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Far-from-equilibrium magnetic granular layers: dynamic patterns, magnetic order and self-assembled swimmers

ALEXEY SNEZHKO, Argonne National Laboratory

Ensembles of interacting particles subject to an external periodic forcing often develop nontrivial collective behavior and self-assembled dynamic patterns. We study emergent phenomena in magnetic granular ensembles suspended at a liquid-air and liquid-liquid interfaces and subjected to a transversal alternating magnetic field. Experiments reveal a new type of nontrivially ordered dynamic self-assembled structures (in particular, "magnetic snakes", "asters", "clams") emerging in such systems in a certain range of excitation parameters. These non-equilibrium dynamic structures emerge as a result of the competition between magnetic and hydrodynamic forces and have complex magnetic ordering. Transition between different self-assembled phases with parameters of external driving magnetic field is observed. I will show that above some frequency threshold magnetic snakes spontaneously break the symmetry of the self-induced surface flows (symmetry breaking instability) and turn into swimmers. Self-induced surface flows symmetry can be also broken in a controlled fashion by introduction of a large bead to a magnetic snake (bead-snake hybrid), that transforms it into a robust self-locomoting entity. Some features of the self-localized structures can be understood in the framework of an amplitude equation for parametric waves coupled to the conservation law equation describing the evolution of the magnetic particle density and the Navier-Stokes equation for hydrodynamic flows.