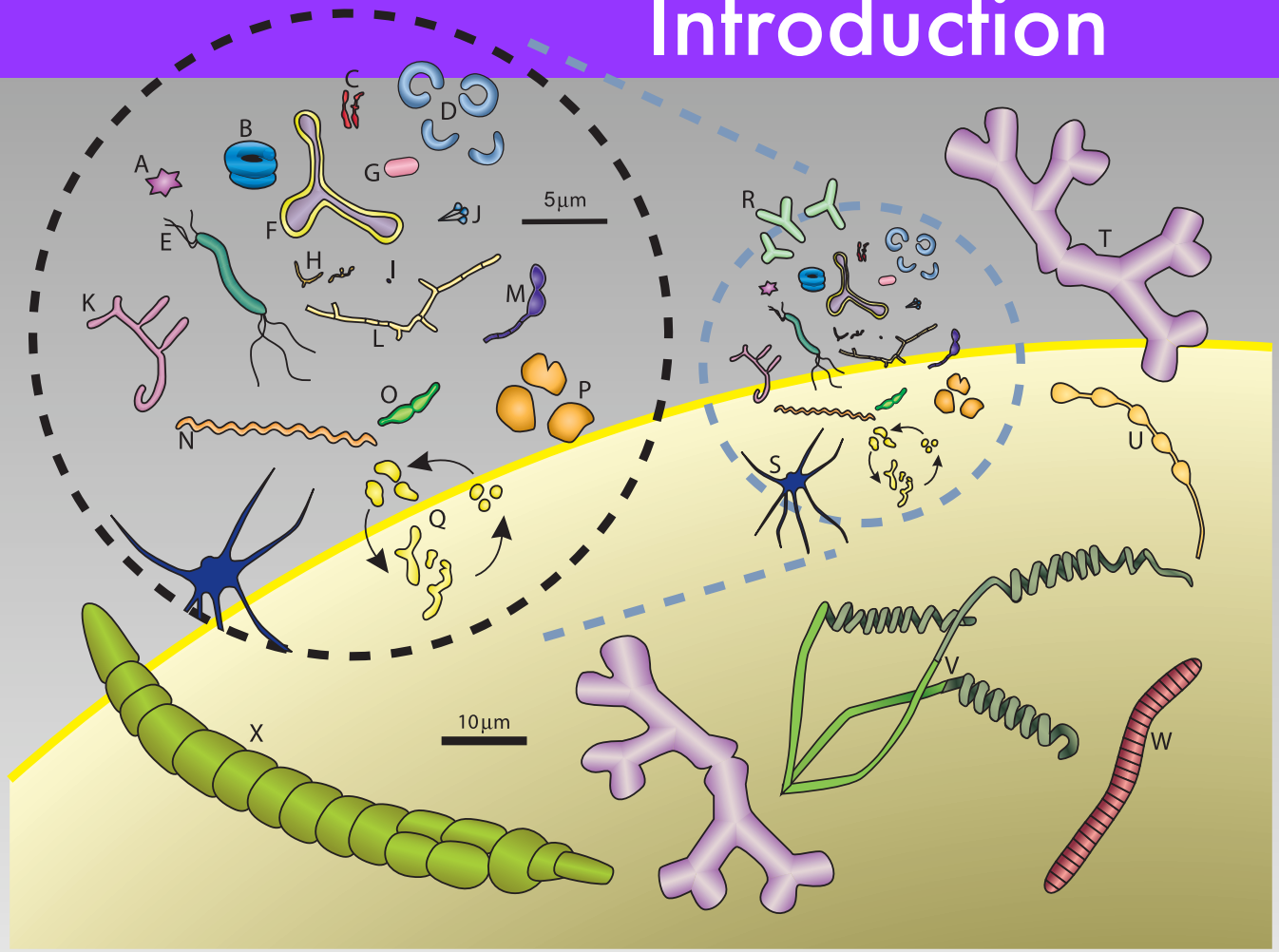


E. coli

B. subtilis



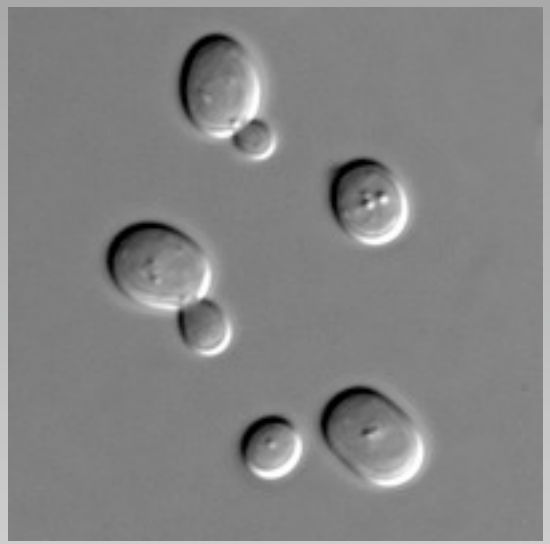
Introduction

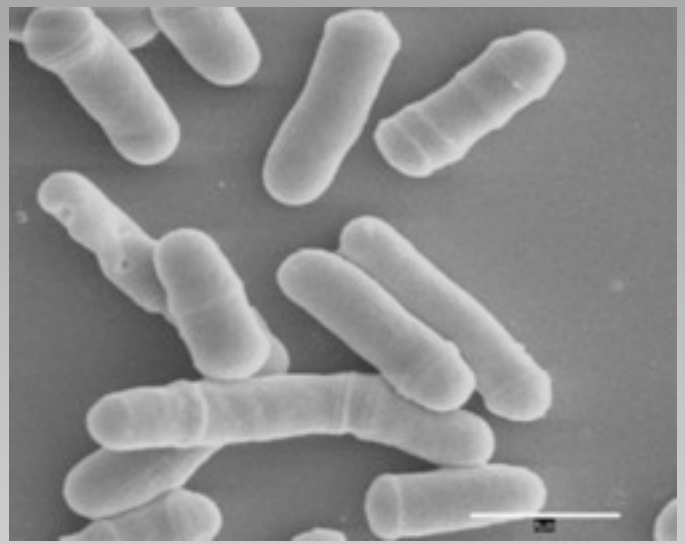


K.D. Young 2006

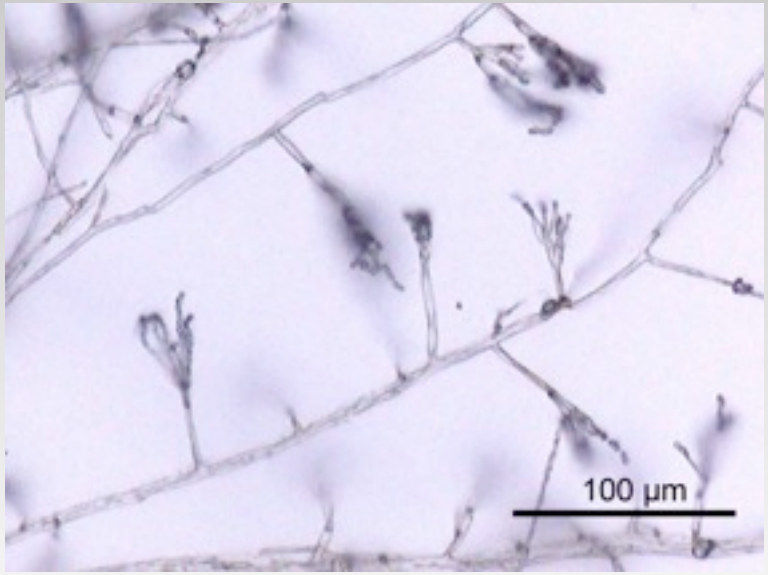
FIG. 1. Variety of prokaryotic shapes. This collage of different cells, unless otherwise stated, is constructed from descriptions and illustrations given by Starr et al. (313) or by Zinder and Dworkin (380). The cells are drawn to scale. Those in the dashed black circle are drawn relative to the 5-µm line. These same cells are included in smaller form in the dashed blue circle to compare their sizes to those of larger bacteria, which are drawn relative to the 10-µm line. (A) *Stella strain* IFAM1312 (380); (B) *Microcyclus* (a genus since renamed *Ancylobacter*) *flavus* (367); (C) *Bifidobacterium bifidum*; (D) *Clostridium cocleatum*; (E) *Aquaspirillum autotrophicum*; (F) *Pyroditium abyssi* (380); (G) *Escherichia coli*; (H) *Bifidobacterium* sp.; (I) transverse section of ratoon stunt-associated bacterium; (J) *Planctomyces* sp. (133); (K) *Nocardia opaca*; (L) Chain of ratoon stunt-associated bacteria; (M) *Caulobacter* sp. (380); (N) *Spirochaeta halophila*; (O) *Prosthecobacter fusiformis*; (P) *Methanogenium cariaci*; (Q) *Arthrobacter globiformis* growth cycle; (R) gram-negative *Alphaproteobacteria* from marine sponges (240); (S) *Ancalomicrobium* sp. (380); (T) *Nevskia ramosa* (133); (U) *Rhodomicrobium vanniellii*; (V) *Streptomyces* sp.; (W) *Caryophanon latum*; (X) *Calothrix* sp. The yellow-lined background orb represents a slice of the giant bacterium *Thiomargarita namibiensis* (290), which is represented to scale with the other organisms.

Introduction





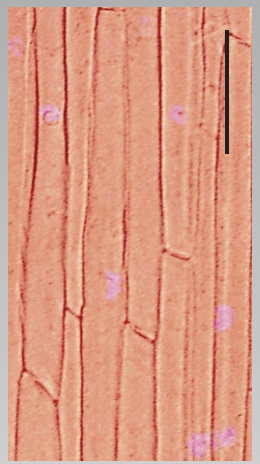
Penicilium



Introduction

Courtesy J. Dumais

Ditengou et al. 2008



Chlamydomonas reinhardtii

Introduction

★A wide occurrence of rod-like shape

★Constraints?

- Nutrients => surface/volume
- Adhesion to substrate
- Resistance (motile)
- Exploration of space (non motile)
- Partition of material between daughter cells

Introduction

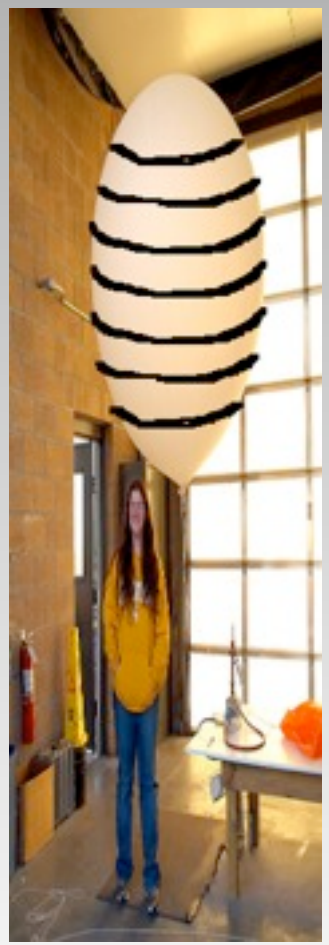
★Stiff casing

★Growth into rod-like shape
- Turgor pressure

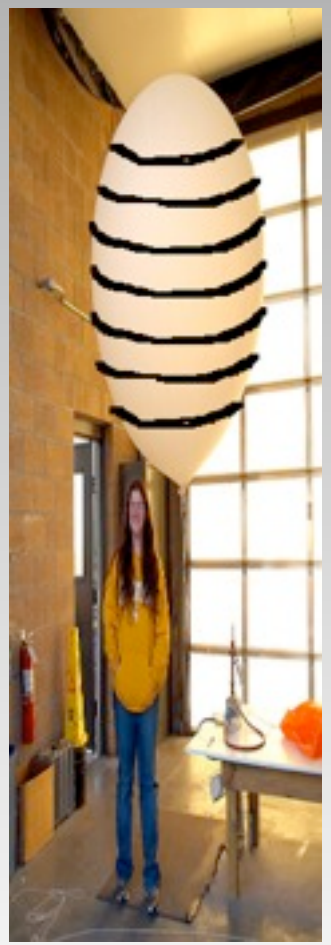
Introduction – Structure

Introduction – Structure

Introduction – Structure



Introduction – Structure

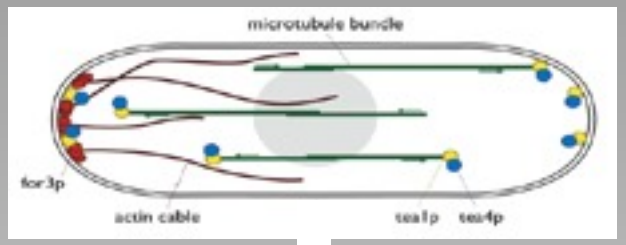


Outline

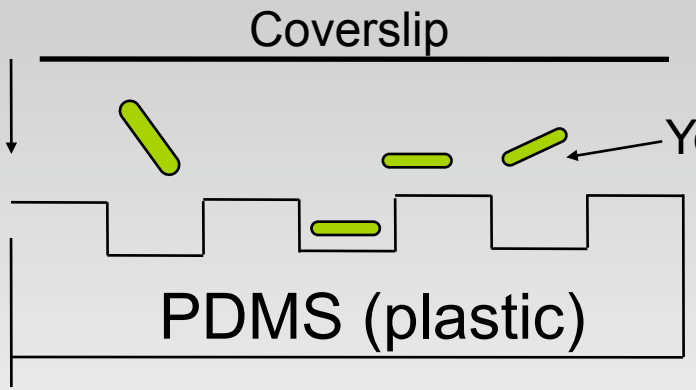
- Fission yeast: Minc et al. 2009–
What are the forces involved?

- Plant cells (*Arabidopsis*): Hamant et al. 2008–
How is anistropic growth controlled?

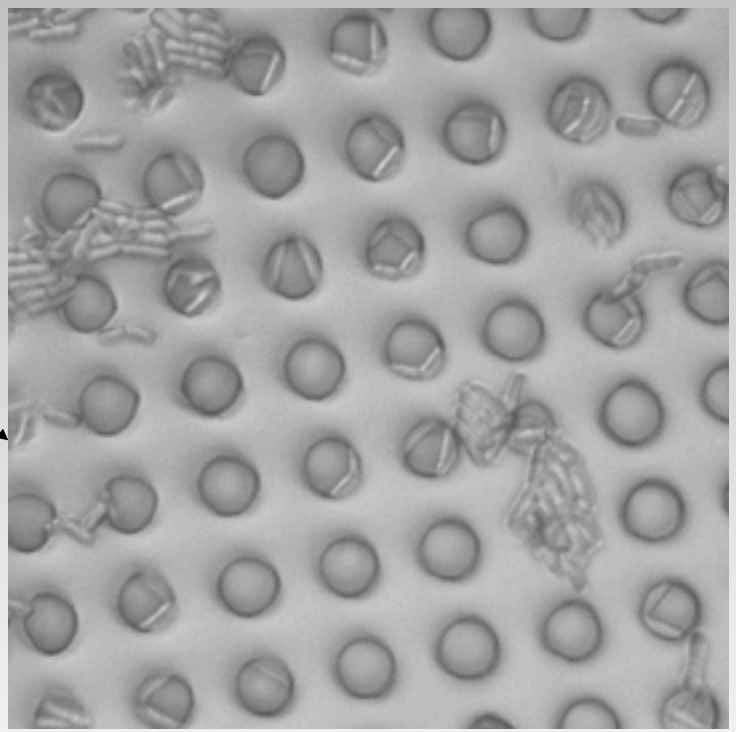
Fission yeast



The fission yeast *Schizosaccharomyces pombe,* is a model system for studying mechanisms of polarized growth. Cell polarity is dynamically regulated by the microtubule and actin cytoskeletons

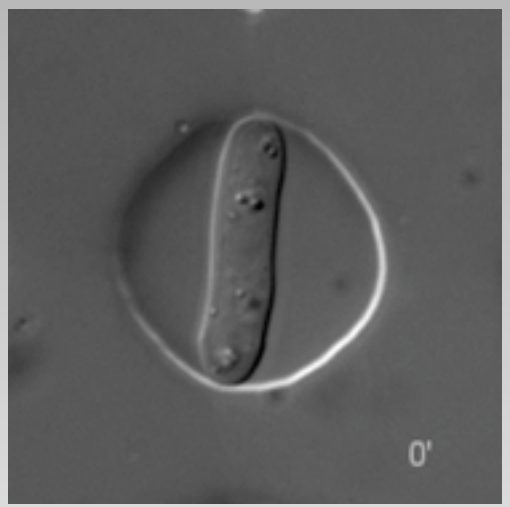


Cells are trapped in the microhole and let to grow.

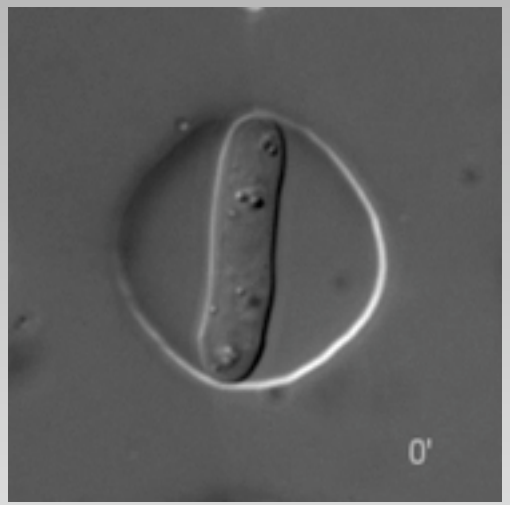


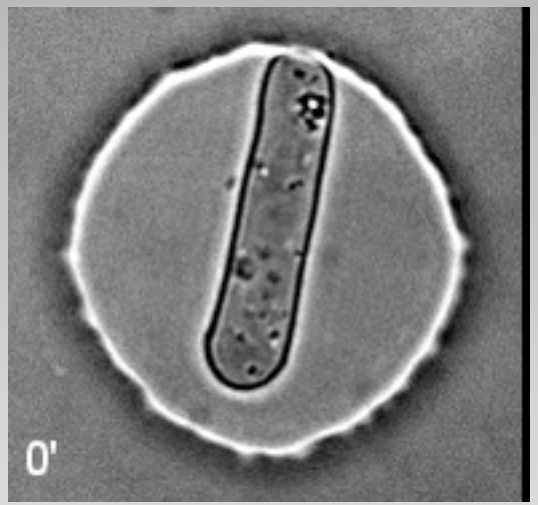
Top view of fission yeast cells trapped in the chambers

Fission yeast

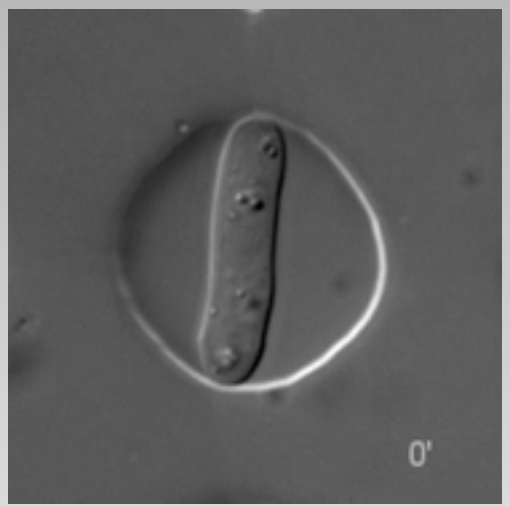


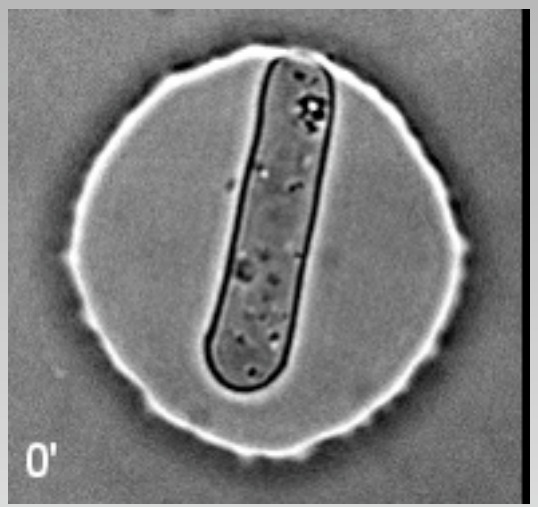
Fission yeast

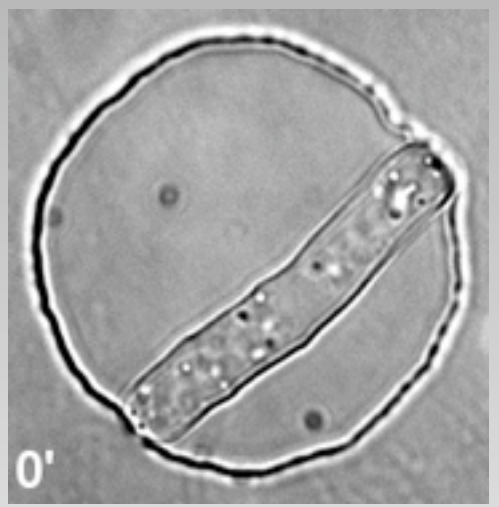




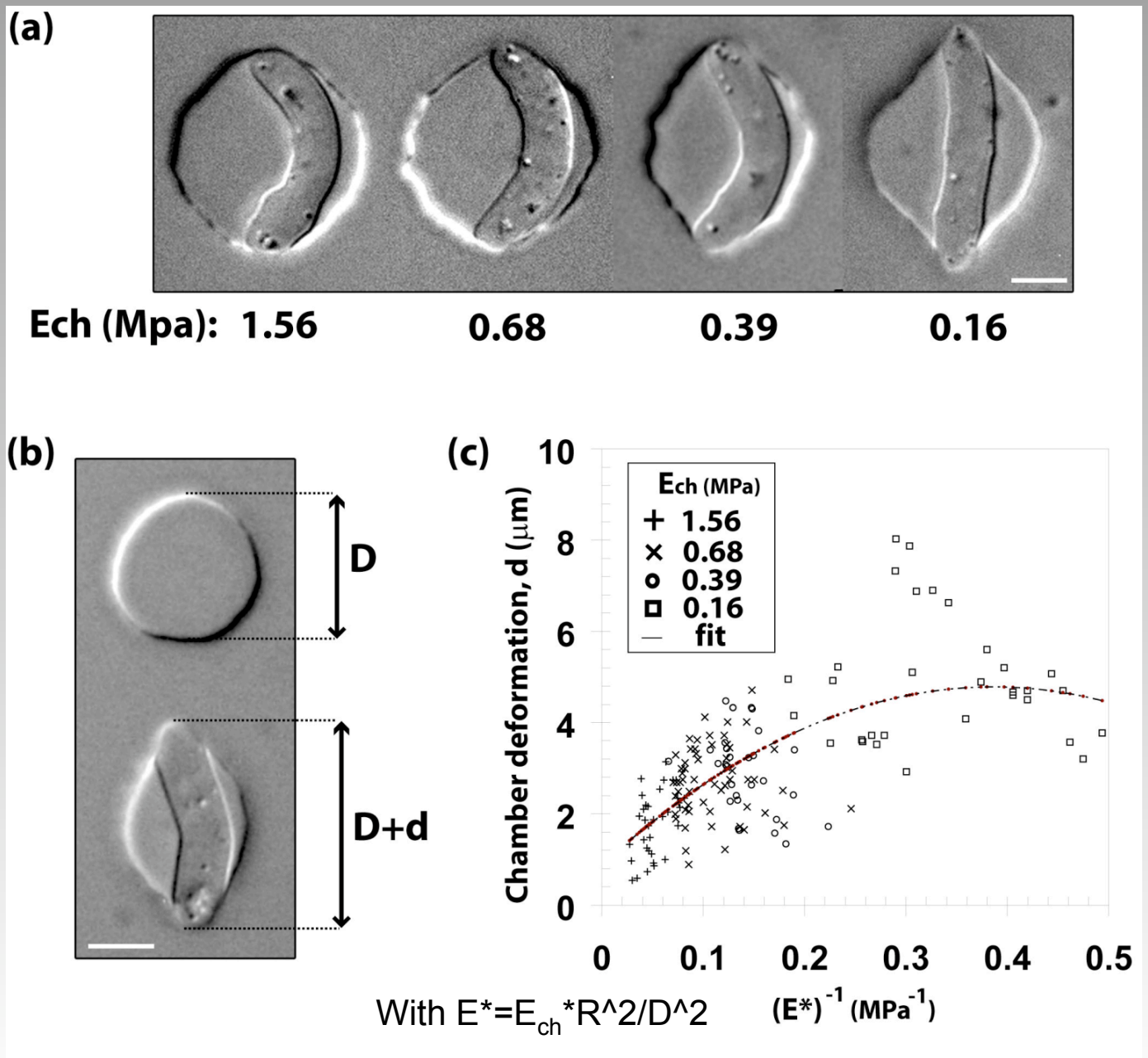
Fission yeast







Fission yeast



$$F_{ch} = \frac{8}{3} E_{ch} R d$$

$$F_B = \frac{\pi I E_{cw}}{L_T^{\,2}}$$

$$I = \pi h R^3$$

Fission yeast

$E_{fission\ yeast} = 100 \pm 30$ MPa

Other fungis:
- **S. cerevisae : 100 Mpa (by micromanipulation) and 0.9 Mpa (by AFM)????**
- **Aspergillus nidulans: 60-100 Mpa (AFM)**

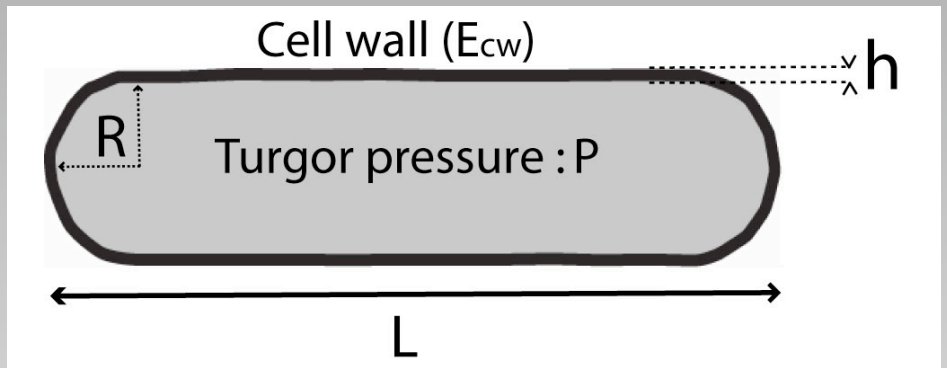
Plants :
-**Root hair (Arabidopsis): 500 Mpa**

Bacteria:
- **E.coli: 25 Mpa**
- **B subtilis: 13-25 Mpa**

Fission yeast

$$T_P = \frac{PR}{2h}$$

$$v_0 = \frac{dL}{dt} = \frac{R}{\tau_V}\frac{T_p}{E} = \frac{P}{\tau_V}\frac{R^2}{2\sigma_{cw}}$$



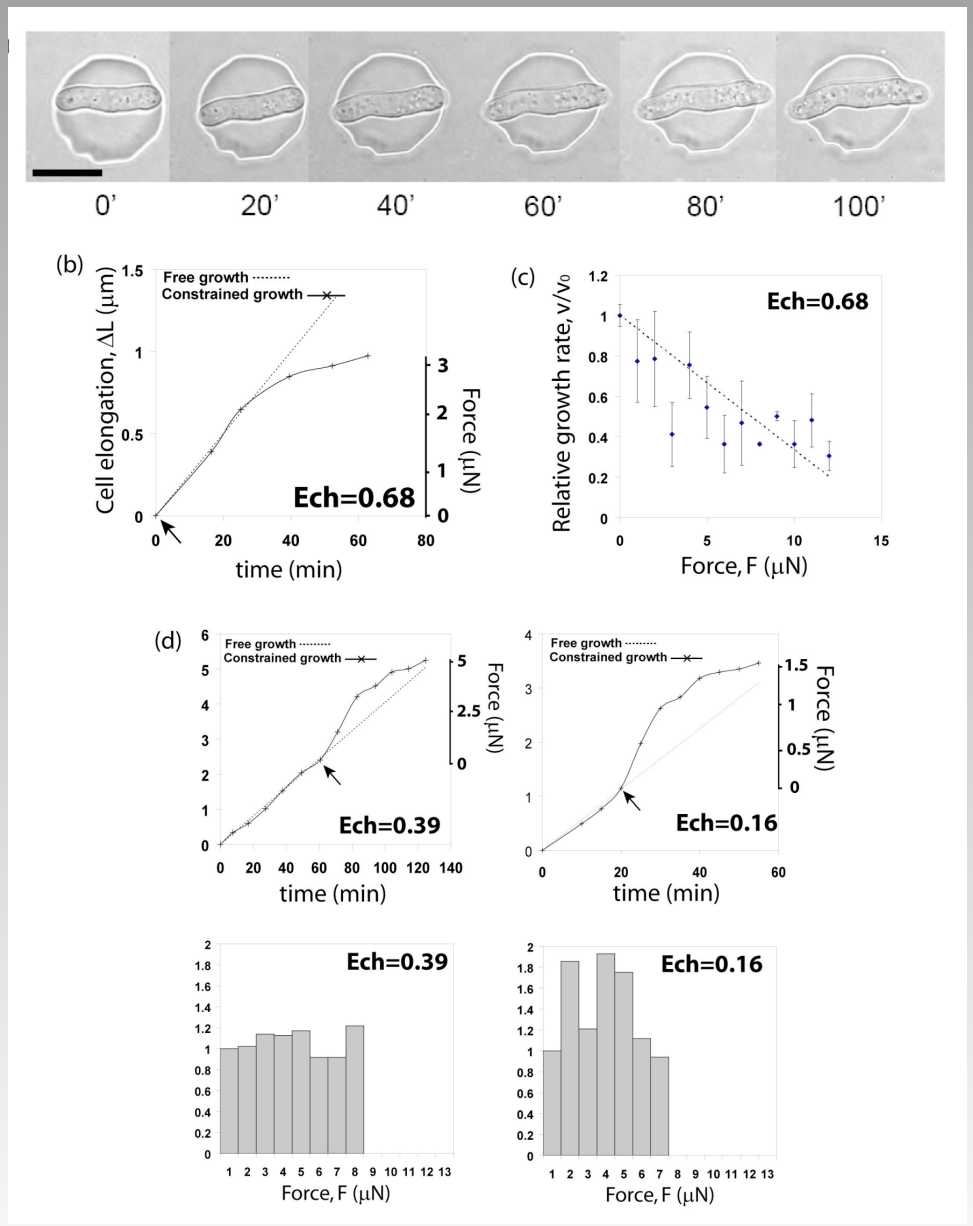
If the cell is growing under an external force F, the tension in the wall is reduced:

$$T = T_P - \frac{F}{2\pi Rh}.$$

$$v(F) = v_0\left(\frac{P}{P_0} - \frac{F}{P_0 S}\right)$$

Fission yeast

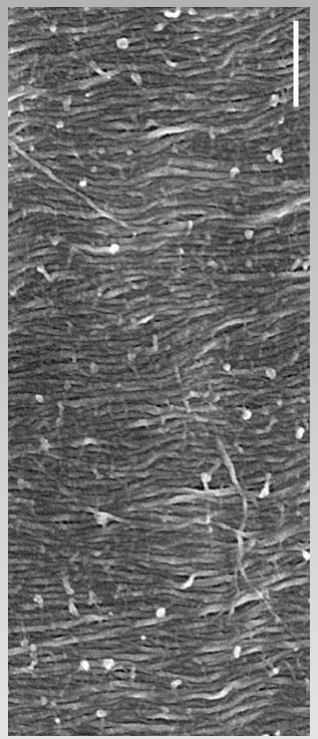
$P_0 = 1.2 \pm 0.1$ MPa.



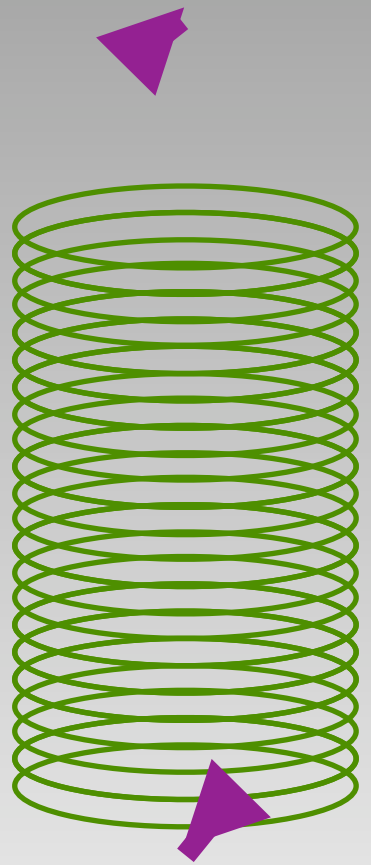
Fission yeast

Work in progress
-Characterise mutants
-Cell division

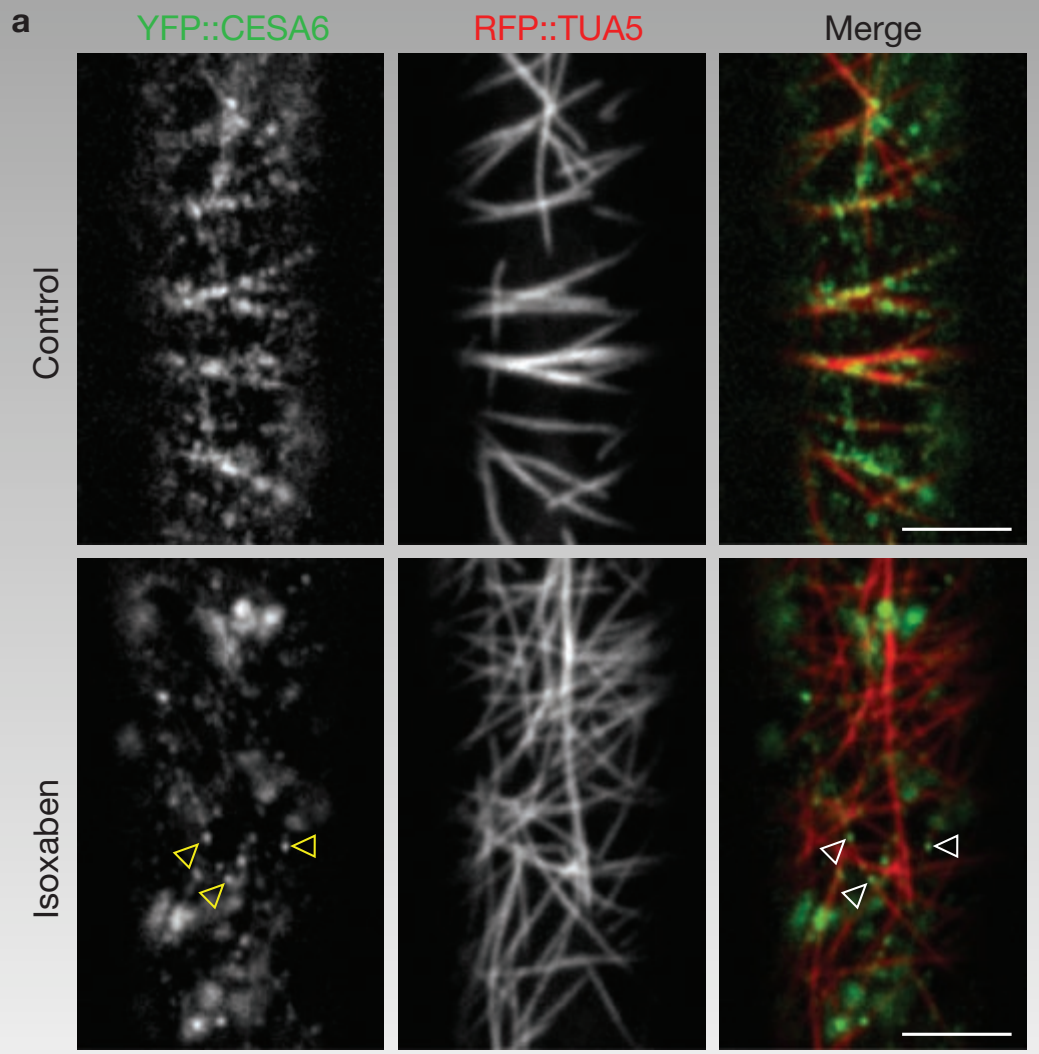
Introduction – Structure



Marga et al. 2005



Introduction – Building the structure

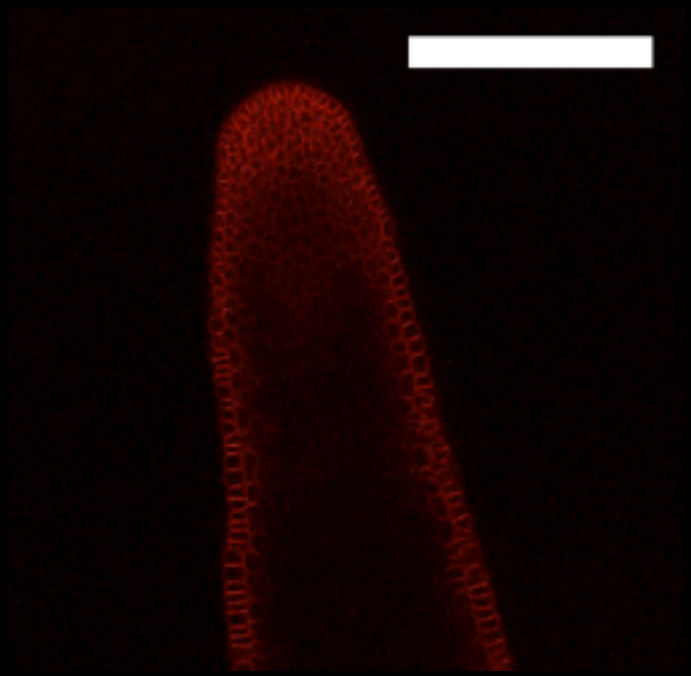


Gutierrez et al. 2009

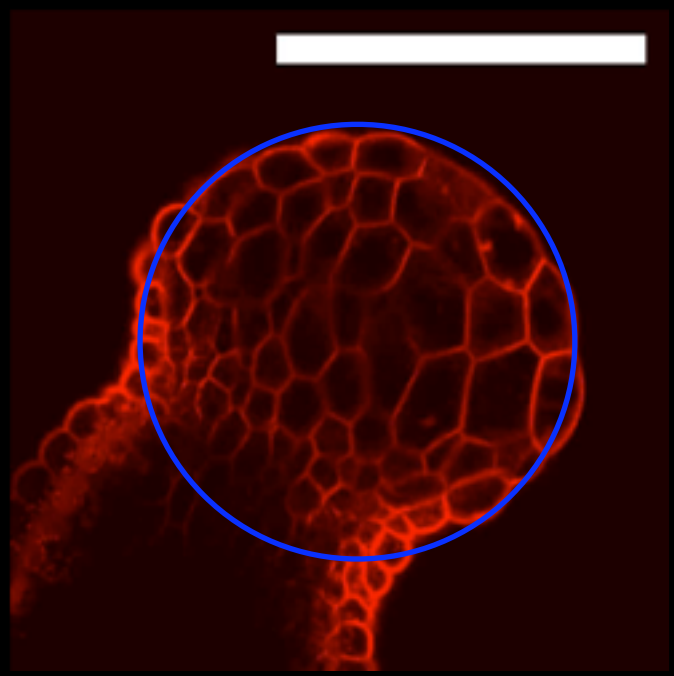
Control of CMT direction?

Playing with CMTs

Grandjean et al. 2004

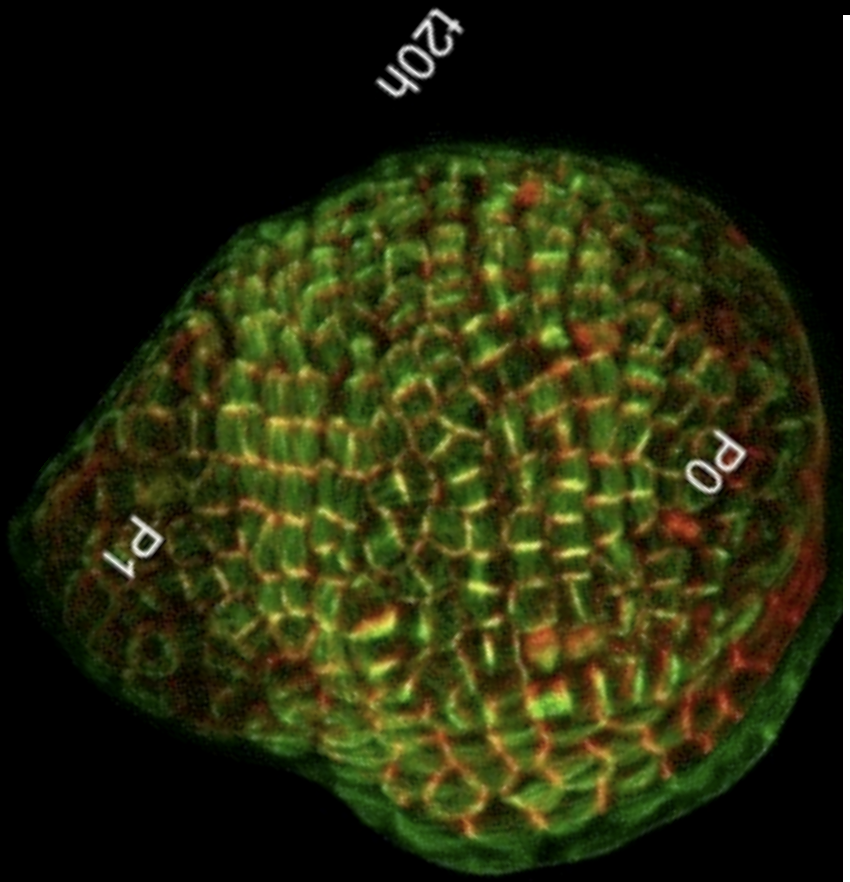


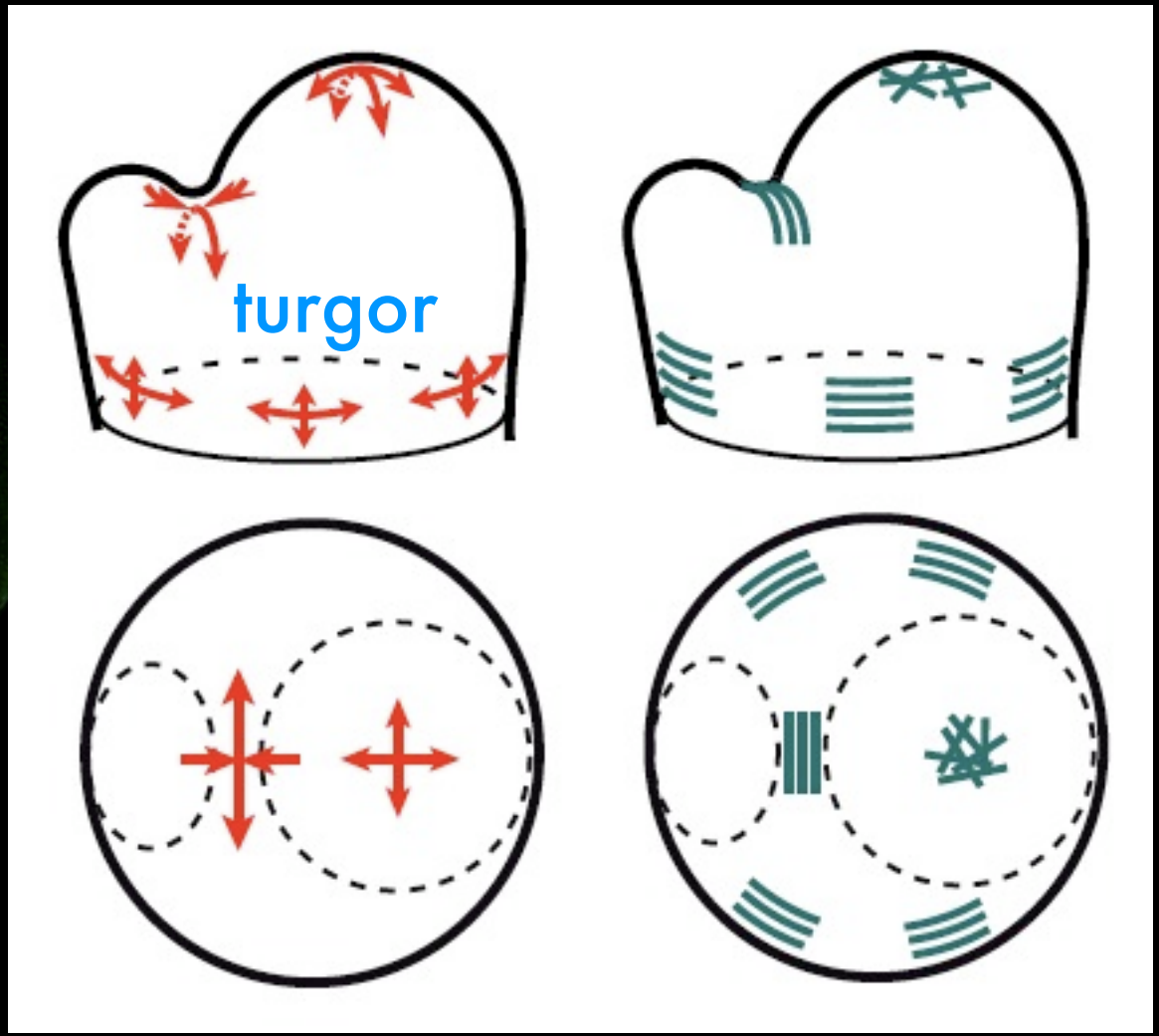
NPA



NPA + oryzalin

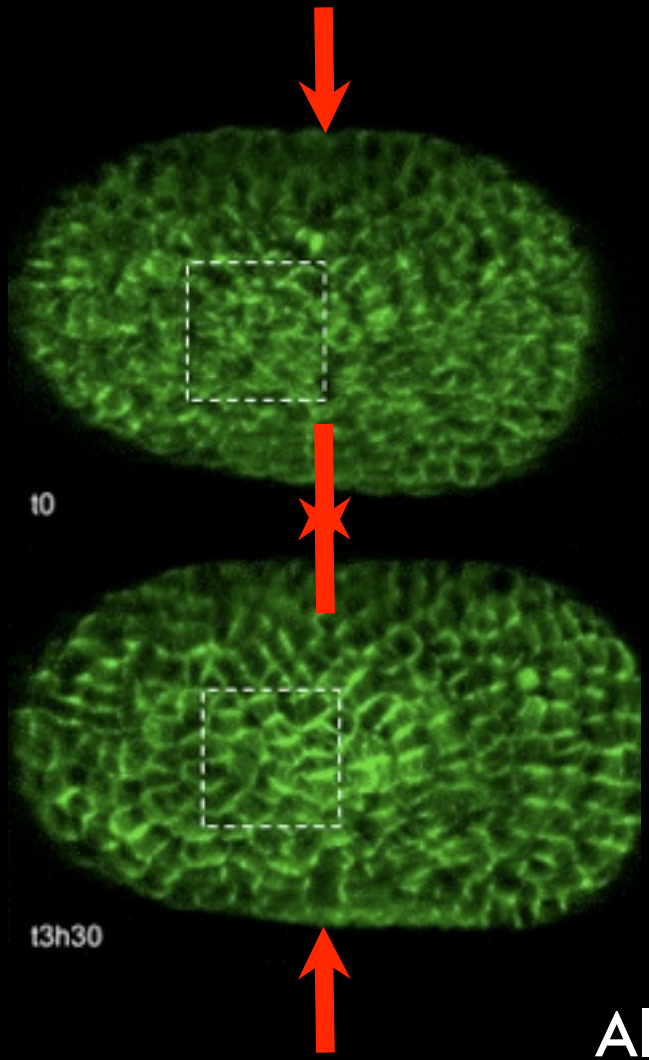
Mechanical forces and CMTs patterns

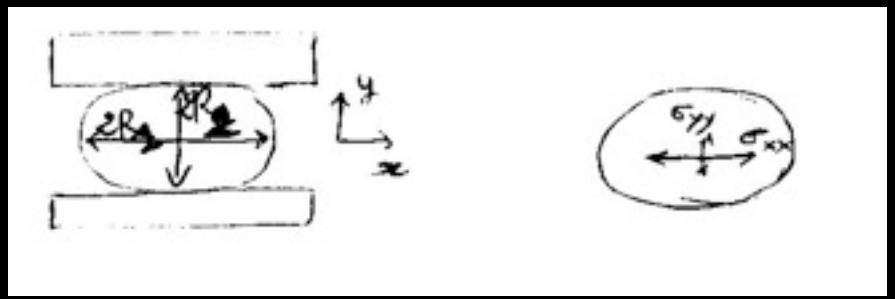




Alignment in the direction of maximal force

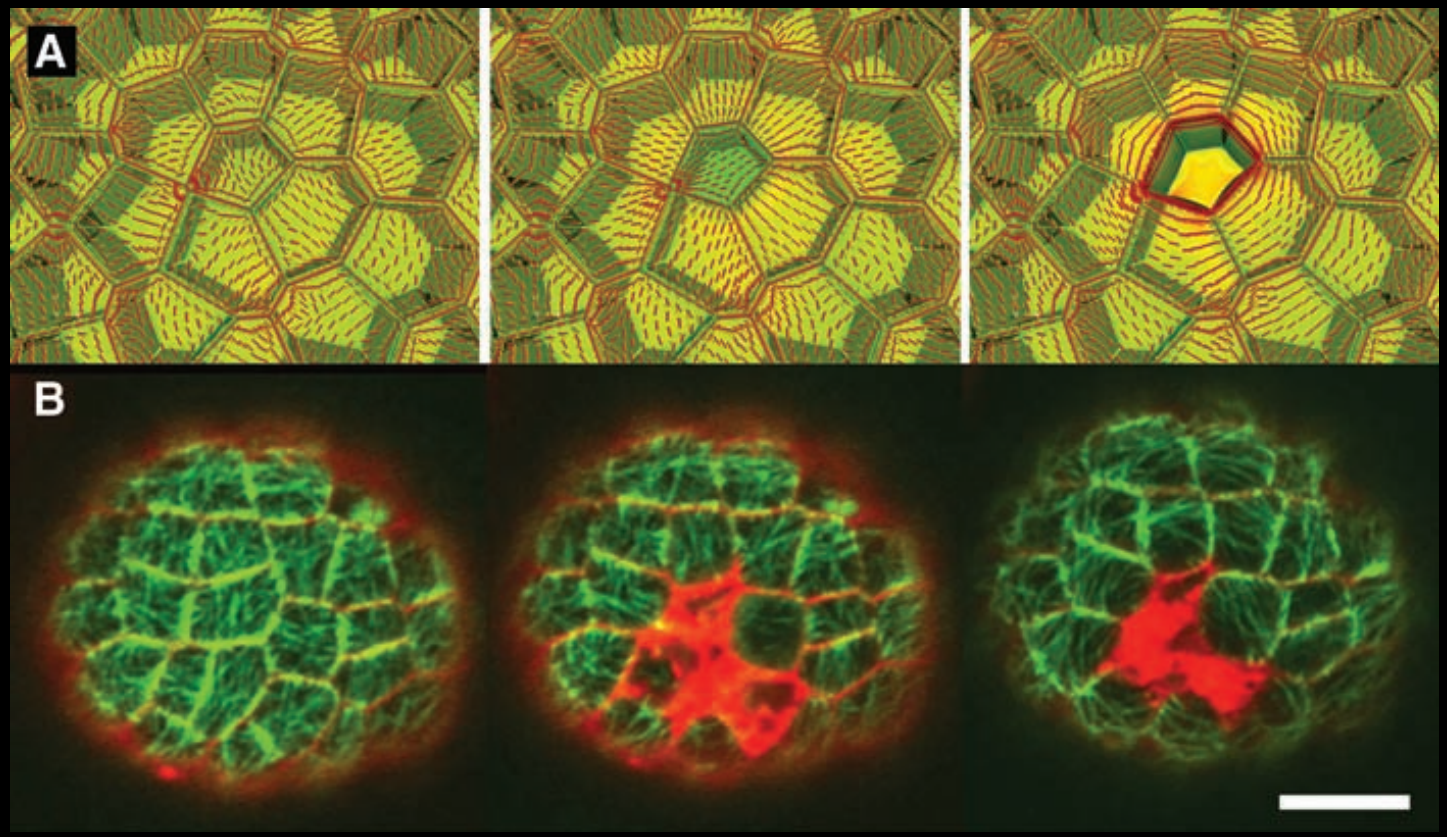
Mechanical forces and CMTs patterns





Alignment in the direction of maximal force

Mechanical forces and CMTs patterns

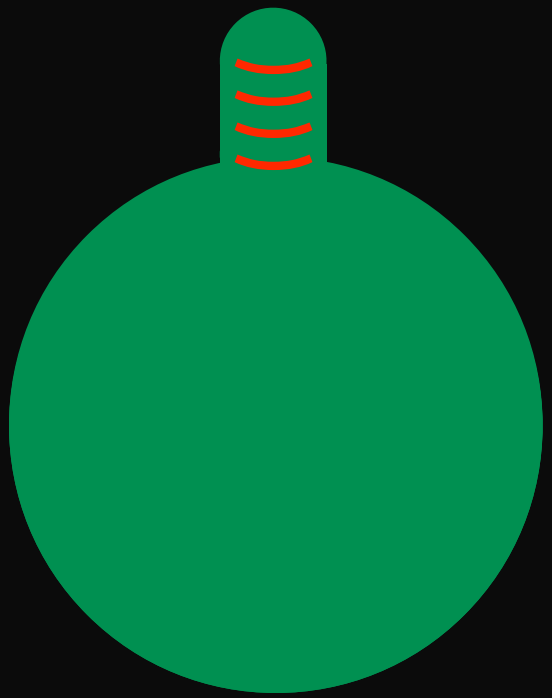


Alignment in the direction of maximal force

Elongated organs and boundaries

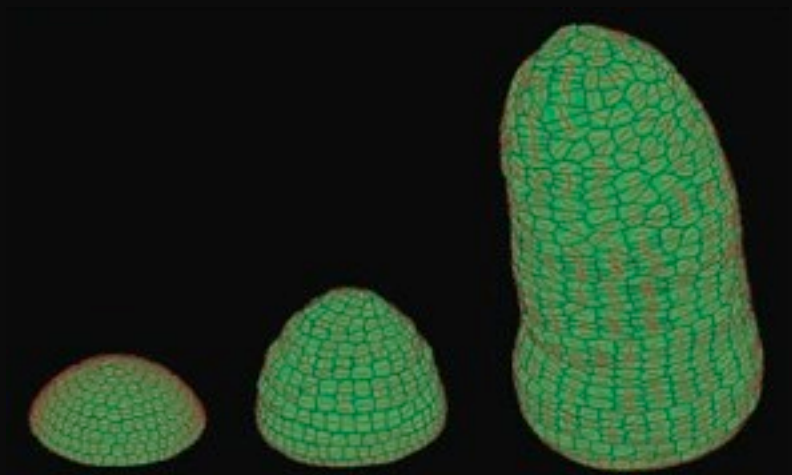
Elongated organs and boundaries

Elongated organs and boundaries



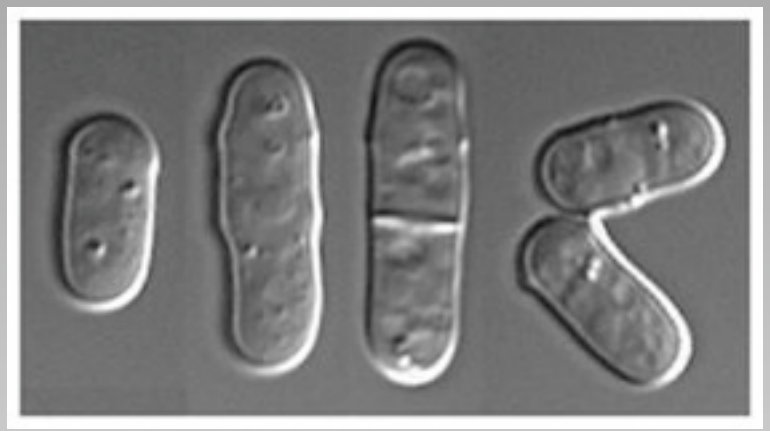
Elongated organs and boundaries

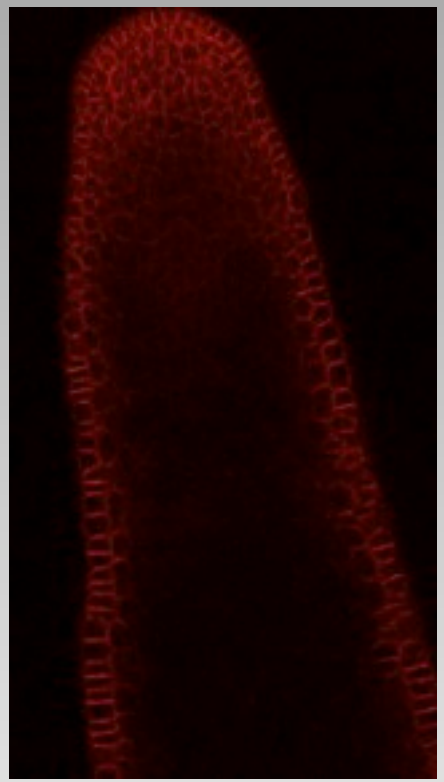
Elongated organs and boundaries



P. Krupinski and H. Jonsson

Conclusion





- Two strategies for anisotropic growth
  - softening the tip => tip growth
  - reinforcing

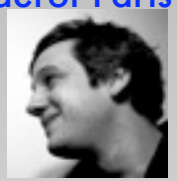
- Plant development: cellular level <=> morphogenesis

Plant cells

Francis Corson
ENS Paris, now Rockefeller University

Olivier Hamant and Jan Traas
INRA and ENS Lyon

Yves Couder and Steffen Bohn
Université Denis Diderot Paris



Experimental collaborations

Elliott Meyerowitz
Caltech

Marcus Heisler
Caltech, now EMBL

Numerical collaborations

Pawel Krupinski and Henrik Jonsson
Lund University

Starting collaboration with Laboratoire Joliot Curie

Fission yeast

Nicolas Minc
Columbia University

Fred Chang
Columbia University