Correlations in active nematic defects

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In equilibrium statistical physics, the fluctuation-compressibility theorem states that the variance of the number of particles, in a region of space with size R, scales as $\sigma_N \sim R^d$, with d the spatial dimension. Active systems, however, often exhibit giant number fluctuations (GNF), where $\sigma_N \sim R^d$, with $\beta > d$. In contrast, when $\beta < d$, the system is classified as hyperuniform (HU). In reciprocal space, hyperuniformity implies that the structure factor scales as $S(q) \sim |q|^\alpha$, with $\alpha = d - \beta$ and q the scattering wavevector, so that $S(q) \to 0$ as $q \to 0$.

We study an active nematic liquid crystal of microtubules at an oil/water interface, driven out of equilibrium by ATP-fueled kinesin–streptavidin complexes. In the active turbulent regime, the system continuously creates and annihilates ±1/2 topological defects [1]. Previous results in our group showed that $\beta < 2$ for the system of active defects, for values of R as large as the system size. The system of active defects is thus HU. Using both hydrodynamics and particle-based simulations, we unravel how defect-defect correlation and their creation/annihilation processes all conspire to result in this behavior [2].

Recent experiments, however, using larger active nematic cells allow accessing smaller q. In this regime, we observe that $S(q)$ does not vanish at the lowest accessible q, but that instead it decays and saturates to a finite non-zero value. This suggests a crossover from hyperuniform to uniform behavior beyond a characteristic length scale. Uniformity suggests that at sufficiently large length scales random noise, akin to thermal effects, dominates over activity-induced fluctuations. To assess this, we compare our results with those of electric charges in equilibrium, finding that the relation between partial structure factors in this system holds for active nematic defects, thus confirming the transition from HU to uniform behavior.

Keywords:
nematic liquid crystals, topological defects, hyperuniformity, number fluctuations, active matter, structure factor

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