Preparing a mechanical oscillator in a nonclassical state

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Review I

Experimental

- Electromechanical Entanglement [1]
- Mechanical Squeezing [2]
- (Close to the) Ground State Cooling [3]
- Nonclassical Photon-Phonon Correlations [4]

Proposals

- Nonclassical states with help of photon counting [5]
- Opto- (Electro-) mechanical Bell test [6]

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[1] Palomaki et al., Science, **342**, 710 (2013).
[2] Lei et al., PRL, **117**, 100801 (2016), Pirkkalainen et al., PRL, **115**, 243601 (2015).
[3] Chan et al. Nature, **478**, 89 (2011), Teufel et al. Nature, **475**, 359 (2011).
[4] Riedinger, Hong et al. Nature, **530**, 313 (2016).
[5] Sekatski et al., PRL, **112**, 080502 (2014), Galland et al., PRL, **112**, 143602 (2014).
[6] Vivoli et al., PRL, **116**, 070405 (2016), Hofer et al., PRL, **116**, 070406 (2016).

Review II

Reviews

- Hammerer, K. et al. in Cavity Optomechanics (eds. Aspelmeyer, M., Kippenberg, T. J. & Marquardt, F.), 25–56 (Springer Berlin Heidelberg, 2014).
- Genes, C. et al. in Advances In Atomic, Molecular, and Optical Physics (eds. Ennio Arimondo, Paul R. Berman & C. C. Lin) **57**, 33–86 (2009).

Paths to nonclassicallity starting from Gaussian states

$$H_{om} = -\hbar g(a_c^\dagger + a_c)(a_m^\dagger + a_m)$$

- ~~Nonlinear interaction~~
- Nonlinear detection
- Nonclassical input state

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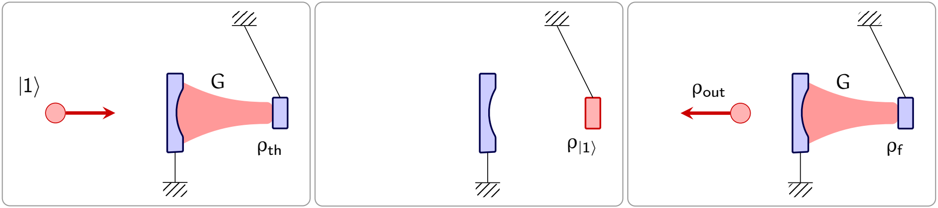
Nonclassical state $|1\rangle$ as input



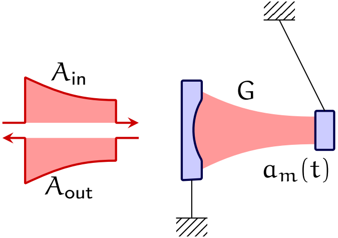
Upload Storage Read out

Pulsed optomechanics

Hofer et al., PRA, **84**, 052327 (2011)

$$A_{out} = \sqrt{1-T}A_{in} \qquad +\sqrt{T}a_m(0),$$
$$a_m(\tau) = \sqrt{1-T}a_m(0) \qquad +\sqrt{T}A_{in}$$

$$T = 1 - \exp(-G\tau)$$



Requirements

- Pumping on lower mechanical (Red) sideband $\omega_{pump} = \omega_{cav} - \omega_m$
- Resolved sideband $\kappa \ll \omega_m$

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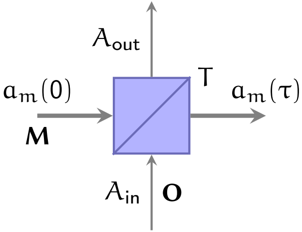

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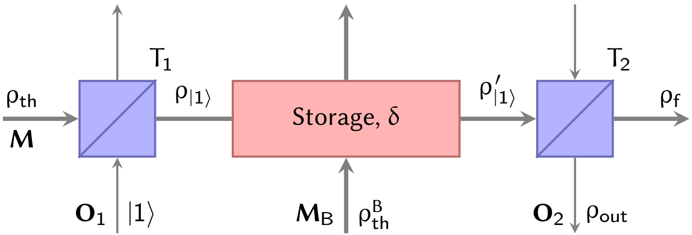
The Equivalent Scheme



- Mechanical bath admixes thermal noise, δ

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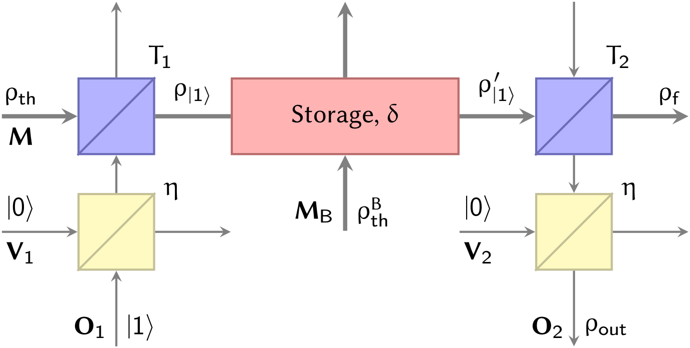

- Mechanical bath admixes thermal noise, δ
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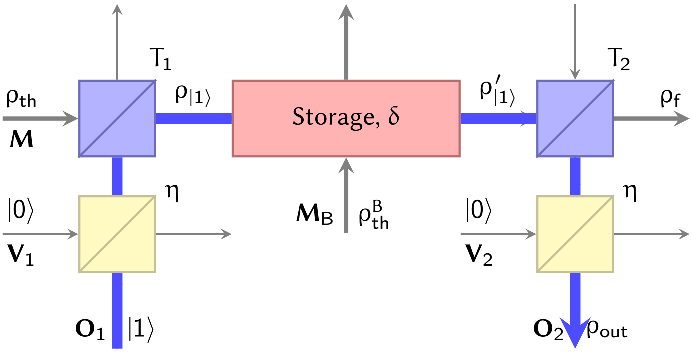

- Mechanical bath admixes thermal noise, δ
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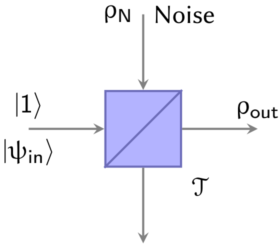
Channel from $\mathbf{O}_1$ to $\mathbf{O}_2$

$$|1\rangle\langle 1| \mapsto \rho_{out}$$

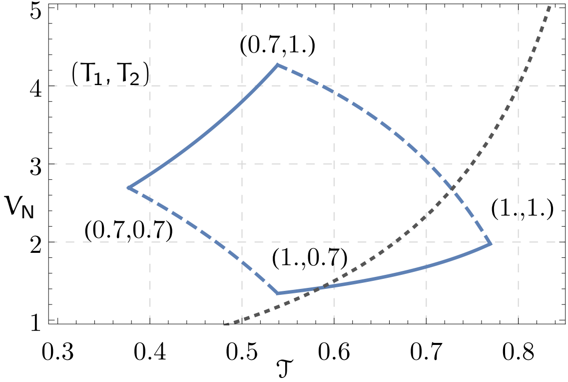
The Optomechanical Channel



$$Q^{out} = \sqrt{\mathcal{T}} Q^{in} + \sqrt{1-\mathcal{T}} Q^{N},$$
$$Q = X, Y$$
$$V_N = \sqrt{\mathrm{Var}\left(X^N\right) \times \mathrm{Var}\left(Y^N\right)}.$$

$$V_N(\mathcal{T})$$

Analysis of $V_N(\mathcal{T})$



$$\mathcal{T} = T_1 T_2 \eta^2 \delta,$$

$$V_N = 1 + 2n_{th} \frac{\eta T_2 (1 - T_1 \delta)}{1 - \mathcal{T}}.$$

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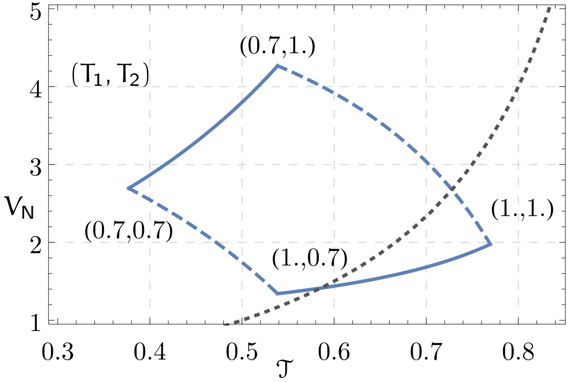

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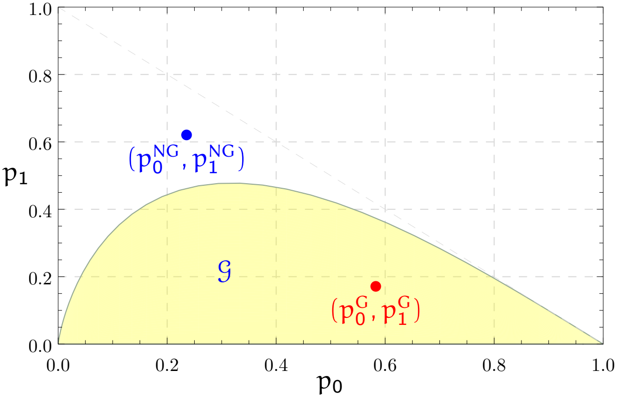
$$\left.\frac{\partial V_N}{\partial \mathcal{T}}\right|_{T_2=\mathrm{const}} = -\frac{4n_{th}\sqrt{T_1 T_2 \delta}(1 - \eta^2 T_2)}{(1-\mathcal{T})^2} \leqslant 0,$$

$$\left.\frac{\partial V_N}{\partial \mathcal{T}}\right|_{T_1=\mathrm{const}} = \frac{4n_{th}\sqrt{T_2}(1 - T_1 \delta)}{\sqrt{T_1 \delta}(1-\mathcal{T})^2} \geqslant 0.$$

Quantum Non-Gaussianity

The criterion of non-Gaussianity[7] specifies maximum single photon detection probability p_1 for a fixed zero-photon detection probability p_0:



$$p_0 = \frac{e^{-d^2(1-\tanh r)}}{\cosh r},$$

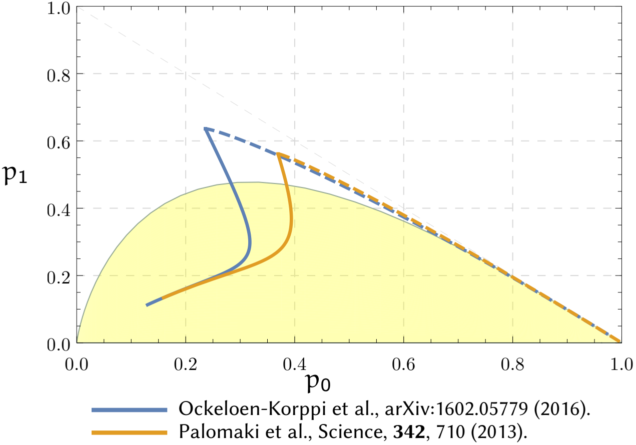
$$p_1 = \frac{d^2 e^{-d^2(1-\tanh r)}}{\cosh^3 r},$$

$$d^2 = \frac{e^{4r} - 1}{4}.$$

$\mathcal{G}$ is the area available to Gaussian states.

[7] Filip and Mišta, PRL, **106**, 200401 (2011), Ježek et al., PRL, **107**, 213602 (2011)

Transfer of Non-Gaussianity



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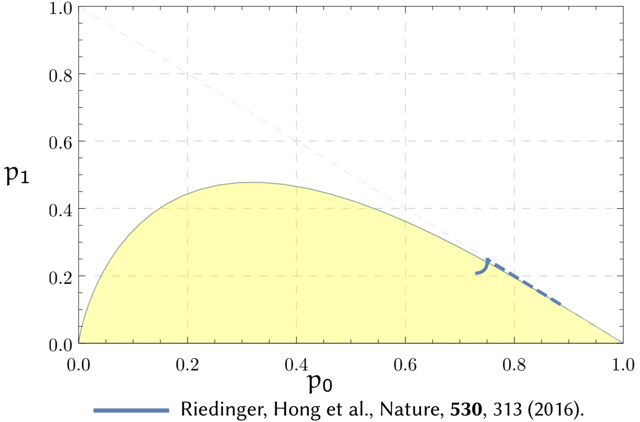

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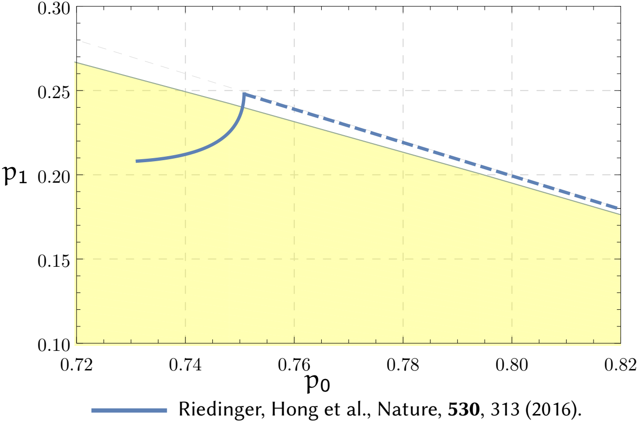
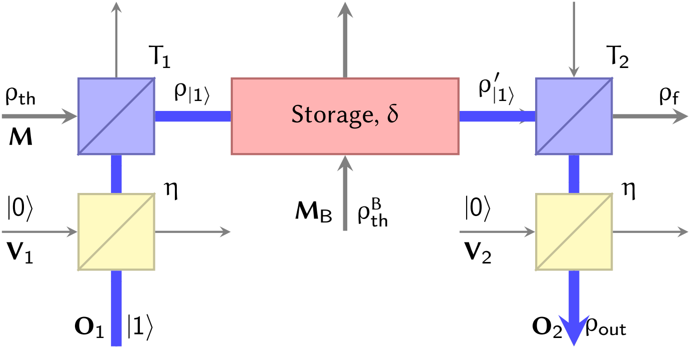
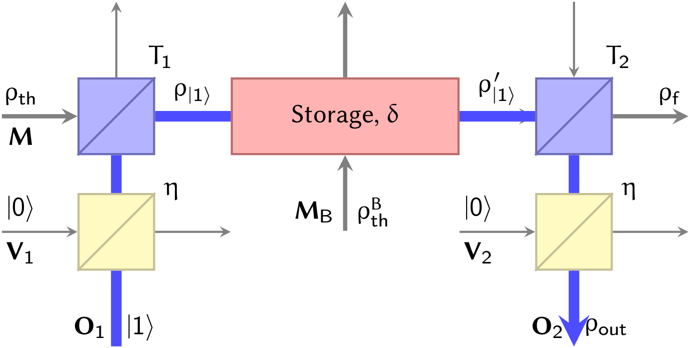


Conclusion



- State of the art electromechanics allows transferring negativity of a single-photon Fock state
- Optomechanics is capable of transferring quantum non-Gaussianity

Conclusion



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Thank You For the Attention!