8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Non-equilibrium mechanics of motor-activated gels and living cells

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Key Words: *Cytoskeleton, Active Gels, Contractility.*

ABSTRACT

Networks of filamentous proteins play a crucial role in cell mechanics. These cytoskeletal networks, incorporating various cross-linking and other associated proteins largely determine the (visco)elastic response of cells. In the cell, these networks are far from equilibrium: their mechanical properties can reflect internal active force generation by molecular motors. We develop a simple three-component in vitro model system consisting of myosin II, actin filaments, and cross-linkers [1]. By measuring the dynamics and mechanical properties, we quantify the effects of non-equilibrium stresses arising from motor activity. We show theoretically and experimentally how this motor activity can result in a 100-fold stiffening of the cytoskeleton. We present a quantitative theoretical model connecting the large-scale mechanical properties of this active gel to molecular force generation [2]. Based in part on this theoretical model, we investigate and explain the large shape fluctuations observed for microtubules in vivo [3]. Although microtubule bending is suppressed by the surrounding elastic cytoskeleton, large motor-induced forces cause significant bending fluctuations on short length scales, which are then frozen-in by the surrounding matrix. These lateral bending fluctuations naturally result in wandering of the orientation of the microtubule tip, and an apparent persistent random walk of the microtubule, with a small non-equilibrium persistence length approximately 100 times smaller than that resulting from thermal fluctuations alone. Thus, large non-thermal forces govern the growth of microtubules and can explain the highly curved shapes observed in the microtubule cytoskeleton of living cells.

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