Spontaneous synchronization and asymptotic entanglement in coupled optomechanical systems dissipating into a common bath

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Coupled physical systems can dissipate collectively into the same environment or common bath, a situation that is known to enable physical phenomena such as decoherence free subspaces, asymptotic entanglement or collective synchronization, amongst others. This dissipation scenario is the opposite of the usually considered separate baths scheme, in which the units of the system dissipate into different uncorrelated thermal baths. The conditions for collective dissipation have been recently established in structured environments [1] in a general theoretical framework.

In this work we consider two mechanically coupled optomechanical systems. Dissipative couplings induced by collective dissipation can arise due to the elastic radiation propagating in the surrounding crystal and have not been characterized so far. Here we analyze the effects of common dissipation onto two different physical phenomena. Firstly, we study the emergence of synchronization between the mechanical oscillators, and we compare the results with the ones of previous studies in which separate mechanical dissipation was considered. In particular we show that collective mechanical dissipation enlarges the region in which spontaneous synchronization can be found. Secondly, we study the presence of entanglement between the mechanical modes in the asymptotic state, below the threshold self-sustained oscillations. Asymptotic entanglement between the mechanical mode and the optical one is known to arise in single optomechanical systems. Here we study the novel cases of mechanically coupled devices dissipating both in common and separate mechanical baths. We report asymptotic entangled states in both cases, and we analyze the strong relation between the presence of entanglement and the degree of optomechanical cooling of the oscillators. Again we find that collective dissipation enhances the presence of asymptotic entanglement in the studied parameter region. We finally explore the presence of quantum synchronization in this regime.

[1] F. Galve, A. Mandarino, M. G. A. Paris, C. Benedetti & R. Zambrini, Scientific Reports **7**, 42050 (2017).

[2] G. Heinrich, M. Ludwig, J. Qian, B. Kubala, F. Marquardt, Phys. Rev. Lett. **107**, 043603 (2011).

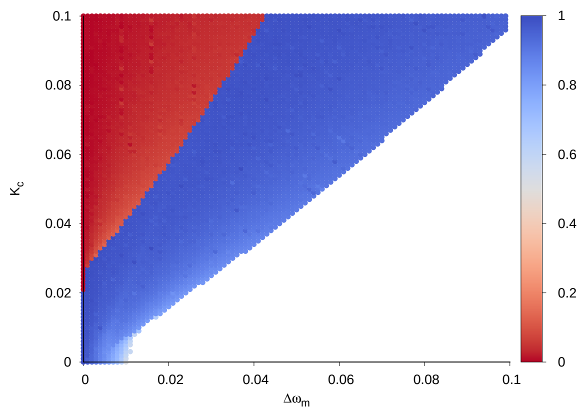

Figure 1: Synchronization diagram for two mechanically coupled optomechanical oscillators dissipating into a common bath: white region corresponds to unsynchronized oscillations, red and blue regions correspond to synchronized oscillations. The phase difference $|\delta\varphi|$ at which the mechanical oscillations lock is encoded in the color scale: dark blue regions correspond to anti-phase synchronization ($|\delta\varphi| = \pi$), dark red regions to in-phase synchronization ($|\delta\varphi| = 0$). The map is obtained varying the mechanical coupling strength K_c and the mechanical frequency detuning $\Delta\omega_m$. The other parameters are fixed to the same values as Ref. [2] in order to compare the results with the ones obtained considering separate mechanical dissipation. In particular the fixed parameter values are: $\mathcal{P}_1 = \mathcal{P}_2 = 0.36$, $\Gamma_1 = \Gamma_2 = 0.01$, $x_{01} = x_{02} = 1$, $\omega_{m1} = 1$ and $\omega_{m2} = \omega_{m1} + \Delta\omega_m$.