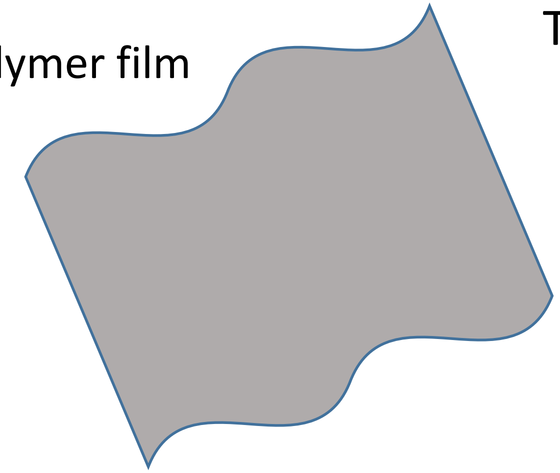
kitp sheets16 talk
feb 1st 2016
narayanan menon

wrapping fluids with thin sheets



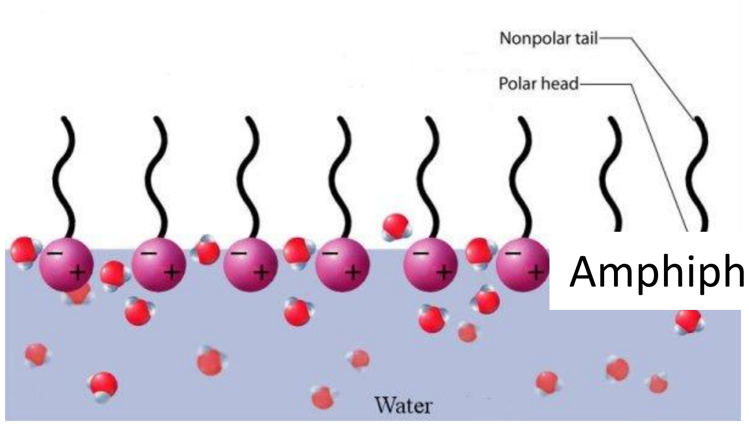
Typical von Karman number: (Width/thickness)^2 ~ (2 cm/50 nm)^2 ~ 10^{11}

Range of vK: 10^9 to 10^{13}

theory Vincent Démery, B. Davidovitch, C. Santangelo

experiments Joey Paulsen, Tom Russell

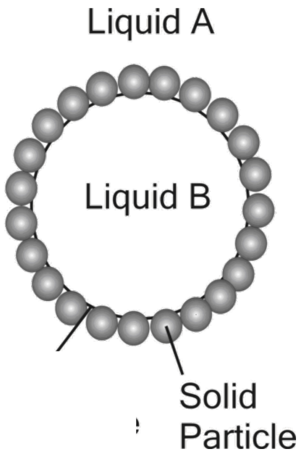
Molecules and particles are traditionally used as surfactants



Amphiphilic molecules

Nerdy-girls.org

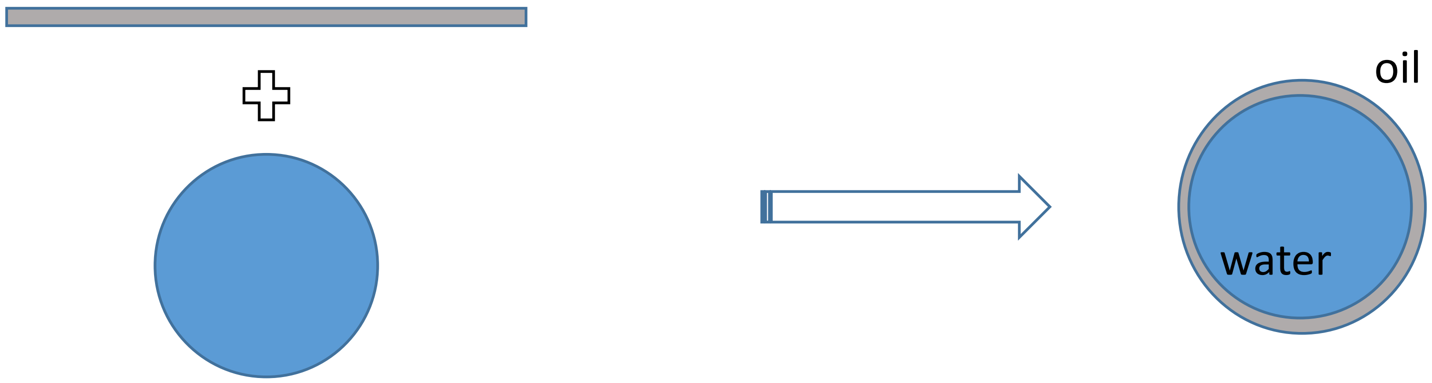
Pickering emulsion



Kleuven.be

These surfactant layers are typically <u>fluid</u>.

Goal: assemble the tools to use flexible sheets as *elastic* surfactants.

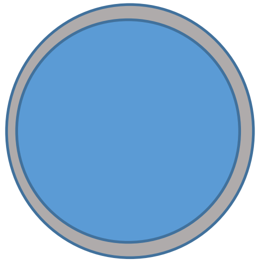


Advantages of solid films

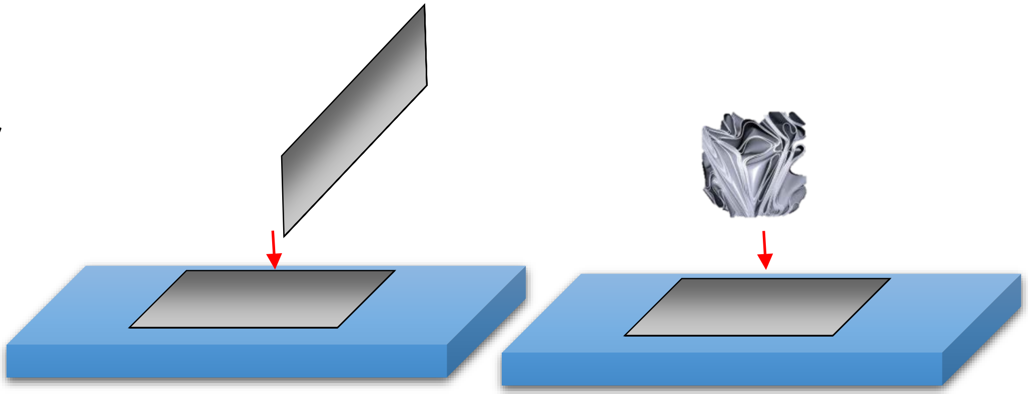
- impart mechanical rigidity
- support arbitrary shapes
- preserve spatial chemical/optical/electrical patterning
- more impervious

Associated science problems

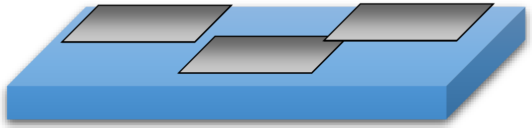
- Wrapped interface or drop
  Shapes, stability, mechanics

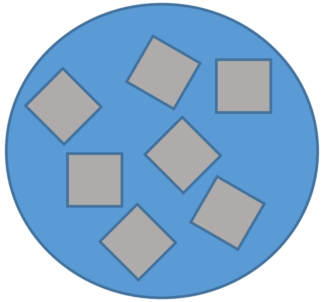


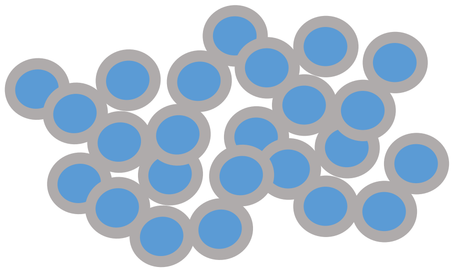
- Dynamics of delivery
  Time-scales, barriers



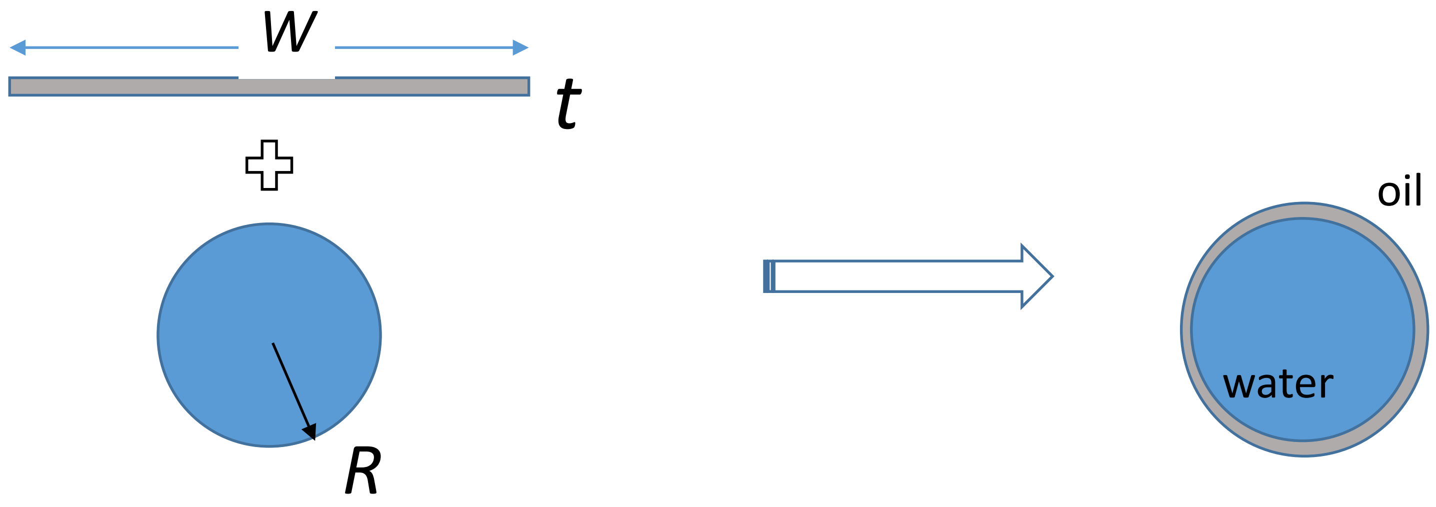
- Collective properties
  Rheology







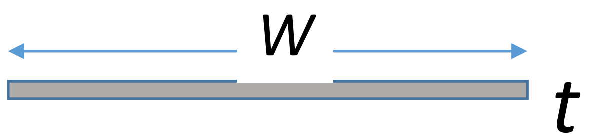
Wrapping a drop



- Gain in surface energy ~γ area
- Cost in energy to bend and stretch the sheet

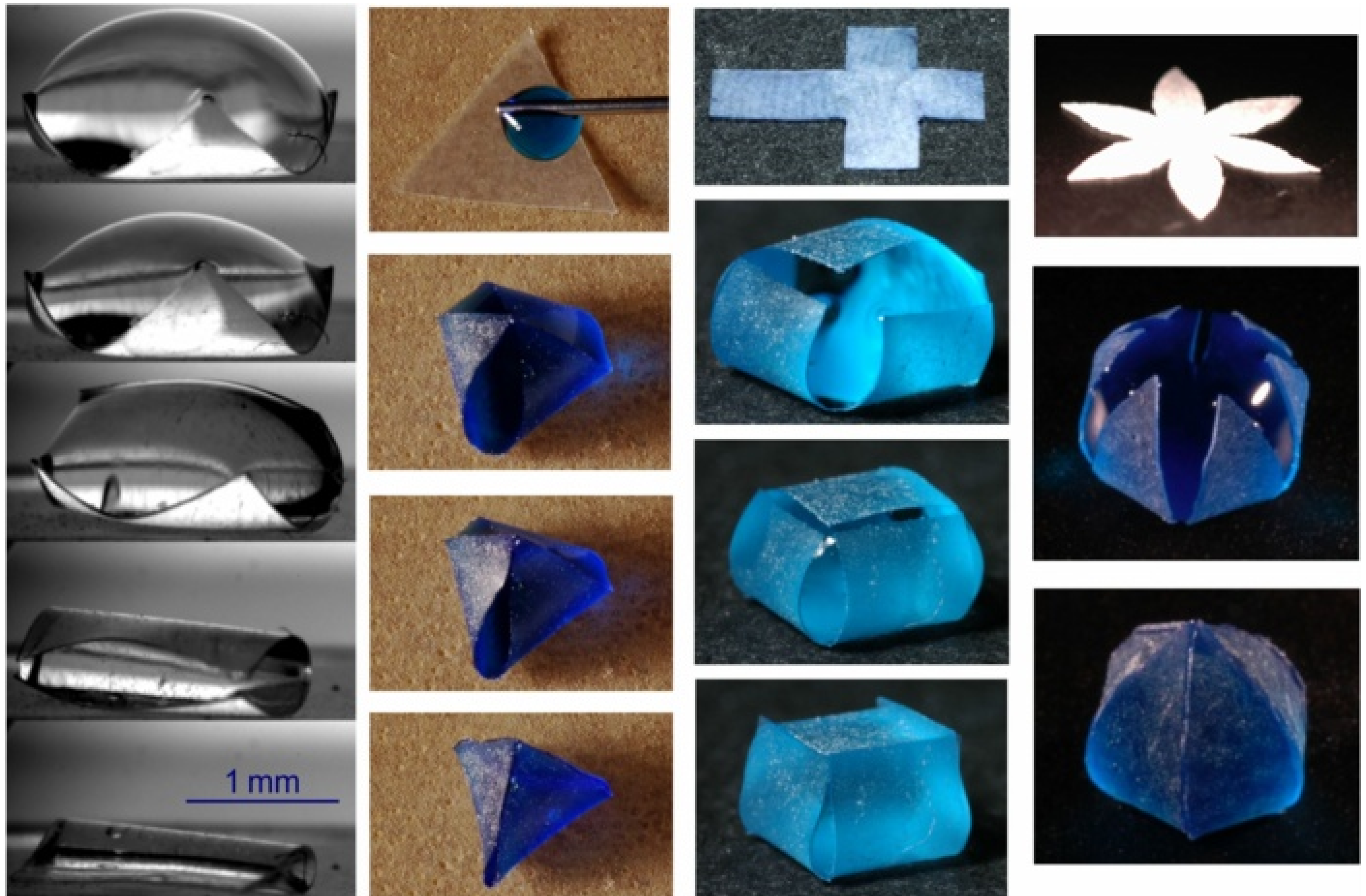
~Et^3 ~Et

Capillary origami



Py, Reverdy, Baroud, Roman, Bico, 2008

$vK \sim (W/t)^2 = (\text{few mm}/50\mu m)^2 \sim 5.10^3$

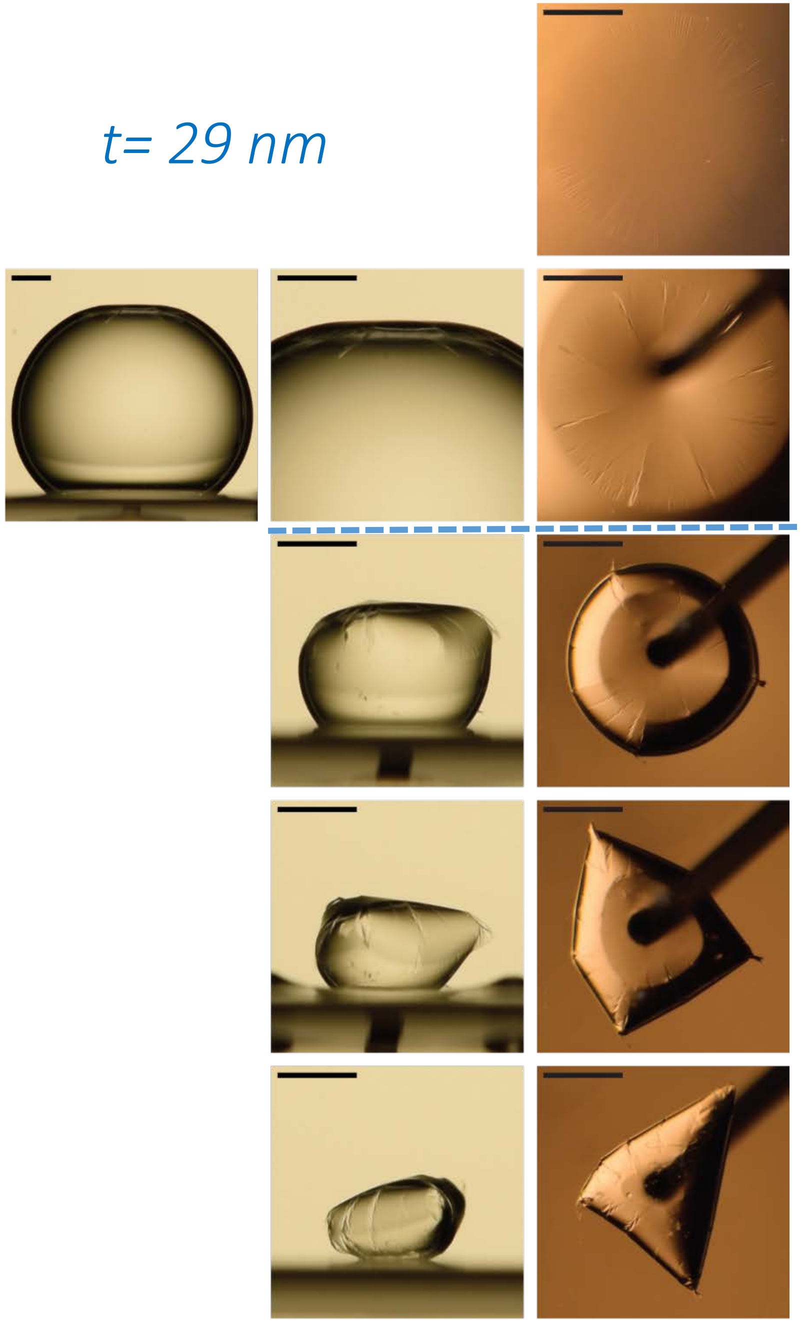


- Bending torque balances capillary forces
- Shapes with flaps cut to allow pure bending

Now for something thinner….

(but why?)

t= 29 nm

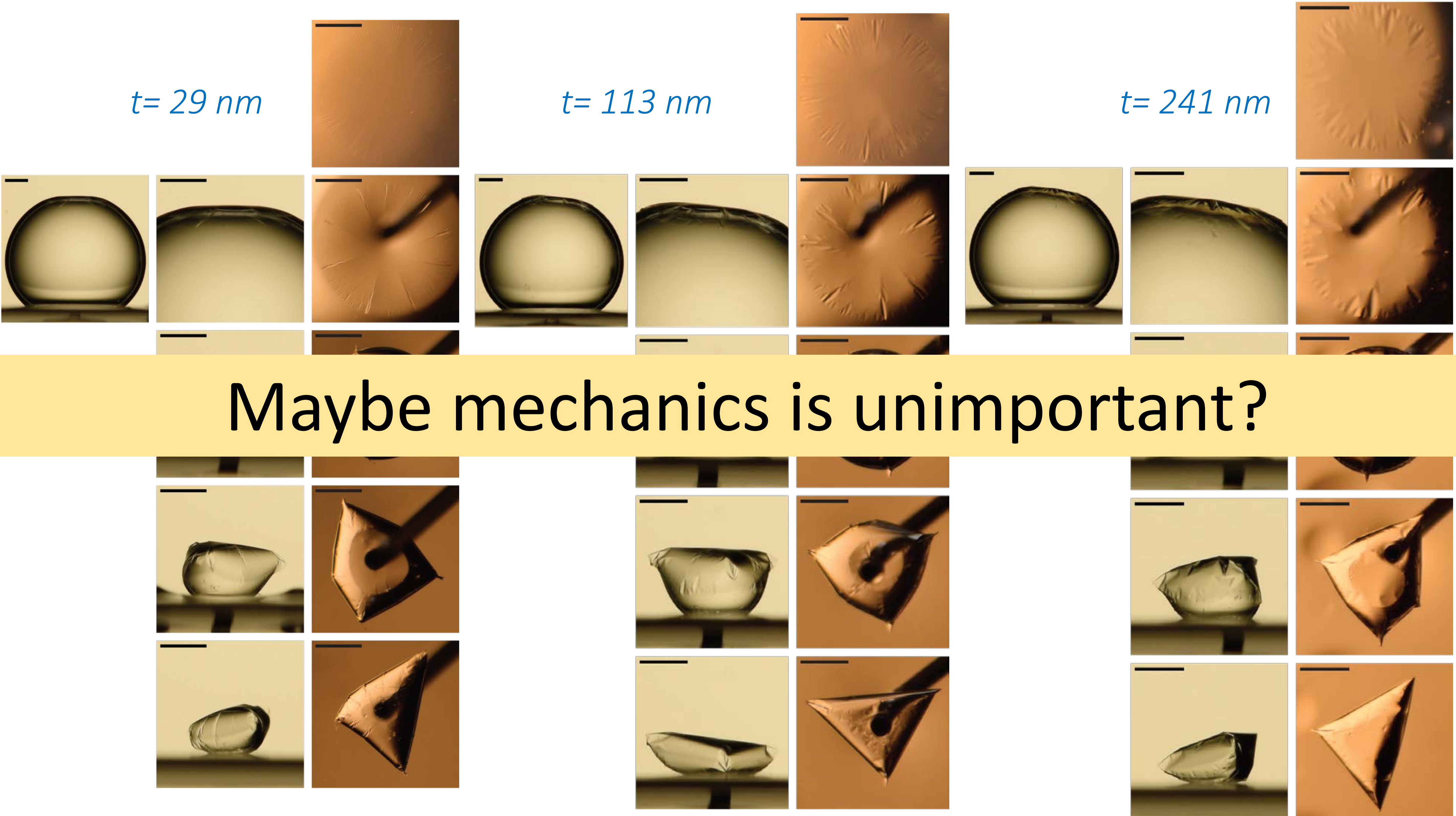


Axially symmetric *wrinkles, crumples*

Polygonal shapes *folds, crumples*

How to understand this sequence of shapes?

Wrinkles, folds, crumples, all interacting on a curved surface



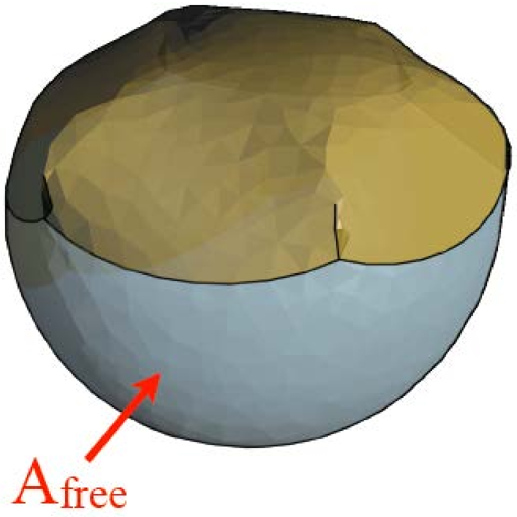
Maybe mechanics is unimportant?

Wrapping with thin sheets

Describe all shapes with a simple equation:

Energy, $U = \gamma A_{free}$

Constraint: free ‘compression’, but no stretching



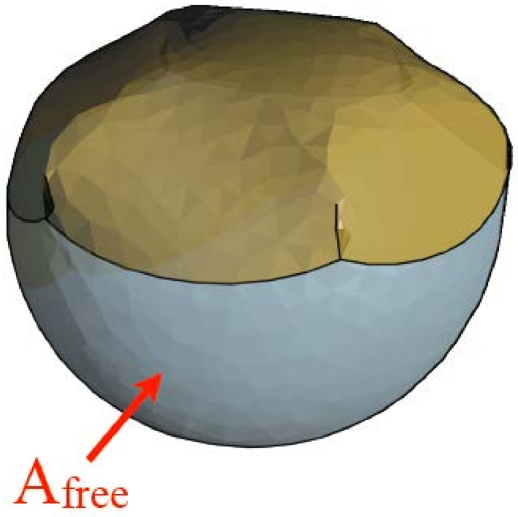
Pure geometry, no material parameters!

Wrapping with thin sheets

Describe all shapes with a simple equation:

Energy, $U = \gamma A_{free}$

Constraint: free 'compression', but no stretching

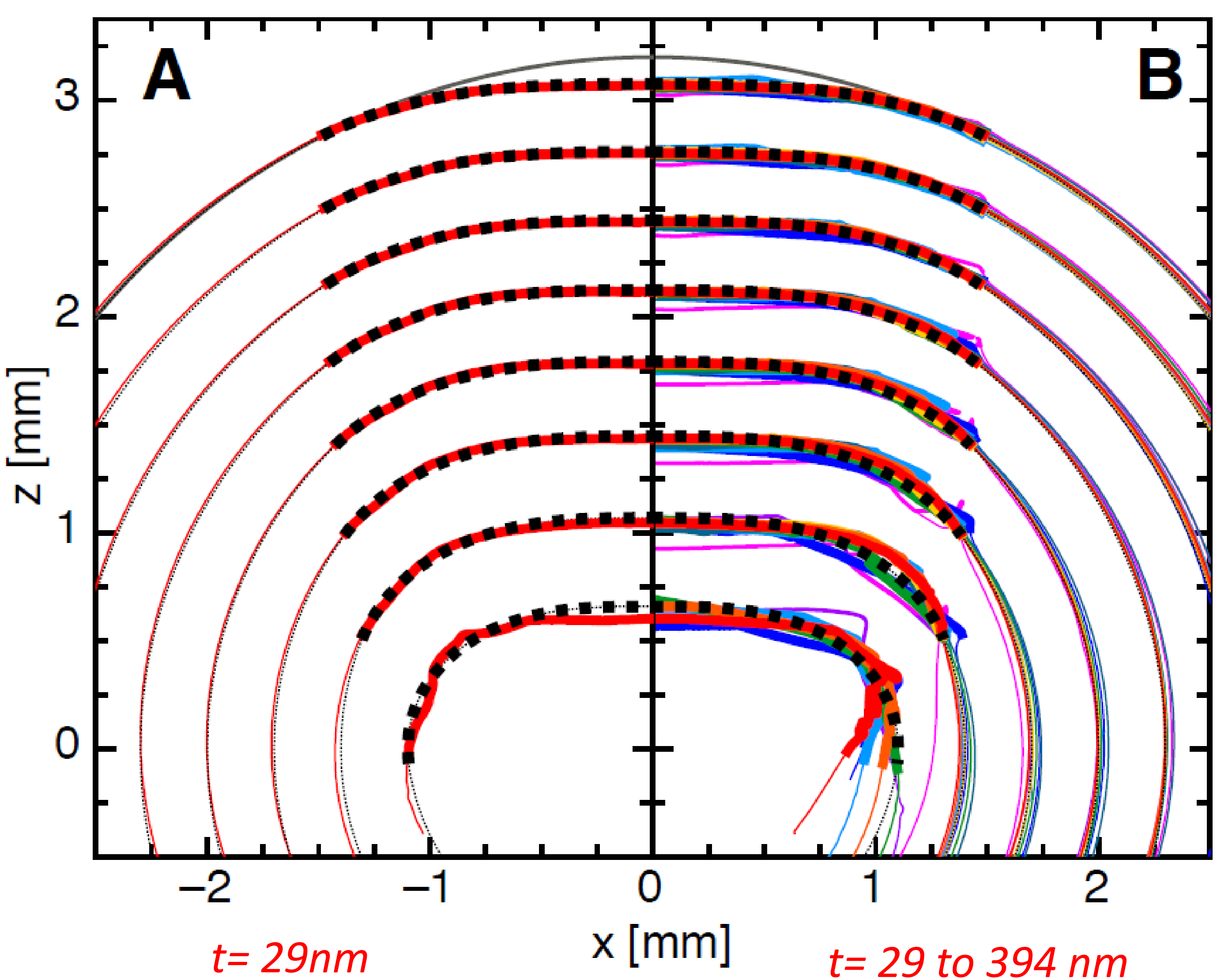


Works when energy scales are separated:

bending << surface << stretching

Et^3/W^2 γ Et

Explains axisymmetric shape

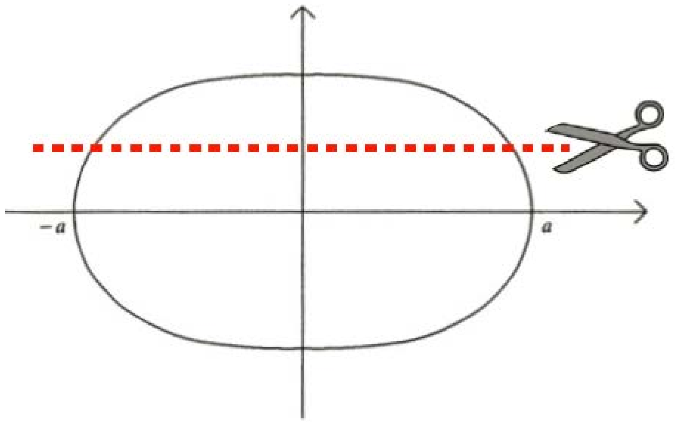


t= 29nm

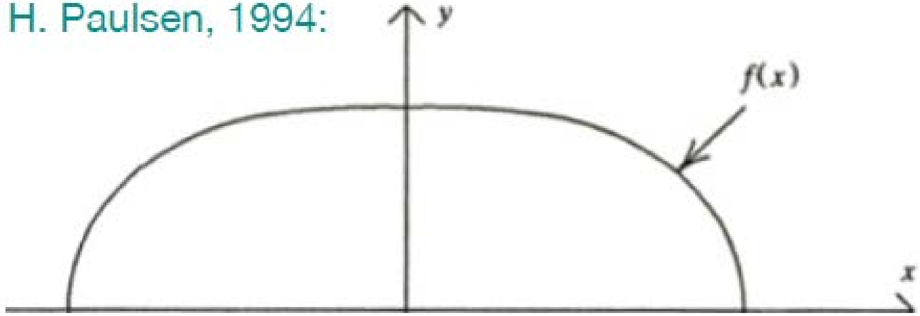
t= 29 to 394 nm

Not section of a sphere!

Section of mylar balloon (Paulsen 1994) or parachute (Taylor 1919)



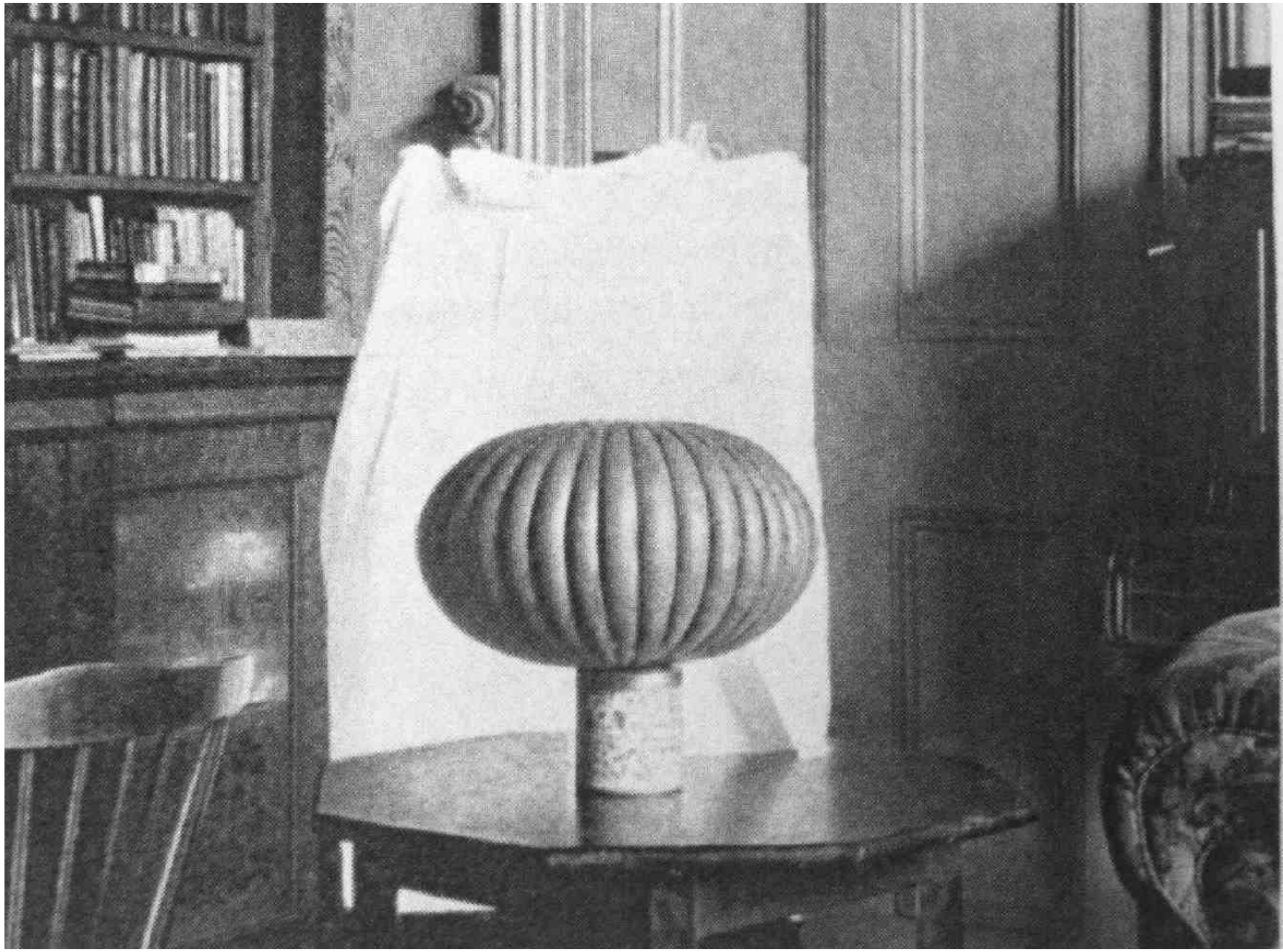
W. H. Paulsen, 1994:



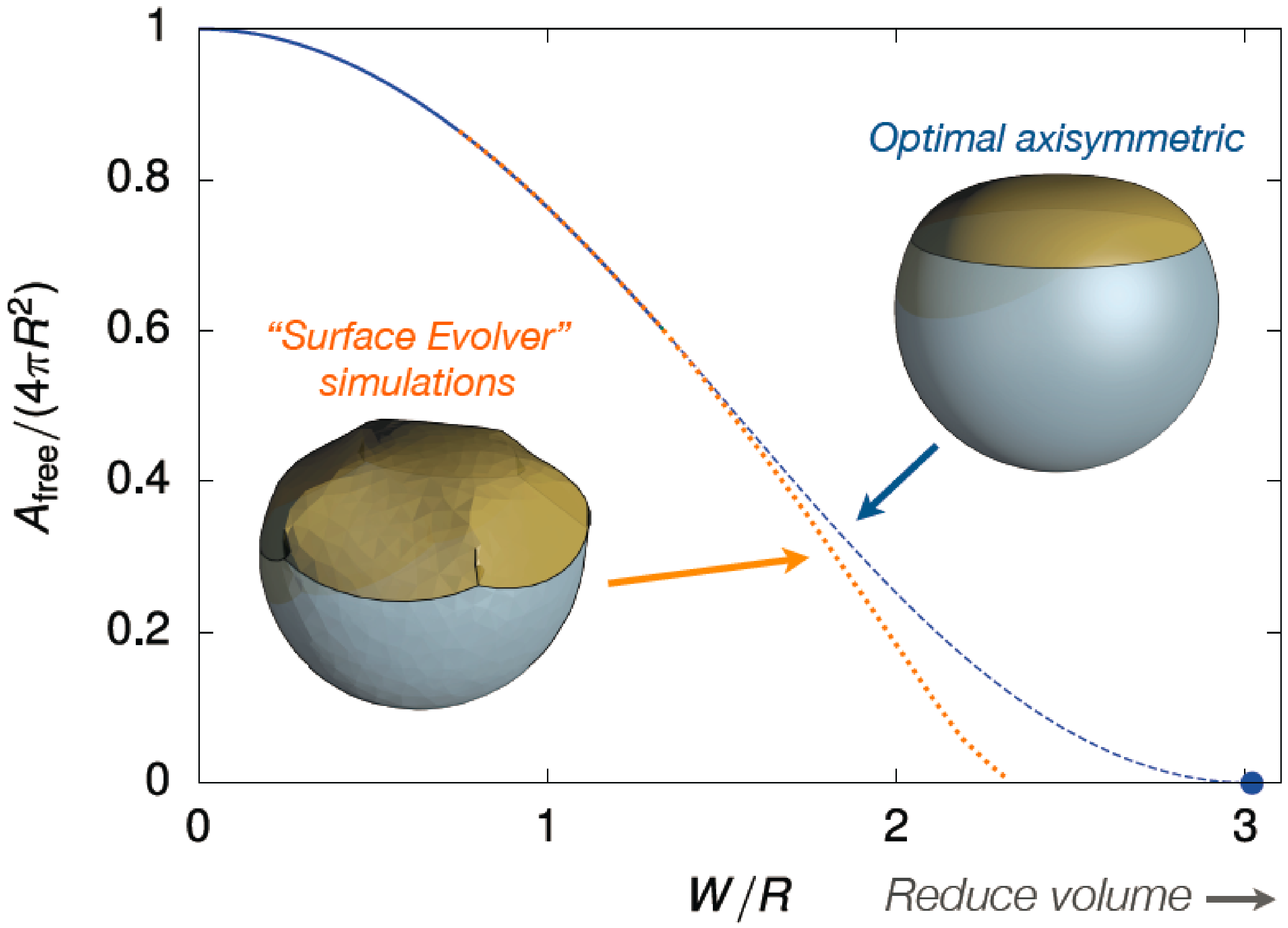
$$f(x) = \int_x^a \frac{t^2}{\sqrt{a^4 - t^4}}\,dt, \qquad (0 \leq x \leq a).$$

This shape maximizes volume enclosed by two discs with no stretching along the radial direction

Taylor 1919

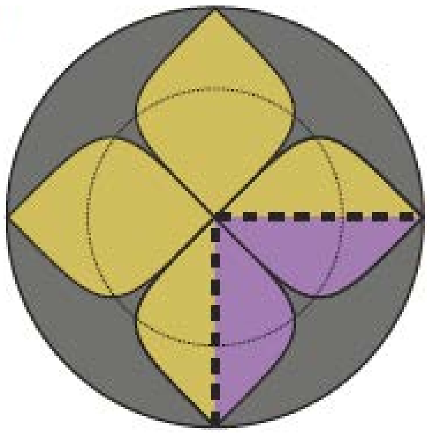


Simulation also finds broken-axisymmetry shape

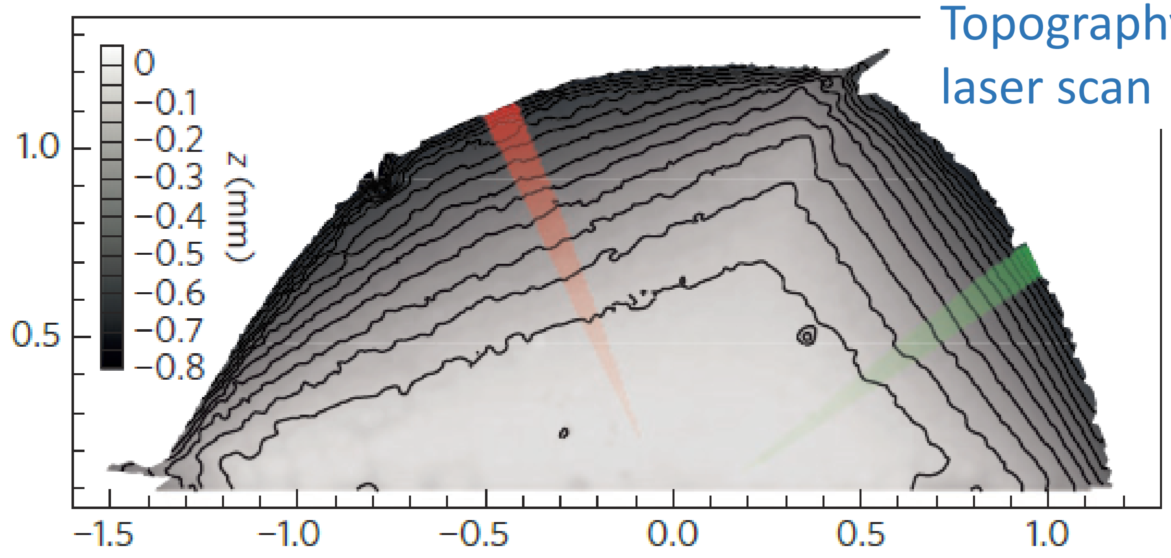


Parachute/mylar balloon no longer the best for W/R > 1.4

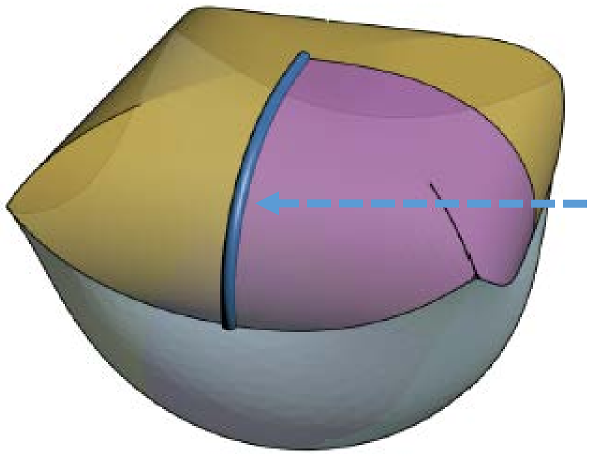
Construct broken-axisymmetry shape



N- fold flat shape with appropriate excess arc length



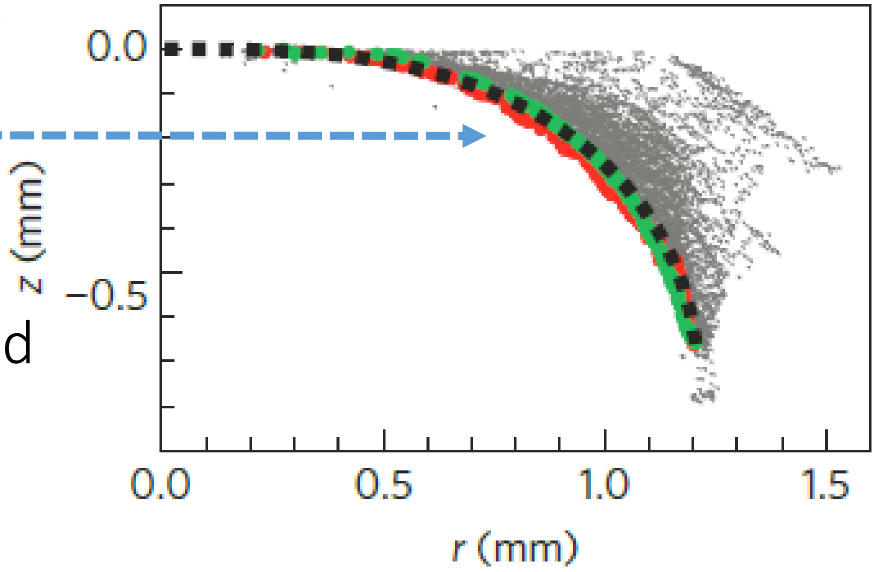
Topography by laser scan



Partial wrapping ansatz
(validated by full simulation)

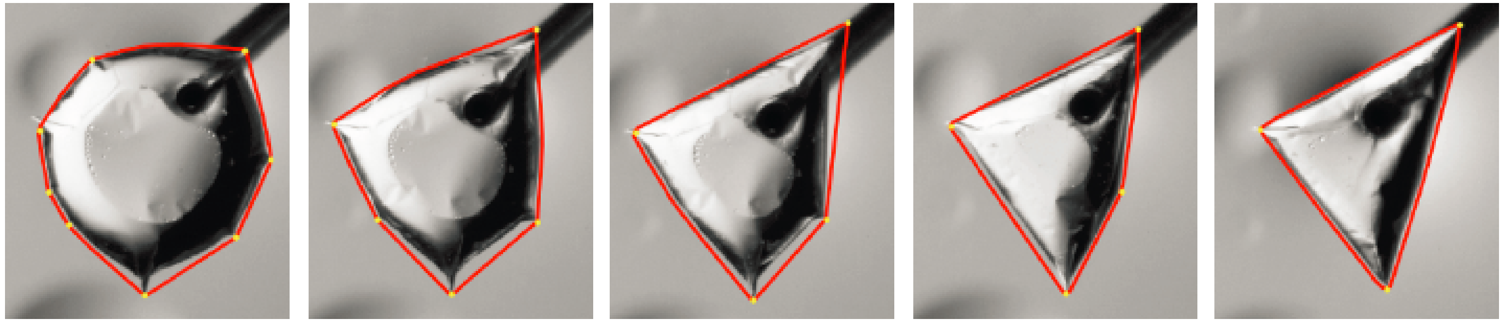
Mid-line is Paulsen shape

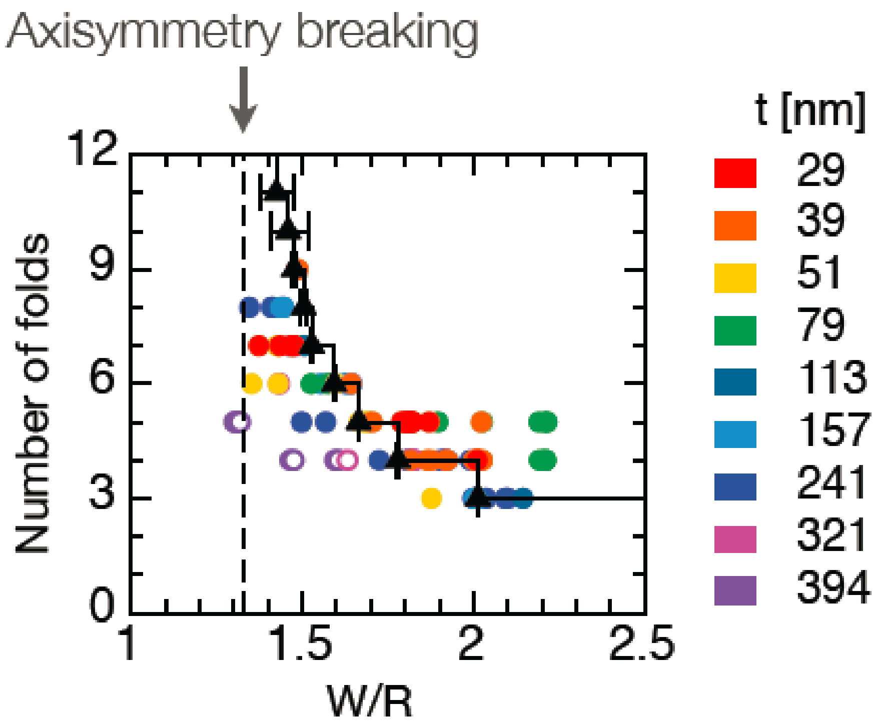
Excess material hidden in fold



Construction predicts non-axisymmetric shapes

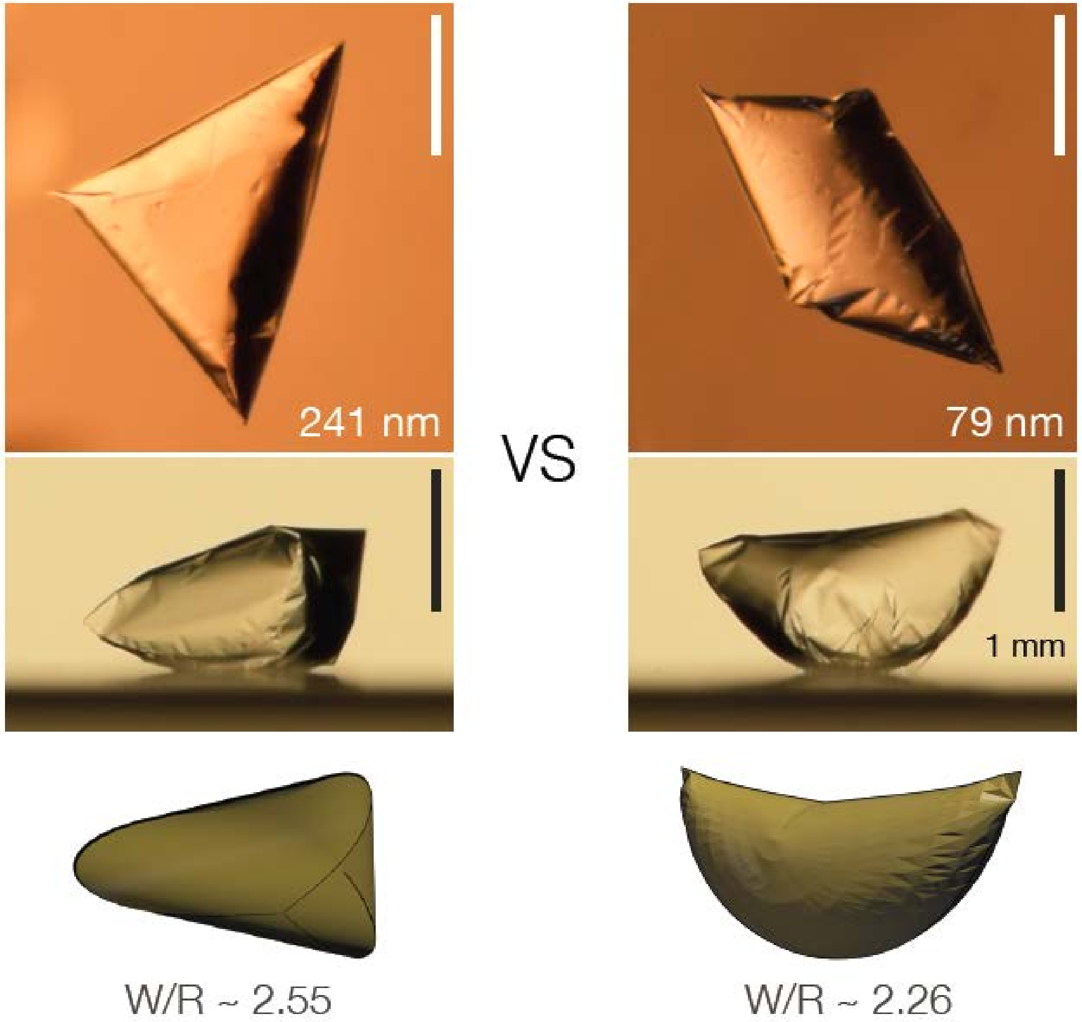
Experiment (t = 241 nm)



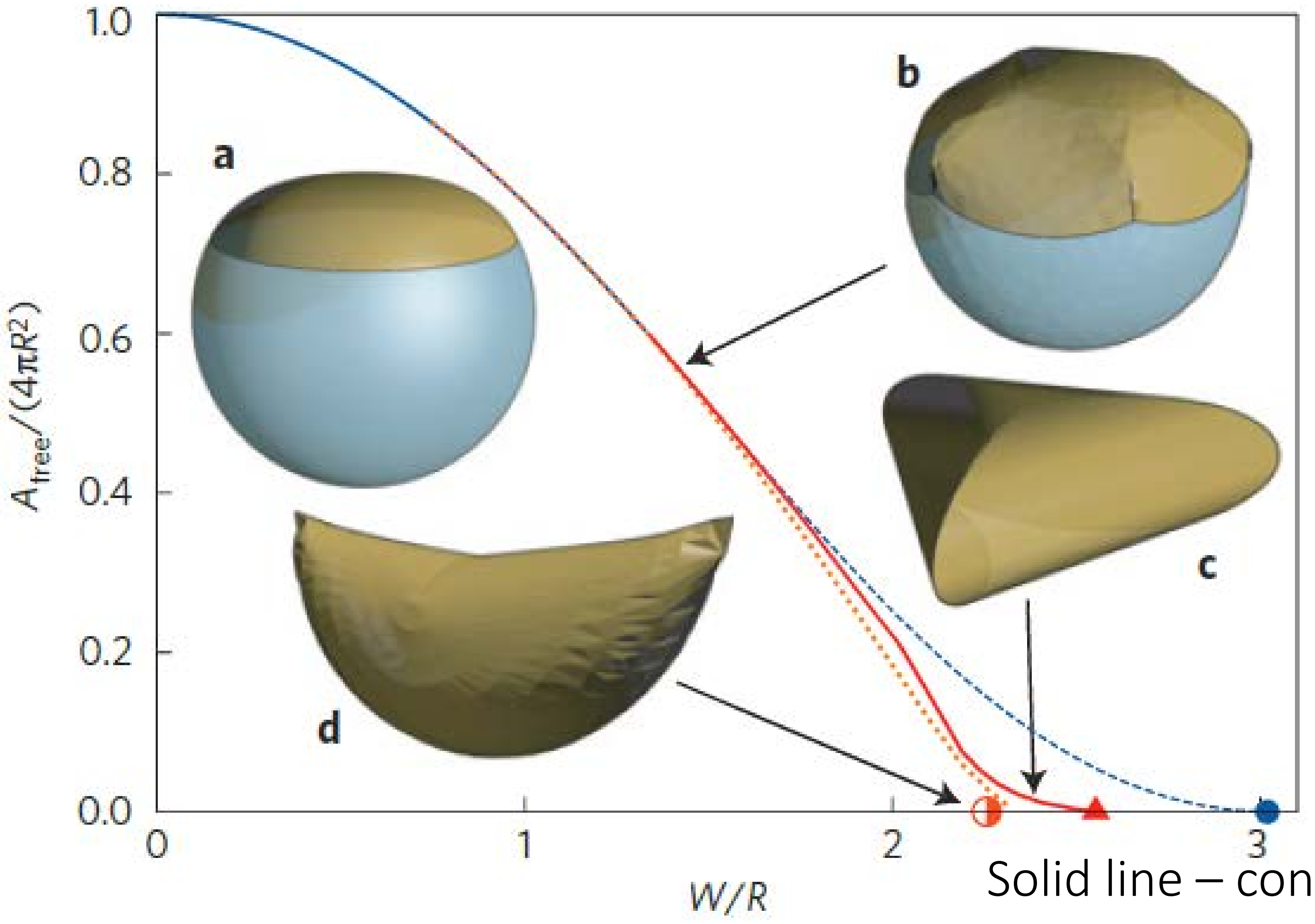


Predicts which polygonal shape is best

Anticipates 2-fold shapes

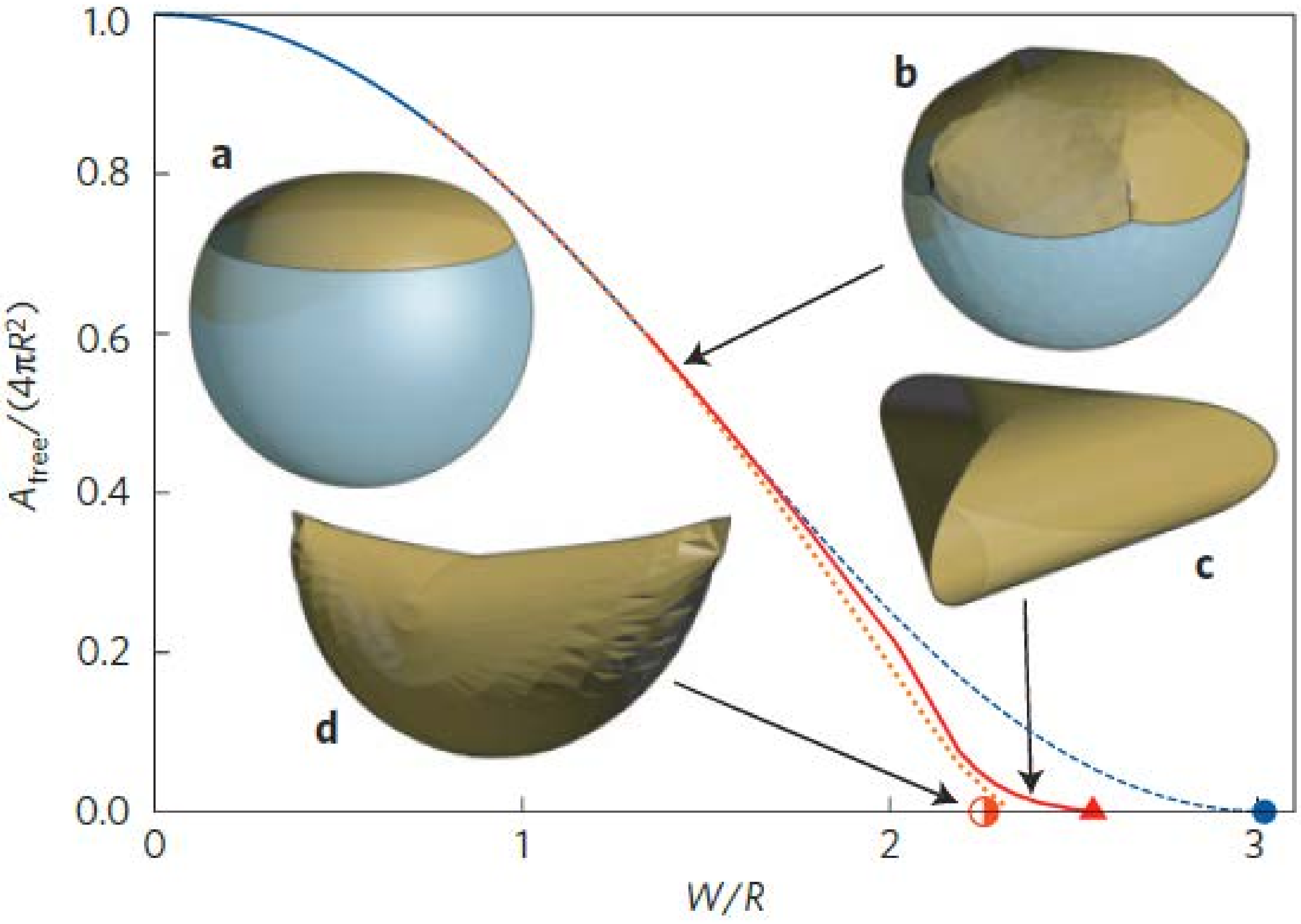


Samosa less efficient than empañada



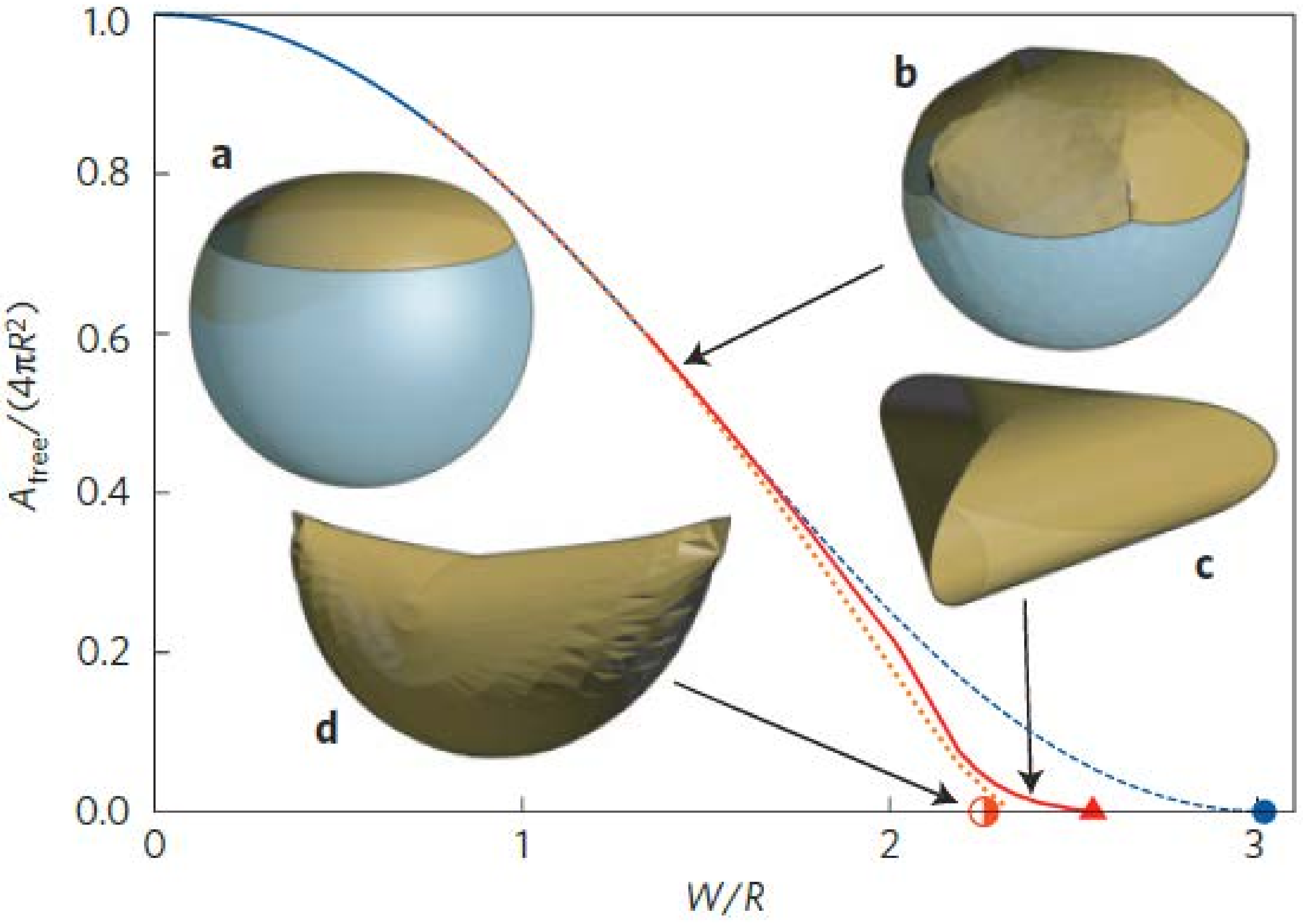
Solid line – construction
Dotted line - simulation

Open issues



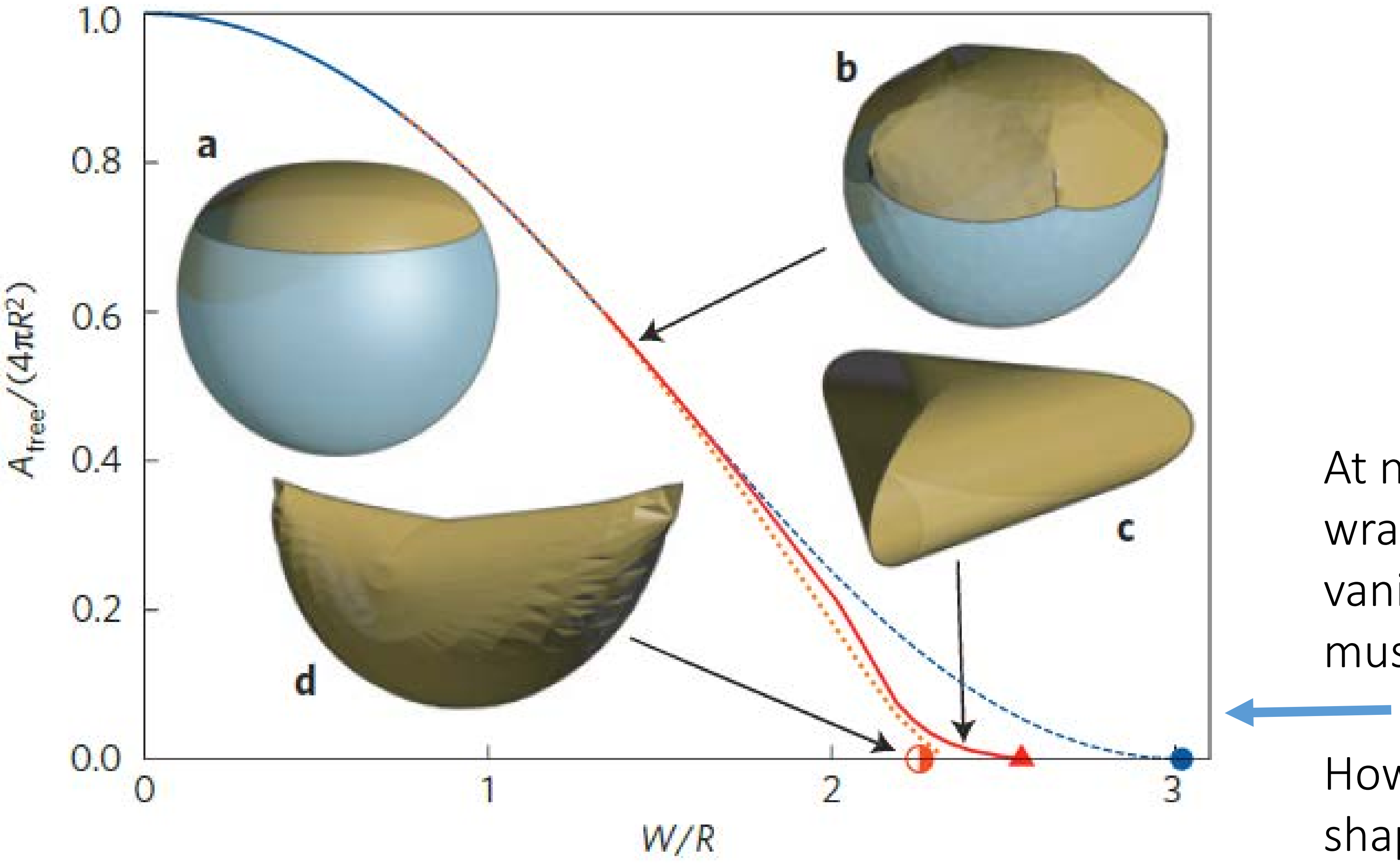
Don’t know the axisymmetry breaking threshold

Open issues



Don’t know whether folds first occur at finite W/R

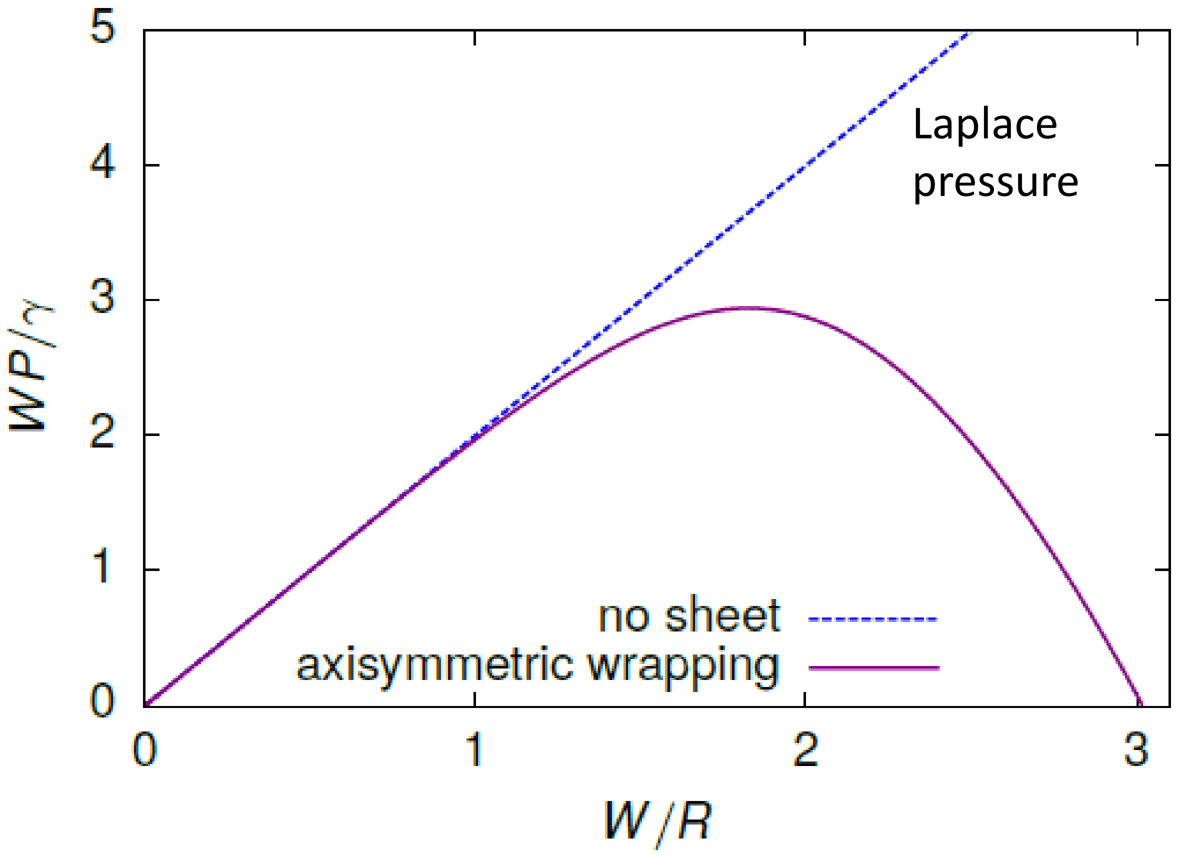
Open issues



At near complete wrapping, surface energy vanishes, so mechanics must re-emerge.

How does this affect shape selection?

Properties near full-wrapping



Pressure peaks and then vanishes as you approach complete wrapping

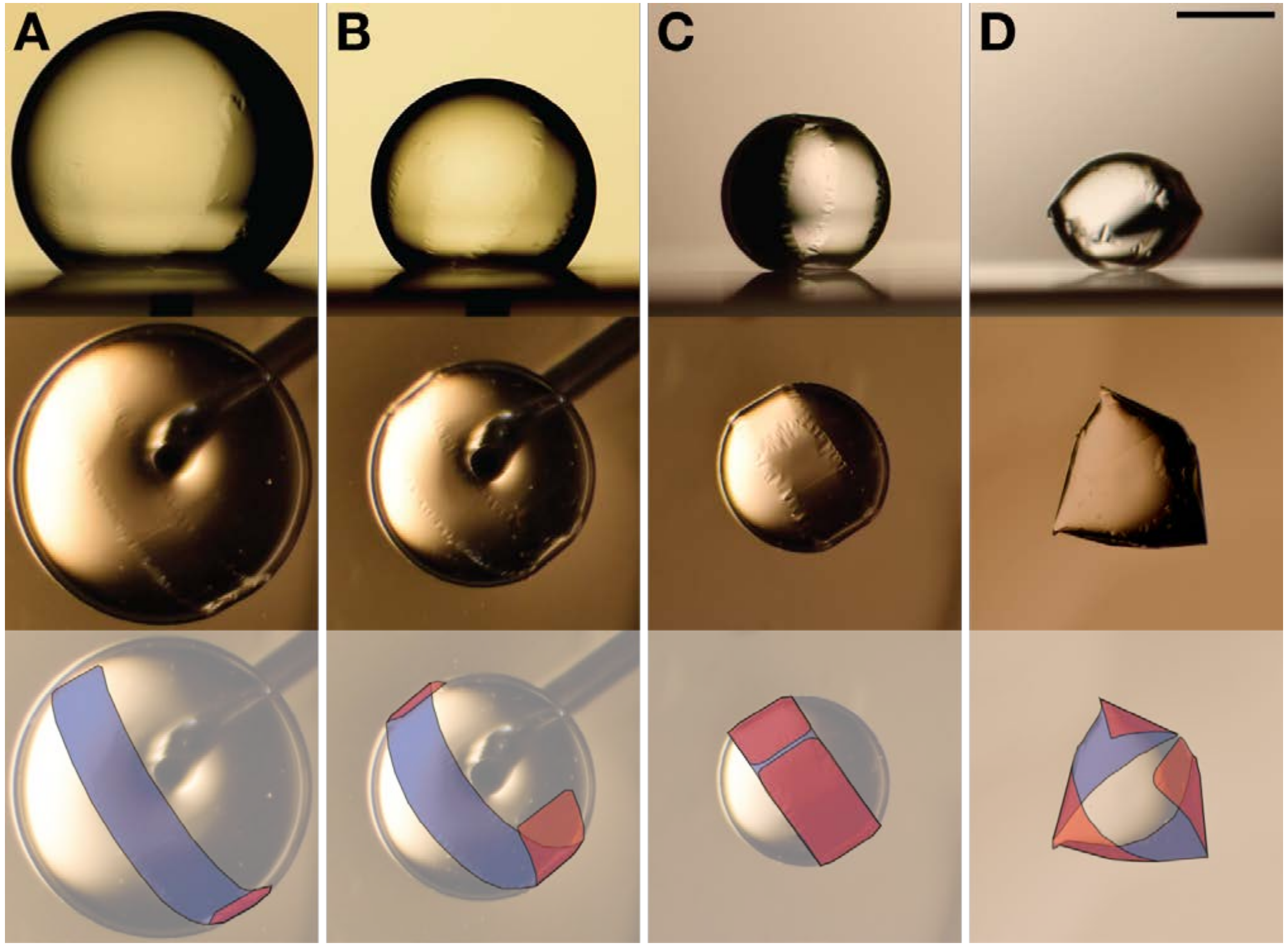
Implications

- A ‘thin’ sheet spontaneously achieves the highest wrapping efficiency
  - No need for careful design
  - Wrinkles, crumples, folds provide many pathways for compression
- Doesn’t rely on material parameters
  - Robust platform on which you can overlay functionality
- A new optimization problem
  - Maximal (incomplete) coverage of a fixed volume

For a given starting shape, what's the best wrapping possible?

For a fixed area, what the best starting shape?

Wrapping with a strip



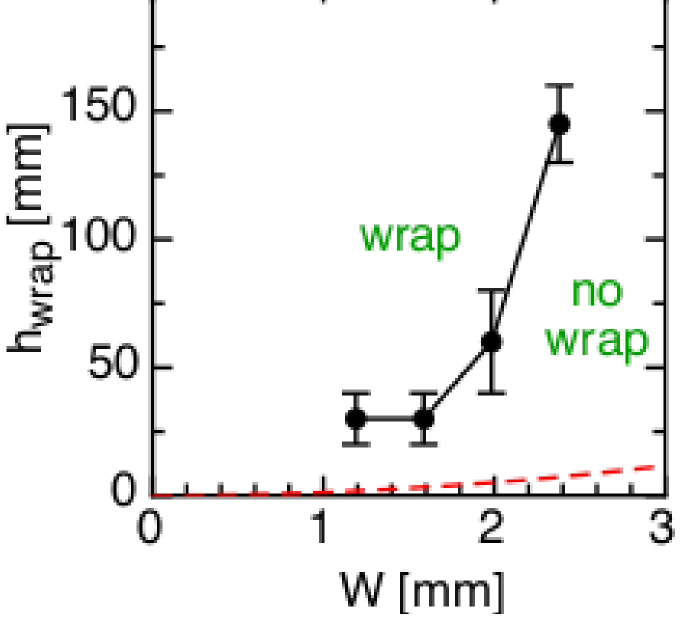
Wrapping with a splash

Fluorinert drop into water

Deepak Kumar, Joey Paulsen

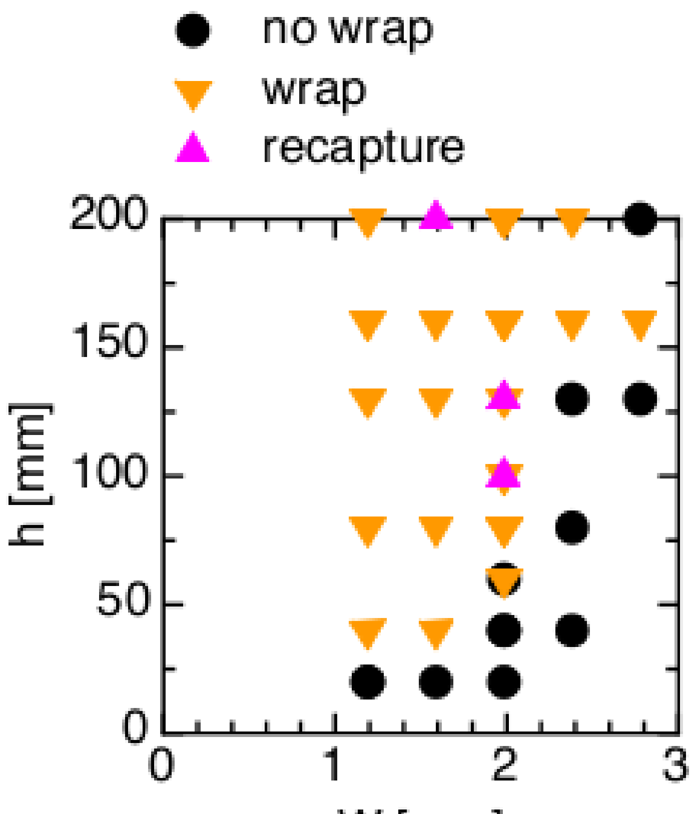
Impact wrapping

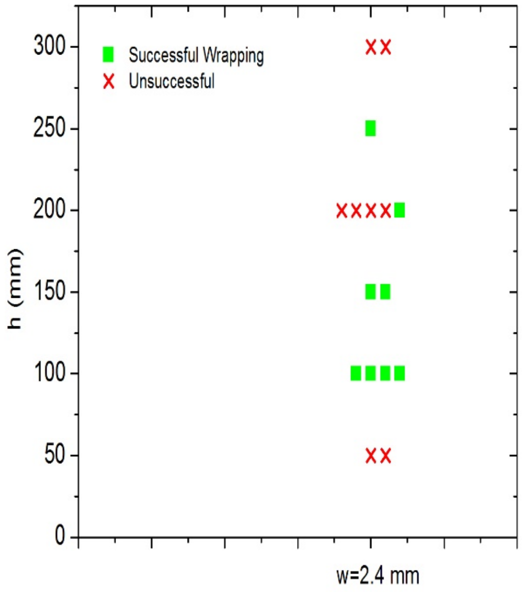
Where does energy go?



Orange line:
$\frac{1}{2} mv^2$ = surface energy gain

Sensitivity to initial velocity?





Wrapping with a splash - recapture

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