Membrane Shape Transformation Induced by Banana-Shaped Proteins

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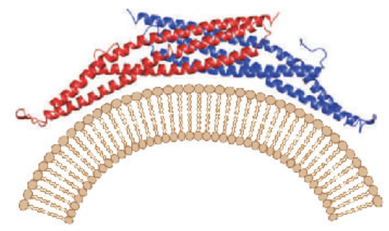
Shape deformations of biomembranes are controlled by various proteins. Many of these proteins contain a binding module known as the BAR (Bin-Amphiphysin-Rvs) domain, which consists of a banana-shaped dimer. We have revealed anisotropic spontaneous curvatures of banana-shaped domains induce assembly of the protein rods and change membrane shapes using implicit-solvent meshless membrane simulations. A small spontaneous curvature perpendicular to the rod stabilizes an percolated network structure and alters the tubulation dynamics.

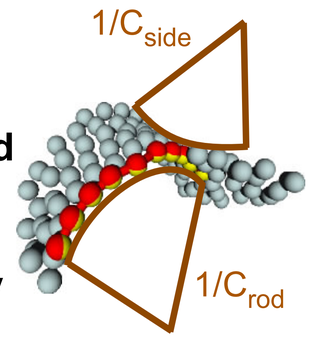
BAR domain



McMahon & Gallop, Nature 438, 590 (2005).

Membrane and Protein Models

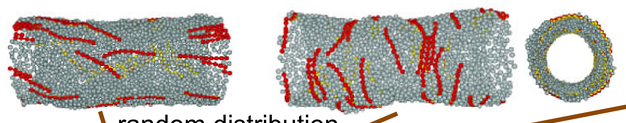
Membrane particles, which have orientational degrees of freedom, self-assemble to form one-layer membrane. A protein rod is modeled by a linear chain of membrane particles.
No direct attractive interactions are taken between the rods. The rods are assembled by membrane-mediated interactions.



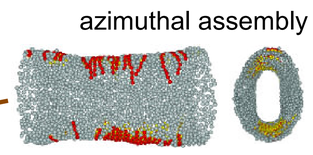
Self-Assembly of Protein Rods [1,2] (C_{side}= 0)

Membrane tube

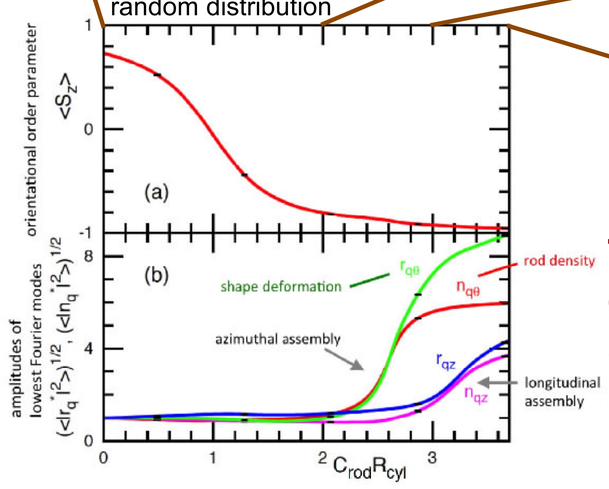
Low rod density ϕ_{rod} = 0.166

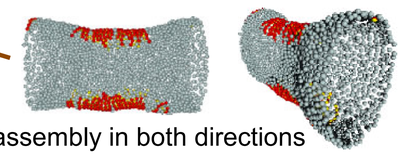


azimuthal assembly



random distribution

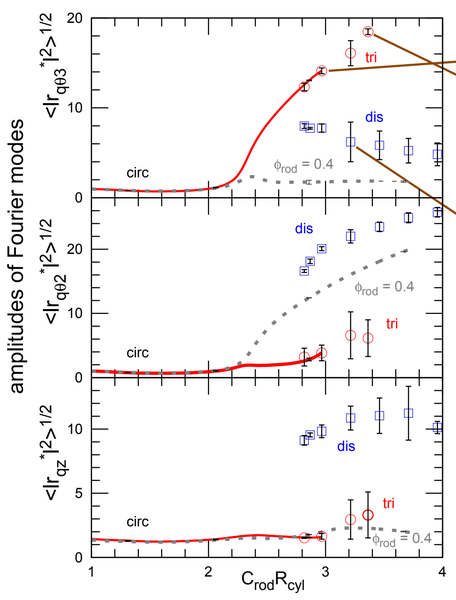


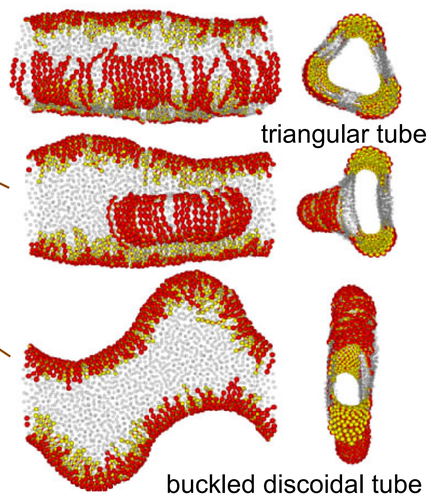


assembly in both directions

The rods assemble via two directional phase separations unlike a conventional 2D phase separation.

High rod density ϕ_{rod} = 0.5





triangular tube

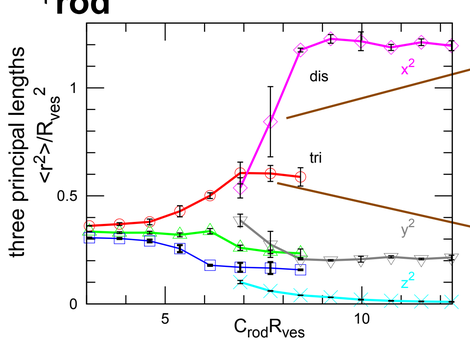
buckled discoidal tube

Triangular and buckled discoidal tubes are formed.

Vesicle

Polyhedral vesicles are formed.

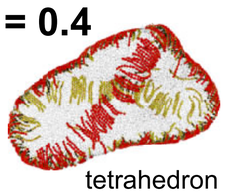
ϕ_{rod} = 0.3



elliptic disk

triangular hosohedron

ϕ_{rod} = 0.4

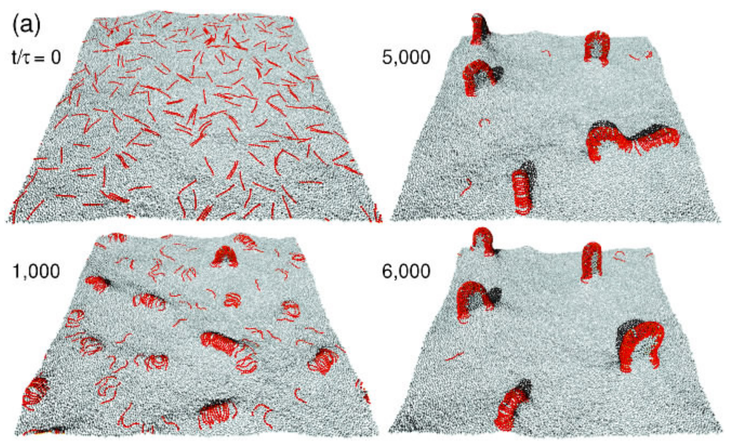


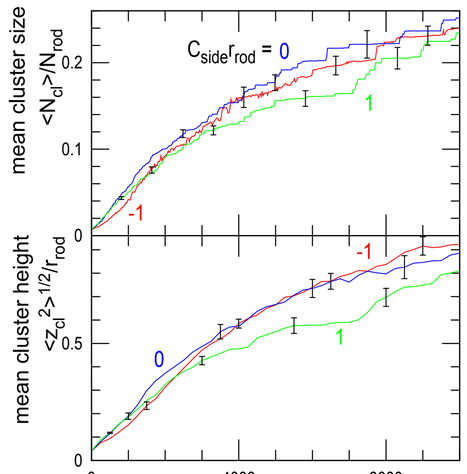
tetrahedron

triangular prism

Tubulation from Flat Membrane [3]

Low rod density ϕ_{rod} = 0.1

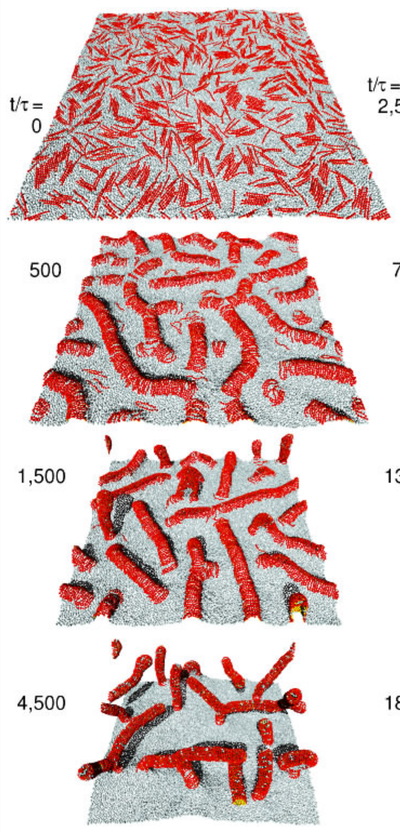




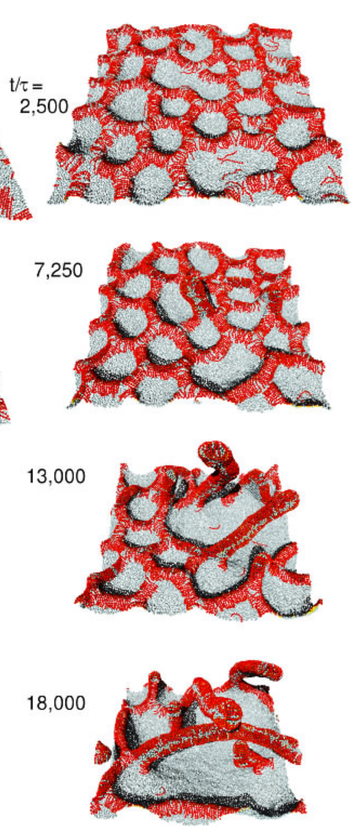
Tubules are formed via rod assembly.
A little dependence on C_{side}.

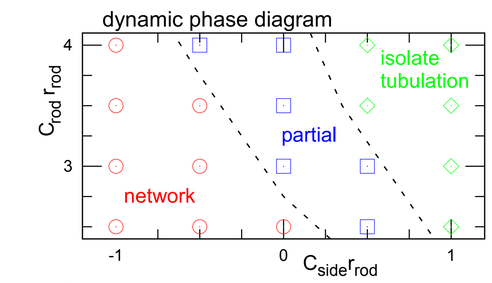
High rod density ϕ_{rod} = 0.4

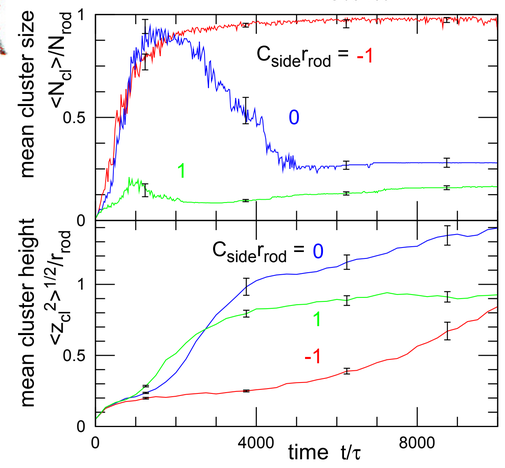
$C_{side}r_{rod}$= 1



$C_{side}r_{rod}$= -1



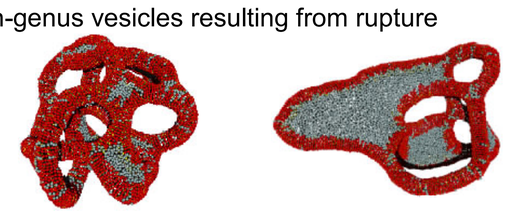




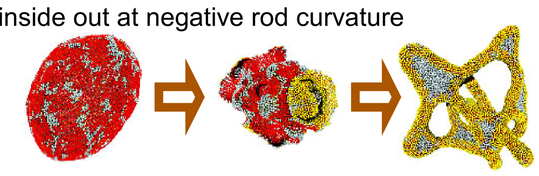
Percolated networks are transiently formed at C_{side}< 0. It suppresses tubule protrusion.

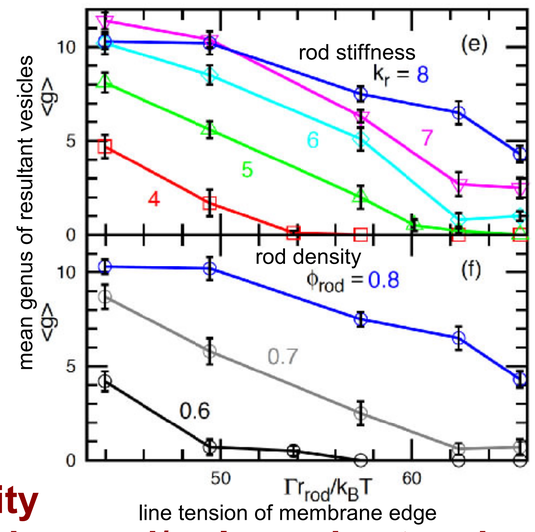
Membrane Rupture [4]

high-genus vesicles resulting from rupture



inside out at negative rod curvature





Vesicles are ruptured for high density of stiff proteins, rapid protein adhesion, and/or low edge tension.

[1] H. Noguchi, EPL 108, 48001 (2014).
[2] H. Noguchi, J. Chem. Phys. 143, 243109 (2015).
[3] H. Noguchi, Sci. Rep. 6, 20935 (2016).
[4] H. Noguchi, Phys. Rev. E 93, 052404 (2016).