University of BRISTOL

Multi-Stable Cylindrical Lattices

A. Pirrera, *X. Lachenal, S. Daynes,*
P.M. Weaver, I.V. Chenchiah

A. Pirrera, X. Lachenal, S. Daynes, P.M. Weaver, I.V. Chenchiah,
Multi-stable cylindrical lattices, *Journal of the Mechanics and Physics of Solids*, Volume 61, Issue 11, 2013.

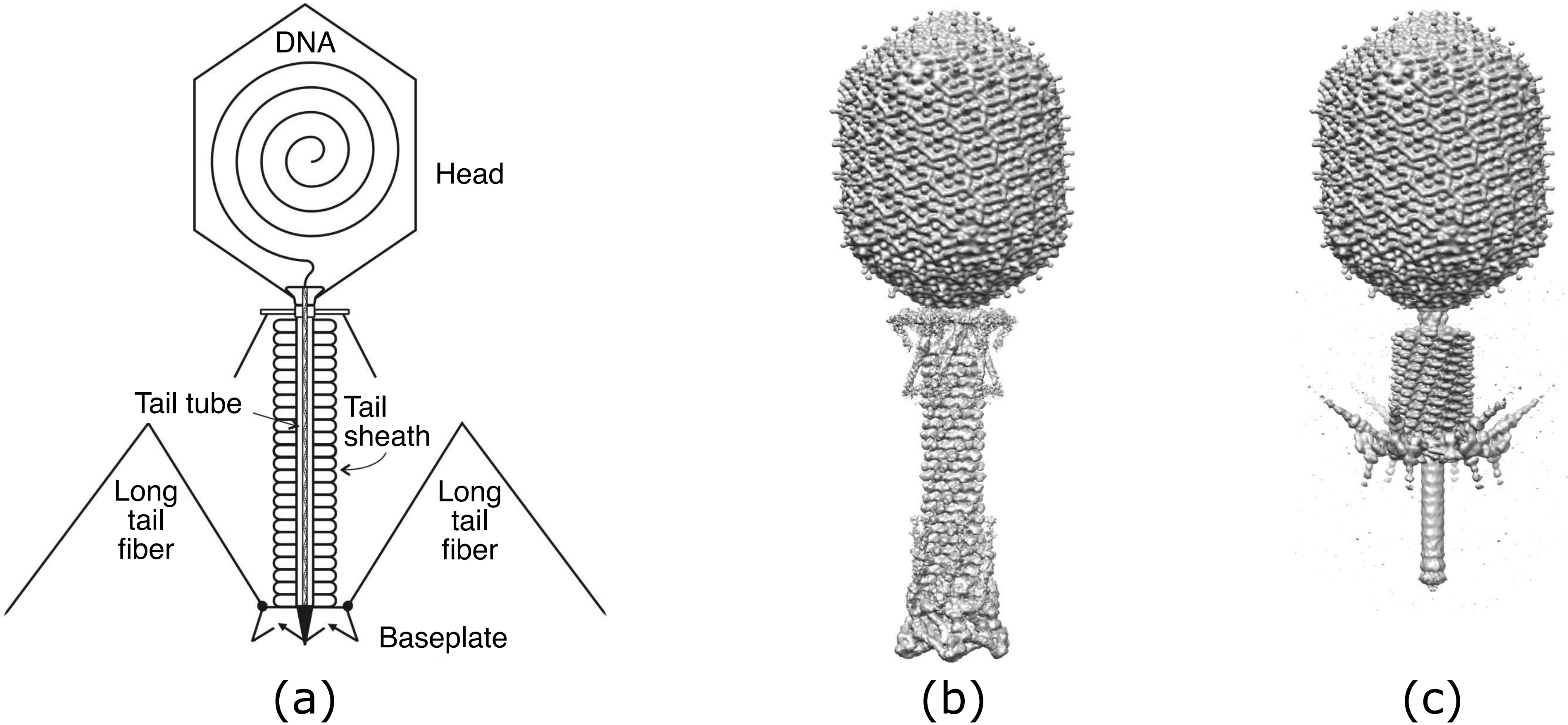
www.bris.ac.uk/composites

ACCIS
ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

Content

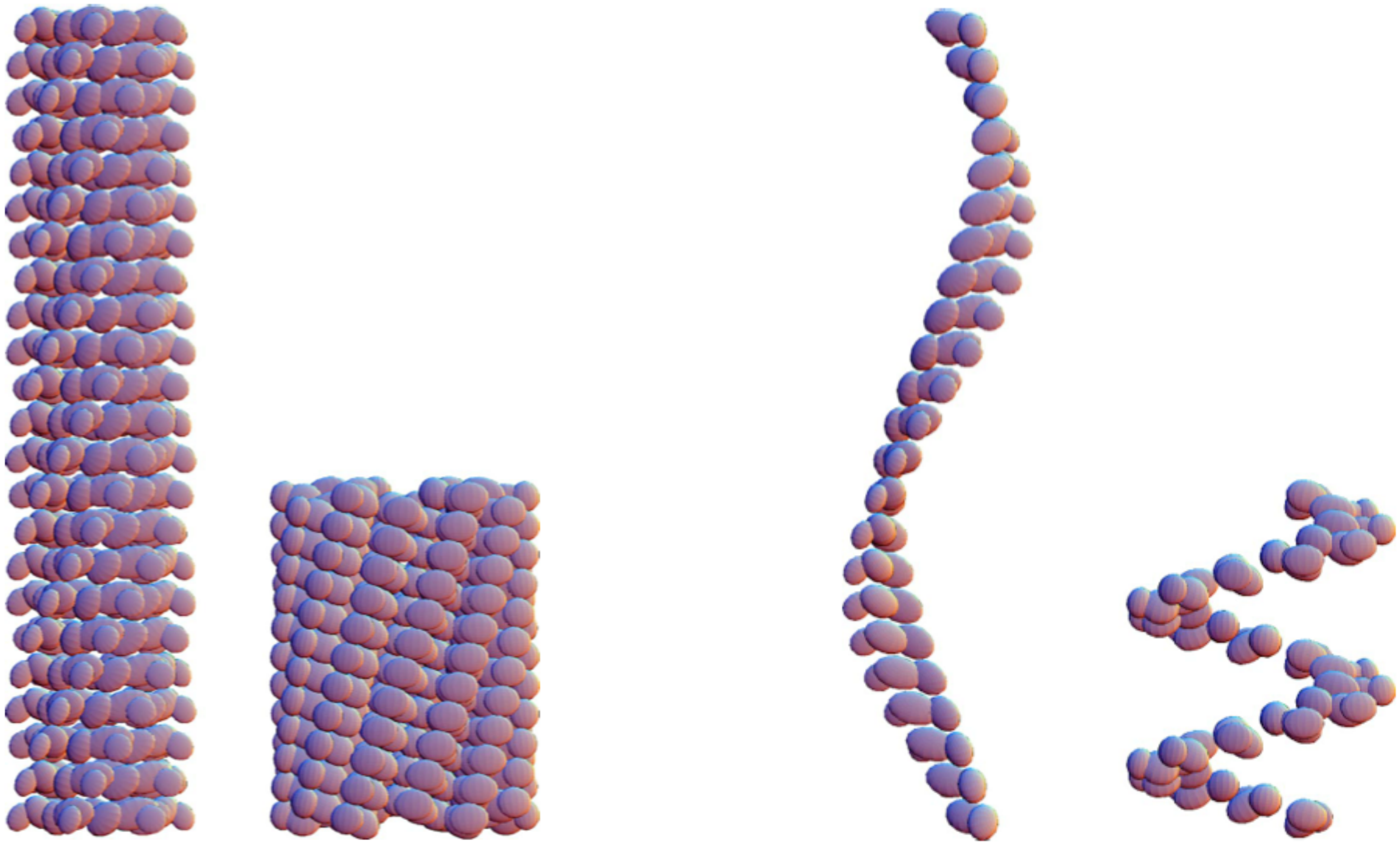
- Inspiration and Motivation
- The device
- Its kinematics and elasticity
- Results, conclusions and take-away message

Inspiration and motivation: Bacteriophage T4



(a) Schematic representation and model of Bacteriophage T4 prior to (b) and upon (c) host cell attachment. Leiman et al. (2010)

Inspiration and motivation: Bacteriophage T4



Visualisation of the (left) tail sheath and (right) one of the six main helices of Bacteriophage T4 in the extended and contracted states. Falk and James (2006).

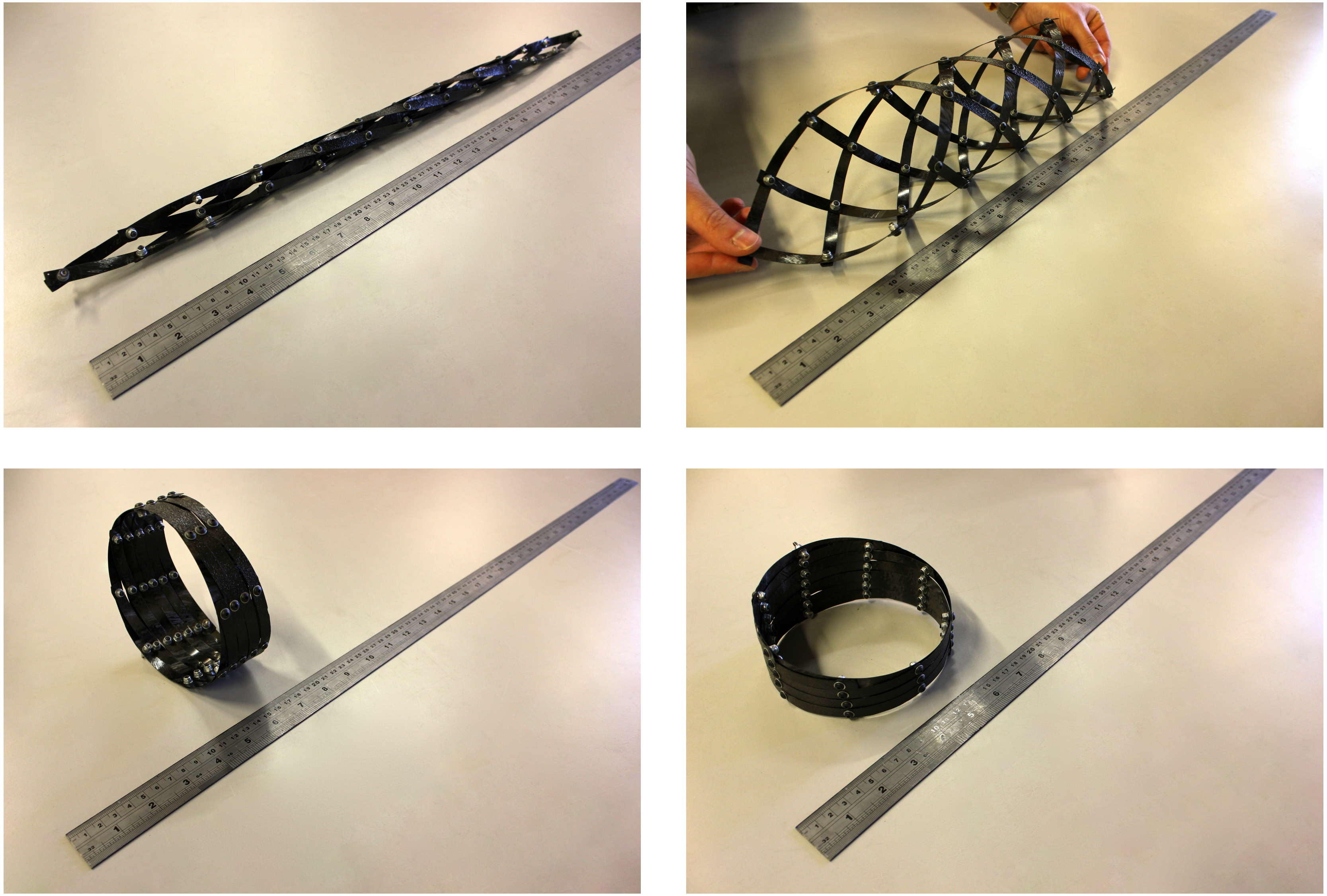
Inspiration and motivation

Why?

Inspiration and motivation

- A multi-stable cylindrical structure is in itself of engineering interest.
- We are motivated by a much broader vision, namely of translating molecular mechanisms into engineer-able mechanisms.

The device



The device

- On the macroscale we have achieved this by using composite materials in a lattice arrangement to exploit interplay between pre-stress, material properties and structural geometry.

- Engineering applications of such multi-stable structures include tailorable non-linear springs, non-linear dampers and shock-absorbers, exoskeletons, and deployable structures, especially for space applications.

Kinematics and elasticity

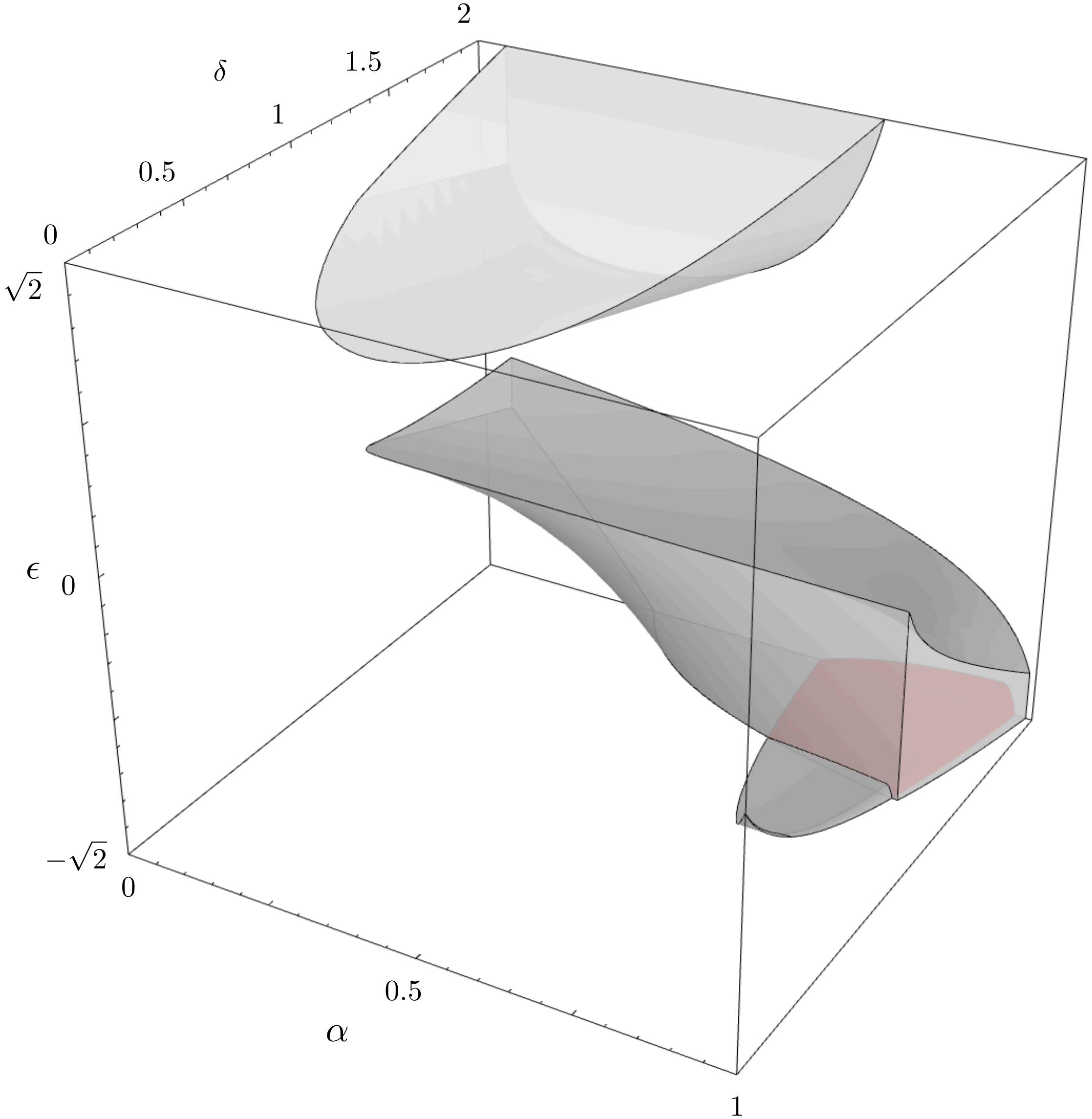
Strain Energy

$$\Pi = \frac{\ell_+}{2R^2}\begin{bmatrix}\cos^2\vartheta_+ - \varkappa_{11}^+ R\\ \sin\vartheta_+\cos\vartheta_+ - \varkappa_{12}^+ R\end{bmatrix}^T \begin{bmatrix} D^+ & D_{16}^{*+}\\ D_{16}^{*+} & D_{66}^{*+}\end{bmatrix}\begin{bmatrix}\cos^2\vartheta_+ - \varkappa_{11}^+ R\\ \sin\vartheta_+\cos\vartheta_+ - \varkappa_{12}^+ R\end{bmatrix}$$
$$+\frac{\ell_-}{2R^2}\begin{bmatrix}\cos^2\vartheta_- - \varkappa_{11}^- R\\ -\sin\vartheta_-\cos\vartheta_- - \varkappa_{12}^- R\end{bmatrix}^T \begin{bmatrix} D^- & D_{16}^{*-}\\ D_{16}^{*-} & D_{66}^{*-}\end{bmatrix}\begin{bmatrix}\cos^2\vartheta_- - \varkappa_{11}^- R\\ -\sin\vartheta_-\cos\vartheta_- - \varkappa_{12}^- R\end{bmatrix}$$

$$\cos\vartheta_- = \frac{1}{2\ell_-}R + \frac{\ell_-^2 - \ell_+^2}{2\ell_-}\frac{1}{R},$$
$$\cos\vartheta_+ = \frac{1}{2\ell_+}R + \frac{\ell_+^2 - \ell_-^2}{2\ell_+}\frac{1}{R}.$$

Design space investigation & Conclusions

- We demonstrate computationally that **multi-stability is a robust phenomenon**.
- We also show analytically that **it is possible to choose the design variables so that the energy is independent of the radius**, thus resulting in every state of the structure being stable.
- Exploitation is the next step…



Questions?