The realization of a continuous time crystal based on a photonic metamaterial

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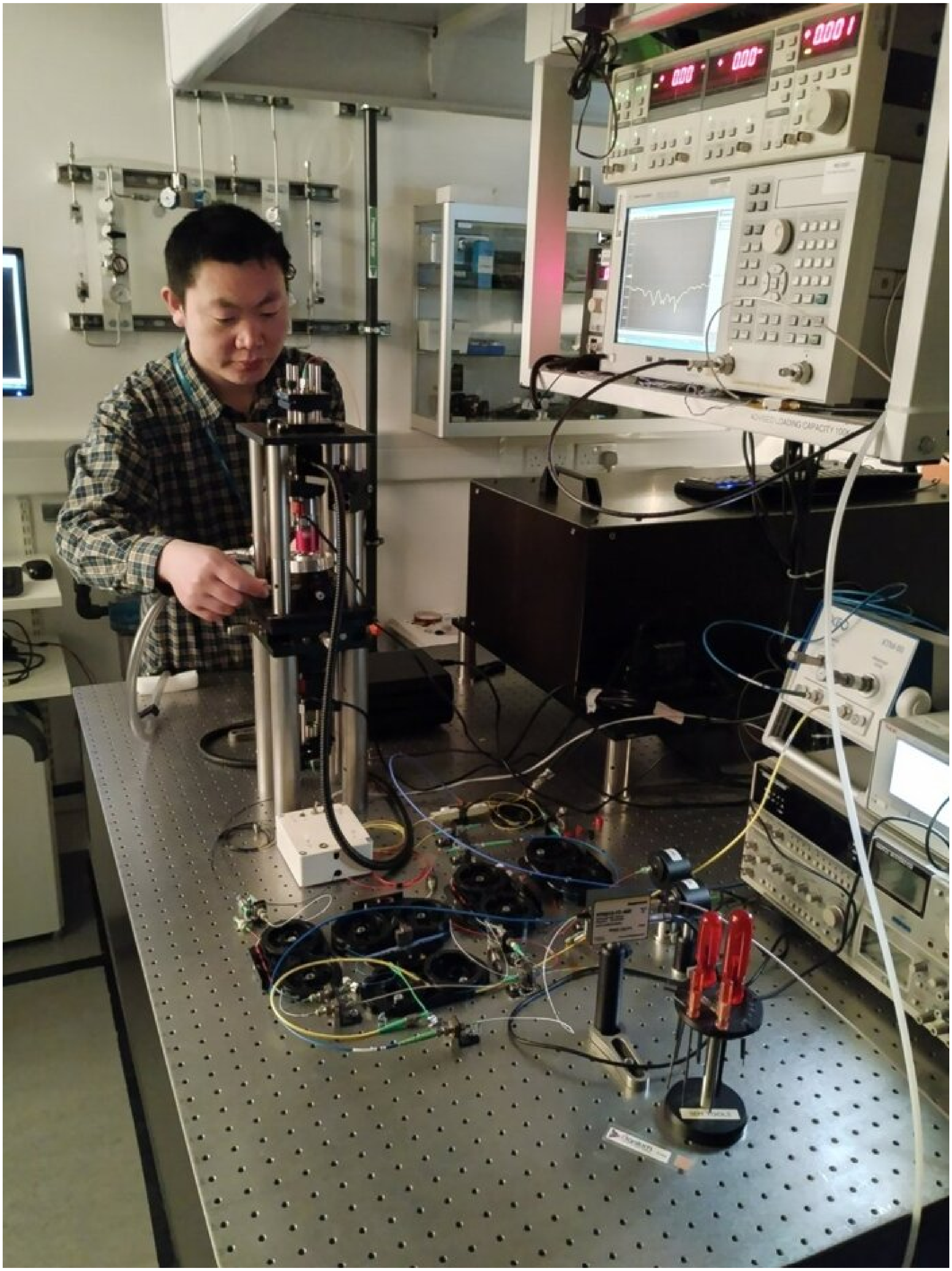

Dr Tongun Liu, University of Southampton, UK performs experiments with the photonic time crystal on the nano-opto-mechanical platform. Credit: Liu et al

A time crystal, as originally proposed in 2012, is a new state of matter in which the particles are in continuous oscillatory motion. Time crystals break time-translation symmetry. Discrete time crystals do so by oscillating under the influence of a periodic external parametric force, and this type of time crystal has been demonstrated in trapped ions, atoms and spin systems.

Continuous time crystals are more interesting and arguably more important, as they exhibit continuous time-translation symmetry but can spontaneously enter a regime of periodic motion, induced by a vanishingly small perturbation. It is now understood that this state is only possible in an open system, and a continuous quantum-time-crystal state has recently been observed in a quantum system of ultracold atoms inside an optical cavity illuminated with light.

In a paper published in *Nature Physics*, researchers at University of Southampton in the U.K. showed that a classical metamaterial nanostructure can be driven to a state that exhibits the same key characteristics of a continuous time crystal.

"We have been studying light-matter interactions with nano-opto-mechanical metamaterials for several years," Nikolay I. Zheludev, one of the researchers who carried out the study, told Phys.org. "We recently realized that this was a perfect platform for demonstrating the time crystal state,"

As part of their recent study, Zheludev and his colleagues set out to realize a continuous time crystal state using a photonic metamaterial.

The system they used is a 2D array of plasmonic metamolecules (i.e., artificial structures that facilitate interaction with light at the nanoscale) supported by flexible nanowires.

The researchers demonstrated that continuously and coherently illuminating this photonic metamaterial with a light that resonates with the plasmonic mode of the metamolecules contained within it caused a spontaneous phase transition to a state that possesses the key properties of a continuous time crystal. This state is characterized by continuous oscillations resulting from many-body interactions between the metamolecules.

"We found that a photonic metamaterial, an array of nanowires decorated with plasmonic nanoparticles, can be driven to the state of coherent oscillations of the nanowires by light-induced interaction between the particles," Zheludev explained. "These oscillations emerge spontaneously upon reaching a threshold of light illumination. Such behavior constitutes a continuous time crystal, a new state of matter."

The recent study by this team of researchers could open new avenues for research into time crystals and dynamic classical many-body states in the strongly correlated regime. In the future, the unique system realized by Zheludev and his colleagues could also pave the way toward the development of new optical and photonic devices.

"We demonstrated a continuous time crystal, a new state of matter on a simple classical platform, which is a substantial step towards applications of the continuous time crustal state in photonics devices," Zheludev added. "The reported observation is only the beginning, and we will continue exploring fundamental properties of the nano-opto-mechanical metamaterial continuous time crystals and their applications."

More information: Tongjun Liu et al, Photonic metamaterial analogue of a continuous time crystal, *Nature Physics* (2023). DOI: 10.1038/s41567-023-02023-5