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Title: Boundary time crystals in collective d-level systems

Abstract: Boundary time crystals (BTC's) are non-equilibrium phases of matter occurring in quantum systems in contact to an environment, for which a macroscopic fraction of the many body system breaks time translation symmetry. We study BTC's in collective d-level systems, focusing in the cases with d = 2, 3 and 4. We find that BTC's appear in different forms for the different cases. We first consider the model with collective d = 2-level systems, whose dynamics is described by a Lindblad master equation, and perform a throughout analysis of its phase diagram and Jacobian stability for different interacting terms in the coherent Hamiltonian. In particular, using perturbation theory for general (non Hermitian) matrices we obtain analytically how a specific Z_2 symmetry breaking Hamiltonian term destroys the BTC phase in the model. Based on these results we define a d = 4 model composed of a pair of collective 2-level systems interacting with each other. We show that this model support richer dynamical phases, ranging from limit-cycles, period-doubling bifurcations and a route to chaotic dynamics. The BTC phase is more robust in this case, not annihilated by the former symmetry breaking Hamiltonian terms. The model with collective d = 3-level systems is defined similarly, as competing pairs of levels, but sharing a common collective level. The dynamics can deviate significantly from the previous cases, supporting phases with the coexistence of multiple limit-cycles, closed orbits and a full degeneracy of zero Lyapunov exponents.