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Motivating semiclassical gravity: a classical-quantum approximation for bipartite quantum systems

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We derive a “classical-quantum”approximation scheme for a broad class of bipartite quantum systems from fully quantum dynamics. In this approximation, one subsystem evolves via classical equations of motion with quantum corrections, and the other subsystem evolves quantum mechanically with equations of motion informed by the evolving classical degrees of freedom. Using perturbation theory, we derive an estimate for the growth rate of entanglement of the subsystems and deduce a “scrambling time”—the time required for the subsystems to become significantly entangled from an initial product state. We argue that a necessary condition for the validity of the classical-quantum approximation is consistency of initial data with the generalized Bohr correspondence principle. We illustrate the general formalism by numerically studying the fully quantum, fully classical, and classical-quantum dynamics of a system of two oscillators with nonlinear coupling. This system exhibits parametric resonance, and we show that quantum effects quench parametric resonance at late times. Lastly, we present a curious late-time scaling relation between the average value of the von Neumann entanglement of the interacting oscillator system and its total energy: ▯~2/3ln ▯.

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