Collective Motion in Active Systems

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Active Matter is a new field of soft matter science, which focuses on the properties of assemblages of interacting self-propelled particles, from molecular motors and synthetic swimmers to living bacteria, motile cells, and large animal swarms. Assemblies of self-propelled organisms are often termed "active fluids" and the study of their collective dynamics has attracted enormous attention in the last decade. Despite simplicity of interactions between the constituents, large assemblies of self-propelled particles exhibit fascinating collective motion. This motion is manifested by spontaneous formation of vortices, jets, and other coherent structures with the characteristic scale significantly exceeding the size of individual particle. In this course I'll systematically overview the most recent progress in the field of Active Matter, and will discuss various approaches to the description of collective motion in this class of out-of-equilibrium systems. I will review various types of microscopic models based on the motion of individual particles, then proceed to the mesoscale kinetic description for the probability distribution functions, and then will derive coarse-grained hydrodynamic description of the collective behavior.

Lecture 1. An Introduction.
Overview of main experimental studies of collective behavior in synthetic and living systems

- patterns in granular systems
- *in vitro* cytoskeletal networks
- suspensions of microswimmers

Lecture 2. Self-Organization of Active Polar Rods: Self-assembly of Microtubules and Molecular Motors

- Brief survey of main experimental observations
- Simple micromechanical calculations: inelastic collisions
- Maxwell model for polar rods: analogy with granular systems
- Orientational instability and Landau expansion
- Spatial localization of interaction and the Boltzmann equation
- Ginzburg-Landau expansion of the Boltzmann equation
- Stationary solutions: Asters and Vortices

Lectures 3&4 . Collective motion of interacting self-propelled particles

- Vicsek model for polar self-propelled particles. Phase transition to collective behavior. Order parameter.
- Phenomenological model of Toner and Tu. Giant Number Fluctuations.
- Probabilistic Boltzmann description of the Vicsek model.
- Ginzburg-Landau expansion. Continuum description. Soliton solutions.
- Vicsek model for particles with apolar (nematic interaction). Band solution and spatio-temporal chaos.