Quantum synchronization and decoherence

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Synchronization, a universal phenomenon in a broad spectrum of complex systems, has been recently explored in the quantum regime also in relation to quantum correlations. After reviewing the role of dissipative couplings on synchronization, optomechanical devices and an application of synchronization for quantum probing will be presented.

When considering systems composed by many components, the emergence of spontaneous synchronization is a rather robust and universal phenomenon, paradigmatic in physical, biological, chemical and social complex systems [1]. More recently it has been considered also in the quantum regime, where the same definition of this phenomenon is still an open question that has given rise to several approaches (see review [2]).

The phenomenon of spontaneous or mutual synchronization refers to the ability of two or more systems, that would display different dynamics when separate, to evolve coherently when coupled. This corresponds to achieving oscillation at a common frequency in the case of oscillatory dynamics, but generalization are well-known in chaotic systems and in presence of noise. In the quantum regime also non-classical effects, in particular entanglement and quantum correlations, become relevant, beyond the dynamical ones.

Mutual synchronization was predicted for spins interacting with a common bath [3] and for the average positions of quantum optomechanical systems [4]. Quantum synchronization in quantum observables in connection with classical and quantum correlations was reported in harmonic networks [5] where it was established that dissipation can induce the emergence of transient and asymptotic synchronization, even in linear systems. The key condition is that dissipation does not act independently and equivalently on all units, but comes from a common or structured environment. Furthermore, the impossibility of a purely dephasing (common) bath to induce synchronization among decoupled spins was shown in [6] confirming the key role of dissipation. This plays a key role also on super-radiance (when a common light environment is present), a collective phenomenon recently related to quantum synchronization among detuned atoms [7].

Dissipative couplings can be present in different platforms due to the presence of a bulk environment [8] and in particular can arise in optomechanical systems, favoring synchronization and entanglement [9]. The presence of synchronization, a part from being a spontaneous dynamical effect naturally appearing when miniaturizing and increasing the number of components of quantum devices, can also represent a tool in applications [10]. A recent proposal of an application of quantum synchronization deals with probing the features of an out-of-equilibrium qubit not accessible by direct measurement and coupled (en eventually synchronizing) with an external one [11].

Work funded from EU project QuProCS (Grant Agreement No. 641277), MINECO and FEDER (Grant No. FIS2014-60343-P).

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