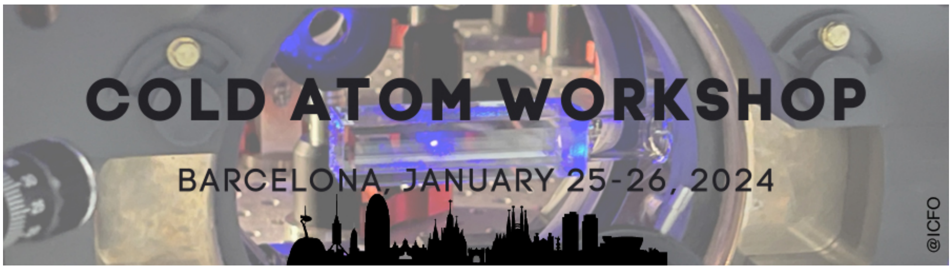

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Multiple symmetry breaking in spontaneous Floquet states

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We study multiple symmetry-breaking in many-body systems, focusing on the specific case of an atomic condensate. We discuss the quantization procedure of the Goldstone mode associated to each broken symmetry. This quantization involves a Berry-Gibbs connection which depends on the macroscopic conserved charges associated to each broken symmetry and is not invariant under generalized gauge transformations. Our results suggest that some traveling solutions in a ring can be potentially misidentified as time crystals since they do not arise from a genuine breaking of time-translation symmetry but rather from a spatial-translation symmetry breaking plus some constant drift. We extend the formalism to a spontaneous Floquet state, a periodic state which breaks continuous time-translation symmetry. We find that each broken symmetry now has an associated Floquet-Goldstone mode with zero quasi-energy. Thus, the temporal Floquet-Goldstone mode arising from the continuous time-translation symmetry-breaking is the characteristic signature of a spontaneous Floquet state, absent in conventional (driven) Floquet systems, and its quantum amplitude provides a rare realization of a time operator in Quantum Mechanics. We apply this formalism to the CES state, which breaks U(1) and time-translation symmetries, providing a temporal analogue of a supersolid. Using numerical simulations based on the Truncated Wigner method, we show that the temporal Floquet-Goldstone can be measured from the density-density correlations.

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