Spectral density of oscillations of inertial active Brownian particles in an harmonic trap

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This work presents initial results of a theoretical and numerical study of inertial active Brownian particles confined by an external trapping potential. The dynamics of such systems is governed by the interplay between thermal fluctuations, dissipation, inertia, and active driving, which leads to nontrivial fluctuation spectra and deviations from classical Brownian behavior. Particular attention is paid to the spectral density of particle fluctuations as an informative and experimentally accessible characteristic of active systems.
At the current stage, the spectral properties of particle motion have been analyzed within a generalized stochastic framework that accounts for translational and rotational inertia. Analytical expressions for the spectral density were obtained in a number of limiting cases, revealing the role of inertial effects in shaping the frequency dependence and characteristic spectral features. These analytical results were systematically verified by extensive numerical simulations performed over a wide range of model parameters. Good agreement between analytical predictions and numerical data was observed.
The performed analysis demonstrates that inertia leads to qualitative and quantitative modifications of fluctuation spectra, including shifts of characteristic frequencies and changes in spectral amplitudes. The obtained results provide a solid basis for further investigation of interacting active particle systems and for the development of non-invasive methods for reconstructing dynamical parameters of active matter from spectral measurements.
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