Coexisting fluid phases in model membranes and biological membranes

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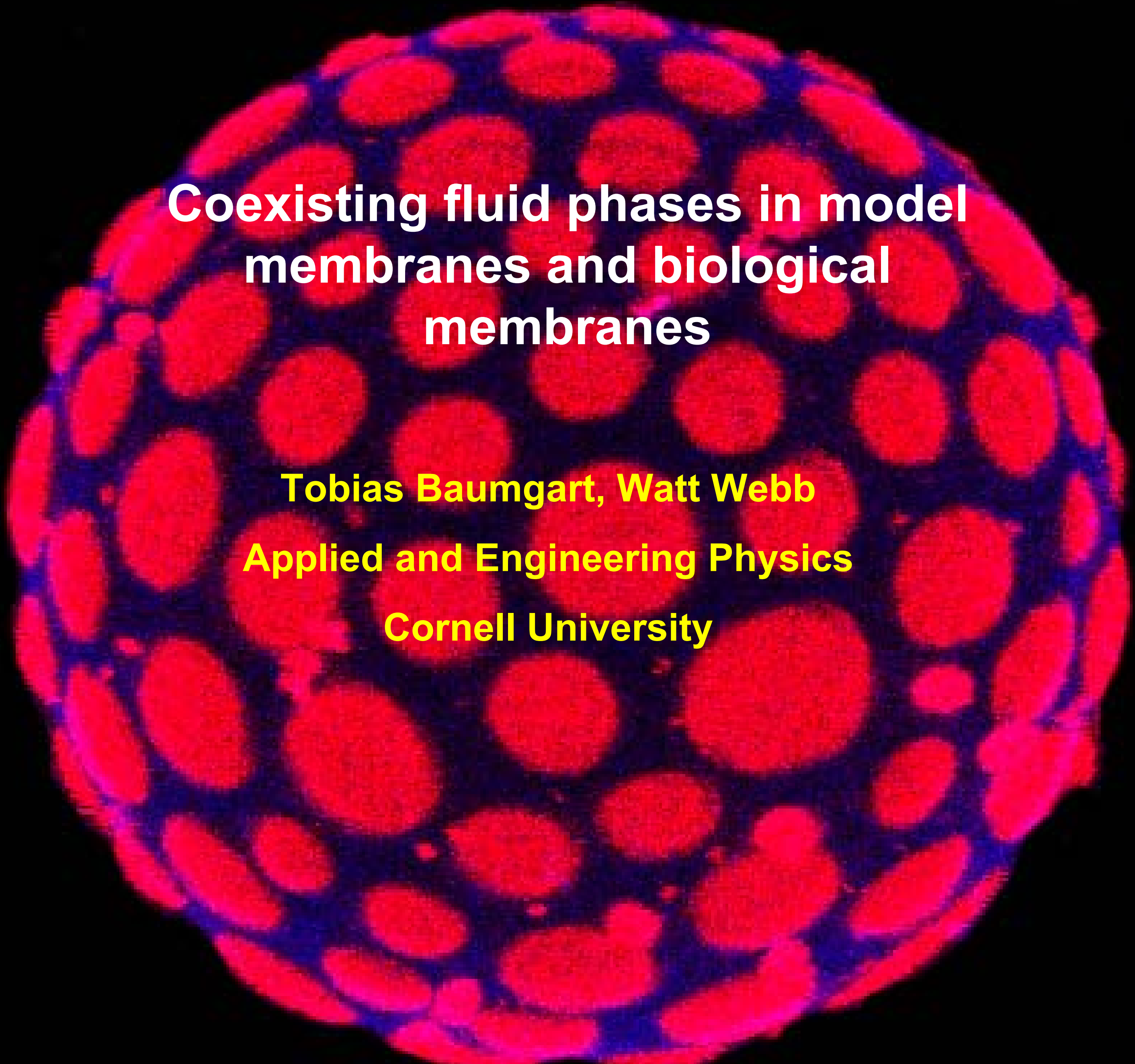
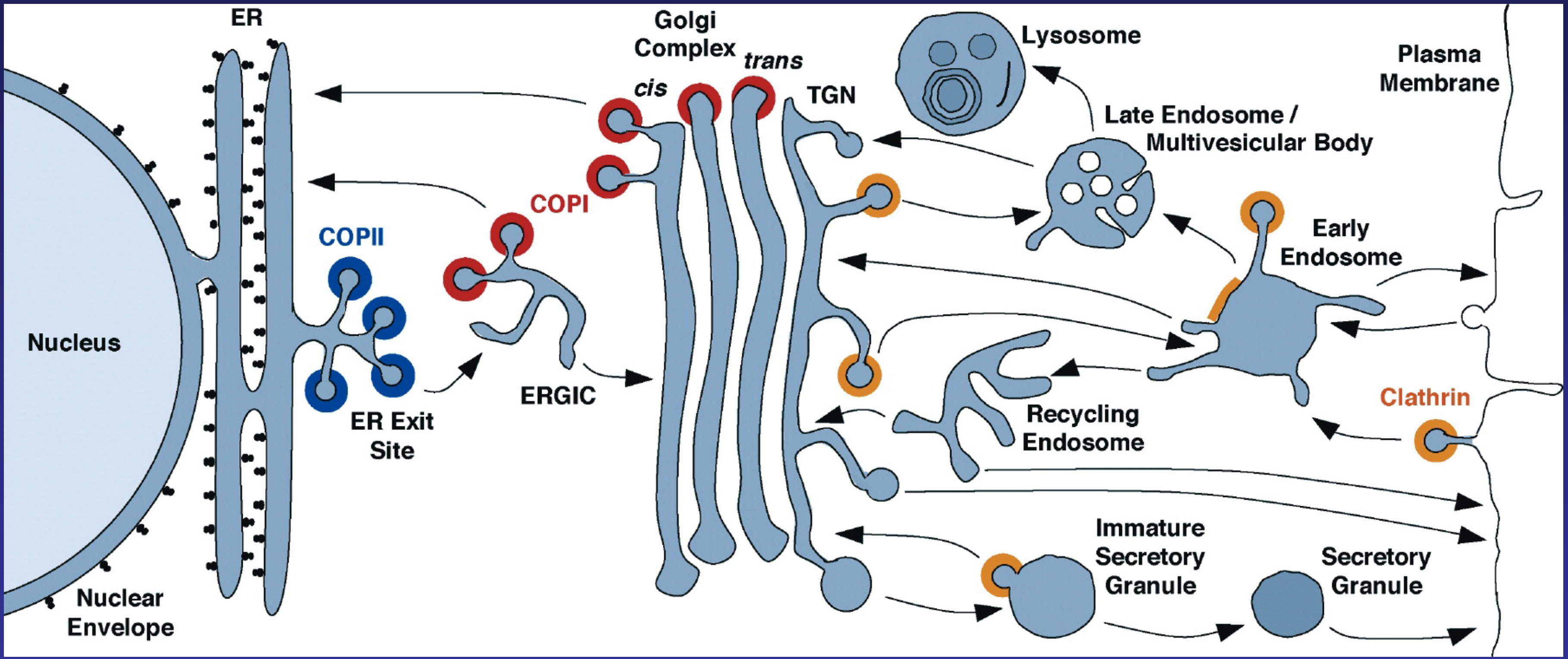


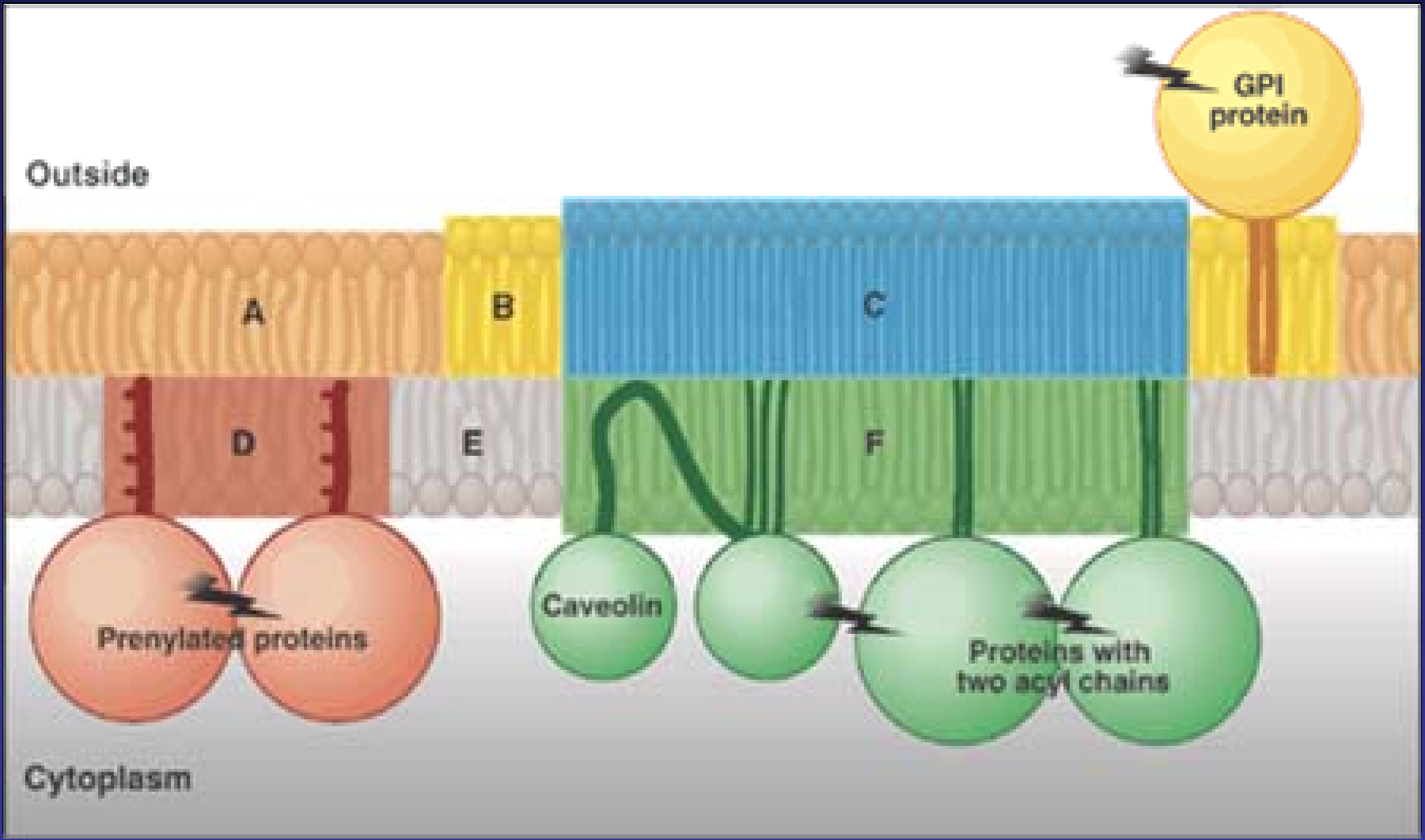
Baumgart et al. 2003, *Nature* 425, 821

Curvature of cell membranes



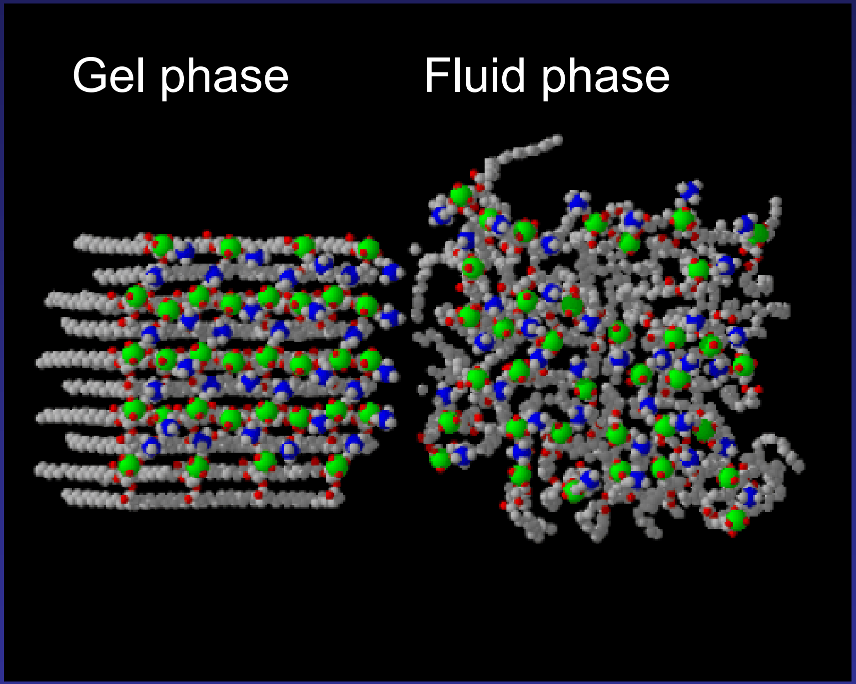
Bonifacino et al., Cell 116, 153

The “raft” hypothesis



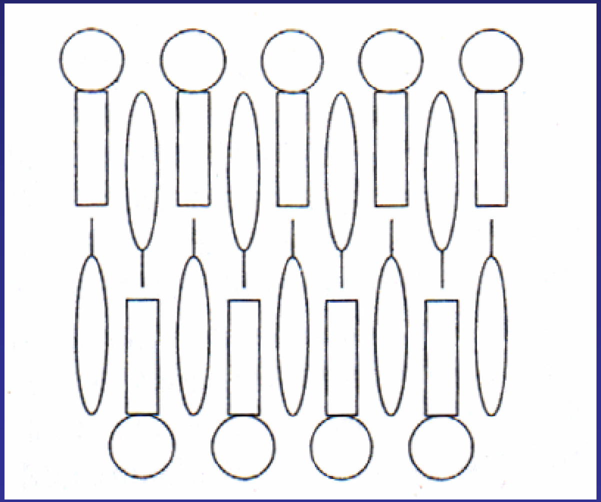
van Meer, G. (2002). Science **296**(5569): 855-+.

Lipid phase behavior

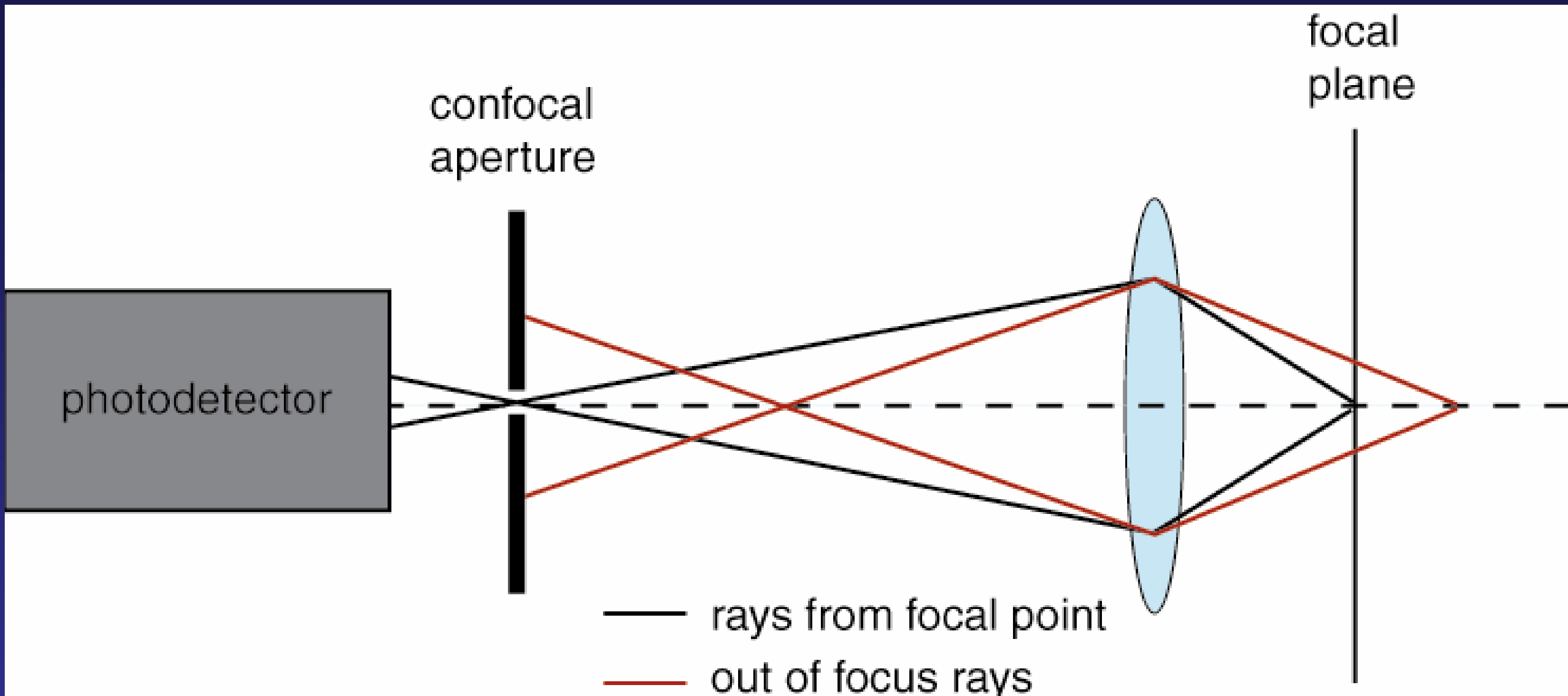


http://persweb.wabash.edu/facstaff/fellers/image.html

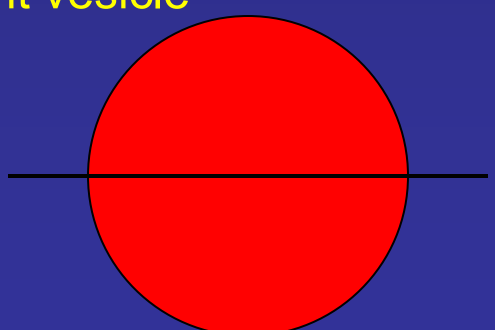
Liquid ordered phase



Confocal fluorescence microscopy

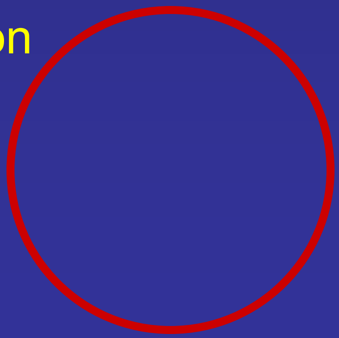


Giant vesicle

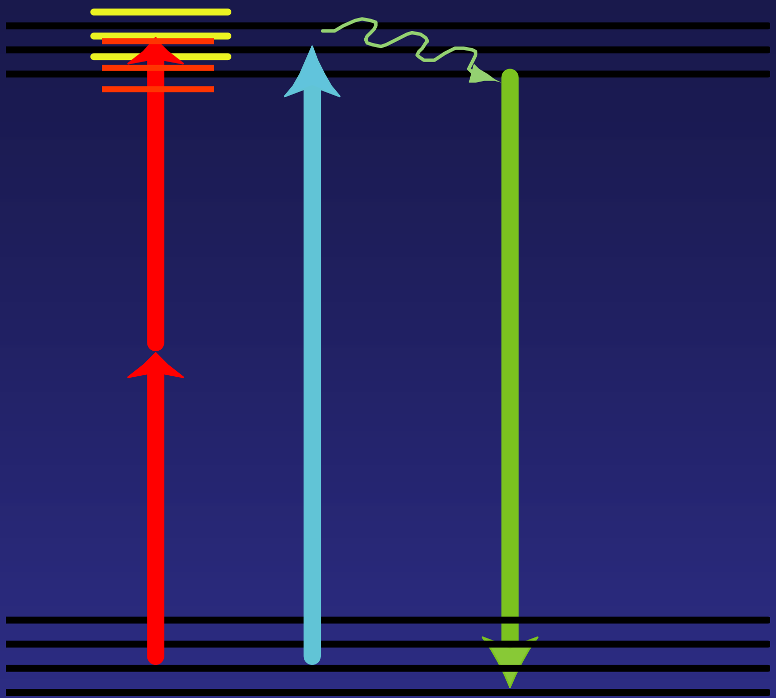


focal plane

Confocal section

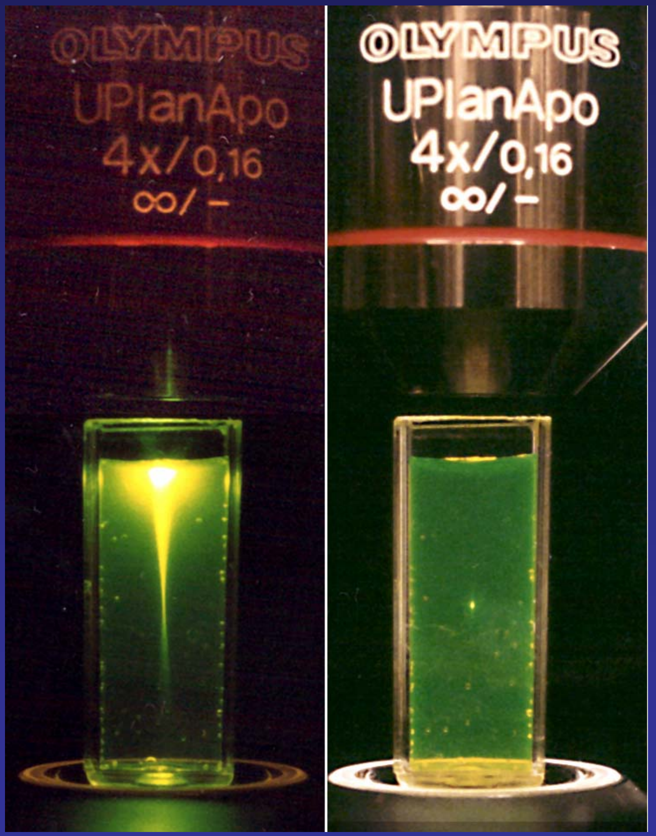


Two photon excited fluorescence microscopy



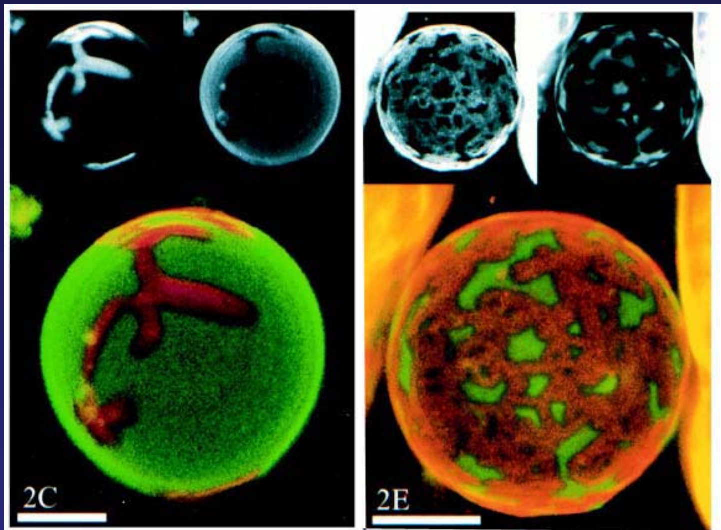
Two photons can interact simultaneously with a molecule adding their energies to produce an excitation equal to the sum of their individual energies.

i.e. 2 red photons = 1 blue photon



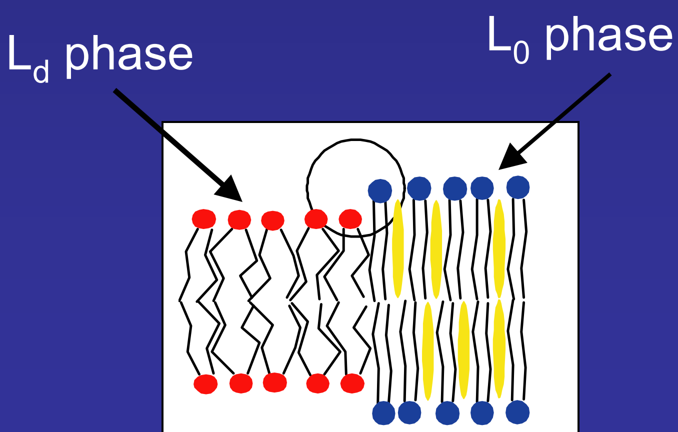
Domain shape: line tension

Gel / fluid phase coexistence

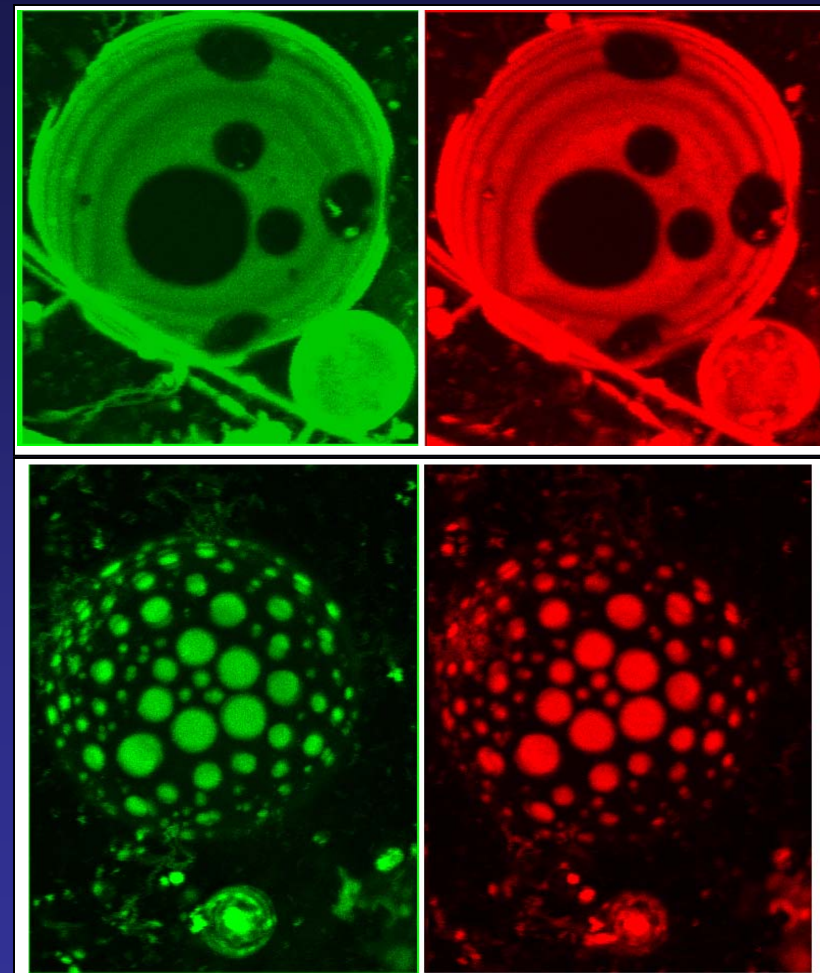


gel and L_d domains with <u>excess</u> perimeter

Korlach J., et al. (1999). <u>PNAS</u> **96**: 8461 - 8466.

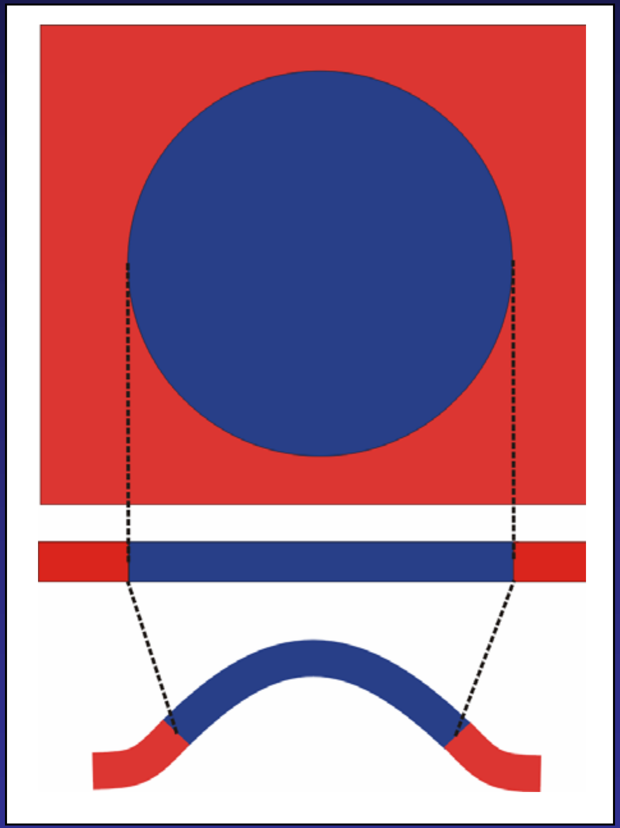


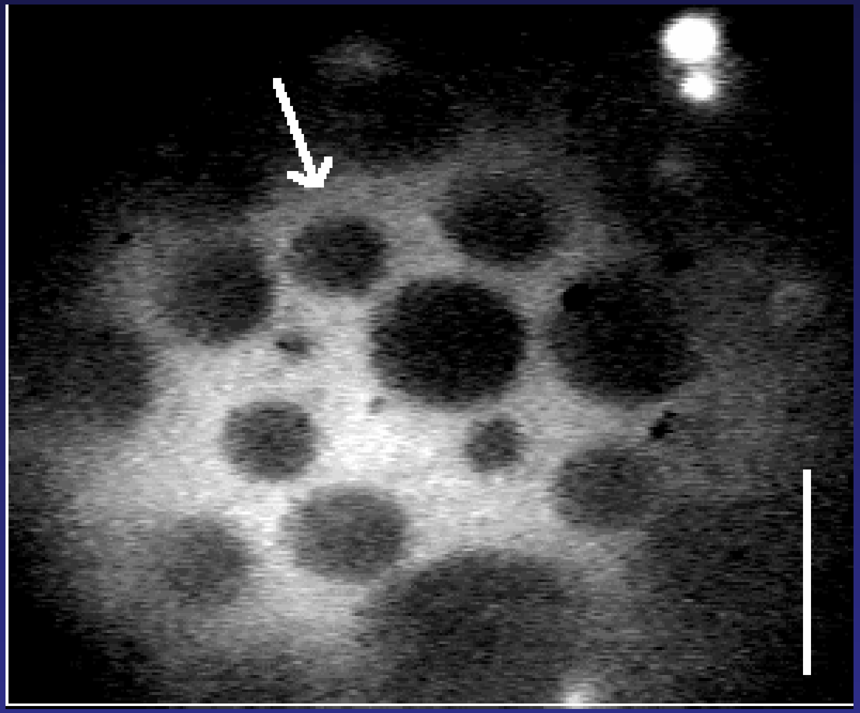
Fluid / fluid phase coexistence



L_o and L_d domains with <u>minimum</u> perimeter

Does line tension couple to curvature?



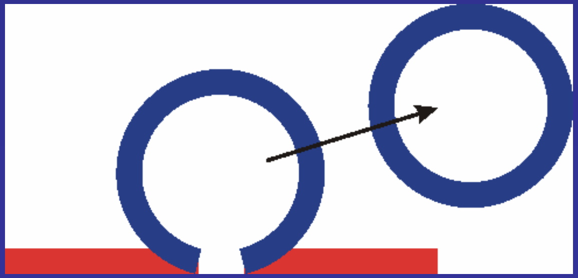


Top view of a vesicle (wide field fluorescence)

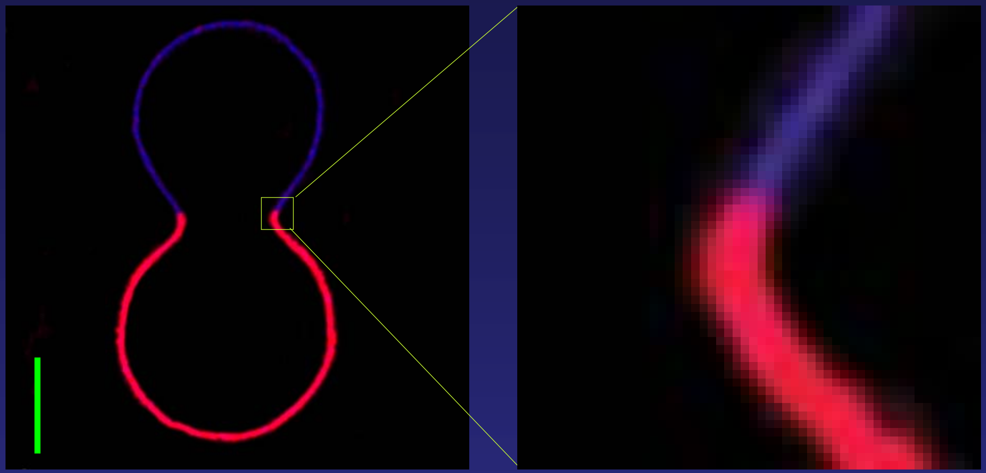
Label lights up only L_d phase

Out of plane domain curvature ➔

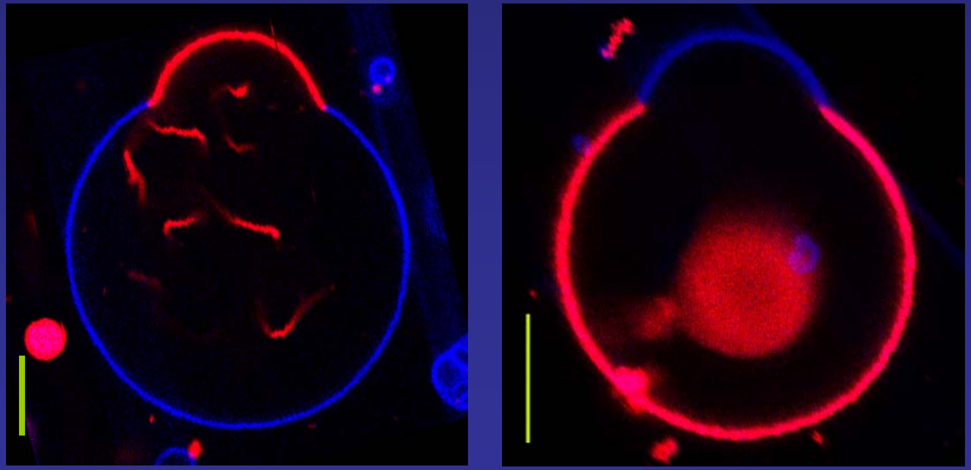
Reduction of Boundary Energy ⇔ Increase of Curvature Energy



GUVs with one domain and excess area



- global shape: truncated spheres (constant curvature within a domain)
- high, but finite meridional curvature in the saddle shaped neck region (no kink!)
- phase boundary not at minimum neck radius ➔ more curvature in the L_d phase



global shape not changed by varying fraction of coexisting phases

⇒ neither different bending moduli nor spontaneous curvatures determine shape significantly

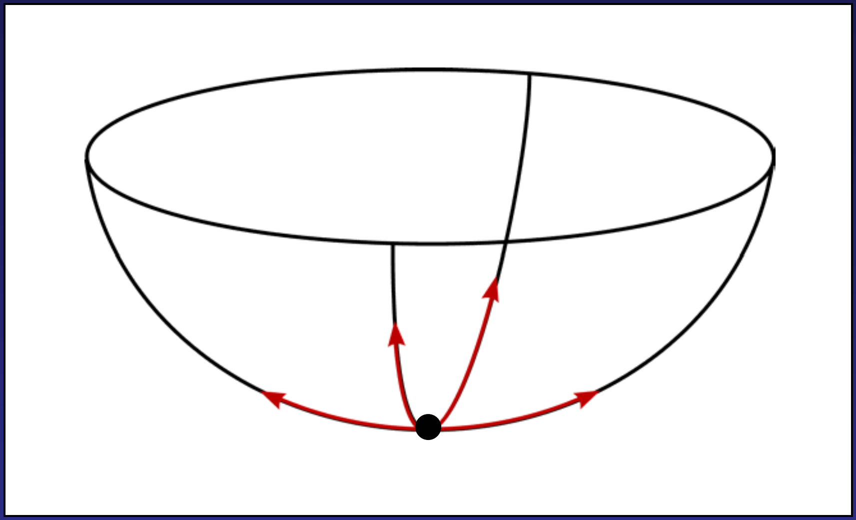
⇒ global shape results from line tension and constraints on domain areas and internal volume

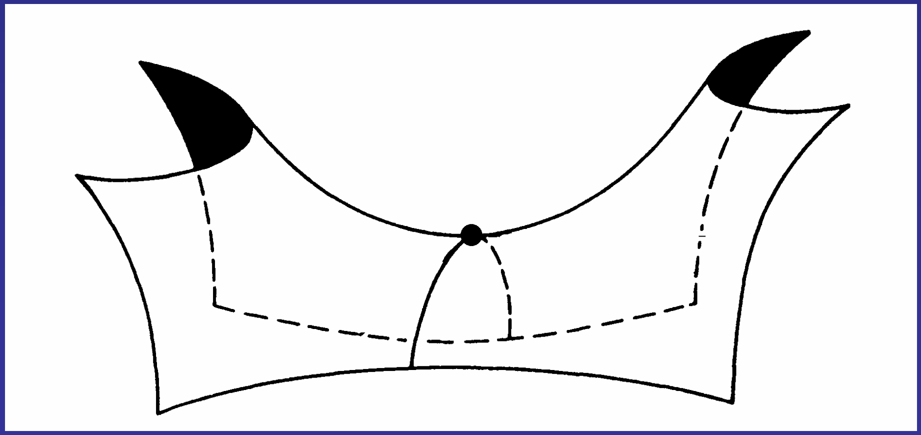
Curvature in a surface

mean curvature: $h = ½(C_1 + C_2)$

Gauss curvature: $k = C_1 * C_2$

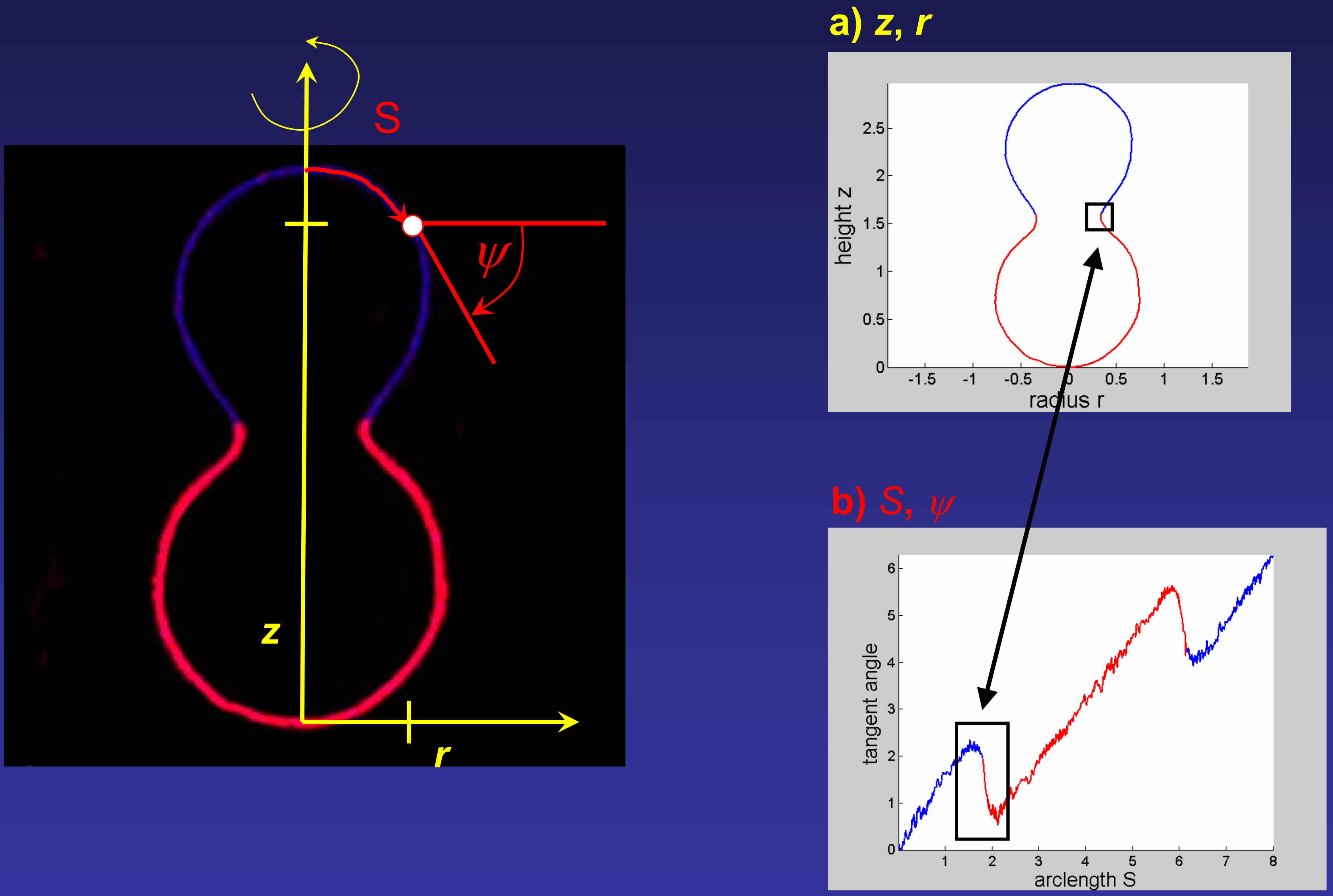
measured along lines in the surface



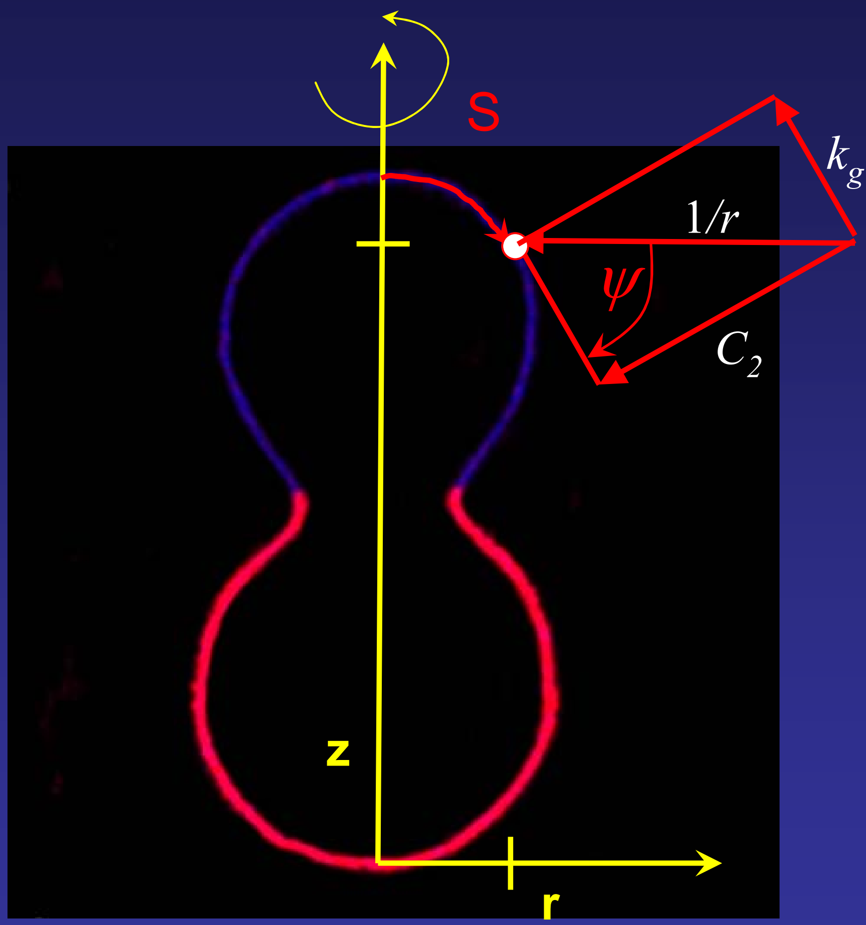


Saddle shapes with zero mean curvature: Gaussian curvature

Parameterizations of experimental vesicles



Axially symmetric surfaces are convenient



Curvature along the meridian:
$C_1 = d\psi / dS$

Curvature along the parallels:
$1/r$

$C_2 = 1/r * \sin\psi$

Geodesic curvature:
$k_g = 1/r * \cos\psi$

Bending energies

$$F_b = 2\kappa \int h^2 dA + \kappa_G \int k dA$$

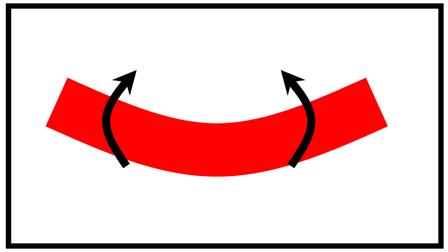
Total bending energy is a sum of bending energy of every point in the surface.

Bending energies arise from:

a) resistance towards mean curvature

b) resistance towards Gauss bending

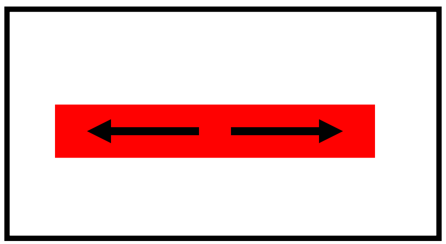
membrane curvature elasticity theory



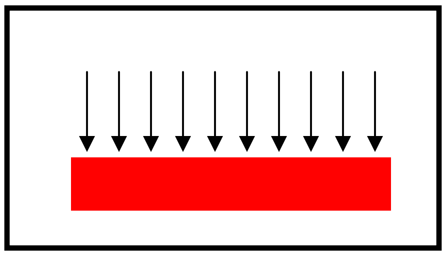
Bending moment: *M*

A) mean curvature

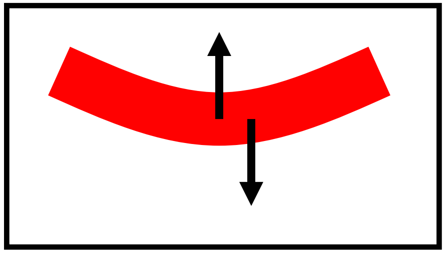
B) Gauss curvature



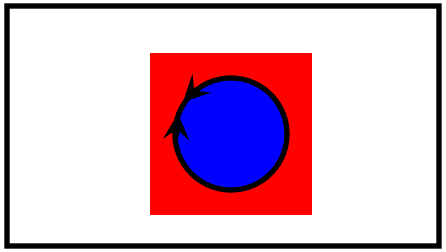
Lateral tension: *T*



Normal pressure difference: *p*



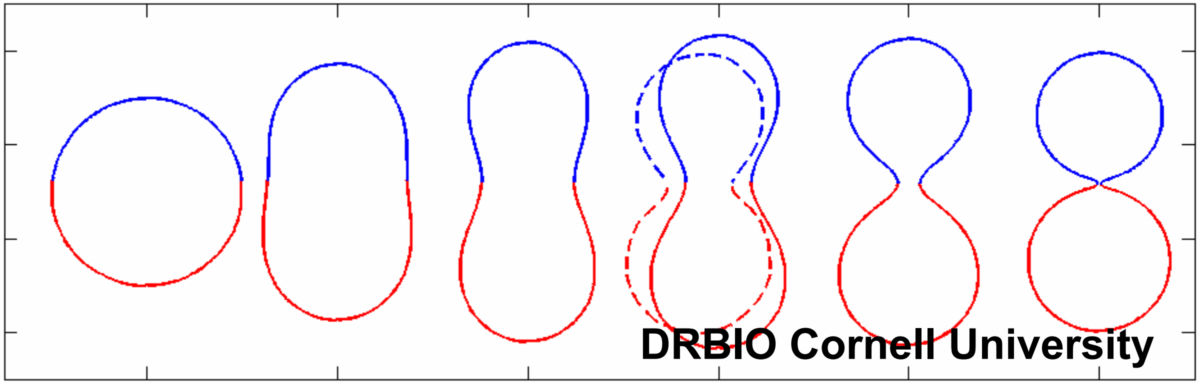
Transverse shear: *Q*



Line tension around domains: *σ*

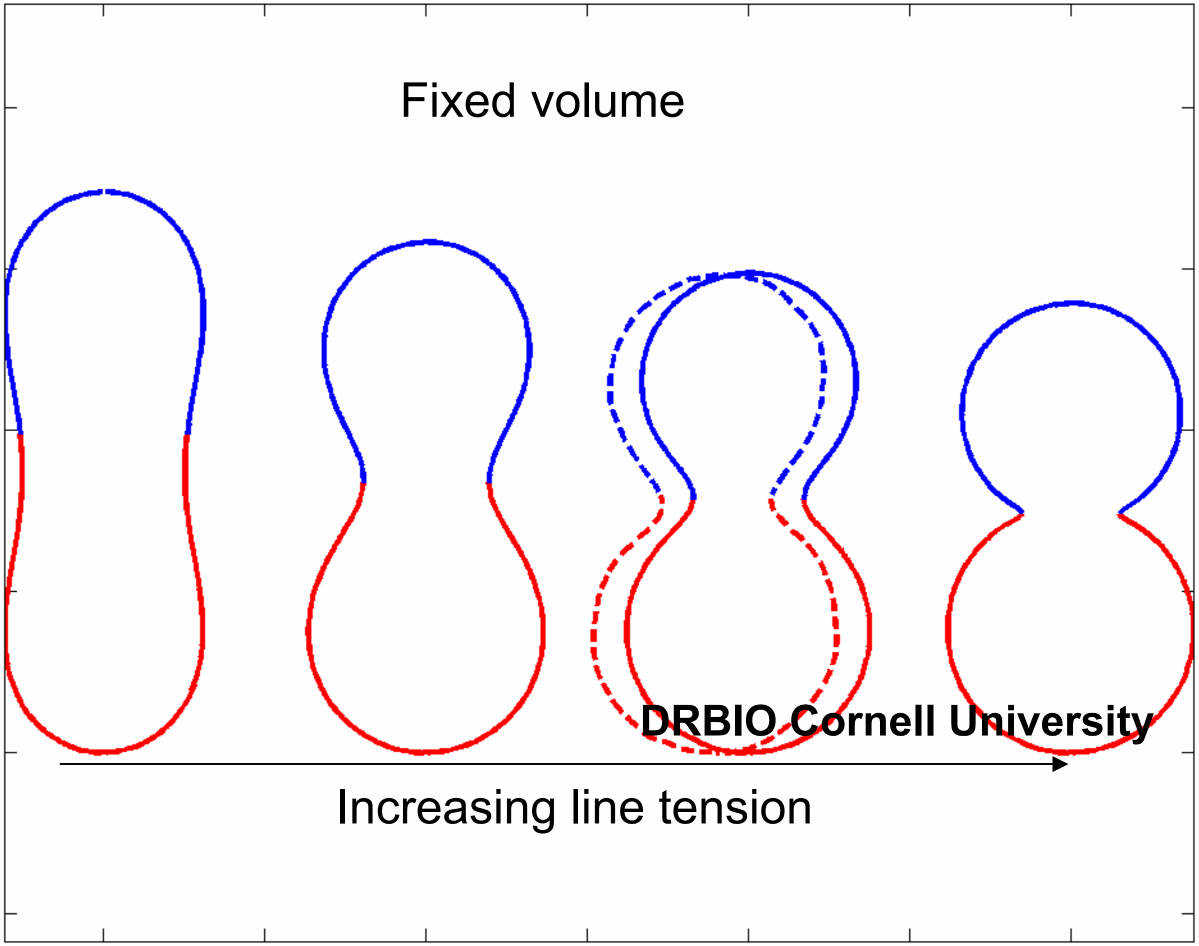
Phase separated membranes with equal bending elasticities

Freely adjustable volume: $p = 0$

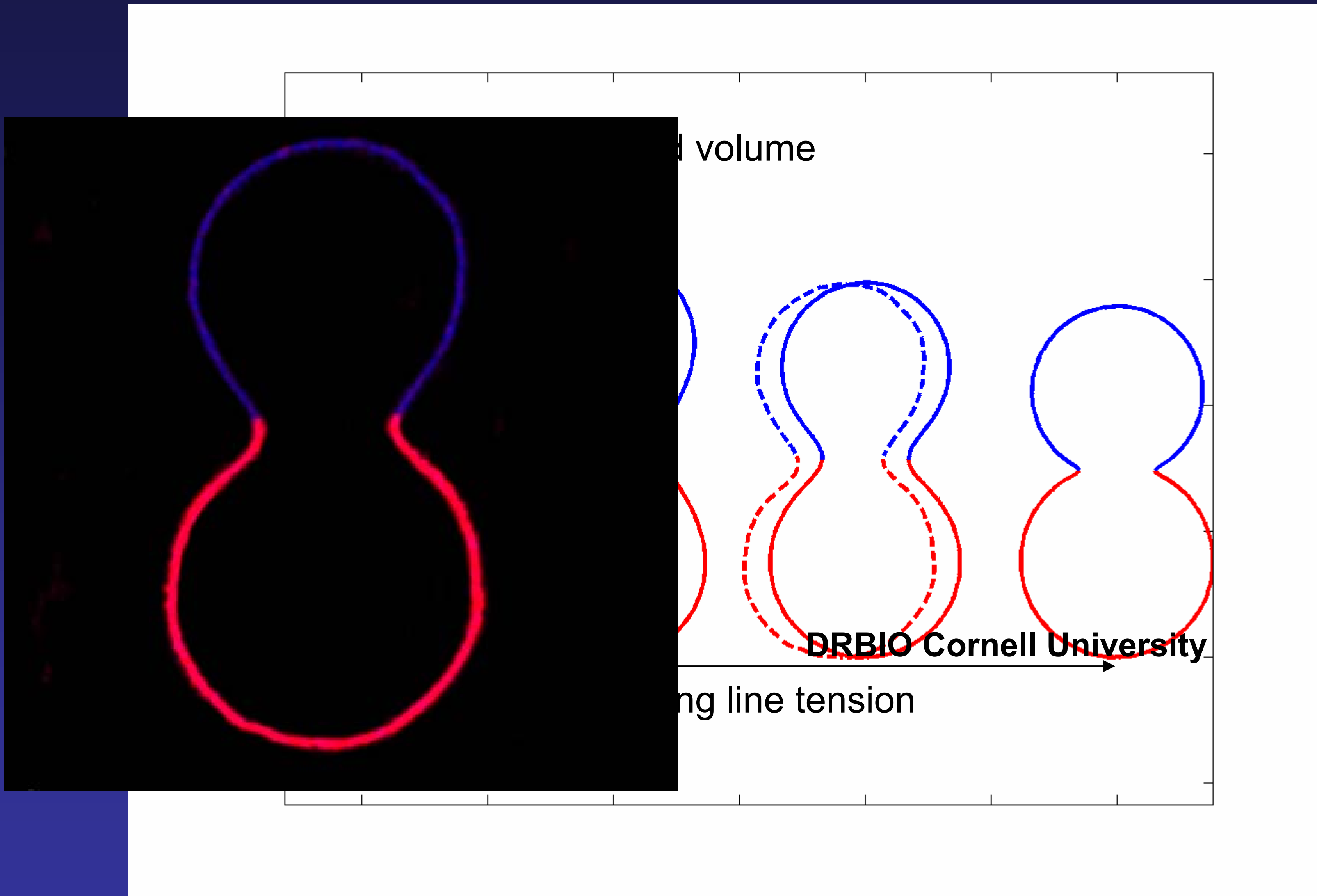


Increasing line tension

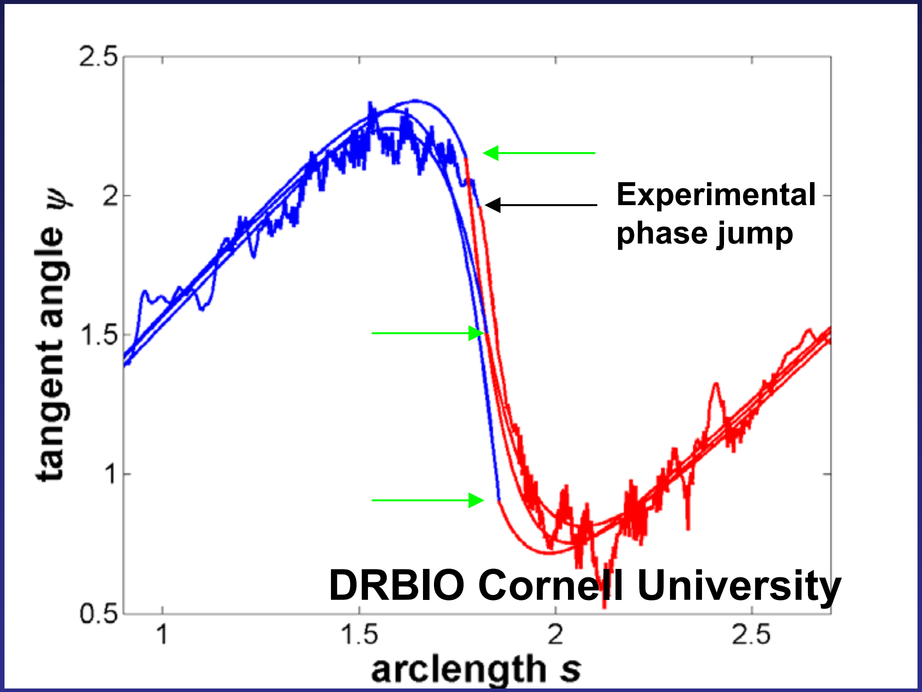
Phase separated membranes with equal bending elasticities

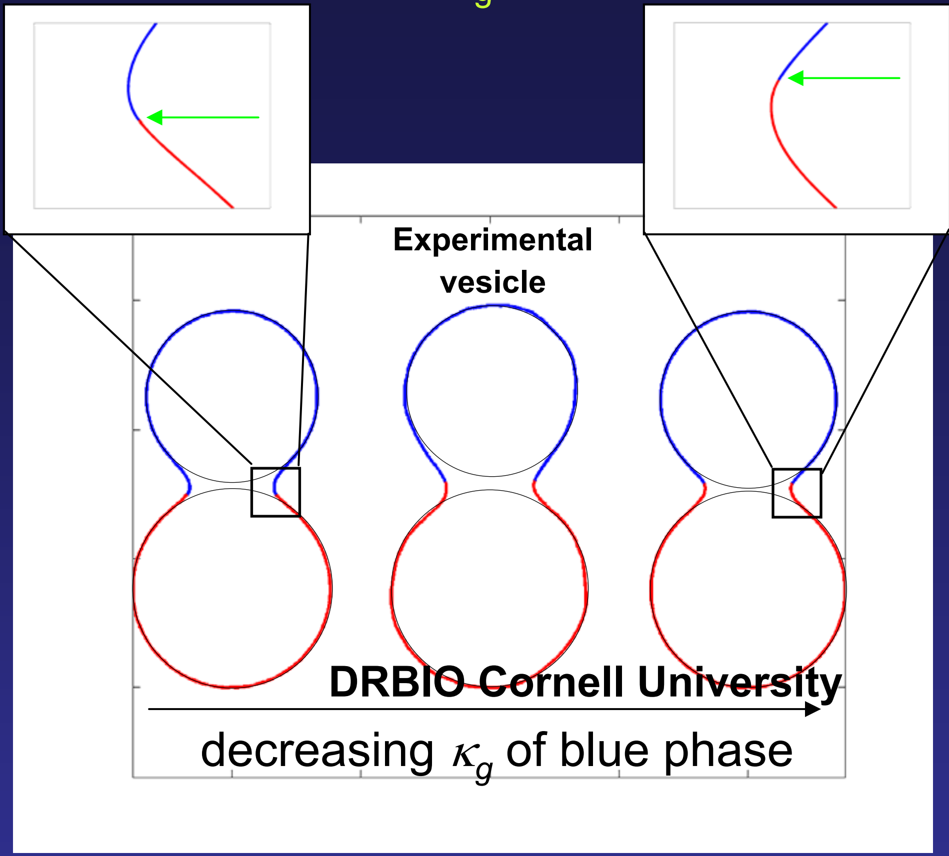


Phase separated membranes with equal bending elasticities



Phase separated membranes with differing κ_g

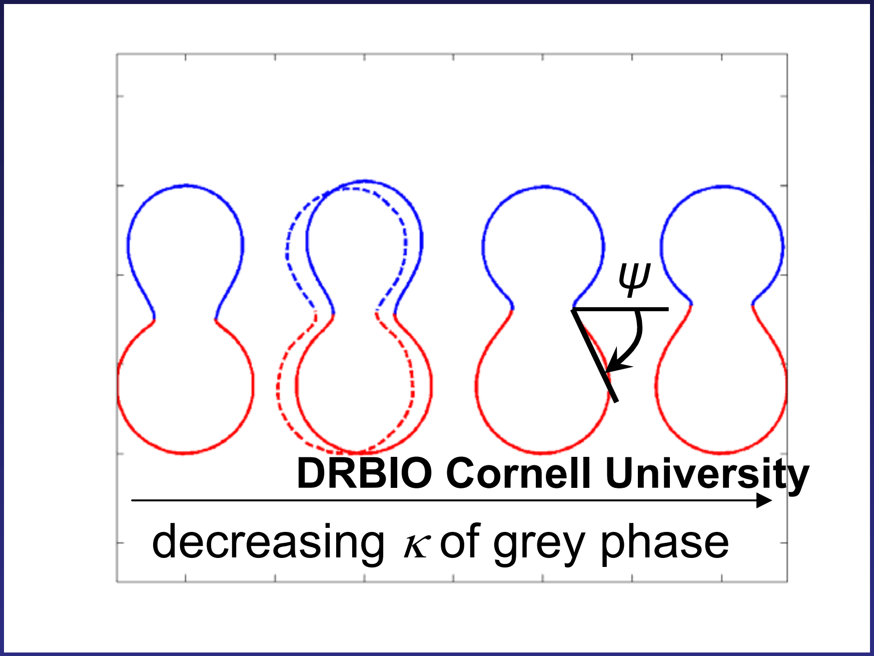


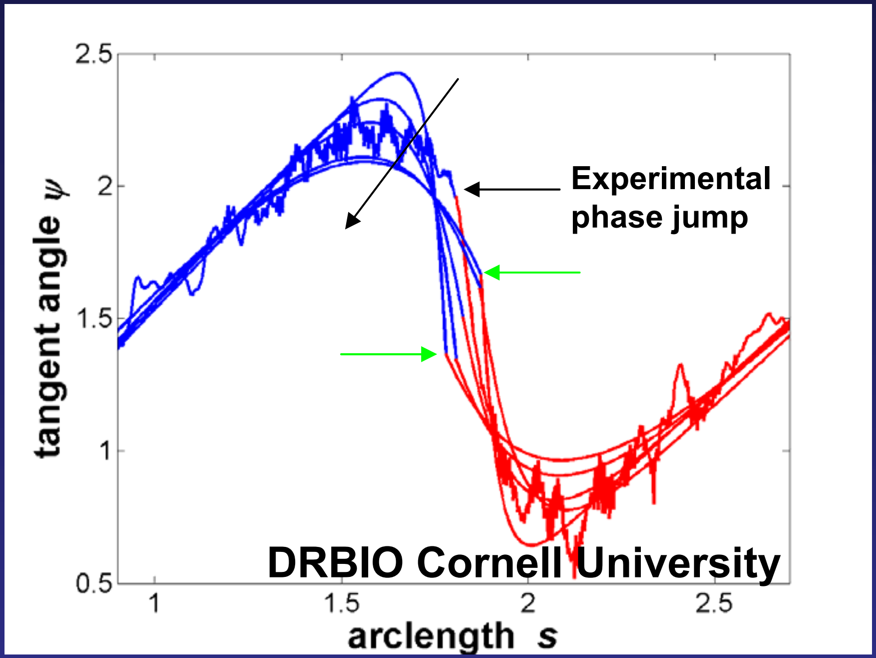


Differing κ_g: - deformes primarily the neck region: a “boundary effect”

- relatively small influence on bulk geometry

Phase separated membranes with differing κ

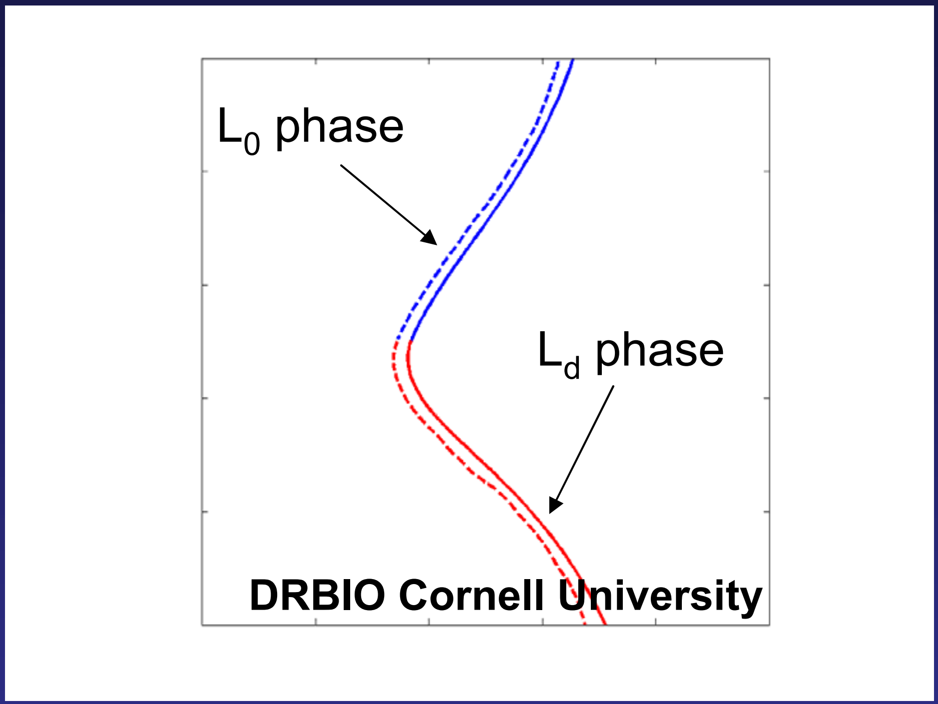


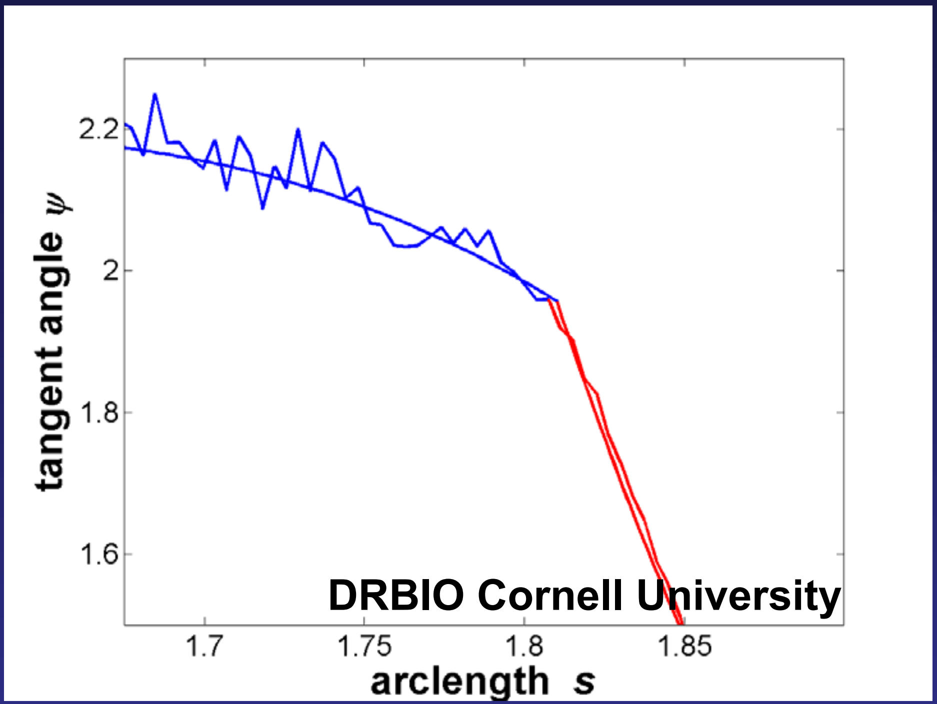


Differing κ:

- droplet shape versus spherical shape: a "bulk effect"
- relatively small influence on the neck geometry

Best fit results



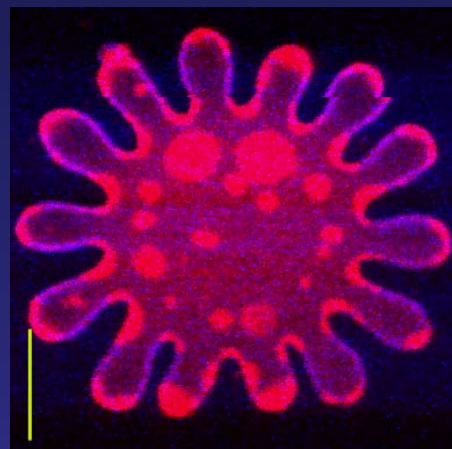


$$\frac{\kappa^{L_o}}{\kappa^{L_d}} \approx 5 \qquad \left(\kappa_g^{L_d} - \kappa_g^{L_o}\right) / \kappa^{L_d} \approx 3.6$$

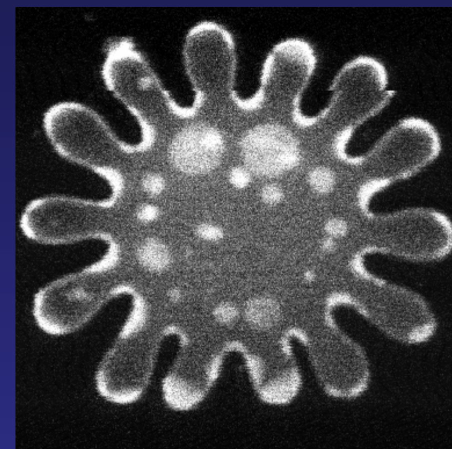
high temperatures: less line tension; starfish and pearls

Cooling of homogenous “Starfish” vesicles and “Strings of Pearls” into the coexistence region:

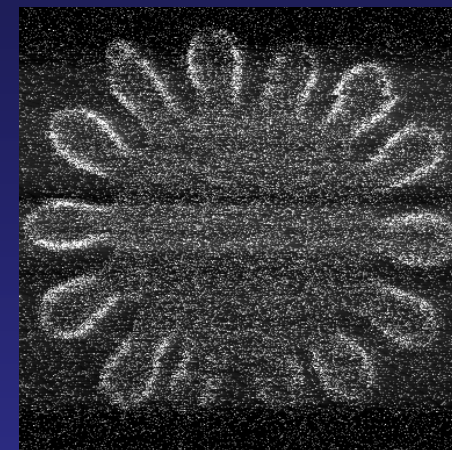
merged



red channel

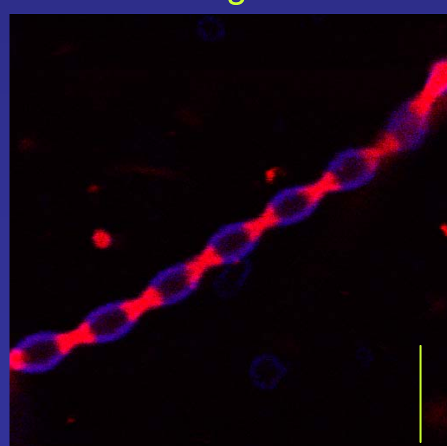


blue channel

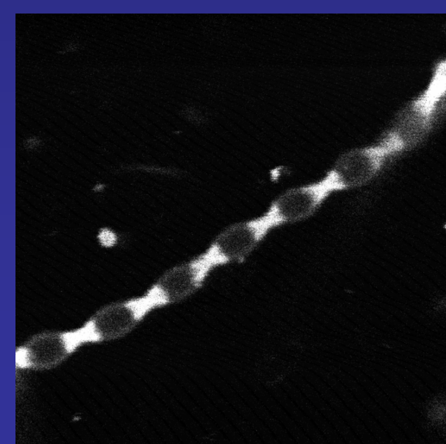


L_d phase domains prefer regions with high curvature

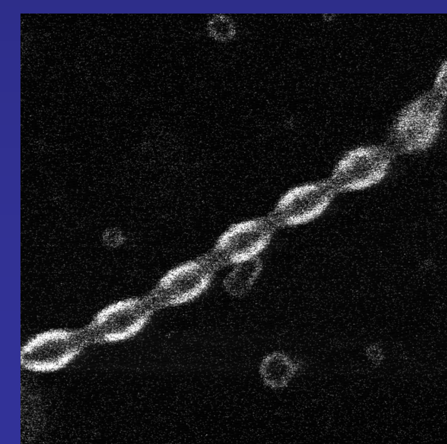
merged



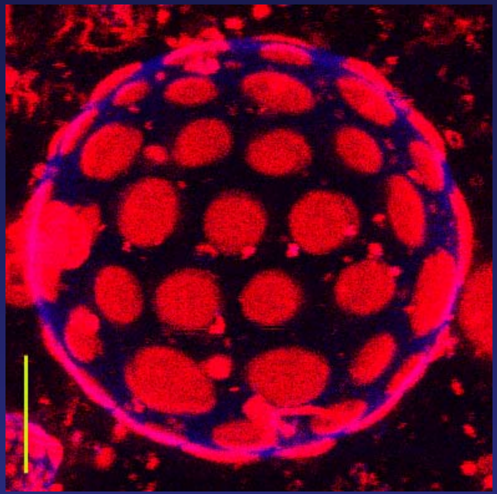
red channel

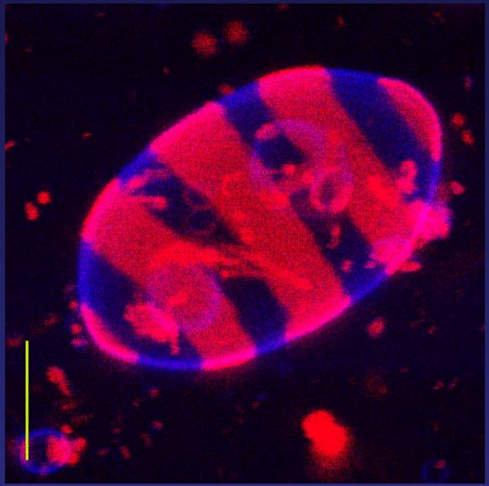


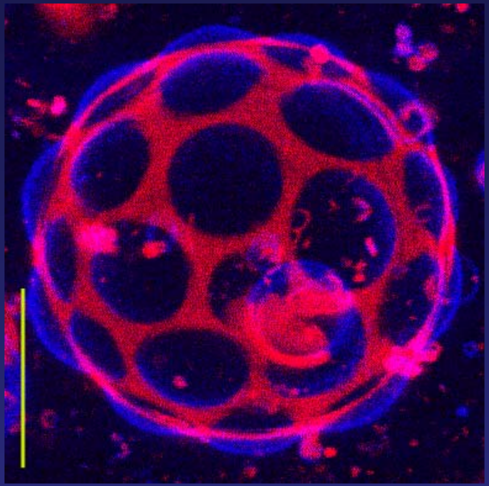
blue channel



stripe- and hexagonally modulated phases







"Every day, nature surprises us with structures and patterns of such beauty as to fill the scientist with *wonder* and the artist with envy"

Silveira et al. *Science* (2003) 287, 1468

Acknowledgements

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Thank you for your attention!