

Title: Circumferential gap propagation in an anisotropic elastic bacterial sacculus

Date: Dec 05, 2013 11:30 AM

URL: <http://pirsa.org/13120014>

Abstract: We have modelled stress concentration around small gaps in anisotropic elastic sheets, corresponding to the peptidoglycan sacculus of bacterial cells, under loading corresponding to the effects of turgor pressure in rod-shaped bacteria. We find that under normal conditions the stress concentration is insufficient to mechanically rupture bacteria, even for gaps up to a micron in length. We then explored the effects of stress-dependent smart-autolysins, as hypothesised by Arthur L Koch. We show that the measured anisotropic elasticity of the PG sacculus can lead to stable circumferential propagation of small gaps in the sacculus. This is consistent with the recent observation of circumferential propagation of PG-associated MreB patches in rod-shaped bacteria. We also find a bistable regime of both circumferential and axial gap propagation, which agrees with behavior reported in cytoskeletal mutants of *B. subtilis*. We conclude that the elastic anisotropies of a bacterial sacculus, as characterised experimentally, may be relevant for maintaining rod-shaped bacterial growth.

How do bacteria grow longer, not wider?

“Circumferential gap propagation in an anisotropic elastic bacterial sacculus”



Andrew Rutenberg
Swadhin Taneja
Ben Levitan
Dalhousie Physics



Waterloo Soft Matter Theory Conference, Dec 2013



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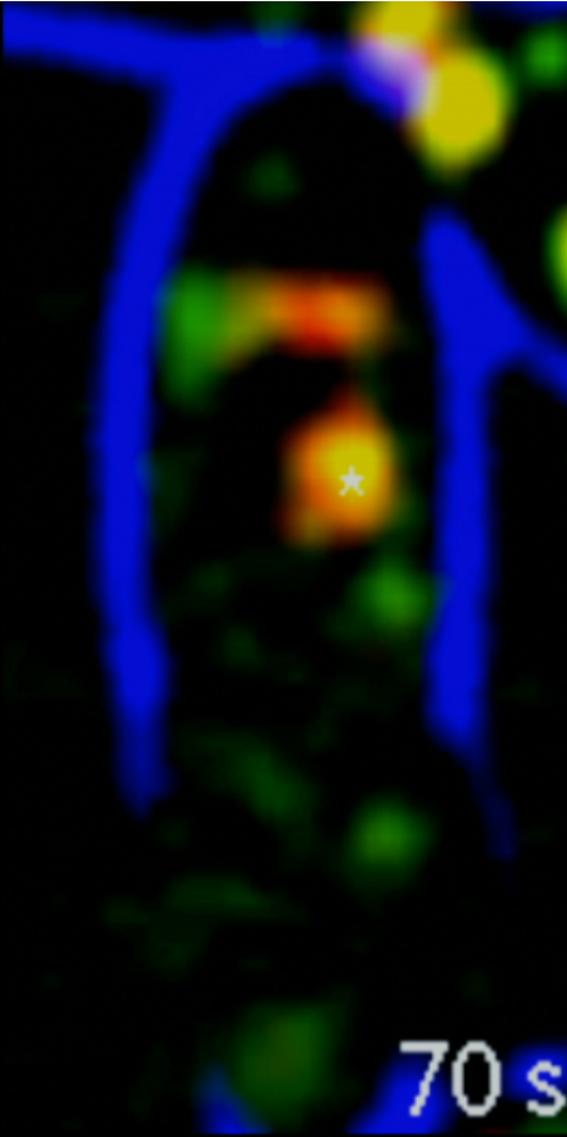
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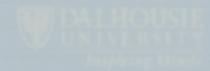


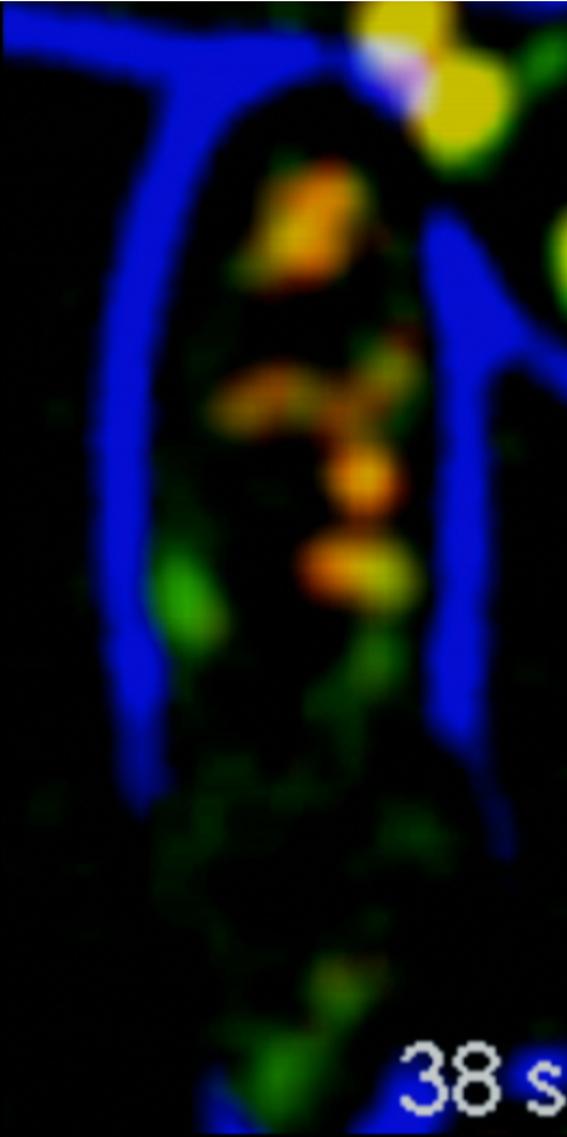
Growth via new hoops

Garner et al, Science **333**, 222 (2011).

Dominguez-Escobar et al, Science **333**, 225 (2011).

van Teefelen et al, PNAS **108**, 15822 (2011).

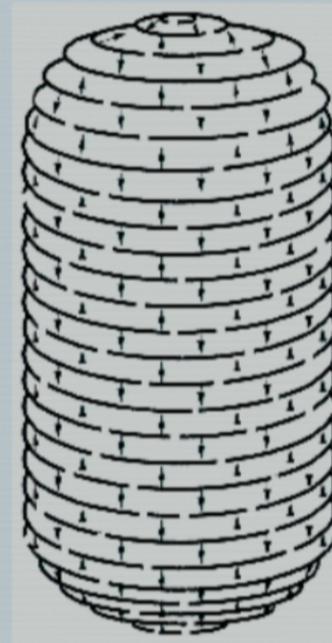




38 s

Growth via new hoops

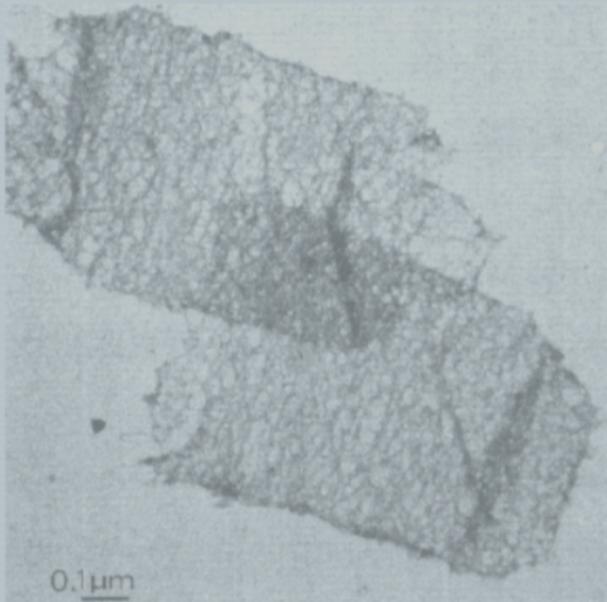
Garner et al, Science 333, 222 (2011).
Dominguez-Escobar et al, Science 333, 225 (2011).
van Teeffelen et al, PNAS 108, 15822 (2011).



what orients hoops?



Local disorder of sacculus



Verwer et al, J Bact **136**, 723 (1978).



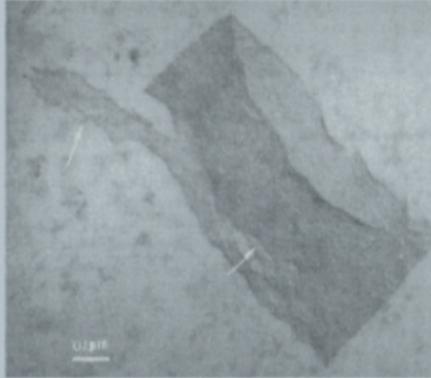
Turner et al, Nature Comm **4**, 1496 (2013).



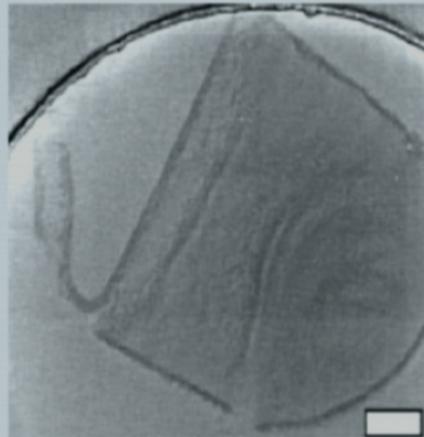
clue: rupture of cylindrical tanks



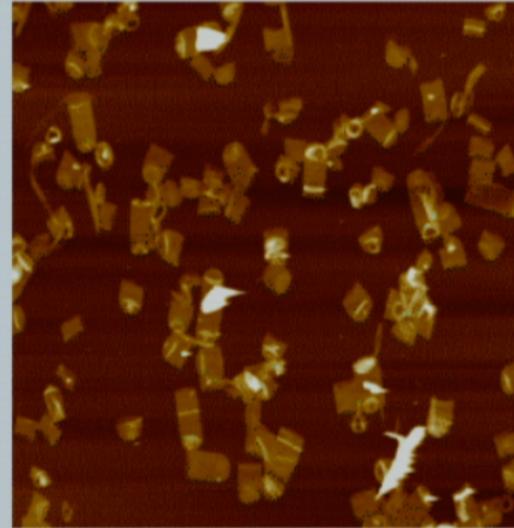
but bacteria split differently



Verwer et al, J Bact **141**, 327 (1980).

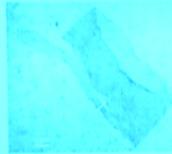


Beeby et al, Mol Micro **88**, 664 (2013).

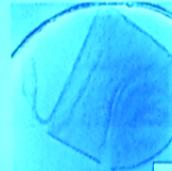


Hayhurst et al, PNAS **105**, 14603 (2008).

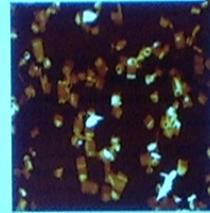
but bacteria split differently



Novor et al. J Bact 181: 3273 (2003)



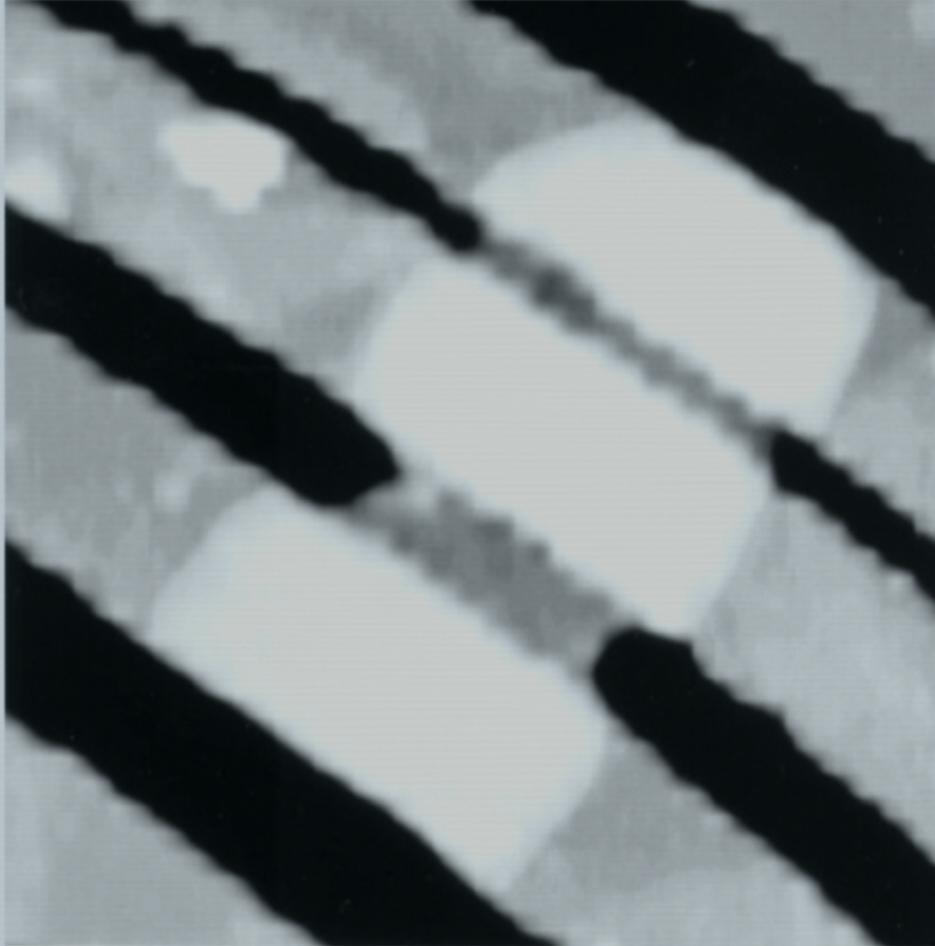
Bely et al. Mol Micro 88: 664 (2013)



Harber et al. PNAS 105: 14003 (2008)

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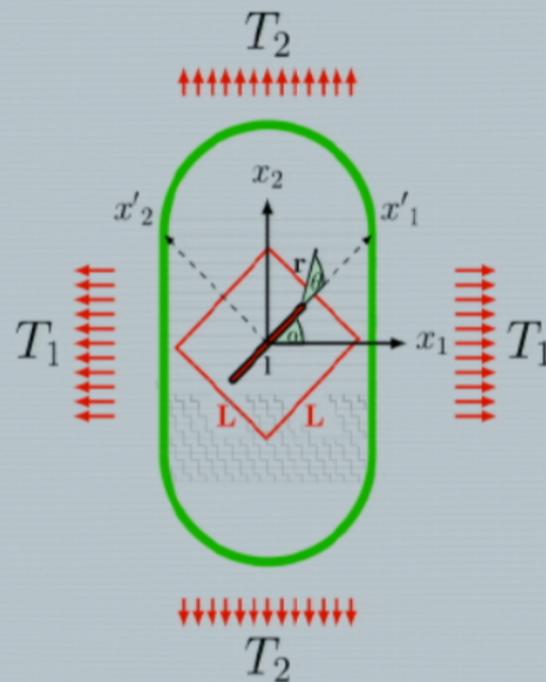
sacculus is anisotropic elastic mesh



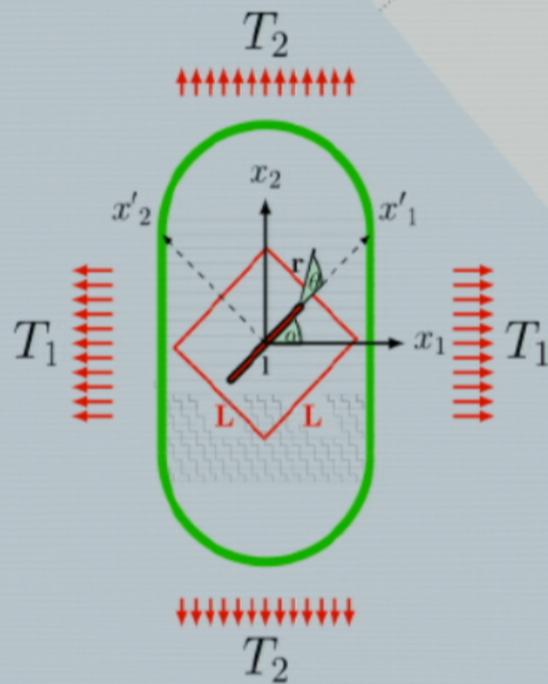
Yao, Jericho, Pink, and Beveridge,
J Bact **181**, 6865 (1999).

$$\eta \equiv \frac{E_1}{E_2} \approx 2$$

In what direction would a crack grow?

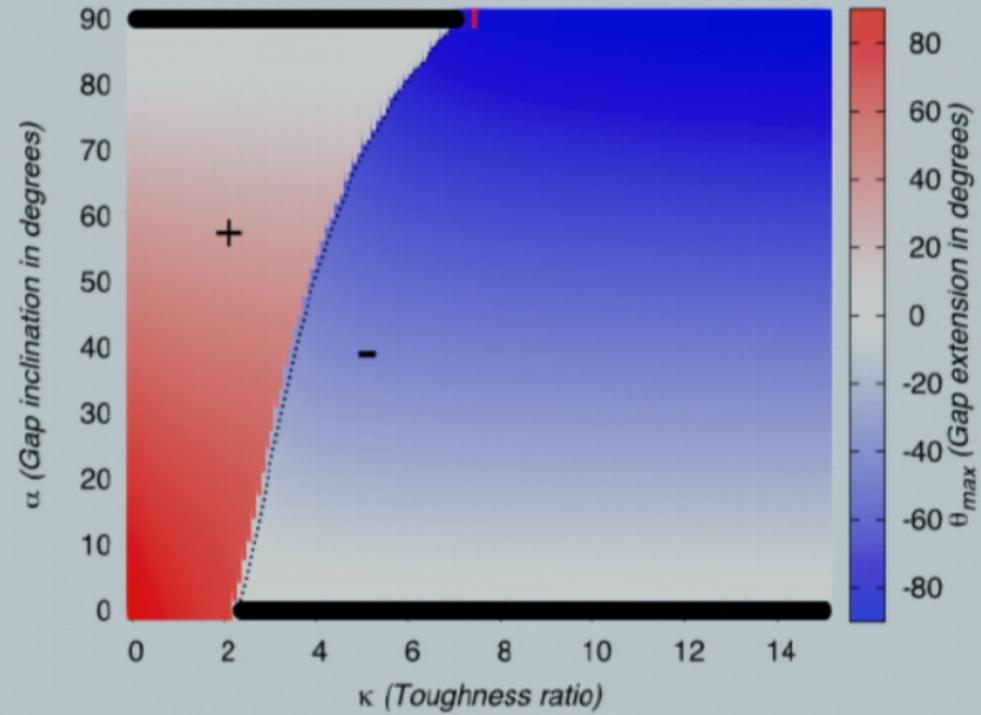
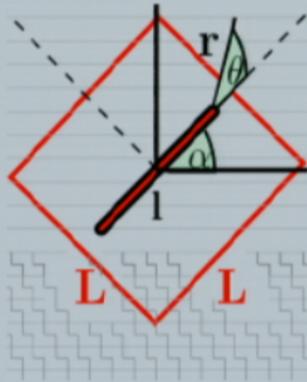


In what direction would

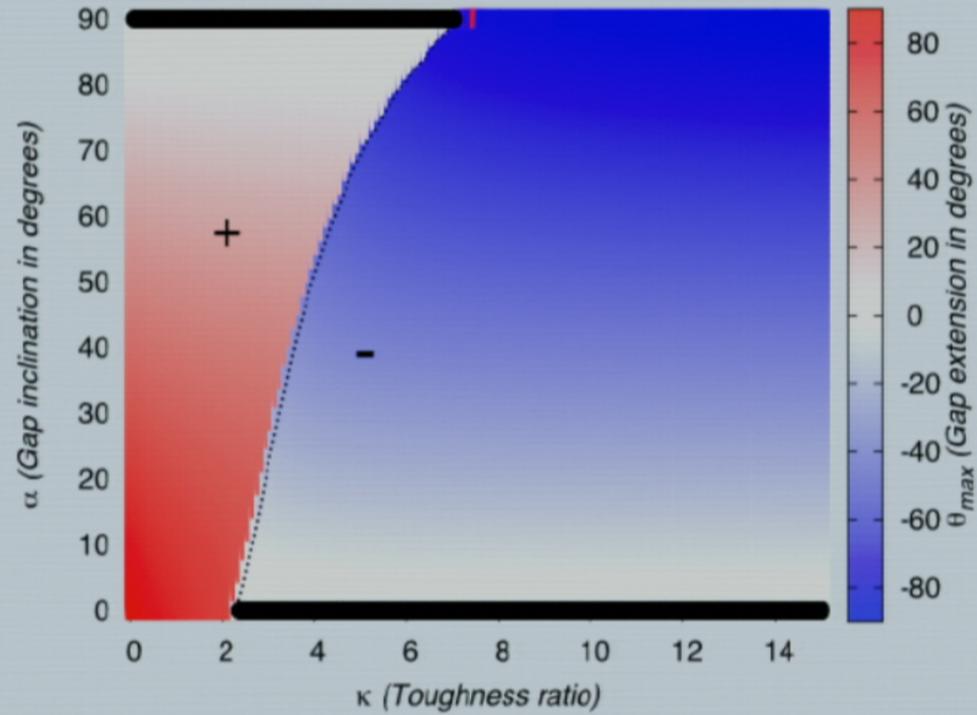
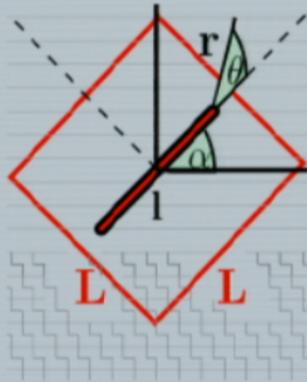


$$\sigma_{ij} = C_{ijkl}\epsilon_{kl}, \quad \epsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}),$$

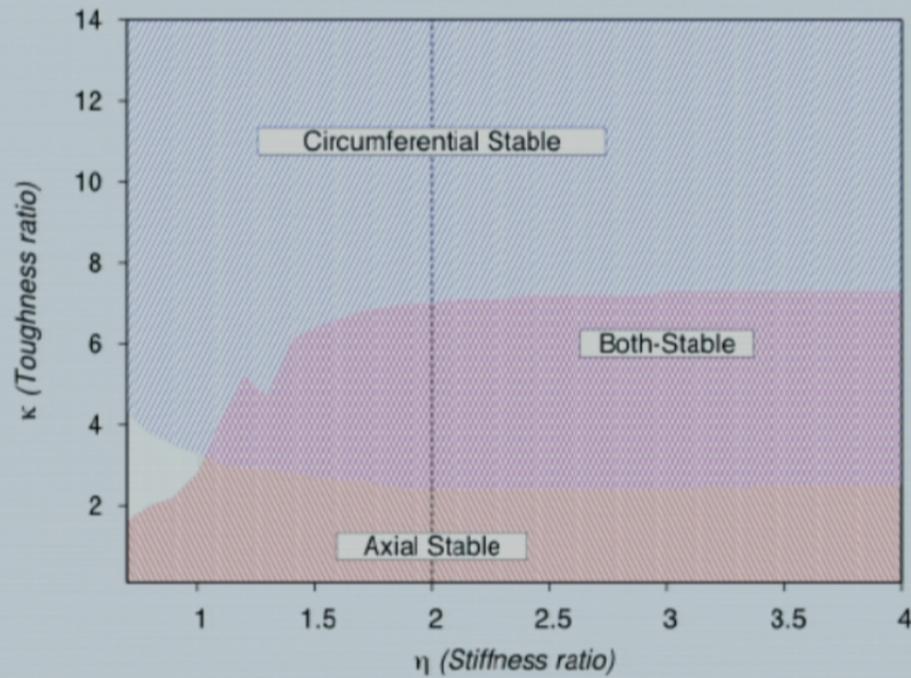
What angle will crack grow?



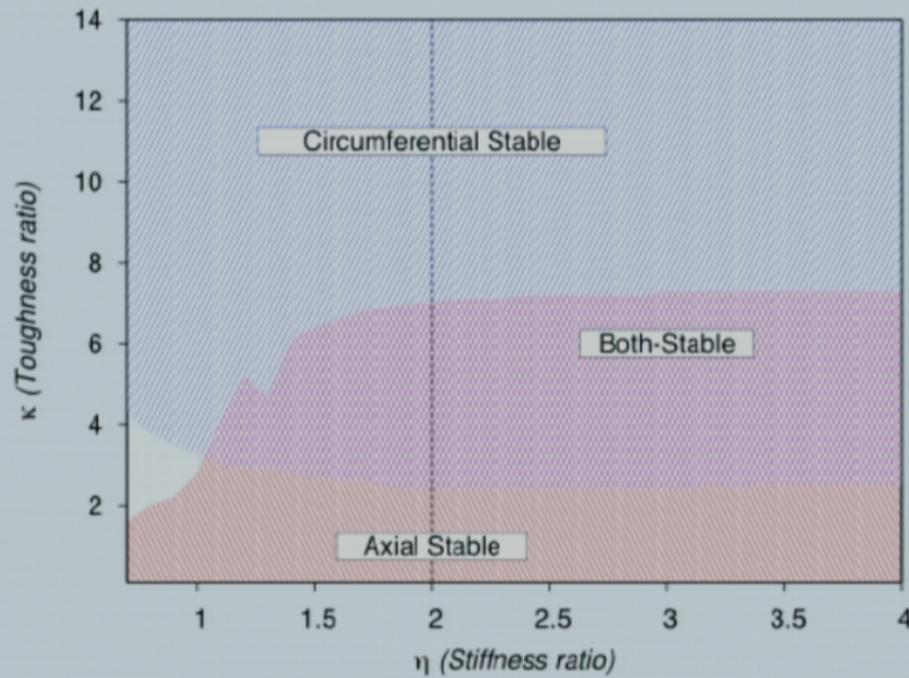
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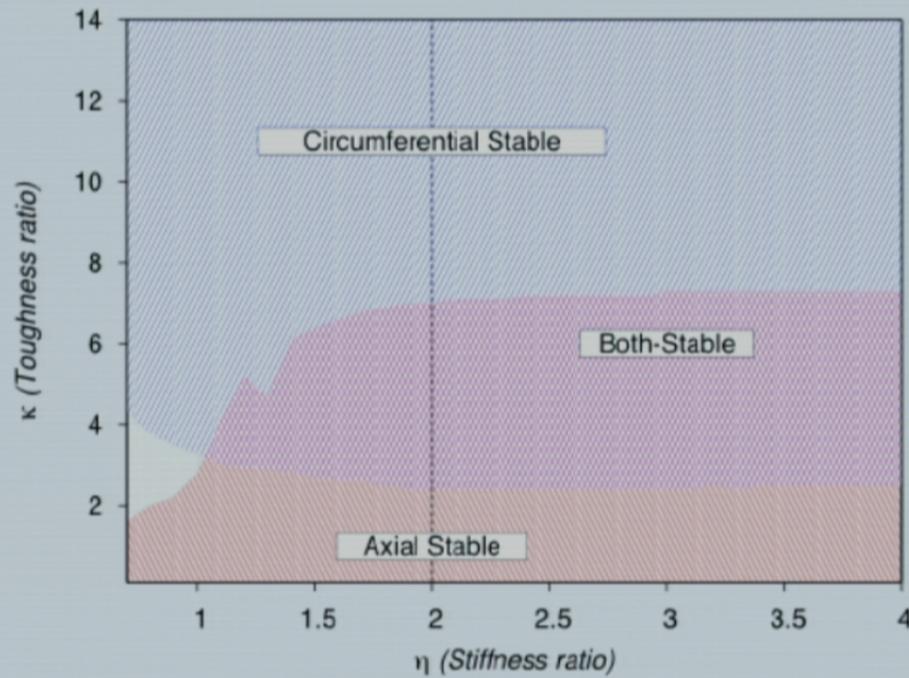
Stability regimes



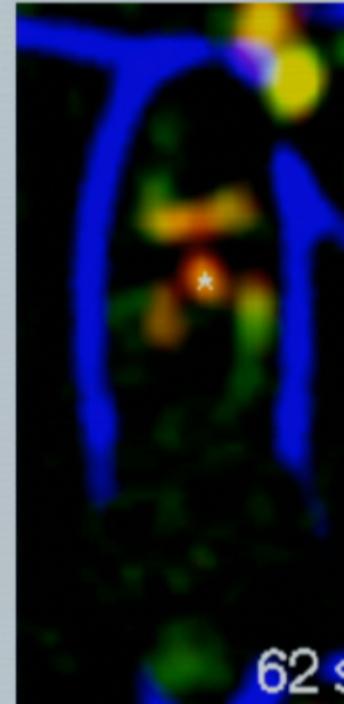
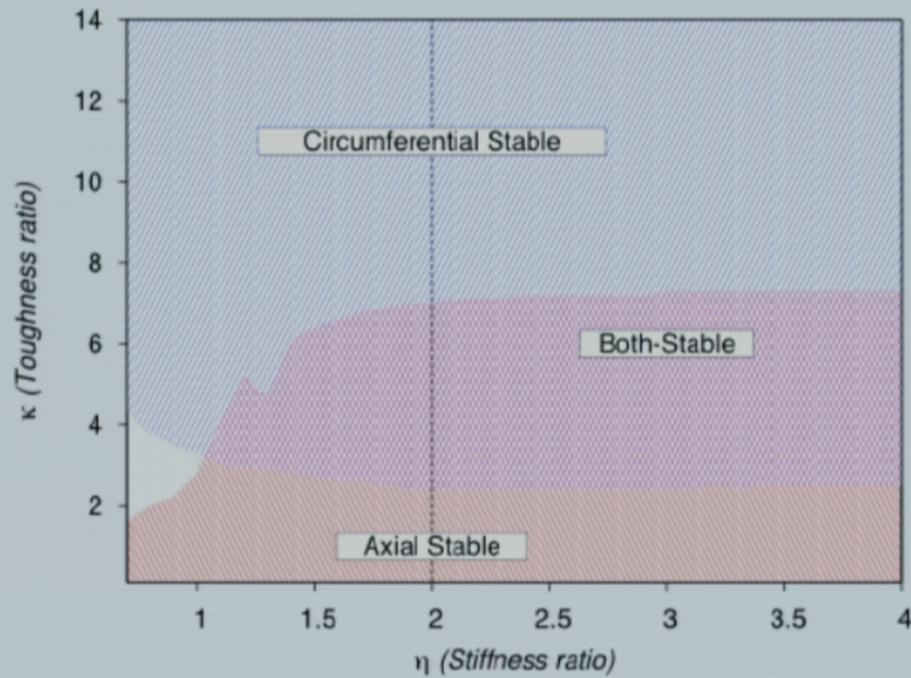
Stability regimes



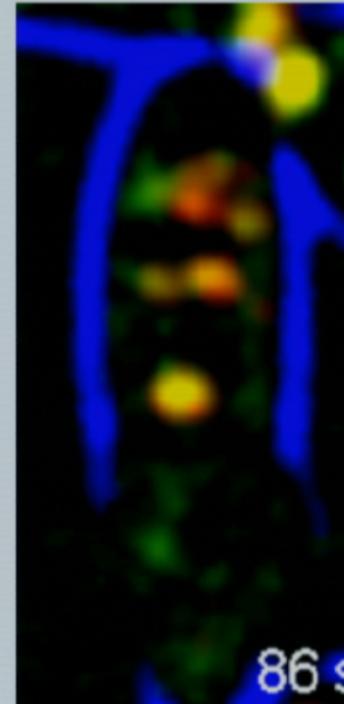
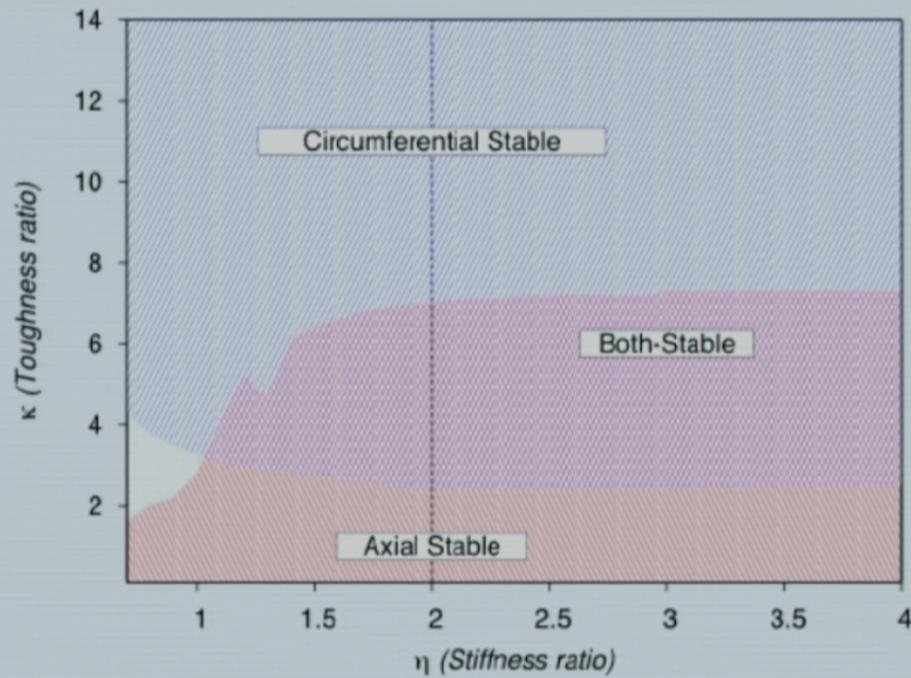
Stability regimes



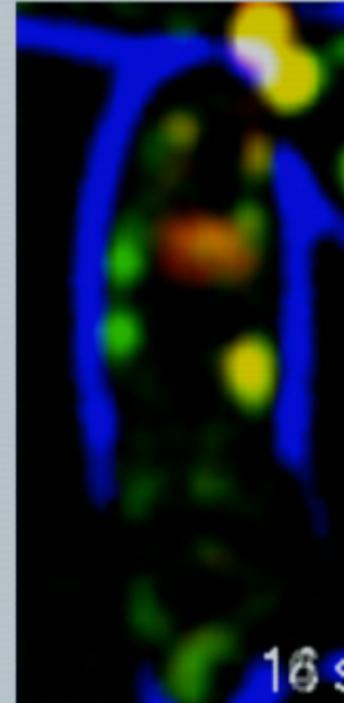
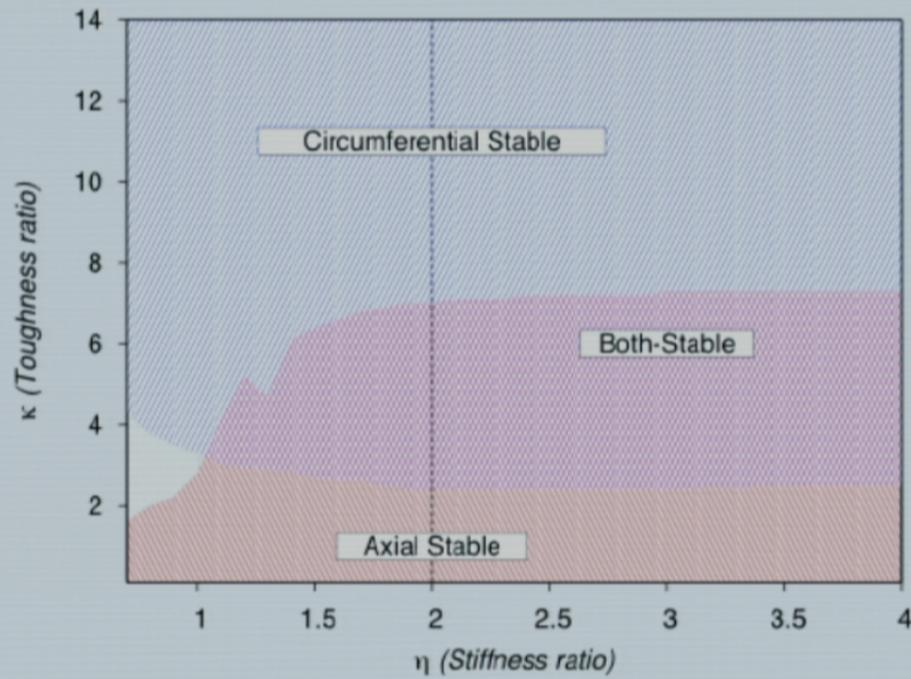
Stability regimes



Stability regimes



Stability regimes



"Anisotropic peptidoglycan orients cracks"

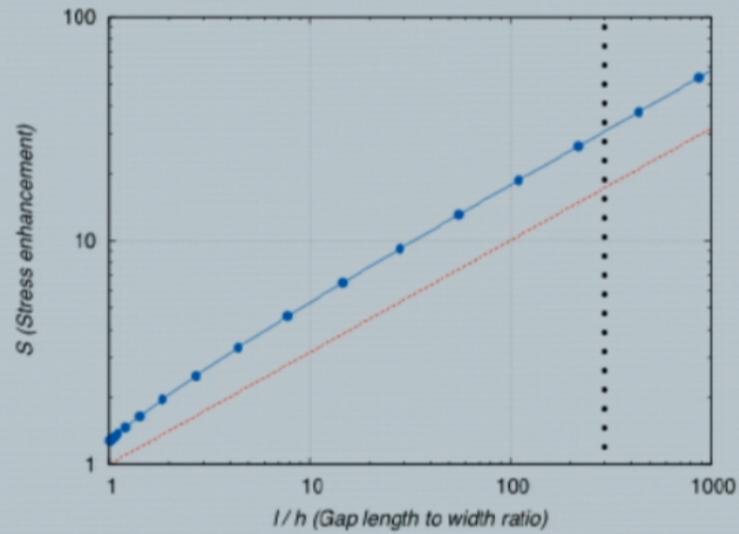
What about growth?

Q1: Mechanical stability without growth?

Q2: How might stress couple to PG degradation?

Q3: How might stress couple to PG synthesis?

Q1: Mechanical stability without growth?



cracks $< 1\mu\text{m}$ stable at 1nN

Q2: How might stress couple to PG degradation?

Koch "smart autolysins"

Koch, Adv Microb Physiol **24**, 301 (1983).

Koch, Res Microbiol **141**, 529 (1990).

mechanoenzymology/mechanochemistry/mechanobiology

del Rio et al, Science **323**, 638 (2009)

exposure of talin/vinculin binding

Zhang et al, Science **324**, 1330 (2009)

access to cleavage site of "von Willebrand factor"

essential PG hydrolases recently identified

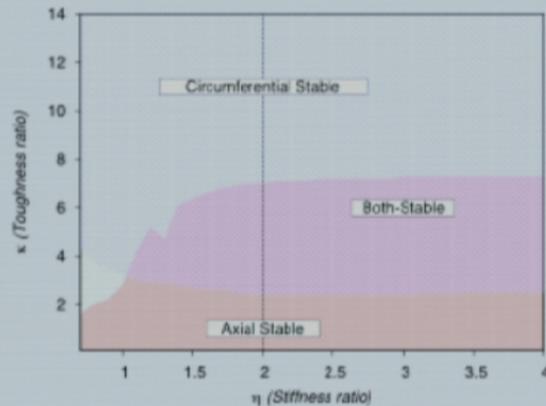
Singh et al, Mol Micro **86**, 1036 (2012).

How do bacteria grow longer, not wider?

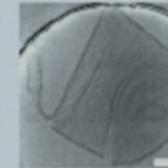
oriented growth

local disorder implies non-local mechanism
and gaps in PG

stress concentration in gaps
and anisotropic elasticity



circumferential fracture



circumferential gap propagation

