Work fluctuations in slow processes: Quantum signatures and optimal control

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An important result in classical stochastic thermodynamics is the work fluctuation-dissipation relation (FDR), which states that the dissipated work done along a slow process is proportional to the resulting work fluctuations. Here we show that slowly-driven quantum systems violate this FDR whenever quantum coherence in the energy basis is generated along the protocol, and derive a quantum generalisation of the work FDR. The additional quantum terms on the FDR are shown to uniquely imply a non-Gaussian work distribution, in contrast to the Gaussian shape found in classical slow processes. Fundamentally, our result shows that quantum fluctuations prohibit finding slow protocols that minimise both dissipation and fluctuations simultaneously. Instead, we develop a quantum geometric framework to find processes with an optimal trade-off between the two quantities.