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Particle and entanglement production in an analogue preheating experiment

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In the leading paradigm of cosmology, most particles are created during a reheating period following inflation. Part of this creation proceeds via parametric resonance [1], a process referred to as preheating. Since inflation dilutes any pre-existing particles, the relevant fields are initially in their vacuum state and particle production is seeded by vacuum fluctuations, a phenomenon of purely quantum origin similar to the dynamical Casimir effect (DCE).

While the predicted quantum origin seems hard to test in the cosmological context, experiments involving genuine quantum fields evolving under similar dynamics have been realised. Ref. [2] reports on such an experiment in an elongated cigar-shaped Bose-Einstein condensate (BEC). The BEC is modulated in time and acts as a strong classical field exciting its own quantum perturbations, created in pairs of opposite momenta ±k. 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 correlations were much weaker than expected and far from the regime indicating entanglement.

In a series of publications, the theoretical description behind the experiment was re-analysed in increasing detail to account for the absence of entanglement. First, in [3], weak dissipation of the excitations was phenomenologically introduced and shown to be able to prevent the generation of entanglement. Fully nonlinear numerical studies of the modulated gas based on the Truncated Wigner Approximation (TWA) were then conducted [4,5]. These confirmed that phonon-phonon interactions can induce an effective dissipation acting against the parametric resonance and degrading or indeed destroying the induced entanglement. In [6], the dominant interaction channel for small occupation numbers in 1D quasi-BEC was identified as Beliaev-Landau scattering between the resonant mode and the thermal population. The associated dissipation rate was analytically derived and checked against TWA simulations. Most recently [7], it has been shown that the phenomenological model of [3], when supplemented by the rate derived in [6], accurately reproduces the dynamics seen in TWA simulations akin to those of [5].

In this talk, I will recount the above history and describe the dynamics at play, emphasising the subtle interplay between growth and dissipation that leads to distinct regimes of particle and entanglement production. Implications for experimental optimisation will also be discussed.

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