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"Free Energy" in Vibrated Granular Non-Equilibrium Steady-States.[1]

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Equilibrium statistical mechanics is generally not applicable to systems with energy input and dissipation present, and identifying relevant tools for understanding these far-from- equilibrium systems poses a serious challenge. Excited granular materials or granular fluids have become a canonical system to explore such ideas since they are inherently dissipative due to inter-particle frictional contacts and inelastic collisions. Granular materials also have far reaching practical importance in a number of industries, but accumulated ad-hoc knowledge is often the only design tool. An important feature of granular fluids is that the driving and dissipation mechanisms can be made to balance such that a Non-Equilibrium Steady-State (NESS) is achieved. We present strong experimental evidence for a NESS first-order phase transition in a vibrated two-dimensional granular fluid. The phase transition between a gas and a crystal is characterized by a discontinuous change in both density and temperature and exhibits rate dependent hysteresis. We measure a "free energy"-like function for the system and compare and contrast this type of transition with an equilibrium first-order phase transition and a hysteretic backward bifurcation in a nonlinear pattern forming system.

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