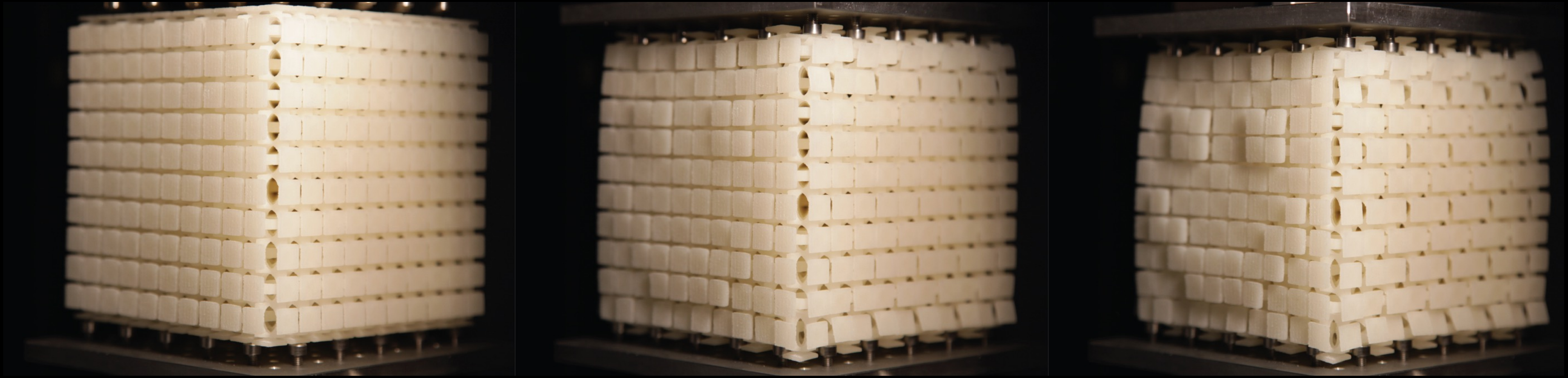
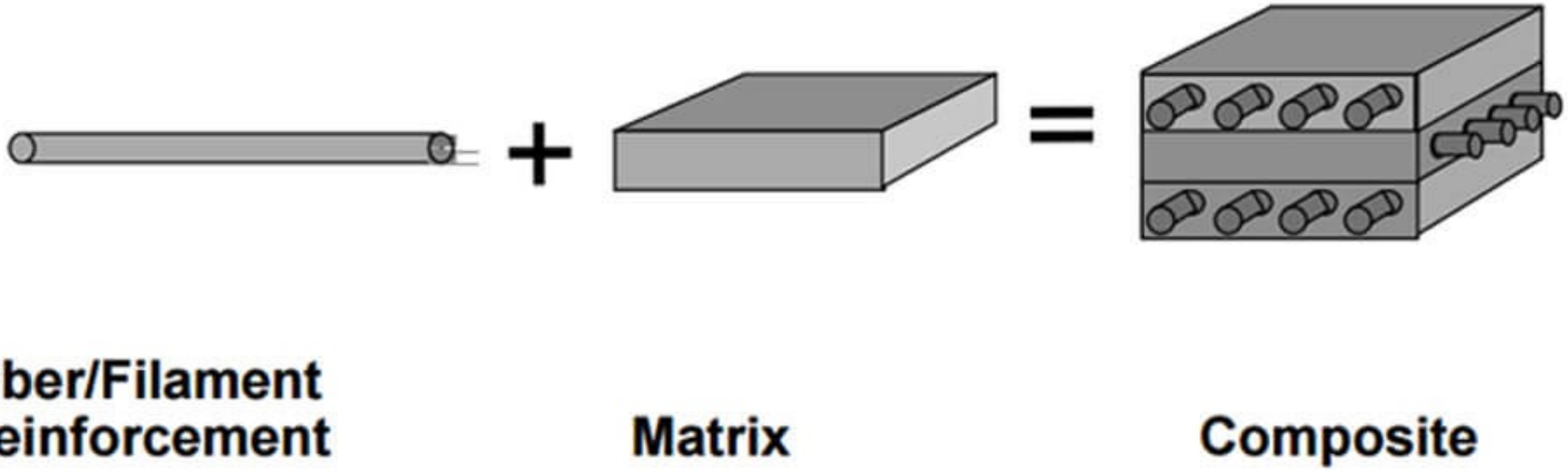
Mechanical Metamaterials



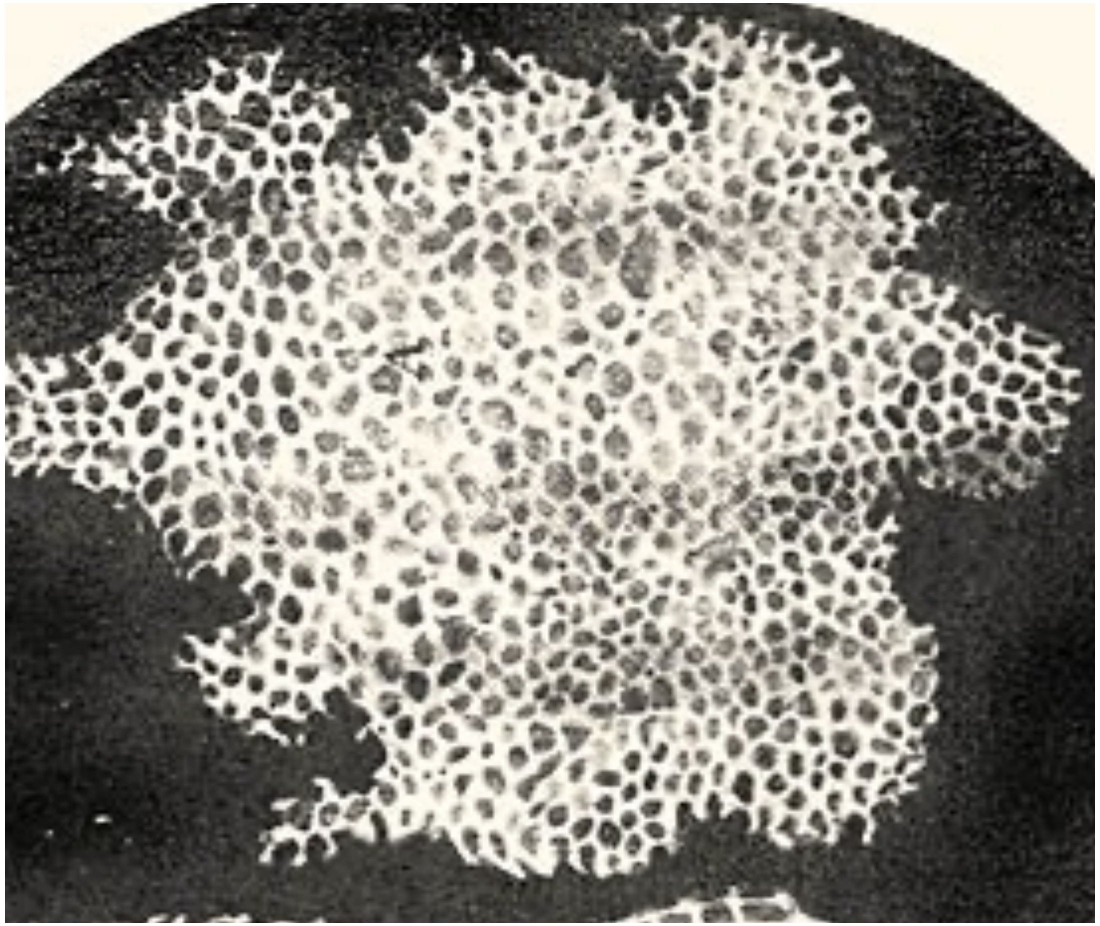
Corentin Coulais

Machine Materials Lab, Institute of Physics, University of Amsterdam

Composite materials



Composite biomaterials



R. Hooke (1665) ***Micrographia***

Scale

m

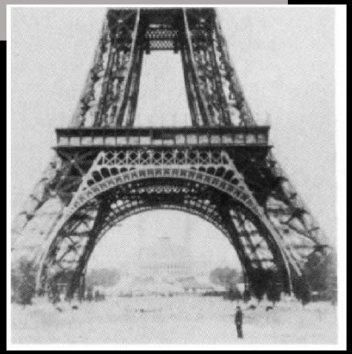
cm

mm

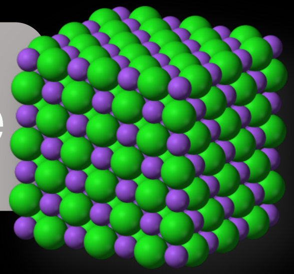
μm

nm

superstructure



microstructure



Scale

m

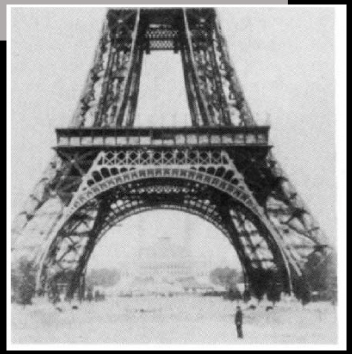
cm

mm

μm

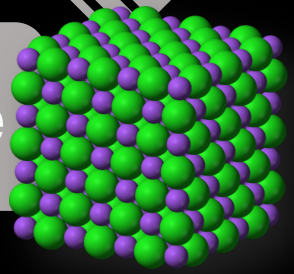
nm

superstructure



Metamaterials

microstructure



Scale

m

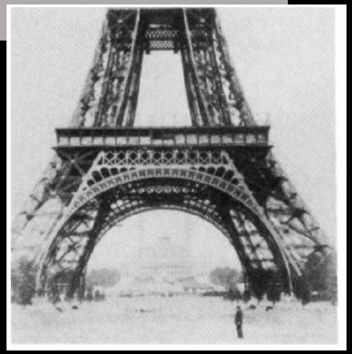
cm

mm

μm

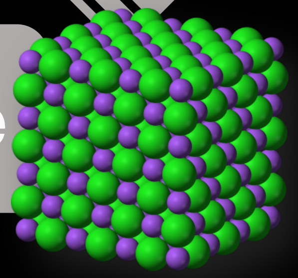
nm

superstructure



Metamaterials

microstructure



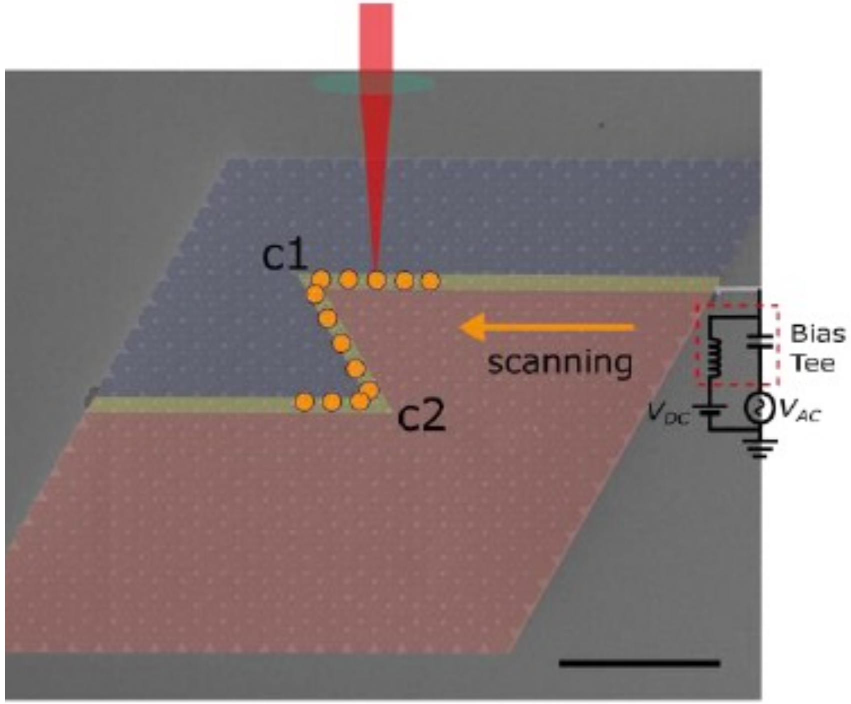
- Relation Structure-Property?
- How far can we go?

Mechanical Metamaterials

Light & Strong materials

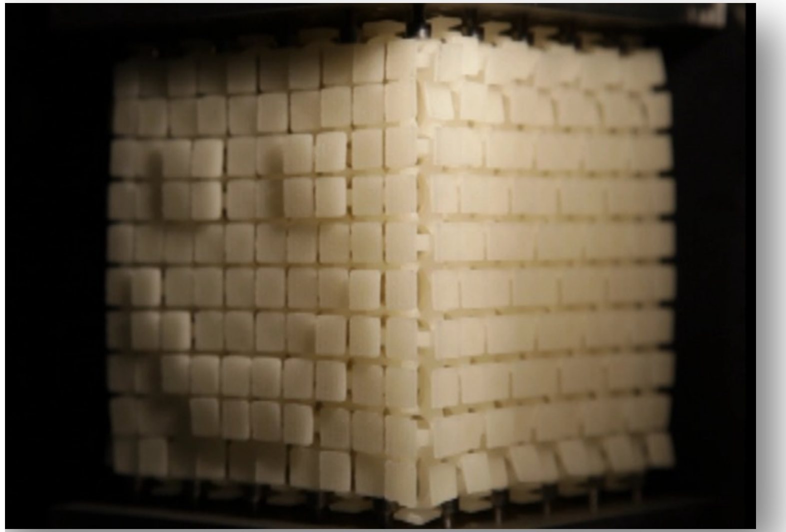
Schaedler et al. (2011) ***Science***

Wave guiding devices



J. Cha et al. (2018) ***Nature***

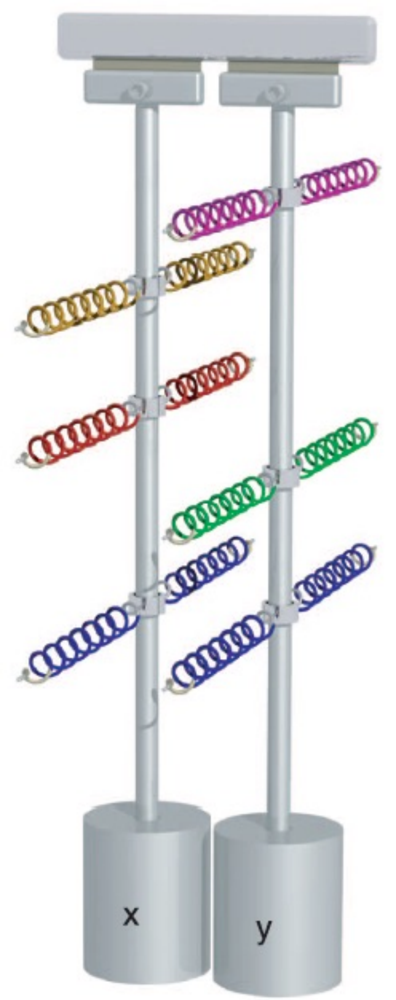
Shape Changers



Coulais et al. (2016) ***Nature***

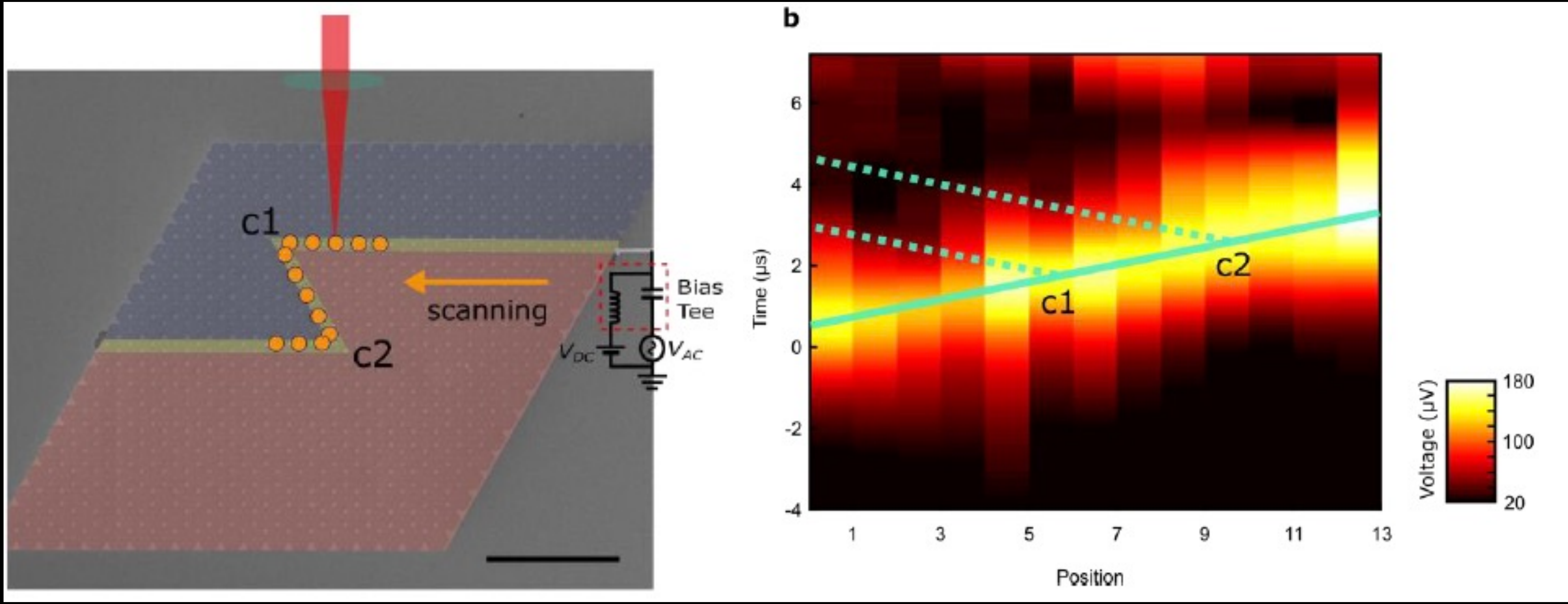
Applications?

Guiding waves (~2Hz)

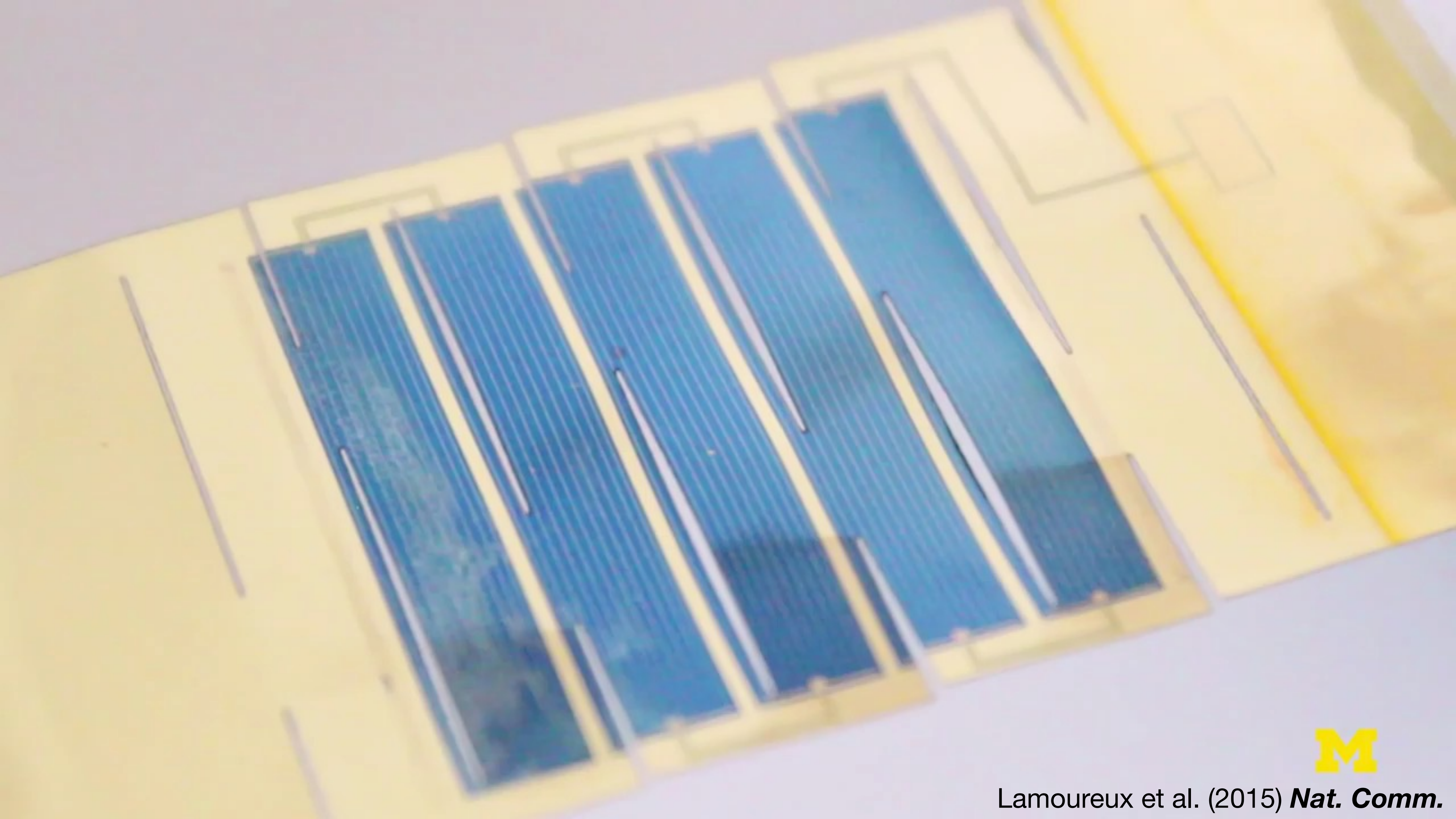


Susstrunk et al. (2015) ***Science***

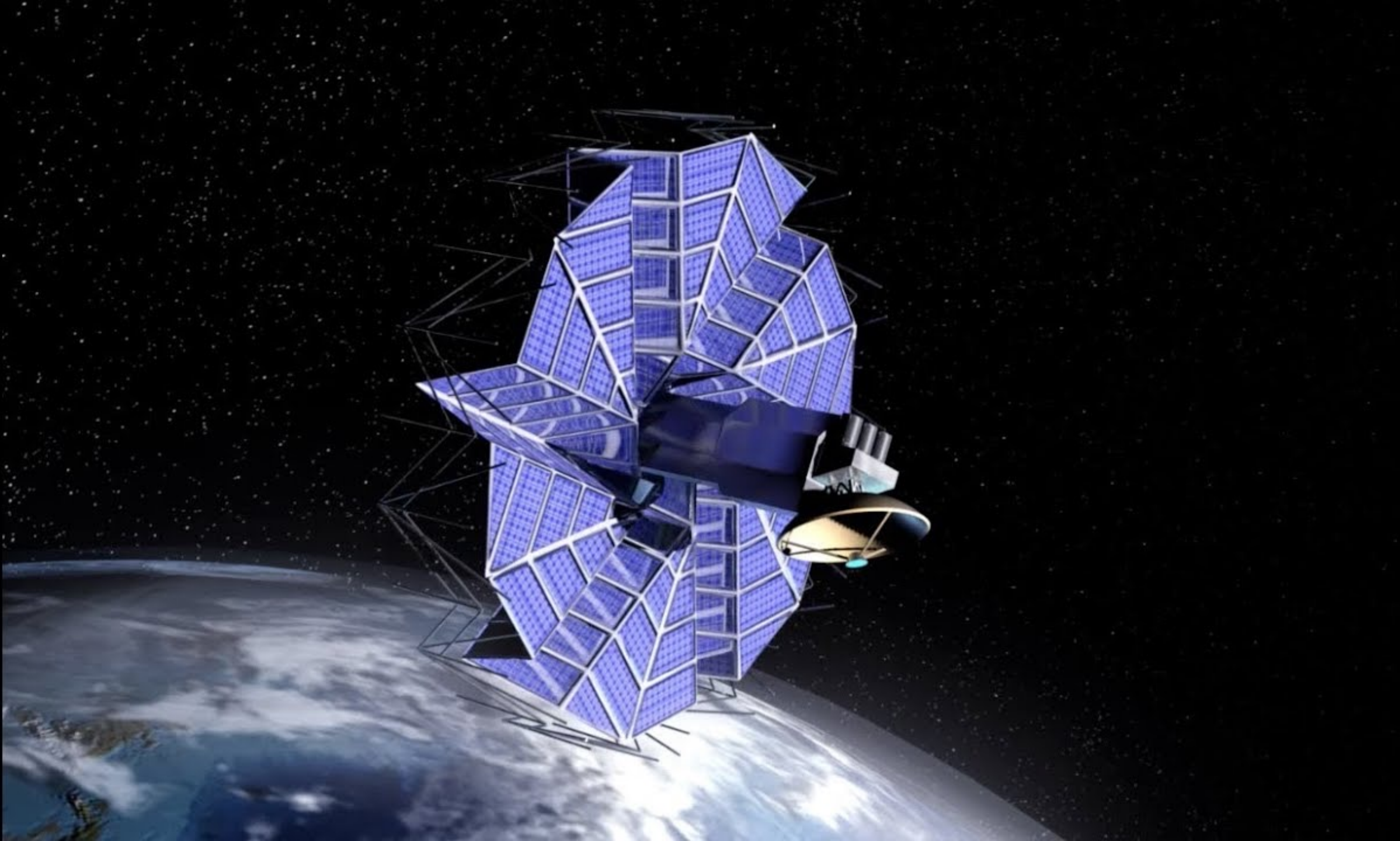
Guiding waves (~10MHz)

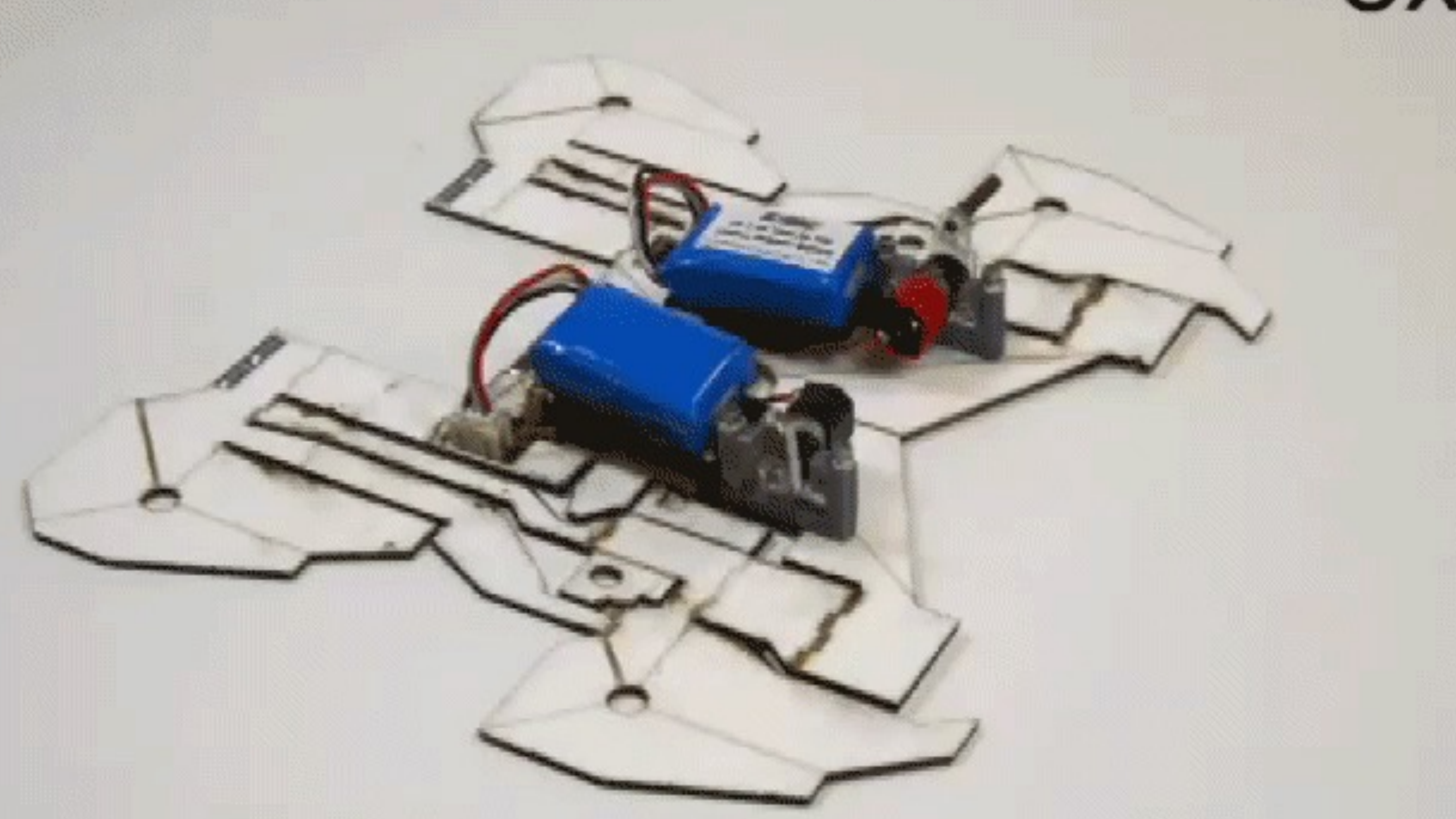


J. Cha et al. (2018) ***Nature***



Lamoureux et al. (2015) ***Nat. Comm.***

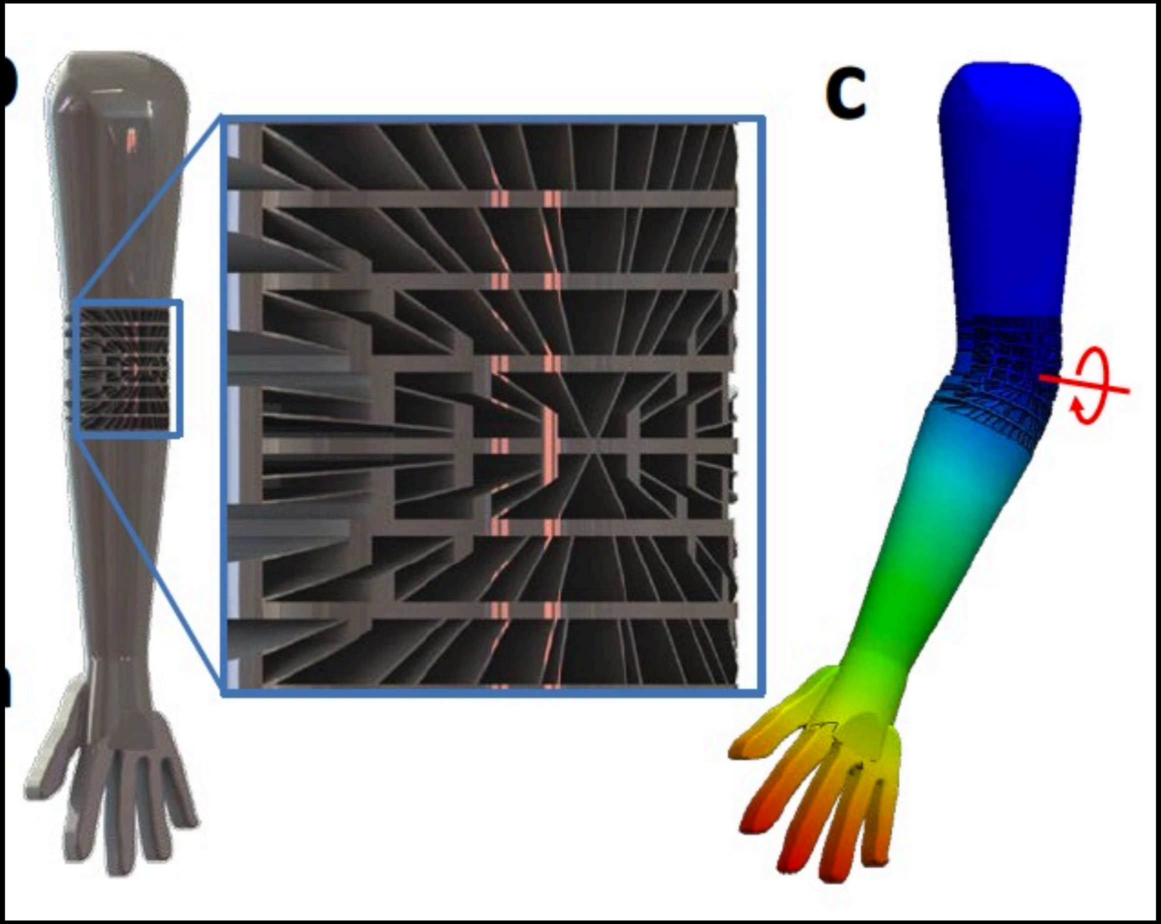




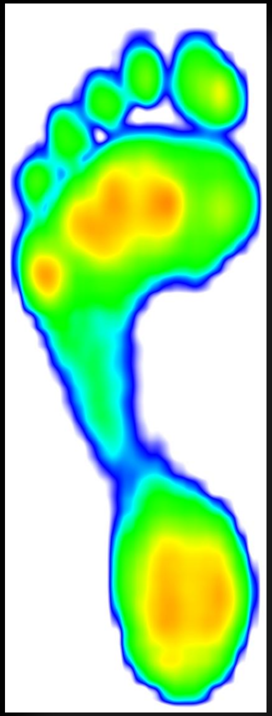
Rafsanjani et al. (2018) ***Sci. Robot.***

Kuribayashi et al. Mat. Sci. Eng. 2006

Prosthetics and Wear-Tech

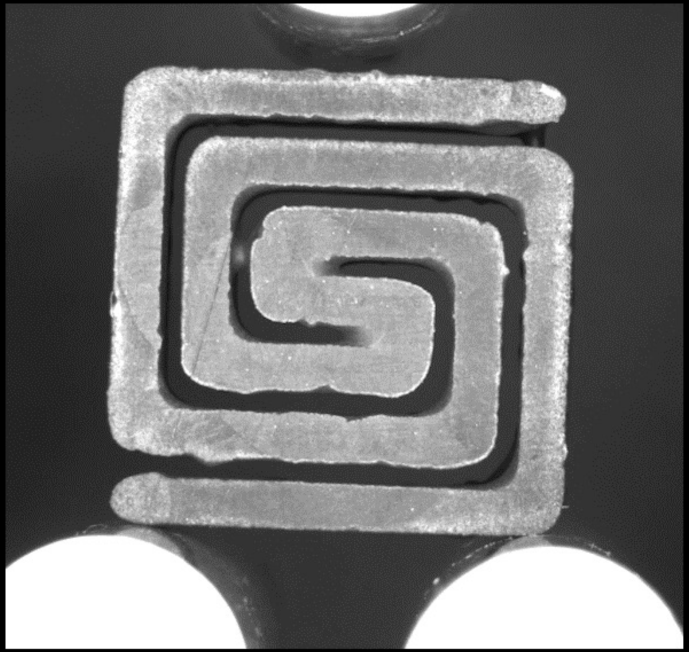


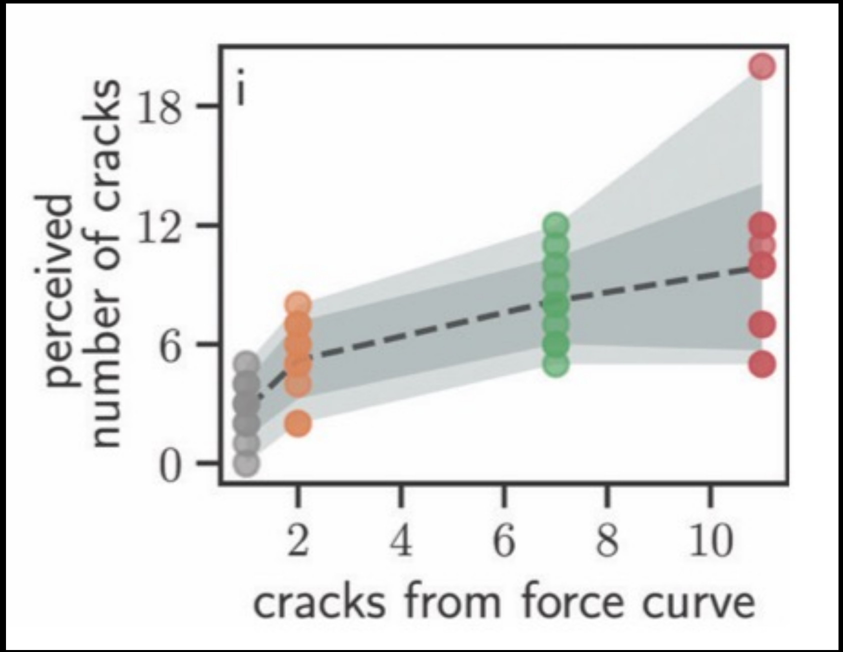
Shaw et al., Nat. Comm. (2019)



LIVIT orthopedie

On demand fracture for food





Souto, Zhang, Aragon, Velikov, Coulais Soft Matter (2022)

How to make a tastier chocolate? Use geometry.

Scientists created various chocolate shapes using a 3D printer to see which was the crunchiest and which one tasters liked best.

By Galadriel Watson
October 5, 2022 at 8:00 a.m. EDT

Científicos afirman haber dado con la receta del chocolate perfecto

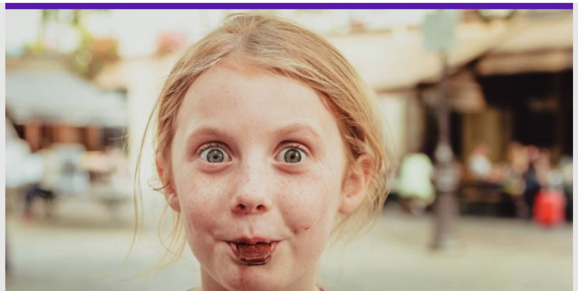
- Tiene forma de espiral y es más crujiente que la típica tableta de chocolate del supermercado, asegura un equipo de investigación de la Universidad de Ámsterdam
- Este es el mejor queso catalán de 2022

Technologies Publié le 27 avril 2022 à 09:36

La spirale est optimale pour de[…] un chocolat, selon une recherche

Have scientists designed the 'perfect' chocolate?

27 Apr 2022 Last updated at 02:58



Have Scientists Designed the Perfect Chocolate?

Part of a burgeoning field of 'edible metamaterials,' Dutch physicists found that 3-D printed spiral-shaped candies give the ideal eating experience

Emily Matchar
Innovation Correspondent
May 11, 2022

MOST POPULAR
1. Scientists Are Find[…] Fungi in Cancerou[…] Tumors
2. Archaeologists Dig[…] 1,400-Year-Old Na[…] American Canal in Alabama
3. The Real History Behind 'The Woma[…] King'
4. Who Was Vivekananda, the Indian Guru Who

Notícia

Projetando o pedaço de chocolate perfeito

A primeira forma de material comestível que os cientistas experimentaram foi um chocolate em forma de S com r[…] que tinha como objetivo testar como esse material quebraria e como essa quebra seria experimentada na boca

Fonte
Universidade de Amsterdã

Data
quinta-feira, 21 abril 2022 16:15

Áreas
Biotecnologia. Ciência e Tecnologia de Alimentos. Engenharia de Alimentos

This course: *Focus on shape-changing metamaterials*

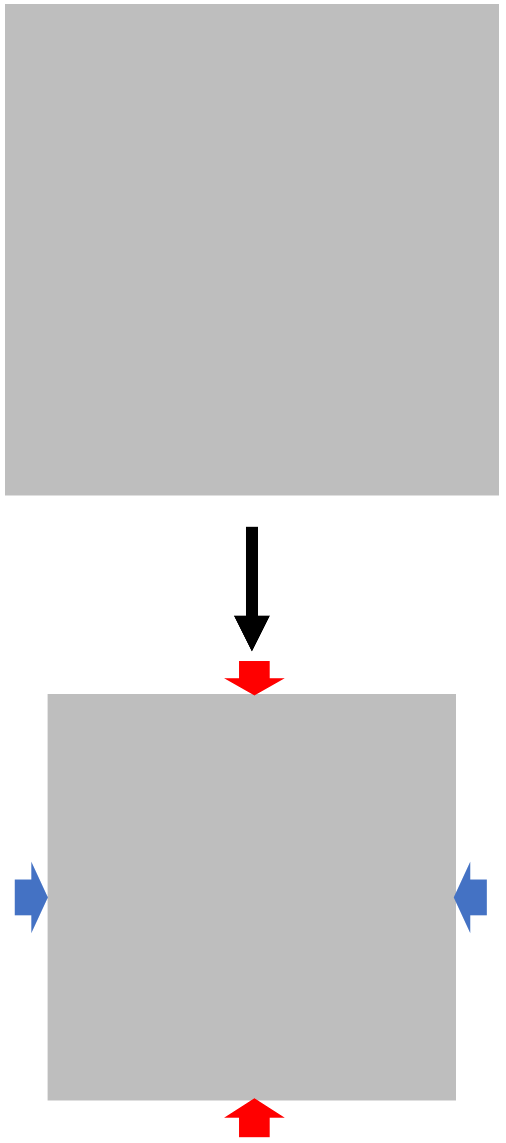
1. **Intuitive examples and tool to characterize metamaterials (today)**

2. Designing metamaterial using combinatorics (Wednesday)

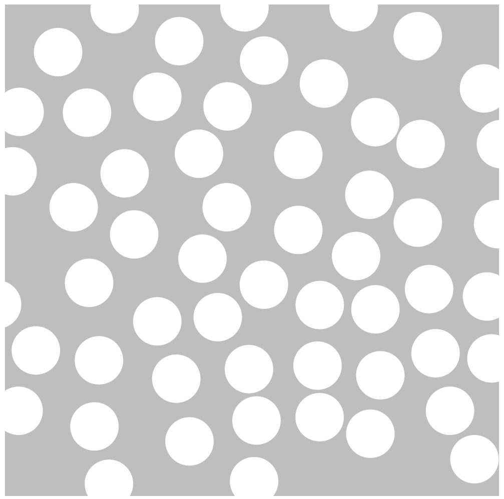
3. Beyond the Unit cell (Thursday)

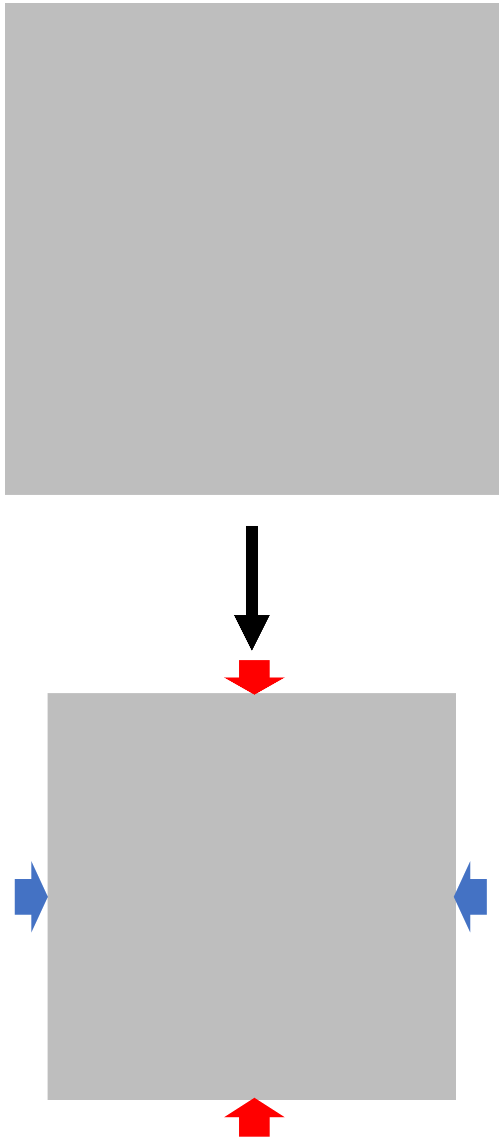
4. Active metamaterials (Friday)

How to relate Structure to Function?

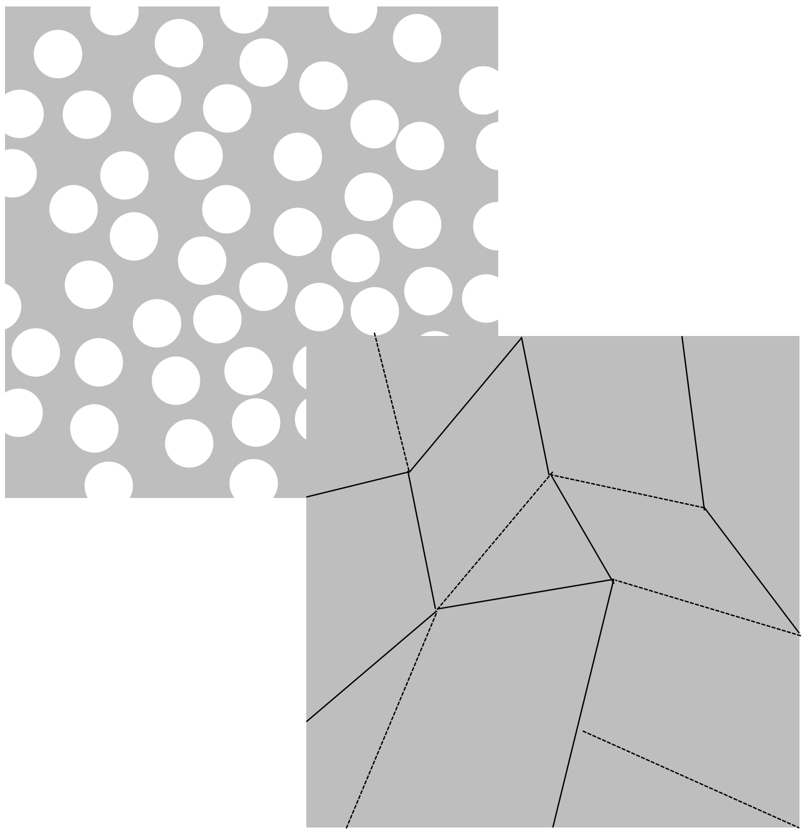


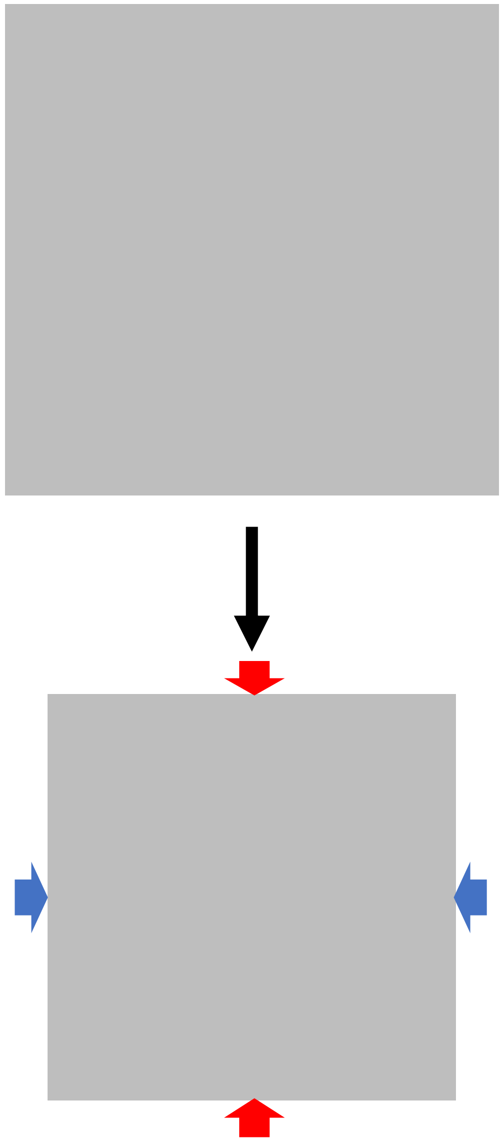
How to relate Structure to Function?



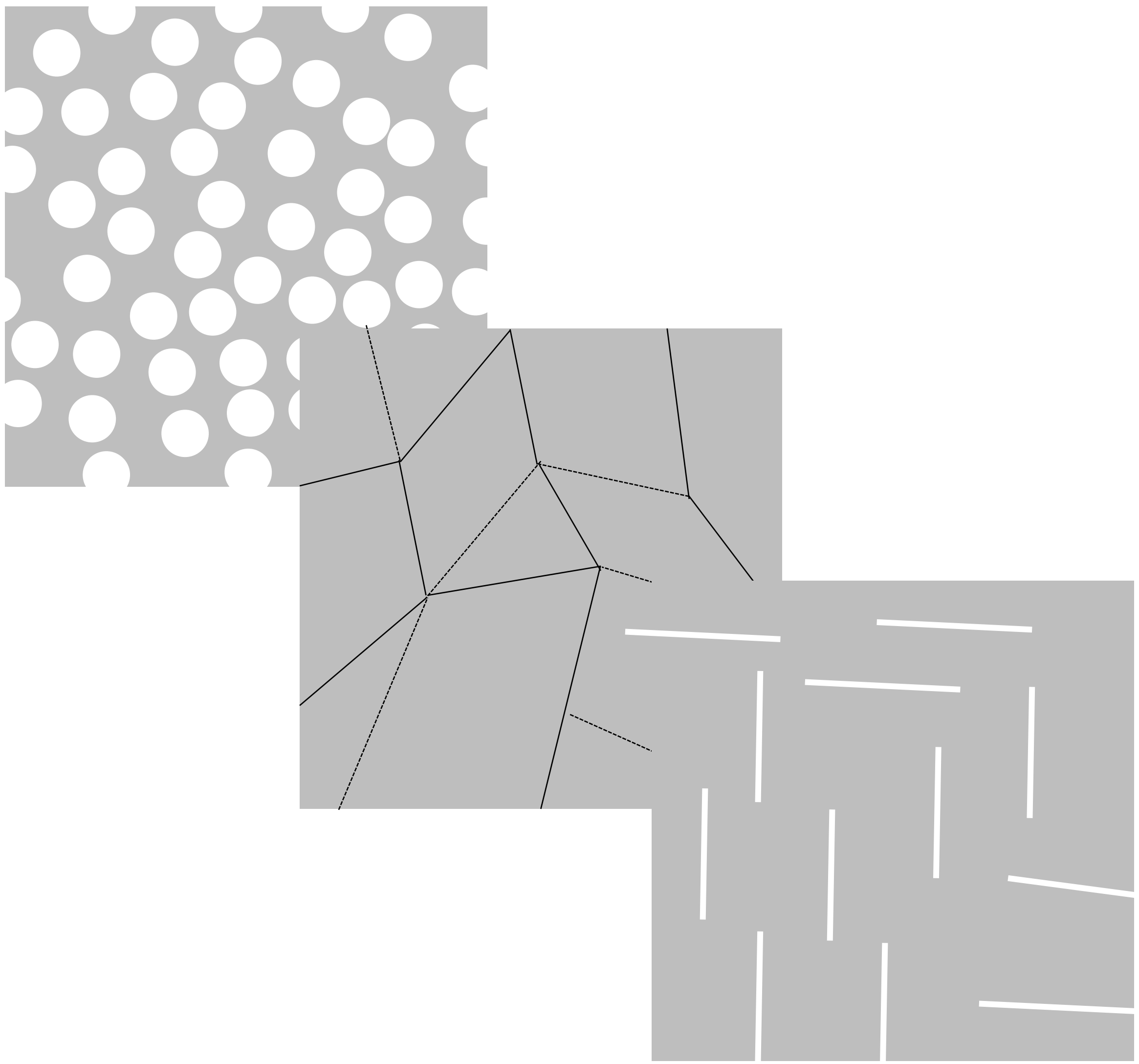


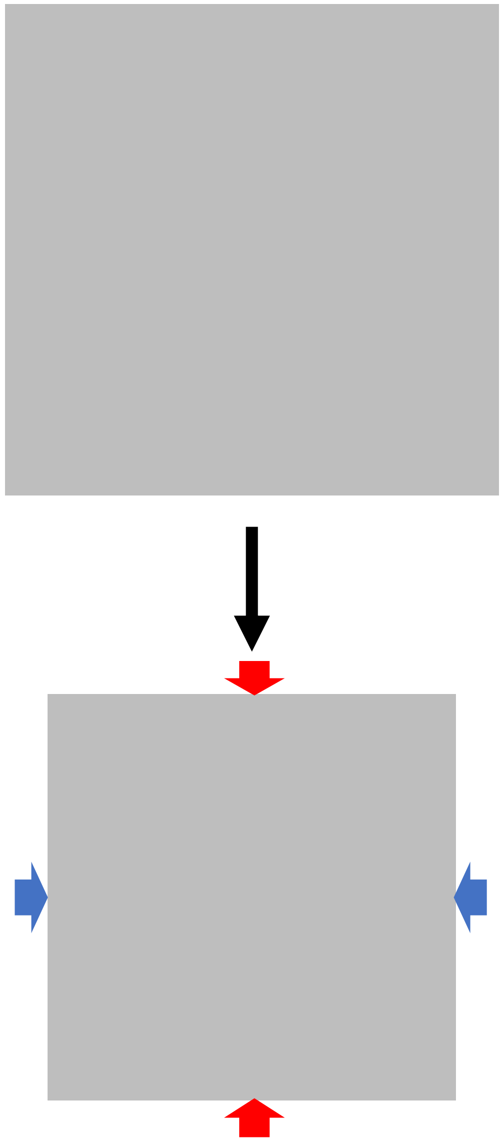
How to relate Structure to Function?



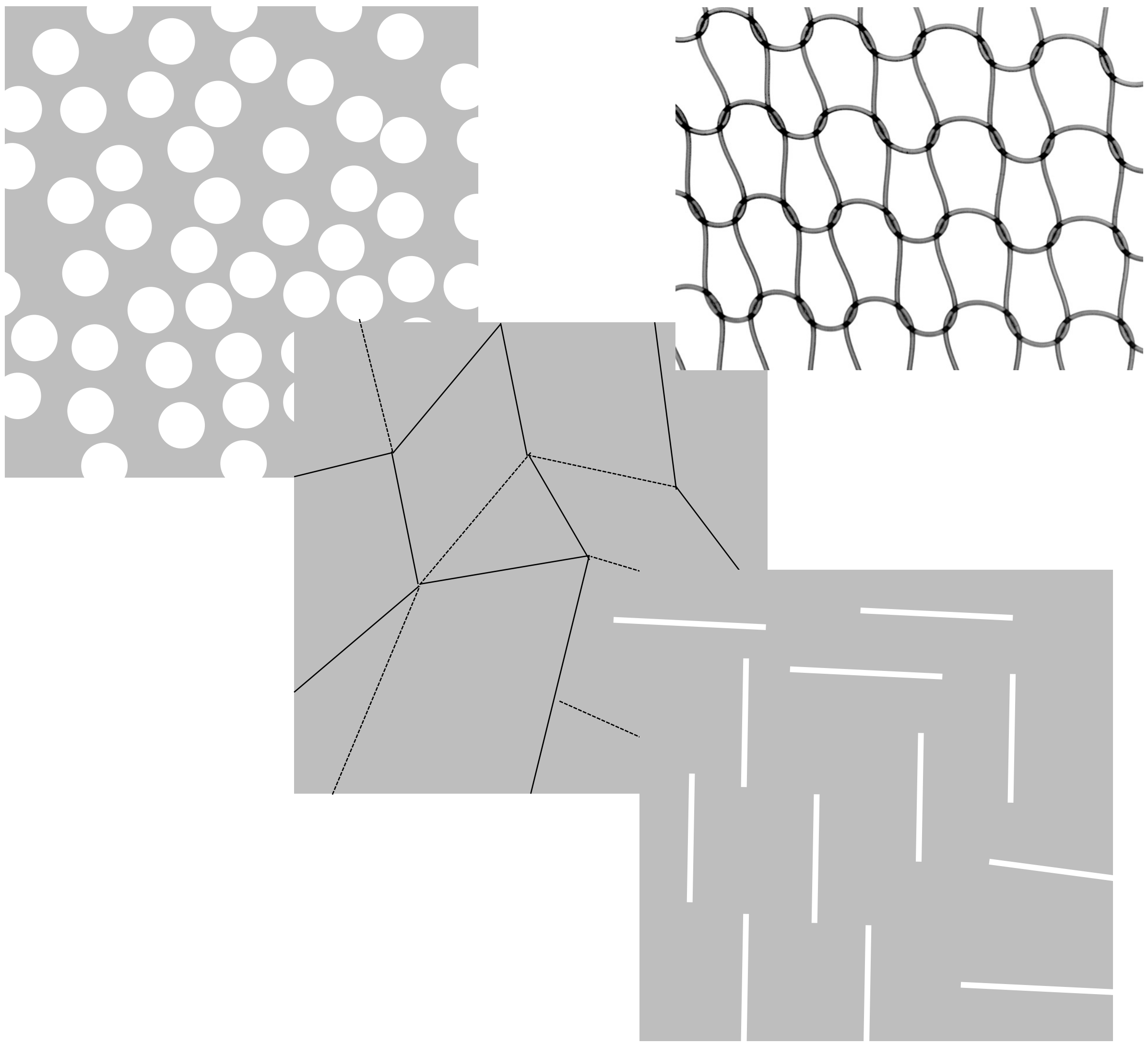


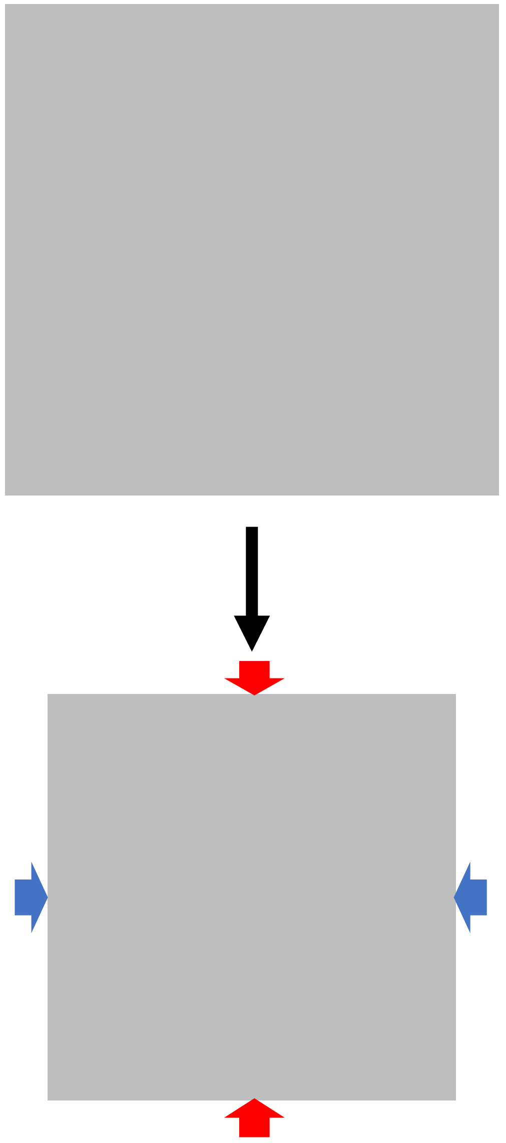
How to relate Structure to Function?



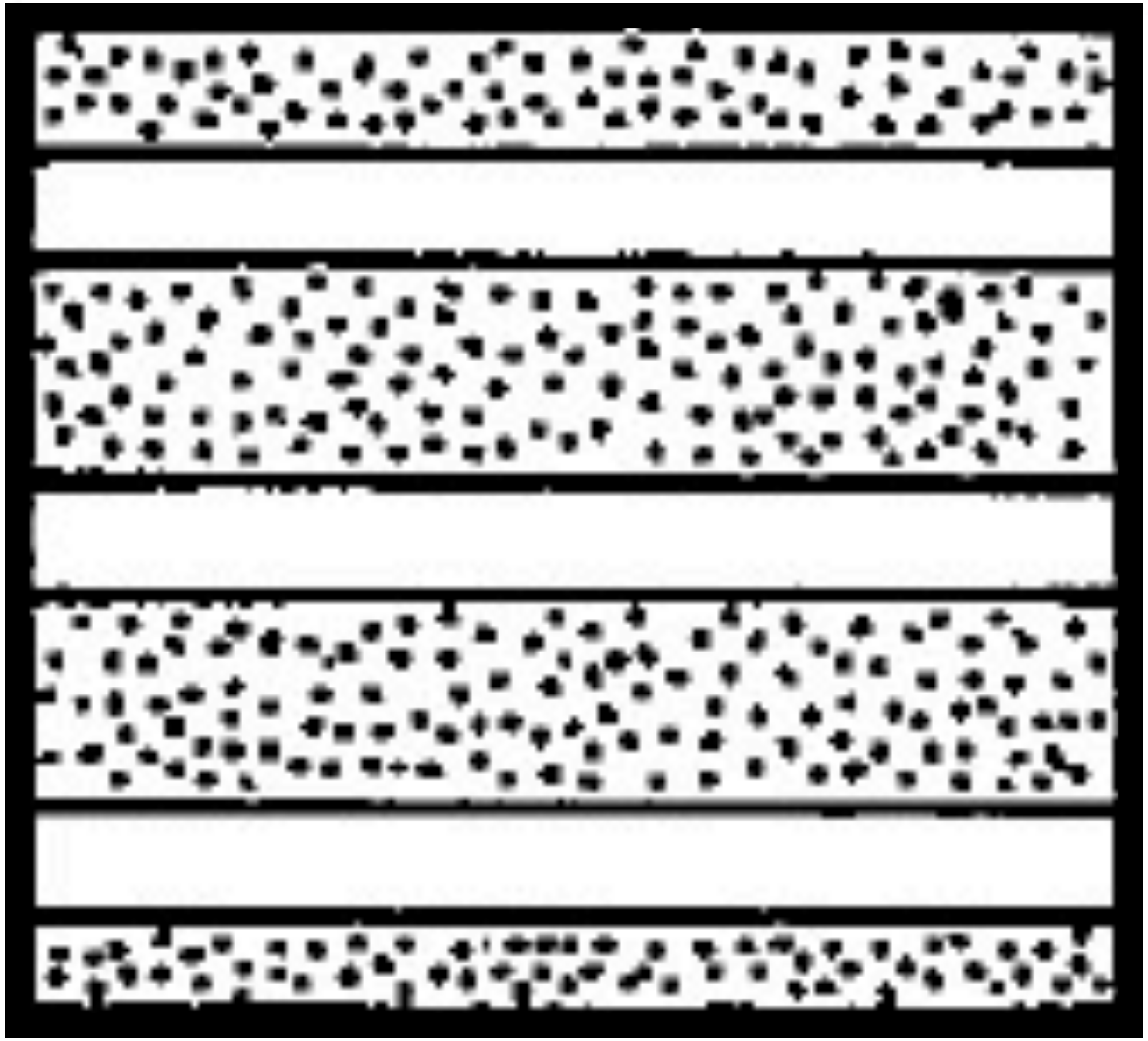


How to relate Structure to Function?



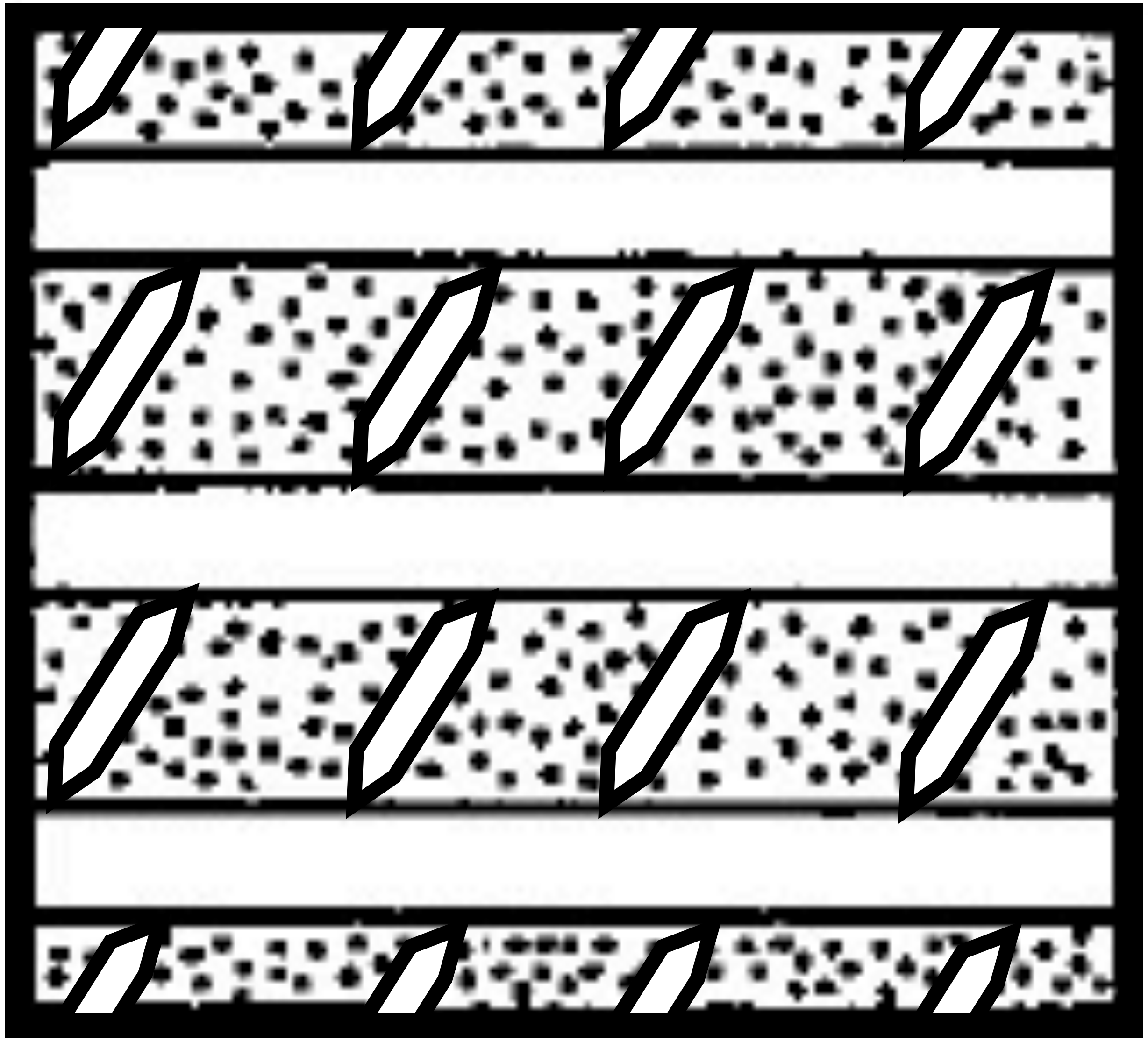


Geometry controls mechanics…



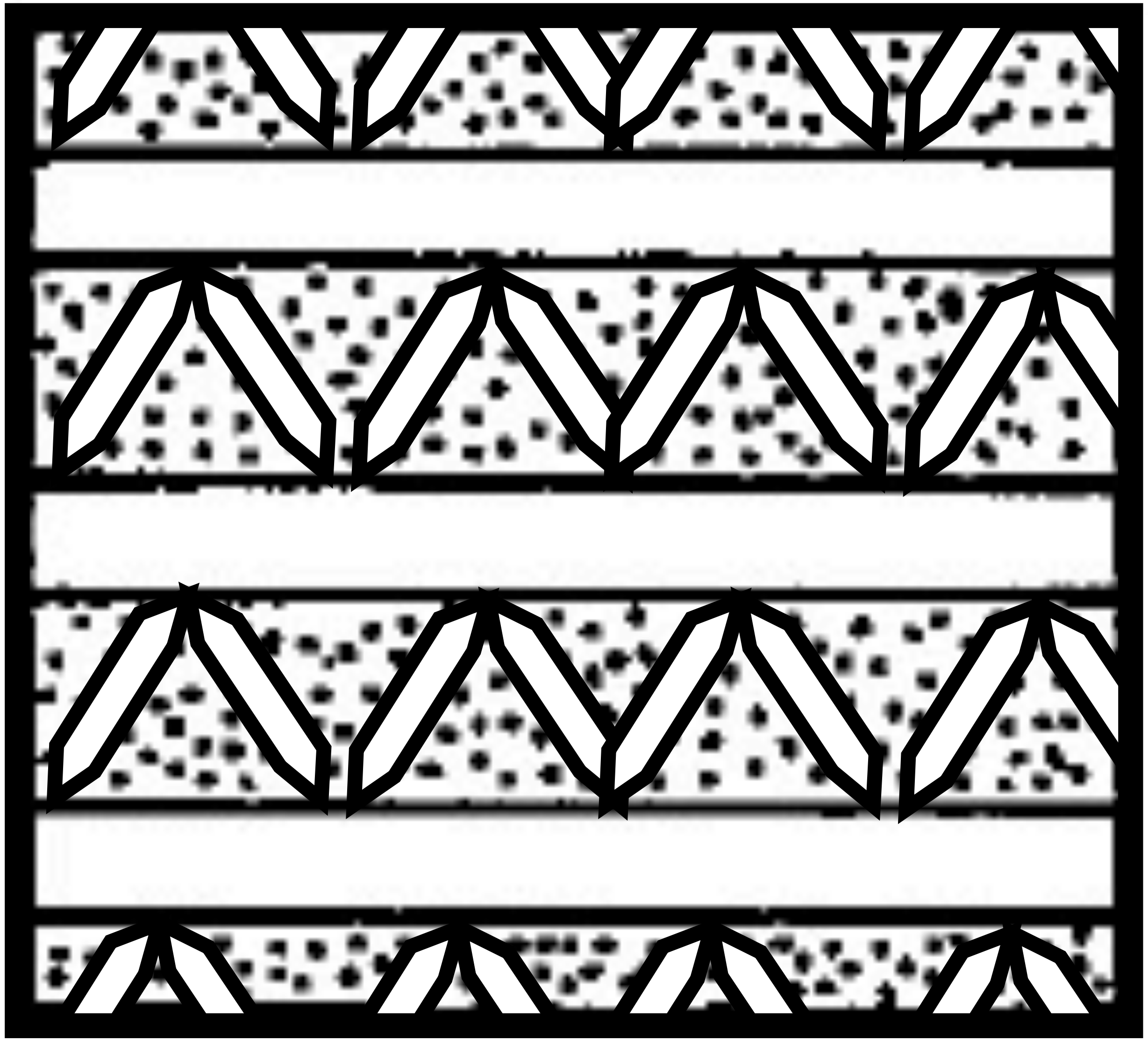
Milton and Cherkaev (1995) **J. Eng. Sc. Tech**

Geometry controls mechanics…



Milton and Cherkaev (1995) **J. Eng. Sc. Tech**

Geometry controls mechanics…



Milton and Cherkaev (1995) **J. Eng. Sc. Tech**

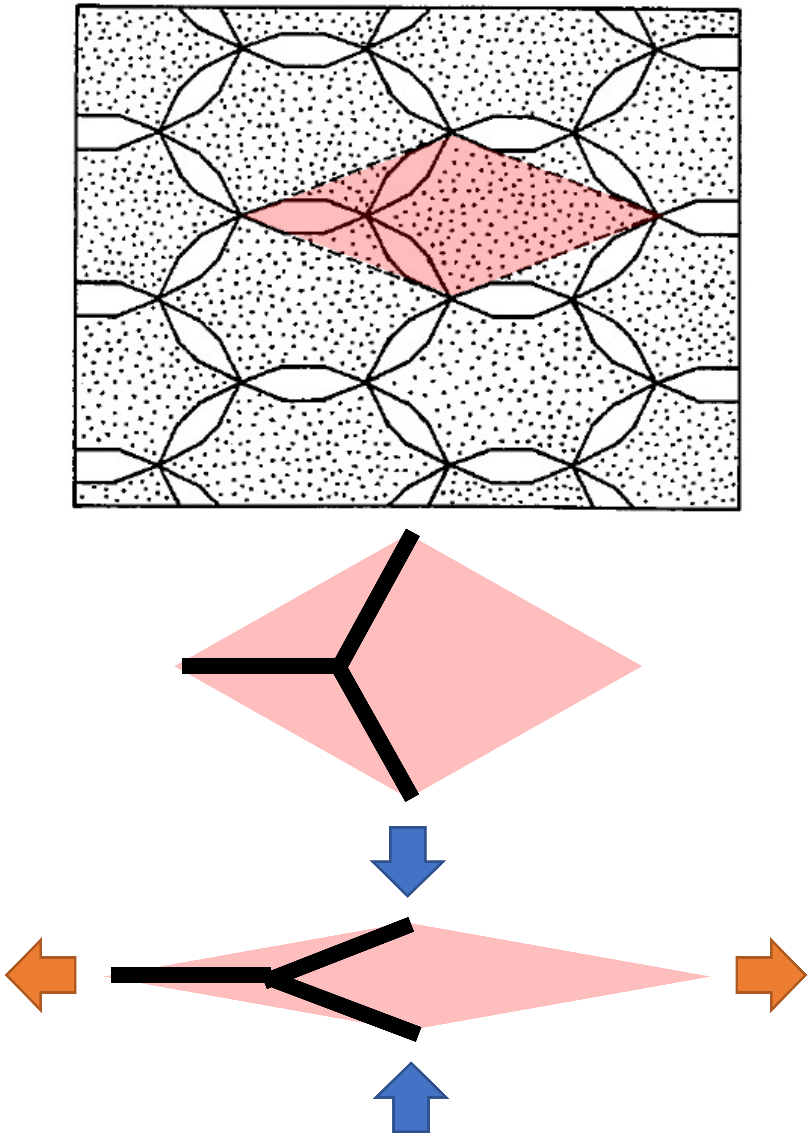
Geometry controls mechanics…

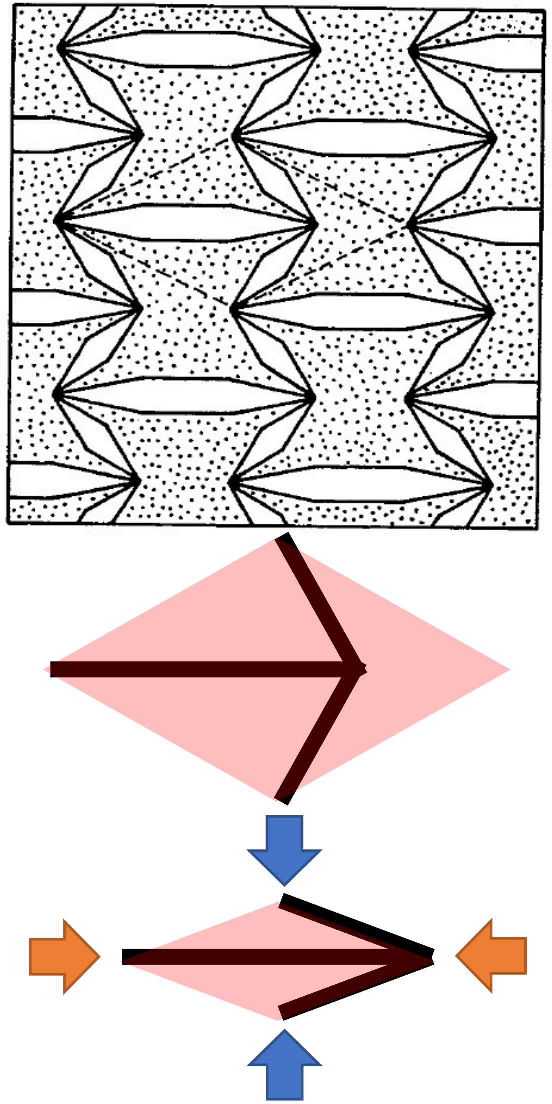
ρ ~ 1 g/L

E~1 kPa

Schaedler et al. (2011) ***Science***

Geometry controls mechanics…

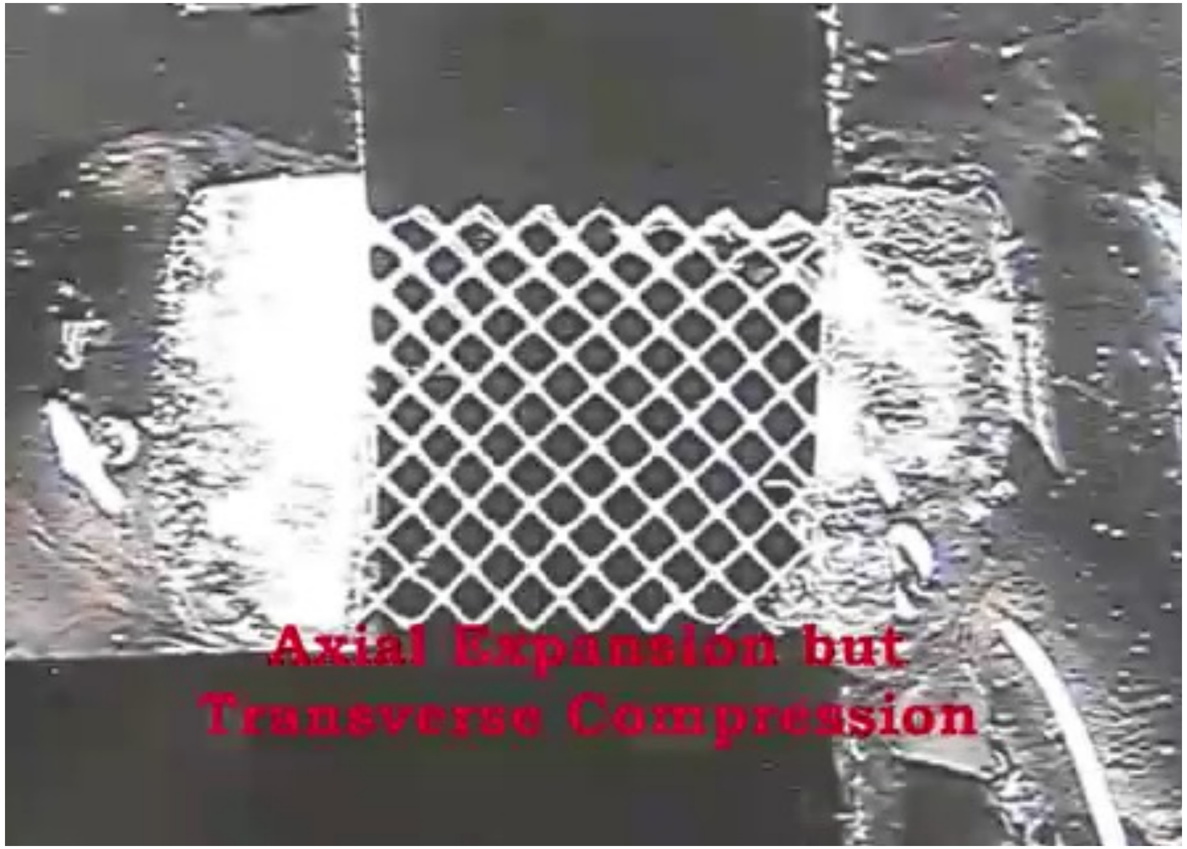




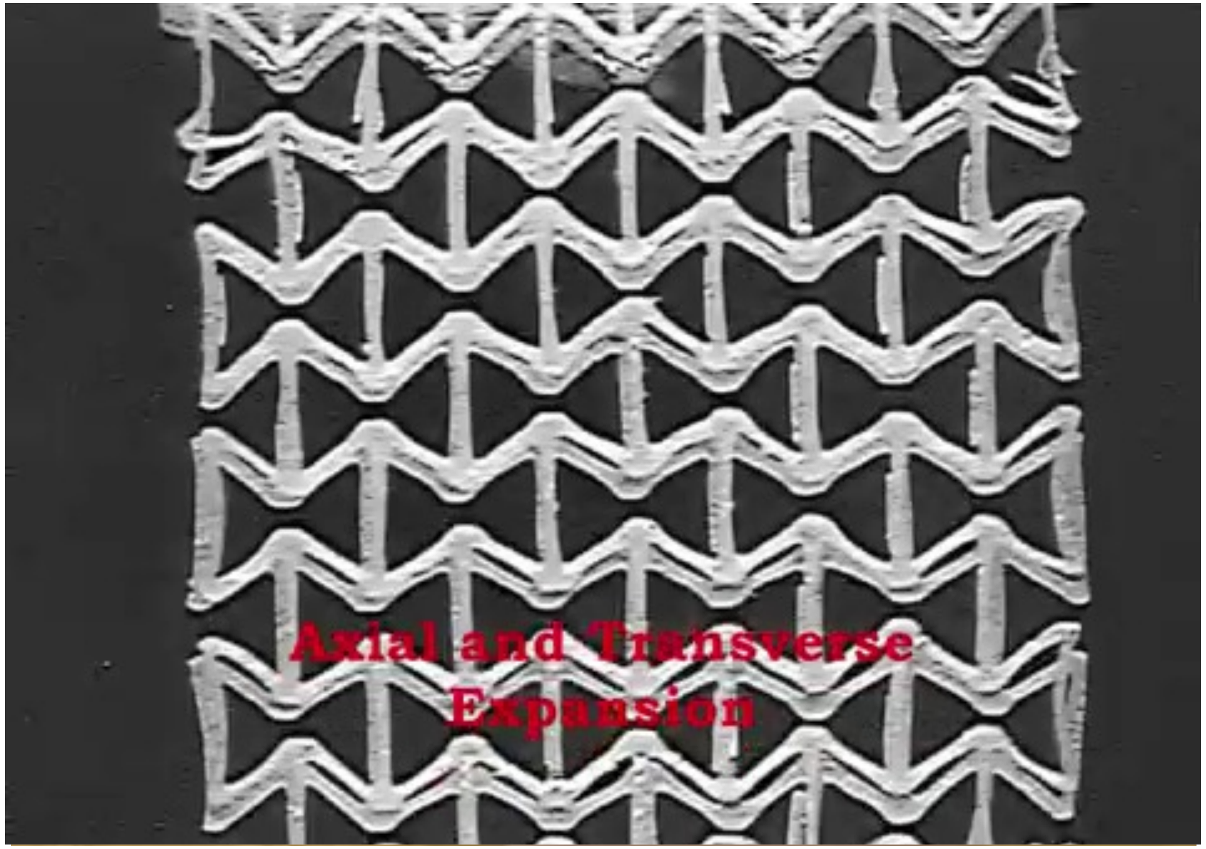
Milton and Cherkaev (1995) **J. Eng. Sc. Tech**

Geometry controls mechanics…

Positive



Negative *(Auxetic)*



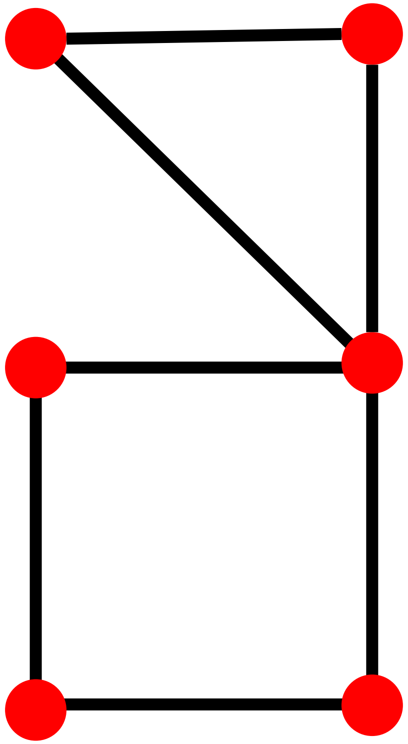
Lakes (1987) **Science**

Geometry controls mechanics…

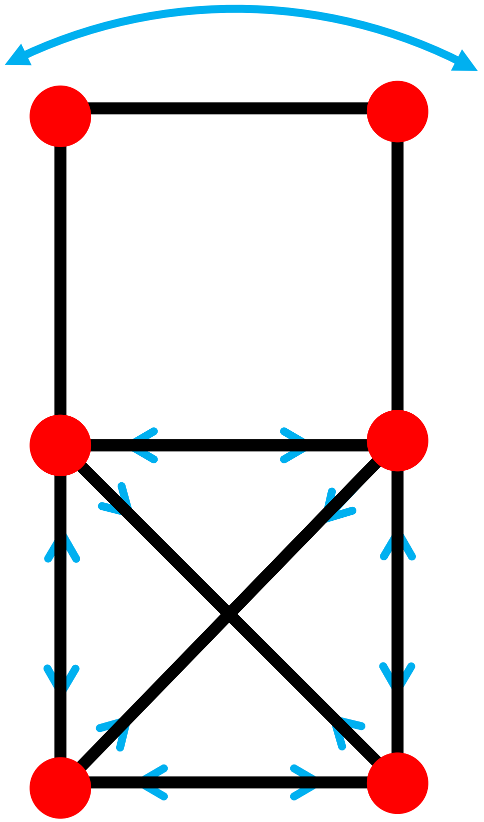
…But how?

Can we go beyond intuition?

The light comes from Maxwell !



Rigidity & floppiness of discrete frames



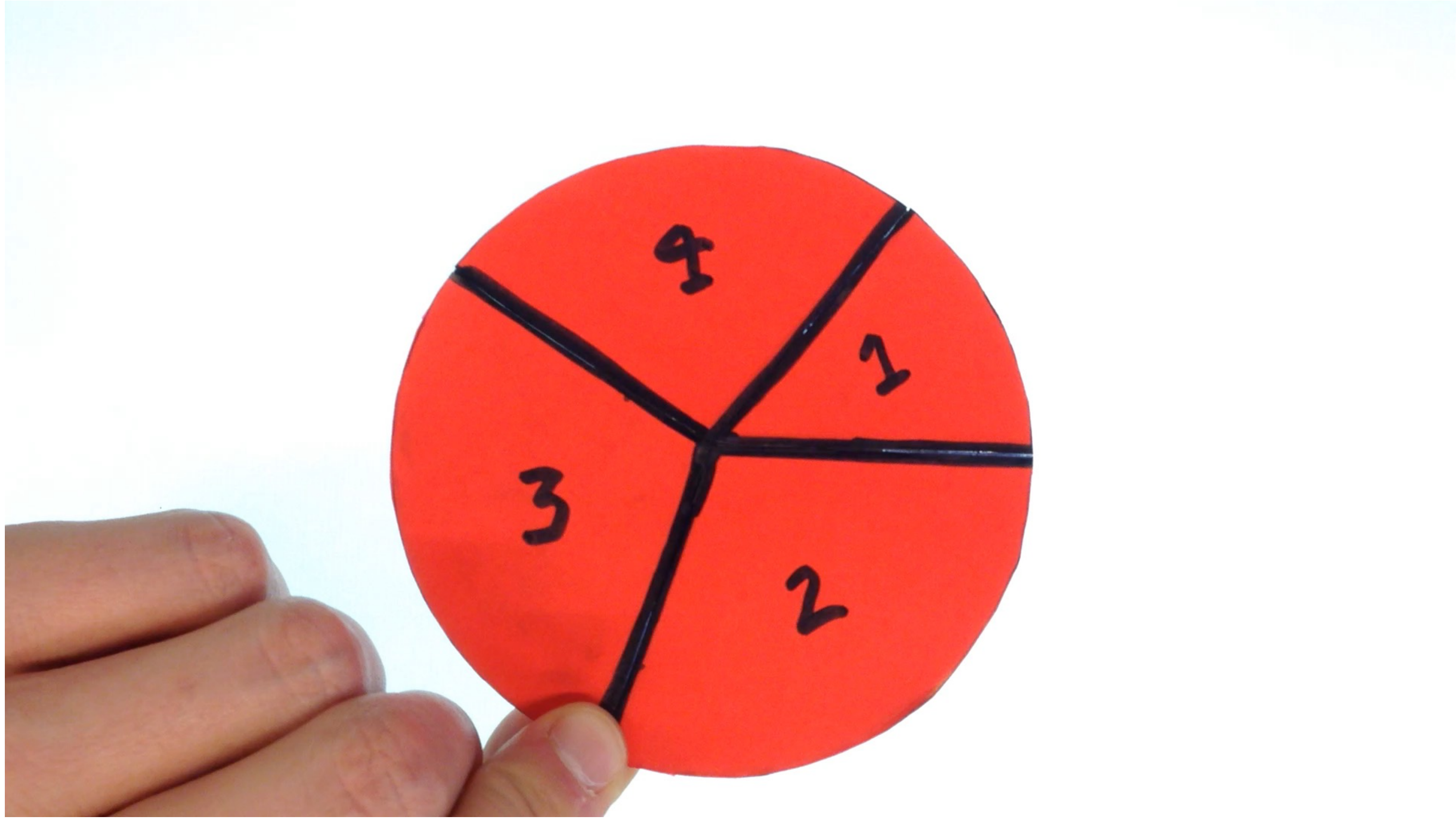
# solid body motions	# floppy motions	# states self-stress	# degrees of freedom (dofs)	# constraints

$$\frac{d(d+1)}{2} + N_0 - N_S = dN - N_B$$

Maxwell (1864) **Phil Mag**
Calladine (1978) **IJSS**
Lubensky et al. (2015) **Rep. Prog. Phys**

Example 1: compute the # of free motions

$$\frac{d(d+1)}{2} + N_0 - N_S = dN - N_B$$

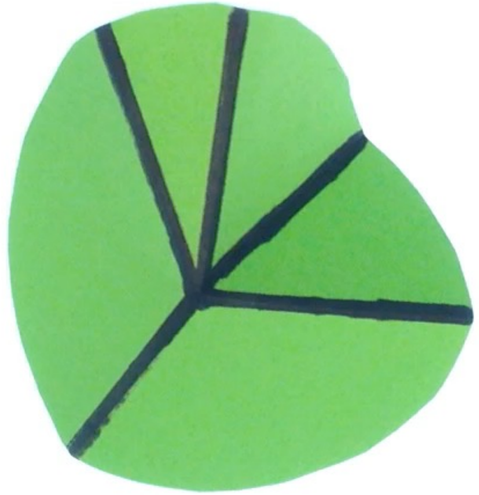


Waitukaitis et al. (2015) ***PRL***

app.wooclap.com/JCGHJC

Example 1: compute the # of free motions

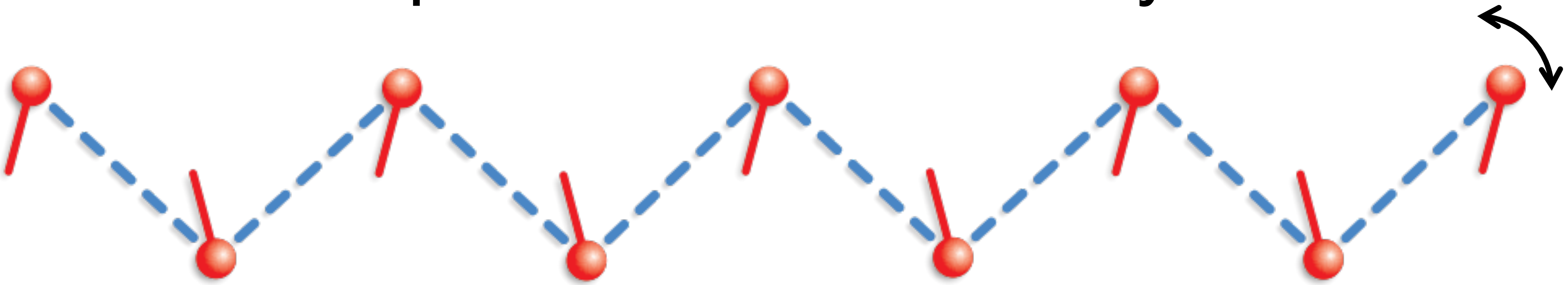
$$\frac{d(d+1)}{2} + N_0 - N_S = dN - N_B$$



Waitukaitis et al. (2015) ***PRL***

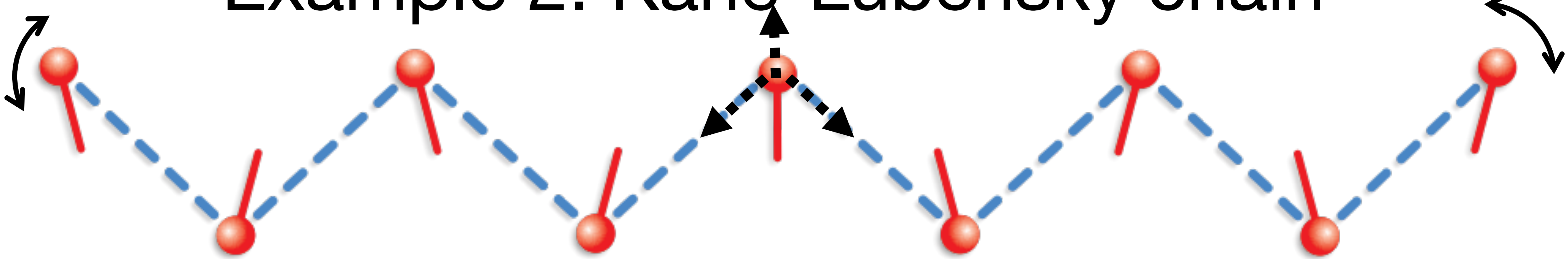
app.wooclap.com/JCGHJC

Example 2: Kane-Lubensky chain



Kane and Lubensky. (2014) ***Nat. Phys.***

Example 2: Kane-Lubensky chain

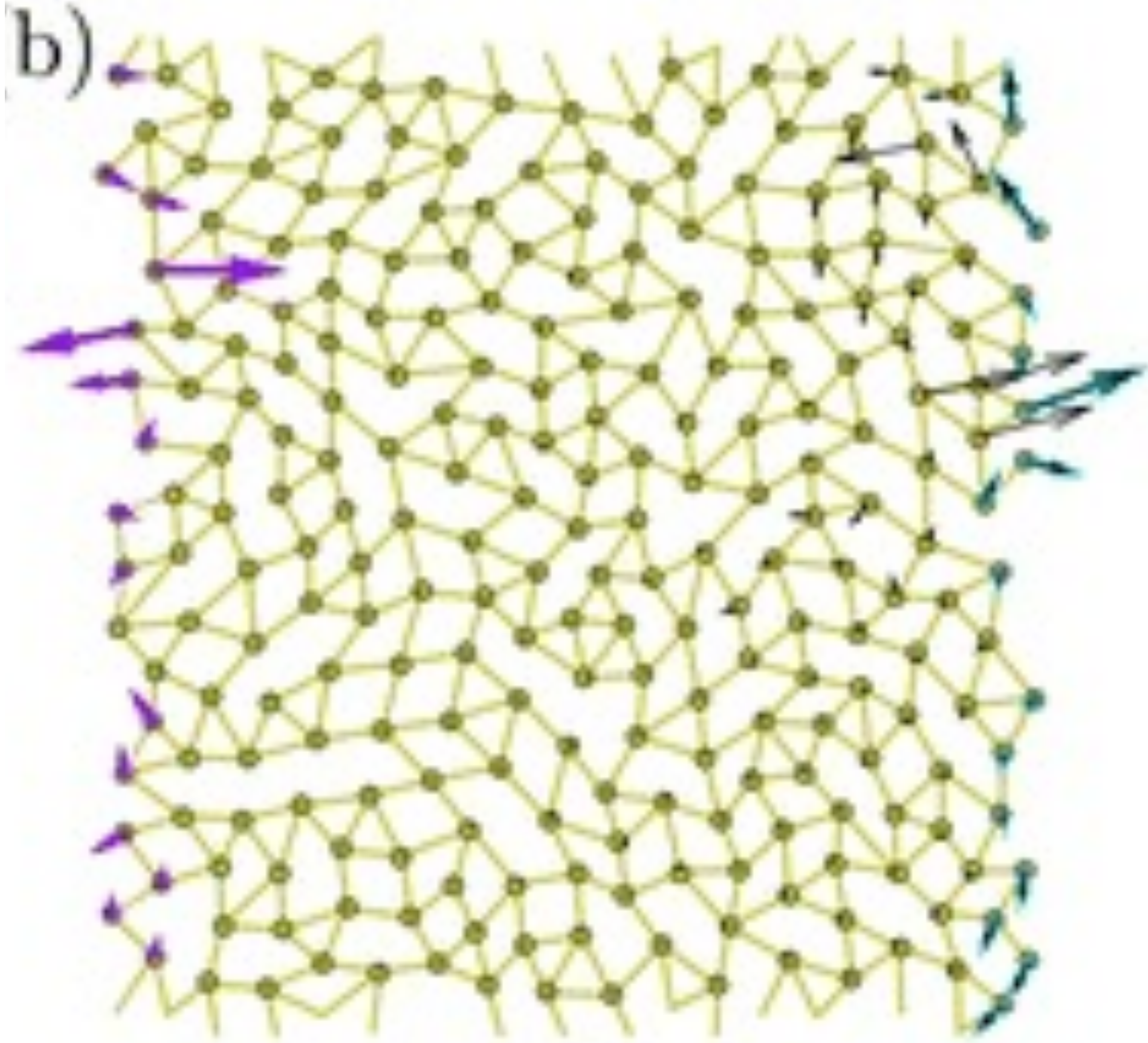


app.wooclap.com/

Kane and Lubensky. (2014) ***Nat. Phys.***

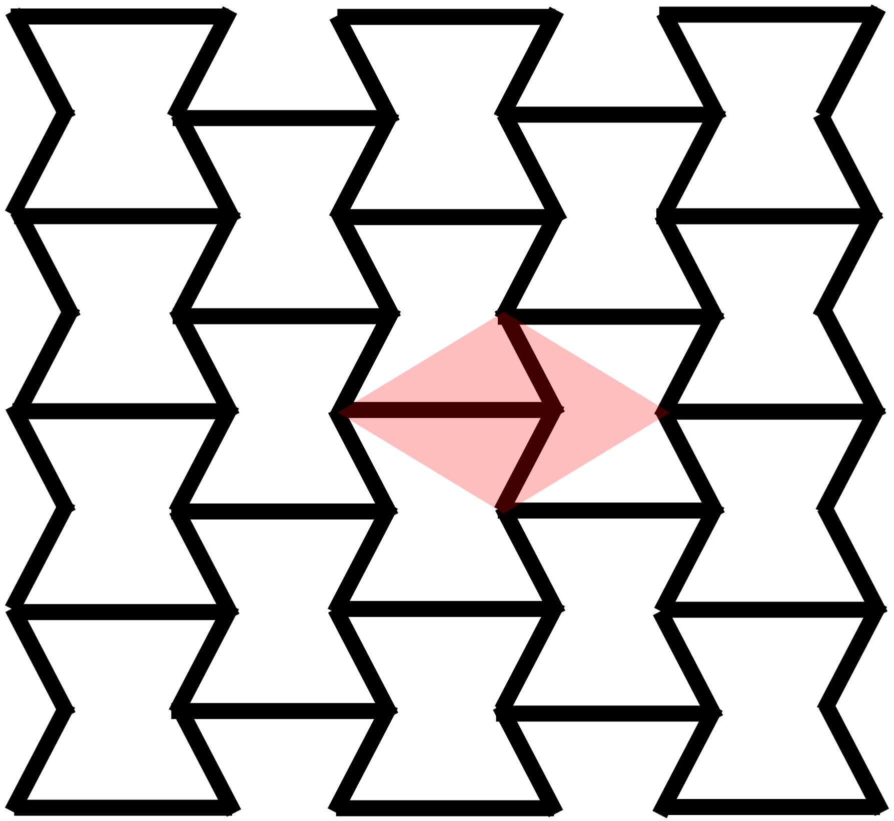
Example 3: disordered materials

$$\frac{d(d+1)}{2} + N_0 - N_S = dN - N_B$$



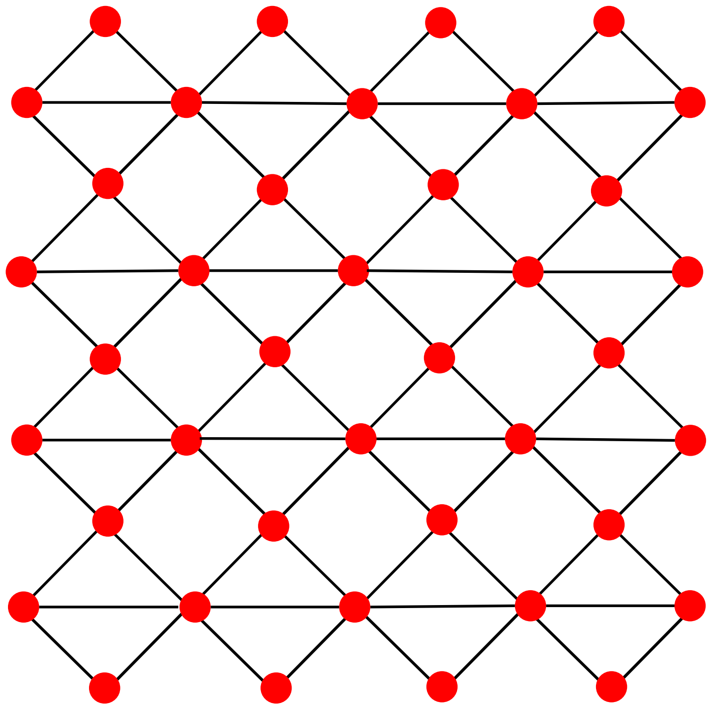
Example 4: Inverted honeycomb lattice

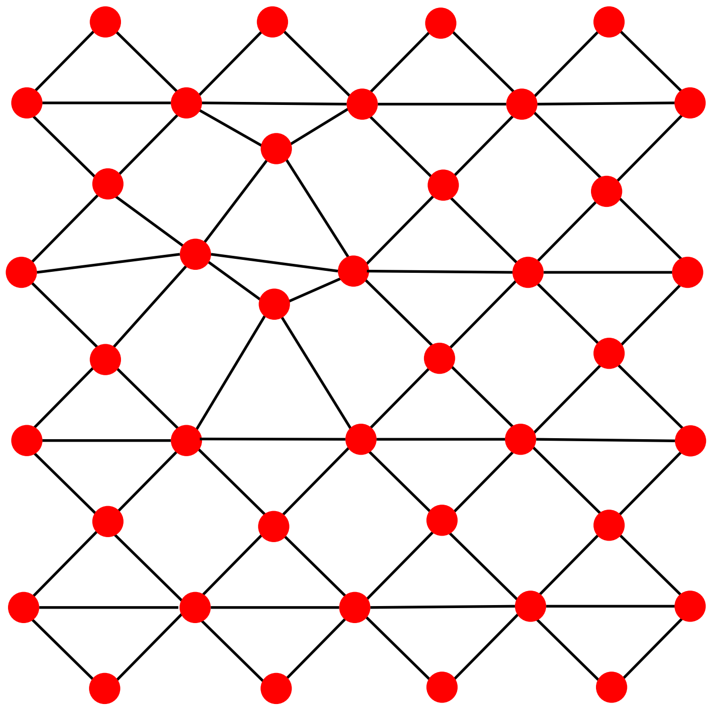
Metamaterial



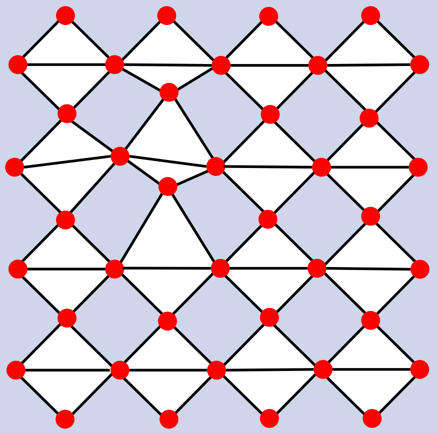
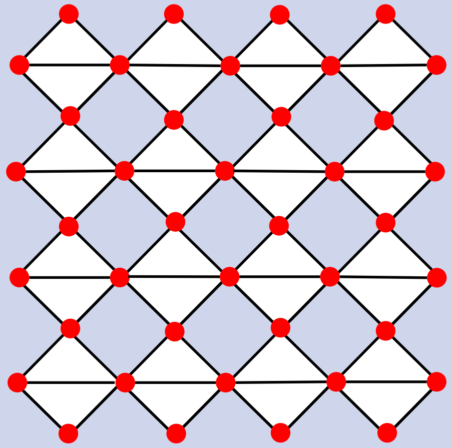
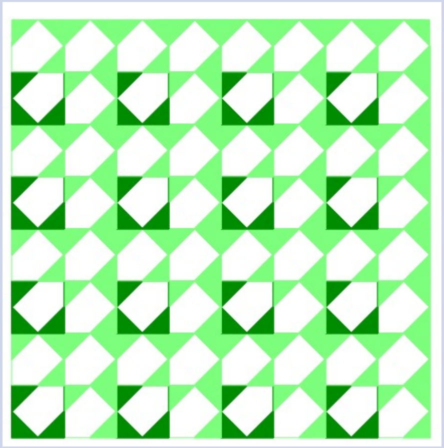
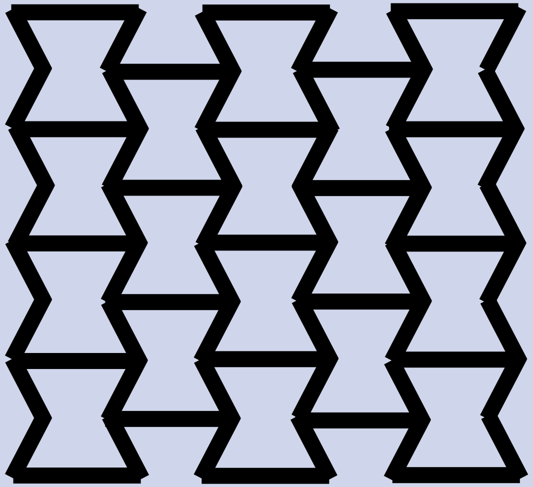
Example 5: Number of Zeros modes and SSS?

$$\frac{d(d+1)}{2} + N_0 - N_S = dN - N_B$$





Classification of flexible metamaterials

Frustrated	Single mode	Oligomodal	Plurimode
N0 = 0	N0 = 1	N0 = O(1) > 1	N0 > O(1) e.g. N0 = O(N)
			

Bossart, Dykstra et al. PNAS (2021)

Exercise (30 min)

$$\frac{d(d+1)}{2} + N_0 - N_S = dN - N_B$$

1. Use Maxwell-Calladine theorem to estimate N_0 – NS in these two structures
2. Determine the zero modes and states of self-stress by intuition
3. Code up the compatibility matrix
4. Compute its null-space to determine the number of zero modes and their shape
5. Compute the null-space of the equilibrium matrix (transpose of the compability matrix)

Reminder:
The compatibility matrix relates the displacement of the nodes to the elongation of the bonds

$$e_\beta = \hat{\boldsymbol{b}}_\beta \cdot (\boldsymbol{u}(s'_\beta) - \boldsymbol{u}(s_\beta)),$$

Hint:
*Define a matrix of node positions (in 2d, Nx2 matrix)
*Define an adjacency matrix (N*N) that has ones when node i and node j share a bond
*Write a function that calculate the bond vector $\hat{\boldsymbol{b}}_\beta \cdot$
*populate the compatibility matrix with the bond vectors
*See Gitlab for help
https://uva-hva.gitlab.host/published-projects/CourseMechanicalMetamaterials