Fluctuating Hydrodynamics for Fun and Profit

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The intrinsic thermal motion of the molecules in a fluid result in microscopic fluctuations that are well-understood at thermodynamic equilibrium. For a fluid in a nonequilibrium state, such as in the presence of gradients of temperature or concentration, these hydrodynamic fluctuations are qualitatively different, potentially becoming macroscopic in amplitude and length scale.

Thermal fluctuations can be modeled accurately using a modification of the Navier-Stokes conservation equations that includes a stochastic forcing, as was originally proposed by Landau and Lifshitz. In this fluctuating hydrodynamics (FHD) formulation, a stochastic flux is added to each dissipative flux associated with the transport of species mass, momentum and energy densities in a manner that satisfies the fluctuation-dissipation balance. The framework of FHD has been useful in understanding the behavior of fluids in various nonequilibrium conditions, but theoretical calculations have been feasible only with simplifying assumptions.

This talk will review the numerical methods for simulations based on the FHD equations for both compressible and incompressible flows. First, the basic ideas will be illustrated using the one-dimensional stochastic heat equation, which can be solved analytically. The concepts will then be extended to the full hydrodynamic equations including multiple species and chemical reactions. Finally, a selection of examples will be reviewed including: gas-phase membranes, electrolyte solutions, wetting instabilities, and turbulence.