

Generating Mechanical Interference Fringes and Brillouin Optomechanical Strong Coupling

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Quantum Measurement Lab

Imperial College
London

Aspen, February 2020

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A. Sveta



S. Qvarfort

**Experimental + Theoretical
Quantum Optics:**

Quantum Sensing
Quantum Information
Table-top Fundamentals

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New Lab Space!

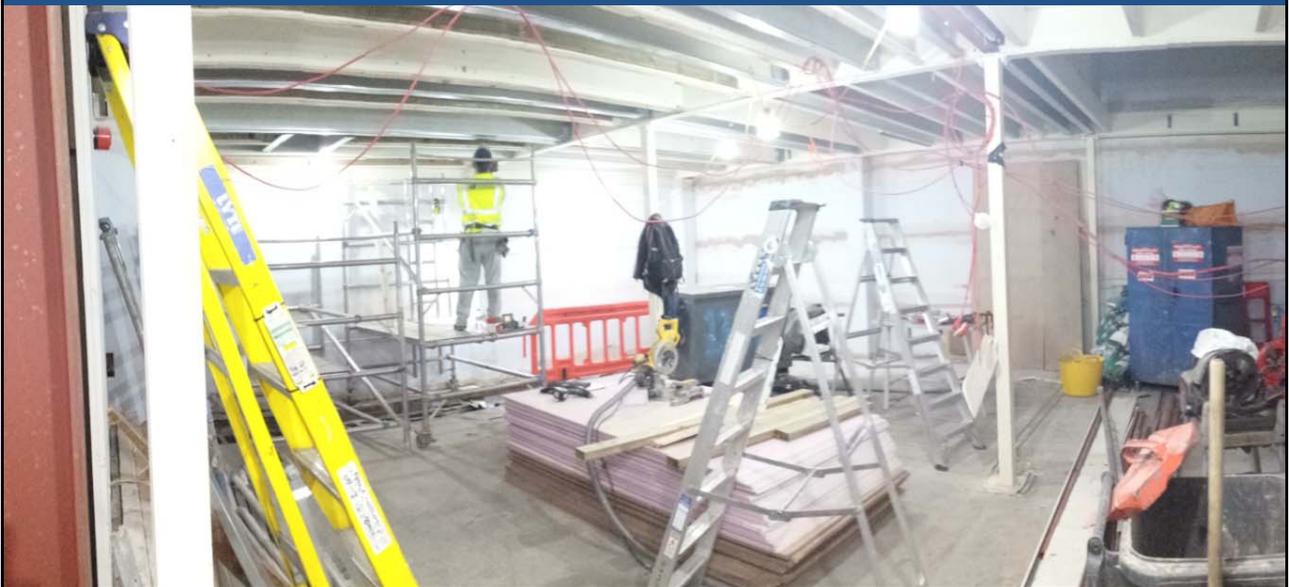
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New Lab Space!

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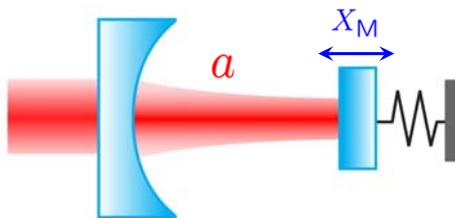


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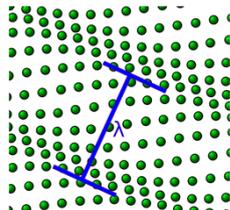
Cavity quantum optomechanics

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Radiation Pressure



Electrostriction



Applications

- Quantum memory
- Quantum transducers
- Force sensors

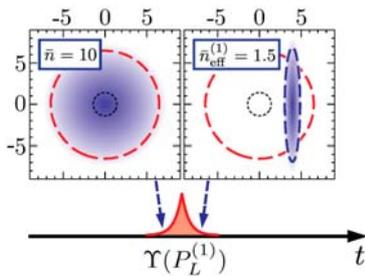
Fundamentals

- QM at macroscopic scale
- Interface between QM and G
- Decoherence, Collapse, ...

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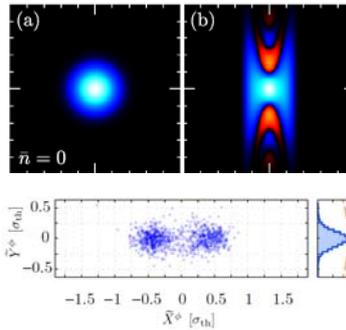
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Pulsed Position Meas.



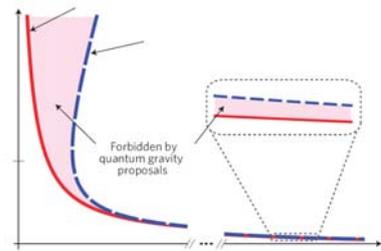
PNAS **108**, 16182 (2011)
 Nat. Comms. **4**, 2295 (2013)
 arXiv:1910.09603 (2019)

X² Measurements



PRX **1**, 021011 (2011)
 Nat. Comms **7**, 10988 (2016)

GUP



$$\Delta x \Delta p = \frac{\hbar}{2} \left(1 + \frac{\beta_0}{M_P^2 c^2} \Delta p^2 \right)$$

Nature Physics **8**, 393 (2012)
 PRA **96**, 023849 (2017)

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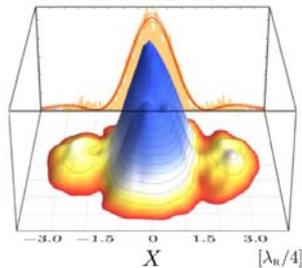
This talk

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*Many thanks Konrad and
 the organizers!*

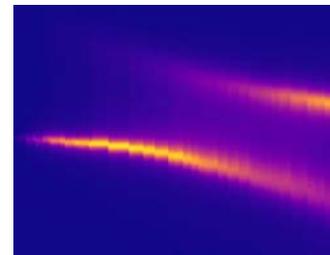


Mechanical Interference Fringes



New J. Phys
20, 053042 (2018).

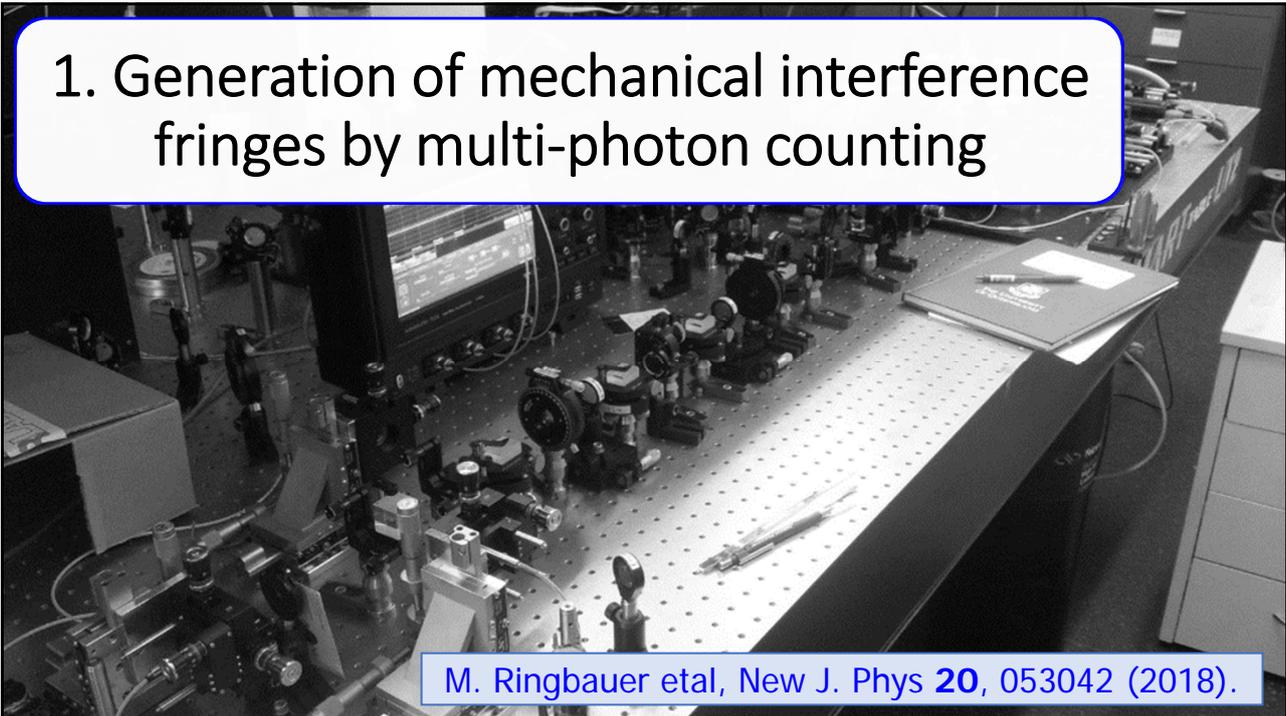
Brillouin Optomech. Strong Coupling



Optica **6**, 7 (2019).

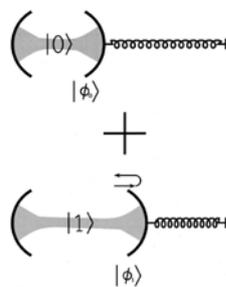
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1. Generation of mechanical interference fringes by multi-photon counting



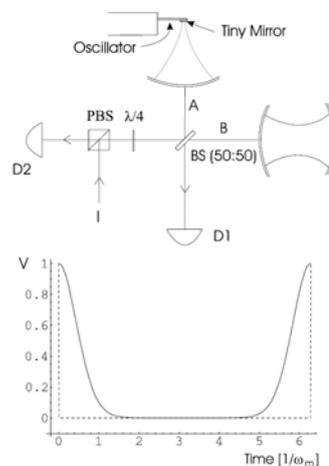
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Optomechanics & Single Photons

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Non-classical intracavity
states of light & mechanics.

S. Bose, K. Jacobs, P. Knight,
PRA **56**, 4175 (1997).
PRA **59**, 3204 (1999).



W. Marshall *et al.*,
PRL **91**, 130401 (2003).

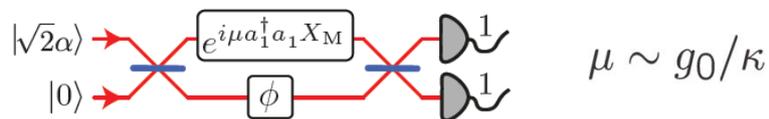
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Our Scheme

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- We operate outside the “resolved sideband regime”: $\kappa \gg \omega_M$
- Pulse duration much shorter than the mechanical period: $\tau \ll \omega_M^{-1}$
- Utilizes full (cubic) interaction: $H/\hbar = g_0 a^\dagger a X_M$

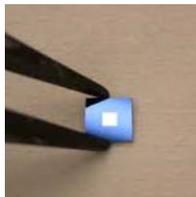
- Protocol:



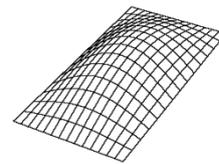
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Experimental Setup

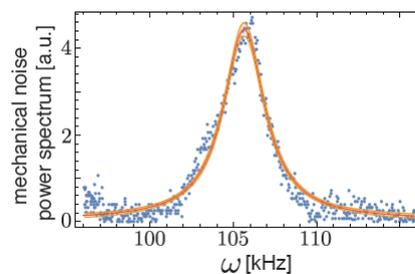
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- Room Temperature
- Atmospheric Pressure
- Piezo drive
- Single prompt reflection



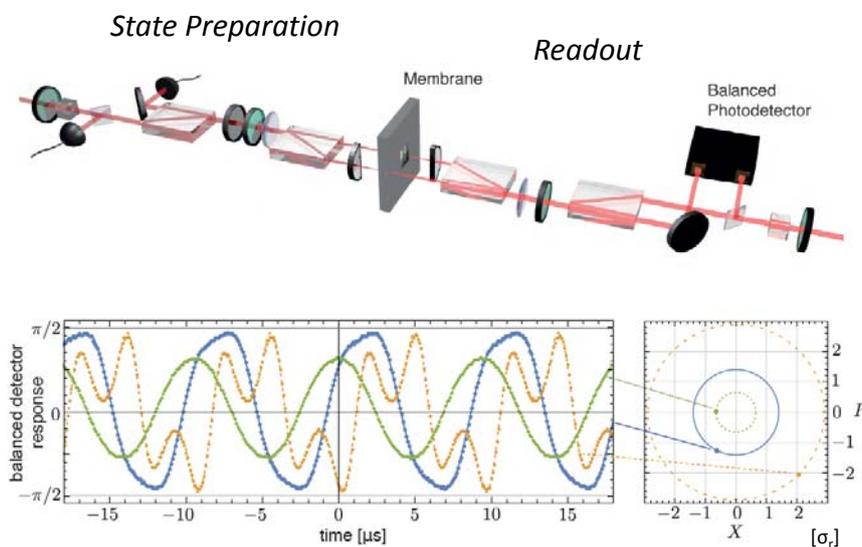
Norcada Si_3N_4 Membrane:
 Dimensions: 1.7 * 1.7 mm * 50 nm
 Effective mass: ~ 100 ng (10^{16} atoms)
 Fundamental drum mode: 106 kHz
 Reflectivity at 795 nm: 23%



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Experimental Setup

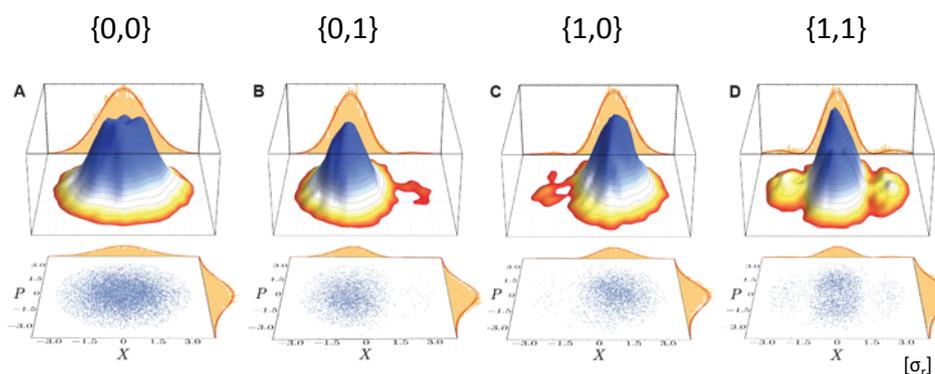
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Results

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- Approximately 3000 samples acquired per plot
- Thermal state RMS motion ~ 200 nm (large phase shifts)

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

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Projection onto higher NOON states

$$\mathcal{P}_N \sim \frac{1}{N!} |\alpha|^{2N}$$

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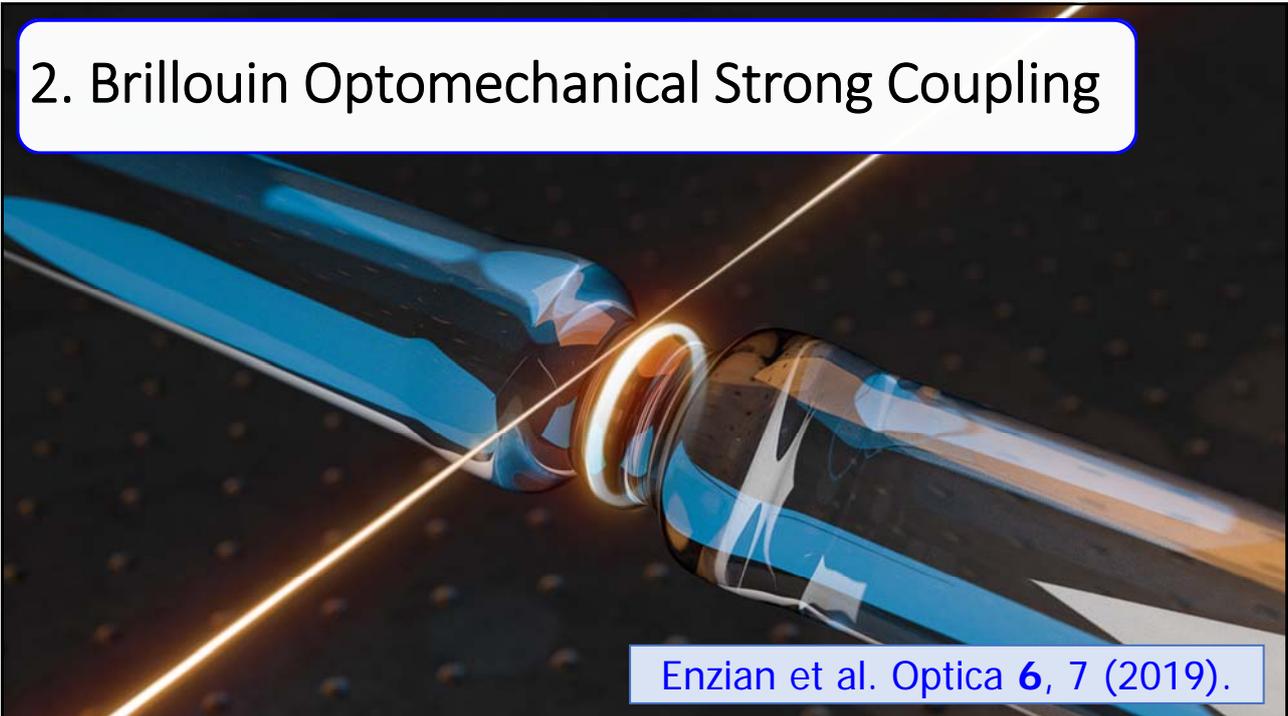
Growing Mechanical Superposition States

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).

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2. Brillouin Optomechanical Strong Coupling

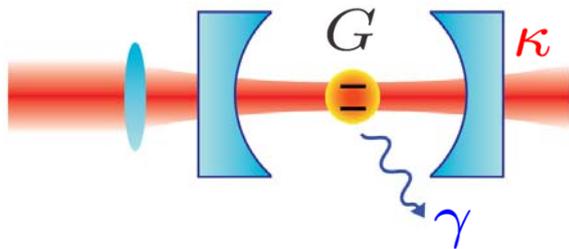


Enzian et al. *Optica* **6**, 7 (2019).

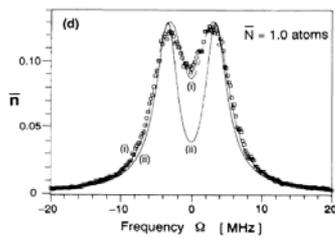
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Strong Coupling in Quantum Science

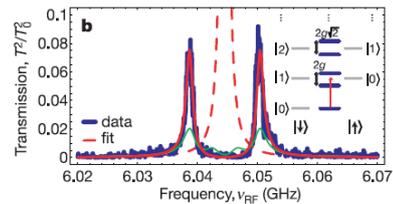
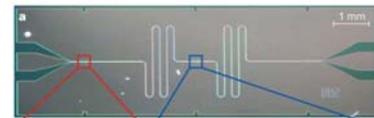
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Strong coupling requires: $G > \kappa, \gamma$



CalTech, PRL **51**, 132 (1992)



Yale, *Nature* **431**, 162 (2004)

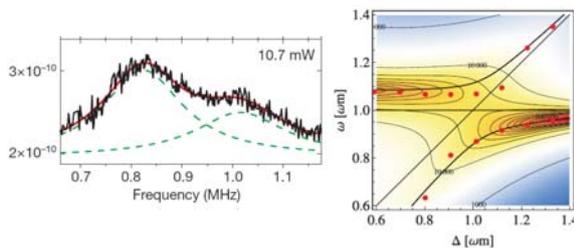
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Optomechanical Strong Coupling

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First observation of
optomechanical strong coupling:

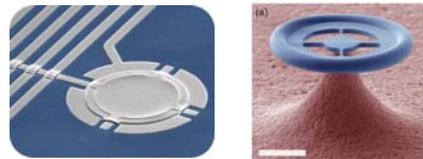
$$G = g_0 \alpha > \kappa, \gamma$$



Vienna, Nature **460**, 724 (2009).

Quantum-coherent coupling:

$$G > \kappa, \bar{n}\gamma$$



Teufel et al Nature **471**, 204 (2011).
Verhagen et al Nature **482**, 63 (2012).

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How to “cook up” an optomechanics experiment?

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A set of desirable ingredients:

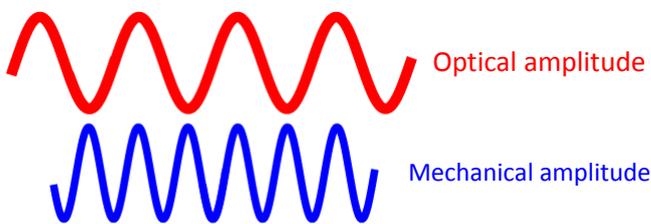
- High mechanical frequency (~10 GHz)
- Strong optomechanical coupling
- Low optical absorption
- Low mechanical decoherence
- High optical collection efficiency
- Good separability of signal from pump



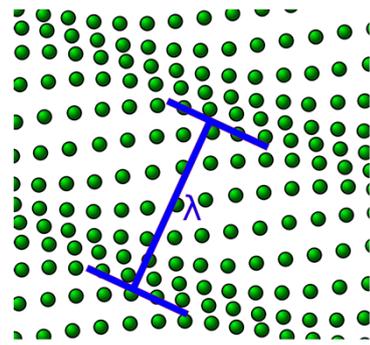
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Brillouin optomechanics

- The light affects the mechanical vibrations via *electrostriction*.
- The mechanical vibrations affect the light via *photoelasticity*.

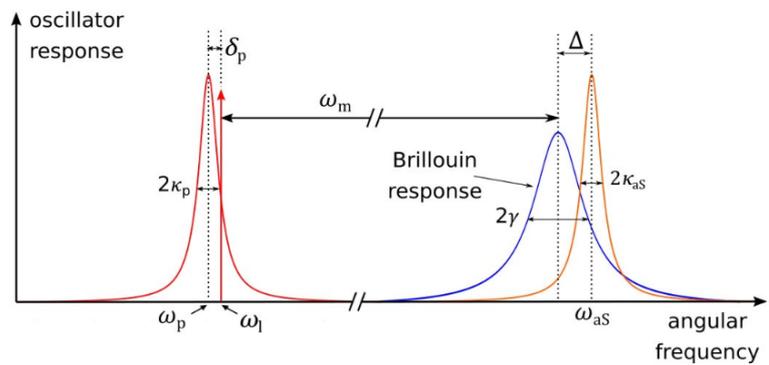
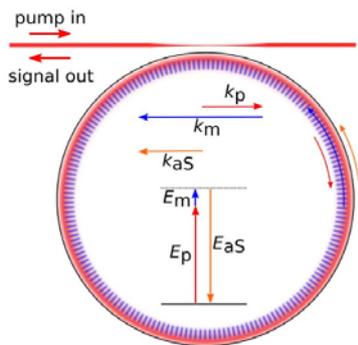


Atoms in material displacement



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Brillouin optomechanics

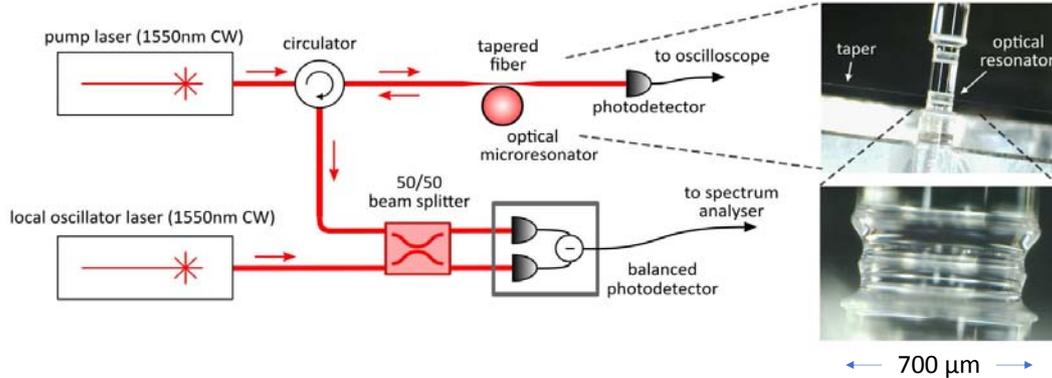


$$\frac{H}{\hbar} = G(a_{aS}^\dagger b + a_{aS} b^\dagger) - \Delta b^\dagger b$$

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Experimental Setup

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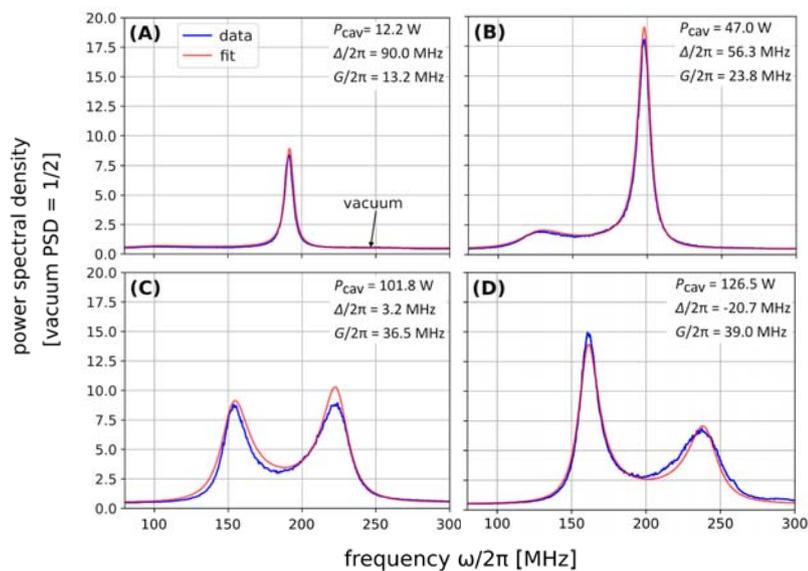


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Brillouin Strong Coupling

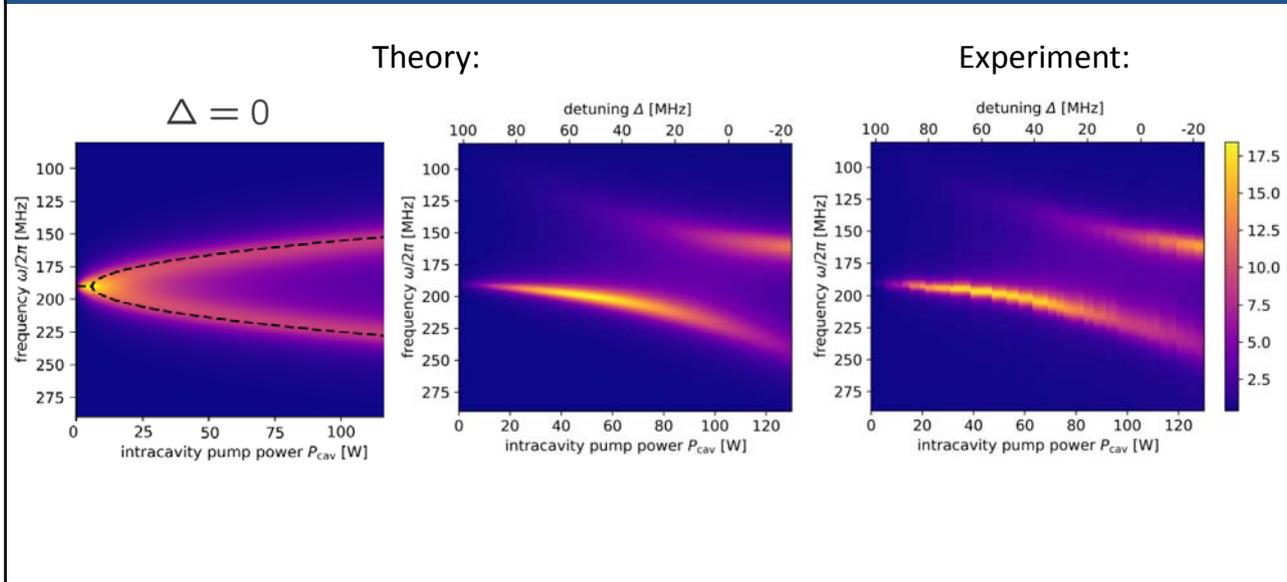
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Brillouin Strong Coupling

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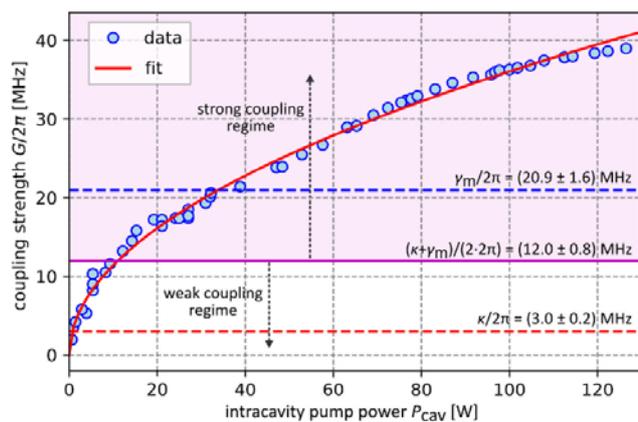


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Strong Coupling Summary

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- First observation of Brillouin strong coupling.
- Bare coupling rate: $g_0 \sim 400$ Hz.
- G is 3.25 times stronger than the hybrid decay rate.
- Provides a promising path for a quantum interface/memory for photons and phonons.



Enzian et al. *Optica* **6**, 7 (2019).

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Funding

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EPSRC [dstl]

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Facilities Council

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Postdoc and PhD positions available!

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Thank you!

Growing Superposition States:

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

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

Brillouin Strong Coupling

Optica **6**, 7 (2019).

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