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Force fluctuations and polymerization dynamics of intracellular microtubules

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Microtubules are dynamic biopolymers within the cytoskeleton of living cells. They play a central role in many biological processes including cell division, migration, and cargo transport. Microtubules are significantly more rigid than other cytoskeletal biopolymers, such as actin filaments, and are insensitive to thermal fluctuations on cellular length scales. However, we show that intracellular microtubules exhibit bending amplitudes with a surprisingly thermal-like wavevector dependence, but with an apparent persistence length about 100 times smaller than that measured *in vitro*. By studying the time-dependent bending fluctuations of individual filaments, we find that the thermal-like bends are fluctuating significantly only on short length scales, while they are frozen-in on longer length scales [1], reminiscent of non-ergodic behavior seen in systems far from equilibrium. Long wavelength bends are suppressed by the surrounding elastic cytoskeleton, which confines bending to short length scales on the order of a few microns [2]. These short wavelength bending fluctuations naturally cause fluctuations in the orientation of the microtubule tip. Tip fluctuations result in a persistent random walk trajectory of microtubule growth, but with a small non-equilibrium persistence length, explaining the origin of quenched thermal-like bends. These results suggest that intracellular motor activity has a highly fluctuating character that dominates over thermal fluctuations, with important consequences for fundamental biological processes.

[1] CP Brangwynne, FC MacKintosh, DA Weitz, *PNAS*, 104:16128 (2007).
[2] CP Brangwynne, FC MacKintosh, S Kumar, NA Geisse, J Talbot, L. Mahadevan, KK Parker, DE Ingber, DA Weitz, *JCB*, 173:733 (2006).