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Quantum Kinetic Uncertainty Relations in Mesoscopic Conductors at Strong Coupling

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Kinetic Uncertainty Relations (KURs) establish quantum transport precision limits by linking signal-to-noise ratio (SNR) to the system's dynamical activity, valid in the weak-coupling regime where particle-like transport dominates. At strong coupling, quantum coherence challenges the validity of KURs and questions the concept of activity itself.

In this work, we achieve two distinct, yet complementary main results. First, we introduce a general definition of dynamical activity valid at arbitrary coupling, which reveals the breakdown of standard KURs at strong coupling. Second, we prove a novel uncertainty relation valid at arbitrary coupling strength, which we denote Quantum KUR (QKUR). This QKUR corresponds to a nontrivial quantum extension of KUR, involving fundamental contributions of the generalized dynamical activity. These two achievements provide a general framework for out-of-equilibrium quantum transport precision analysis.

Explicit steady-state expressions are obtained within Green's-function and Landauer-Büttiker formalisms. We illustrate these concepts for paradigmatic quantum-coherent mesoscopic devices: a single quantum channel pinched by a quantum point contact and open single- and double-quantum dot systems.

Reference:Blasi, Rodriguez, Moskalets, Lopez, Haack, arXiv:2505.13200 (2025).

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