

Picophotonics and Continuous Time Crystals

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Recent advances in picometer scale visualization and localization techniques with electron beams and topologically structured light allow the detection of atomic level displacements in opto-mechanical systems and the study of dynamics and statistics of their picometre scale thermal and driven movements. This opens opportunity to develop pico/nano-opto-mechanical systems, in particular flexible plasmonic metamaterial arrays as a powerful platform to investigate **classical many-body effects in the strongly correlated regime** induced by light that complements the cold atom and spin platforms where many-body quantum states of bosonic or fermionic matter can be studied.

Among these many-body strongly correlated systems is the **time crystal** that is an eagerly sought phase of matter with **broken time-translation symmetry**. Quantum time crystals with discretely broken time-translation symmetry have been demonstrated in trapped ions, atoms and spins while continuously broken time-translation symmetry has only been observed in an atomic condensate inside an optical cavity.

Here we demonstrate experimentally that a classical metamaterial nanostructure, a two-dimensional array of plasmonic metamolecules supported on nanowires, exhibit complex picometer scale dynamics in presence of light. It can be driven to a state possessing all the key features of a continuous time crystal: continuous coherent illumination by light resonant with the metamolecules' plasmonic mode triggers a **spontaneous first order phase transition to a superradiant-like state** of transmissivity oscillations, resulting from many-body interactions among the metamolecules, characterized by long-range order in space and time. The continuous time crystal state results from synchronization of picometer scale stochastic thermal movements of the nanowires that is driven by light-induced interactions of plasmonic metamolecules. In interpretation of these experiments, we discuss different routes to synchronization including the Kuramoto-like mechanism that rely on nonlinearity of the mechanical sub-system of the array and the mechanism involving non-reciprocal non-Hamiltonian forces of light pressure.

We argue that the continuous time crystal state is of interest to applications in all-optical modulation, frequency conversion, timing and all-optical computing.