Observation of quantum phase-synchronization in a nuclear spin-system

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Inspired by the ubiquity and stability of classical synchronization, quantum synchronization has been field of intense study. Studies have shown fundamental implications of quantum synchronization to other fields such as entanglement generation, thermodynamics, etc. To study synchronization, the quantum analogue of phase space is constructed using quasiprobability distributions such as Husimi function and Wigner function, from which measures of synchronization are developed. These measures help establish a valid limit cycle that is robust against external perturbations and possesses a neutral free phase, and exhibits phase-localization upon synchronization. Experimental demonstration of quantum synchronization is in general challenging since measurements typically require the system to settle into a steady state, which necessitates the need for long waiting times. Such long wait times allow for other experimental noise sources to interfere with the signal. Besides this, tomographic reconstruction of the state scales exponentially with the system size, making experimental studies further cumbersome.

Here, we present an experimental study of phase-synchronization in a pair of interacting nuclear spins subjected to an external drive in NMR architecture. A weak transition-selective radio-frequency field applied on one of the spins is observed to cause phase-localization, which is experimentally established by measuring the Husimi distribution function under various drive conditions. We have developed a general interferometric technique to directly extract values of the Husimi function via the transverse magnetization of the undriven nuclear spin, bypassing the need for state tomography. We further verify the robustness of synchronization to detuning in the system by studying the Arnold tongue behaviour. This work opens up avenues for studying the implications of synchronization in areas such as spectroscopy, quantum computing and quantum thermodynamics.

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