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Time-crystal phase transition, fluctuations and quantum correlations in an emitter-waveguide system with feedback

We investigate the creation and control of emergent collective behavior and quantum correlations using feedback in an emitter-waveguide system using a minimal model. Employing homodyne detection of photons emitted from a laser-driven emitter ensemble into the modes of a waveguide allows to generate intricate dynamical phases. In particular, we show the emergence of a time-crystal phase, the transition to which is controlled by the feedback strength. Feedback enables furthermore the control of many-body quantum correlations, which become manifest in spin squeezing in the emitter ensemble. Developing a theory for the dynamics of fluctuation operators we discuss how the feedback strength controls the squeezing and investigate its temporal dynamics and dependence on system size. These results allow to quantify spin squeezing and fluctuations in the limit of large number of emitters, revealing critical scaling of the squeezing close to the transition to the time-crystal.