Big Time Crystals in a Bouncing BEC

Chamali Gunawardana[1], Ali Zaheer[1], Arpana Singh[1], Tien Tran[1], Satoshi Tojo[1,2], Krzysztof Giergel[1,3], Andrei Sidorov[1], Krzysztof Sacha[3], Peter Hannaford[1]

[1] Optical Sciences Centre, Swinburne University of Technology, Melbourne, Australia
[2] Chuo University, Tokyo, Japan
[3] Institute of Theoretical Physics, Jagiellonian University, Krakow, Poland

Discrete time crystals created in a Bose-Einstein condensate (BEC) bouncing resonantly on a periodically driven atom mirror can involve dramatic breaking of discrete time translation symmetry [1] with response periods up to s ≈ 100 times the driving period T [2]. This allows the creation of big time crystals having a large number of temporal lattice sites. By choosing suitable Fourier components in the periodic driving of the atom mirror, such a system enables effective potentials to be constructed in time lattices with nearly any shape, which provides a flexible platform for realising a broad range of condensed matter phenomena in the time dimension. Predicted phenomena include topologically protected edge states in time, Mott insulator states in the time dimension, and time crystals exhibiting temporal disorder, quasi-crystalline order and exotic long-range interactions [3].

Here, we report experimental progress towards creating big time crystals in a bouncing potassium-39 BEC system. The BEC is prepared in a 1064 nm crossed optical dipole trap above an oscillating 532 nm light-sheet atom mirror, which is driven with frequency corresponding to the selected s : 1 resonance for a given drop height and with amplitude adjusted to produce stable resonance islands located around periodic orbits with period sT. The BEC is then released from the optical dipole trap to fall on to the oscillating mirror under strong transverse confinement. When the particle interaction is raised above a critical value to spontaneously break the time-translation symmetry, a stable localized wave-packet evolves without tunnelling to other wave-packets, i.e., a discrete time crystal is formed.

1. K. Sacha, *Phys. Rev.* A **91**, 033617 (2015).
2. K. Giergiel, T. Tran, A. Zaheer, A. Singh, A. Sidorov, K. Sacha and P. Hannaford, *New J. Phys.* **22**, 085004 (2020).
3. K. Sacha, *Time Crystals*, Springer (2020).