

MA T H E M A T I C A L P H Y S I C S S E M I N A R
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Hill Center - Room 705

**Fluctuations out of Equilibrium: Symmetries and Phase
Transitions**

Pablo Hurtado Fernandez, University of Granada
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Abstract

Fluctuations arise universally in Nature as a reflection of the discrete microscopic world at the macroscopic level. Despite their apparent noisy origin, fluctuations encode fundamental aspects of the physics of the system at hand, crucial to understand irreversibility and nonequilibrium behavior. In order to sustain a given fluctuation, a system traverses a precise optimal path in phase space. Here we show that by demanding invariance of optimal paths under symmetry transformations, new and general fluctuation relations valid arbitrarily far from equilibrium are unveiled. This opens an unexplored route toward a deeper understanding of nonequilibrium physics by bringing symmetry principles to the realm of fluctuations. We illustrate this concept studying symmetries of the current distribution out of equilibrium. In particular we derive an isometric fluctuation relation which links in a strikingly simple manner the probabilities of any pair of isometric current fluctuations. This relation, which results from the time-reversibility of the dynamics, includes as a particular instance the Gallavotti-Cohen fluctuation theorem in this context but adds a completely new perspective on the high level of symmetry imposed by time-reversibility on the statistics of nonequilibrium fluctuations. The new symmetry implies remarkable hierarchies of equations for the current cumulants and the nonlinear response coefficients, going far beyond Onsager's reciprocity relations and Green-Kubo formulae. We confirm the validity of the new symmetry relation in extensive numerical simulations, and suggest that the idea of symmetry in fluctuations as invariance of optimal paths has far-reaching consequences in diverse fields.

In a second part, we briefly discuss the presence of phase transitions at the fluctuating level which are not allowed in equilibrium steady states.

In particular, we observe this striking and general phenomenon measuring current fluctuations in an isolated diffusive system. While small fluctuations result from weakly-correlated, incoherent local events, for currents above a critical threshold the system self-organizes into a coherent traveling wave which facilitates the current deviation by gathering energy in a localized packet, thus breaking translation invariance. This results in Gaussian statistics for small fluctuations but non-Gaussian tails above the critical current. Our observations, which agree with predictions derived from hydrodynamic fluctuation theory, strongly suggest that rare events are generically associated with coherent, self-organized patterns which enhance their probability.