OSCILLATORS DRIVEN TO NONCLASSICALITY BY ABSORPTION

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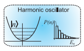
THE PLAY:

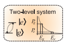
We are interested in generating nonclassicality in thermal equilibrium states by methods which are feasible and deterministic. We show that it can be accomplished by passive interaction between a continuous and a discreet system if their temperatures are different [1,2].

THE ACTORS:



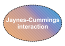
Quantum harmonic oscillator. Represents state of motion of a trapped ion, but can be also used to model a collective spin of cloud of atoms, optomechanical oscillator, or a single mode of electromagnetic field.

$$\hat\rho_{HO} = \sum_{n=0}^{\infty} \frac{\bar n^n}{(\bar n+1)^{n+1}} |n\rangle\langle n| \qquad \bar n = \left[\exp(\frac{\hbar\omega}{k_B T_{HO}}) - 1\right]^{-1}$$



Two-level system. Represents internal energy levels of a trapped ion. Can also model an atom in cavity QED or a polarization state of a single photon.

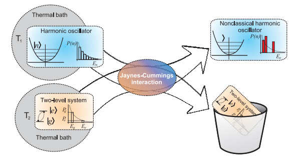
$$\hat\rho_{TLS} = p_e|e\rangle\langle e| + (1-p_e)|g\rangle\langle g| \qquad p_e = \left[\exp(\frac{\hbar\omega}{k_B T_{TLS}}) + 1\right]^{-1}$$



Jaynes-Cummings interaction. The elementary coupling facilitating energy transfer between the oscillator and the two level system in a wide range of physical configurations.

$$\hat H_{JC} = g\,(\hat a^\dagger \otimes |g\rangle\langle e| + \hat a \otimes |e\rangle\langle g|)$$

THE STAGE:



The systems are in a thermal equilibrium states with temperatures T_1 and T_2. They interact and the two level system is discarded.

Nonclassicality is a property of quantum states. Nonclassicality is a necessary prerequisite for advanced application of quantum information, such as quantum computing [3].

Nonclassical states are those that cannot be represented as mixtures of coherent states. They can be recognized by a number of witnesses. Some of them are:

Negative values of Wigner function of the state. For example, $W(0,0) = \mathrm{Tr}\left[\sum_{n=1}^{\infty}(-1)^n|n\rangle\langle n|\hat\rho\right]$.

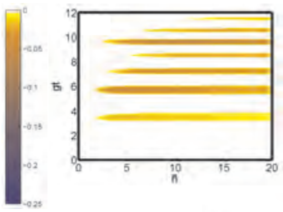
Entanglement potential [4]: $LN(\rho_{split}) = \log_2 ||\rho_{split}^{PT}||$

$$\hat\rho_{\rm split} = e^{\frac{\pi}{4}(\hat a\hat b^\dagger - \hat a^\dagger \hat b)} \rho_{out} \otimes |0\rangle\langle 0| e^{-\frac{\pi}{4}(\hat a\hat b^\dagger - \hat a^\dagger \hat b)}$$

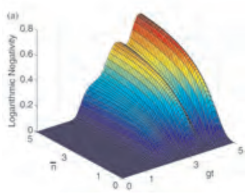
Number distribution not satisfying classicality conditions [2,5].

ACT I: PURE ABSORPTION

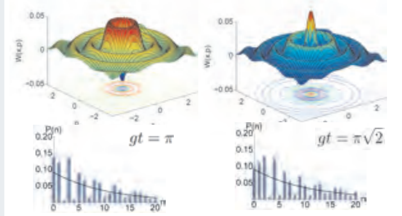
Here we show that a nonclassical state of the oscillator can be obtained through absorbtion by a single two level system, which is initially in the ground state.



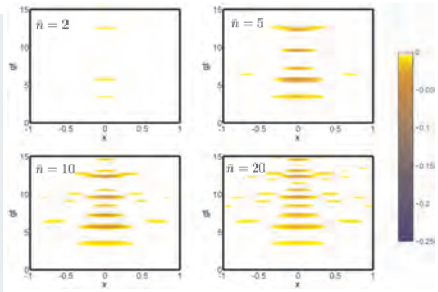
For specific values of the interaction constant gt, the Wigner fuction at the origin, W(0,0) shows negativity for all initial temperatures of the oscillator.



The logarithmic negativity of the split state, however, is strictly positive once $gt > \frac{\pi}{2}$



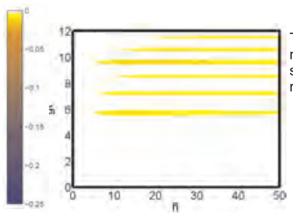
Specific examples of the the generated Wigner functions and the respective number distributions for $\bar n = 10$.



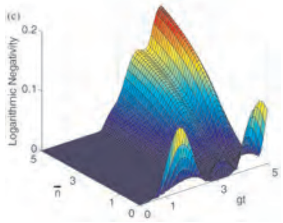
Here we see the cut through the Wigner function of the generated state, W(x,0). As the initial temperature of the oscillator increases, the Wigner function of the produced state shows more intricate patterns. This goes well in hand with increase of nonclassicality represented by the logarithmic negativity potential.

ACT II: ENERGY EXCHANGE

The two level system is now in a thermal equlibrium state with $p_e = 0.3$



The Wigner function still shows negativity at W(0,0), even though it is smaller and the number of negative regions has diminished.



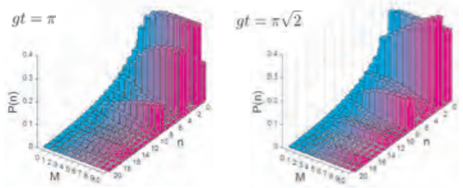
The logarithmic negativity now exhibits two different regions. For small n, temperature of the TLS is higher than that of the oscillator and nonclassicality appears for almost all values of gt. This corresponds to emission of a single quantum of energy.

For high n, the oscillator experiences absorption similarly as in ACT I., even though the nonclassicality values are smaller.

When the temperatures of the systems are equal, no nonclassicality is generated.

ACT III: WHY DOES IT WORK?

Each absorption, apart from reducing the overal energy, also redistributes it among the number states. Each state is affected differently and this leads to generation of a nontrivial number distribution.



For values $gt = \pi\sqrt{k}$, some number states do not decay and, after M times repeated absorptions, the state converges to $\hat\rho = \sum_{n=0} p_n |kn^2\rangle\langle kn^2|$, which is a strongly nonclassical state.

ACKNOWLEDGEMENTS AND REFERENCES

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[1] Opt. Express **24**, 7858 (2016).
[2] Phys. Rev. A **94**, 013850 (2016).
[3] Phys. Rev Lett. **109**, 230503 (2012); Rev. Mod. Phys. **84**, 621 (2012).
[4] Phys. Rev. A **65**, 032314 (2002); Phys. Rev. Lett. **94**, 173602 (2005); Phys. Rev. Lett. **95**, 090503 (2005).
[5] Phys. Lett. A **213**, 7 (1996).