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Clustering for Budding

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Biological membranes are much more than mere cell boundaries. Consisting of a myriad of lipids and protein species, membranes play a multifaceted role crucial for cell function . They are involved in many essential cellular processes such as communication, transportation, as well as growth, and repair. A key membrane feature is its ability to adapt to a variety of shapes, essential for many cellular processes. One of the main sources of membrane shape remodeling is proteins that locally induce curvature and act cooperatively. This cooperation can be amplified by membrane-mediated interactions, where proteins' direct interaction with the membrane leads to the emergence of an effective interaction between the proteins. While these interactions are well studied for a few particles systems (two and three), the behavior of these forces for many body systems remains unclear.

In this work, we characterize the cooperative impact of non-interacting proteins that locally induce both curvature and stiffness on a fluctuating, tensionless membrane patch using a dynamically triangulated surface model. Our results reveal distinct phenomena depending on the protein density and the level of local perturbations, such as membrane tubulation, vesiculation, membrane softening, or protein aggregation. These phenomena can be linked to membrane shapes and properties found in nature.