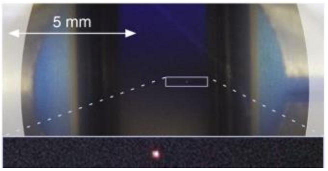
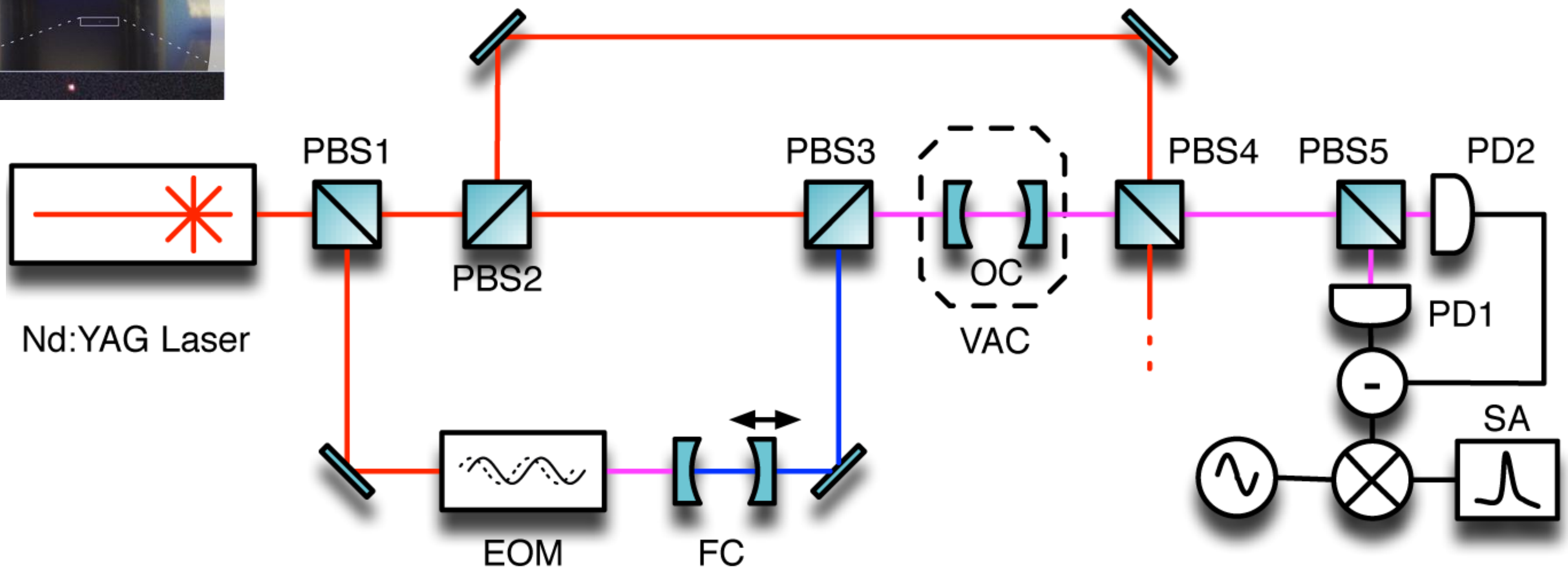
Our Experimental Setup





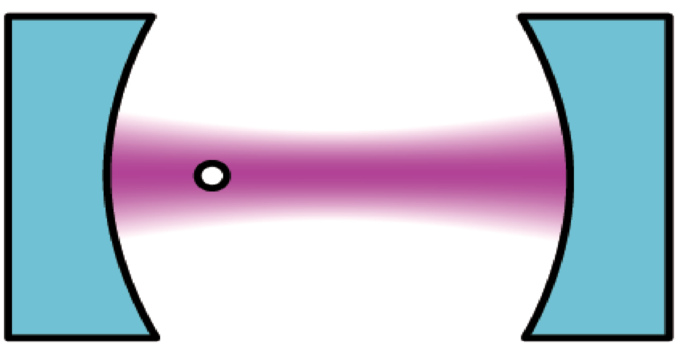
trap

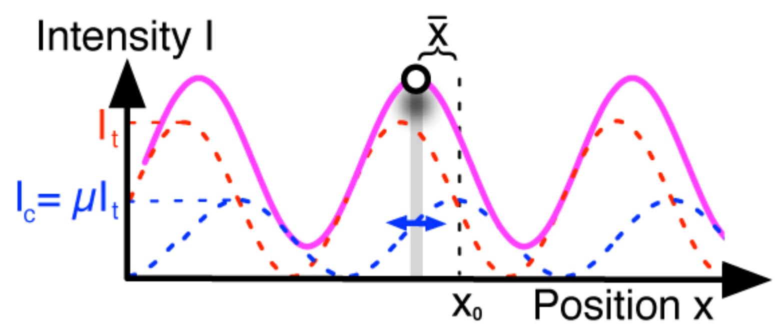
ω_c

$\omega_c + \Delta$

$+FSR$

cooling



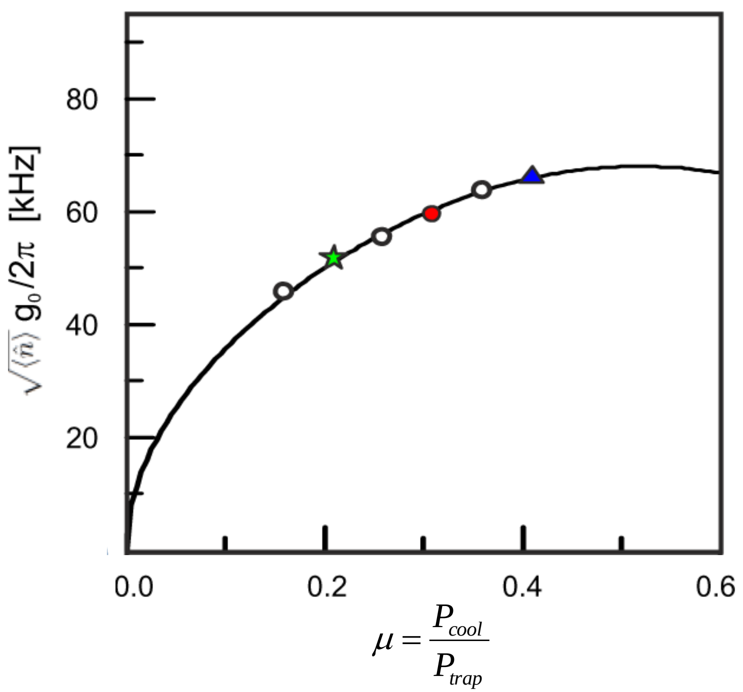


Kiesel, Blaser, Delic, Grass, Kaltenbaek, Aspelmeyer, PNAS 110, 14180 (2013)

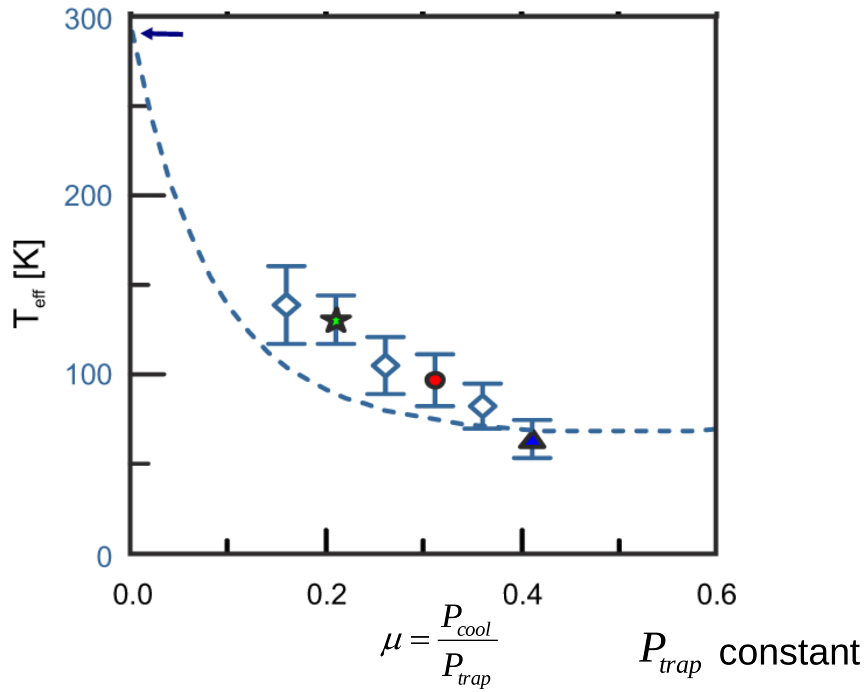
Cooling to approx. 50 K

Kiesel, N. et al., *PNAS 110*, 14180 (2013)

Optomechanical Coupling



Optomechanical Cooling



Cooling rate effectively up to approx. 40 kHz → Pressure range for ground state cooling $p<10^{-7}$ mbar

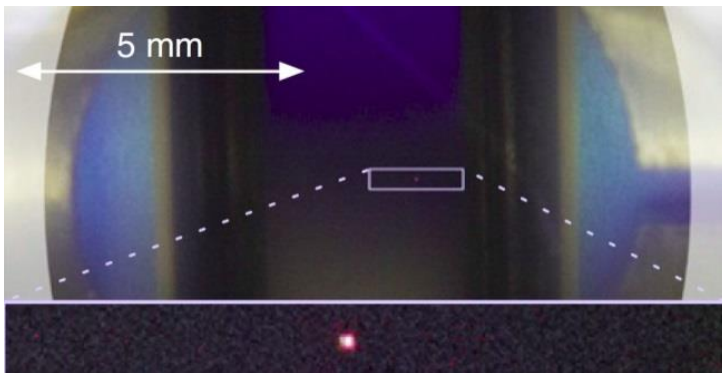
Rates are already comparable typical MHz- Cavity Optomechanics

Limitation currently – particle loss when reducing pressure

Nanoparticle in a cavity

Cavity cooling of a trapped sphere

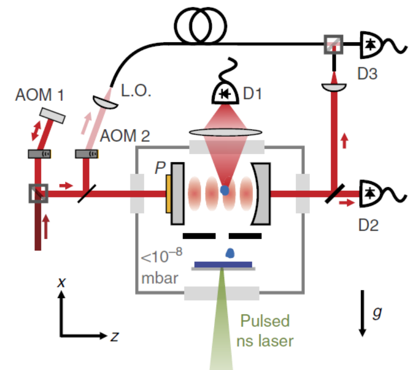
Uni Vienna



Kiesel, Blaser, Delic, Grass, Kaltenbaek, Aspelmeyer, PNAS 110, 14180 (2013)

Cavity cooling of a free particle

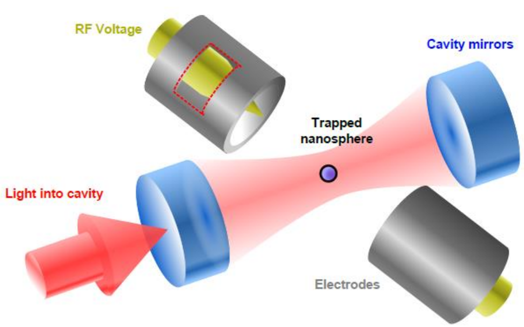
Uni Vienna



Asenbaum et al., Nature Communications 4, 2743 (2013)

Cooling in hybrid electro-optical trap

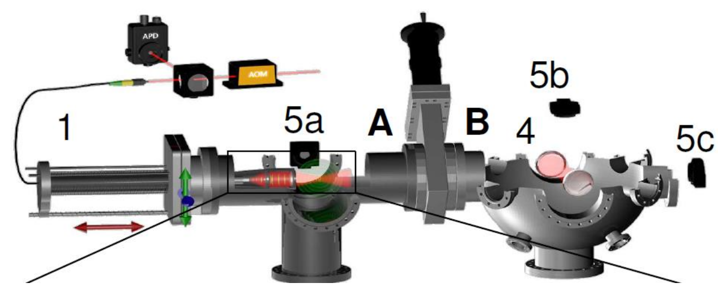
UCL



Millen et al., Phys. Rev. Lett. 114, 123602 (2015)

Transport and cavity transition in UHV

ICFO

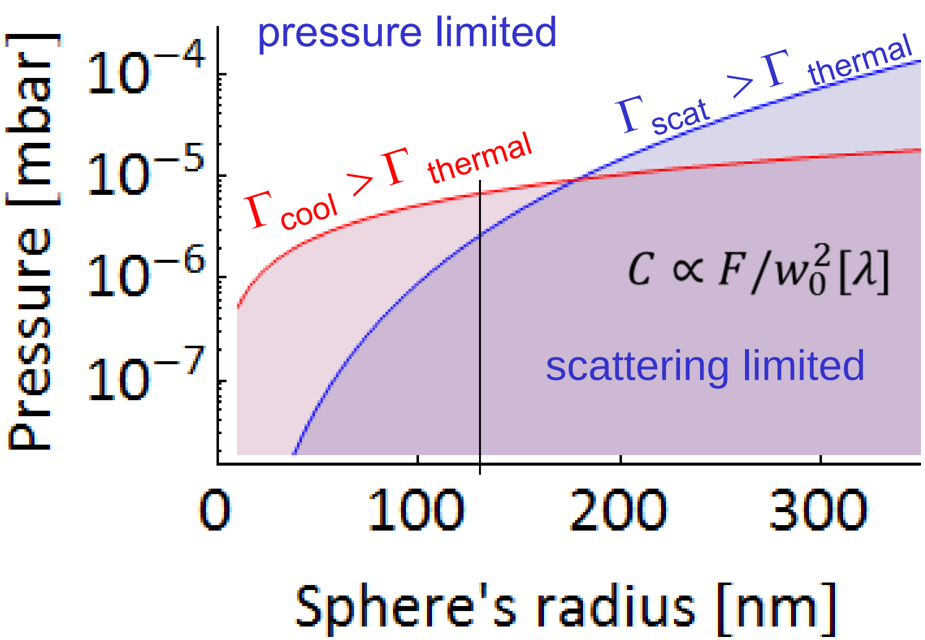


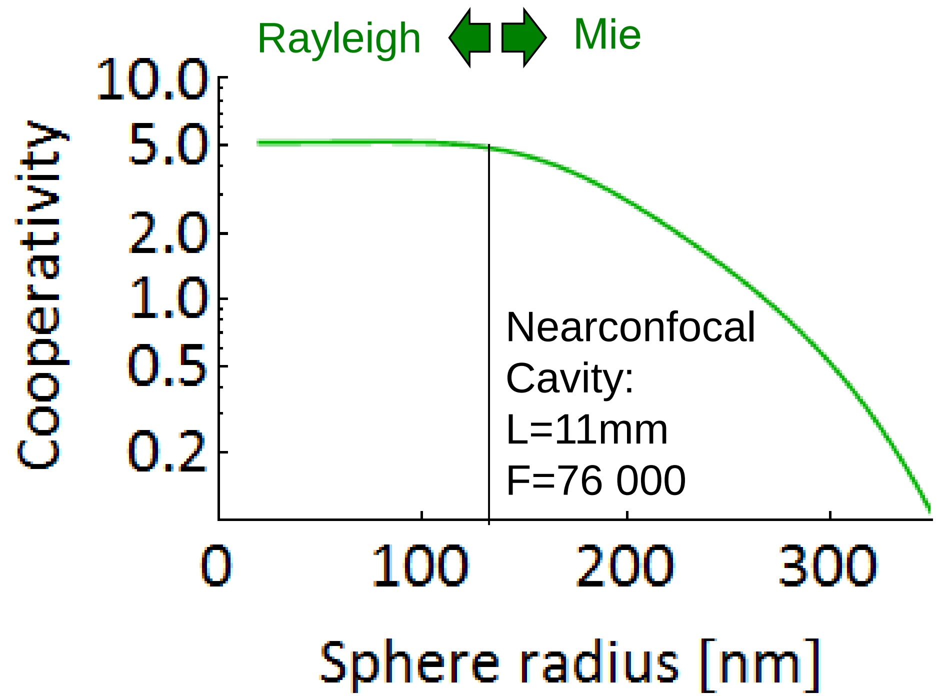
Mestres et al., Appl. Phys. Lett. 107, 151102 (2015)

Towards the quantum regime - Cooperativity

Heating by gas (thermal) and photon (recoil) scattering

$$C = \frac{g^2}{\kappa \Gamma}\ , \qquad \Gamma = \Gamma_{\text{recoil}} + \Gamma_{\text{thermal}} = \Gamma_{\text{recoil}} + n_{\text{th}}\gamma_{\text{th}}$$

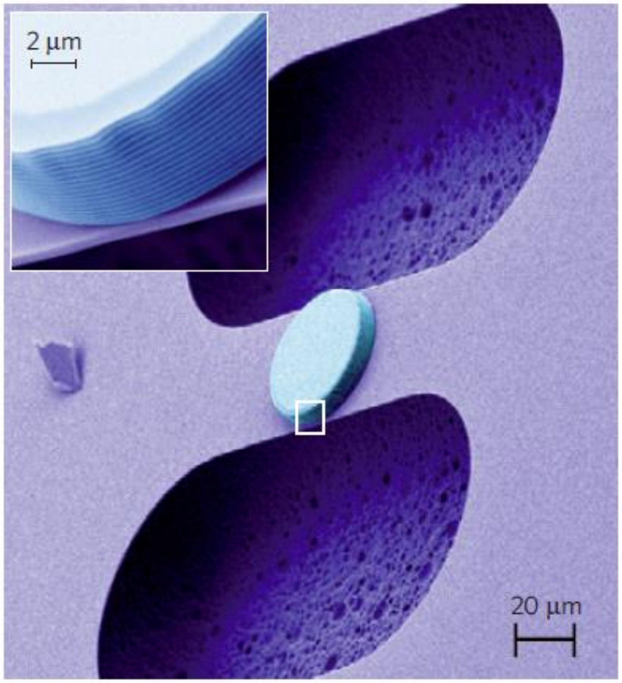




C>1 / ground state cooling achievable, pressure $p < 10^{-6}$ mbar

Using: Pflanzer, A., Romero-Isart, O. Cirac, J, I. PRA 86, 013802 (2012)

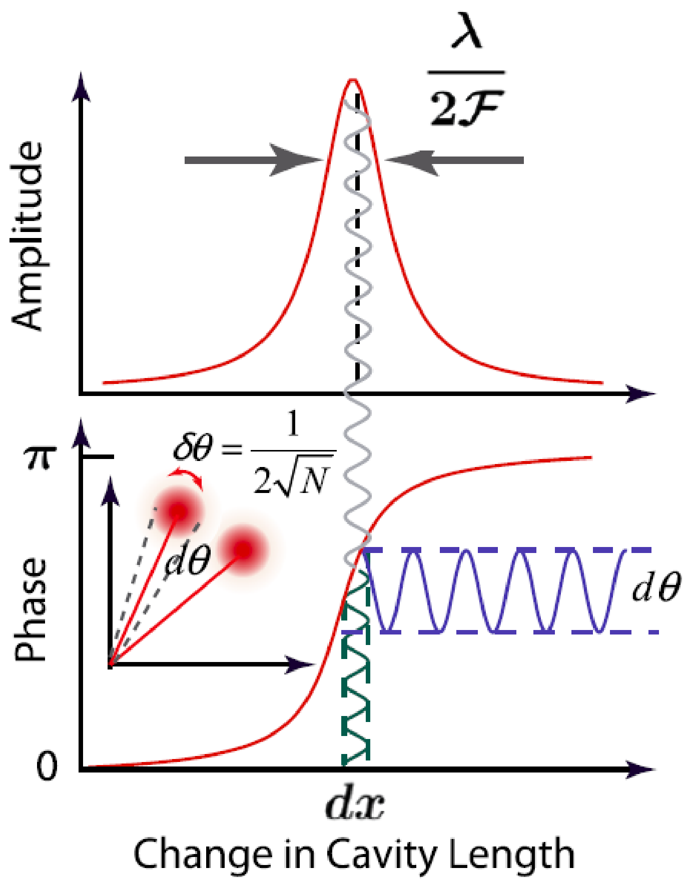
Detection of small displacements

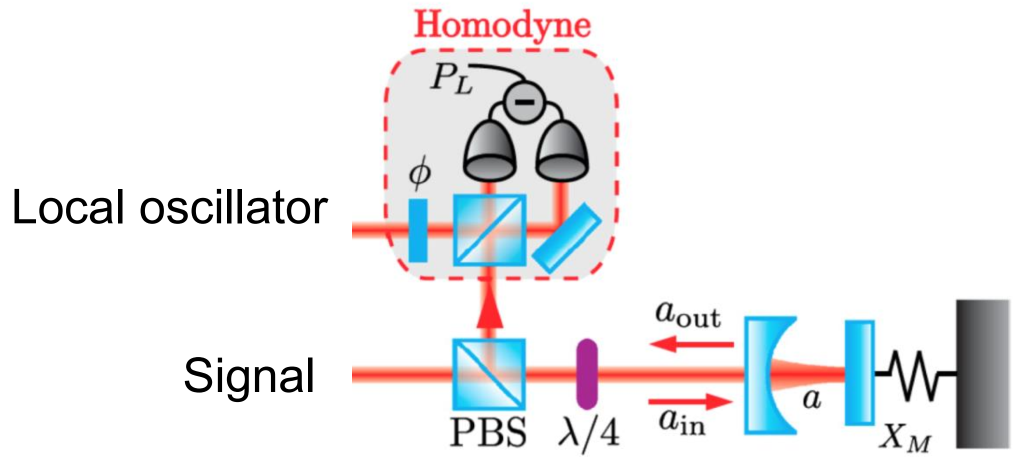


Ground state extension ~ 10^{-16} m

Recent Event:
Strain ~ 10^{-21}
Displacement ~ 10^{-17} m
(LIGO 4km arm length)

Quantum Limited Readout

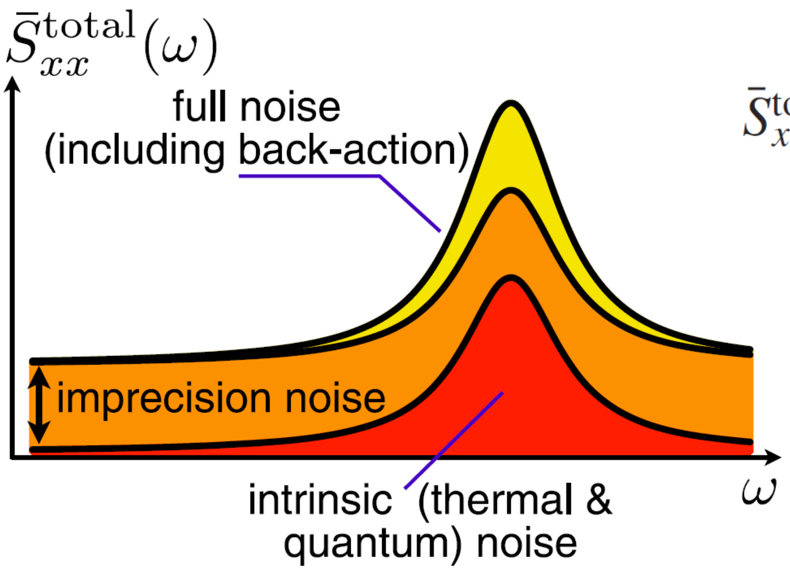


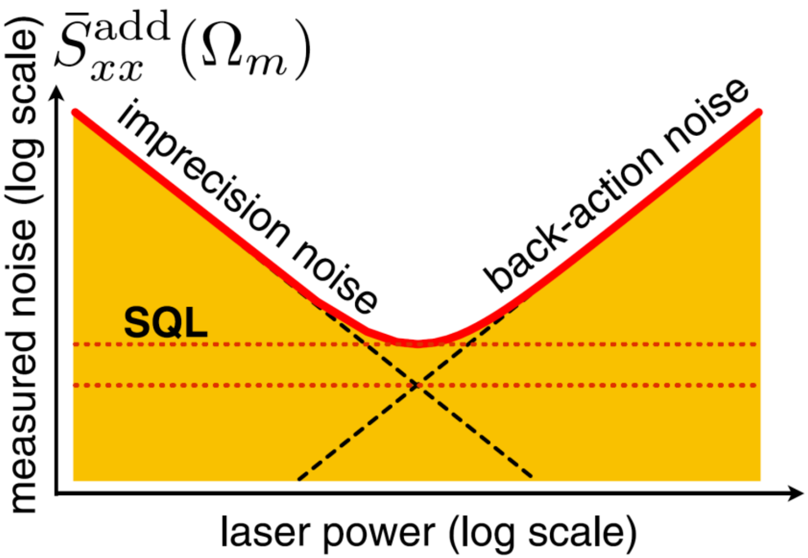


$$\bar{S}_{xx}^{\mathrm{imp}}(\omega) = \frac{\kappa}{16\bar{n}_{\mathrm{cav}}G^2}\left(1 + 4\frac{\omega^2}{\kappa^2}\right)$$

Aspelmeyer, Kippenberg, Marquardt, Rev. Mod. Phys. 86, 1391 (2014)

Readout – What do we want to detect ?





$$\bar{S}_{xx}^{\mathrm{total}}(\omega) = \bar{S}_{xx}^{\mathrm{th}}(\omega) + \bar{S}_{xx}^{\mathrm{imp}}(\omega) + \bar{S}_{FF}(\omega)|\chi_m(\omega)|^2.$$

$$\bar{S}_{xx}^{\mathrm{imp}}(\omega)\bar{S}_{FF}(\omega) \geq \frac{\hbar^2}{4}$$

$$\bar{S}_{xx}^{\mathrm{imp}}(\omega) = \frac{\kappa}{16\bar{n}_{\mathrm{cav}}G^2}\left(1 + 4\frac{\omega^2}{\kappa^2}\right)$$

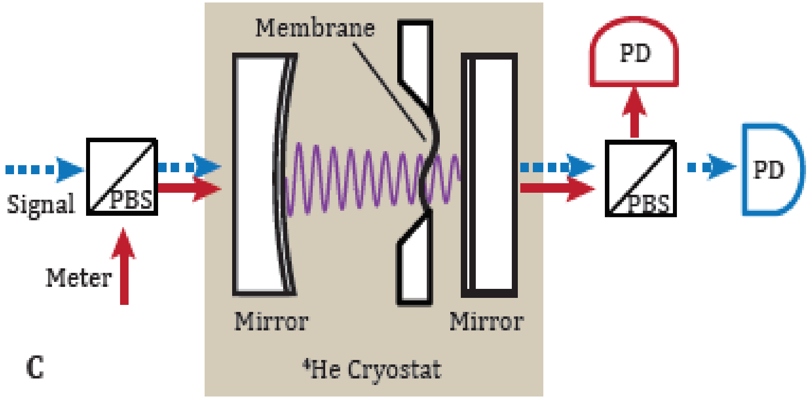
$$\bar{S}_{FF}(\omega) = \bar{n}_{\mathrm{cav}}\frac{4\hbar^2G^2}{\kappa}\left(1 + 4\frac{\omega^2}{\kappa^2}\right)^{-1}$$

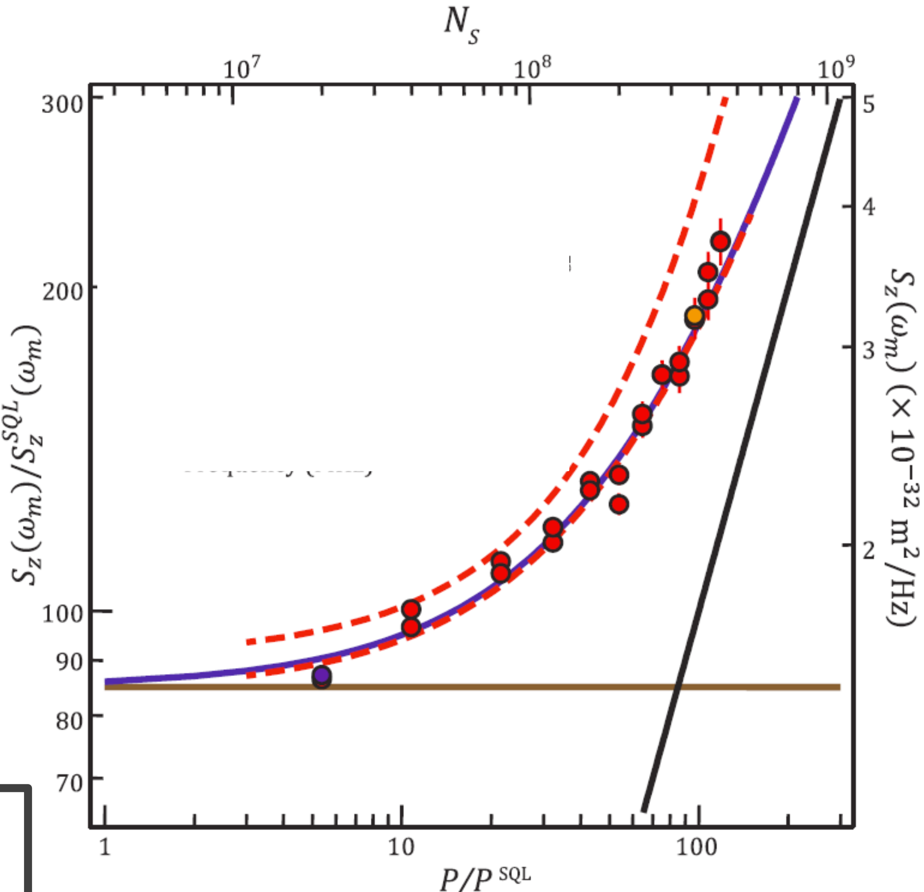
$$\bar{S}_{xx}^{\mathrm{add}}(\Omega_m) = \bar{S}_{xx}^{\mathrm{ZPF}}(\Omega_m) = \hbar/m_{\mathrm{eff}}\Omega_m\Gamma_m$$

Quantum Noise in Massive Systems

Membrane in the middle

Purdy, T. P., R.W. Peterson, and C. A. Regal, Science 339, 801 (2013).





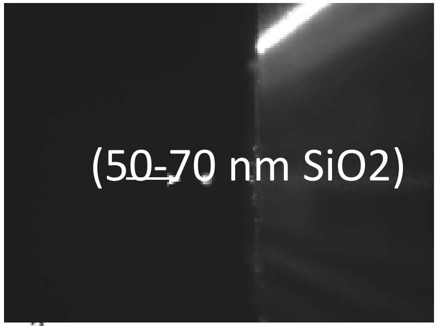
$g_0/2\pi$ = 16.1 +/- 0.3 Hz,	N = 7.0 *10^6,
$\kappa/2\pi$ = 0.89 MHz,	$\omega_m/2\pi$ = 1.551 MHz,
$\Delta_s/2\pi$ = 2.0 +/- 0.5 kHz,	$\gamma_m/2\pi$ = 0.47 Hz
$\Delta_m/2\pi$ = 0.7MHz,	m=7ng, T~5K

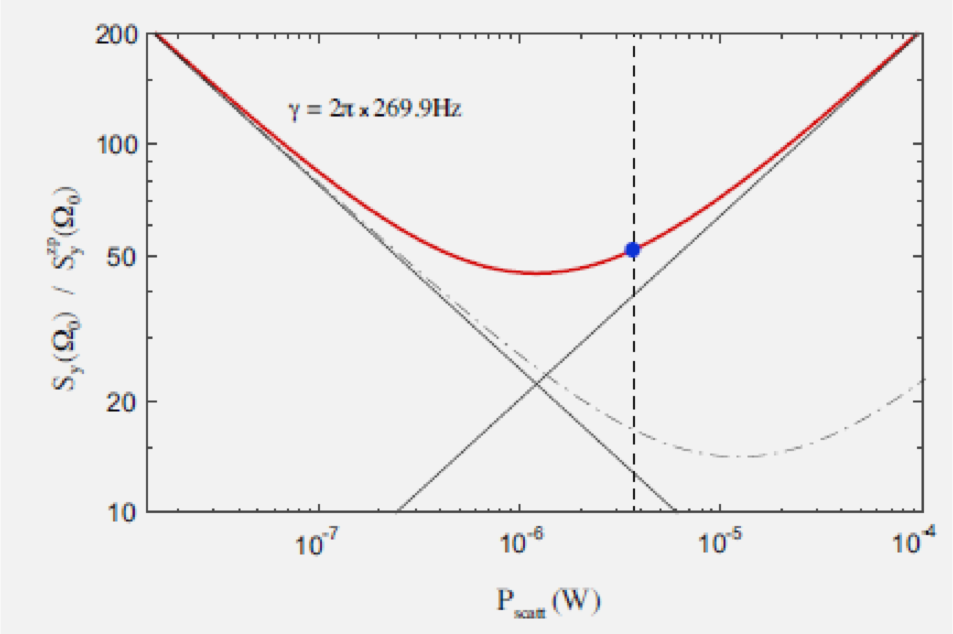
Cold Atoms Murch, K.W., K. L. Moore, S. Gupta, and D. M. Stamper-Kurn, Nat. Phys. 4, 561, (2008)

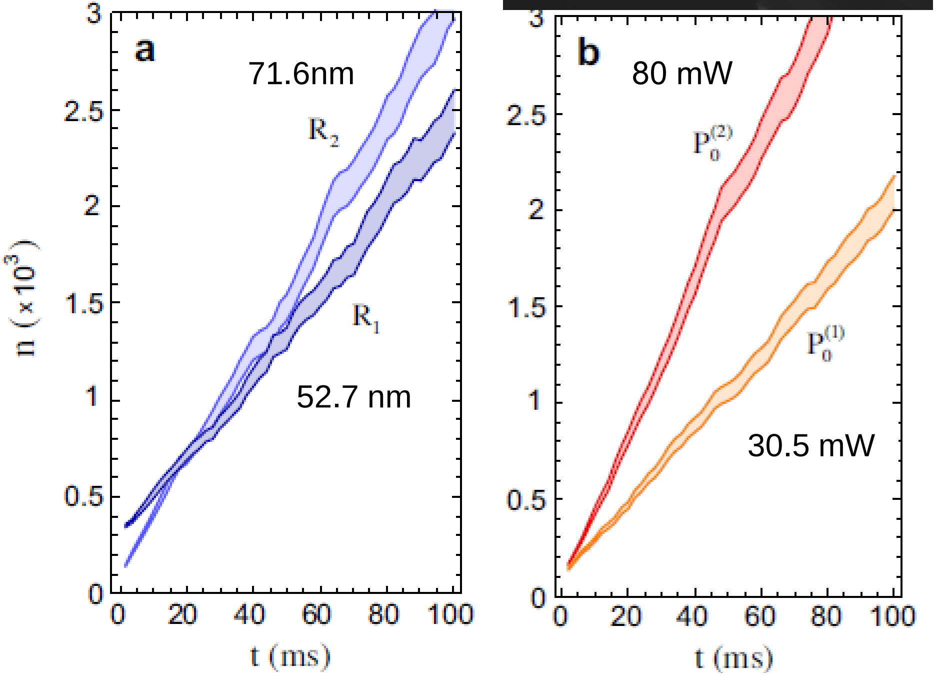
Direct measurement of photon recoil

Direct Measurement of Photon Recoil from a Levitated Nanoparticle

Vijay Jain[1,2], Jan Gieseler[1], Clemens Moritz[3], Christoph Dellago[3], Romain Quidant[4,5], and Lukas Novotny[1*]
[1] *ETH Zürich, Photonics Laboratory, 8093 Zürich, Switzerland.*
[2] *University of Rochester, Department of Physics and Astronomy, Rochester, NY 14627, USA.*
[3] *University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria.*
[4] *ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain. and*
[5] *ICREA-Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain.*
(Dated: March 25, 2016)



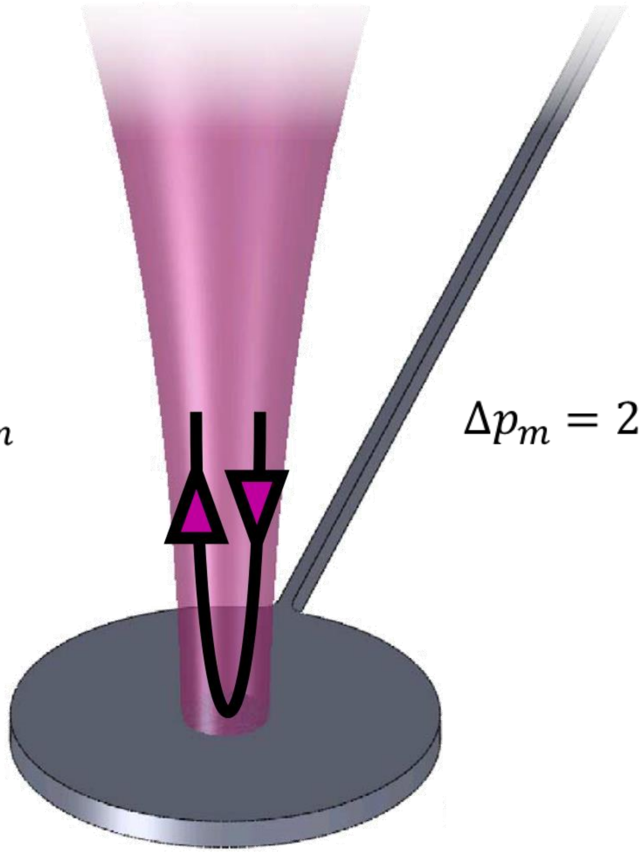




Recoil equilibrium $k_B T_\infty = \hbar\Omega_0 n_\infty \sim \hbar\omega_0$

Pulsed Optomechanics

$$\Delta\varphi = 2\frac{2\pi}{\lambda}\,x_m$$



$$\Delta p_m = 2\frac{\hbar\omega}{c}\,N_{ph}$$

QND Measurement of Position

for short interaction

Measurement with pulses in cavity

Measurement of mechanical position quadrature (X_M) by homodyne phase measurement of short optical pulses.

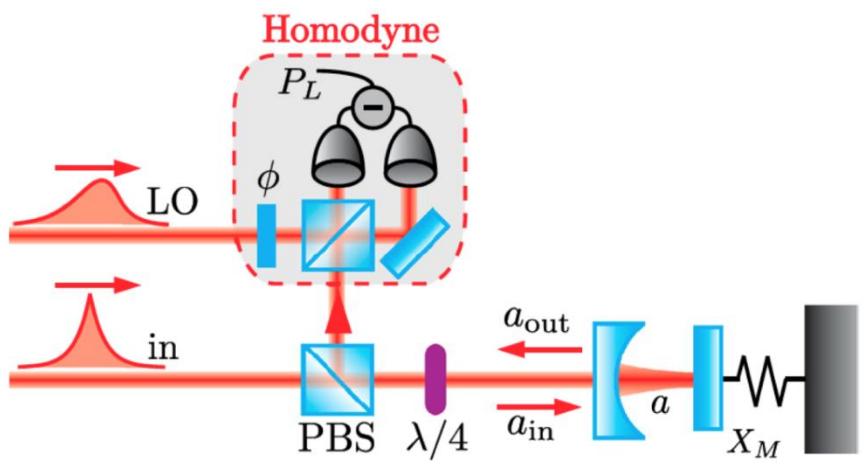
QND on X_M,

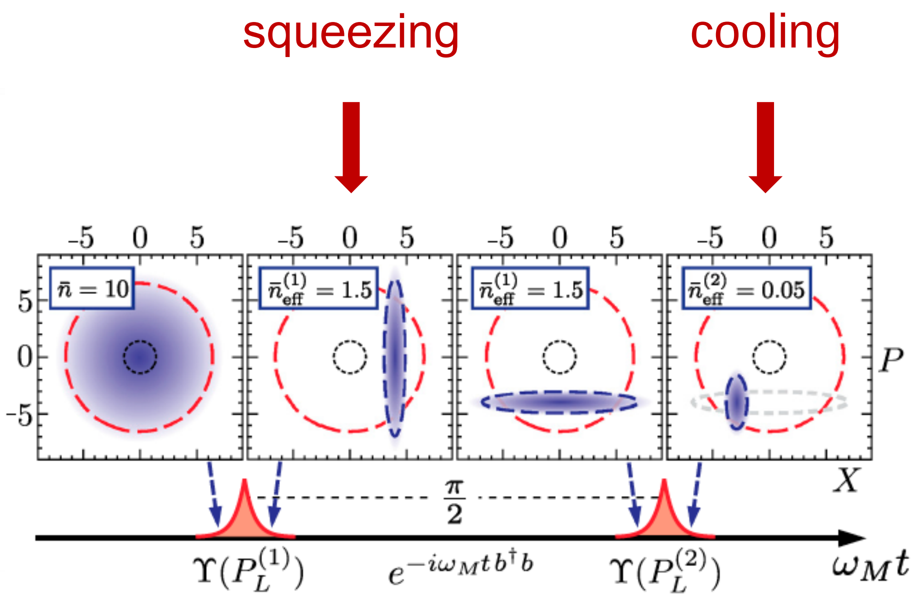
Measurement back-action only on P_M

The measured X_M restores at every mechanical (half) period.

"Strength of Measurement" χ~1:

resolving zero-point motion $X_{M,ZPM}$ with shot-noise limited laser





When χ >1

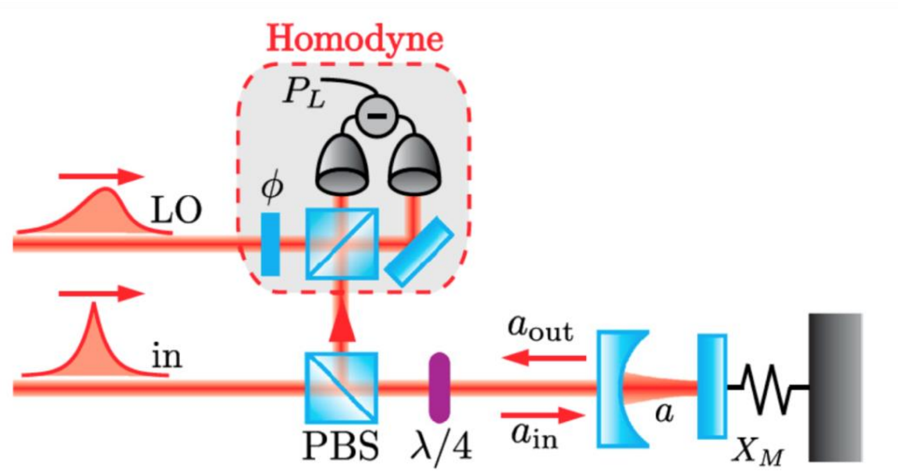
Quantum state preparation: ‘preparation-by-measurement’

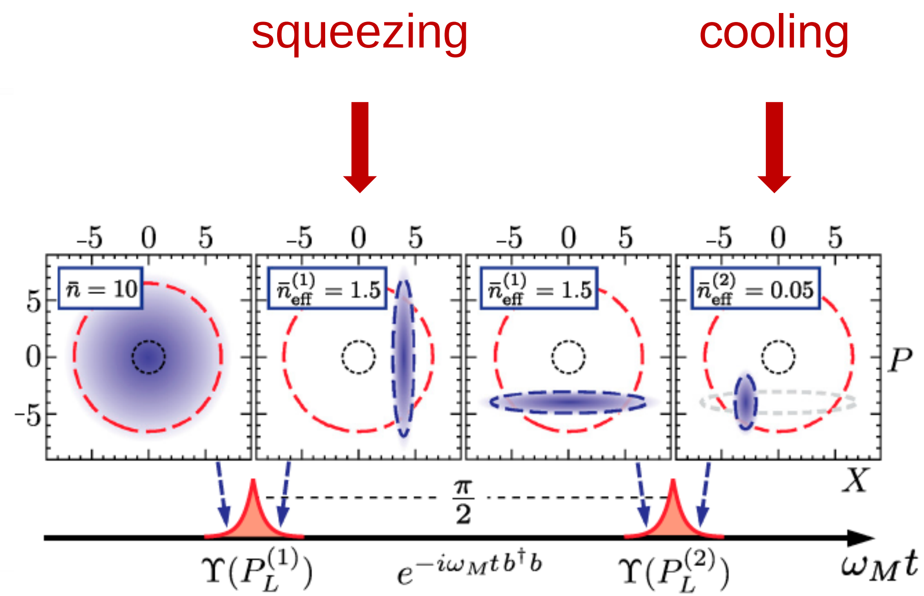
Single pulse: Squeezed X_M state.

Two pulses: pure state preparation.

‘Quantum’ state tomography

X_M measurement precision beyond SQL

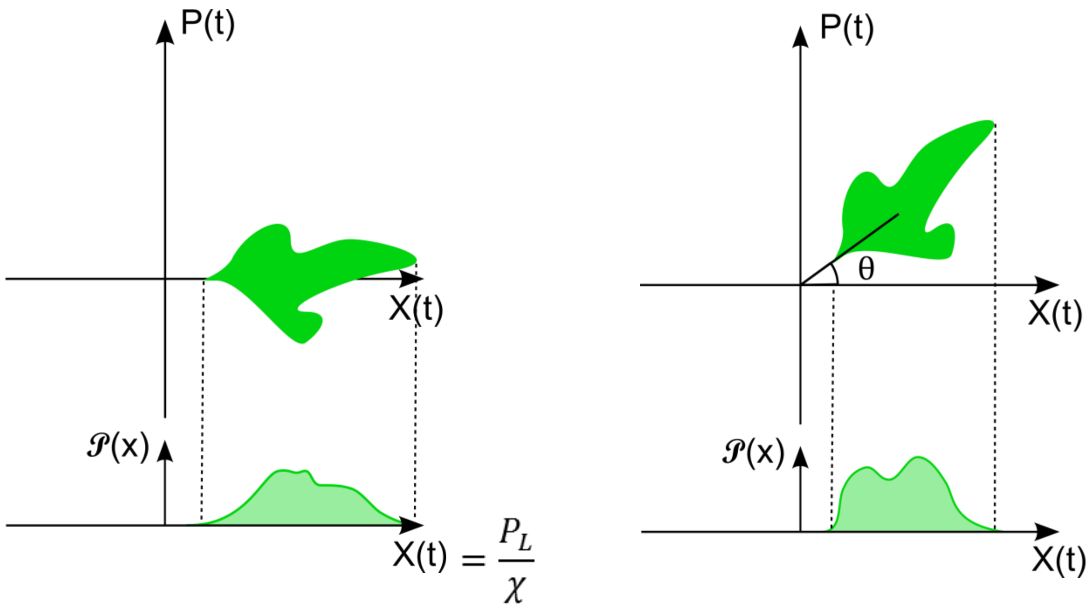




Tomography

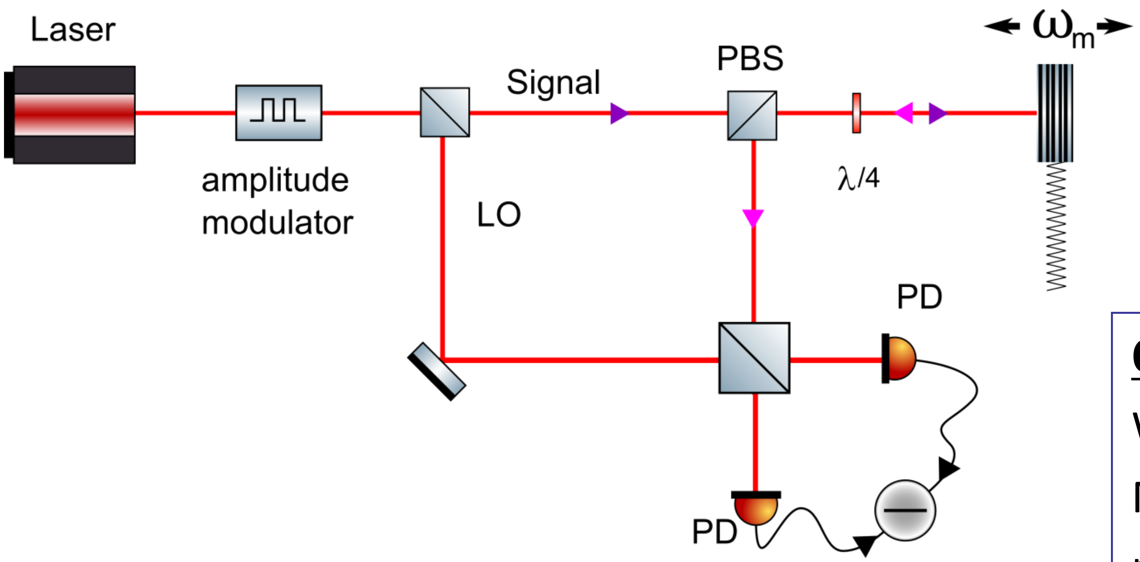
Dynamics: harmonic oscillator

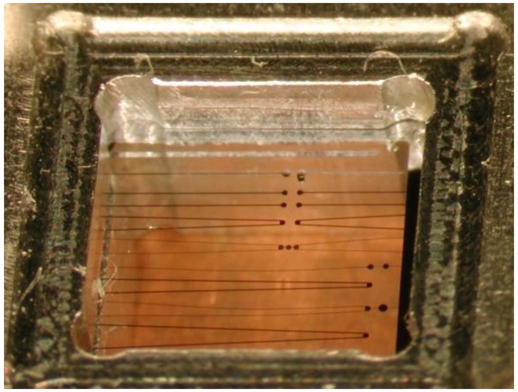
$$X(t) = X_0 \cos(\omega_m t) + P_0 \sin(\omega_m t)$$



Setup

Homodyne setup to read out the phase shift





Optomechanical system

Without cavity

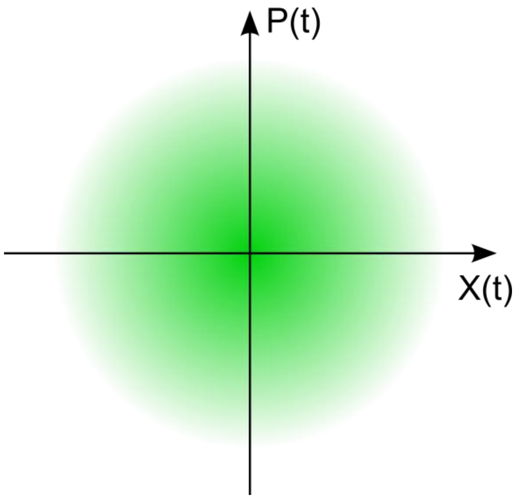
Micromechanical pendulum

m ~ 260 ng, f_m ~ 1 kHz, Q_m ~ 3 x 10^4

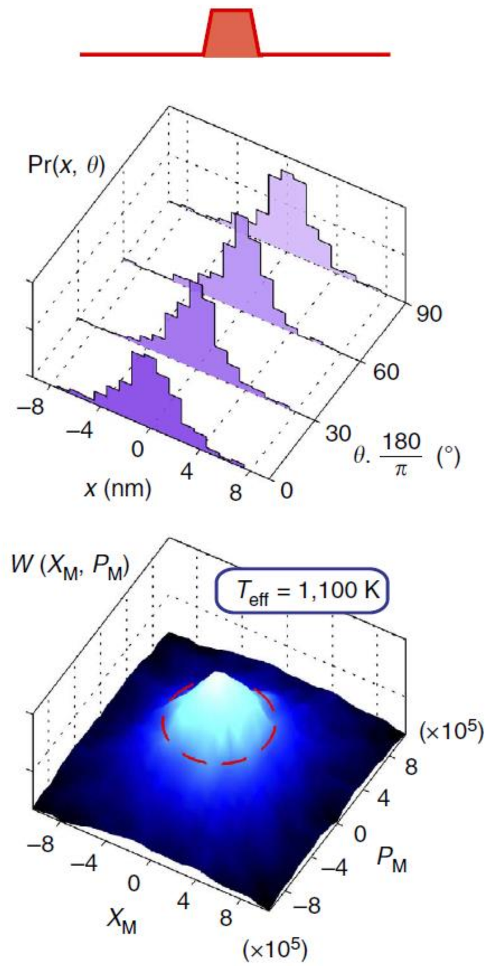
$\chi \sim 2.1 \times 10^{-4}$ ($\sigma_x \approx 1/\chi$)

Vanner, M. R., et al. (2013).
Nature communications, *4*, 2295.

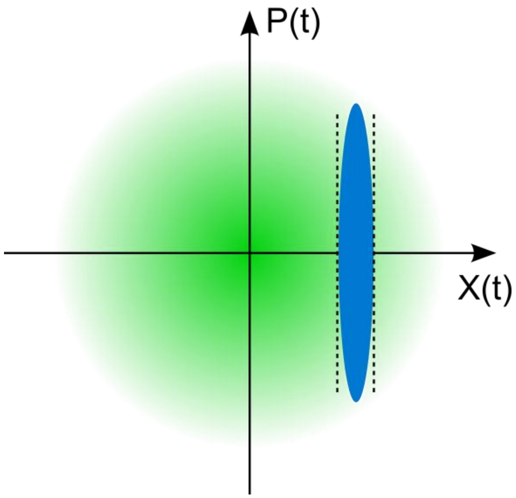
Thermal State

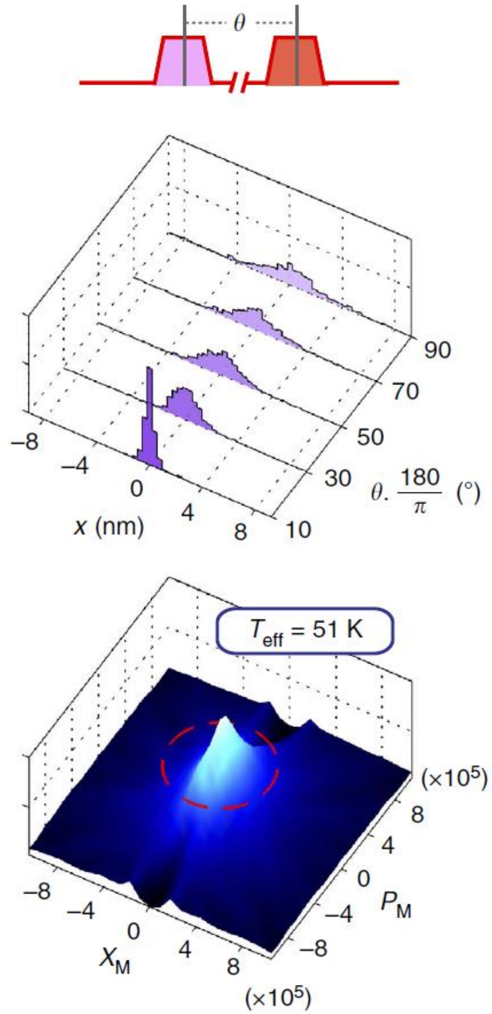


$$k_B T_{eff} = m_{eff}\omega_m^2\,({\sigma_x}^2)$$

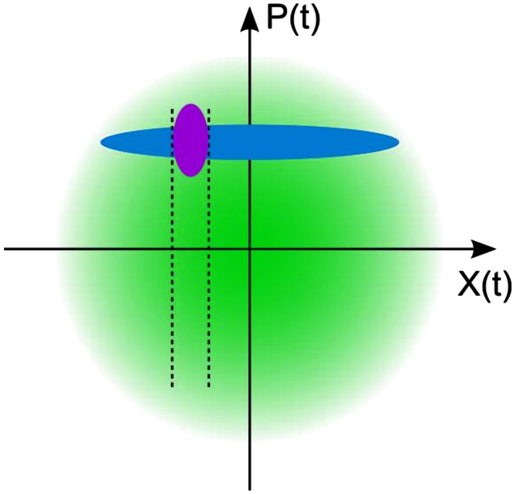


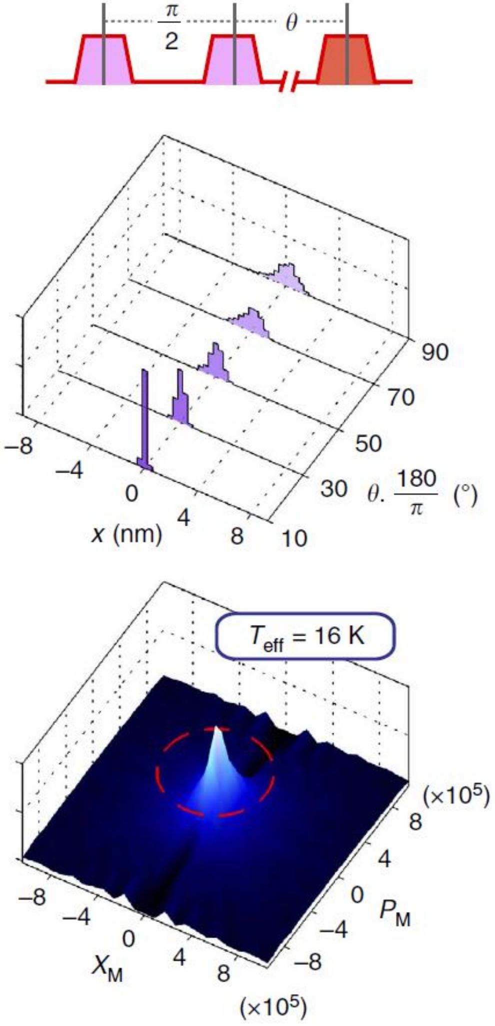
“Squashed” State



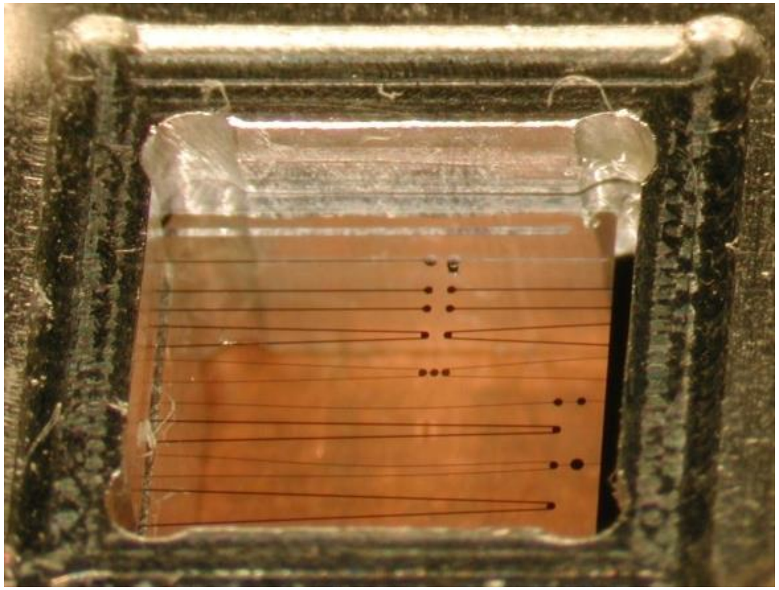


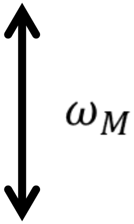
Cooled State

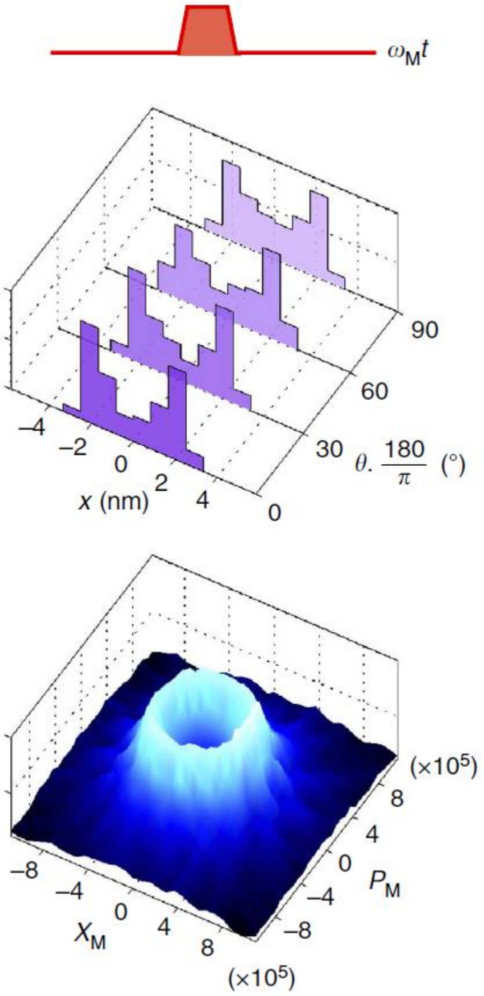




Driven State







Road to χ >1

Enhancing χ using,

strong optomechanical coupling (**g_0 ~ 0.5 MHz**)

Optical cavity

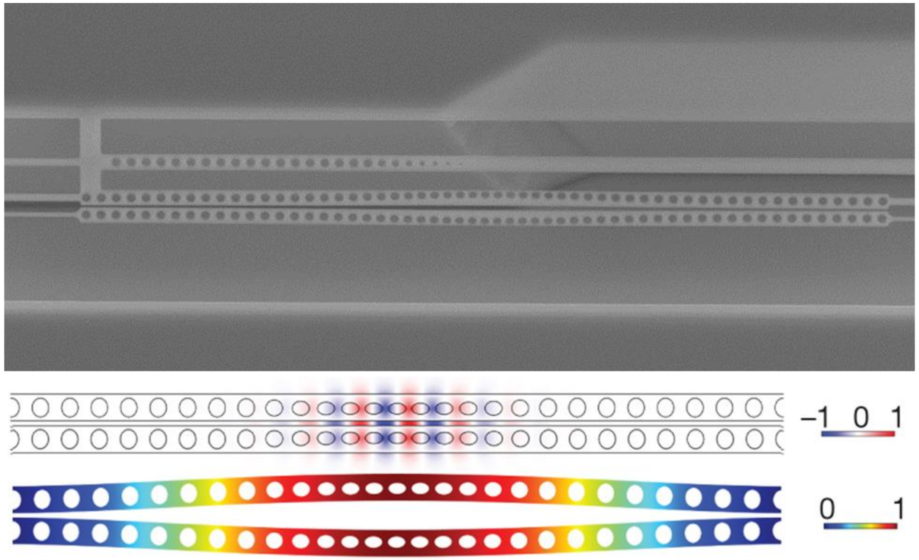
λ ~ 1550 nm, κ ~ 2 GHz

Mechanical oscillator

f_m ~ 1 MHz, Q_m ~ 10^6

$\chi \sim 4$,

for P_{in} ~ 5mW & τ ~ 10 ns



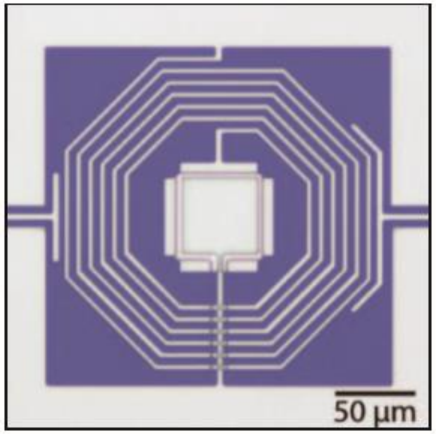
AH S-Naeini *et al. Nature* **500**, 185-189 (2013)

SQUEEZED MECHANICS

Quantum squeezing of motion in a mechanical resonator

E. E. Wollman,[1]* C. U. Lei,[1]* A. J. Weinstein,[1]* J. Suh,[2] A. Kronwald,[3] F. Marquardt,[3,4] A. A. Clerk,[5] K. C. Schwab[1]†

Science, 349, 952 (2015)



PHYSICAL REVIEW X **5,** 041037 (2015)

Quantum Nondemolition Measurement of a Nonclassical State of a Massive Object

F. Lecocq, J. B. Clark, R. W. Simmonds, J. Aumentado, and J. D. Teufel*
National Institute of Standards and Technology, 325 Broadway, Boulder, Colorado 80305, USA
(Received 22 September 2015; published 7 December 2015)

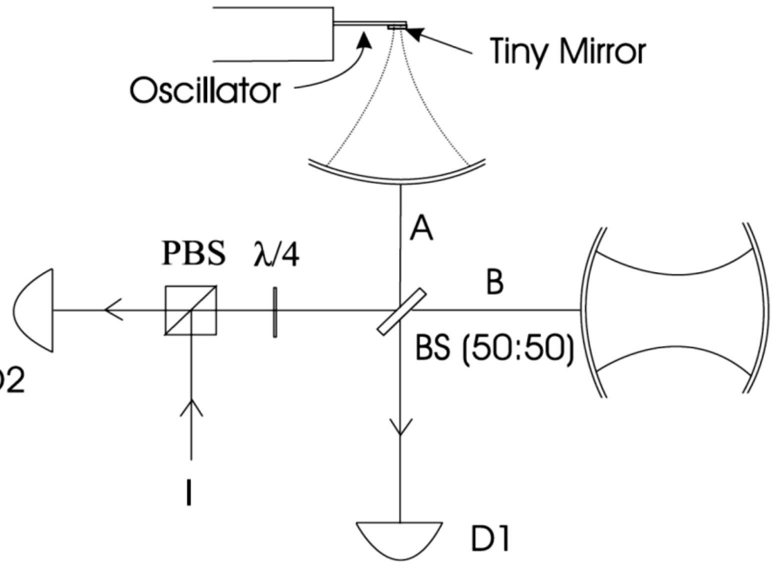
Selected for a Viewpoint in *Physics*
PRL **115,** 243601 (2015) PHYSICAL REVIEW LETTERS week ending 11 DECEMBER 201

Squeezing of Quantum Noise of Motion in a Micromechanical Resonator

J.-M. Pirkkalainen,[1] E. Damskägg,[1] M. Brandt,[1] F. Massel,[2] and M. A. Sillanpää[1,*]
[1]*Department of Applied Physics, Aalto University, P.O. Box 11100, FI-00076 Aalto, Finland*
[2]*Department of Physics, Nanoscience Center, University of Jyväskylä, P.O. Box 35 (YFL), Jyväskylä FI-40014, Finland*
(Received 15 July 2015; revised manuscript received 26 August 2015; published 7 December 2015)

A conceptually simple approach

Marshall, Simon, Penrose, Bouwmeester,
PRL 91, 130401 (2003)



also: A.D. Armour, M.P. Blencowe, and K. Schwab, PRL 88, 148301 (2002.)

Light-mirror entanglement

Bose, Jacobs, Knight, Phys. Rev. A **56**, 4175 (1997)

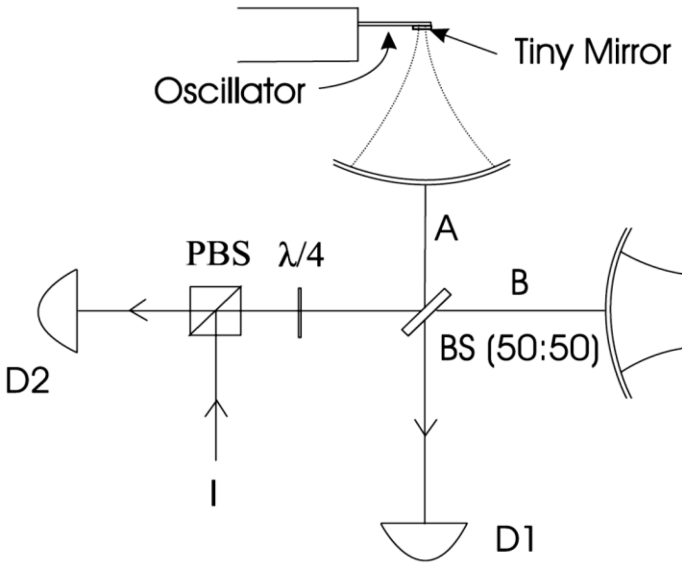
Mancini, Manko, P. Tombesi, Phys. Rev. A **55**, 3042 (1997)

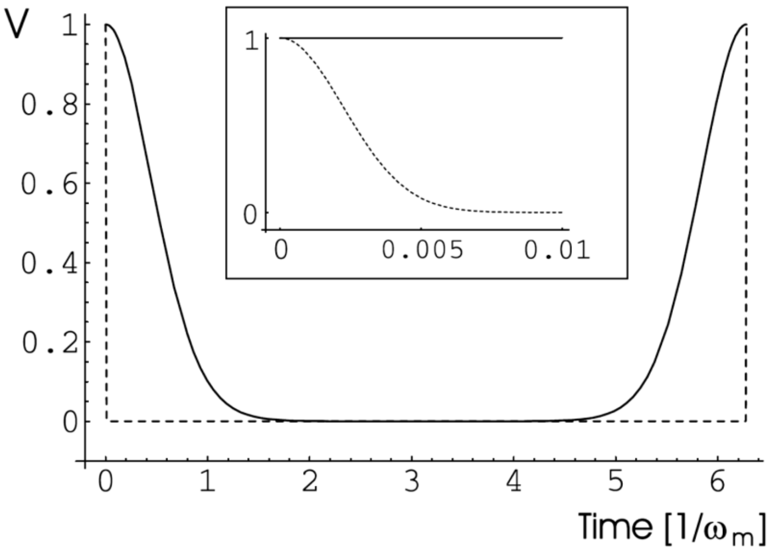
Macroscopic quantum coherence

Bouwmeester, Schmiedmayer, Weinfurter, Zeilinger, in: Gravitation and Relativity, IUCAA 1998

Entangling Photons with Phonons

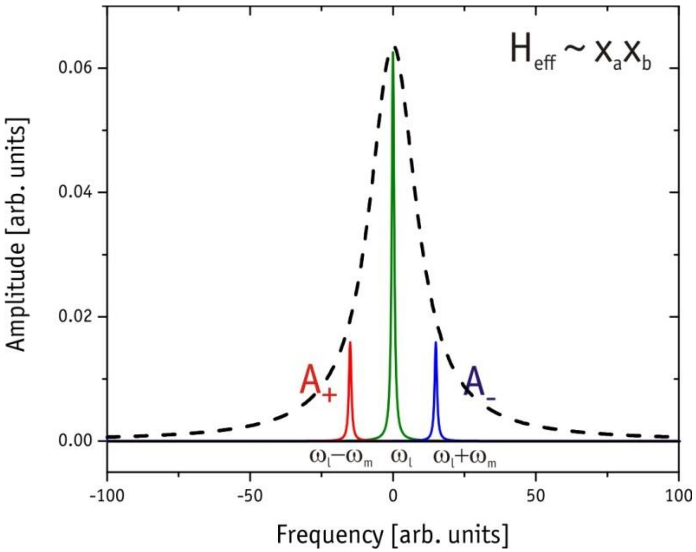
Marshall, Simon, Penrose, Bouwmeester,
PRL 91, 130401 (2003)



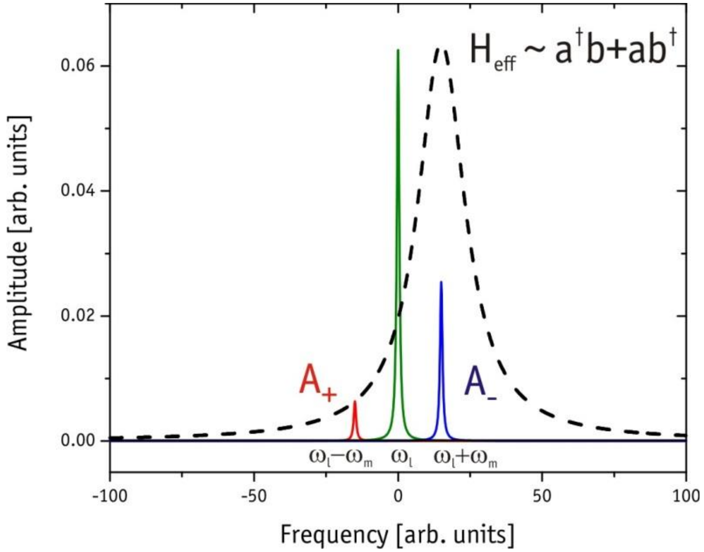


Outlook and conclusions.—In principle the proposed setup has the potential to test wave function reduction models, in particular, the one of Ref. [5]. We estimate that the ratio Q/T needs to be improved by about 6 orders of magnitude from the values discussed in this Letter ($Q = 10^5$ and $T = 2$ mK) to make the predicted wave function decoherence rate comparable to the environmental deco-

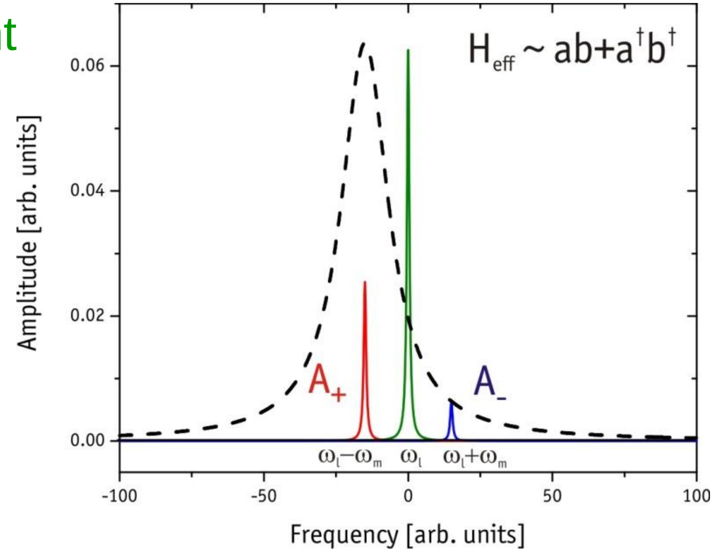
Choose your interaction



QND Measurement



Beamsplitter Interaction



Squeezing Interaction

Teleportation

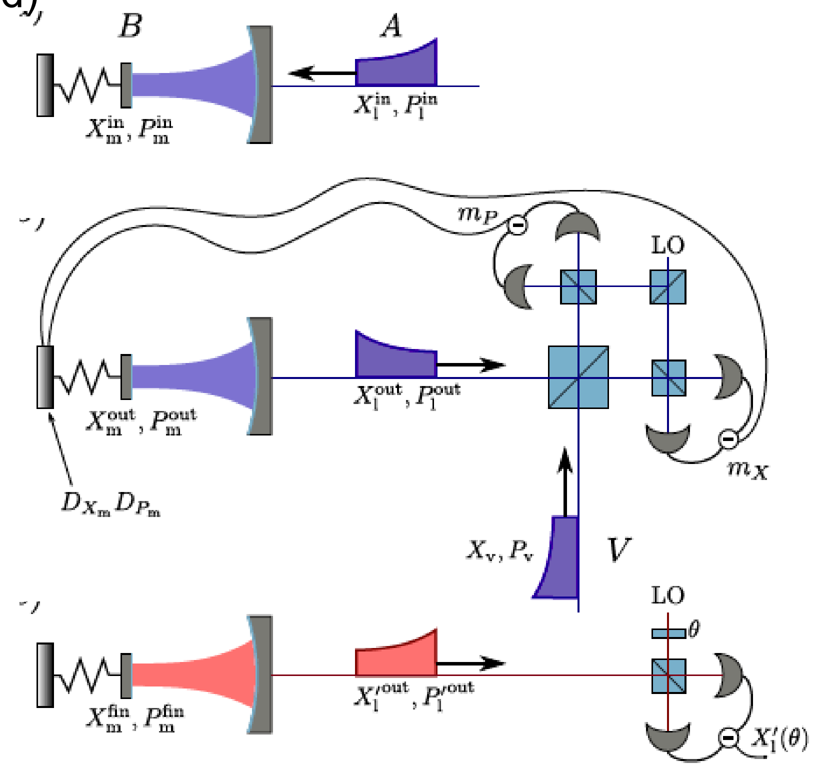
Optomechanical correlations: EPR

$$\Delta_{\mathrm{EPR}} = \Delta(x_1 - x_2)^2 + \Delta(p_1 + p_2)^2 \rightarrow 0 (< 2)$$ entangled

requires: $x_- = x_1 - x_2 \rightarrow 0$ (correlated)

$p_+ = p_1 + p_2 \rightarrow 0$ (anticorrelated)

use entanglement for optomechanical teleportation



Entanglement schemes

Bose, Jacobs, Knight, PRA 56, 4175 (1997)

D. Vitali et al. PRL 98, 030405 (2007)

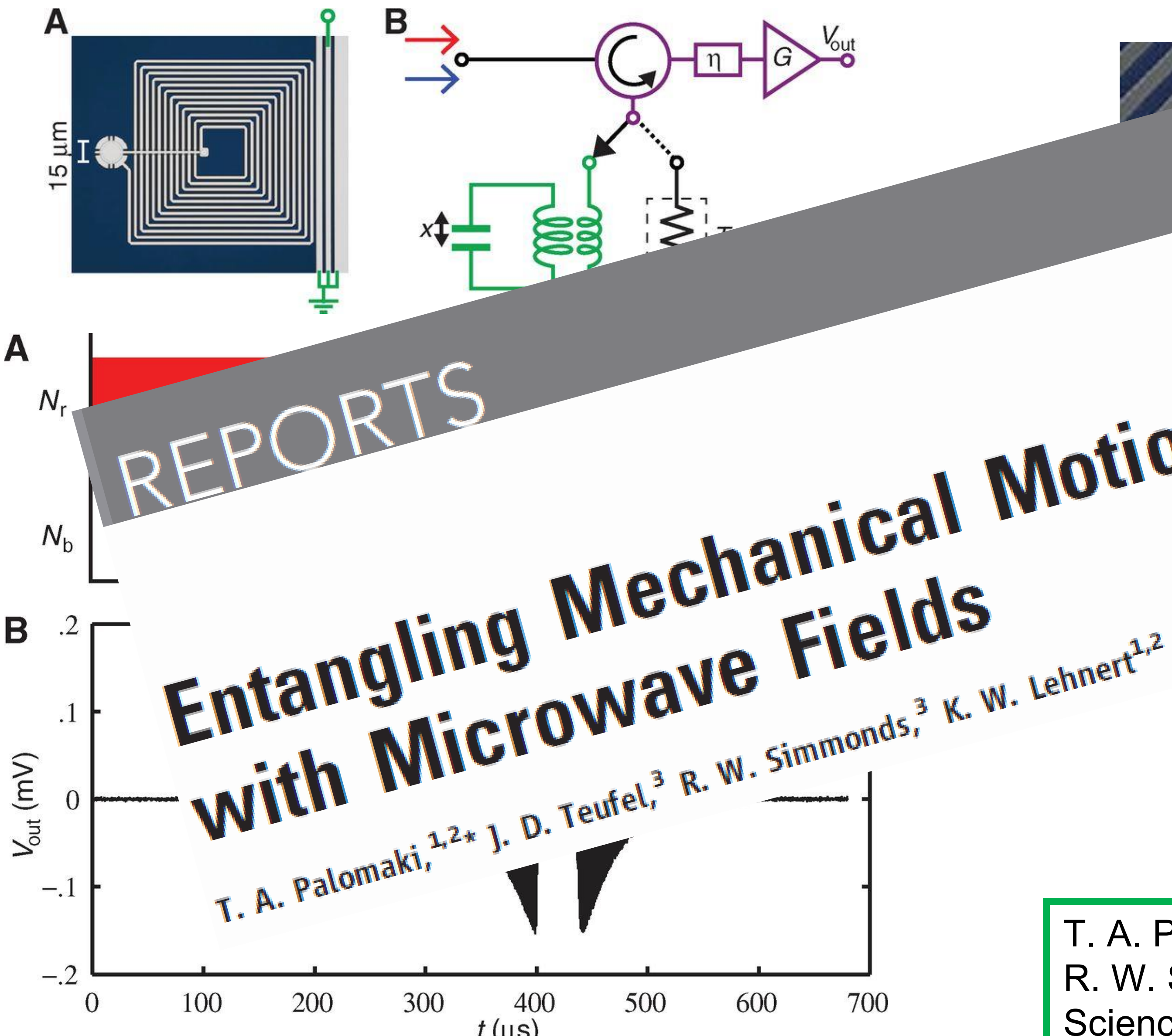
M. Paternostro et al.PRL 99, 250401 (2007)

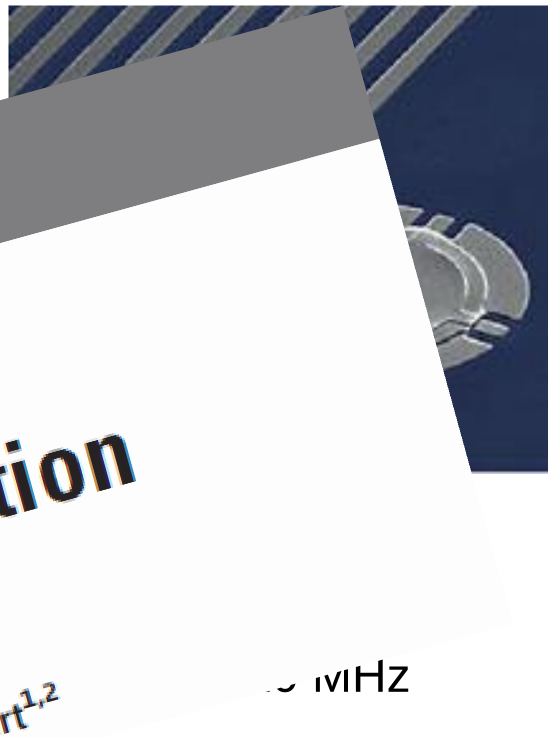
Romero-Isart O, Phys. Rev. A. 83, 013803 (2011).

Hofer, S. G., et al., 2011, Phys. Rev. A 84, 052327.

Hofer, Sebastian: Thesis - Quantum Control of Optomechanical Systems

EPR – Entanglement Experimentally

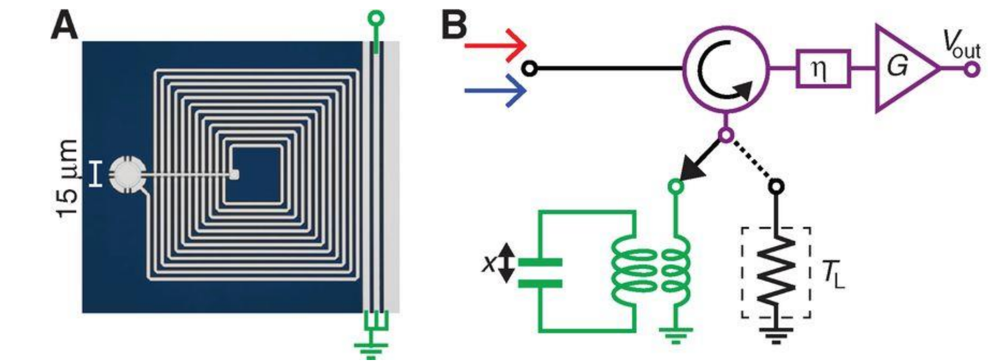


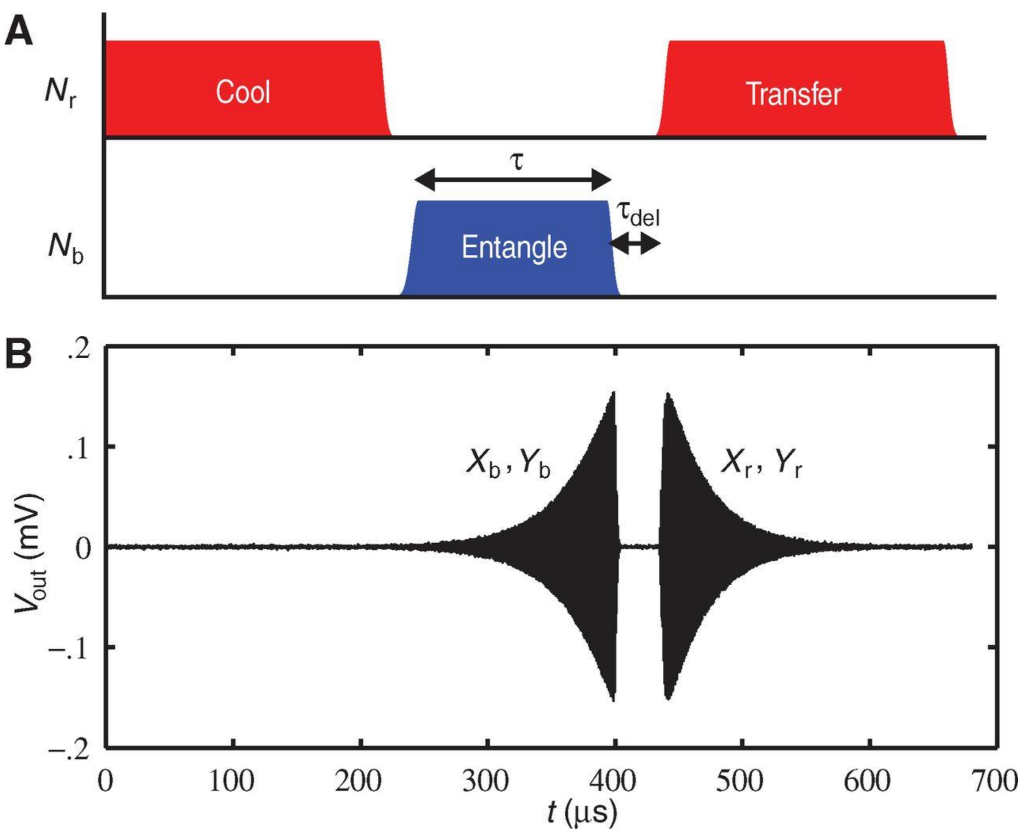


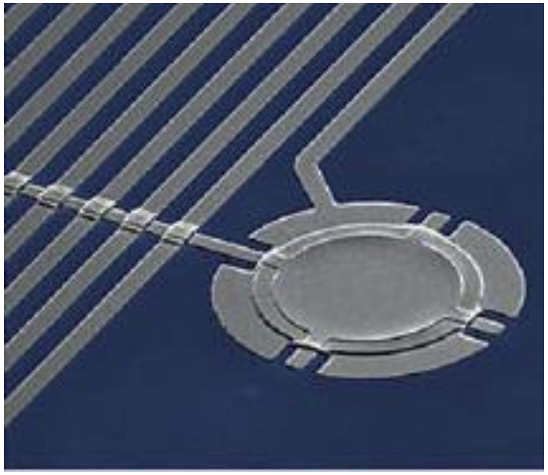
$\omega_{MW} \sim 7{,}7$GHz
$\kappa = 360$kHz
$\gamma = 35$Hz

T. A. Palomaki, J. D. Teufel, R. W. Simmonds, K. W. Lehnert, Science 342, 710 (2013)

EPR – Entanglement Experimentally





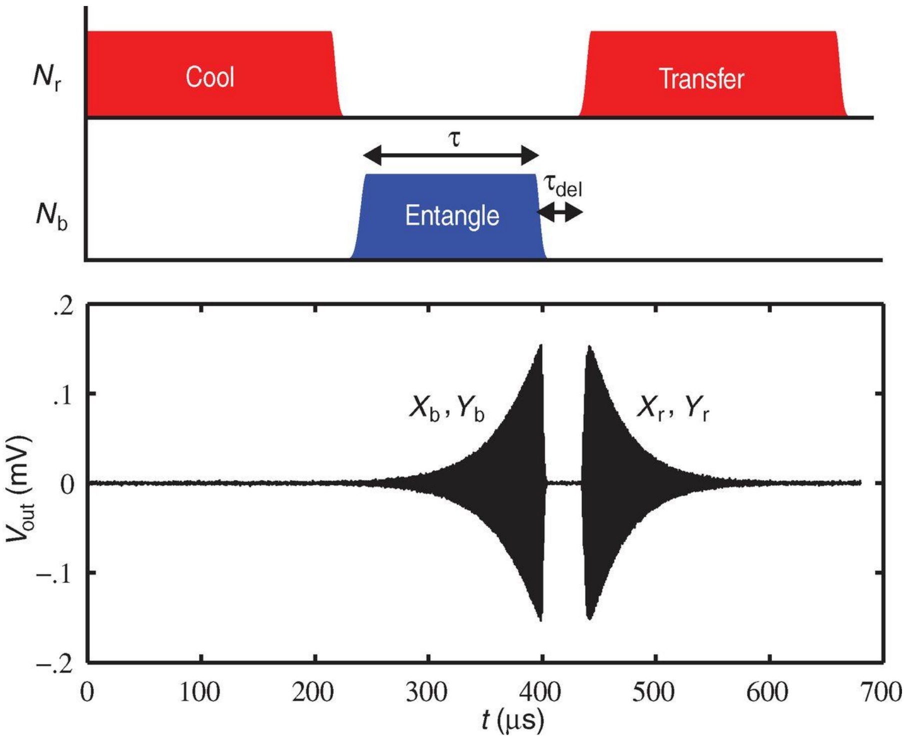


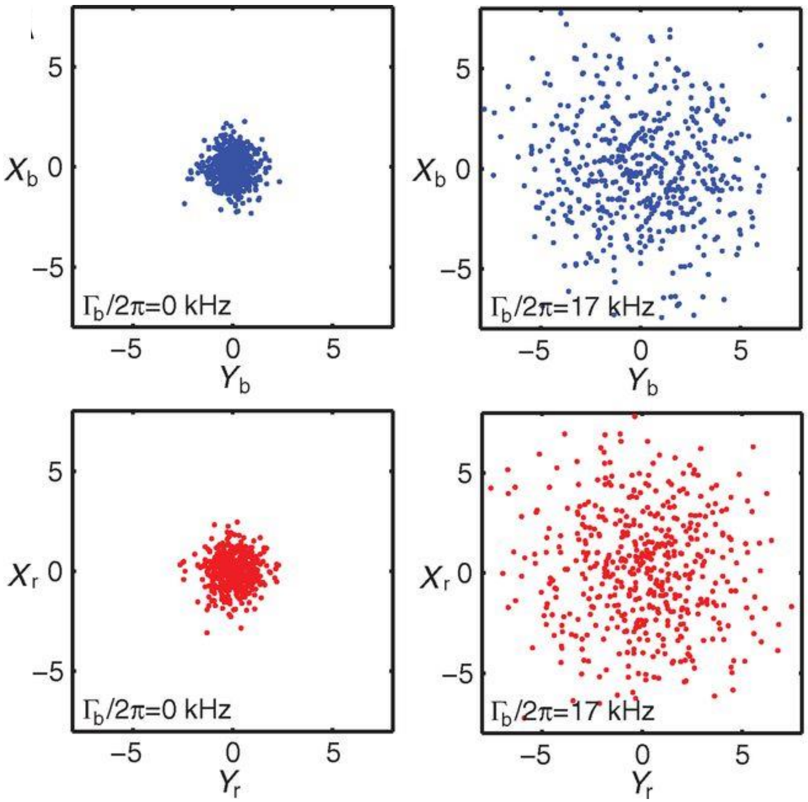
Mass ~ 50pg
ω_m ~ 10 MHz

ω_{MW} ~ 7,7GHz
κ = 360kHz
γ = 35Hz

T. A. Palomaki, J. D. Teufel, R. W. Simmonds, K. W. Lehnert, Science 342, 710 (2013)

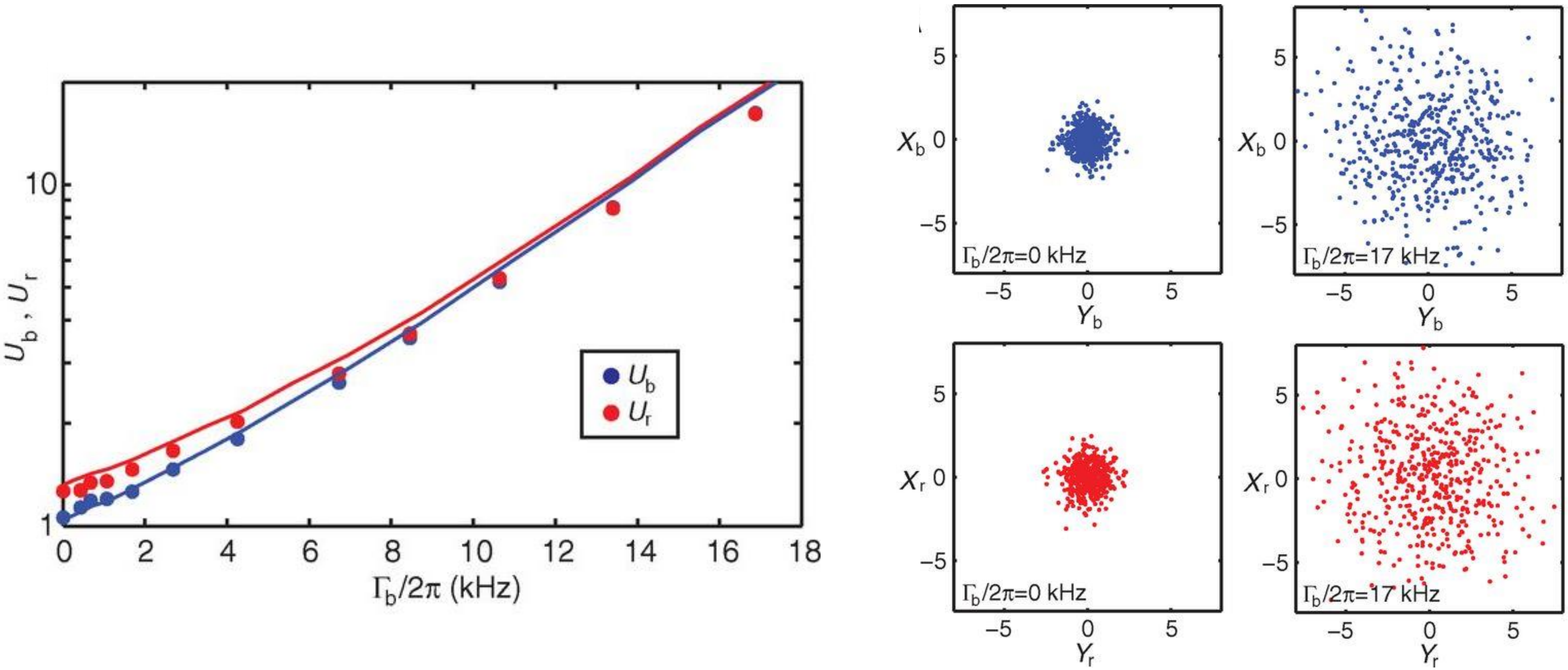
EPR – Entanglement Experimentally





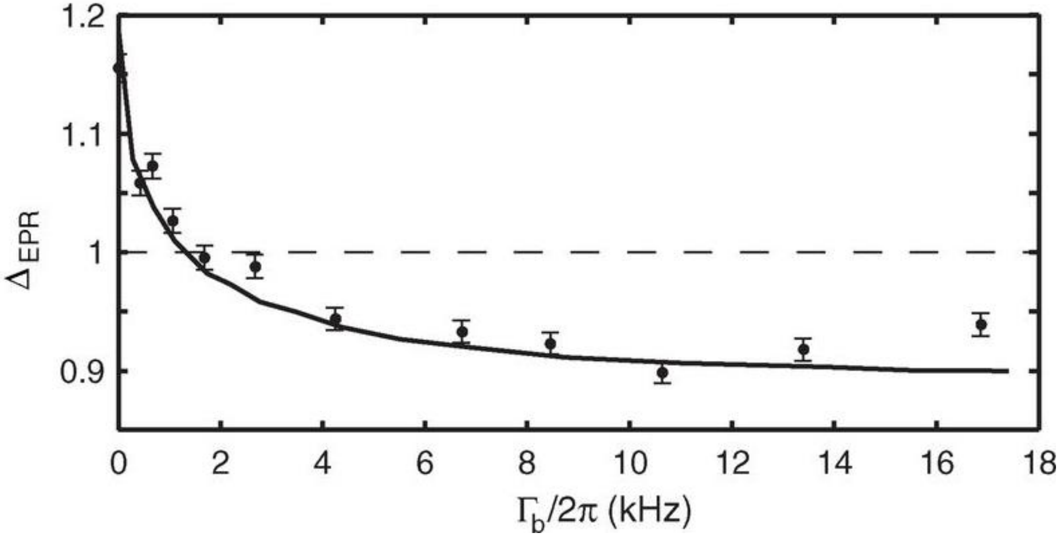
T. A. Palomaki, J. D. Teufel, R. W. Simmonds, K. W. Lehnert, Science 342, 710 (2013)

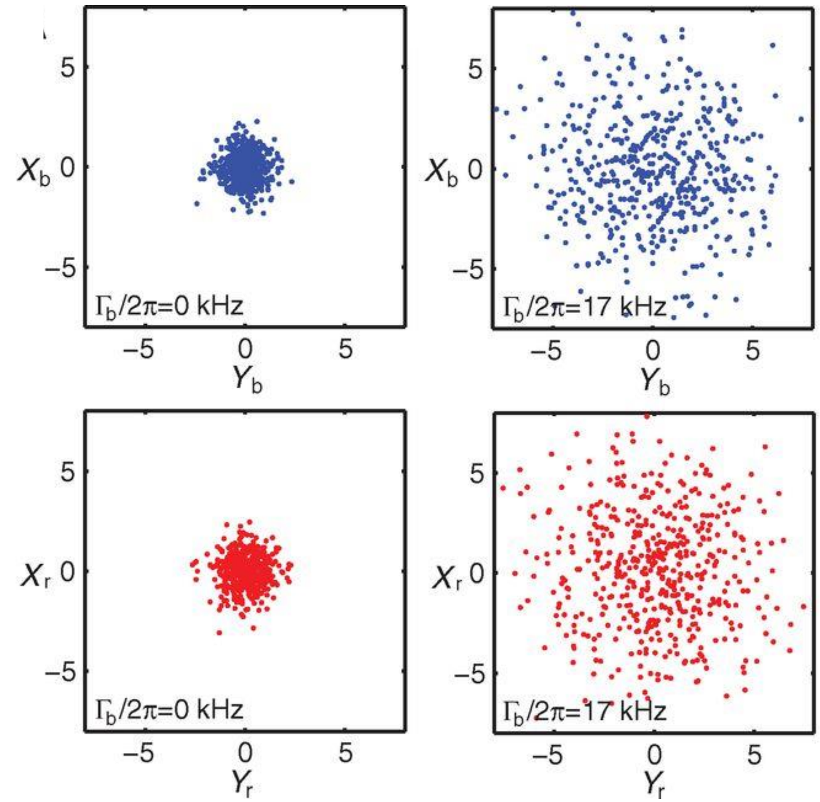
EPR – Entanglement Experimentally



T. A. Palomaki, J. D. Teufel, R. W. Simmonds, K. W. Lehnert, Science 342, 710 (2013)

EPR – Entanglement Experimentally





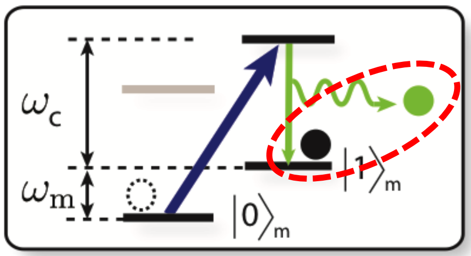
$$\Delta_{EPR} = \frac{1}{2}\left[\mathrm{Var}(X_r + Y_b) + \mathrm{Var}(X_b + Y_r)\right]$$

Corrected for detection efficiency η=0.2:

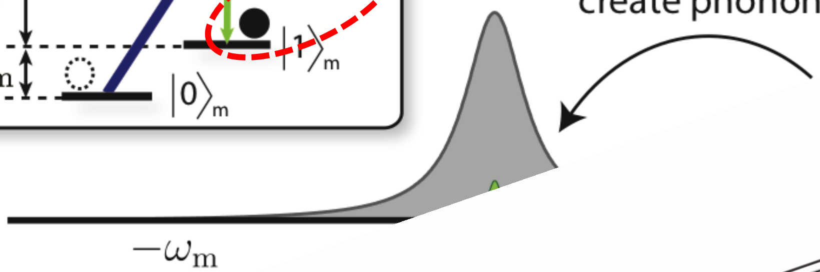
Δ_{EPR} ~ 0.5

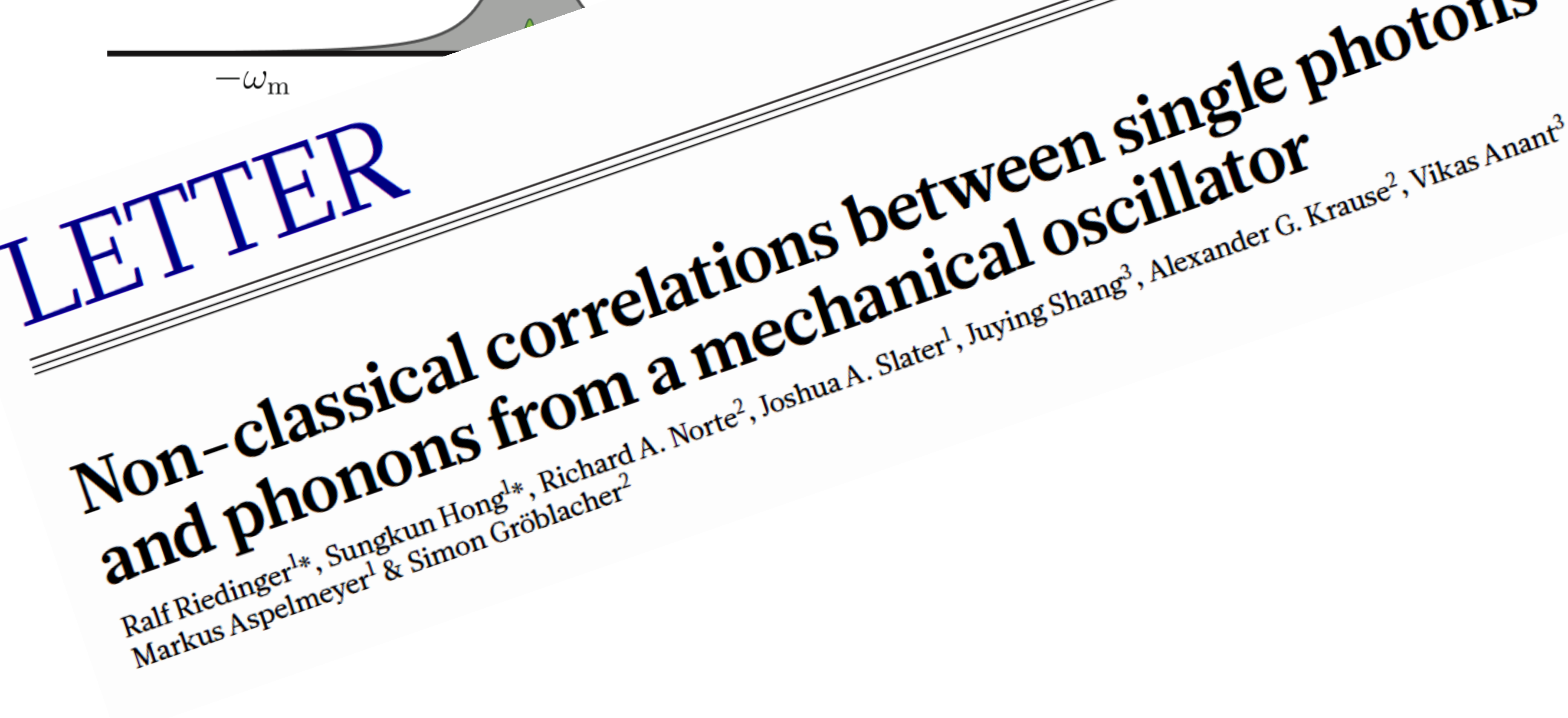
T. A. Palomaki, J. D. Teufel,
R. W. Simmonds, K. W. Lehnert,
Science 342, 710 (2013)

Entangling Photons with Phonons



$$H_{eff} \propto a^\dagger b^\dagger + ab$$




LETTER

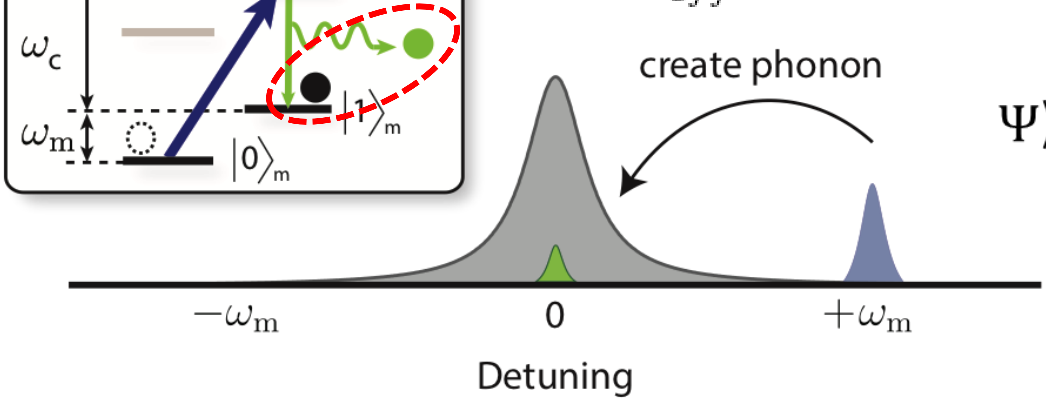
doi:10.1038/nature16536

Non-classical correlations between single photons and phonons from a mechanical oscillator

Ralf Riedinger[1*], Sungkun Hong[1*], Richard A. Norte[2], Joshua A. Slater[1], Juying Shang[3], Alexander G. Krause[2], Vikas Anant[3], Markus Aspelmeyer[1] & Simon Gröblacher[2]

Entangling Photons with Phonons

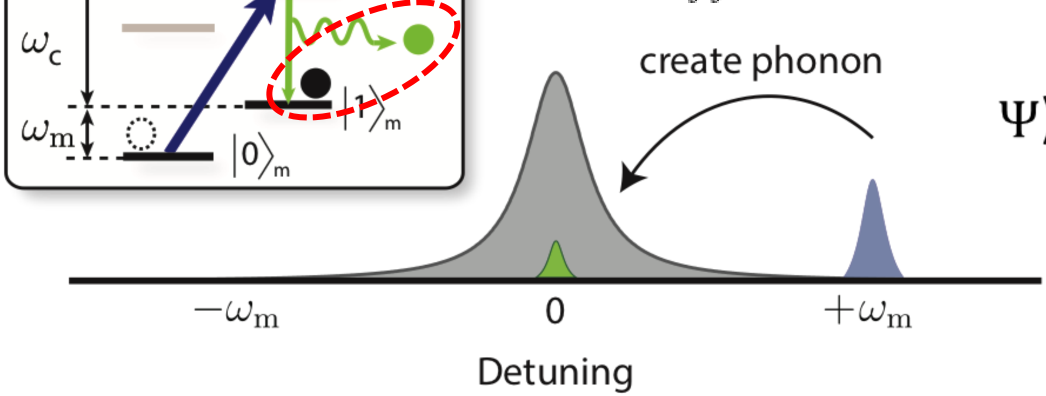
$$H_{eff} \propto a^{\dagger} b^{\dagger} + ab$$



$$\Psi\rangle_{OM} \sim |0\rangle_O |0\rangle_M + \sqrt{p}\, |1\rangle_O |1\rangle_M + \cdots$$

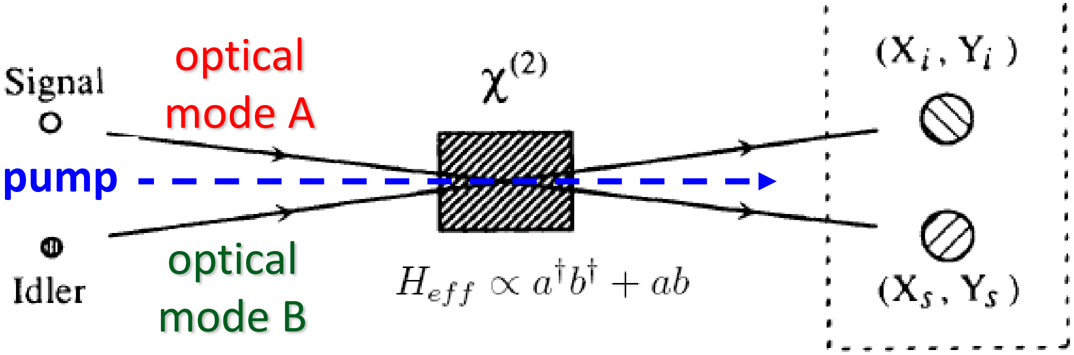
Entangling Photons with Phonons

$$H_{eff} \propto a^\dagger b^\dagger + ab$$



$$|\Psi\rangle_{OM} \sim |0\rangle_O |0\rangle_M + \sqrt{p}\,|1\rangle_O |1\rangle_M + \cdots$$

... Analogous to 2-mode quantum optics

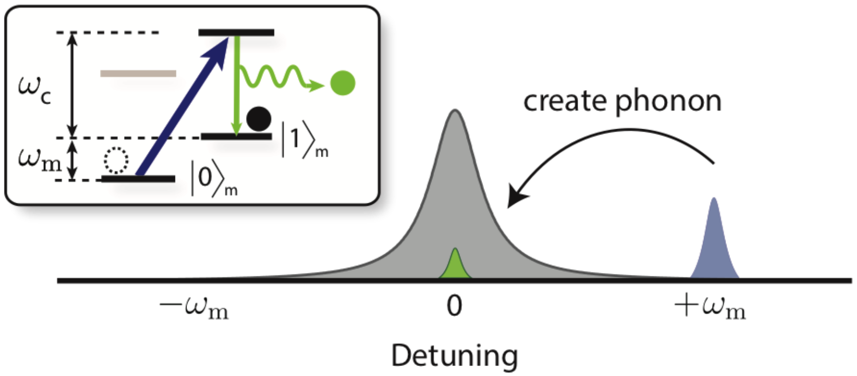


Realization of the EPR Paradox for Continuous Variables
Ou, Pereira, Kimble, Peng, PRL 68, 3663 (1992)
Theory: Reid & Drummond, PRL 60, 2731 (1988)

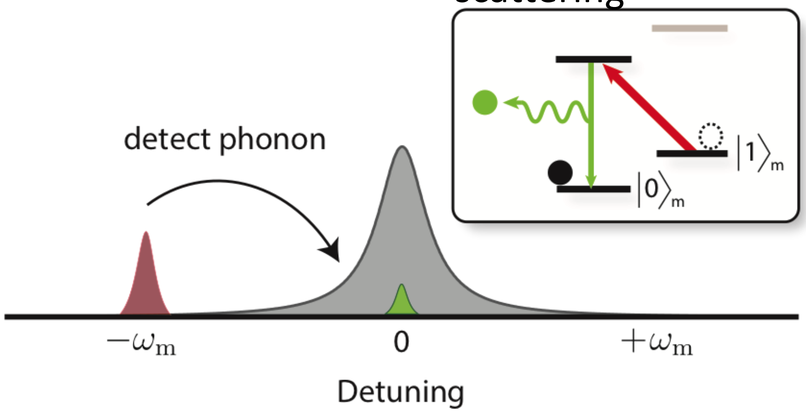
$$|\Psi\rangle_{AB} \sim |0\rangle_A |0\rangle_B + \sqrt{p}\,|1\rangle_A |1\rangle_B + \cdots$$

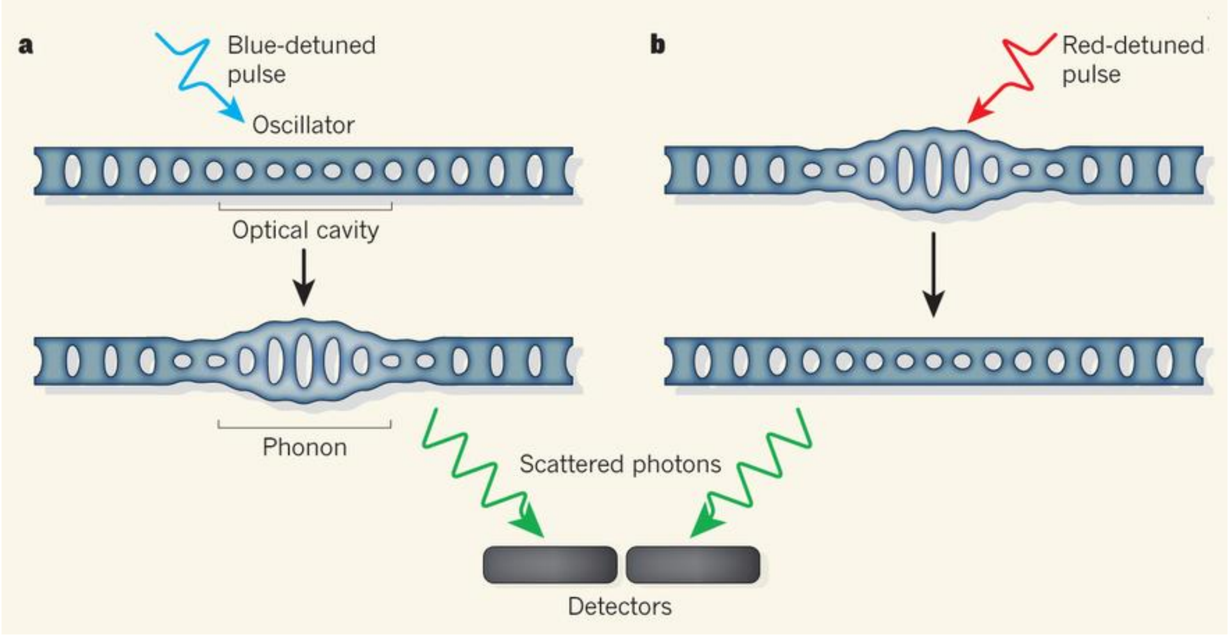
Entangling Photons with Phonons

1. create photon-phonon pairs by Stokes scattering events (and readout photon)



2. readout phonon by Anti-Stokes scattering



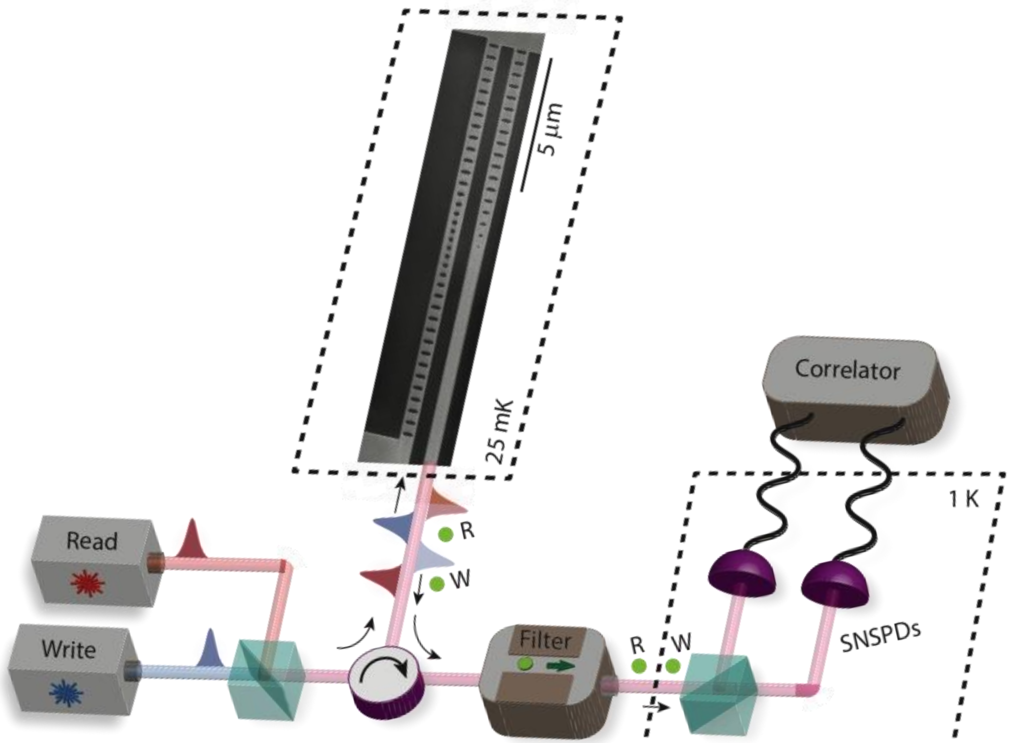


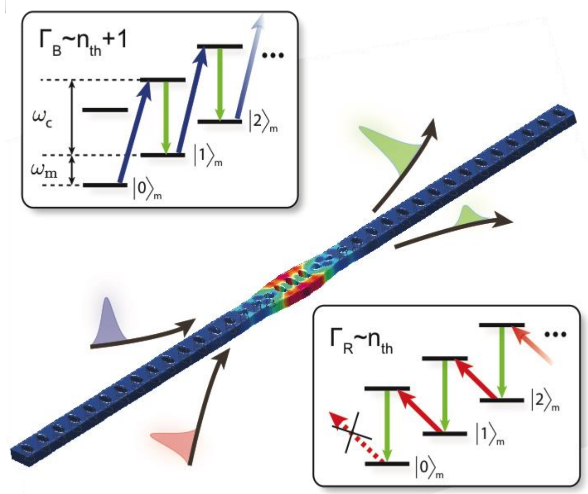
News and Views,
M. Blencowe,
Nature 530, 284–285
(18 Feb 2016)

Ground State Preparation

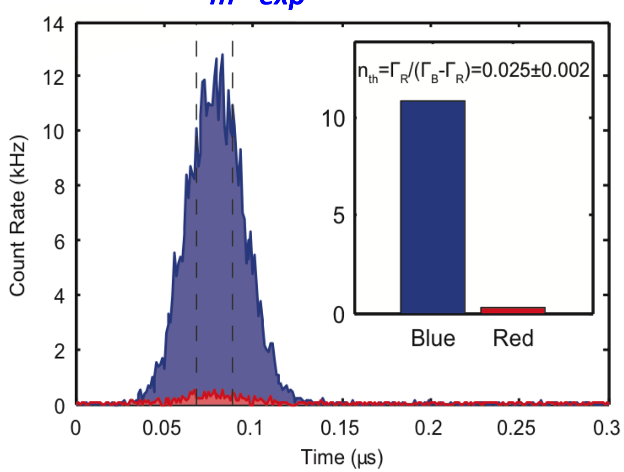
R. Riedinger*, Sungkun Hong*, .., M. Aspelmeyer, S. Gröblacher, Nature 530, 313–316 (2016)

$\omega_m/2\pi$ = 5.3 GHz ➔ $\langle n_m \rangle$~ 2 x 10^{-5} @ 25 mK



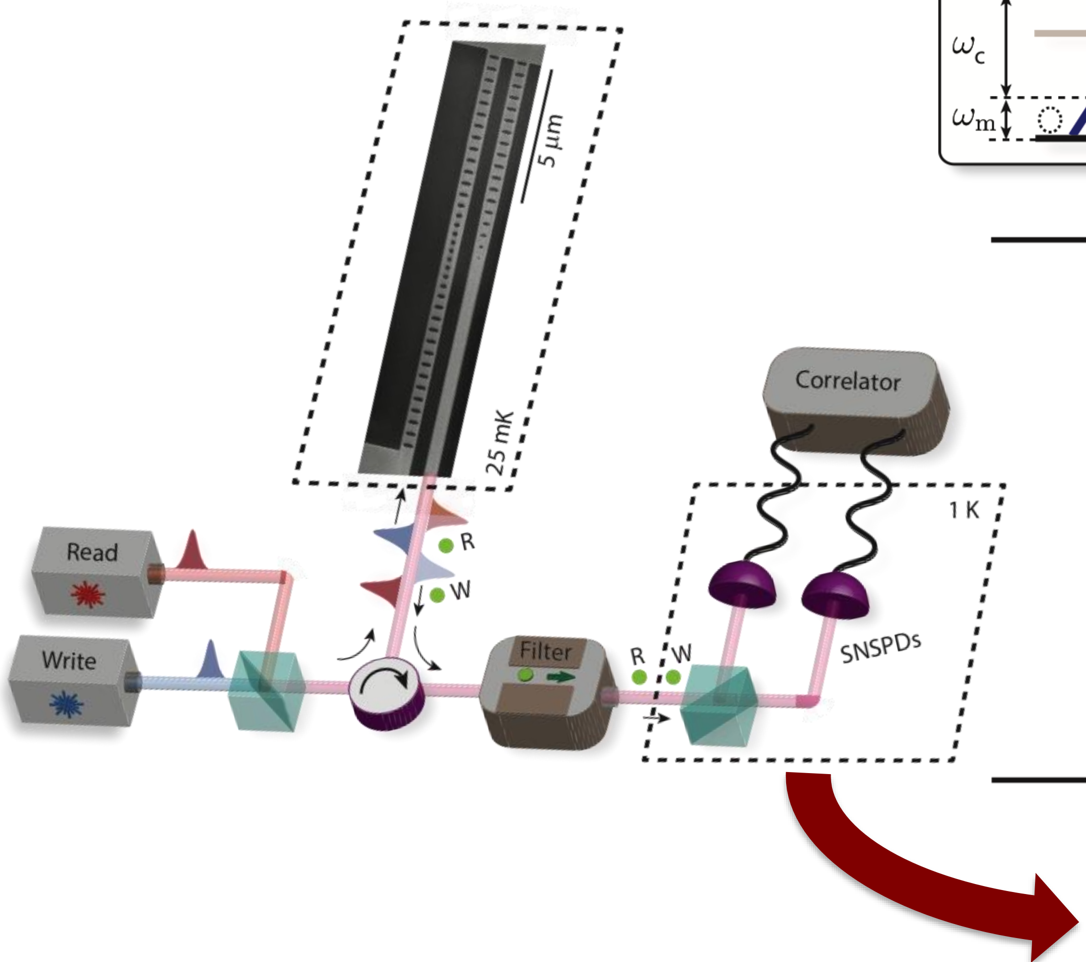


$\langle n_m \rangle_{exp} \lesssim 2.5 \times 10^{-2}$

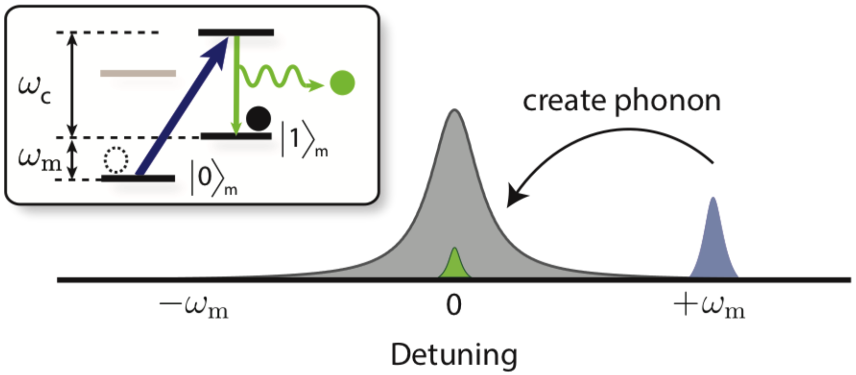


Experimental Detection of Quantum Correlations

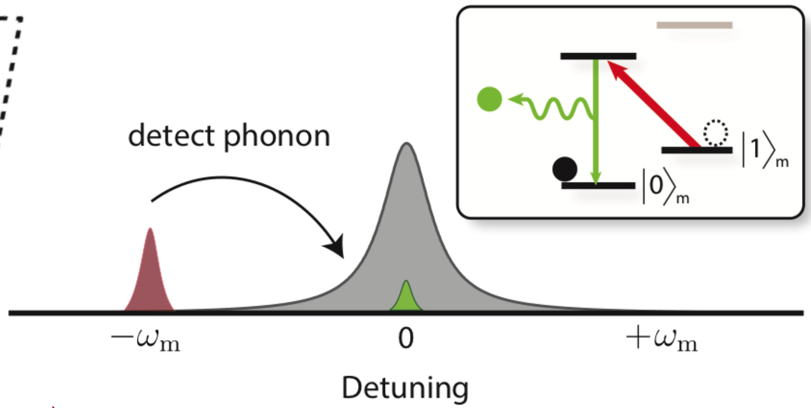
R. Riedinger*, Sungkun Hong*, .., M. Aspelmeyer, S. Gröblacher, Nature 530, 313–316 (2016)



1. create photon-phonon pairs by Stokes scattering events (and readout photon)

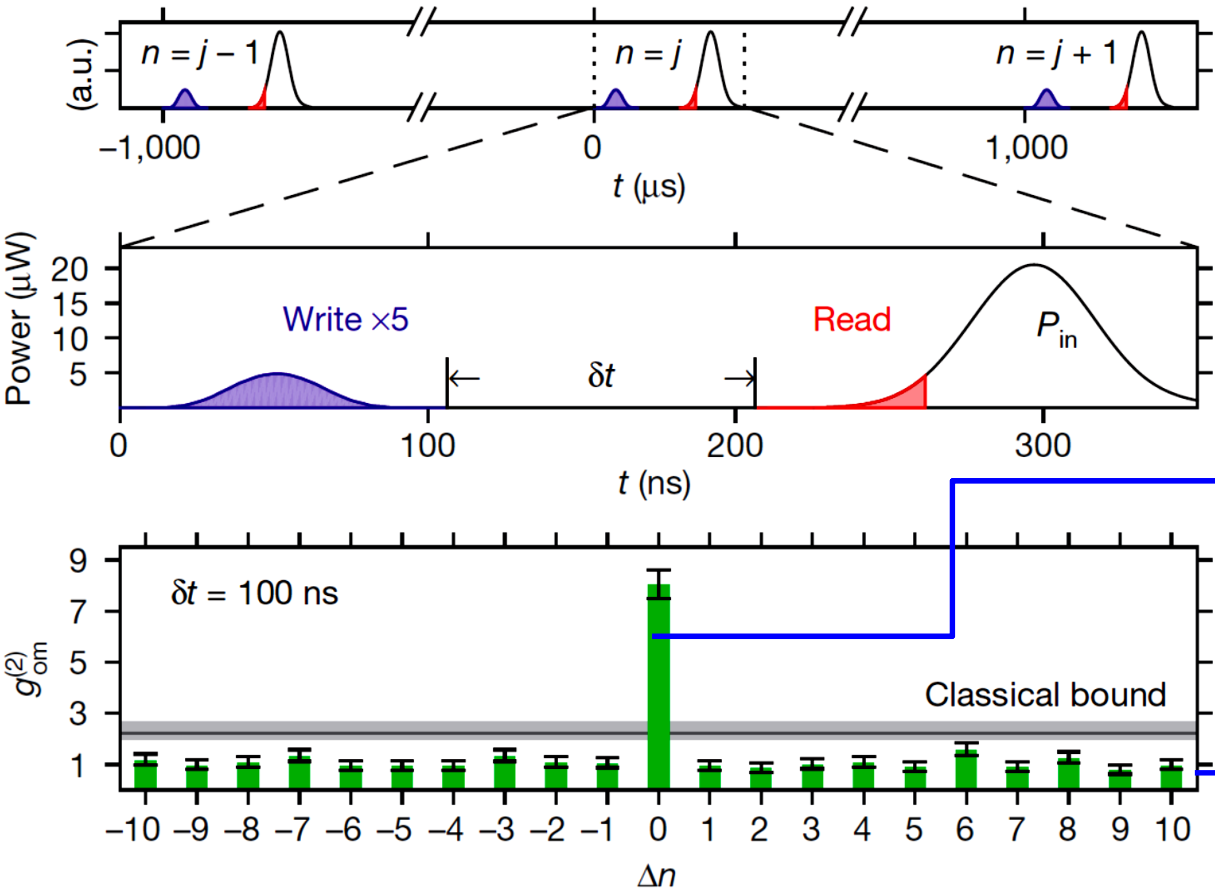


2. readout phonon by Anti-Stokes scattering



3. correlate!!

Non-classical correlations



Cauchy Schwarz inequality

$$\langle AB\rangle^2 \leq \langle A^2\rangle\langle B^2\rangle$$

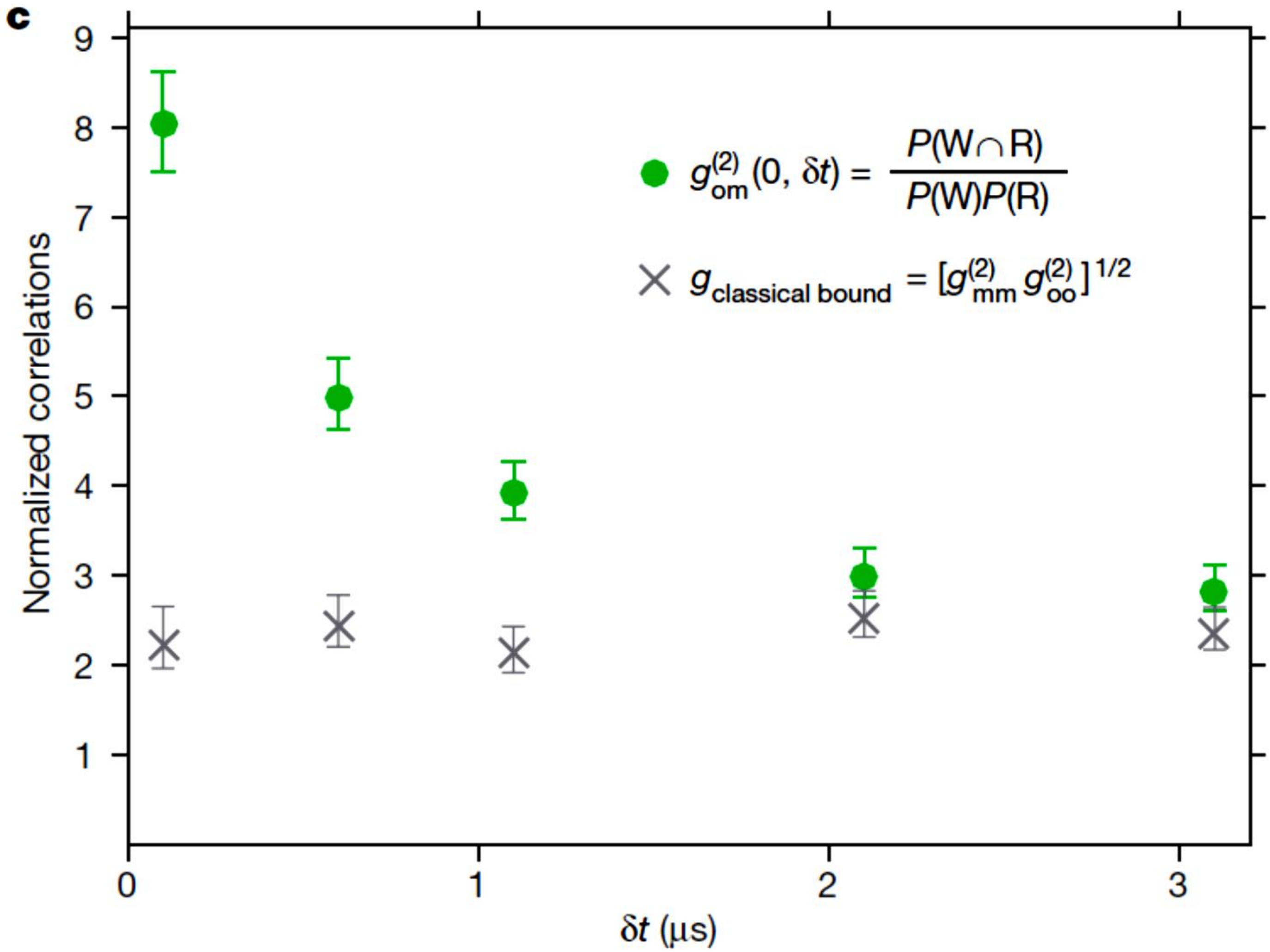
$$g_{AB}^{(2)} \leq \sqrt{g_{AA}^{(2)} \cdot g_{BB}^{(2)}}$$

'O-M' correlations , same pair of pulses: Violation of Cauchy-Schwarz

'O-M' correlations, different pair of pulses

R. Riedinger*, Sungkun Hong*, .., M. Aspelmeyer, S. Gröblacher, Nature 530, 313–316 (2016)

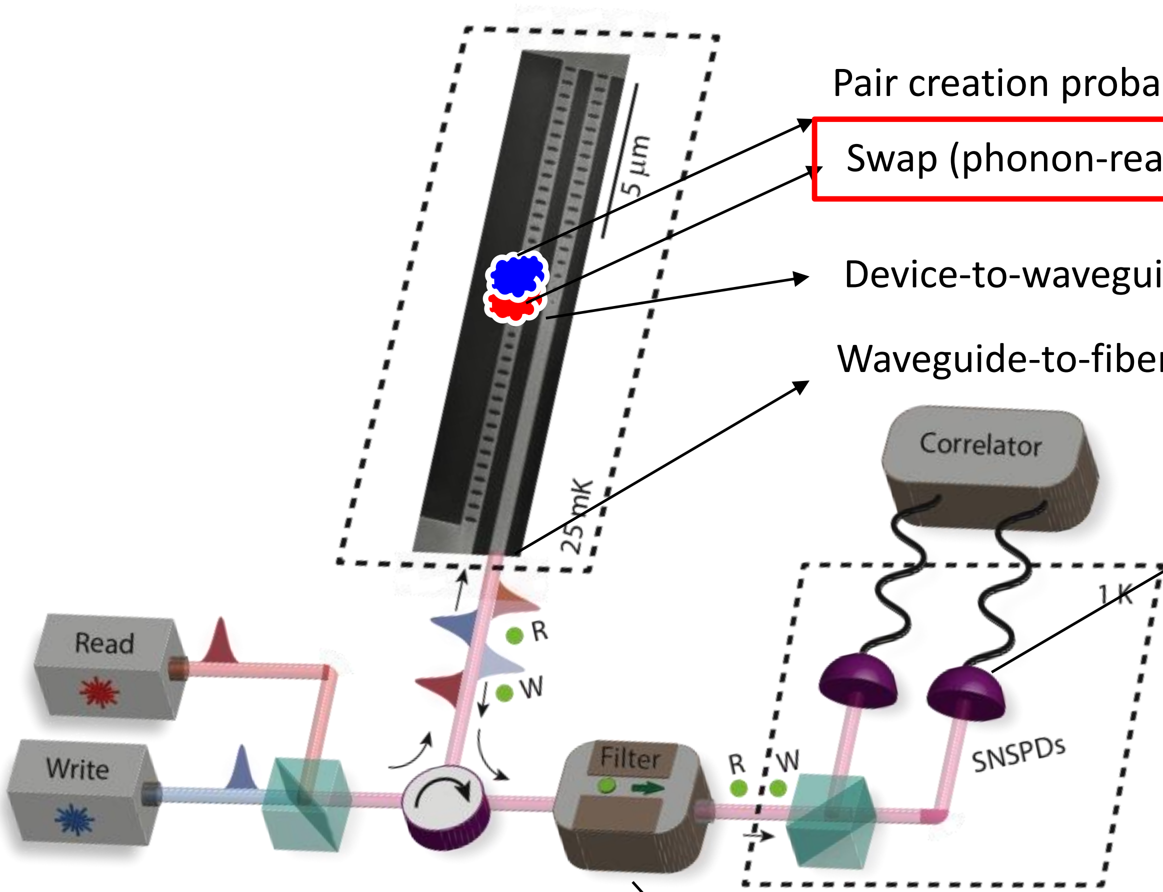
Non-classical correlations



R. Riedinger*, Sungkun Hong*, .., M. Aspelmeyer, S. Gröblacher, Nature 530, 313–316 (2016)

Efficiency Budget

Photon detection probability (per pulse)



Pair creation probability ~ 3%

Swap (phonon-readout) probability ~ 3.7%

Limited by absorption heating!!

Device-to-waveguide ~ 50 %

Waveguide-to-fiber ~ 60 %

Detector efficiency ~90(60) %

… detection probability: 0.08 ~ 0.10 %

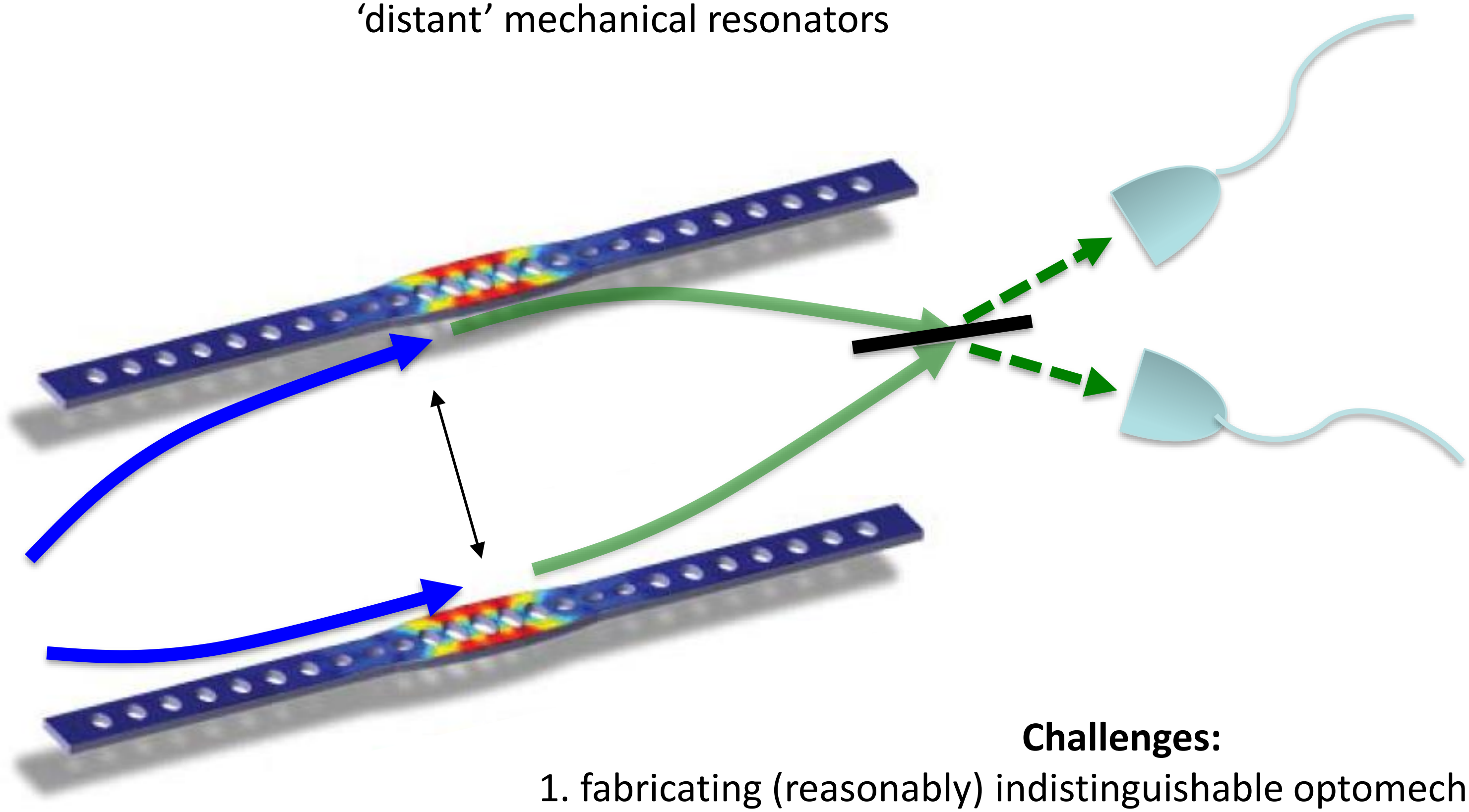
Filter transmission ~ 40 %

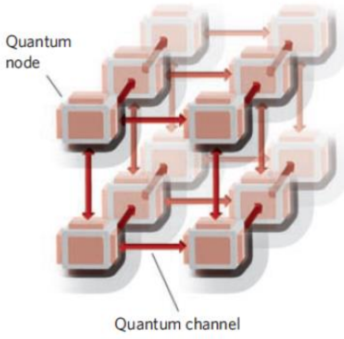
Duty cycle: ~ 1 ms
(**limited by heating!!**)
➔ Count rate ~ 1 Hz
➔ **Coincidence rate ~ 1 mHz (~ 15 min)**

Effect of other component losses ~ 30 %

Outlook

Full implementation of Duan-Lukin-Cirac-Zoller scheme:
Heralded generation of phonon-phonon entanglement from two 'distant' mechanical resonators

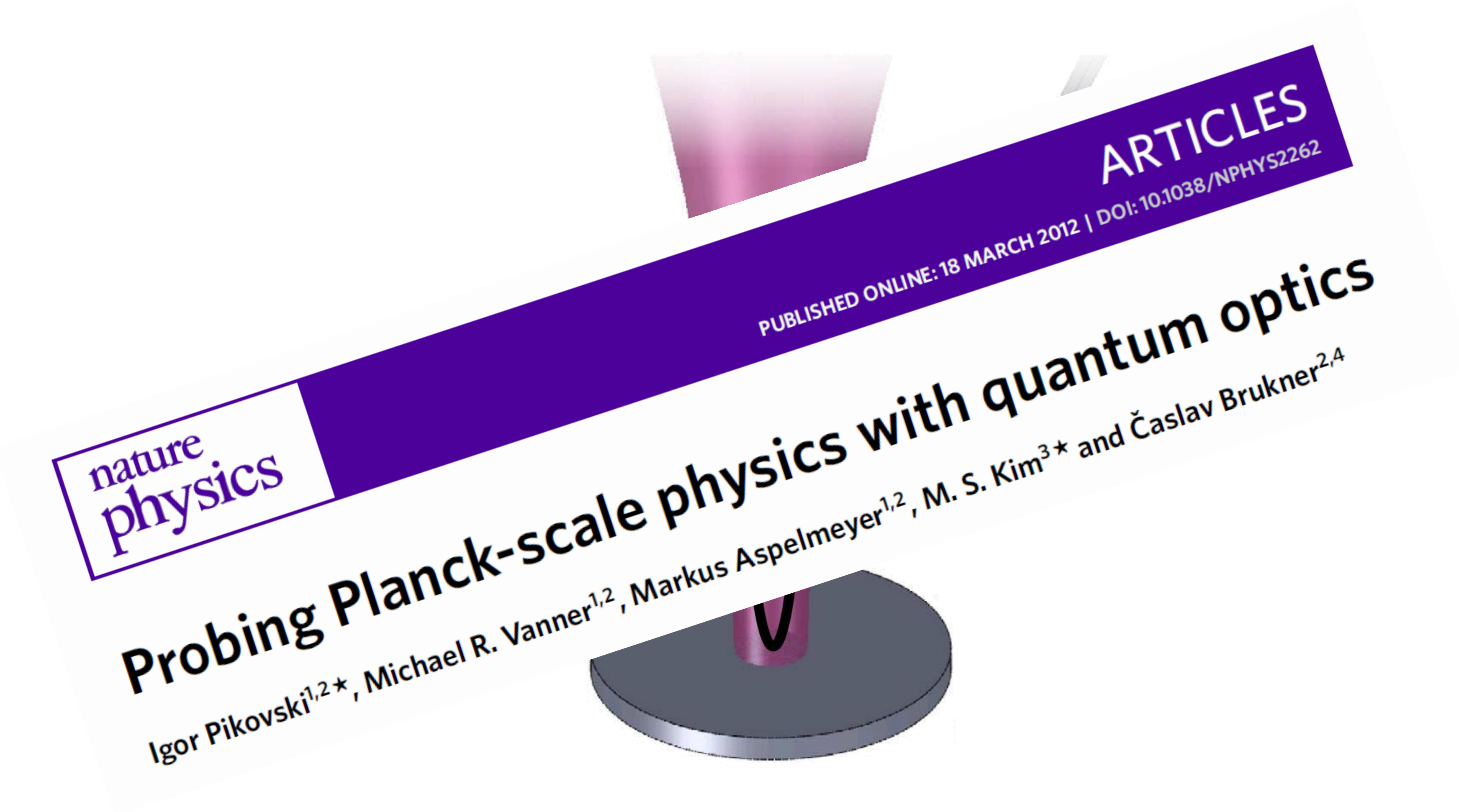




H. J. Kimble, Nature 453, (2008)

Challenges:
1. fabricating (reasonably) indistinguishable optomechanical devices
2. Heating, low detection efficiency,…

Pulsed Optomechanics


nature physics

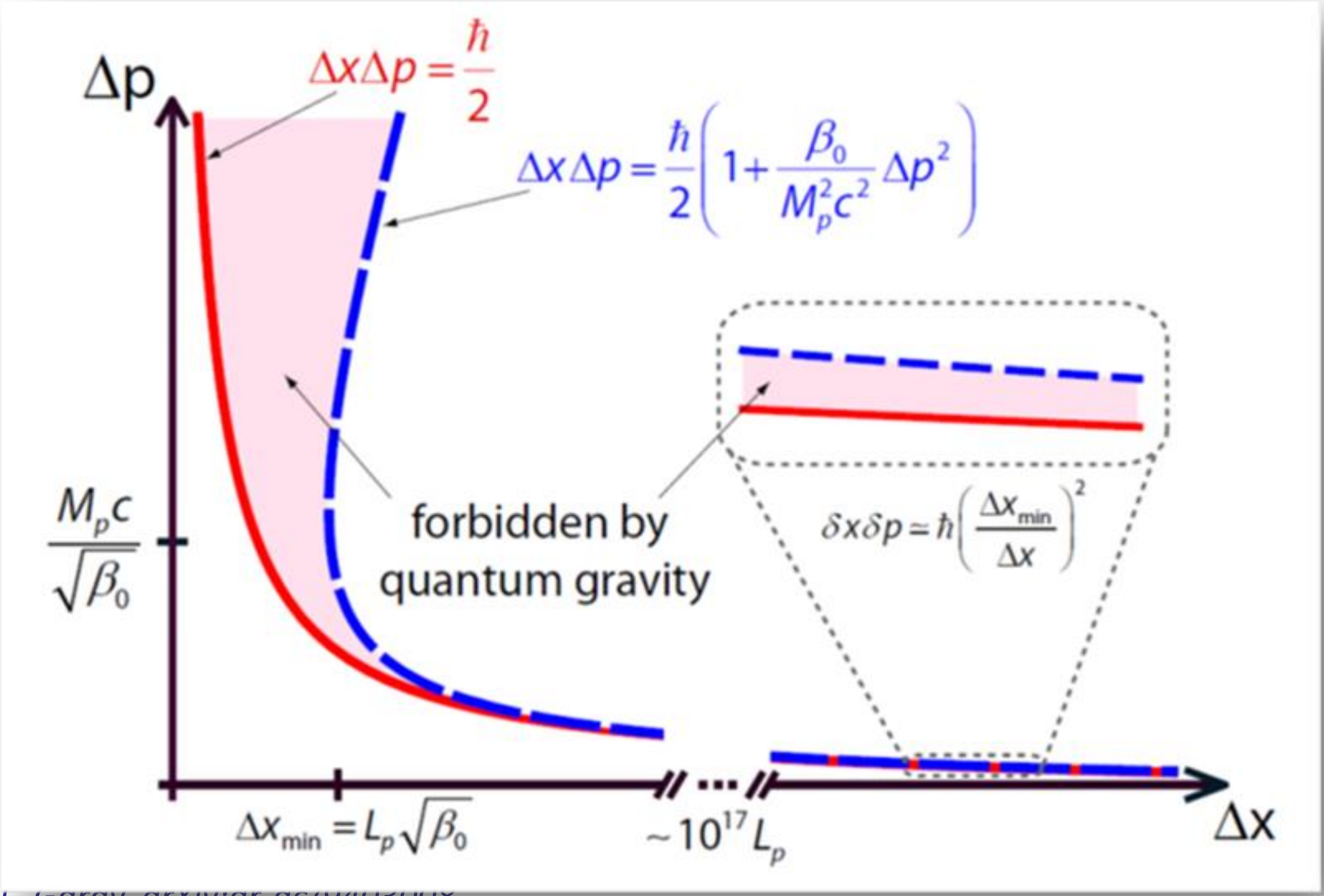
ARTICLES

PUBLISHED ONLINE: 18 MARCH 2012 | DOI: 10.1038/NPHYS2262

Probing Planck-scale physics with quantum optics

Igor Pikovski[1,2]*, Michael R. Vanner[1,2], Markus Aspelmeyer[1,2], M. S. Kim[3]* and Časlav Brukner[2,4]

Canonical Commutator of a massive system



e.g. L. Garay, arXiv:gr-qc/9403008

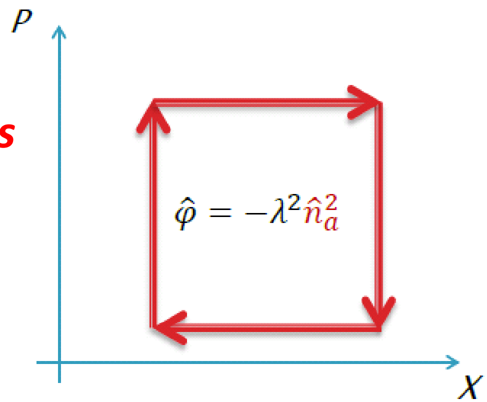
Canonical Commutator of a massive system

Idea: **Closed loop** in (mechanical) phase space generates an (optical) **phase** related to the (mechanical) **commutator**

$$\hat{\xi} = e^{i\lambda \hat{n}_a \hat{P}}\, e^{-i\lambda \hat{n}_a \hat{X}}\, e^{-i\lambda \hat{n}_a \hat{P}}\, e^{i\lambda \hat{n}_a \hat{X}}$$

$$= e^{-\lambda^2 \hat{n}_a^2 [\hat{X}, \hat{P}]}$$

mechanics



By measuring the ancilla one can obtain a measure of the commutator.

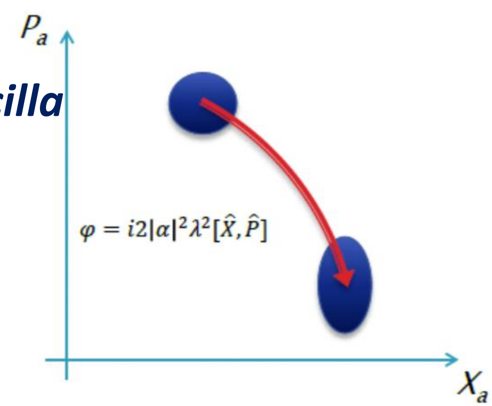
For an initial coherent state:

$$\langle \hat{a}_a \rangle = \langle \alpha | \hat{\xi}^{+} \hat{a}_a \hat{\xi} | \alpha \rangle$$

$$= \alpha e^{-\lambda^2 [\hat{X}, \hat{P}]} e^{-|\alpha|^2 \left(1 - e^{-2\lambda^2 [\hat{X}, \hat{P}]}\right)}$$

$$\approx \alpha e^{-2|\alpha|^2 \lambda^2 [\hat{X}, \hat{P}]} \qquad (\text{for } \lambda^2 [\hat{X}, \hat{P}] \ll 1)$$

optical ancilla



Phase shift scales with the intensity of the input state.
$\Rightarrow$ Can measure the commutator even for small coupling λ!

Pikovski et al. Nature Physics (2012); doi:10.1038/nphys2262

Without ancilla: see e.g. ion experiments *Leibfried et al., Nature 422, 427 (2003)*

Test of Quantum Gravity Predictions

Different proposals in the literature

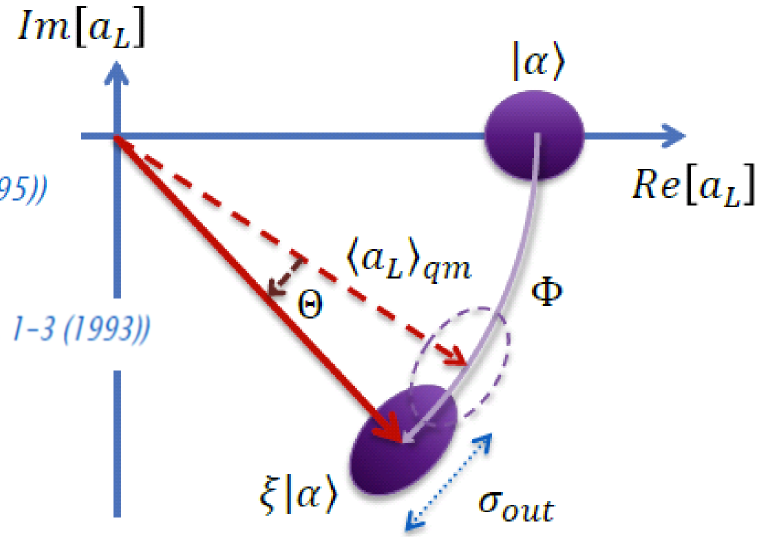
$$[x,p]_{\beta_0} = i\hbar\left(1+\beta_0\left(\frac{p}{M_{Pl}\,c}\right)^2\right)$$

(Kempf et al, PRD, 52, 2 (1995))

$$[x,p]_{\mu_0} = i\hbar\sqrt{1+2\mu_0\frac{(p/c)^2+m^2}{M_{Pl}^2}}$$

(Maggiore, Physics Letters B, 319, 1-3 (1993))

$$[x,p]_{\gamma_0} = i\hbar\left(1-\gamma_0\frac{p}{M_{Pl}\,c}+\gamma_0^2\left(\frac{p}{M_{Pl}\,c}\right)^2\right)$$



$$\langle a_L\rangle \simeq \langle a_L\rangle_{qm}\, e^{-i\Theta}$$

Provides a feasible route to put **experimental upper bounds on possible modifications**

	$[x,p]$	label	Θ
1)	0	classical	-
2)	$i\hbar$	quantum	0
3)	Eq. (2)	β-mod.	$\beta_0 \frac{4\hbar\omega_m m}{3(M_{Pl}c)^2} N_P^3 \lambda^4\, e^{-i6\lambda^2}$
4)	Eq. (3)	μ-mod.	$\mu_0 \frac{2m^2}{M_{Pl}^2} N_P \lambda^2 e^{-i2\lambda^2}$
5)	Eq. (4)	γ-mod.	$\gamma_0 \frac{3\sqrt{\hbar m\omega_m}}{2M_{Pl}c} N_P^2 \lambda^3\, e^{-i4\lambda^2}$

Pikovski et al. Nature Physics (2012); doi:10.1038/nphys2262

Test of Quantum Gravity Predictions

Current state of the art:

system/ experiment	$\beta_{0,max}$	$\gamma_{0,max}$
Position measurements	10^{24}	10^{24}
Lamb shift in Hydrogen	10^{36}	10^{10}
Electron tunneling	10^{33}	10^{11}

Pikovski et al.
Nature Physics (2012);
doi:10.1038/nphys2262

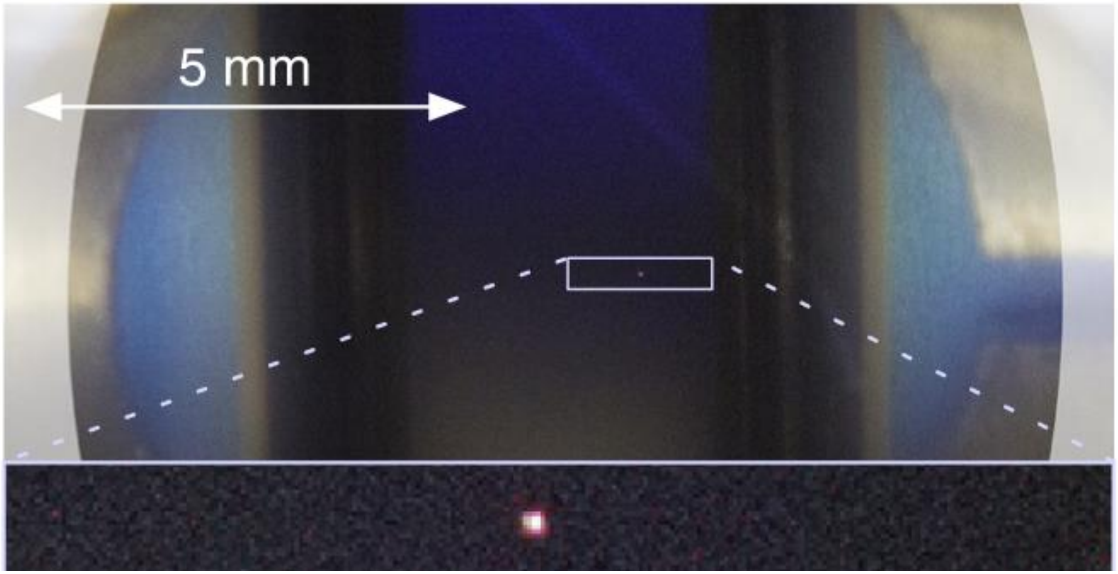
Estimates for optomechanics scheme:

$[X_m, P_m]$ $\lvert\Theta\rvert$	Eq. 2 $\mu_0 \frac{32\hbar\mathcal{F}^2 m N_P}{M_P^2 \lambda_L^2 \omega_m}$	Eq. 3 $\gamma_0 \frac{96\hbar^2\mathcal{F}^3 N_P^2}{M_P c \lambda_L^3 m \omega_m}$	Eq. 1 $\beta_0 \frac{1024\hbar^3\mathcal{F}^4 N_P^3}{3M_P^2 c^2 \lambda_L^4 m \omega_m}$
$\mathcal{F}$	10^5	2×10^5	5×10^5
m	10^{-11} kg	10^{-11} kg	10^{-6} kg
$\omega_m/2\pi$	10^5 Hz	10^5 Hz	10^5 Hz
λ_L	1064 nm	1064 nm	532 nm
N_p	10^8	5×10^{10}	10^{14}
N_r	1	10^2	10^4
$\delta\langle\Phi\rangle$	10^{-4}	5×10^{-7}	10^{-8}

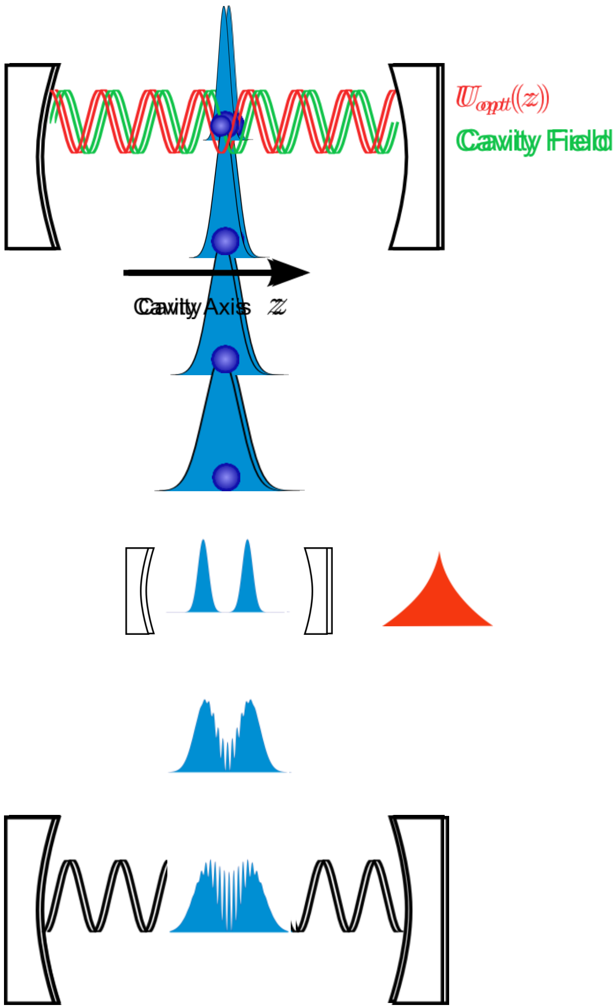
→ **Improvement by more than 20 orders of magnitude compared to existing bounds !**

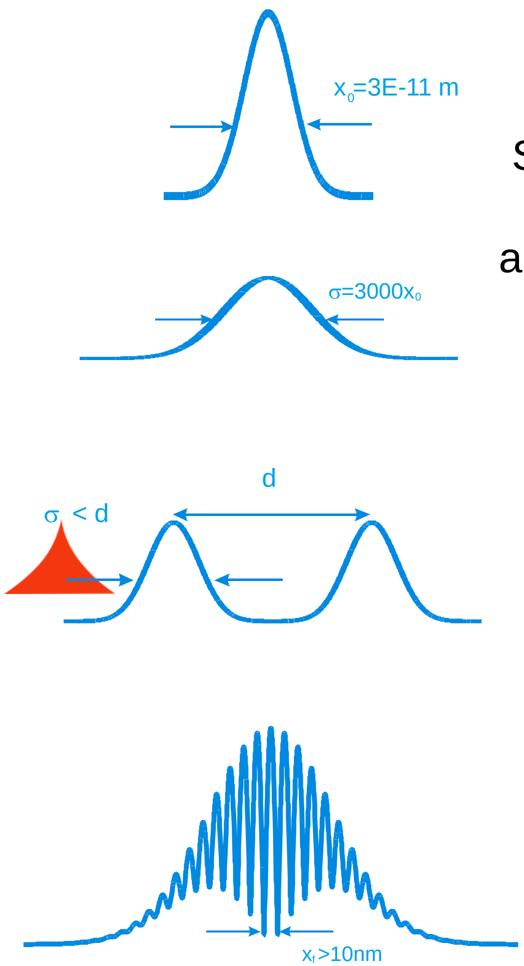
$\delta\mu_0 \sim 1$, $\delta\gamma_0 \sim 1$ and $\delta\beta_0 \sim 1$ → measuring **Planck-scale deformations**

Particle falling out of a cavity



Potential Parameter Set





Object: D=40nm
Silica Sphere

Sideband Cooling of Nanosphere
to 0.1 phonons
analogous to cooling of micromirror

3.3 ms

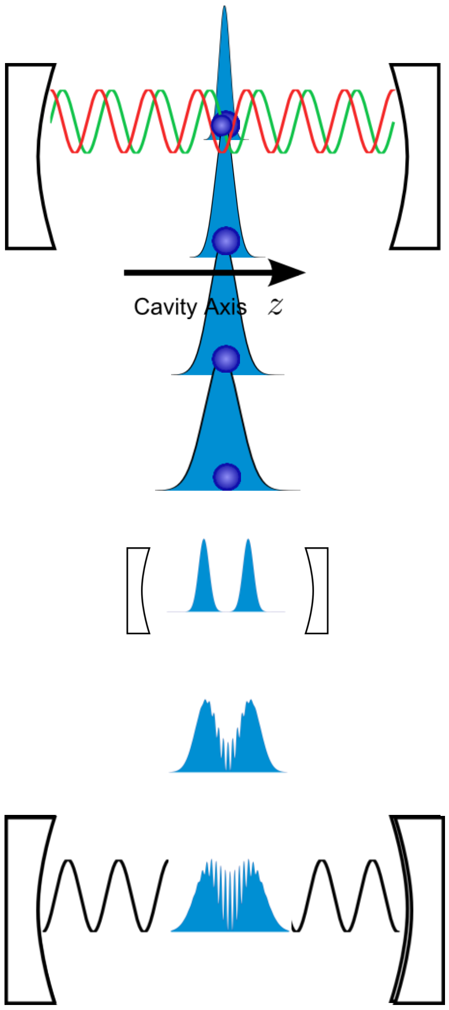
Short Pulse
x^2–readout Projection
on Cat-State $|x\rangle + |-x\rangle$
(Cavity: L=2μm, F=130000)

125 ms

Position Detection
Precision: 10nm

O. Romero-Isart et al., PRL 107, 020405 (2011)
O. Romero-Isart , Phys. Rev. A 84, 052121

Ground-based experiment I/II



Decoherence According to Quantum Theory

- Gas collisions

Pressure 10^{-16} Torr

- Scattering of Light from x^2-Detection Pulse
- Scattering of black-body radiation
- Absorption & emission of black-body radiation

Optical Grade Fused Silica – (low absorption)

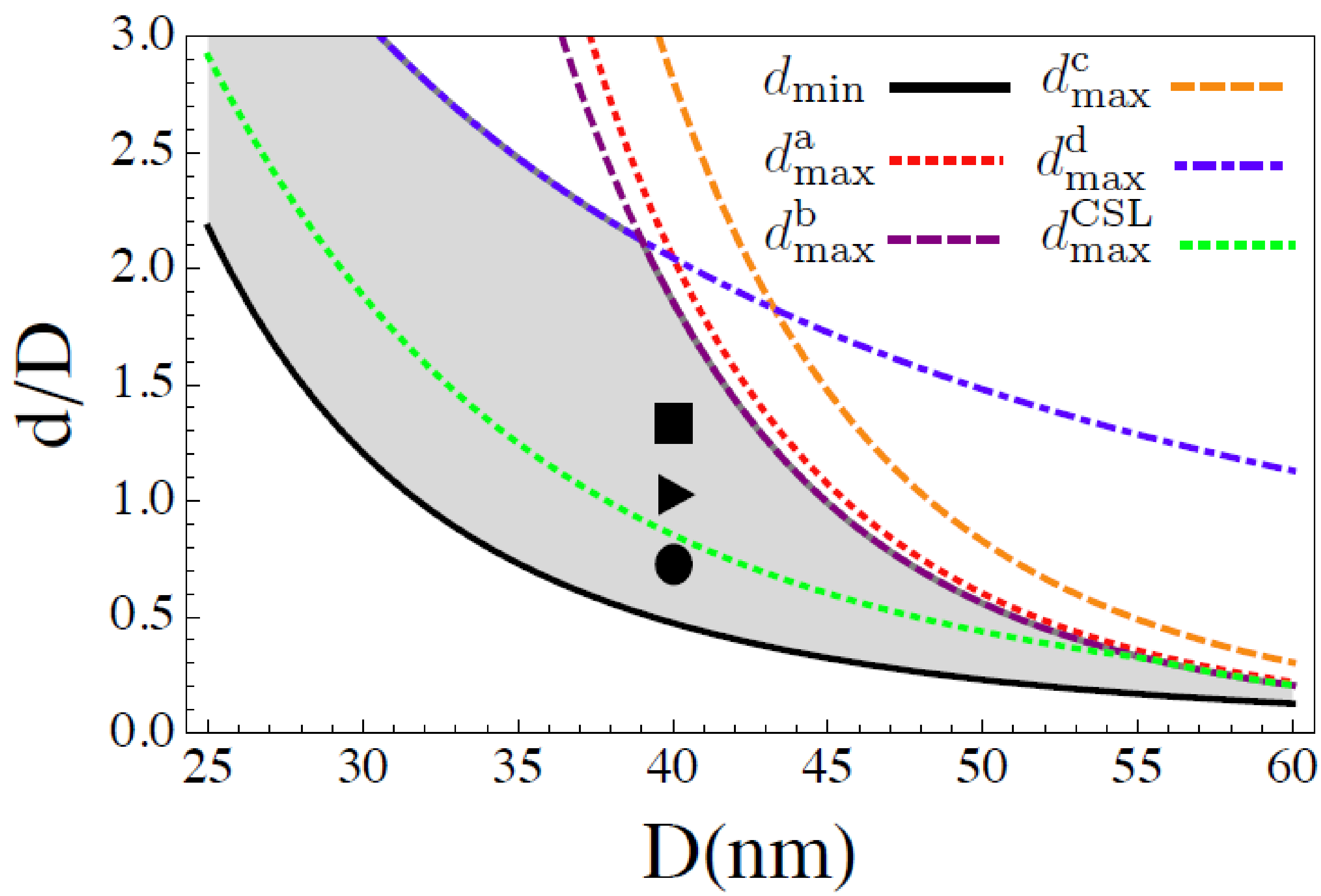
External Temperature 4.5 K

Internal Temperature 206 K

O. Romero-Isart et al., PRL 107, 020405 (2011)

O. Romero-Isart , Phys. Rev. A 84, 052121

Simulation for OM doube slit



O. Romero-Isart et al., PRL 107, 020405 (2011)

O. Romero-Isart , Phys. Rev. A 84, 052121