Cavity Quantum Optomechanics:
Testing the foundations of physics on a table top

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Quantum Sensors for Fundamental Physics
Oxford, October 2018

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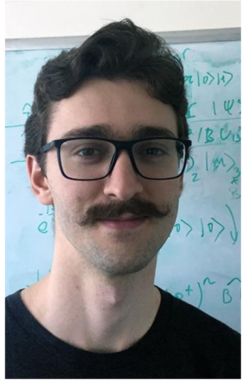

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A. Svela

M. Szczykulska

Experimental + Theoretical Quantum Optics:

Quantum Sensing

Quantum Information

Table-top Fundamentals

Quantum Sensors for Fundamental Physics

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- *Many thanks Ian and the organizers!*
- *I'm enjoying engaging with our broader fundamental physics community.*
- *I'd like to now share some of our current research on the interface between QM + G using optomechanics.*

What is quantum optomechanics?

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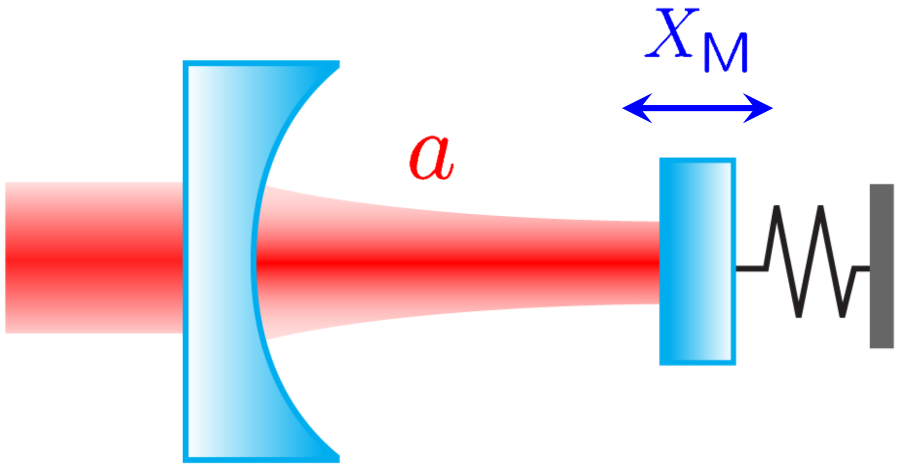

$$H/\hbar = g_0 a^\dagger a X_M$$

Control of the motion of mechanical oscillators using light.

Applications

- Quantum memory
- Quantum transducers
- Force sensors

Fundamentals

- QM at macroscopic scale
- Decoherence, Collapse, …
- GUP, …

This talk

1. **How can we prepare macroscopic superposition states?**

2. **A scheme to measure GUP. How to constrain $\beta \sim 1$?**

3. **How else can quantum optomechanics contribute?**
   (Objective collapse, GW, Surface forces,…)


Diosi-Penrose type collapse
GUP
CSL

This talk

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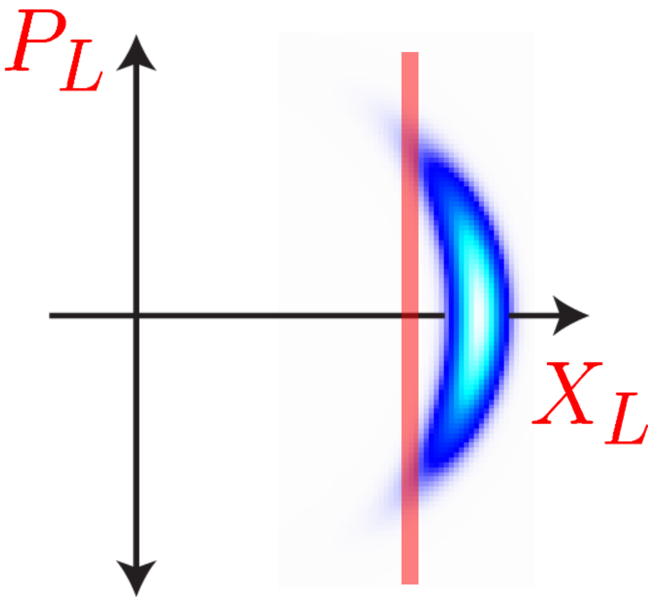
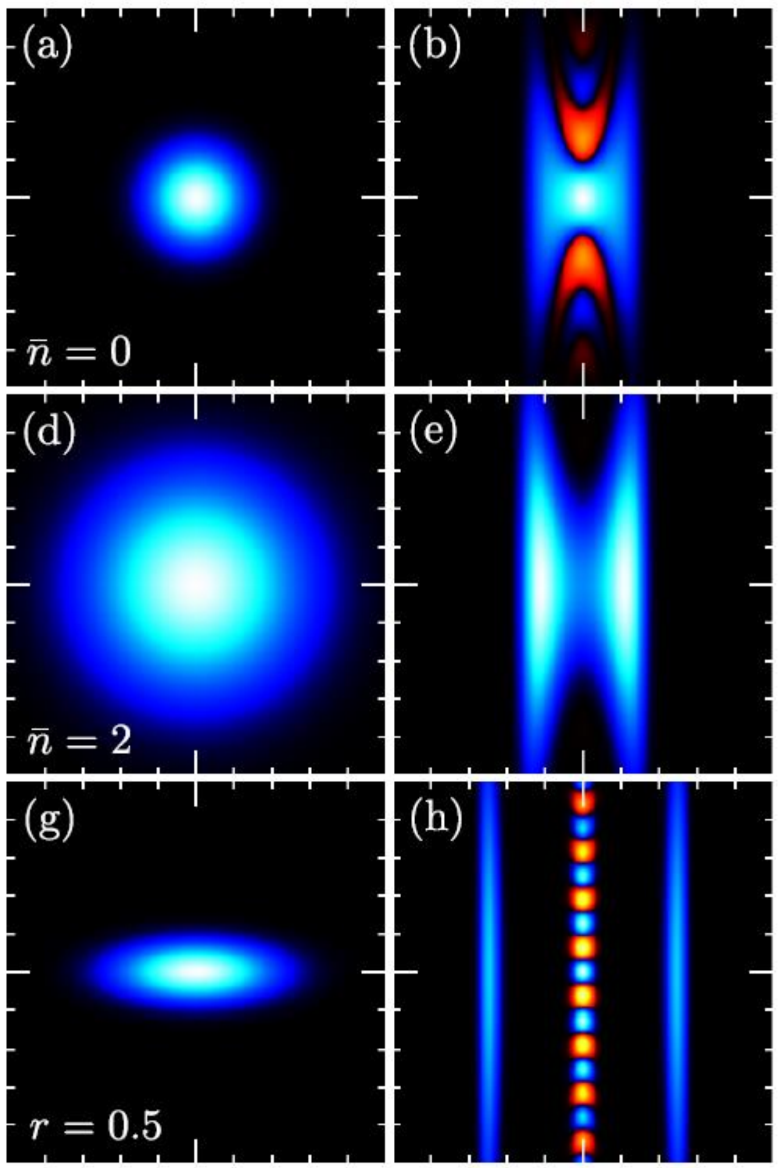
Towards Quantum Superposition States

Non-linear interaction

$$H/\hbar = g_0 a^\dagger a X_M$$



MRV, Phys. Rev. X **1**, 021011 (2011).



Towards Quantum Superposition States

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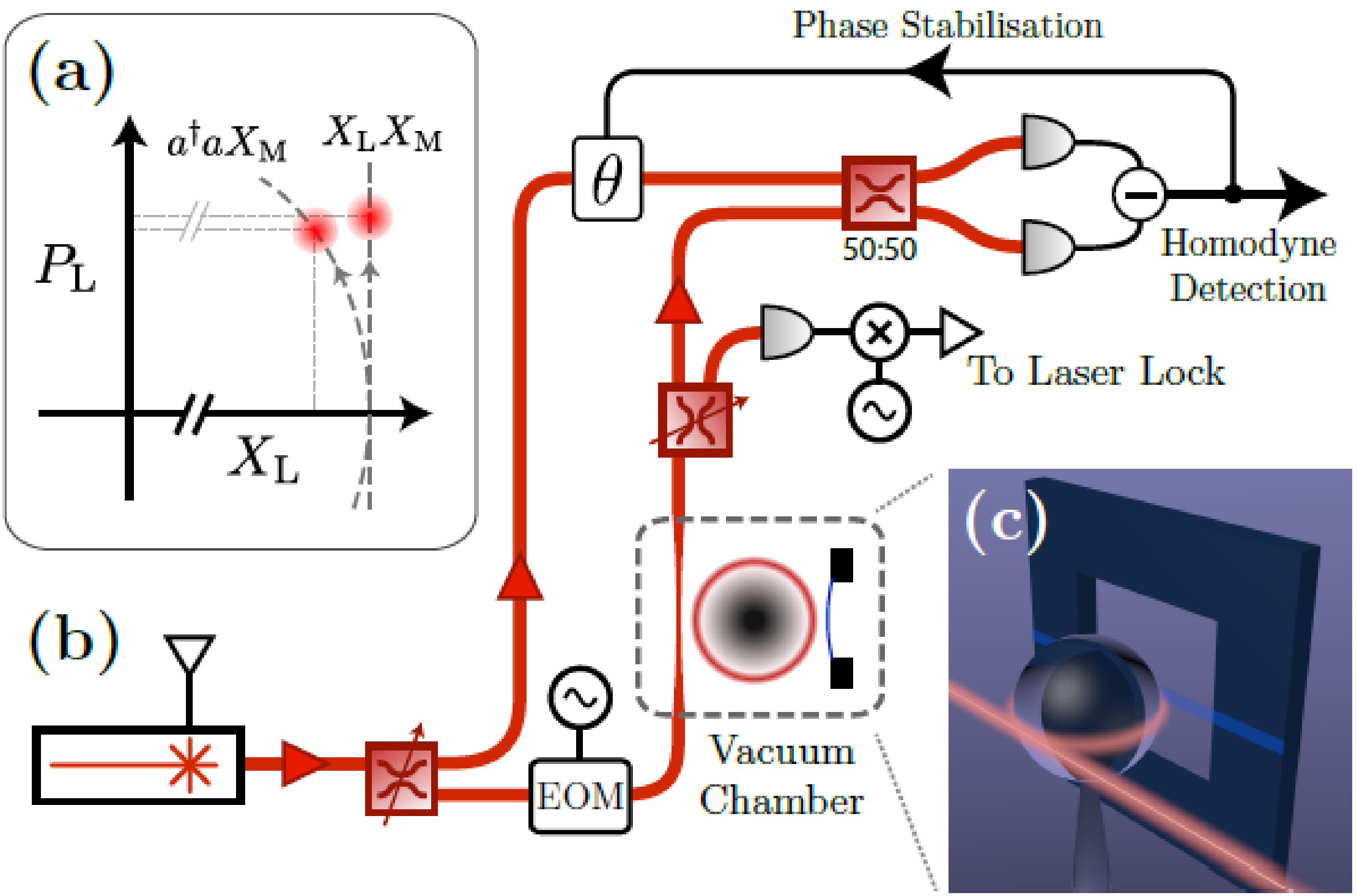

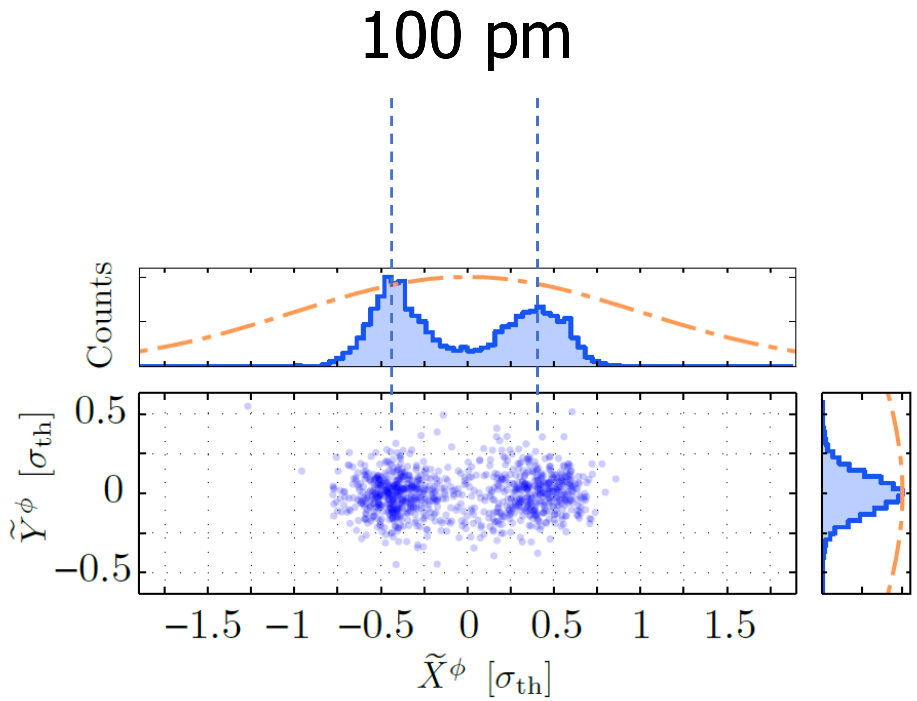

G. A. Brawley et al, Nature Communications **7**, 10988 (2016).

Mechanical interference fringes

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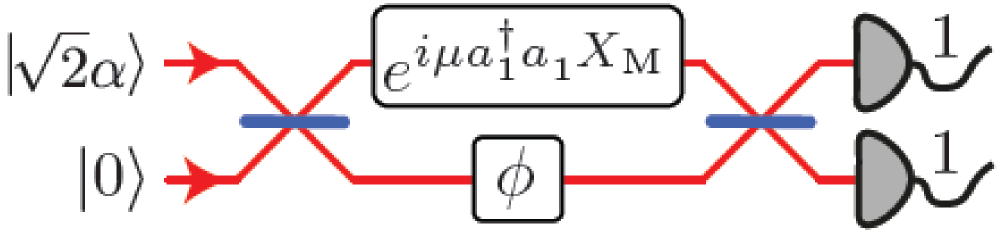
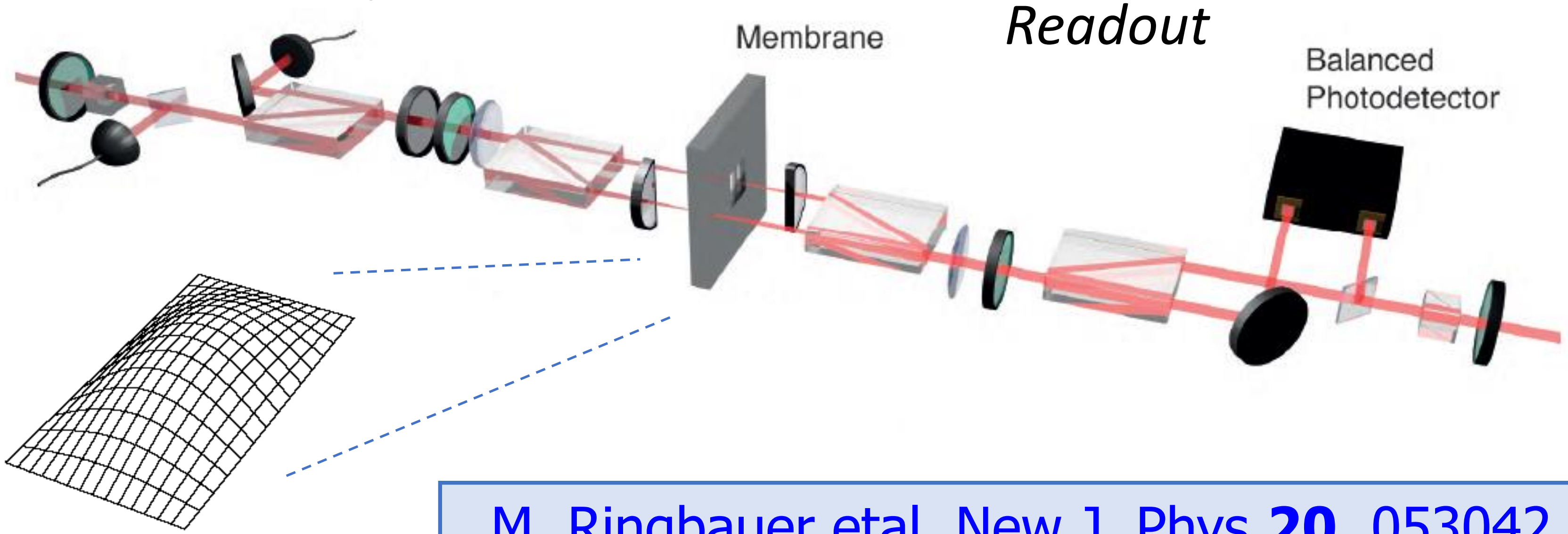
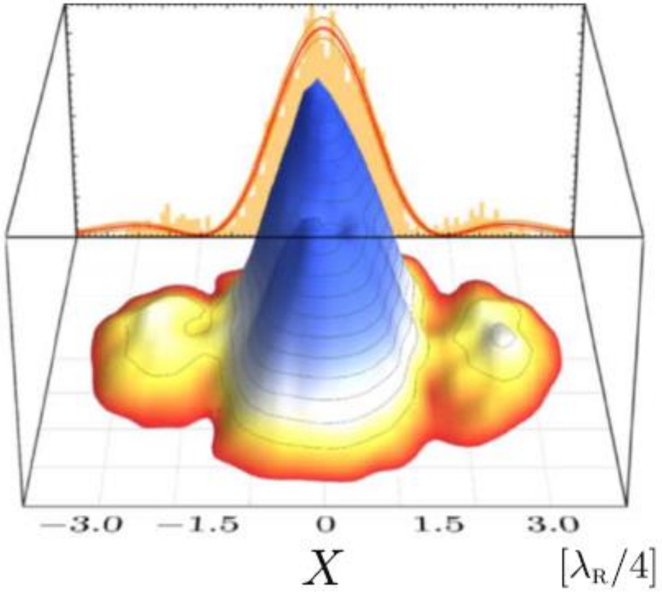


- Room Temperature + Atmospheric Pressure
- Piezo drive
- Dimensions: 1.7 * 1.7 mm * 50 nm
- Effective mass: ~100 ng (10^{16} atoms)
- Fundamental drum mode: 106 kHz

State Preparation

Readout





M. Ringbauer etal, New J. Phys **20**, 053042 (2018).

Growing Mechanical Superposition States

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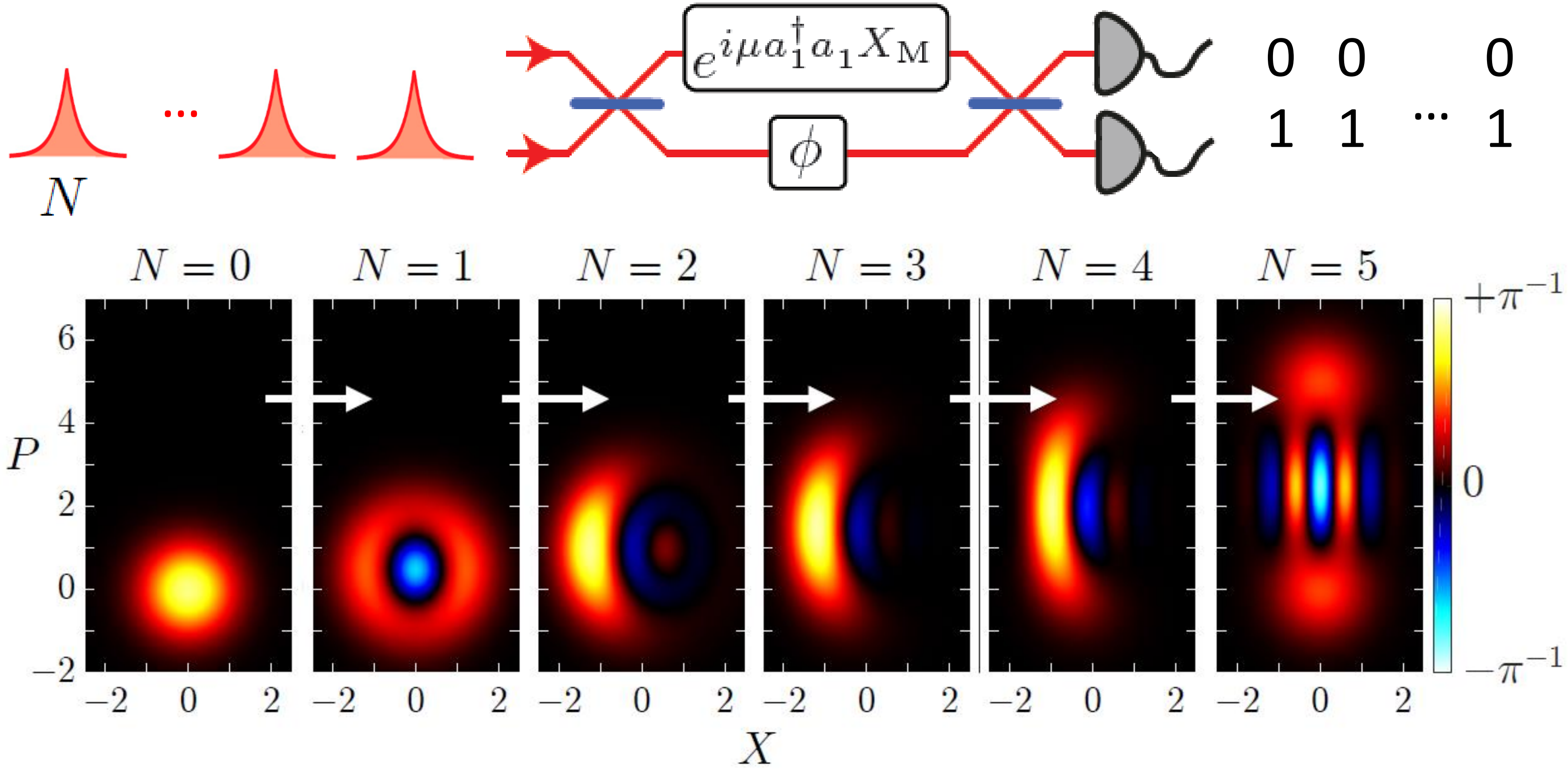

Here $\mu = 1$ $\bar{n} = 0.1$ Phase sequence: $\phi_j = 2\pi j/N + \pi$

J. Clarke and MRV, Quantum Science & Technology **4**, 014003 (2018).

This talk

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1. How can we prepare macroscopic superposition states?

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3. How else can quantum optomechanics contribute?

Generalized Uncertainty Principle (GUP)

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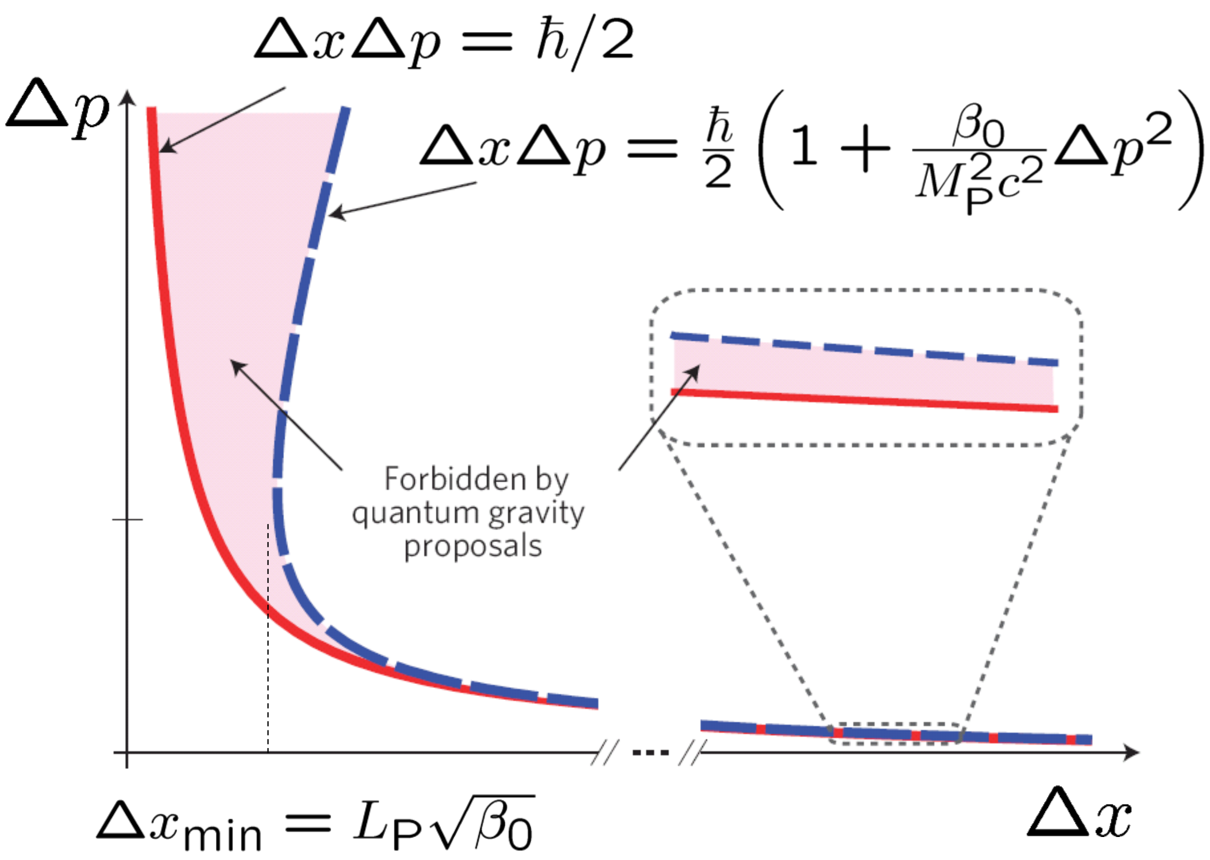

Current Bounds on β_0 :

Position measurement in LIGO: $< 10^{34}$

Hydrogen Lamb Shift: $< 10^{36}$

Electron tunnelling: $< 10^{33}$

Weber bar measurements: $< 10^{33}$

Kempf etal, Phys. Rev. D **52**, 1108 (1995).

How to experimentally constrain β_0 ?

Probing Planck-scale physics with OM

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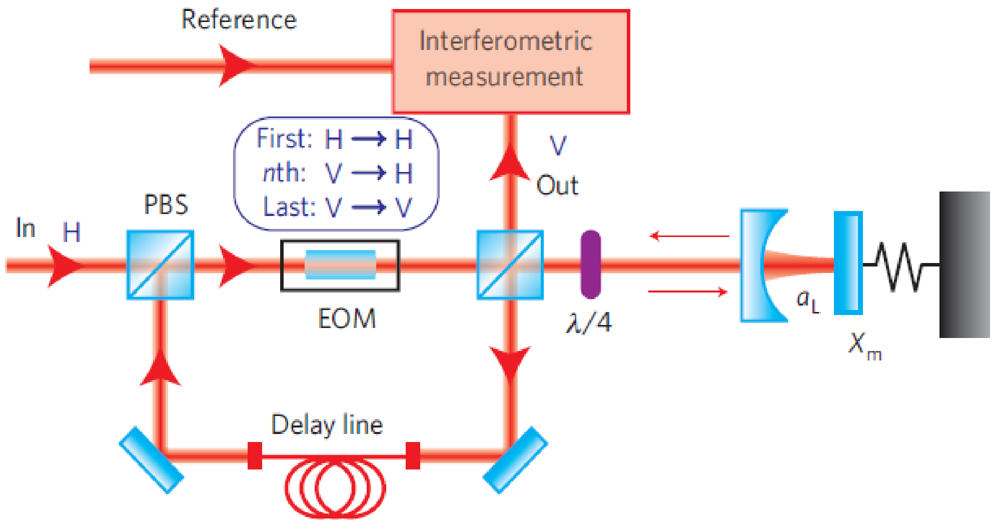

$$\xi = e^{i\lambda a^\dagger a P_M} e^{-i\lambda a^\dagger a X_M} e^{-i\lambda a^\dagger a P_M} e^{i\lambda a^\dagger a X_M}$$

$$\langle \xi^\dagger a \xi \rangle = \langle \xi^\dagger a \xi \rangle_{\mathrm{qm}} e^{-i\Phi}$$

where $\Phi = f([X_M, P_M])$

Suggested parameter set:

$\lvert\Theta\rvert$	$\beta_0 \dfrac{1024\hbar^3 \mathcal{F}^4 N_p^3}{3M_p^2 c^2 \lambda_L^4 m \omega_m}$
$\mathcal{F}$	4×10^5
m	10^{-7} kg
$\omega_m/2\pi$	10^5 Hz
λ_L	532 nm
N_p	10^{14}
N_r	10^6
$\delta\langle\Phi\rangle$	10^{-10}

$$\beta_0 < 1$$

I. Pikovski etal Nature Physics **8**, 393 (2012).

P. Bosso etal Phys. Rev. A **96**, 023849 (2017).

This talk

1. How can we prepare macroscopic superposition states?

2. A scheme to measure GUP. How to constrain $\beta \sim 1$?

3. **How else can quantum optomechanics contribute?**

How else can quantum optomechanics contribute?

Related Talks

- Sougato Bose (UCL)
- Konrad Lehnert (JILA)
- Mike Tobar (UWA)
- Haixing Miao (Birm.)
- Peter Barker (UCL)
- Gavin Morley (Warwick)
- Peter Leek (Oxford)
- *Also, Lucas, Steane and Godun, & others*

Objective collapse

Diosi-Penrose, Ghirardi-Rimini-Weber, Pearle, Adler, others

Gravitational Wave Detection

e.g. Arvanitaki & Gerarci, PRL **110**, 071105 (2013).

Near-surface forces

e.g. Chiaverini et al, PRL **90**, 151101 (2003).

Thank you!

Position-Squared Measurements:

Phys. Rev. X **1**, 021011 (2011).

Nature Comm. **7**, 10988 (2016).

Toward Testing GUP:

Nature Physics **8**, 393 (2012).

Phys. Rev. A **96**, 023849 (2017).

Growing Superposition States:

New J. Phys **20**, 053042 (2018).

Q. Sci. & Tech. **4**, 014003 (2018).

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