Cooperative phenomena in the mechanical behaviour of filamentous materials with molecular motors

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Biological cells sense and respond to mechanical stimuli in a rather intricate manner. Indeed, cell mechanosensing involves the interplay of several cytoskeletal constituents, primarily filaments, such as actin microfilaments or microtubules, crosslinking proteins, and molecular motors. The organization of actin filaments into several spatio-temporal structures governs eukaryotic cell shape and movement. Mechanical force acting on actin structures is shared between molecular motors such as myosins and different actin crosslinkers. Furthermore, transport of various types of cargoes in cells is based on molecular motors moving along mechanically loaded actin networks. Under these conditions, molecular motors often work more efficiently in small teams rather than as isolated molecules [1]. In this paper we want to determine the effects of elastic interaction in the cooperative dynamics of small number of motor complexes.

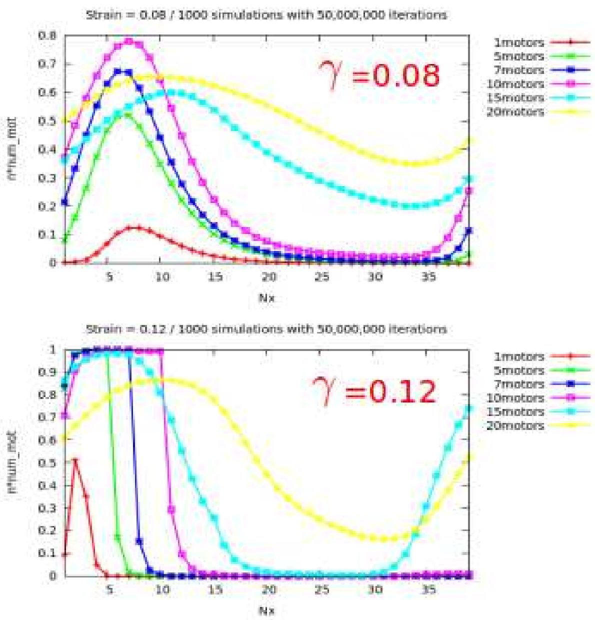

Figure 1: Motor density profiles for an applied strain γ equal to 0.08 (top) and 0.12 (bottom).

In our study, we mainly use the worm-like chain as the starting model to characterize the cytoskeletal filaments and we apply different Monte Carlo techniques to statistically characterize the mechanical response of filaments, crosslinks, and motors under various modes of deformation. Different types of cell deformation trigger distinct responses, with molecular motors responding or reacting against length dilation or shear [2]. The reversible nature of crosslink binding in conjunction with motor dynamics and the non-affine deformation of the filaments leads, for instance, to collective phenomena such as sudden and discontinuous unbinding processes, characteristic of a first order transition [3]. Here, we provide evidence of cooperative behavior due to motor reorganizations under controlled deformation conditions. We report out of equilibrium cooperative behavior as a result of processive motor clustering under mechanical strain. Elastic interactions facilitate the development of spatial correlations among motors, i.e. opposing forces near an energy barrier, slow down the motion of motors favoring the formation of motor clusters. These correlated motor complexes exhibit a fluctuating zipper-like dynamics, and taking advantage of these cooperativity they are eventually able to surmount energy barriers. Depending on the externally applied strain, a minimum amount of motors in the team might be needed. In Fig. 1, we represent the motor density profiles along an actin chain under strain-controlled deformation, i.e. for strain values $\gamma = 0.08$ and $\gamma = 0.12$. The amount of motors needed to surmount the barrier increases with the applied strain. Our observations help to determine the influence of motor density on the collective system response.

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[1] S. Klumpp, C. Keller, F. Berger and R. Lipowsky in, *Multiscale Modeling in Biomechanics and Mechanobiology, S. De et al. eds.* (Springer Verlag, London, 2015).

[2] D. Strehle et al., *"Transiently crosslinked F-actin bundles"* Eur. Biophys. J. 40, 93 (2011).

[3] C. Heussinger, *"Stress relaxation through crosslink unbinding in cytoskeletal networks"* New Journal of Physics 14, 095029 (2012).