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Active stresses and hydrodynamics of microtubule/motor-protein assemblies

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In biologically-inspired soft active materials, chemical energy (typically from ATP) is transduced to generate active stresses arising from reconiguration or forcing of the microstructure. This can lead to novel material organization, mechanical properties, and active flows. While much focus has been on active gels and motile suspensions, another important class are suspensions of microtubules (MTs) crosslinked by motile molecular motors. These are central actors in biological phenomena such as pronuclear transport and spindle formation. Here we develop a multi-scale theory for studying such systems. At the discrete level, we use Brownian dynamics of MTs with moving crosslinks to study microscopic organization and active stress development. We observe, surprisingly, that activity generated extensile stresses arise from both polarity sorting and crosslink relaxation. These simulations estimate polarity-dependent active stress coeffcients in a Doi-Onsager kinetic theory – similar to those developed previously for motile suspensions – that captures polarity sorting and induced hydrodynamic flows. In simulating recent experiments of active flows on immersed surfaces, the model exhibits turbulent-like dynamics, and the continous generation and annihilation of disclination defects associated with coherent flow structures. We can associate the system's coherent features with instabilities of aligned linear and nonlinear states.