

Noise-Enhanced Metastability and Perception in Complex Systems: From Lévy Flights to Memristors, Quantum Escape, Josephson junction based Axion Detection, and Biological Systems

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Many-body and complex systems, both classical and quantum, often exhibit slow, nonlinear relaxation toward stationary states due to the presence of metastable configurations and environmental fluctuations. Such metastable dynamics arise across a wide range of fields, from condensed matter and high-energy physics to cosmology and biology, with noise-induced effects playing a crucial role in shaping nonequilibrium behavior.

In this contribution, we present a unified perspective on noise-assisted stabilization and the statistical properties of metastable systems. We first analyze escape processes driven by Lévy flights in smooth metastable potentials, highlighting the emergence of nonmonotonic residence-time behavior. We then extend these concepts to stochastic resistive switching in memristive devices, where noise can enhance stability and reproducibility. The framework is further applied to driven dissipative quantum bistable systems, where the interplay between external driving and system–environment coupling modifies escape pathways and lifetimes.

We also discuss switching-time statistics in current-biased Josephson junctions as a potential tool for axion detection, exploiting noise-induced resonant activation. Finally, we present experimental evidence of noise-enhanced signal perception in biological systems. In particular, behavioral experiments on the stink bug *Nezara viridula* reveal that the source-direction movement (SDM) ratio exhibits a nonmonotonic dependence on noise intensity, with two distinct maxima. This provides evidence of double stochastic resonance, a phenomenon previously predicted theoretically but not observed in living systems. Notably, the noise levels employed in the laboratory closely match those in natural environments, underscoring the ecological relevance of the results.

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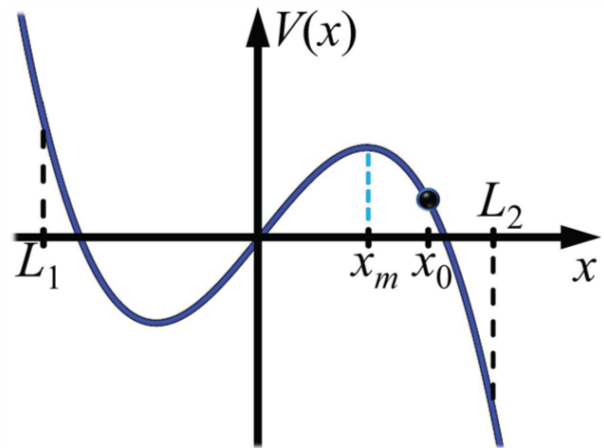


Image 2

