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Decoherence in analogue preheating experiment

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In the leading paradigm of cosmology the elementary particles are created at the end of a period of accelerated expansion (inflation). Part of this process is expected to proceed via parametric resonance [1]. If the fields are initially in their vacuum state, this phenomenon is of purely quantum origin and similar to a dynamical Casimir effect (DCE).

The predicted quantum origin seems hard to test in the cosmological context but quantum simulation experiments of it have been realized. Ref. [2] reports on such an experiment in an elongated cigar-shaped Bose-Einstein condensate (BEC). The BEC is periodically modulated and acts as a classical field exciting its own quantum perturbations (phonons), which are created in correlated pairs in number $n_k = \langle b_k^\dagger b_k \rangle$. Entanglement of the generated pairs is known to be a signature of pair production seeded by vacuum fluctuations [3] but is also fragile.

Indeed, in [2] the observed pair correlation $c_k = \langle b_k b_{-k} \rangle$ was much weaker than expected and far from the regime $n_k - c_k < 0$ indicating entanglement. It was shown in [3] that a weak dissipation could account for this absence. In [4] a numerical study of the system confirmed the presence of an effective dissipation mediated by nonlinear interactions between phonons when the number of created pairs is large. The resulting loss of entanglement was shown to occur relatively rapidly, being the first departure from the ideal DCE scenario.

We will present an analysis of non-linear processes leading to decoherence in the case of a one-dimensional quasi-condensate in connection with [2,3,4]. The focus will be on small numbers of produced pairs, where the chance of observing entanglement is optimized [4].

[1] D. Figueroa and F. Torrentí, JCAP02(2017)001 (2016)
[2] J.-C. Jaskula *et al.*, *Phys. Rev. Lett.* **109**, 220401 (2012)
[3] X. Busch, R. Parentani and S. Robertson, *Phys. Rev. A* **89**, 063606 (2014)
[4] S. Robertson, F. Michel and R. Parentani, *Phys. Rev. D* **98**, 056003 (2018)

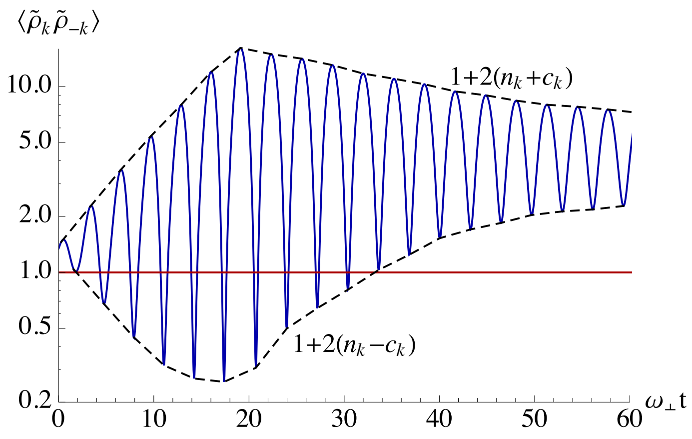

Figure 1: Typical behavior of the rescaled density-density correlation, as a function of time, for a phonon mode *k* in resonance with the modulation of the condensate. The phonons are entangled whenever the lower envelope is below 1 [4], indicated here by the red line. The modulation creates entangled phonons, and afterwards (here, $\omega_\perp t > 20$) we observe decoherence and eventual loss of entanglement. Experimental parameters are close to those of [2], but with a temperature about an order of magnitude smaller.