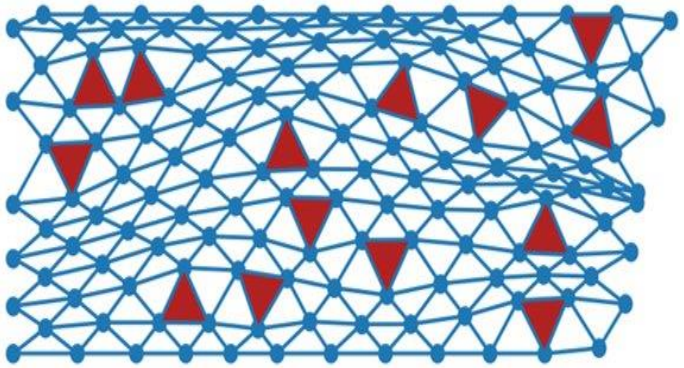
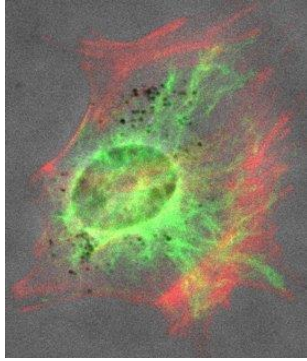


Loops versus lines and the compression stiffening of cells



Mahesh Gandikota, A. E. Patteson and J. M. Schwarz

Dept. of Physics, Syracuse University, USA

Katarzyna Pogoda

Institute of Nuclear Physics, Polish Academy of Sciences, Poland

Anne van Oosten

Leiden Academic center for drug research, Netherlands

T. A. Engstrom

Dept. of Physics, Hobart & William Smith Colleges, USA

P. A. Janmey

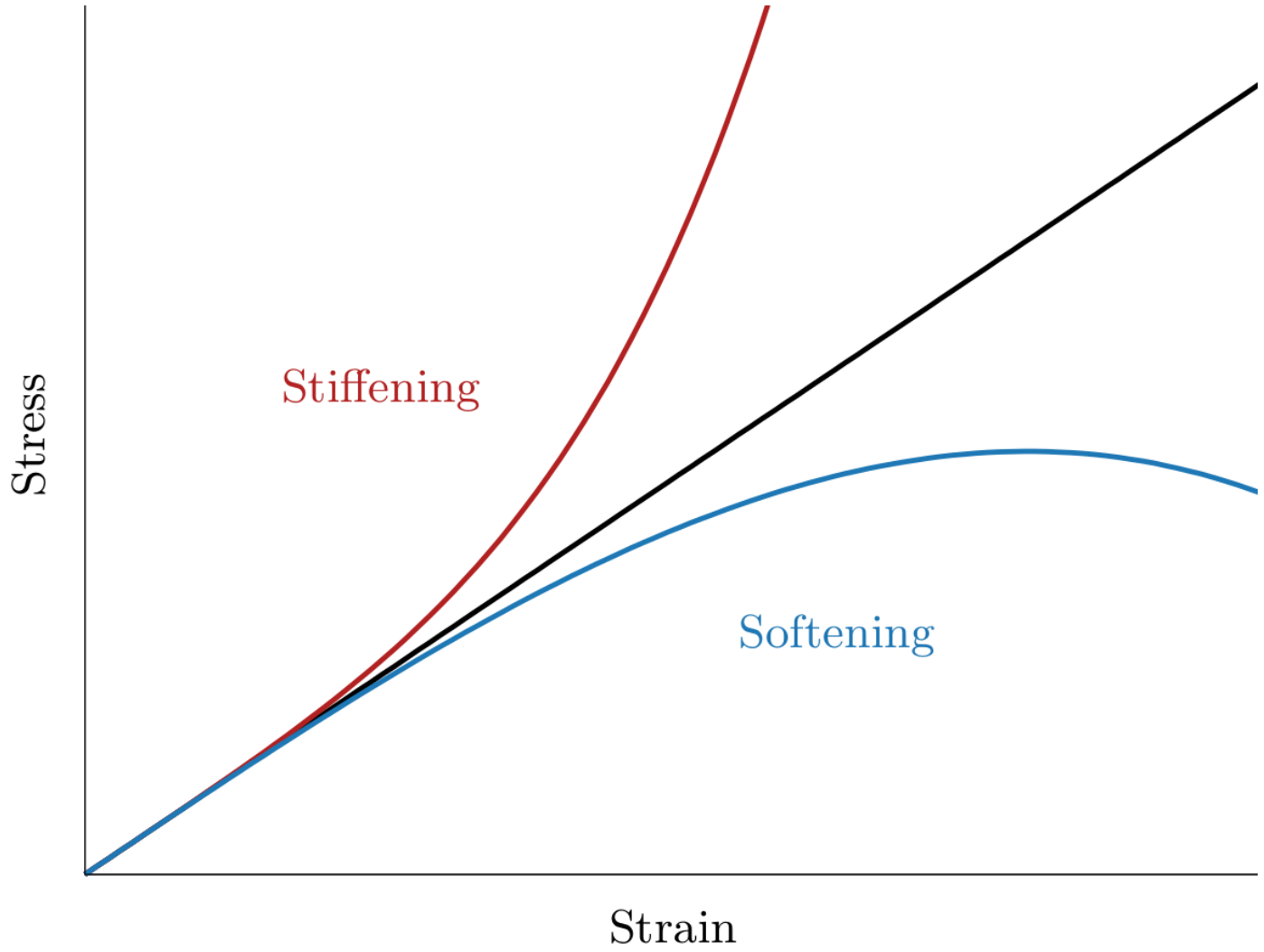
Departments of Physiology and Physics & Astronomy, University of Pennsylvania, USA

National Science Centre Poland

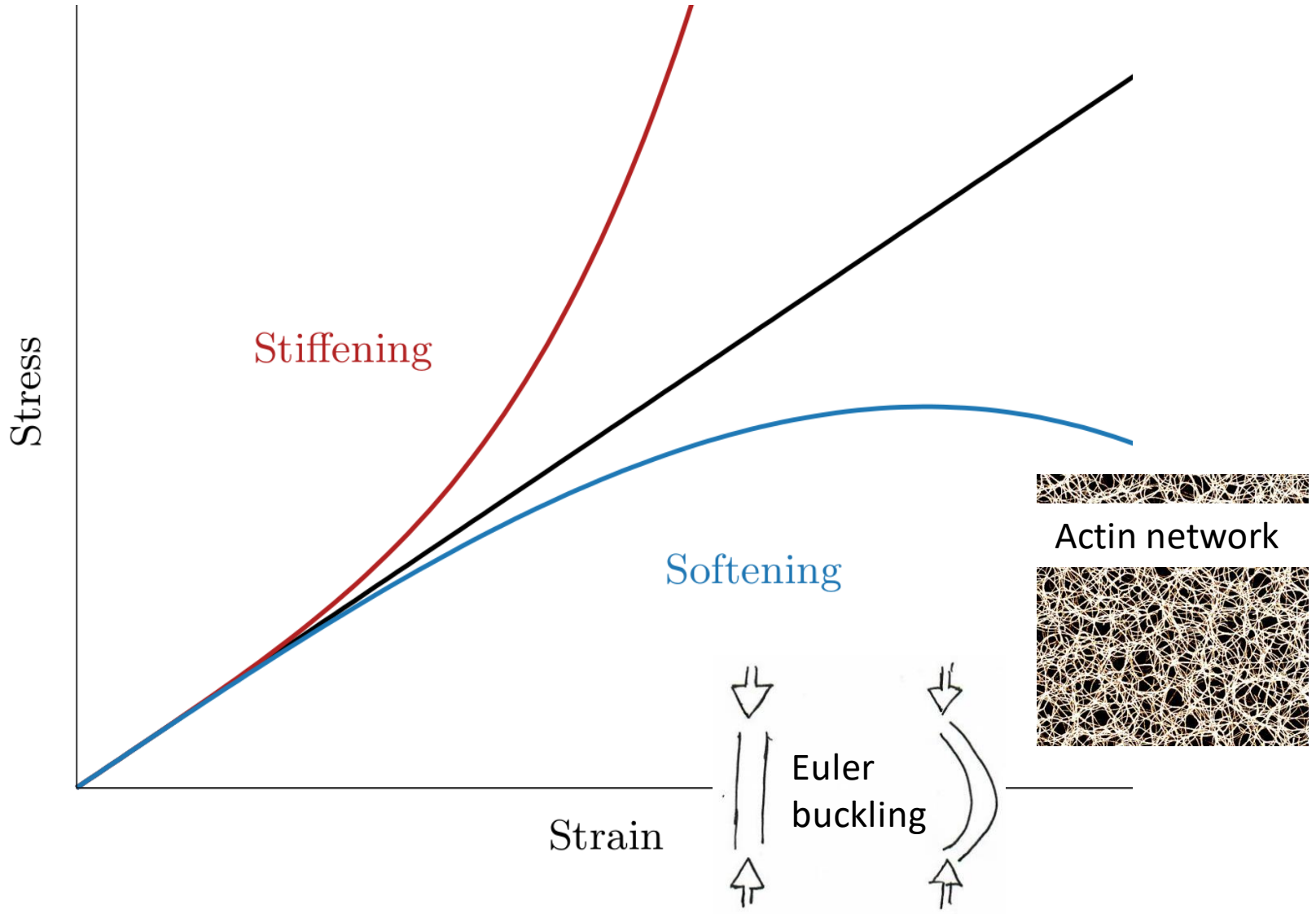
NIH

NSF

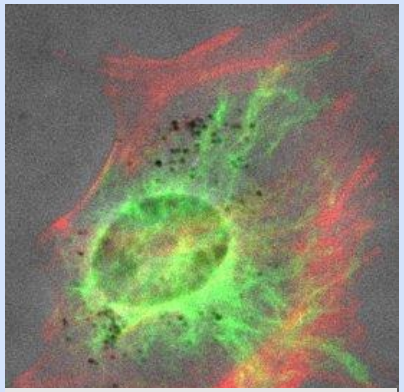
What will happen if you compress anything?



What will happen if you compress anything?

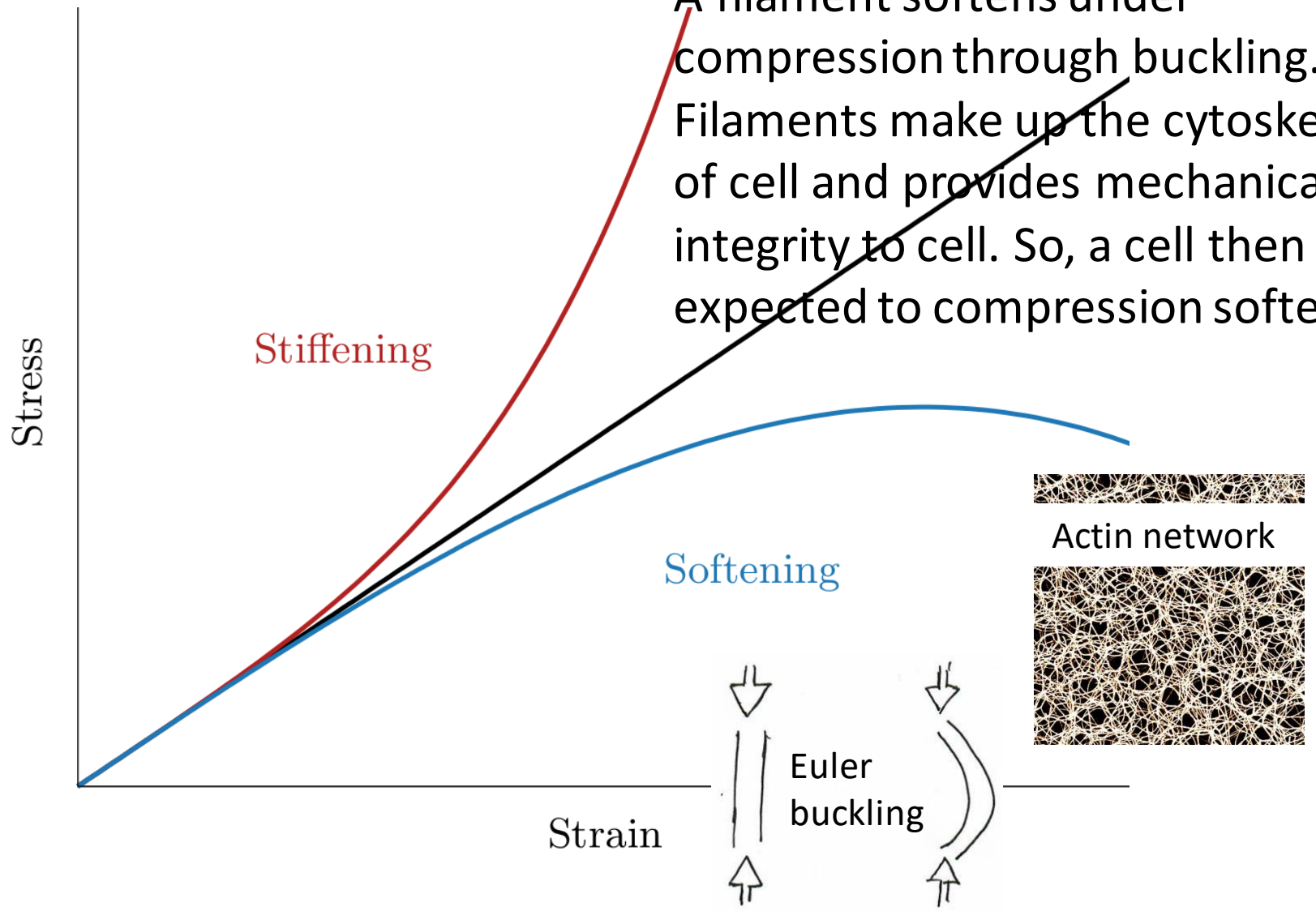


What will happen if you compress a cell?

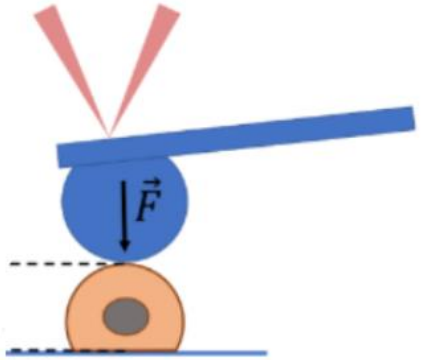


F-Actin Vimentin

A filament softens under compression through buckling. Filaments make up the cytoskeleton of cell and provides mechanical integrity to cell. So, a cell then is expected to compression soften.

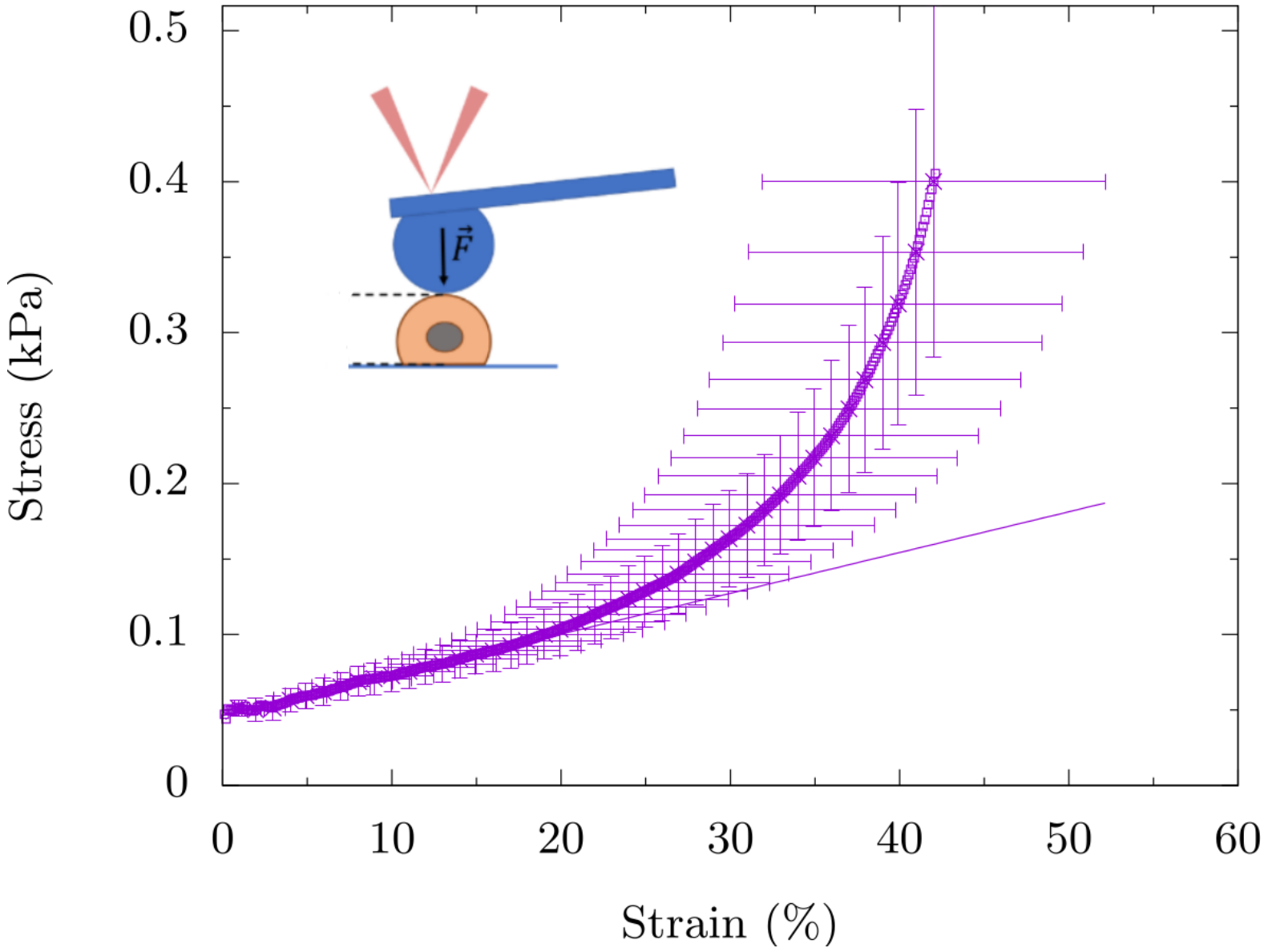


Atomic force microscopy of mouse embryo fibroblast (mEF)

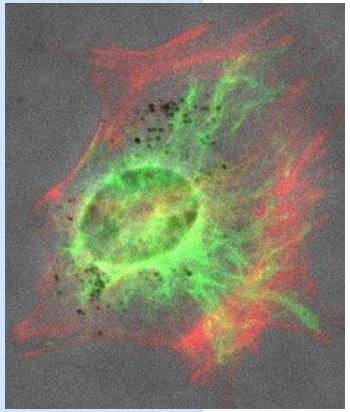


Atomic force microscopy of mouse embryo fibroblast (mEF)

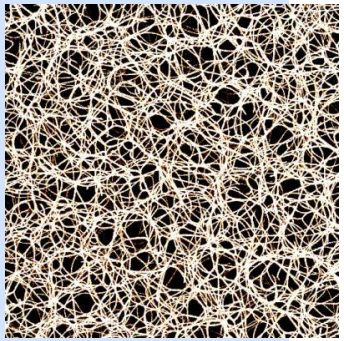
Compression stiffening

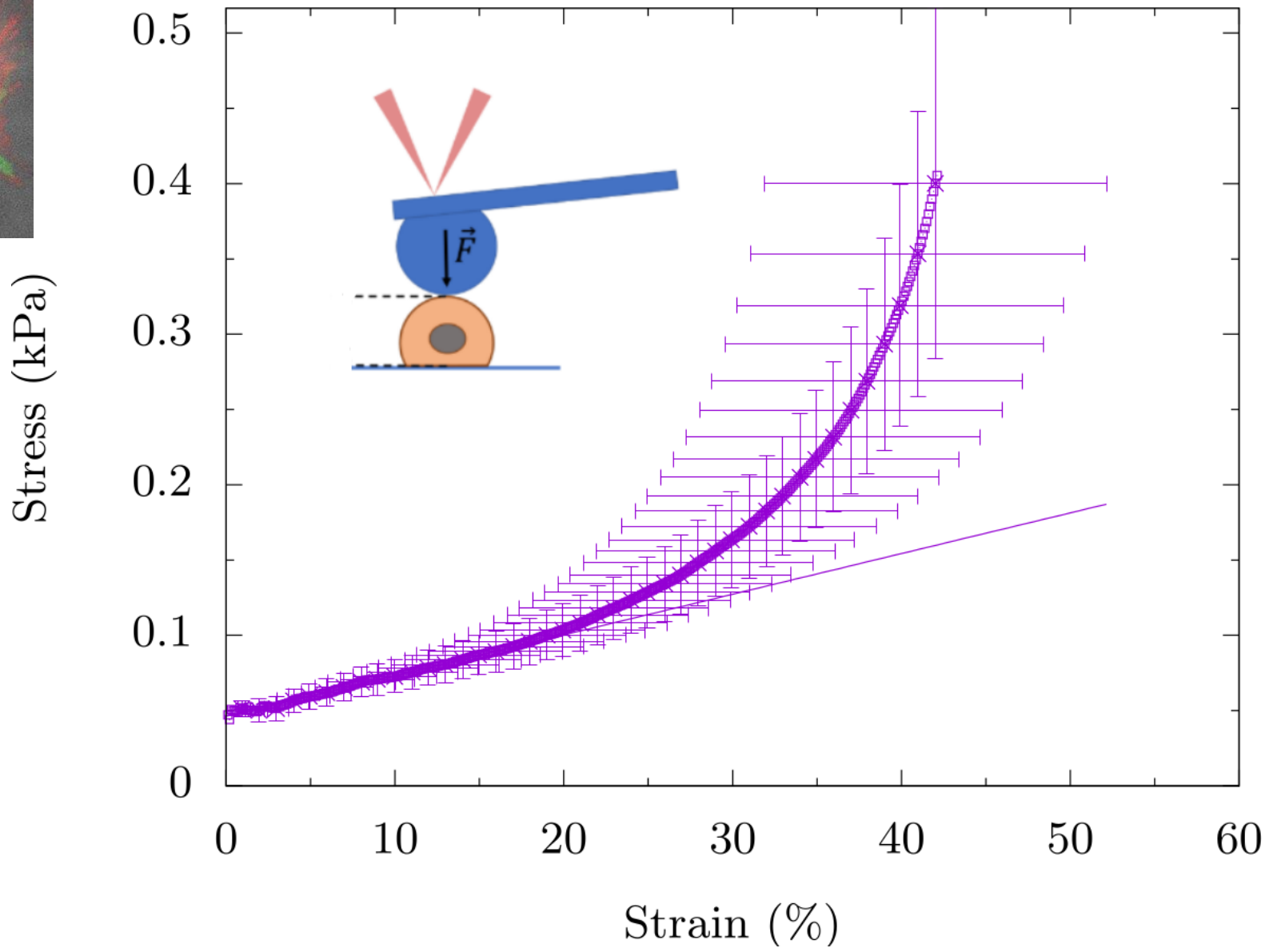


QUESTION

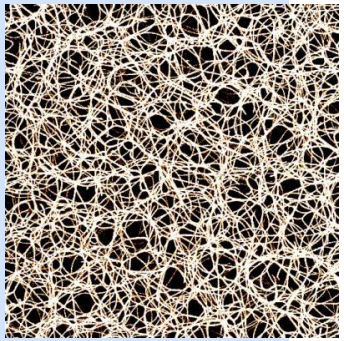


How can a cell compression stiffen when fiber networks compression soften?



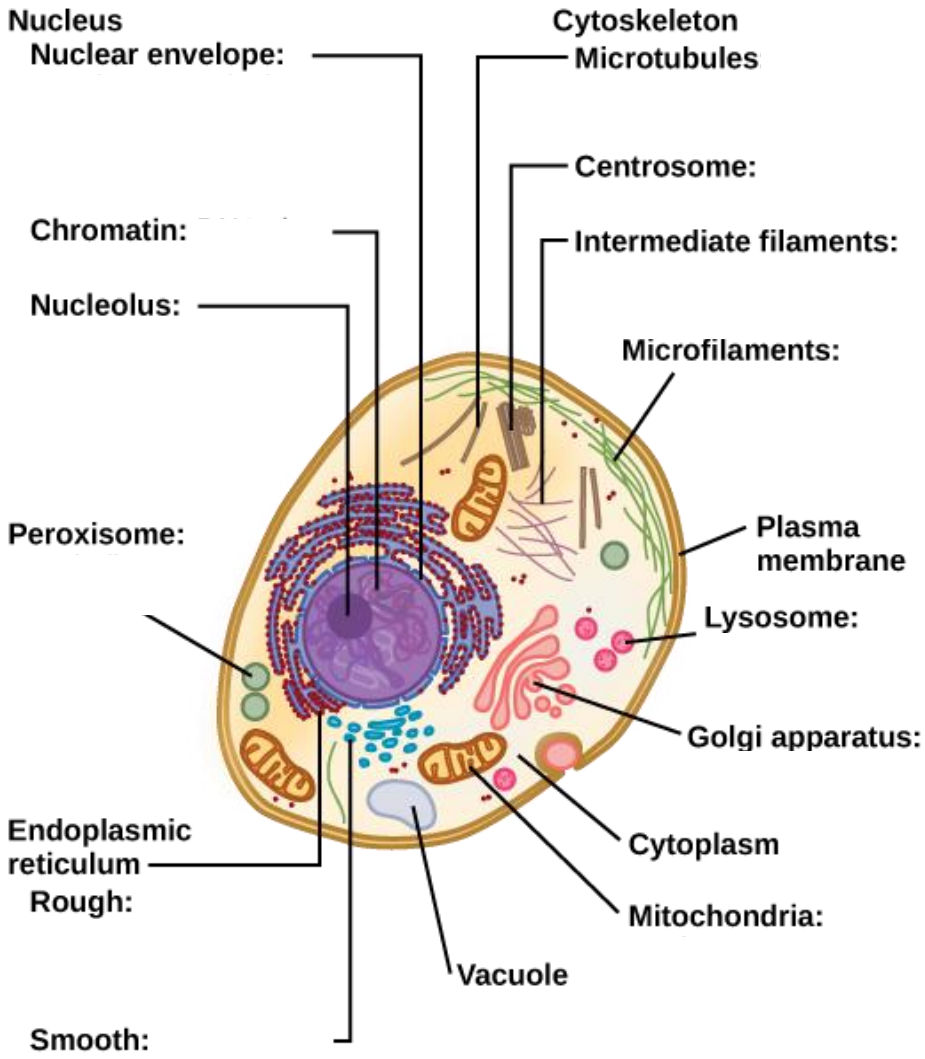


How can a cell compression stiffen when fiber networks compression soften?



[1] OpenStax College <https://legacy.cnx.org/content/m44407/1.14/>

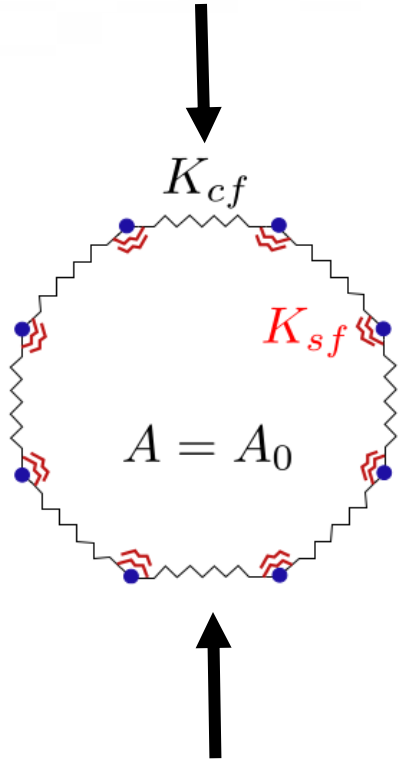
Cell is more than a cytoskeletal network



One Loop

$$H = \frac{1}{2}K_{cf}\sum_{<ij>}(l_{ij}-l_o)^2 + \frac{1}{2}K_{sf}\sum_{<ijk>}(\theta_{ijk}-\theta_o)^2 + \lambda(A-A_0),$$

$$\tilde{\kappa} = \frac{K_{cf}l_0^2}{K_{sf}}$$

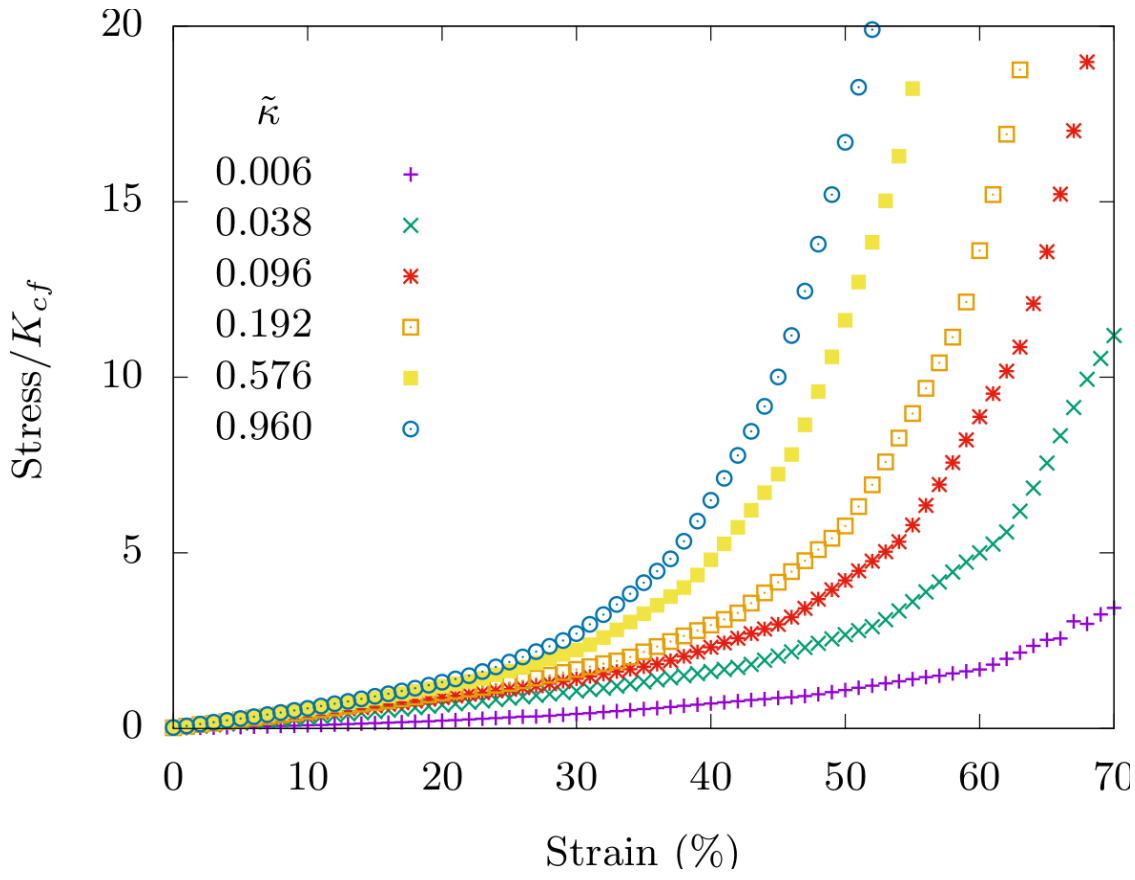


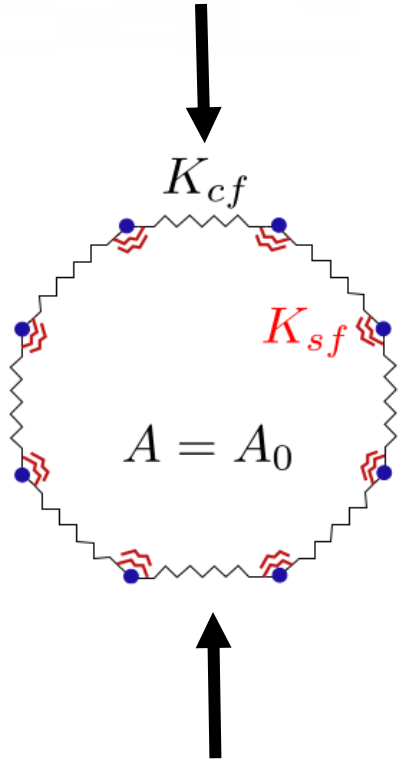
One Loop

Compression stiffening determined by $\tilde{\kappa}$

$$H = \frac{1}{2}K_{cf}\sum_{<ij>}(l_{ij}-l_o)^2 + \frac{1}{2}K_{sf}\sum_{<ijk>}(\theta_{ijk}-\theta_o)^2 + \lambda(A-A_0),$$

$$\tilde{\kappa} = \frac{K_{cf}l_0^2}{K_{sf}}$$



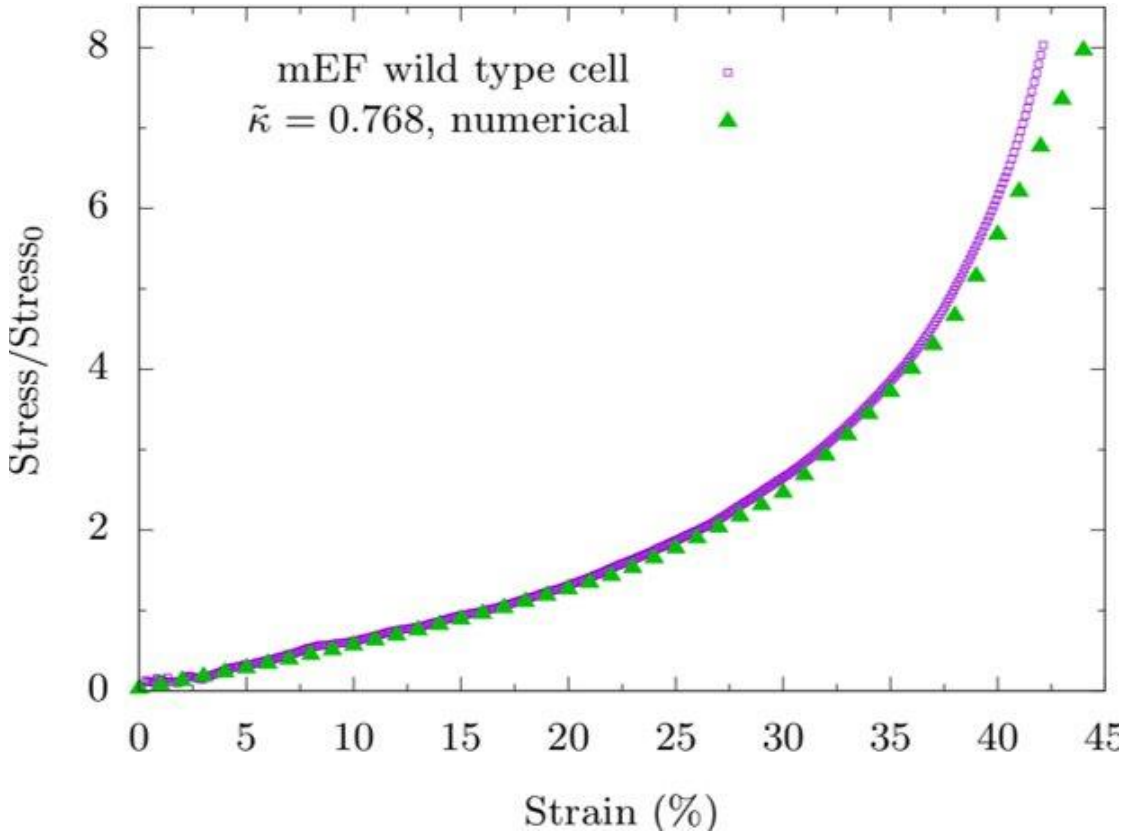


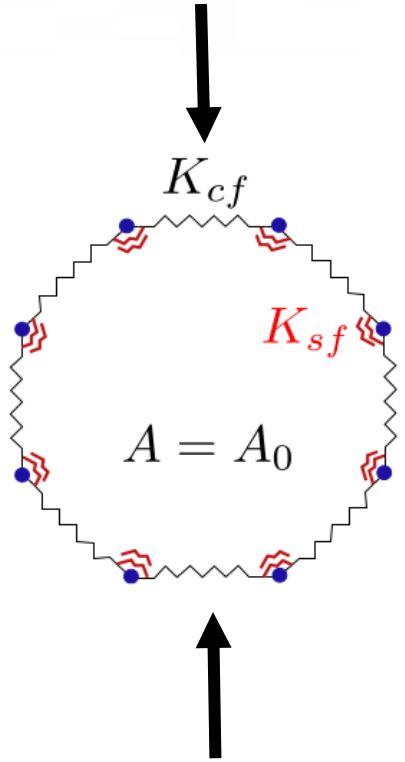
One Loop

"Quantitative" agreement with experiment

$$H = \frac{1}{2}K_{cf}\sum_{<ij>}(l_{ij}-l_o)^2 + \frac{1}{2}K_{sf}\sum_{<ijk>}(\theta_{ijk}-\theta_o)^2 + \lambda(A-A_0),$$

$$\tilde{\kappa} = \frac{K_{cf}l_0^2}{K_{sf}}$$

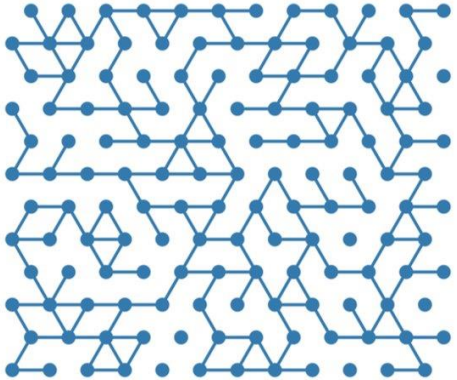




Fiber networks in the innards of a cell

$$H = \frac{1}{2} K_{cf} \sum_{<ij>} p_{ij} \, (l_{ij} - l_0)^2 + \frac{1}{2} K_{sf} \sum_{ijk=\pi} p_{ij} p_{jk} \, (\theta_{ijk} - \pi)^2$$

$$p_{ij} = \begin{cases} 1 & \text{with probability } p \\ 0 & \text{with probability } 1 - p \end{cases}$$



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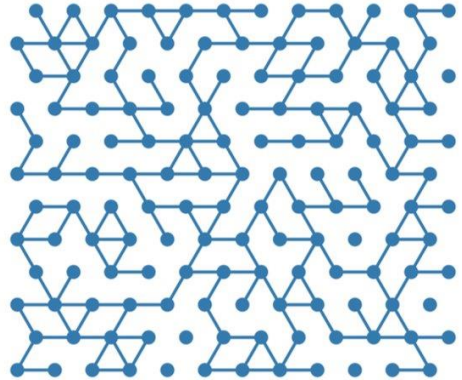
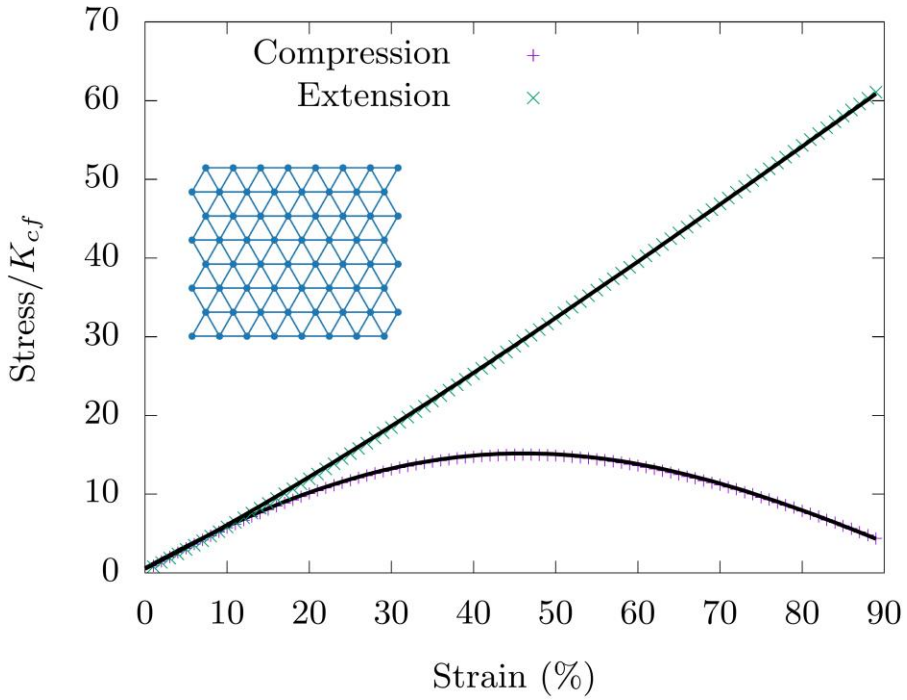




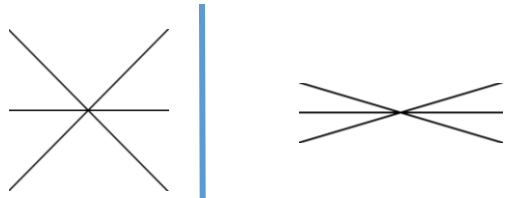
Bare network

↓

Affine behaviour

↓

Collapse of springs



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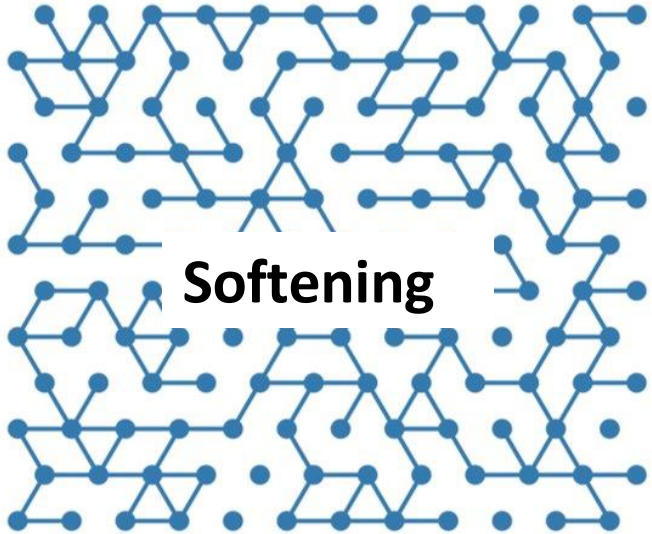
Compression softening

Cell as a collection of organelles within a fiber network

+



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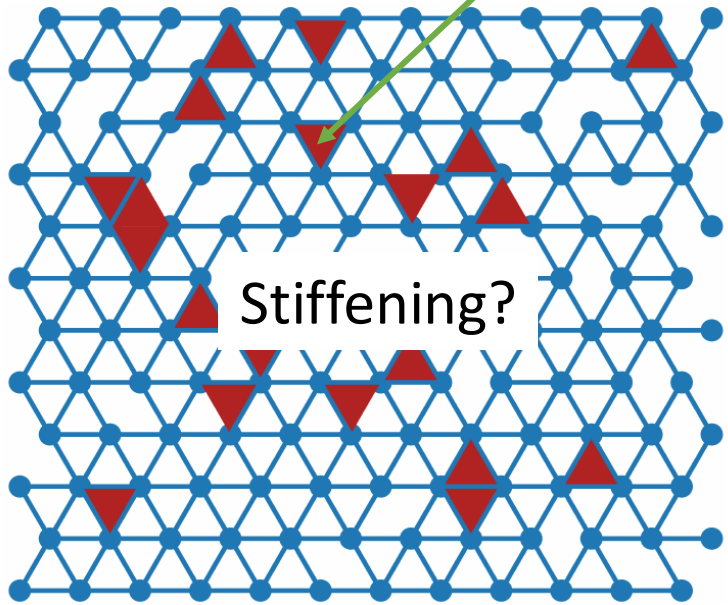

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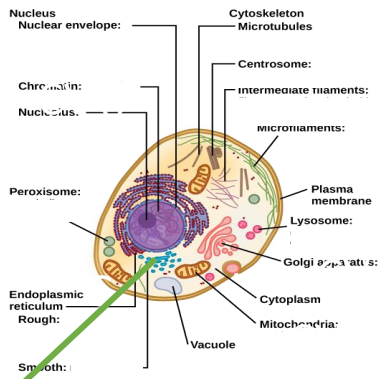
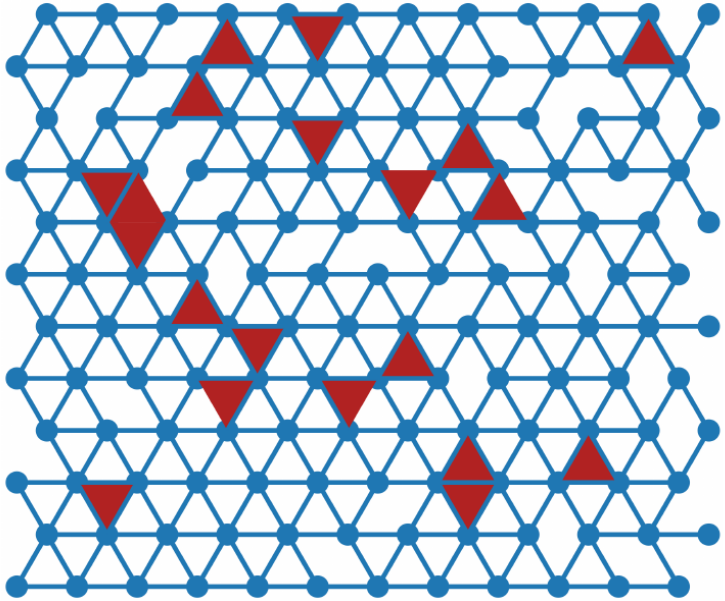


N Loop

Add area conserving triangles

$$H = \frac{1}{2}K_{cf}\sum_{<ij>} p_{ij}\,(l_{ij}-l_0)^2 + \frac{1}{2}K_{sf}\sum_{ijk=\pi} p_{ij}p_{jk}\,(\theta_{ijk}-\pi)^2 + \frac{1}{2}K_A\sum_{i'=1} q_{i'}(A_{i'}-A_0)^2$$



N Loop

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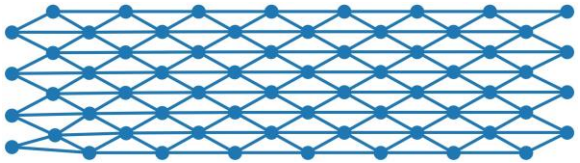
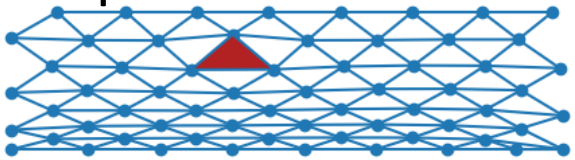
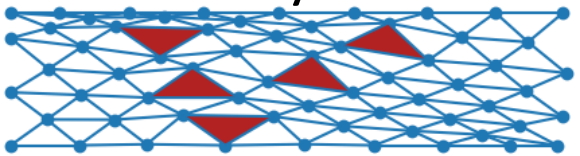
$$H = \frac{1}{2}K_{cf}\sum_{<ij>} p_{ij}\,(l_{ij}-l_0)^2 + \frac{1}{2}K_{sf}\sum_{ijk=\pi} p_{ij}p_{jk}\,(\theta_{ijk}-\pi)^2$$
$$+\frac{1}{2}K_A\sum_{i'=1} q_{i'}(A_{i'}-A_0)^2$$



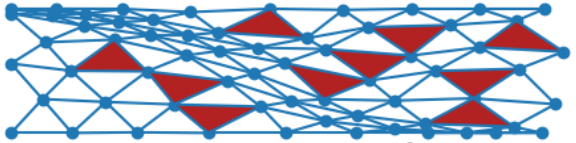
Loops conserve area



Non-affinity in network



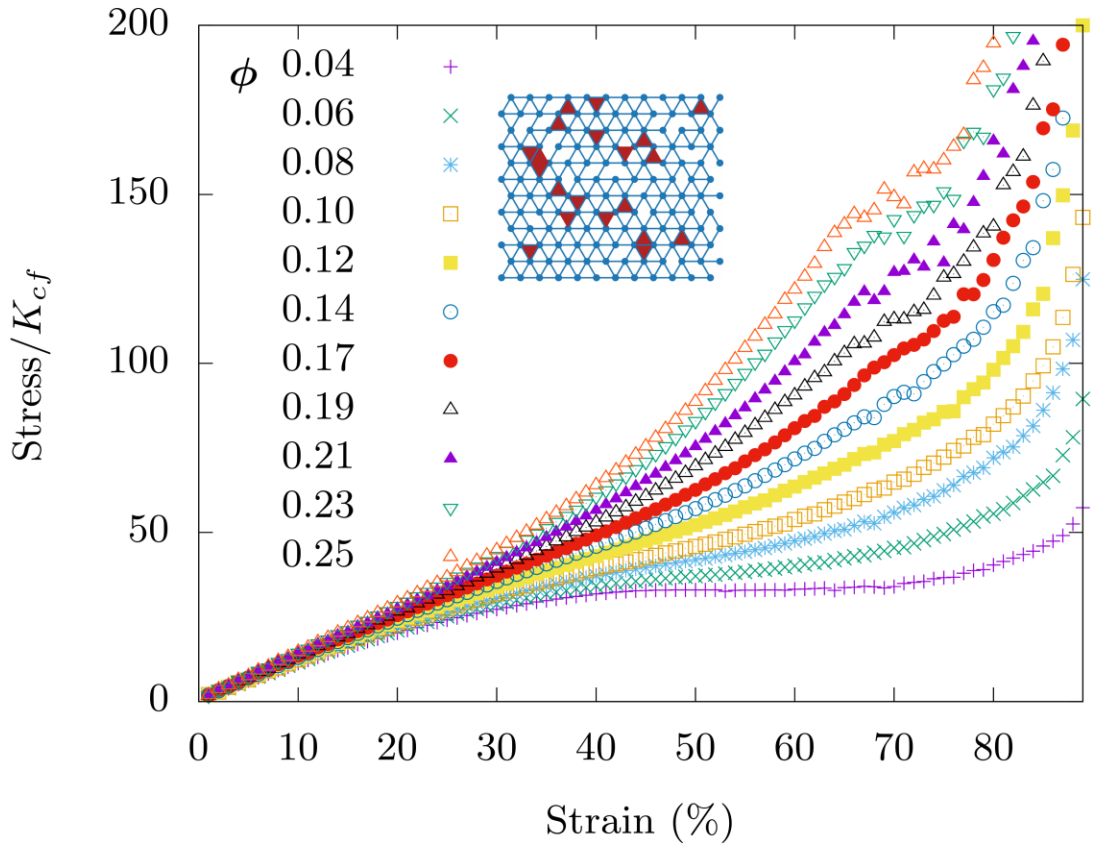
Bending modes

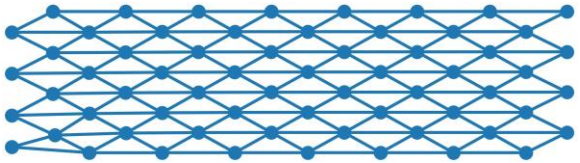


N Loop

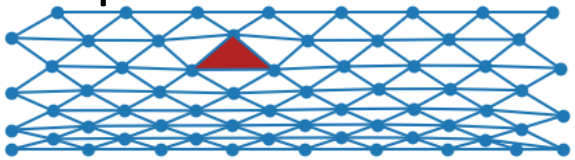
Compression stiffening determined by number of loops

$$H = \frac{1}{2}K_{cf}\sum_{<ij>} p_{ij}\,(l_{ij}-l_0)^2 + \frac{1}{2}K_{sf}\sum_{ijk=\pi} p_{ij}p_{jk}\,(\theta_{ijk}-\pi)^2 + \frac{1}{2}K_A\sum_{i'=1} q_{i'}(A_{i'}-A_0)^2$$

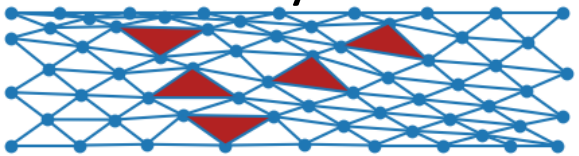




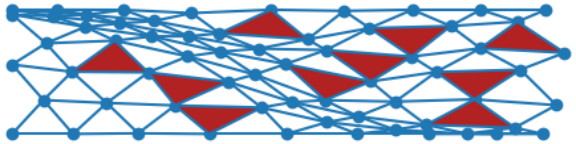
Loops conserve area



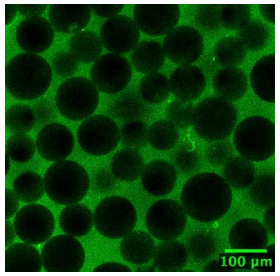
Non-affinity in network



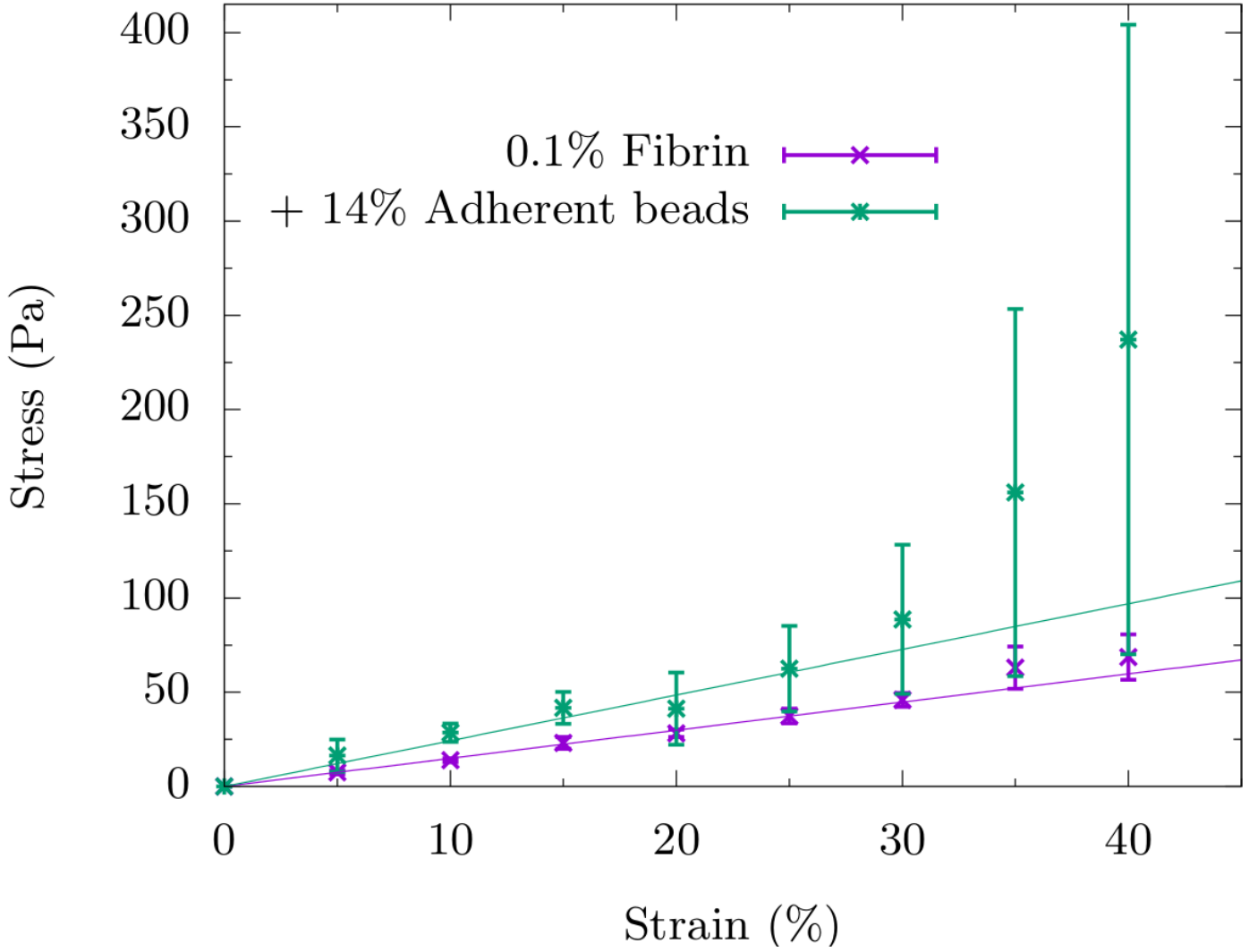
Bending modes



Dextran beads in fiber network

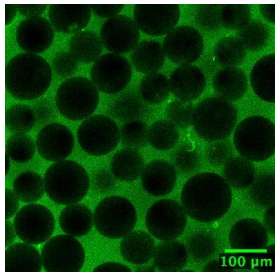


[2]

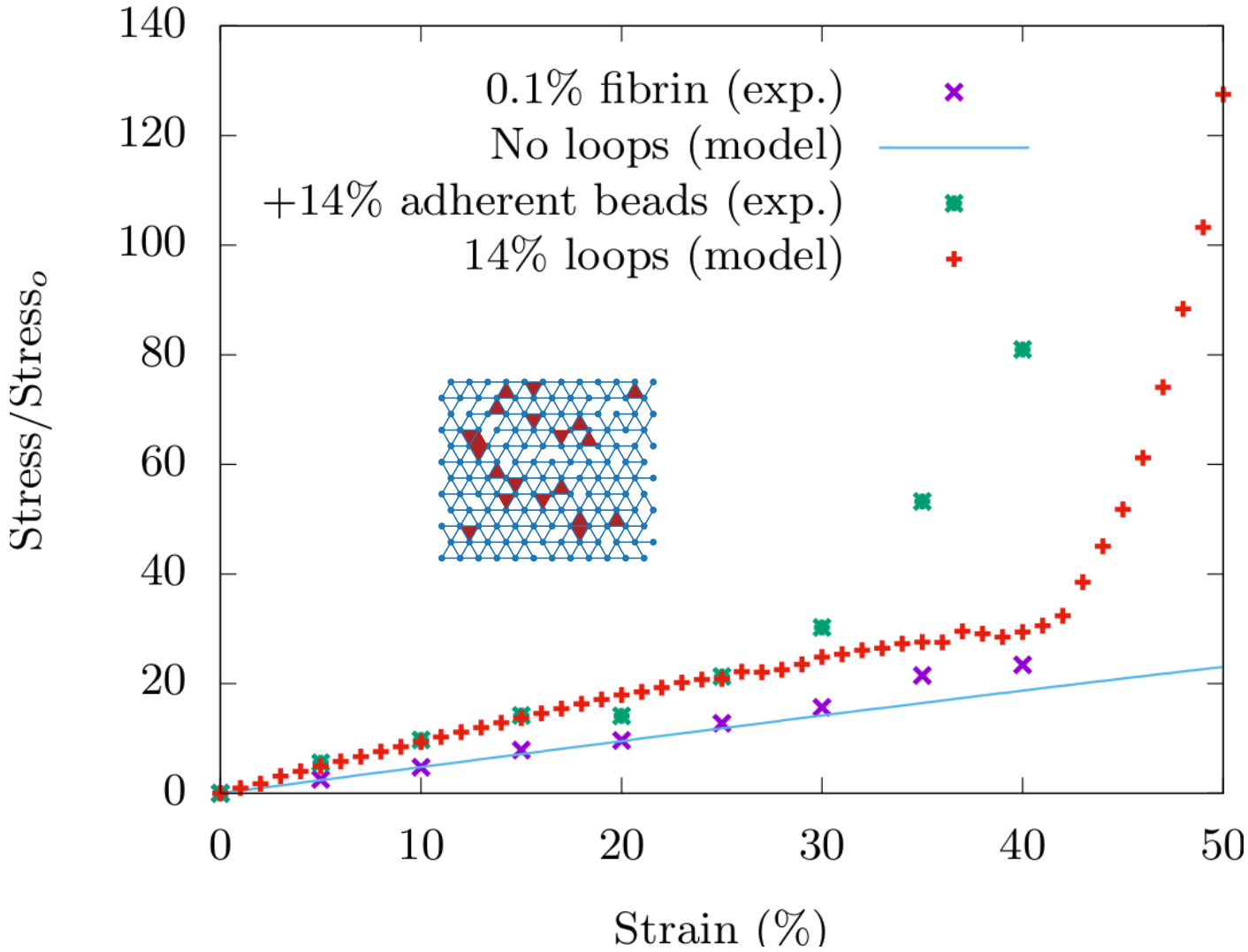


[2] van Oosten, Anne SG, et al. *Nature* (2019)

Qualitative agreement with experiment

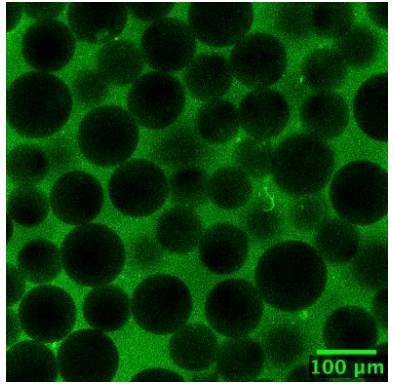


[2]

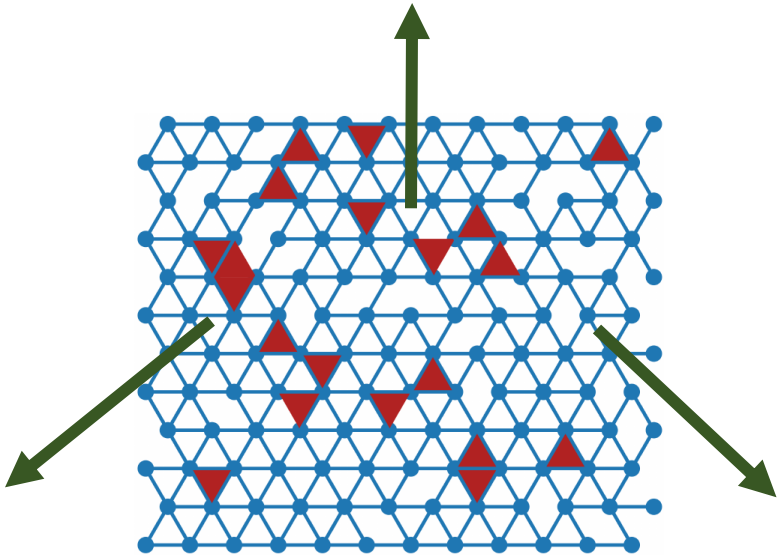


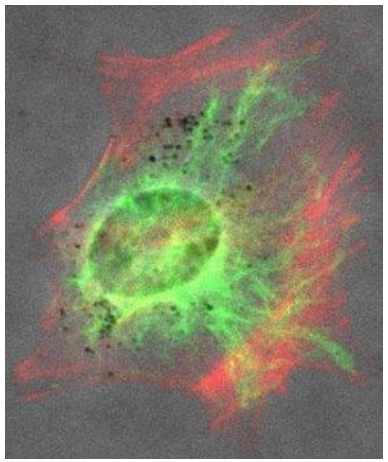
[2] van Oosten, Anne SG, et al. *Nature* (2019)

Compression stiffening across scales

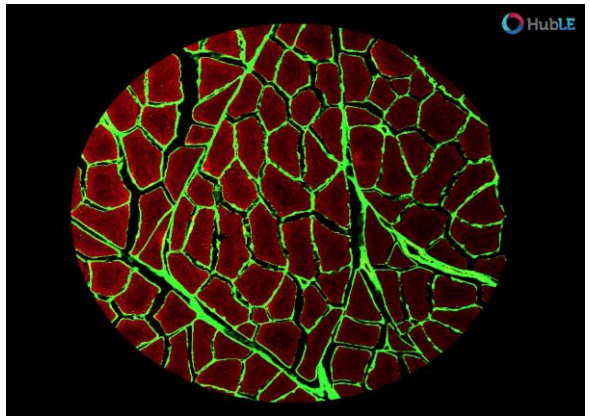


Dextran beads in fibrin [2]





Organelles in cytokeleton



Cells in extra cellular matrix [4]

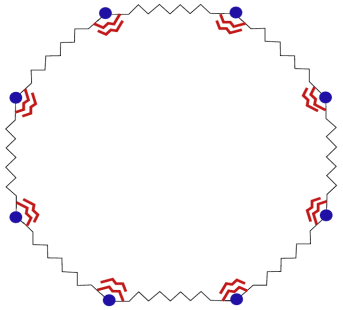
[2] van Oosten, Anne SG, et al. *Nature* (2019)
[4] C. Bendzinski and B. Wheatley – Bucknell University, PA - https://www.huble.org/huble-images/

Summary

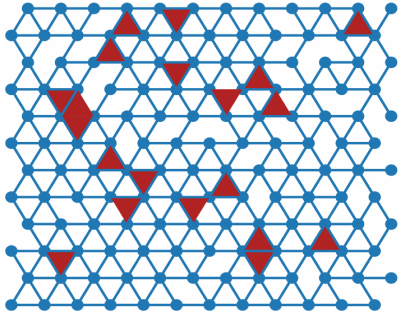
Question How can a mEF cell compression stiffen when fiber networks compression soften?

Three potential compression stiffening mechanisms proposed:

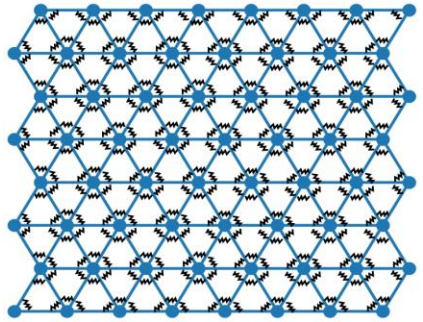
One Loop



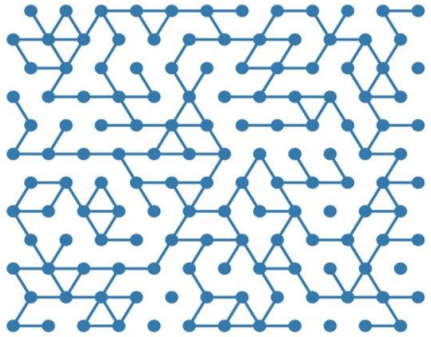
N Loop



Crosslinker Angular Springs



Collapse of springs brings compression softening in fiber networks.



References:

1) `**Loops versus lines and compression stiffening of cells**', **Soft Matter** 2020,**16**,4389-4406 **arXiv:1908.03725v2**

2) van Oosten, Anne SG, et al. *Nature* (2019)

3) Shivers et al., arXiv:2002.07220