Spontaneous Symmetry Breaking in a Discrete Space-Time Crystal

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We have created a cigar-shaped Bose-Einstein condensate, in which we excite a radial breathing mode that drives a high-order axial mode through the non-linear interaction. We observe that the excited axial mode oscillates with a period doubled with respect to the drive, is robust to small fluctuations in the system, and oscillates with negligible dissipation, which are all properties of a discrete time-crystal. Since the axial mode has a well-defined spatial periodicity, we have observed a space-time crystal [1]. Our system is free of disorder, which precludes many-body localization as the mechanism which prevents heating. No appreciable heating is observed over the entire experimental run, even when the system is probed after a long time, and it is concluded that our observed space-time crystal is a pre-thermal phase of the system. By studying the underlying Lagrangian, equations of motion are derived which describe both growth of the crystal and the amplitude of the crystal at saturation in the experiment [2]. The phase lag ϕ of the space-time crystal with respect to the drive is determined in the model up to a factor π with the two solutions having equal energy. By studying the statistics, the solutions ϕ and $\phi+\pi$ show a 50/50 split. From this we conclude the two-fold $\mathbb{Z}_2$ symmetry is spontaneously broken.

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