Actin-Membrane Interactions in Membrane Nanotubes

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***Short Abstract* — Membrane nanotubes are membrane structures that contain actin and connect cells over long distances. To gain insight into membrane nanotubes, we use theory and computer simulations to study continuum models of semiflexible polymers confined within elastic membrane tubes. Monte Carlo simulations allow characterization of typical configurations of the polymer and membrane as a function of parameters such as polymer persistence length and membrane bending rigidity. In the regime of low membrane bending rigidity, we find the presence of a polymer within the membrane suppresses membrane shape fluctuations, which is reflected in a decrease in the specific heat of the membrane.**

I. INTRODUCTION

MEMBRANE nanotubes are long and slender tubes formed from the plasma membrane, and can vary in size, structure, and formation processes. It is speculated that cells use membrane nanotubes as a means of intercellular communication over long distances, and it has been shown that viruses can propagate from one cell to another by means of membrane nanotubes [1-3].

A number of theoretical and computational studies have investigated tubular extensions from cells [3-5]. However, the relatively recent discovery of membrane nanotubes provides an interesting model system that may provide a greater understanding of membrane-cytoskeleton interactions. We study membrane nanotubes using a theoretical framework based on continuum models. On the length scales relevant to membrane nanotubes, many key attributes of actin filaments and cell membranes can be captured by regarding them as semiflexible polymers and thin elastic sheets, respectively. We employ analytical theory and Monte Carlo computer simulation methods to explore properties of polymer-membrane systems. We simulate discretized representations of both polymers and membranes in which particles are connected by edges to represent the objects. For the flexible membranes, we consider triangulated surfaces in which the vertex connectivity is not fixed as a way to confer fluidity to the membrane.

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II. RESULTS

We begin by using analytical theory to calculate the energies of various polymer-membrane configurations. This provides a reference point for analyzing later results and suggests the favorability of certain polymer configurations. We then use Monte Carlo simulations to study the equilibrium properties of membranes in isolation. We consider effects of the membrane bending rigidity, and at small values, we observe a peak in the specific heat of the membrane, which is calculated based on energy fluctuations. Characterizing the membrane shapes sampled in simulations indicate that this peak is associated with a transition from a crumpled membrane to a locally flat membrane.

We next consider the effect of a semiflexible polymer, representing a bundle of actin, within an elastic tube. We find that fluctuating tubes allow enclosed polymers to equilibrate more quickly when compared with polymers confined within rigid tubes, but that the presence of a polymer has small effect on properties of the membrane at typical cell parameters. At low bending rigidity, we find that the peak in the specific heat of the membrane can be suppressed by the polymer in a manner that depends on the length and persistence length of the polymer.

III. CONCLUSION

Membrane nanotubes provide a novel system from the perspective of studying membrane-cytoskeleton interactions, and our results suggest an interesting interplay between polymer and membrane properties. Further efforts are needed to understand the role of additional factors (e.g., actin-associated proteins) and their behavior in biological contexts.

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