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Title: From a continuous to a discrete dissipative time crystal and the onset of entrainment

Abstract: The quantum version of the weakly non-linear van der Pol oscillator is a paradigmatic system in the context of quantum synchronization. When forced by a squeezed-drive this system is known to display subharmonic entrainment in the quantum regime. Here we analyze the relation of this phenomenon with that of dissipative time crystals and spontaneous parity-symmetry breaking. In particular, we analyze how time-translation symmetry and parity-symmetry can be spontaneously broken in the infinite-excitation limit, by means of a finite-size analysis of the Liouvillian and Floquet map spectrum, and of the amplitude and two-time correlations dynamics. We find the system to display two dynamical regimes depending on whether time-translation symmetry is broken continuously or in a discrete fashion. The continuous breakdown of the time-periodicity set by the forcing indicates the lack of synchronization, while the discrete one indicates perfect entrainment. We show the latter to be enabled by the emergence of a second stationary state that breaks the underlying parity-symmetry of the model through a symmetry breaking dissipative phase transition.