Towards room temperature quantum squeezing of a mechanical resonator

Chao Meng, Soroush Khamedi, Amy van der Hel, George Brawley, James Bennett, Elizabeth Bridge, Michael Vanner and Warwick Bowen

The University Of Queensland AUSTRALIA

QUEENSLAND QUANTUM OPTICS

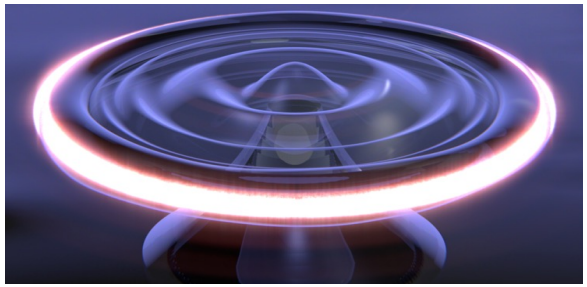
Air Force Office of Scientific Research · United States Air Force

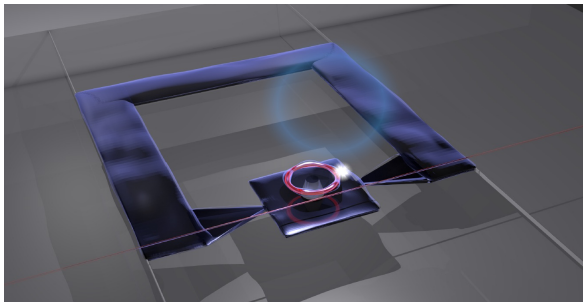
Australian Government
Australian Research Council

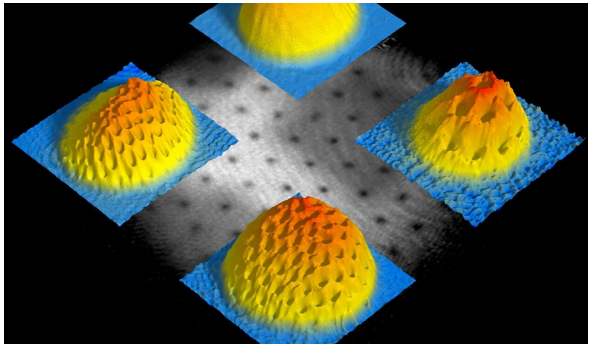
EQUS

Precision Sensing Initiative
The University of Queensland

Superfluid physics

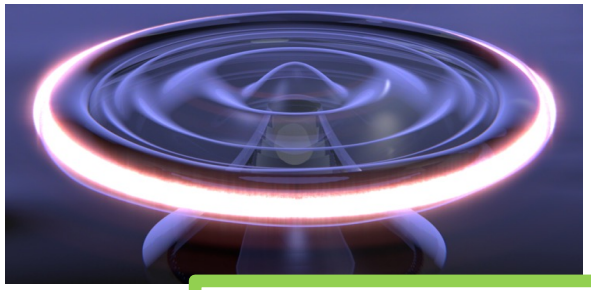


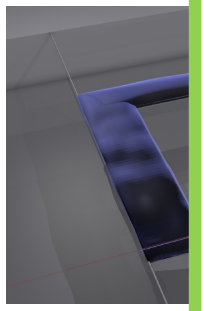


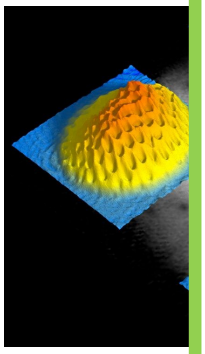


Sawadski *et al* arXiv:2208.05660 (2022). Sfendla *et al* npj Quantum Info. **7** 62 (2021); He *et al* Nature Physics **16** 417 (2020); Sachkou *et al* Science **366** 1480 (2019); Harris *et al* Nature Physics **12** 788 (2016).

Superfluid physics







Sawadski *et al* arXiv:2208.05660 (2022). Sfendla *et al* npj Quantum Info. **7** 62 (2021); He *et al* Nature Physics **16** 417 (2020); Sachkou *et al* Science **366** 1480 (2019); Harris *et al* Nature Physics **12** 788 (2016).

Engineered entropic forces allow ultrastrong dynamical backaction

13 December 2022 18:45
Exhibition Halls F & G (Adelaide Convention Centre)

Chris Baker

Superfluid Optomechanical Dissipative Solitons

13 December 2022 16:45
Room E2 (Adelaide Convention Centre)

Walter Wasserman

Confining sound in superfluids via optomechanics

13 December 2022 16:00
Room E2 (Adelaide Convention Centre)

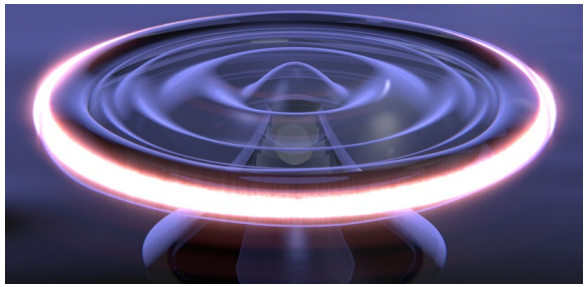
Ray Harrison

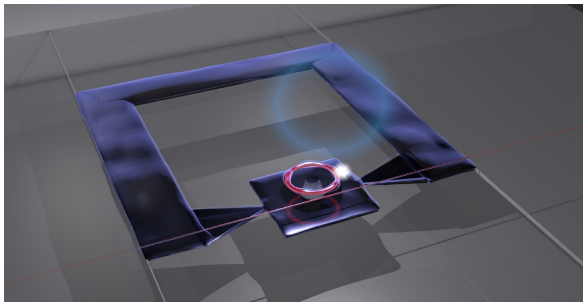
A New Approach to Low-Mass Dark Matter Detection

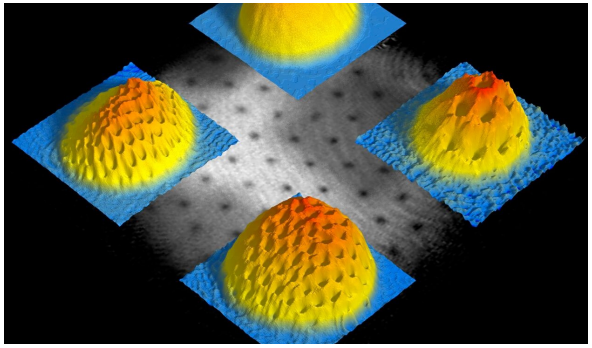
15 December 2022 18:45
Exhibition Halls F & G (Adelaide Convention Centre)

Glen Harris

Superfluid physics

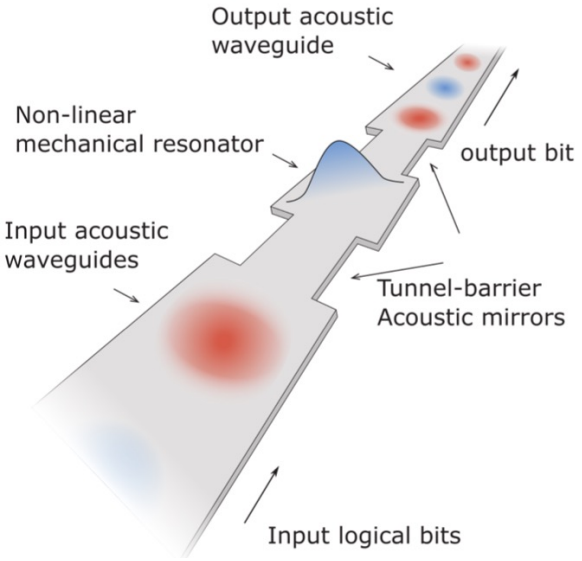


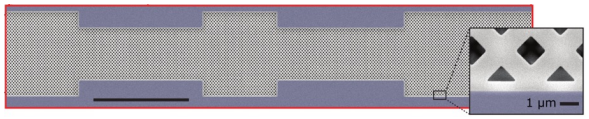


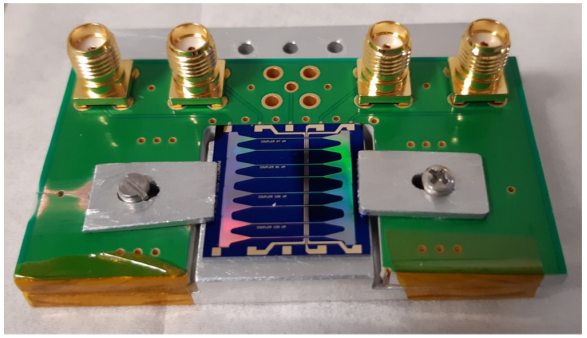


Sawadski *et al* arXiv:2208.05660 (2022). Sfendla *et al* npj Quantum Info. **7** 62 (2021); He *et al* Nature Physics **16** 417 (2020); Sachkou *et al* Science **366** 1480 (2019); Harris *et al* Nature Physics **12** 788 (2016).

Phononics

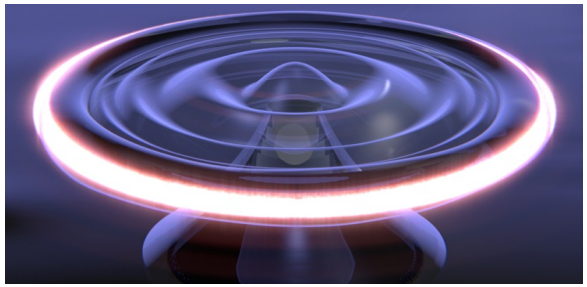


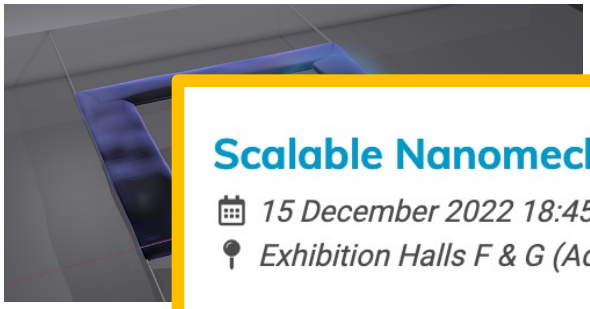


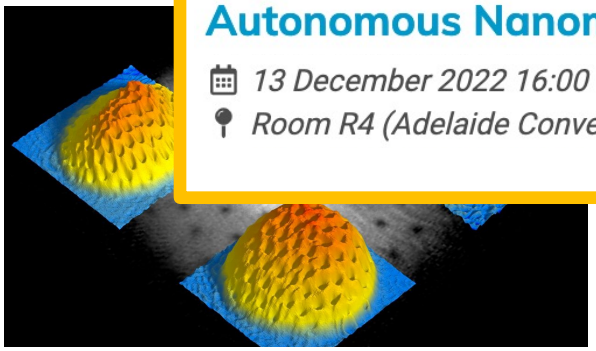


Romero *et al* arxiv:2206.11661 (2022); PR Applied **13** 044007 (2020); Mauranyapin *et al* PR Applied **15** 054036 (2021).

Superfluid physics

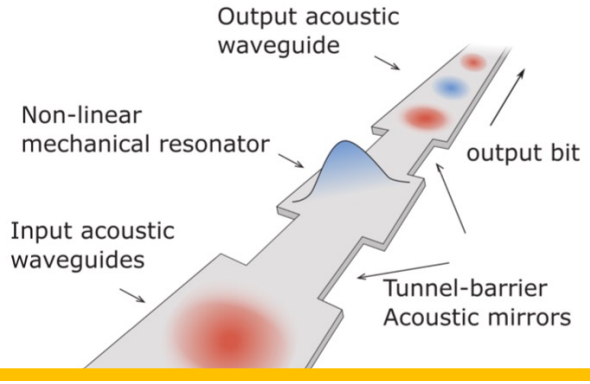






Sawadski *et al* arXiv:2208.05660 (2022). Sfendla *et al* npj Quantum Info. **7** 62 (2021); He *et al* Nature Physics **16** 417 (2020); Sachkou *et al* Science **366** 1480 (2019); Harris *et al* Nature Physics **12** 788 (2016).

Phononics



Scalable Nanomechanical Computing

15 December 2022 18:45

Exhibition Halls F & G (Adelaide Convention Centre)

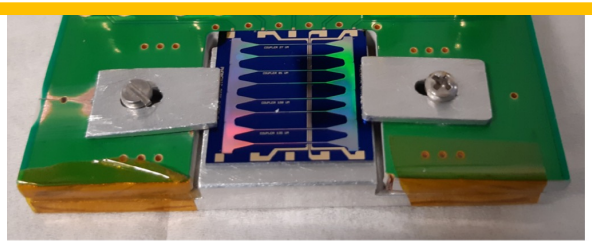
Tim Hirsch

Autonomous Nanomechanical Error Correction

13 December 2022 16:00

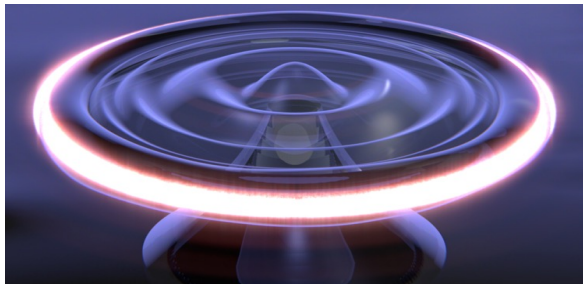
Room R4 (Adelaide Convention Centre)

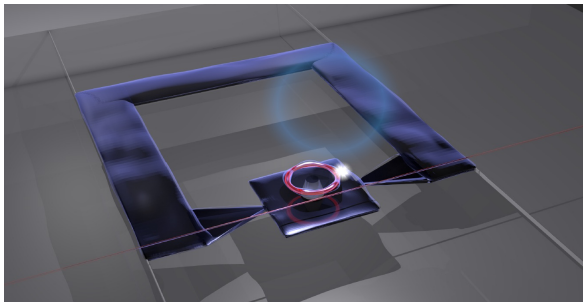
Tina Jin

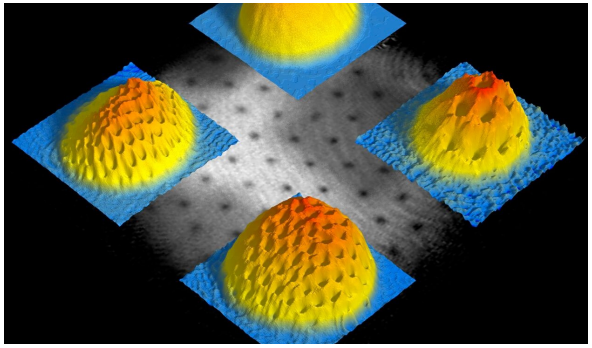


Romero *et al* arxiv:2206.11661 (2022); PR Applied **13** 044007 (2020); Mauranyapin *et al* PR Applied **15** 054036 (2021).

Superfluid physics

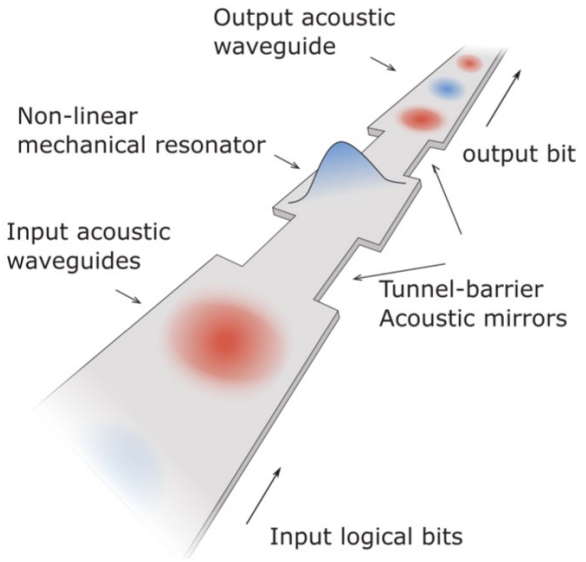


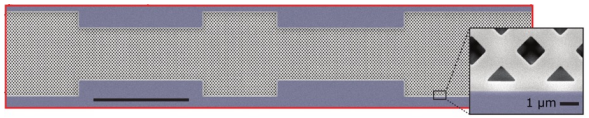


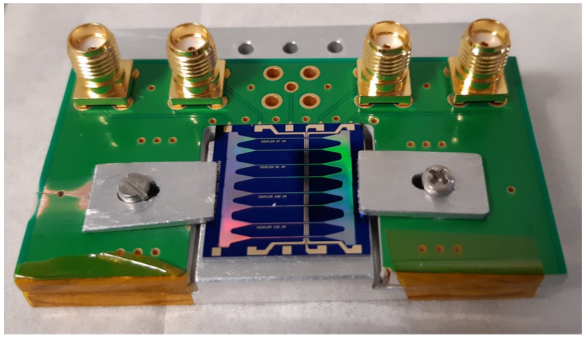


Sawadski *et al* arXiv:2208.05660 (2022). Sfendla *et al* npj Quantum Info. **7** 62 (2021); He *et al* Nature Physics **16** 417 (2020); Sachkou *et al* Science **366** 1480 (2019); Harris *et al* Nature Physics **12** 788 (2016).

Phononics

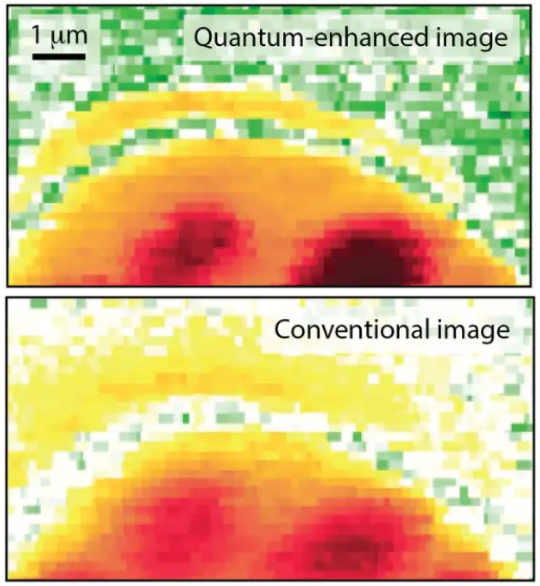






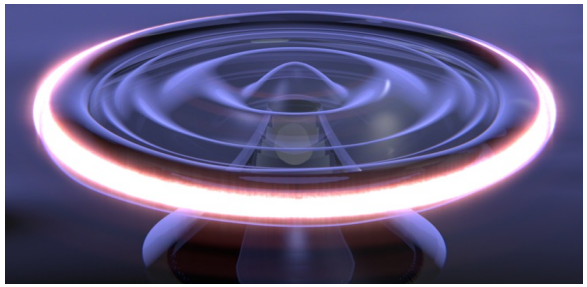
Romero *et al* arxiv:2206.11661 (2022); PR Applied **13** 044007 (2020); Mauranyapin *et al* PR Applied **15** 054036 (2021).

Quantum microscopy



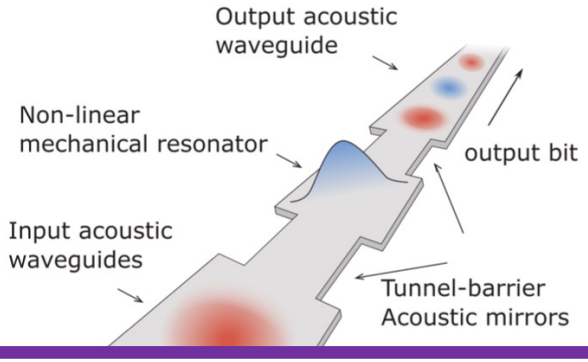
Andrade et al. Nature 594 201 (2021); Madsen et al. Nat. Phot. **15** 386 (2021); Mauranyapin et al. Nat. Phot. **11** 477 (2017); Taylor et al. Nat. Phot. **9** 669 (2015); PRX **4** 011017 (2014); Nat. Phot. **7** 229 (2013).

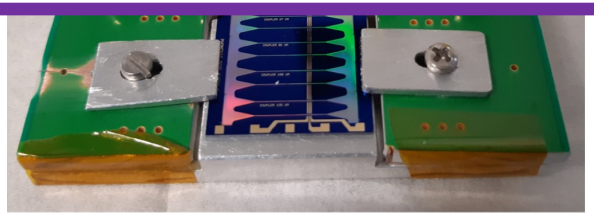
Superfluid physics



Sawadski *et al* arXiv:2208.05660 (2022). Sfendla *et al* npj Quantum Info. **7** 62 (2021); He *et al* Nature Physics **16** 417 (2020); Sachkou *et al* Science **366** 1480 (2019); Harris *et al* Nature Physics **12** 788 (2016).

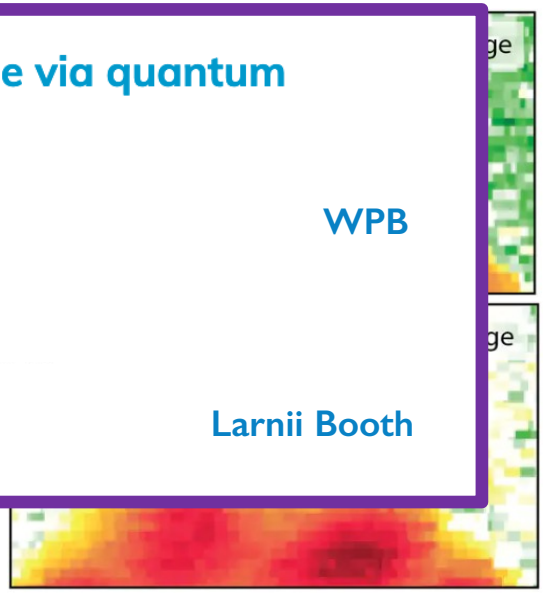
Phononics





Romero *et al* arxiv:2206.11661 (2022); PR Applied **13** 044007 (2020); Mauranyapin *et al* PR Applied **15** 054036 (2021).

Quantum microscopy



Andrade et al. Nature 594 201 (2021); Madsen et al. Nat. Phot. **15** 386 (2021); Mauranyapin et al. Nat. Phot. **11** 477 (2017); Taylor et al. Nat. Phot. **9** 669 (2015); PRX **4** 011017 (2014); Nat. Phot. **7** 229 (2013).

Quantum-light microscopy: evading biological photodamage via quantum correlations

14 December 2022 14:00
Hall C (Adelaide Convention Centre)

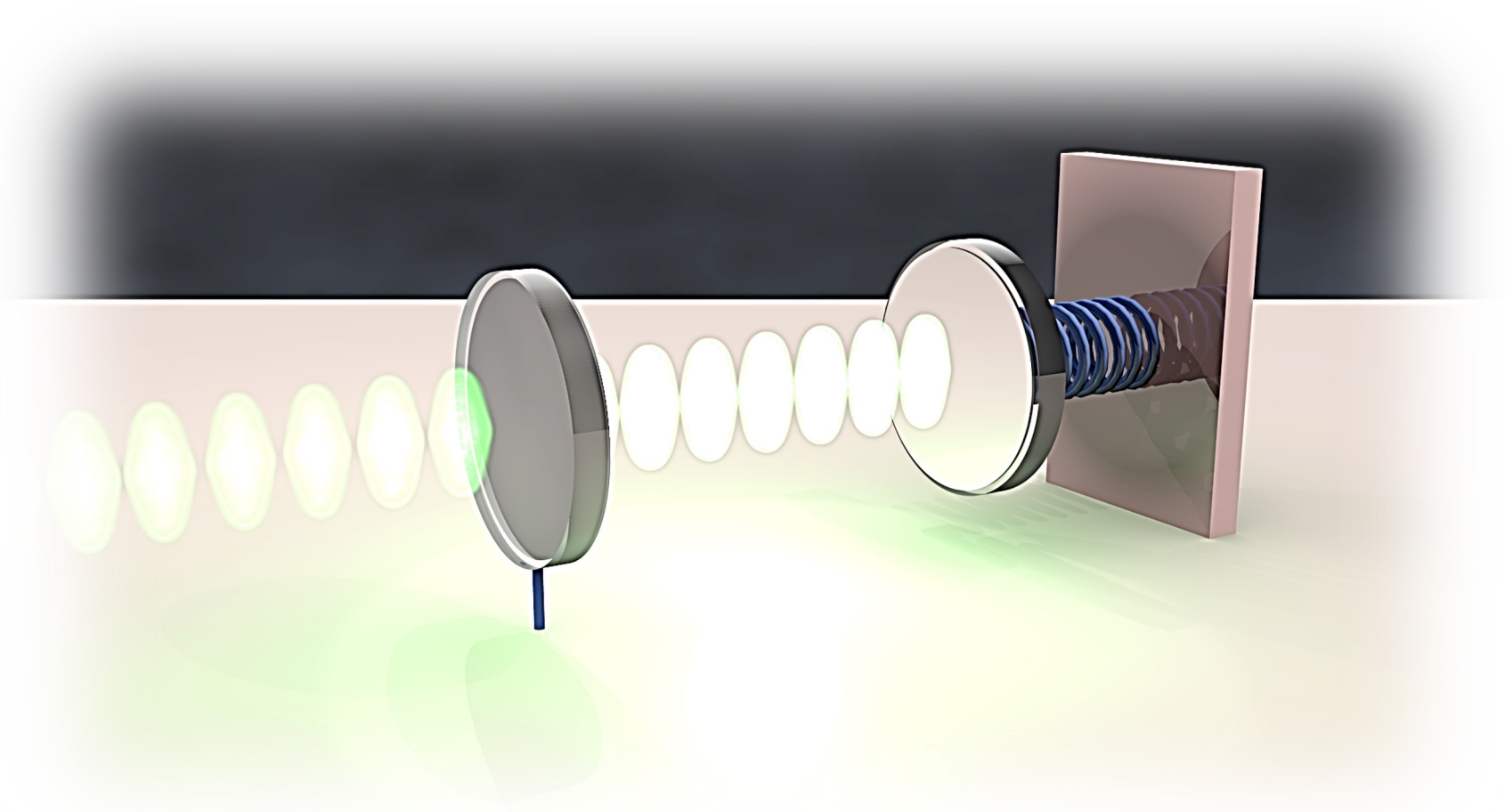
WPB

Quantum-enabled super resolution imaging

15 December 2022 15:00
Room R5 (Adelaide Convention Centre)

Larnii Booth

Quantum optomechanics



Bowen & Milburn, *Quantum Optomechanics* (2016)

Quantum optomechanics

Conditional quantum states of a continuously monitored mechanical oscillator

15 December 2022 14:45
Room R6 (Adelaide Convention Centre)

Soroush Khademi

Coupled Photonic Resonators for High-Performance Optomechanical Sensors

15 December 2022 16:30
Room R5 (Adelaide Convention Centre)

Ben Carey

Fibre-based Optomechanical Acoustic Sensing

12 December 2022 14:45
Hall A (Adelaide Convention Centre)

Lauren McQueen

Integrated optomechanical Magnetometer

13 December 2022 17:15
Room R5 (Adelaide Convention Centre)

Fernando Gotardo

Bowen & Milburn, *Quantum Optomechanics* (2016)

Measurement-based state preparation

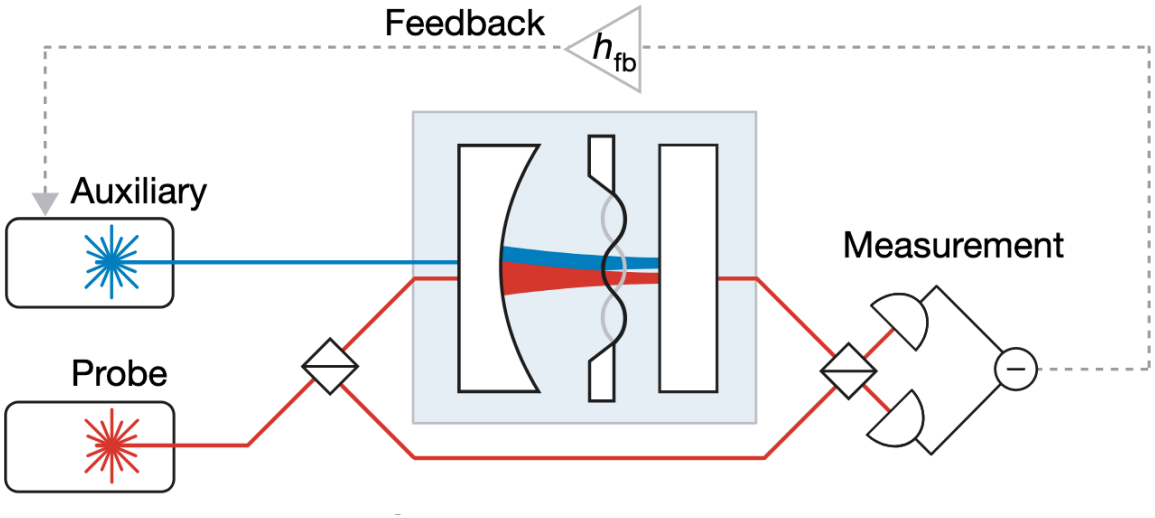
ARTICLE

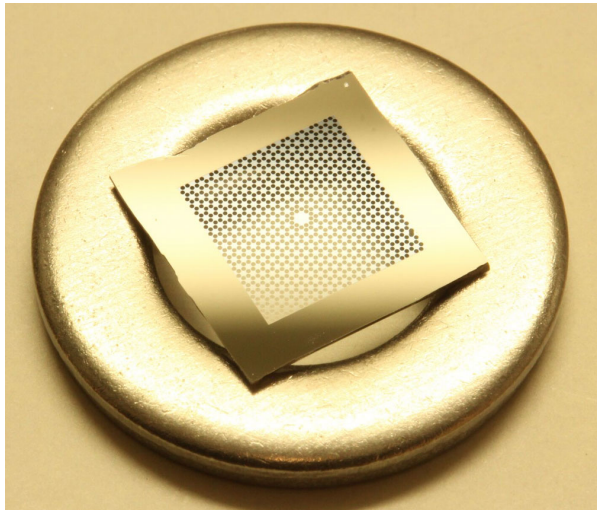
1 NOVEMBER 2018 | VOL 563 | NATURE | 53

https://doi.org/10.1038/s41586-018-0643-8

Measurement-based quantum control of mechanical motion

Massimiliano Rossi[1,2,3], David Mason[1,2,3], Junxin Chen[1,2,3], Yeghishe Tsaturyan[1] & Albert Schliesser[1,2]*





Measurement-based state preparation

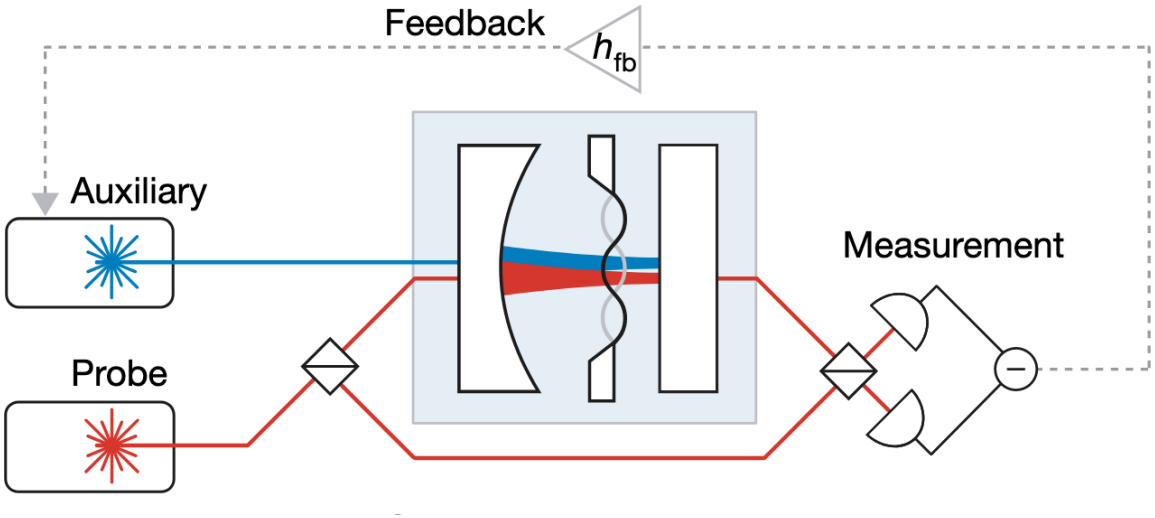
ARTICLE

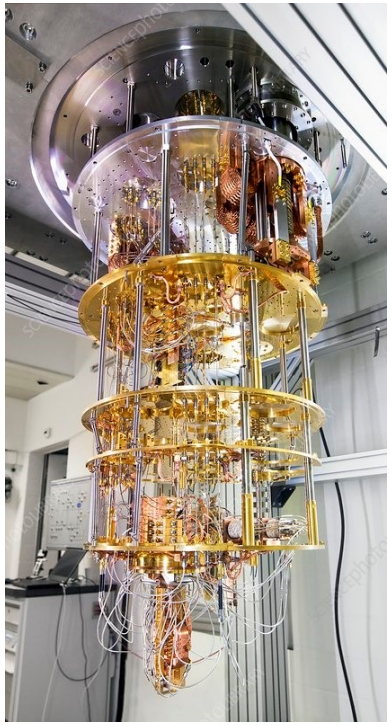
1 NOVEMBER 2018 | VOL 563 | NATURE | 53

https://doi.org/10.1038/s41586-018-0643-8

Measurement-based quantum control of mechanical motion

Massimiliano Rossi[1,2,3], David Mason[1,2,3], Junxin Chen[1,2,3], Yeghishe Tsaturyan[1] & Albert Schliesser[1,2]*





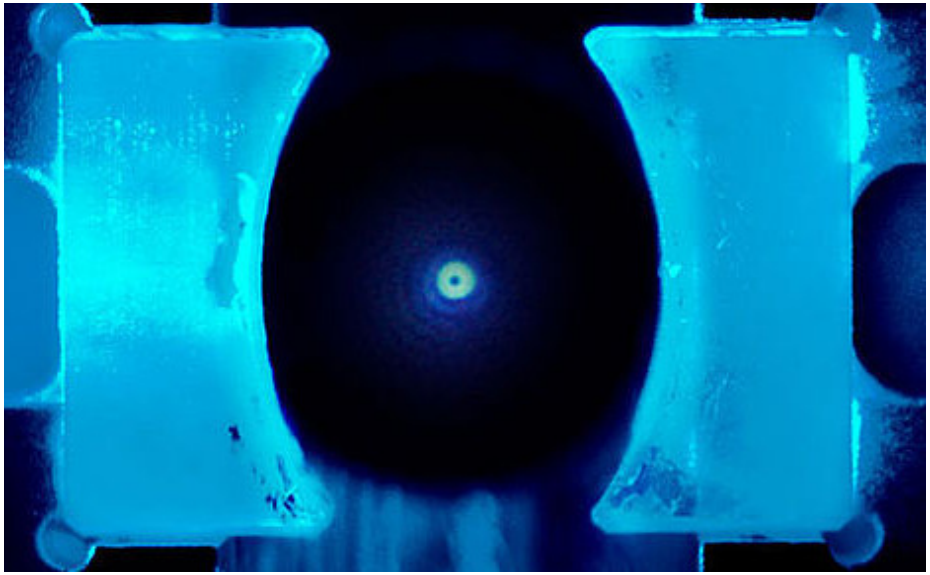
Measurement-based state preparation

Article

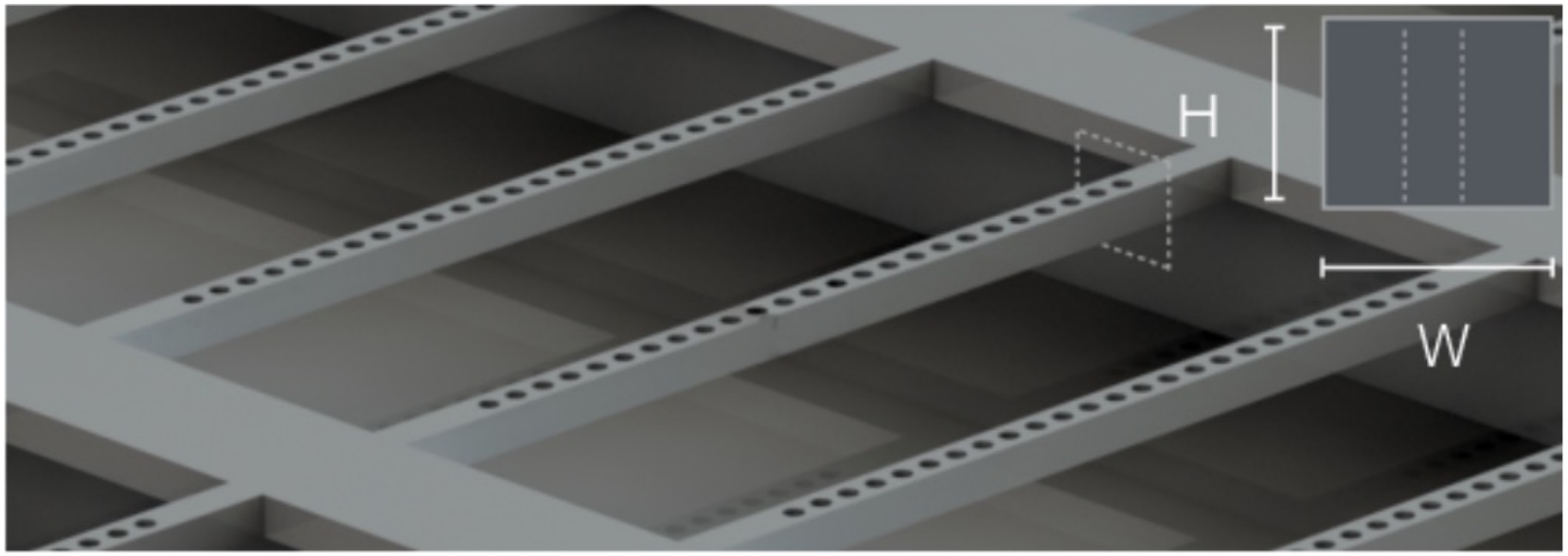
Real-time optimal quantum control of mechanical motion at room temperature

Lorenzo Magrini[1]✉, Philipp Rosenzweig[2], Constanze Bach[1], Andreas Deutschmann-Olek[2], Sebastian G. Hofer[1], Sungkun Hong[3,4], Nikolai Kiesel[1], Andreas Kugi[2,5] & Markus Aspelmeyer[1,6]✉

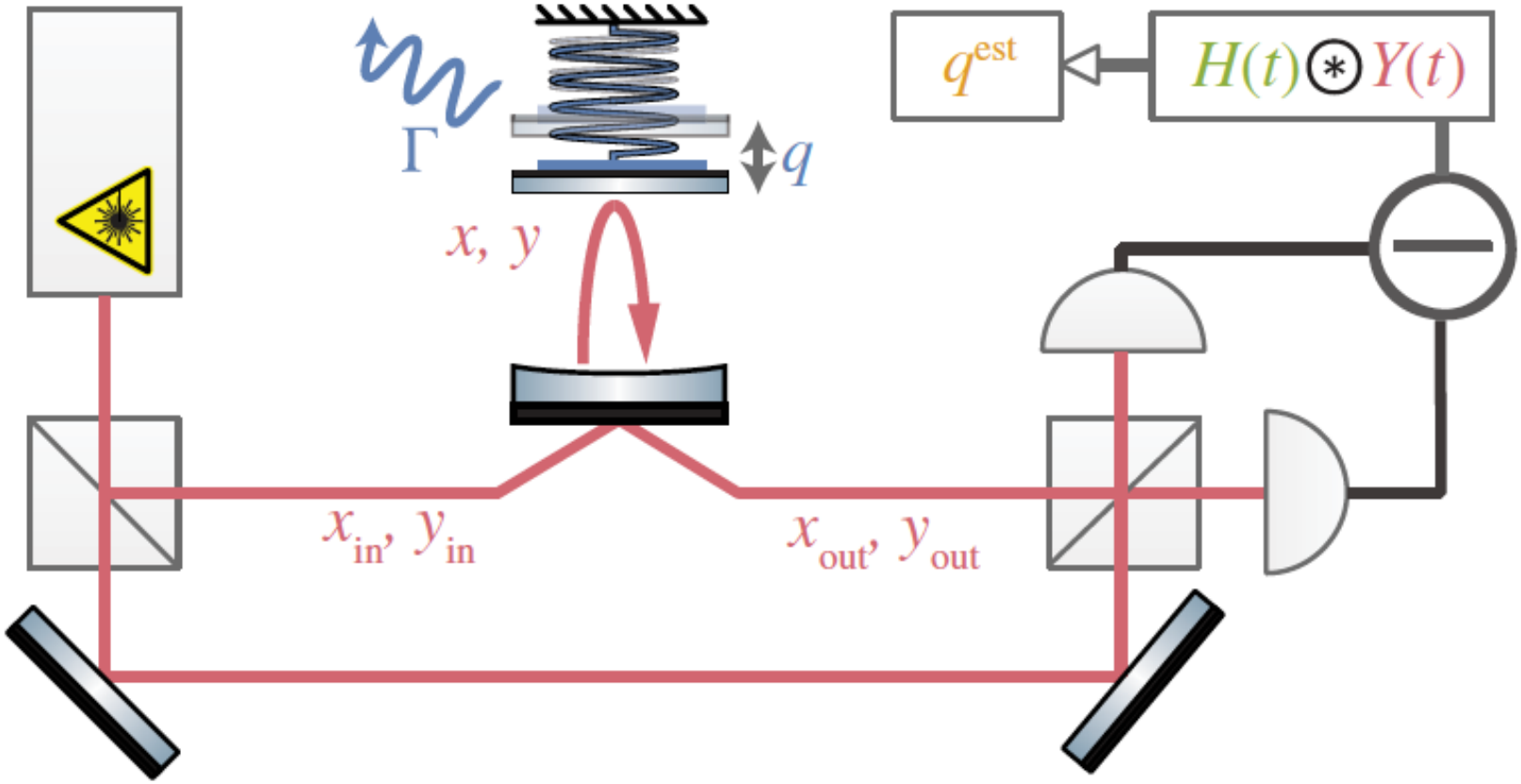
Nature | Vol 595 | 15 July 2021 | 373



Measurement-based state preparation



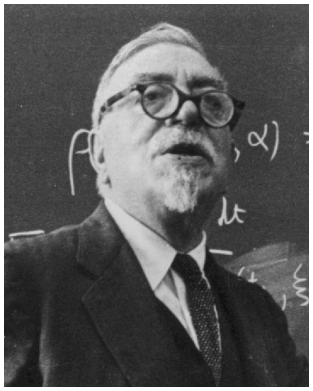
Measurement-based state preparation



Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation

Wiener or Kalman Filter

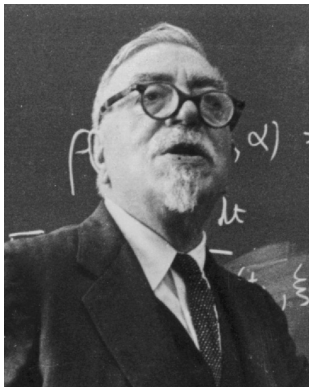


N. Wiener

R.E. Kalman

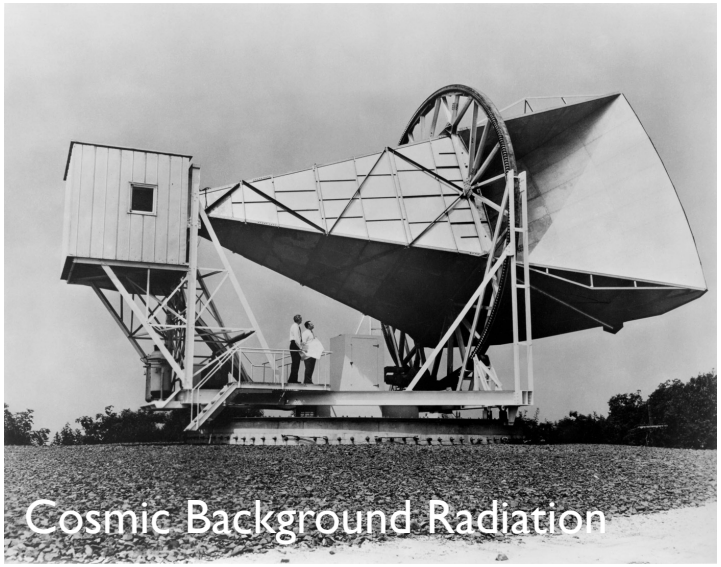
Measurement-based state preparation

Wiener or Kalman Filter



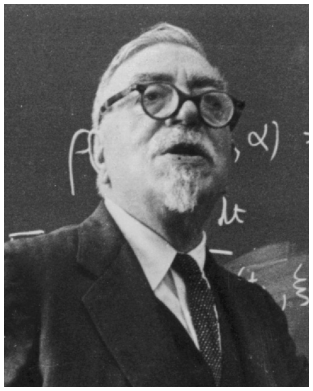
N. Wiener

R.E. Kalman



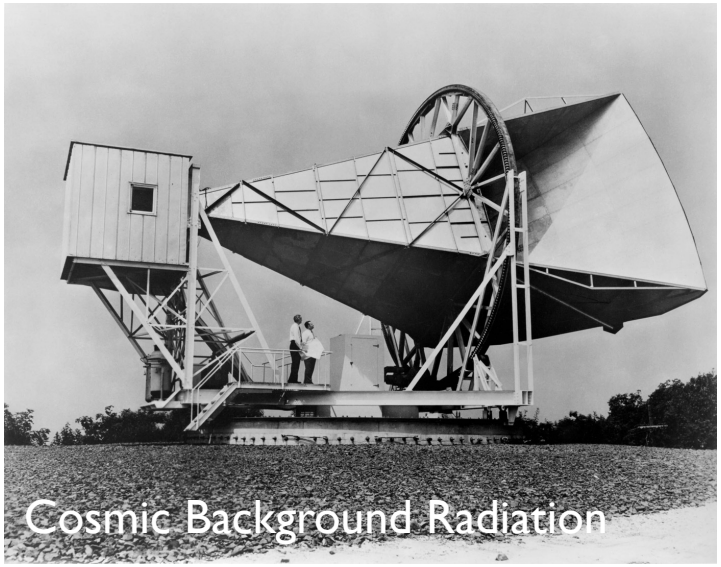
Measurement-based state preparation

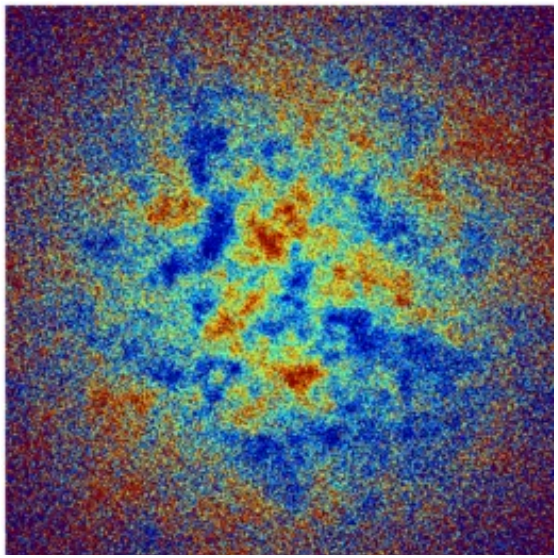
Wiener or Kalman Filter



N. Wiener

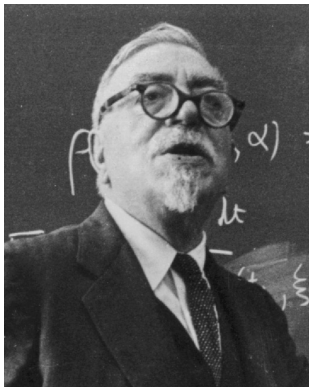
R.E. Kalman





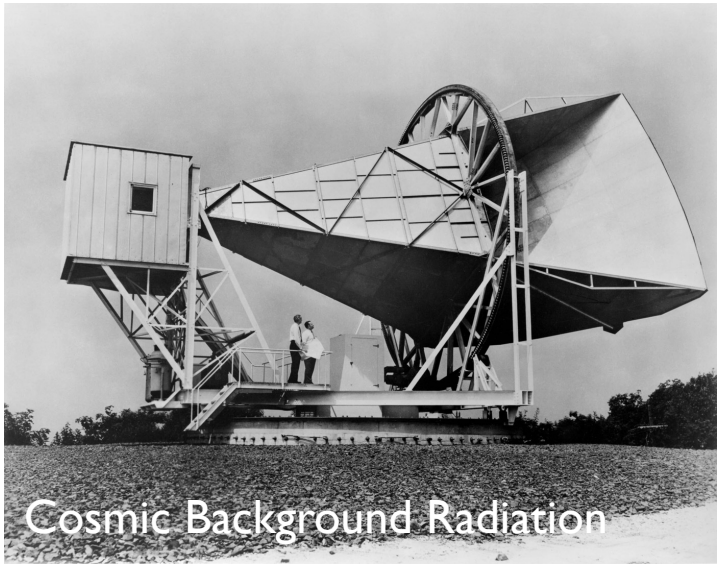
Measurement-based state preparation

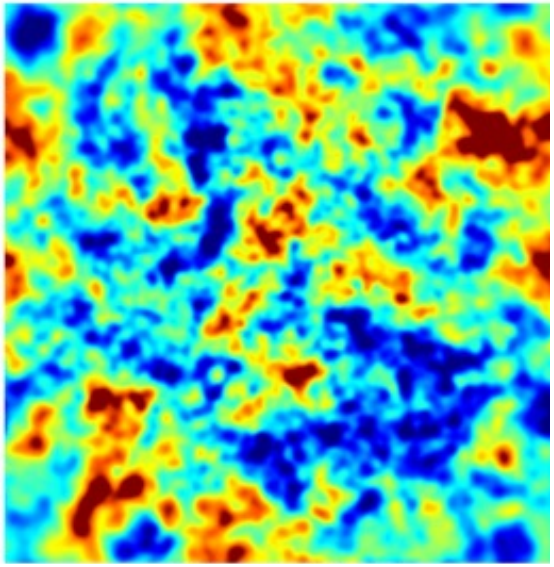
Wiener or Kalman Filter



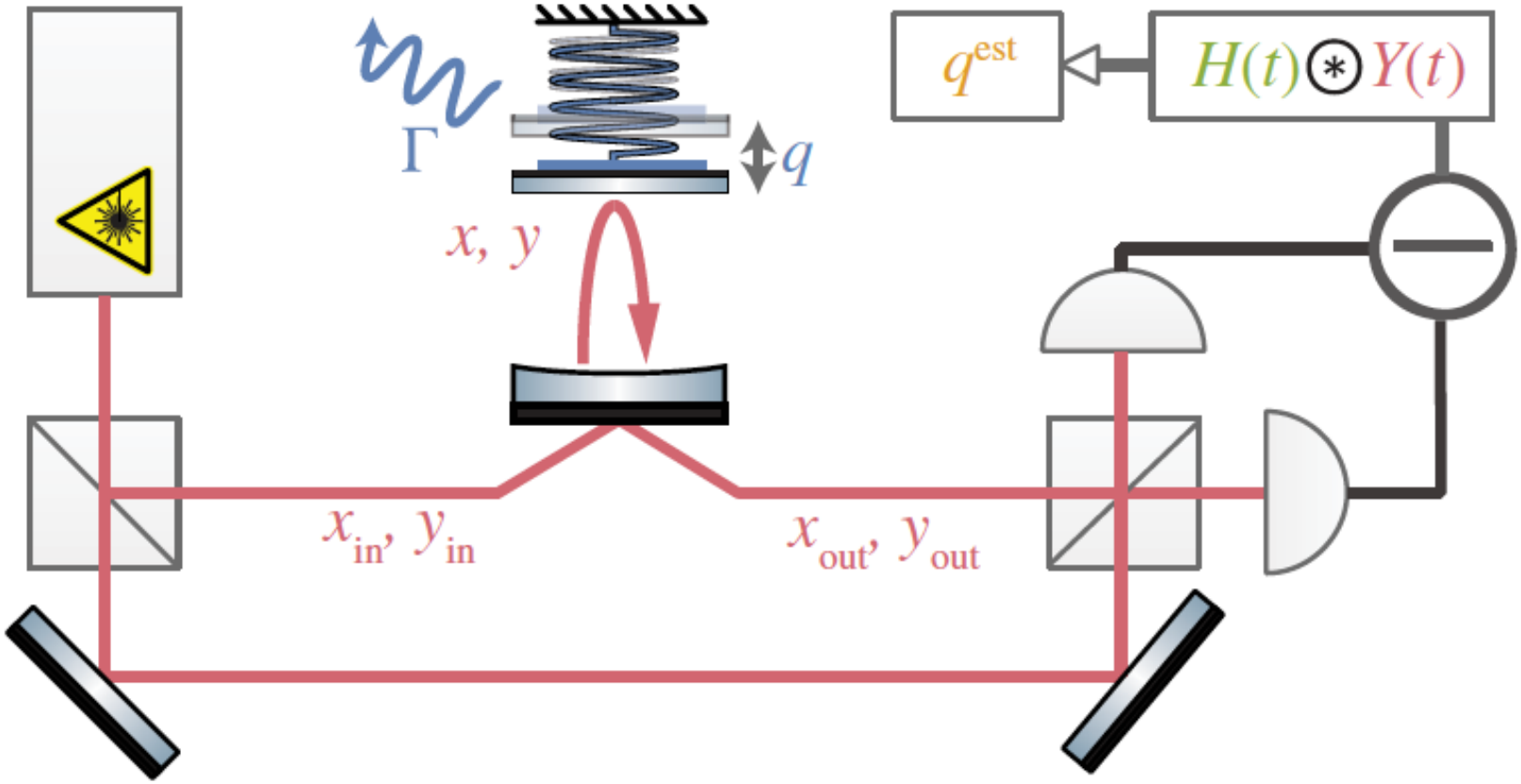
N. Wiener

R.E. Kalman



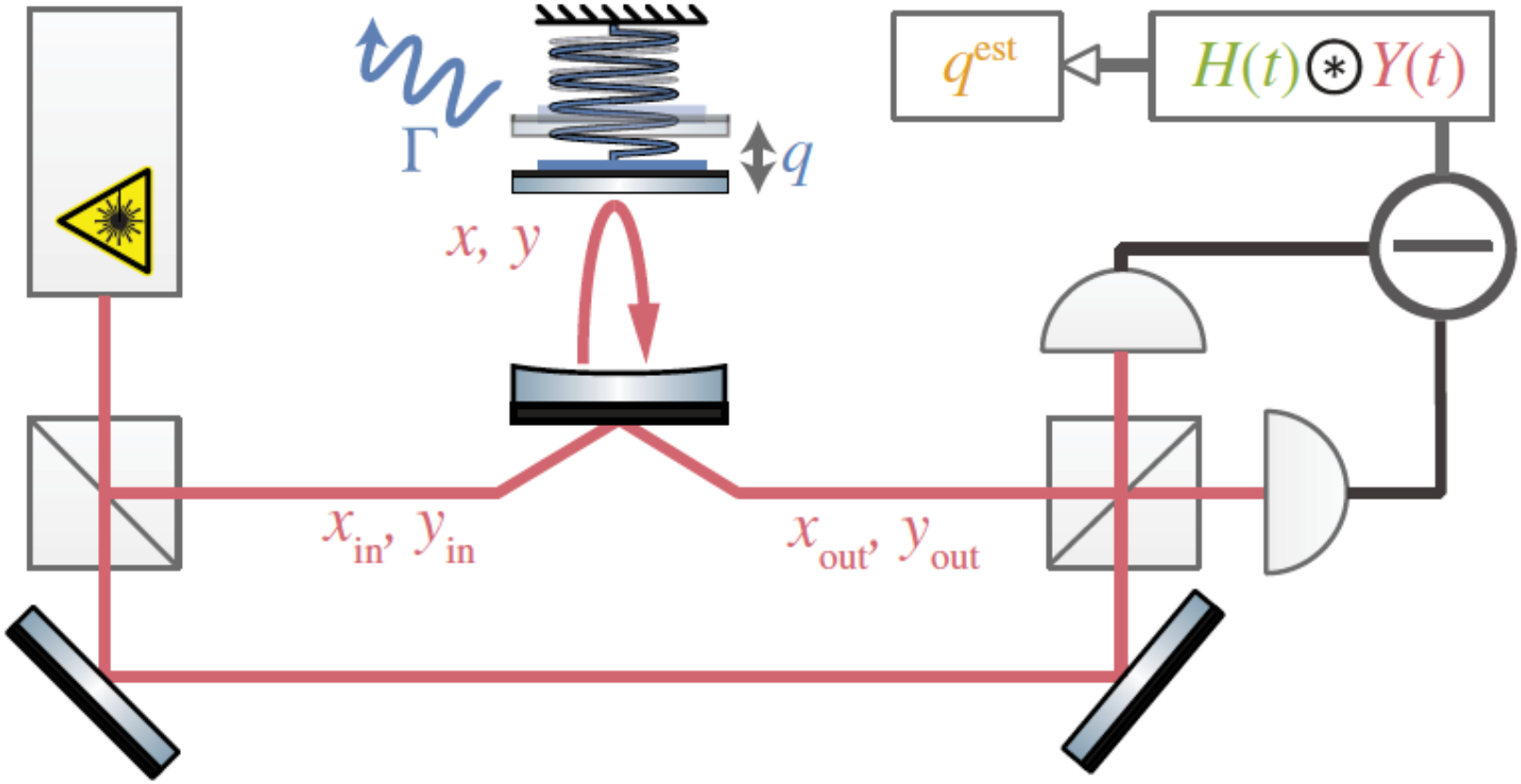


Measurement-based state preparation



Meng *et al.* PRL **125** 043604 (2020)

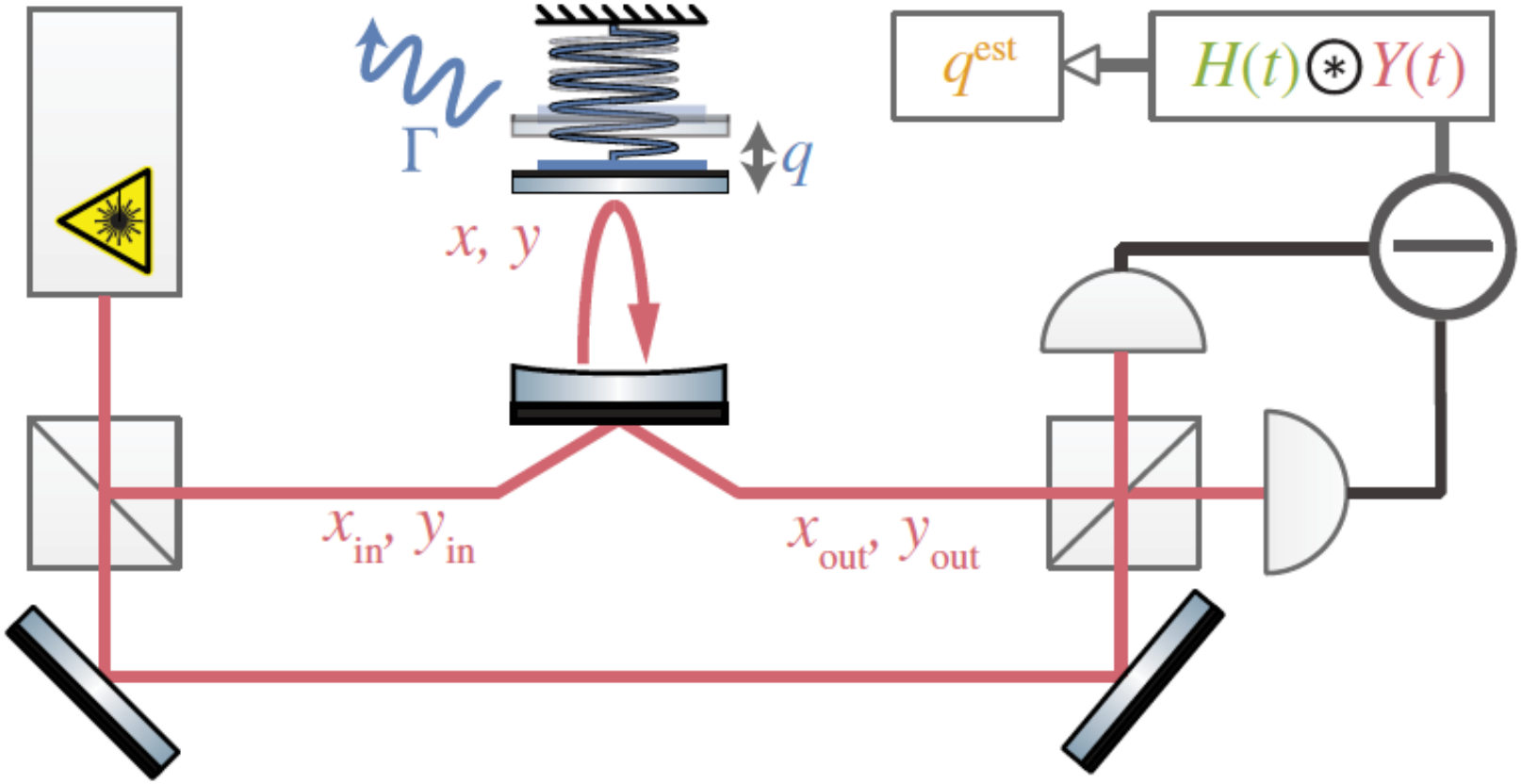
Measurement-based state preparation



$$[Y(t), Y(t')] = 0$$

Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation

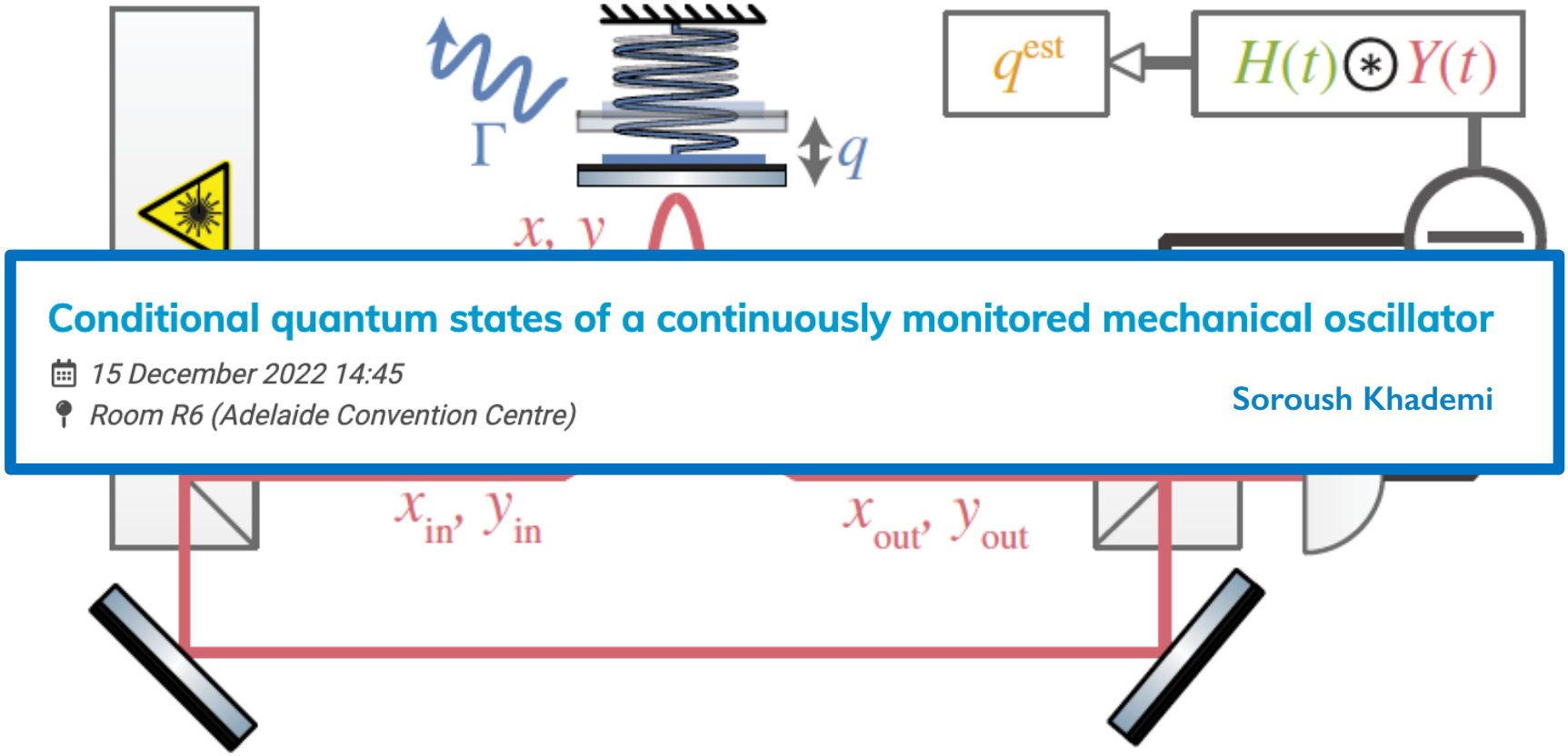


$[Y(t), Y(t')] = 0$

$[Y(t), q(t')] = [Y(t), p(t')] = 0 \text{ for } t \lesssim t'$

Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation

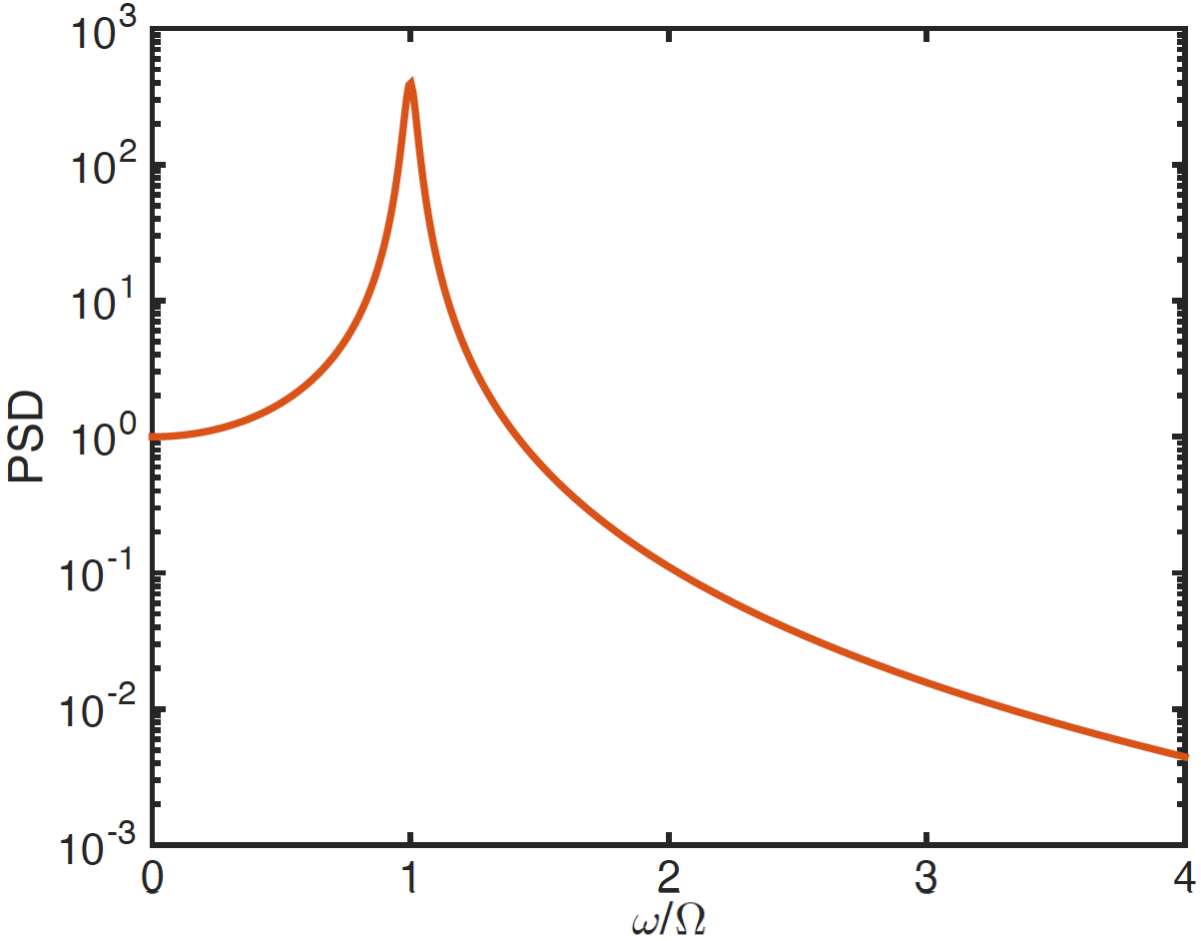


$[Y(t), Y(t')] = 0$

$[Y(t), q(t')] = [Y(t), p(t')] = 0 \text{ for } t \lesssim t'$

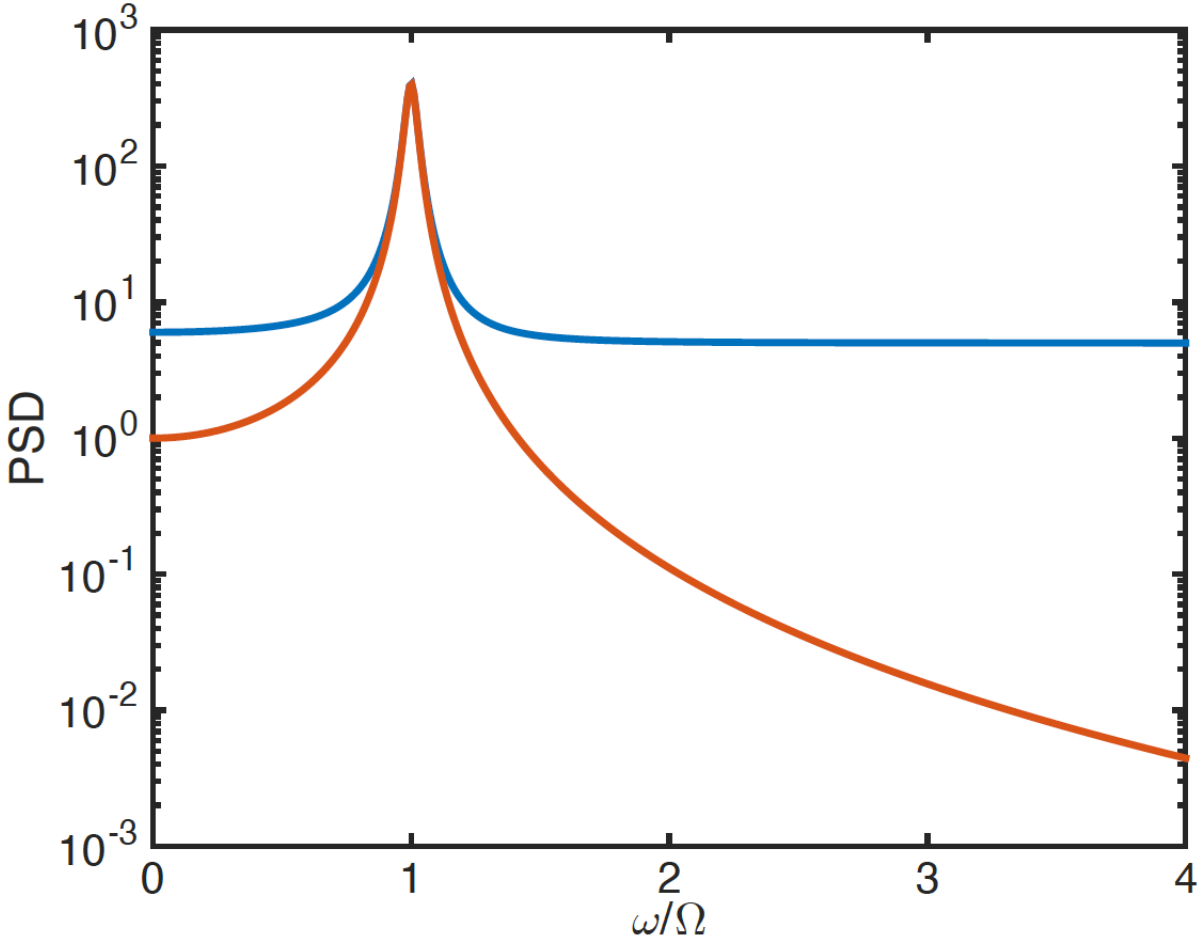
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



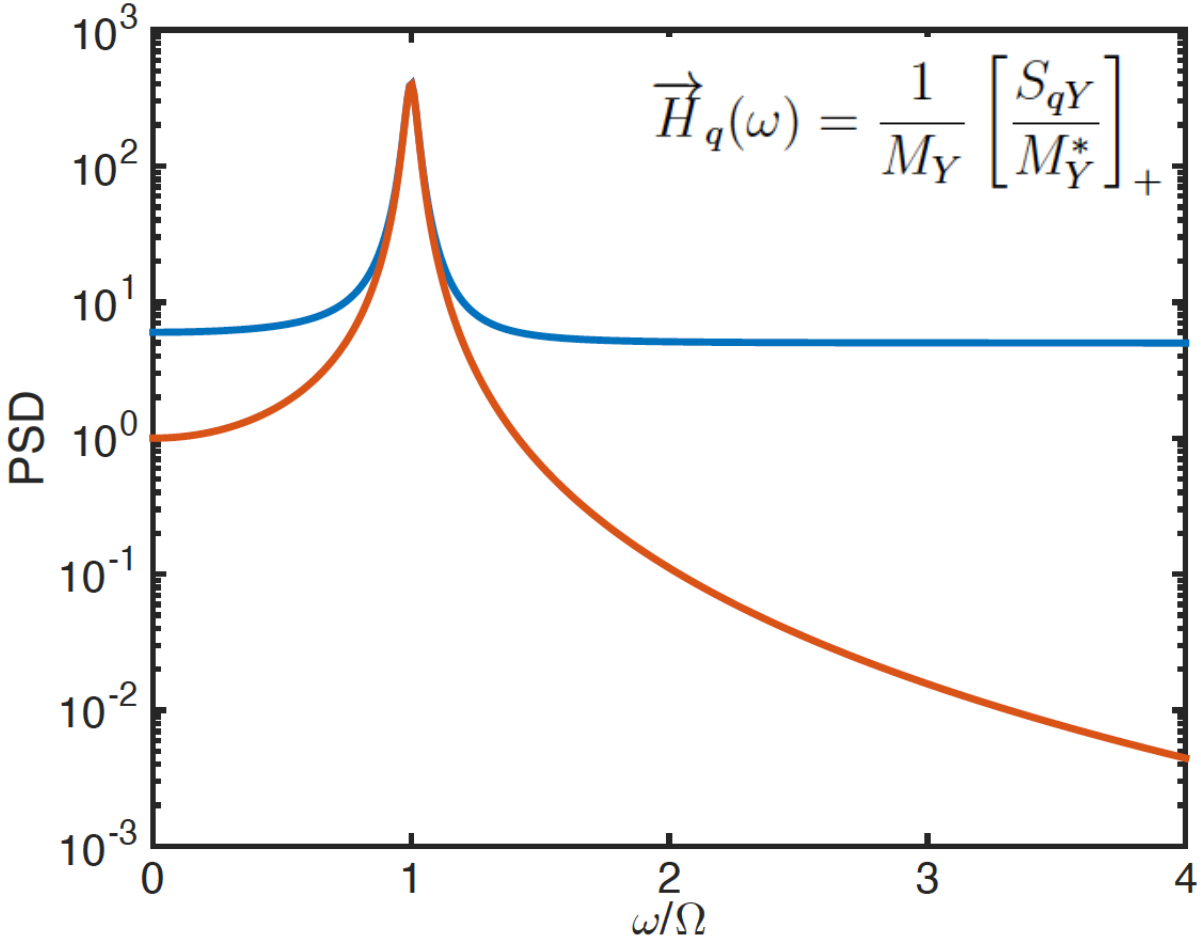
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



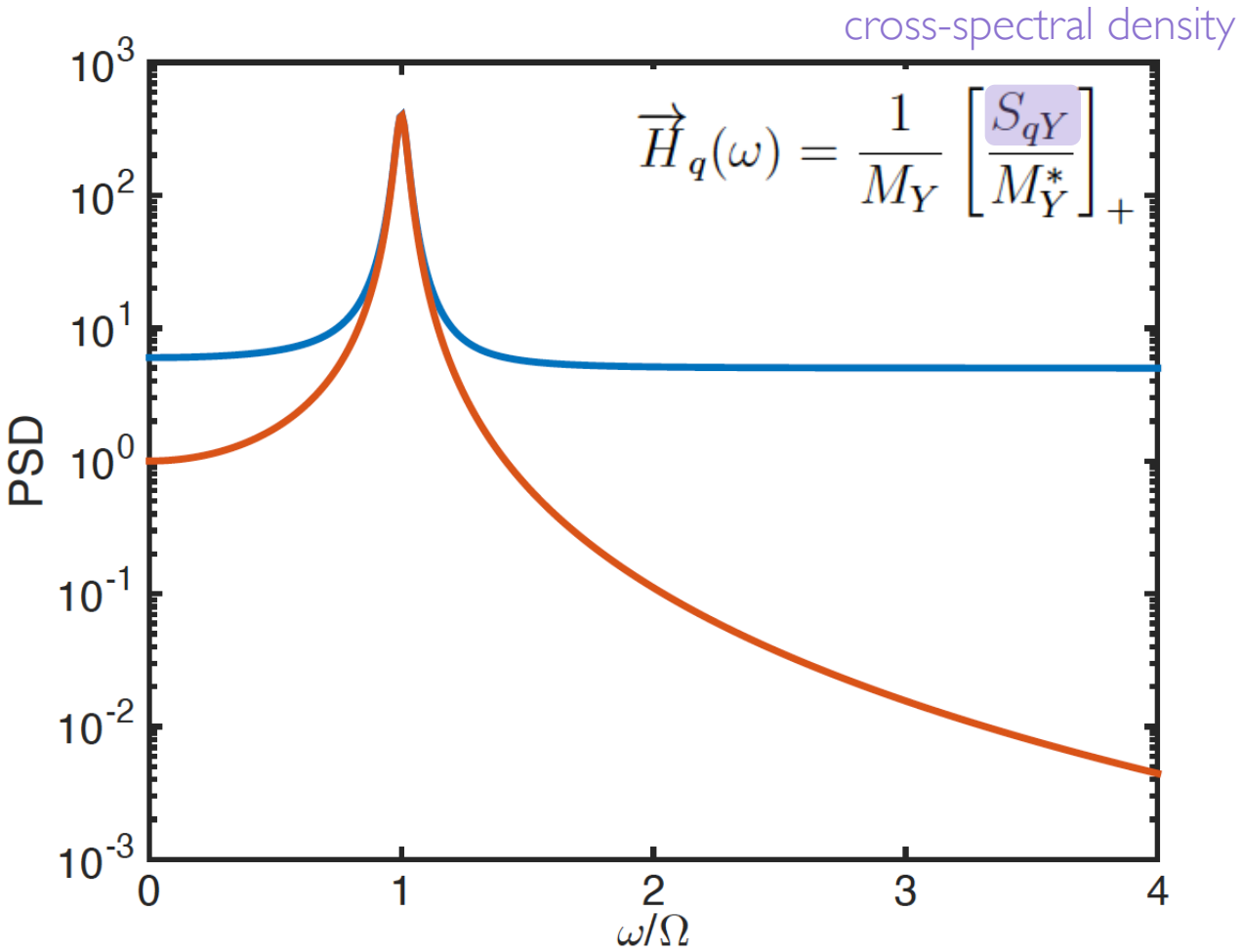
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



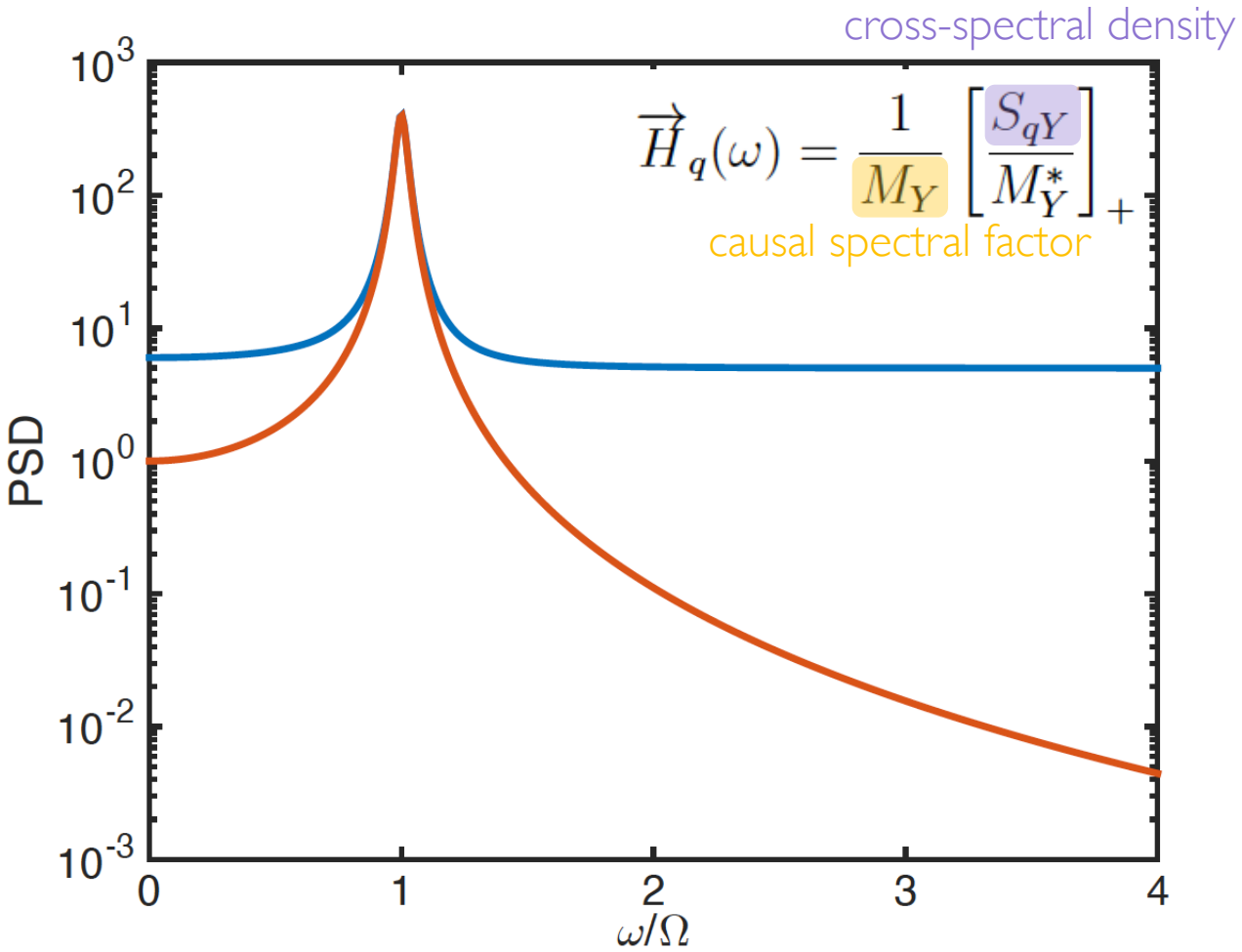
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



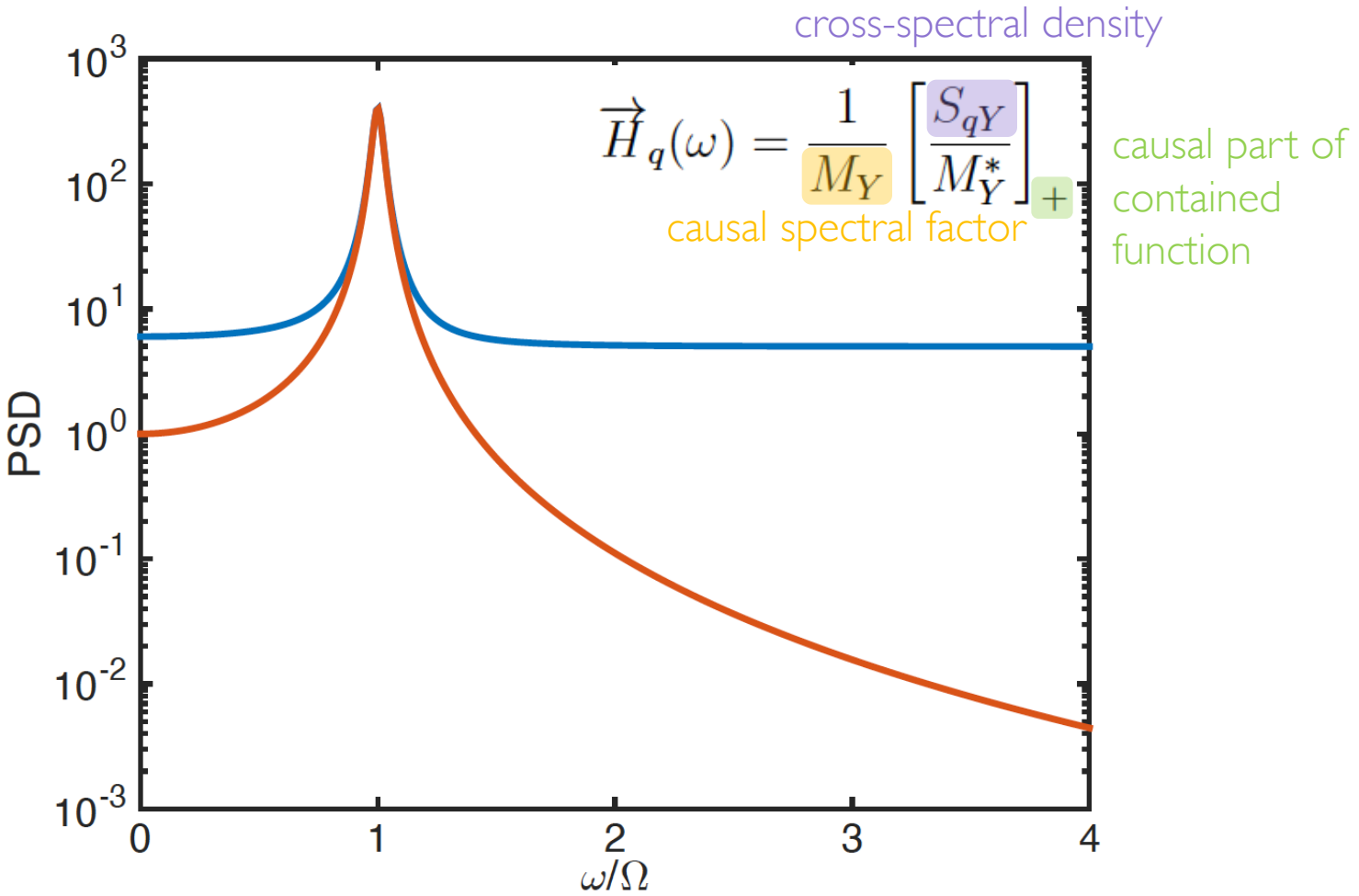
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



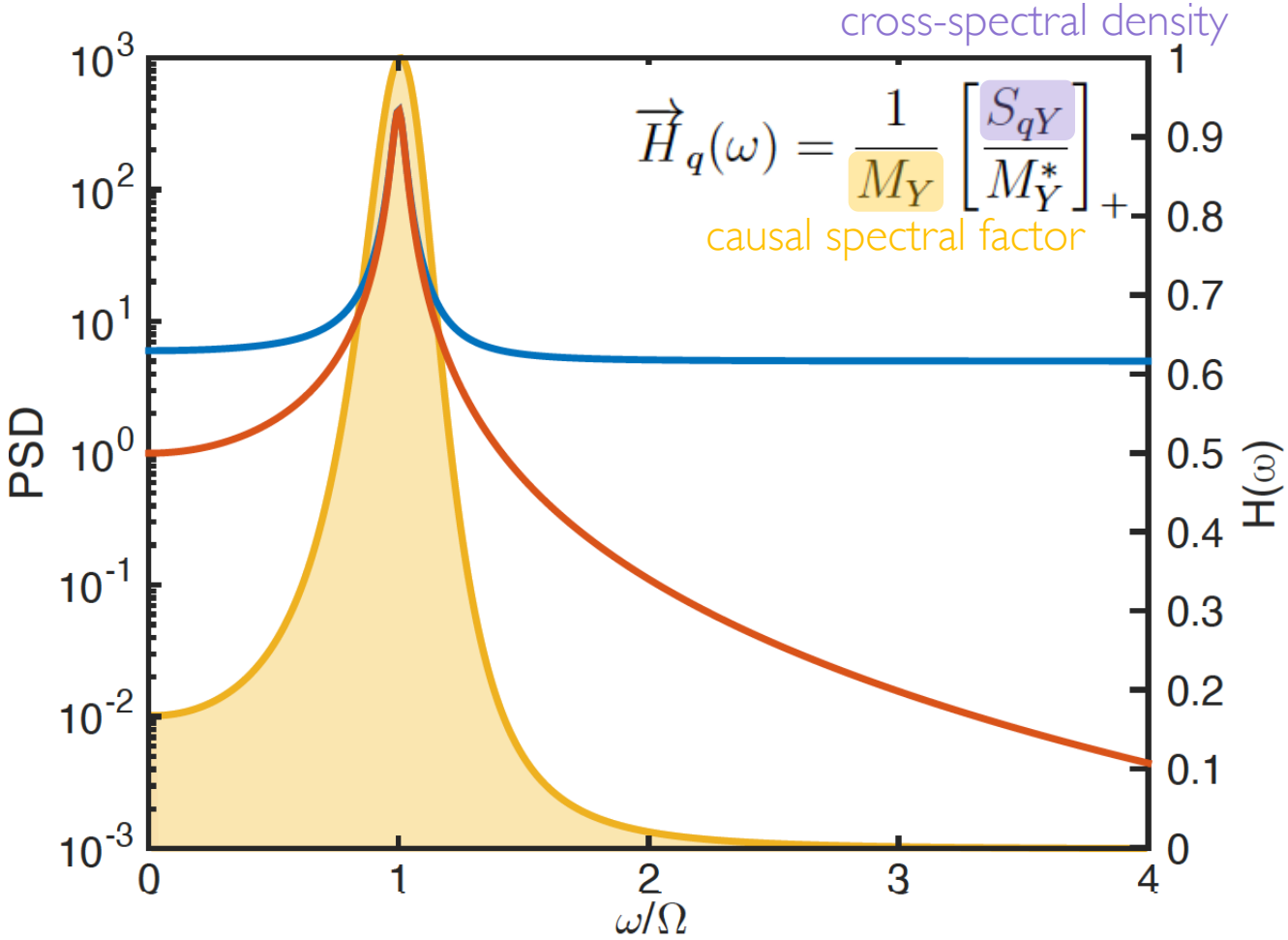
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



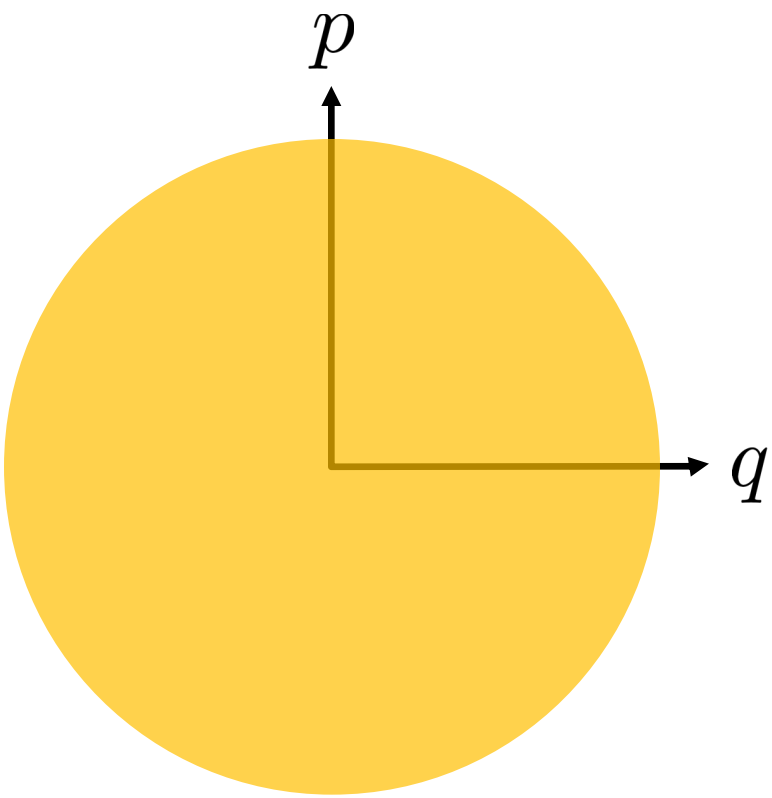
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



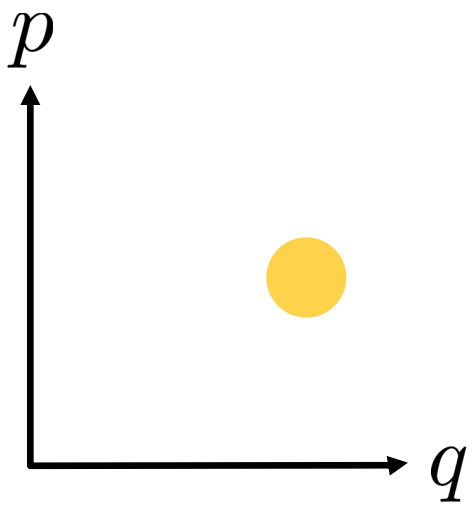
Meng *et al.* PRL **125** 043604 (2020)

Measurement-based state preparation



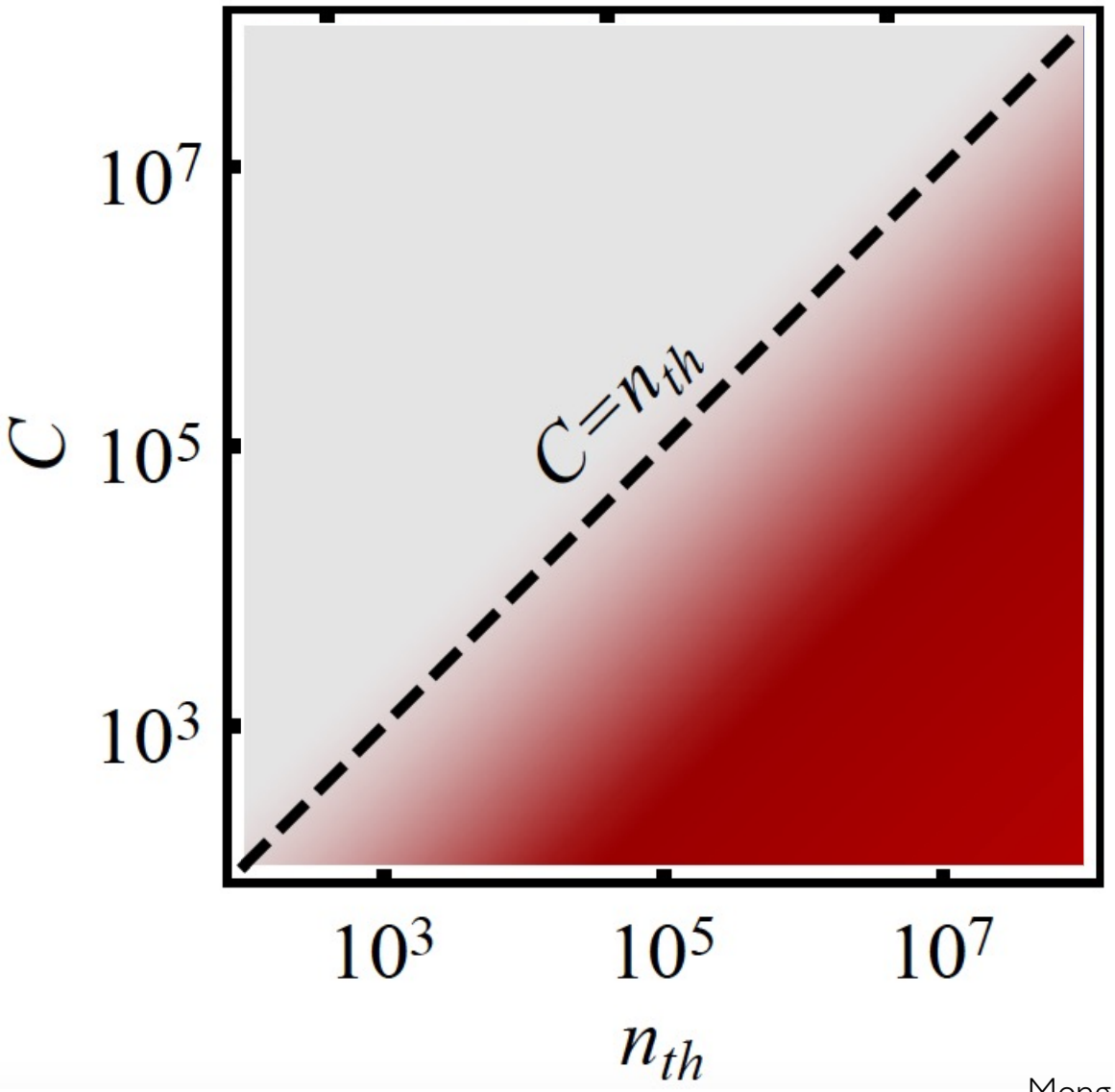
Bowen & Milburn, *Quantum Optomechanics* (2016)

Measurement-based state preparation



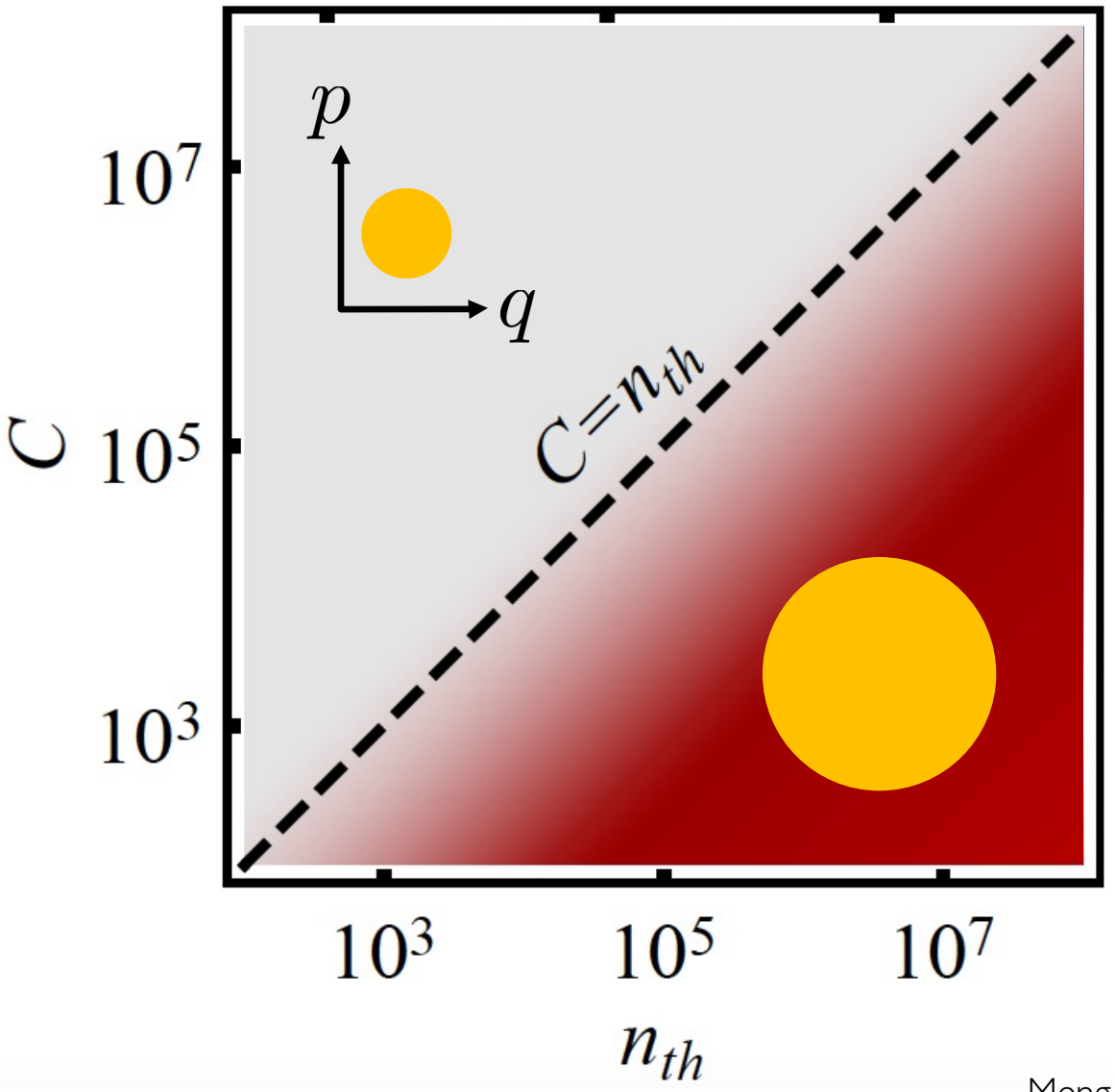
Bowen & Milburn, *Quantum Optomechanics* (2016)

Conditional position variance



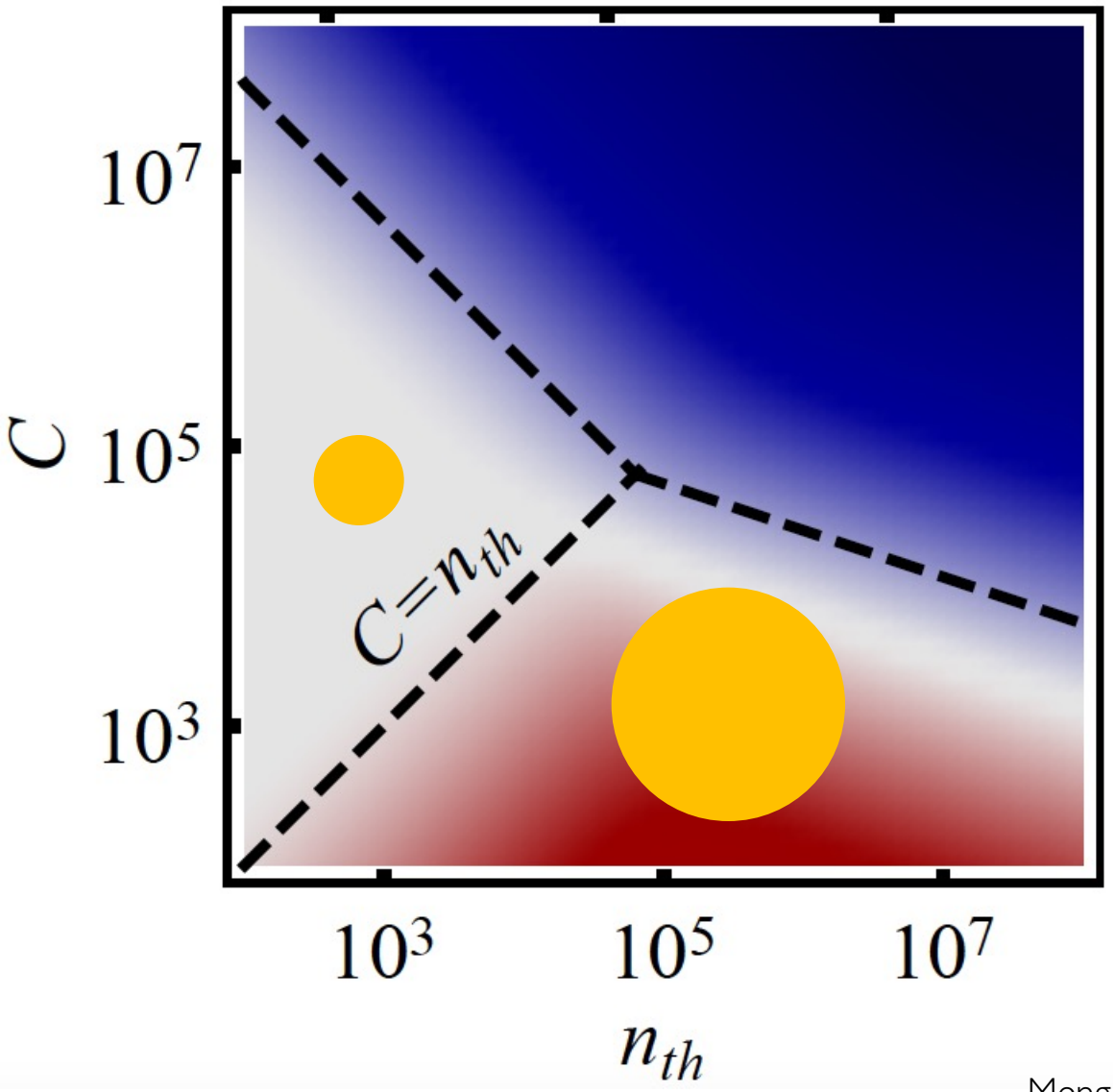
Meng *et al.* PRL **125** 043604 (2020)

Conditional position variance



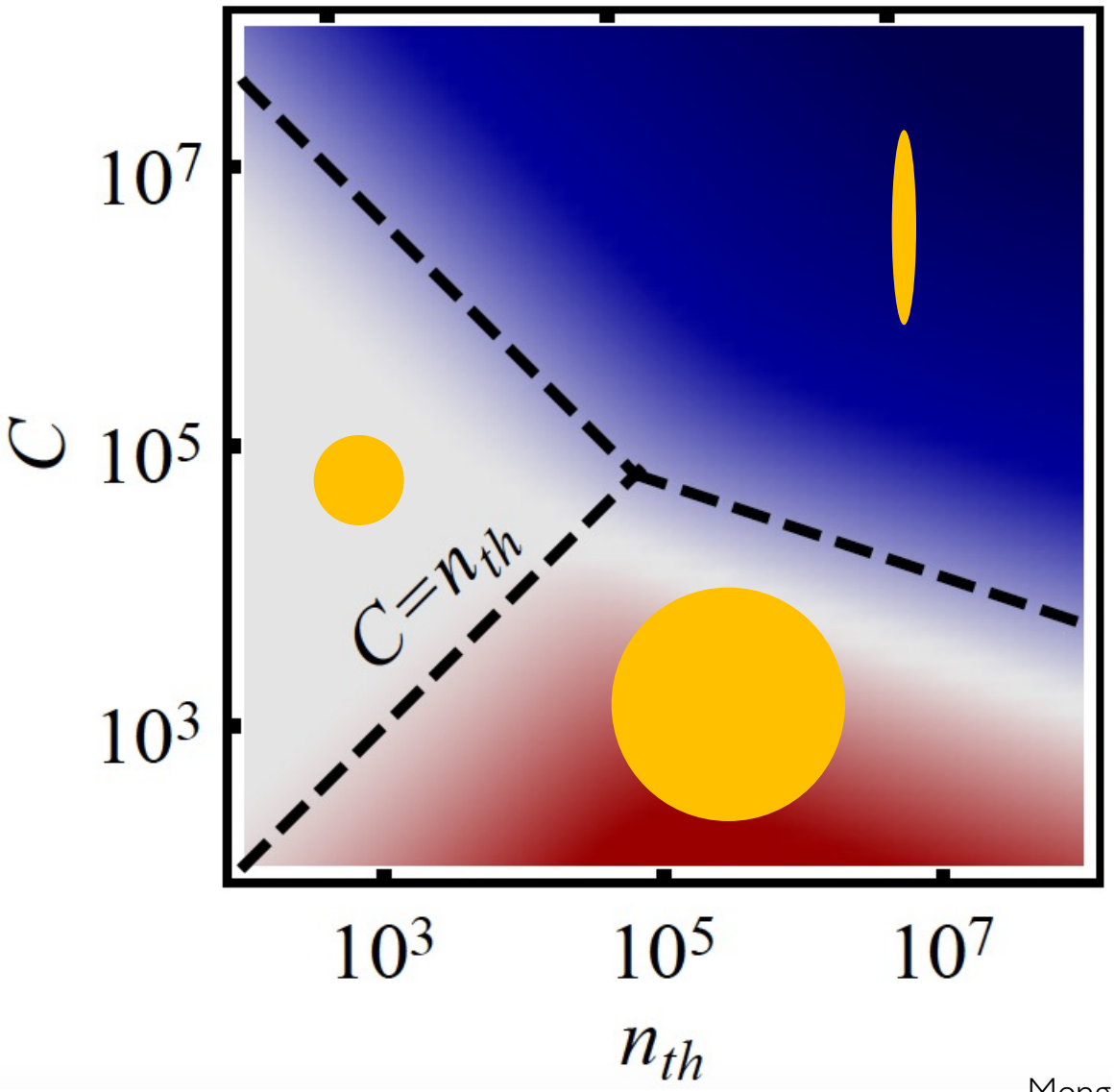
Meng *et al.* PRL **125** 043604 (2020)

Conditional position variance



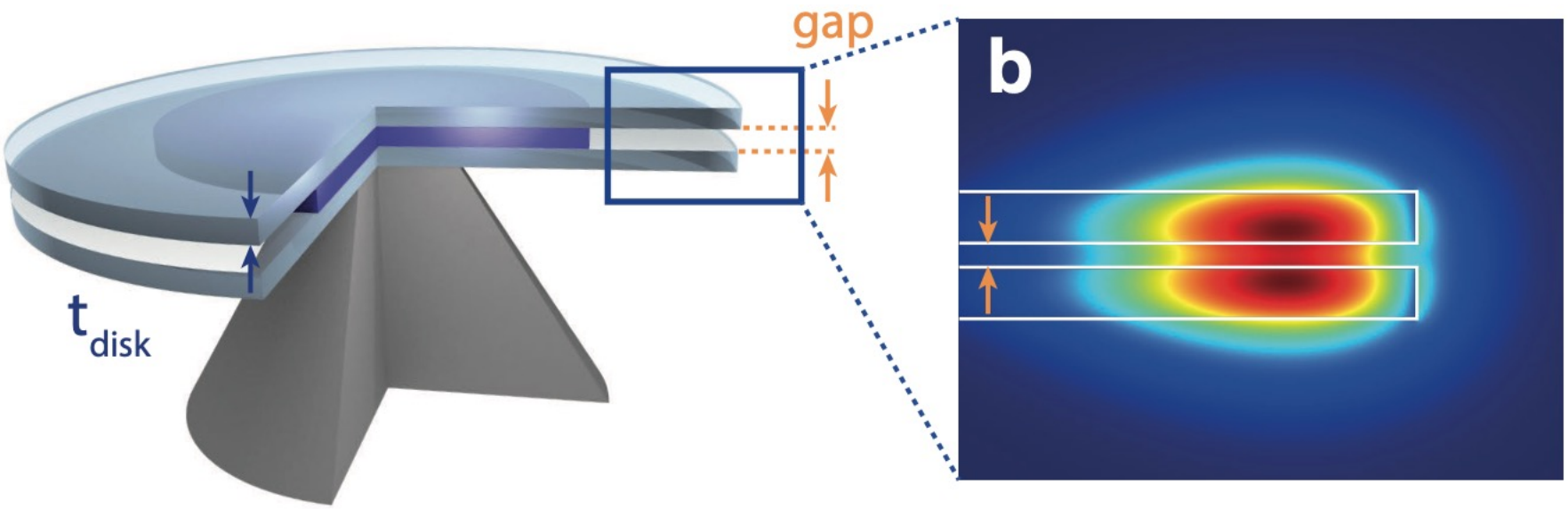
Meng *et al.* PRL **125** 043604 (2020)

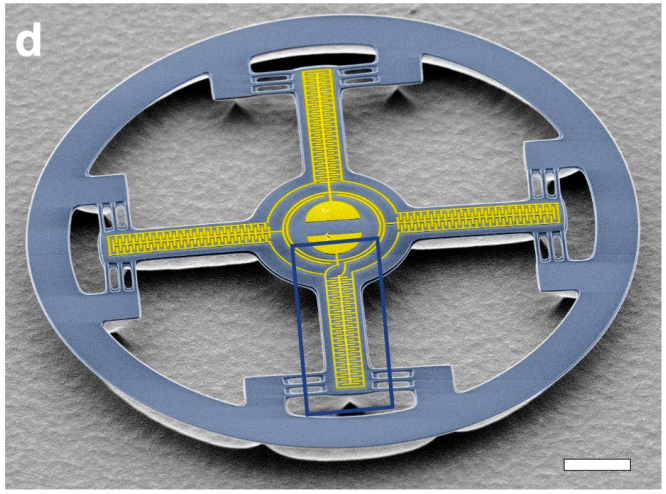
Conditional position variance

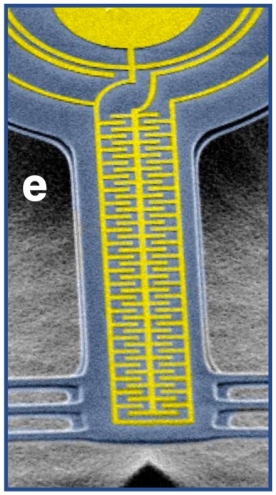


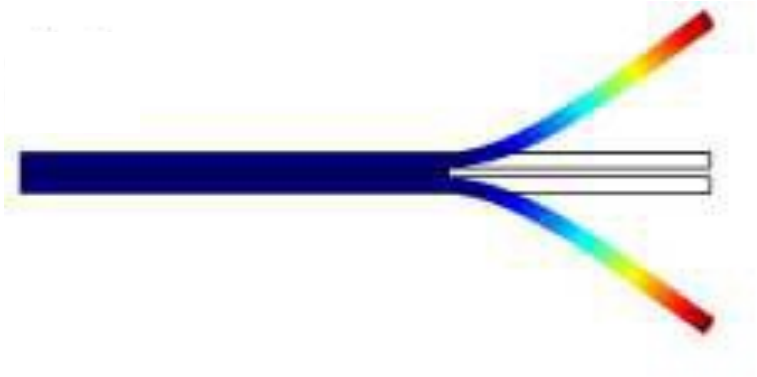
Meng *et al.* PRL **125** 043604 (2020)

Device design



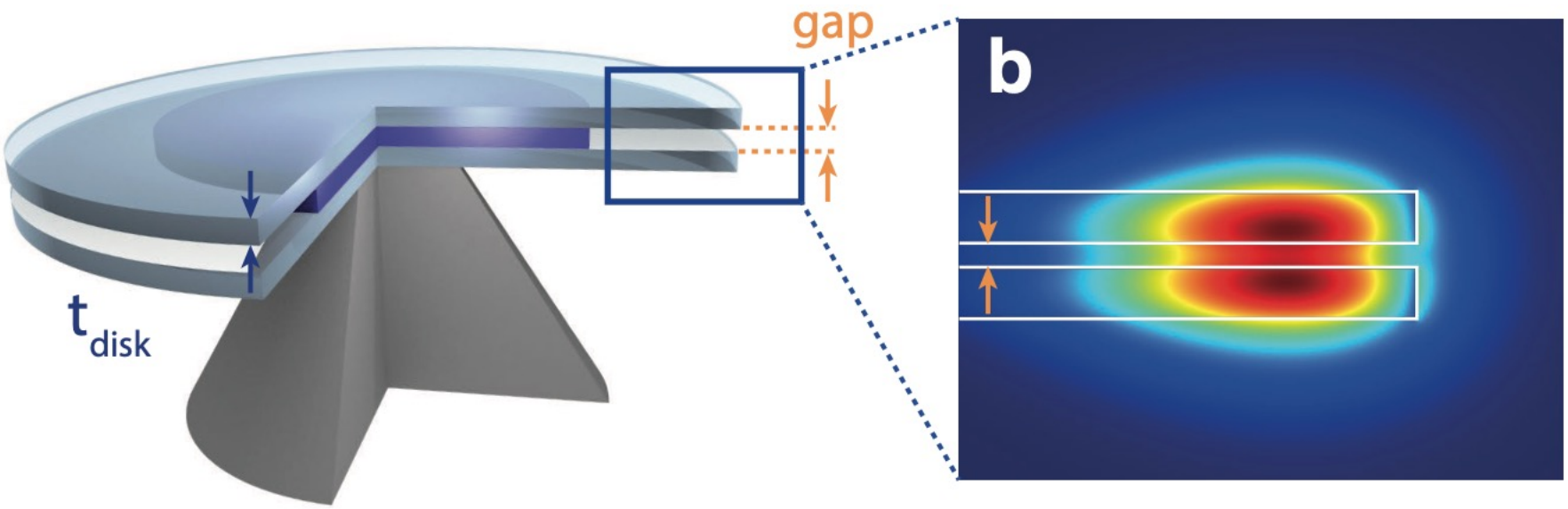


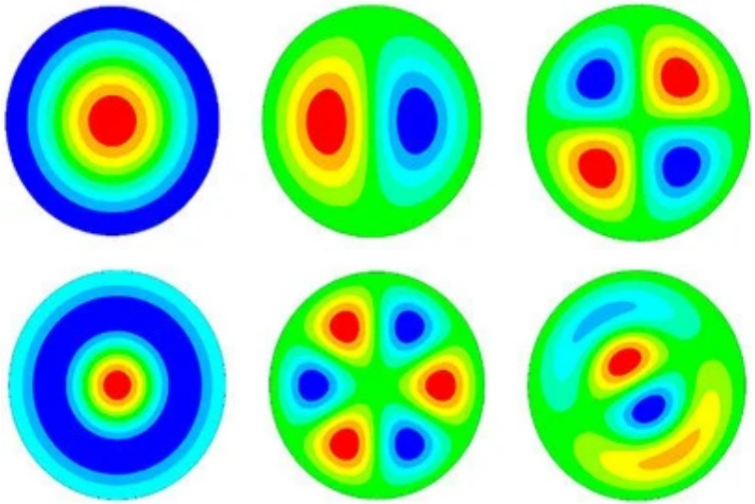


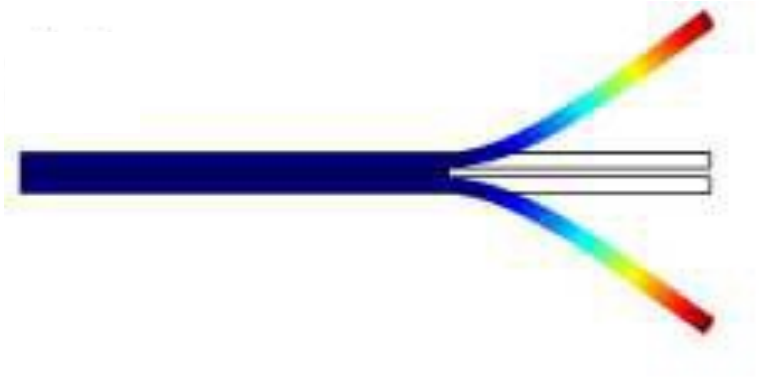


Qiang Lin et al. Nature Photonics **4** 236 (2010)
Bekker *et al* Opt. Exp. **26** 33649 (2018)

Device design

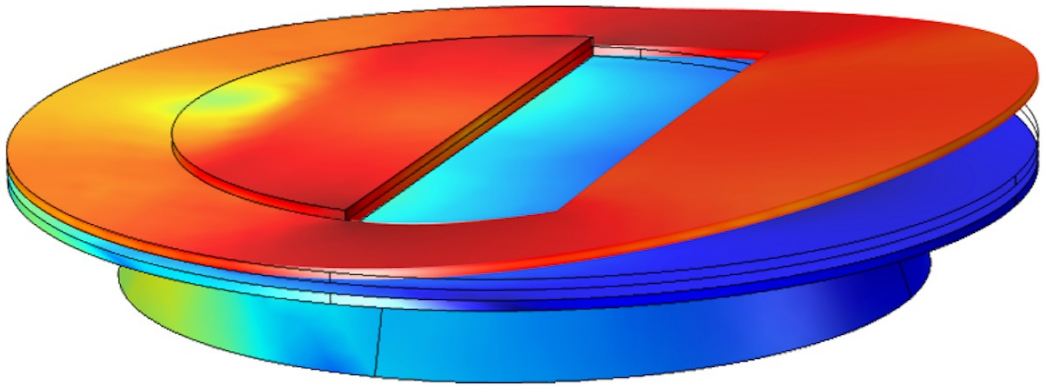






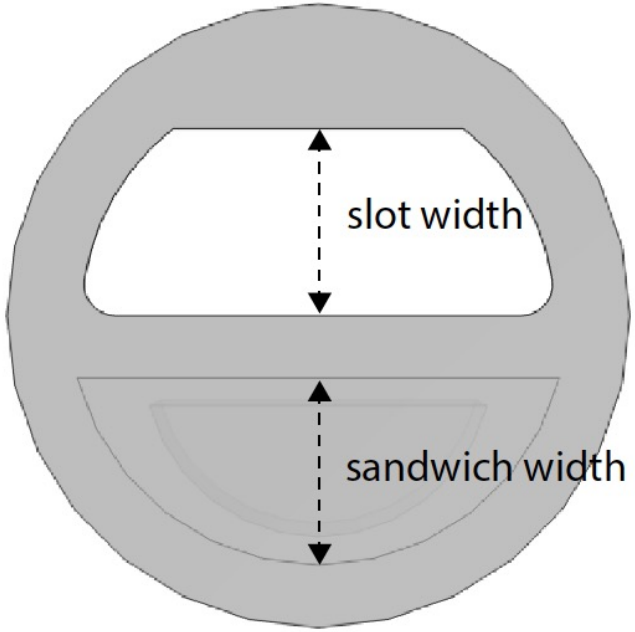
Qiang Lin et al. Nature Photonics **4** 236 (2010)
Bekker *et al* Opt. Exp. **26** 33649 (2018)

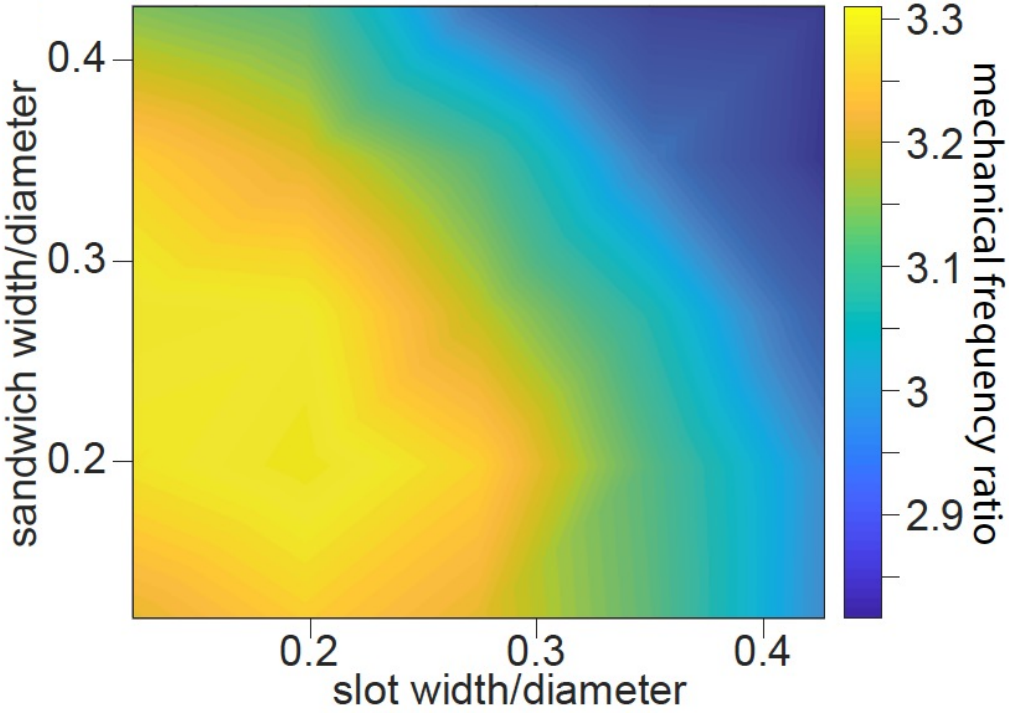
Device design



Meng *et al.* Science Advances **8** eabm7585 (2022)

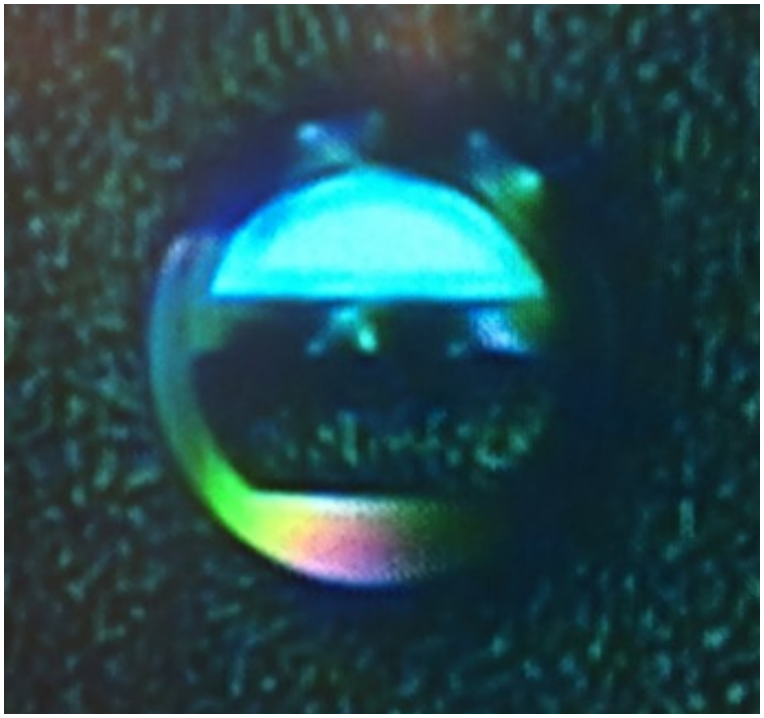
Device design





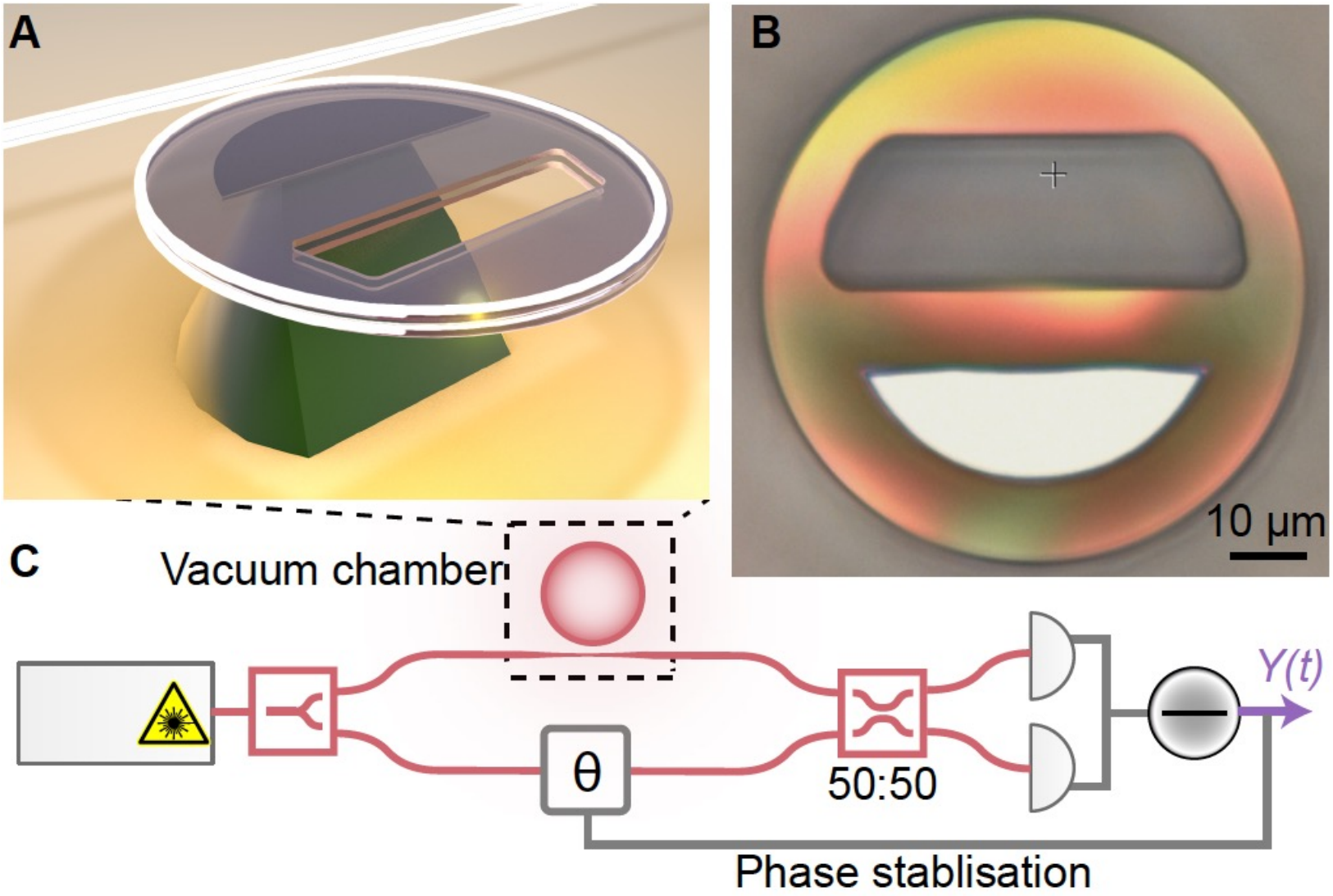
Meng *et al.* Science Advances **8** eabm7585 (2022)

Device design



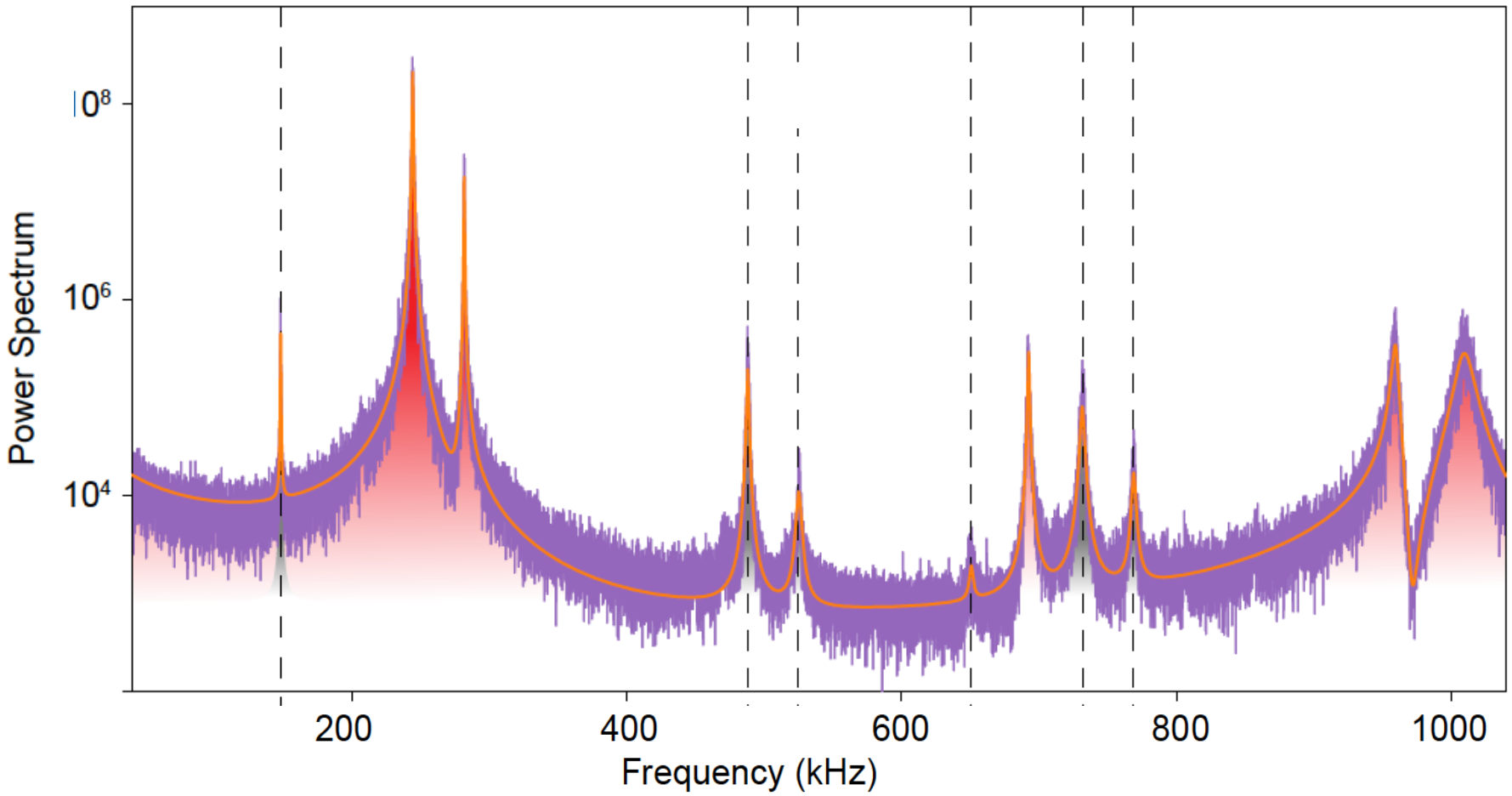
Meng *et al.* Science Advances **8** eabm7585 (2022)

Experiment



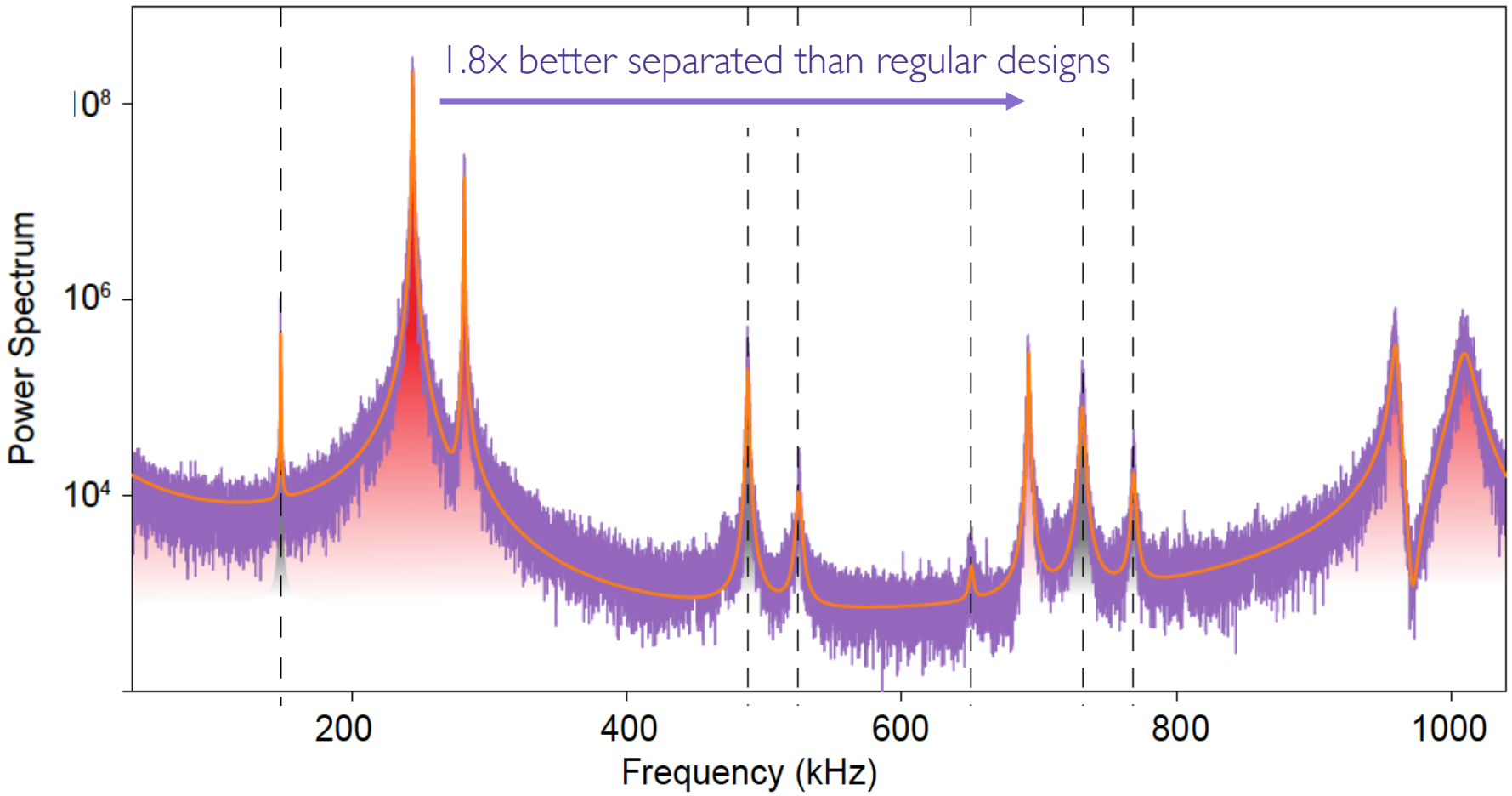
Meng *et al.* Science Advances **8** eabm7585 (2022)

Experiment



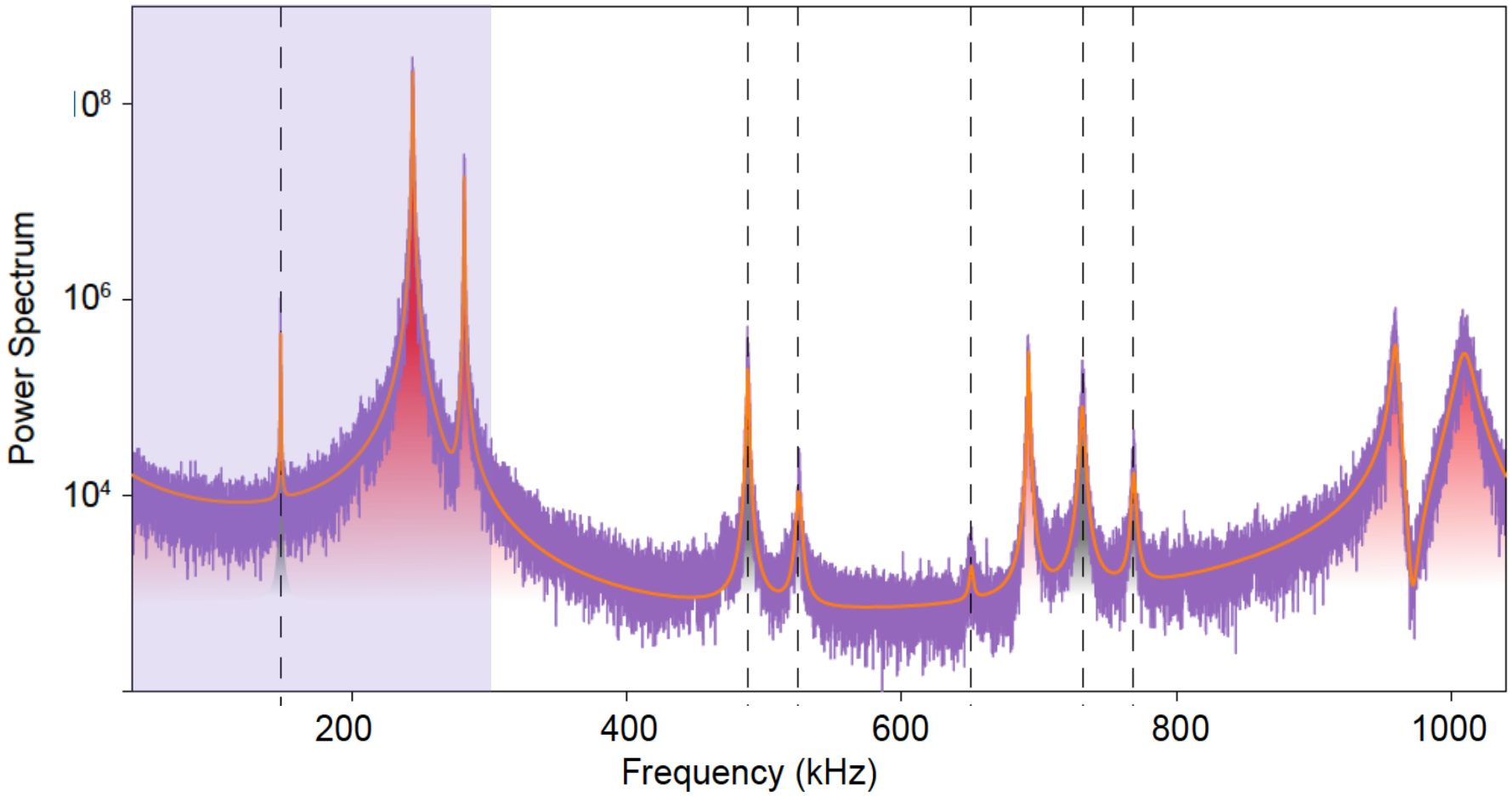
Meng *et al.* Science Advances **8** eabm7585 (2022)

Experiment



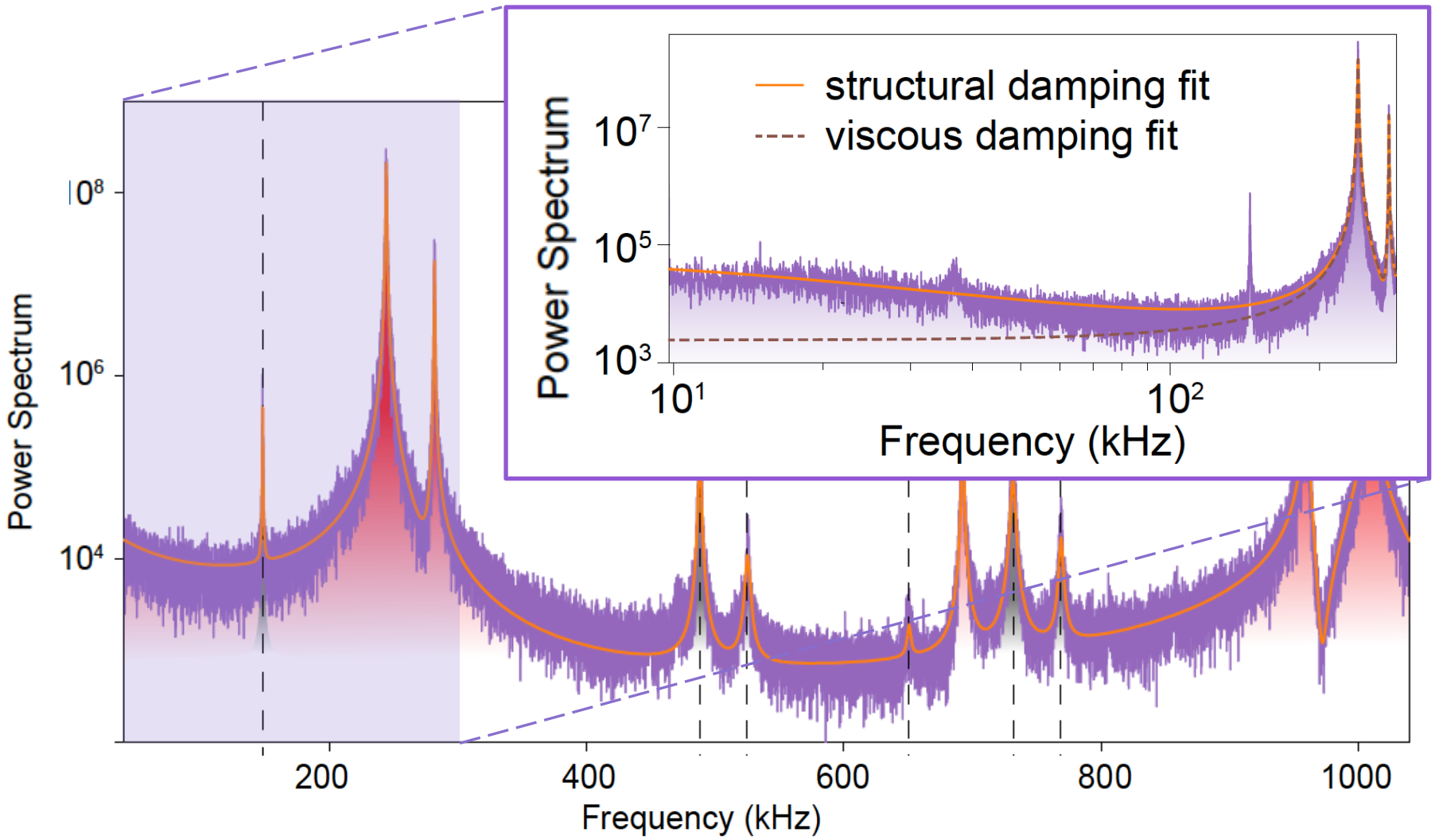
Meng *et al.* Science Advances **8** eabm7585 (2022)

Experiment



Meng *et al.* Science Advances **8** eabm7585 (2022)

Structural damping



Meng *et al.* Science Advances **8** eabm7585 (2022)

Structural damping

LETTER

https://doi.org/10.1038/s41586-019-1051-4

Measurement of quantum back action in the audio band at room temperature

Jonathan Cripe[1]*, Nancy Aggarwal[2], Robert Lanza[2], Adam Libson[2], Robinjeet Singh[1], Paula Heu[3,4], David Follman[3,4], Garrett D. Cole[3,4,5], Nergis Mavalvala[2] & Thomas Corbitt[1]*

ARTICLES
https://doi.org/10.1038/s41567-020-0877-x
nature physics

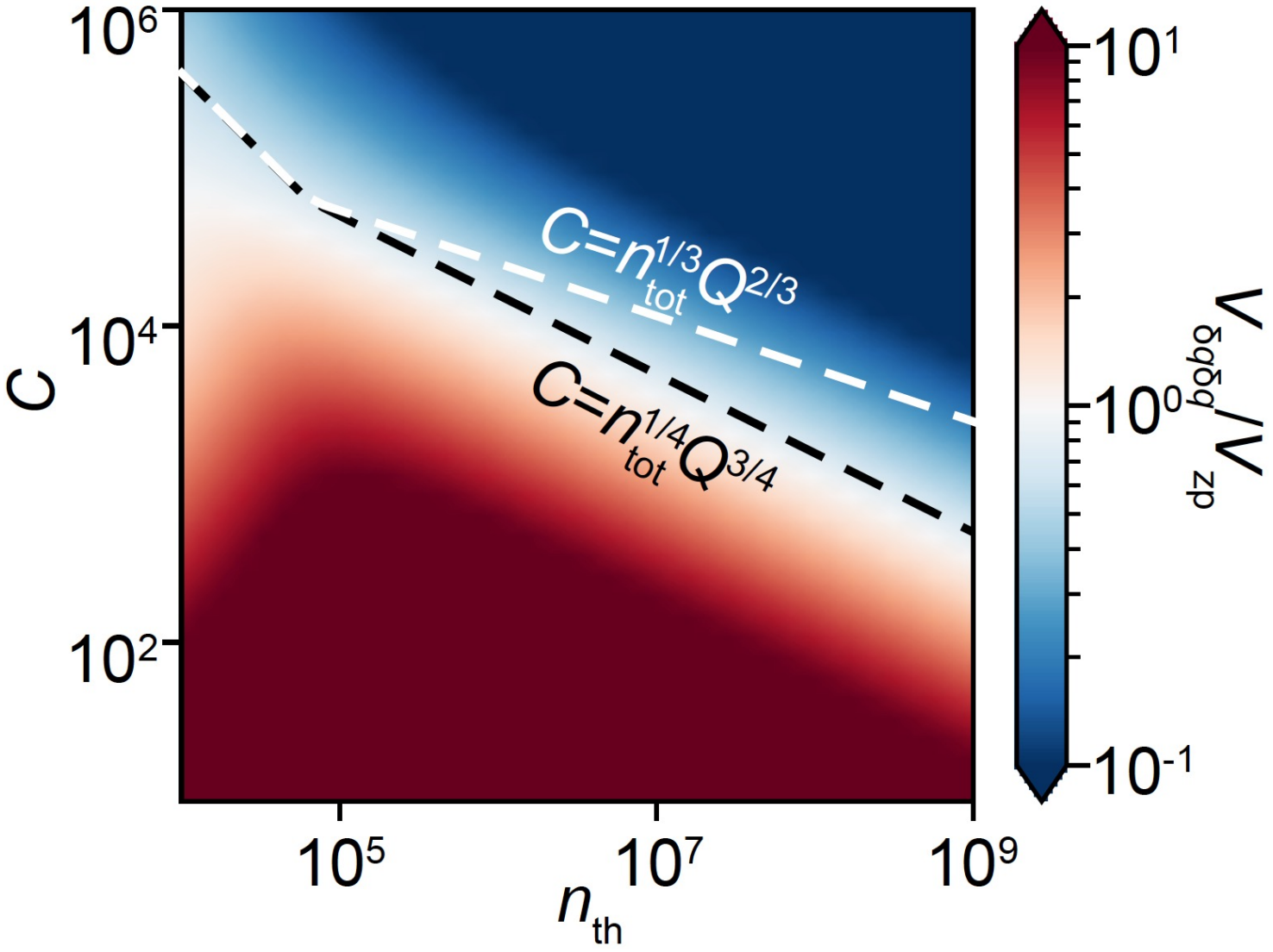
Check for updates

Room-temperature optomechanical squeezing

Nancy Aggarwal[1,4]✉, Torrey J. Cullen[2], Jonathan Cripe[2], Garrett D. Cole[3,5], Robert Lanza[1], Adam Libson[1], David Follman[3,5], Paula Heu[3], Thomas Corbitt[2]✉ and Nergis Mavalvala[1]✉

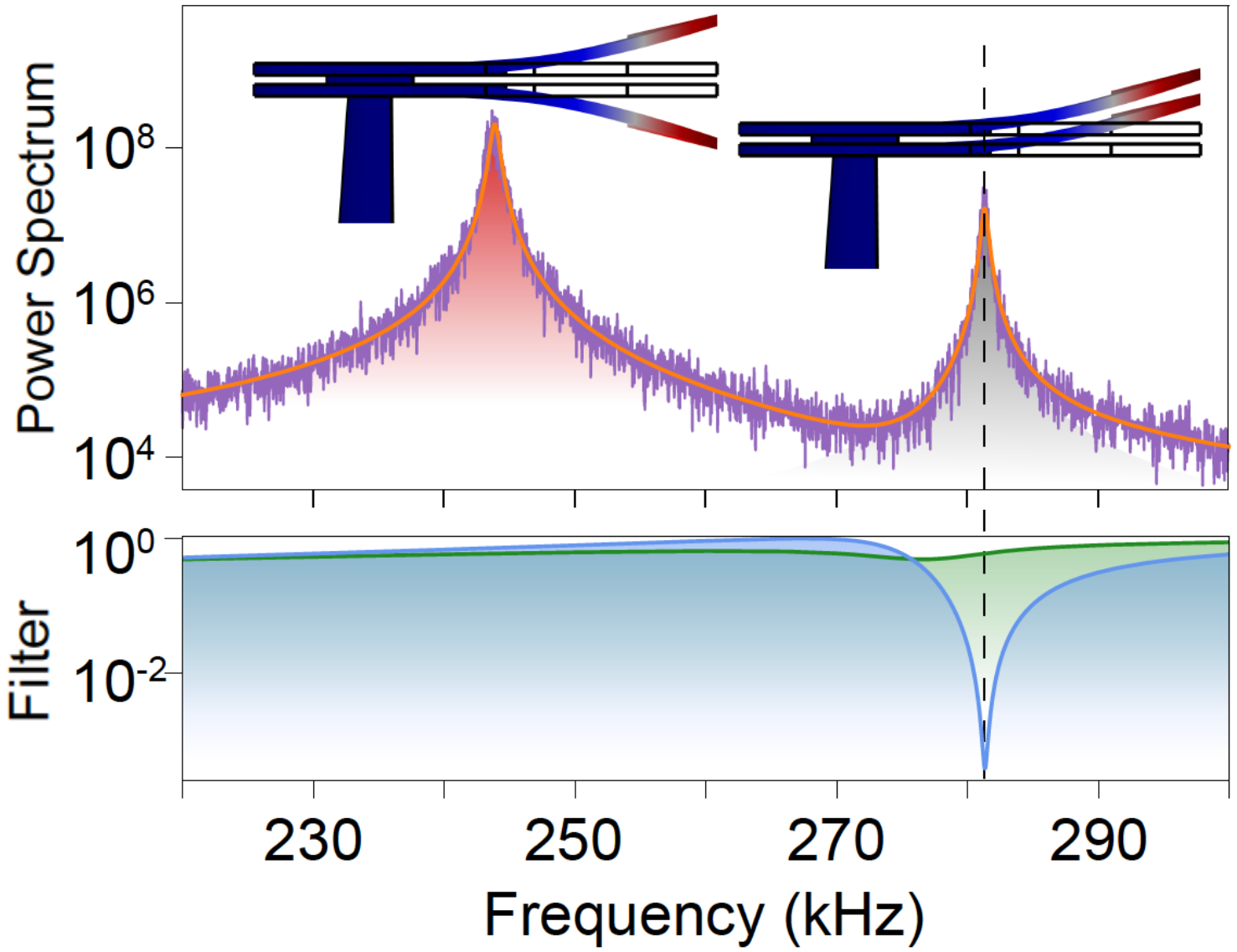
Meng *et al.* Science Advances **8** eabm7585 (2022)

Structural damping



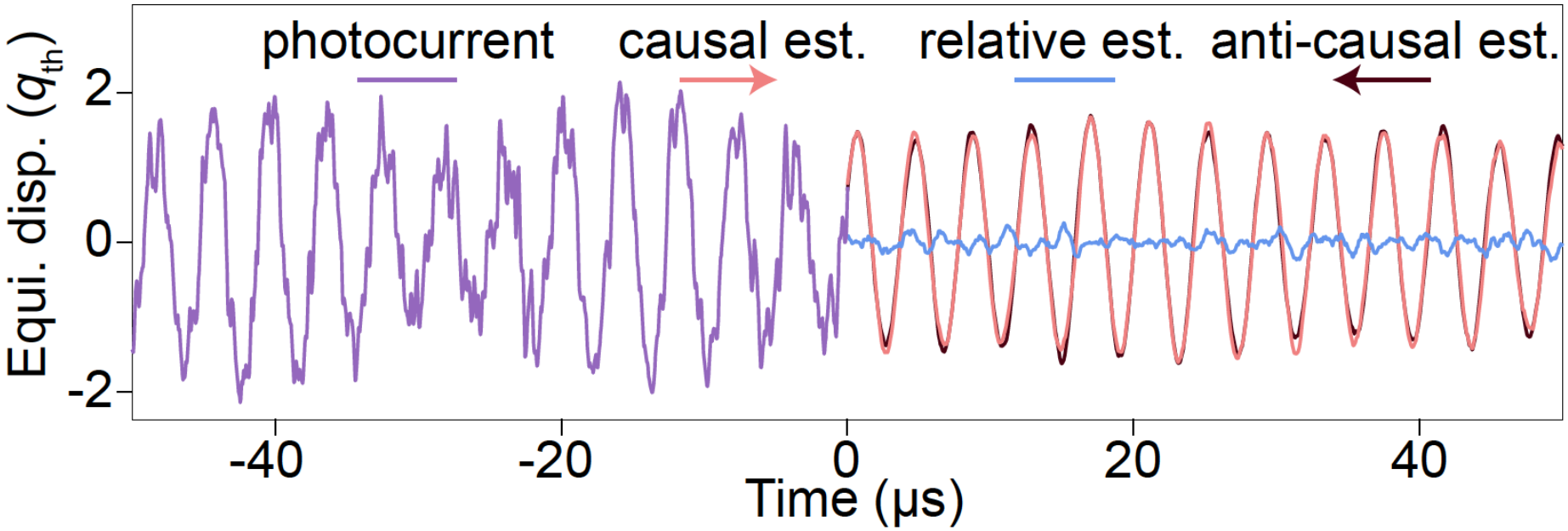
Meng *et al.* Science Advances **8** eabm7585 (2022)

State conditioning



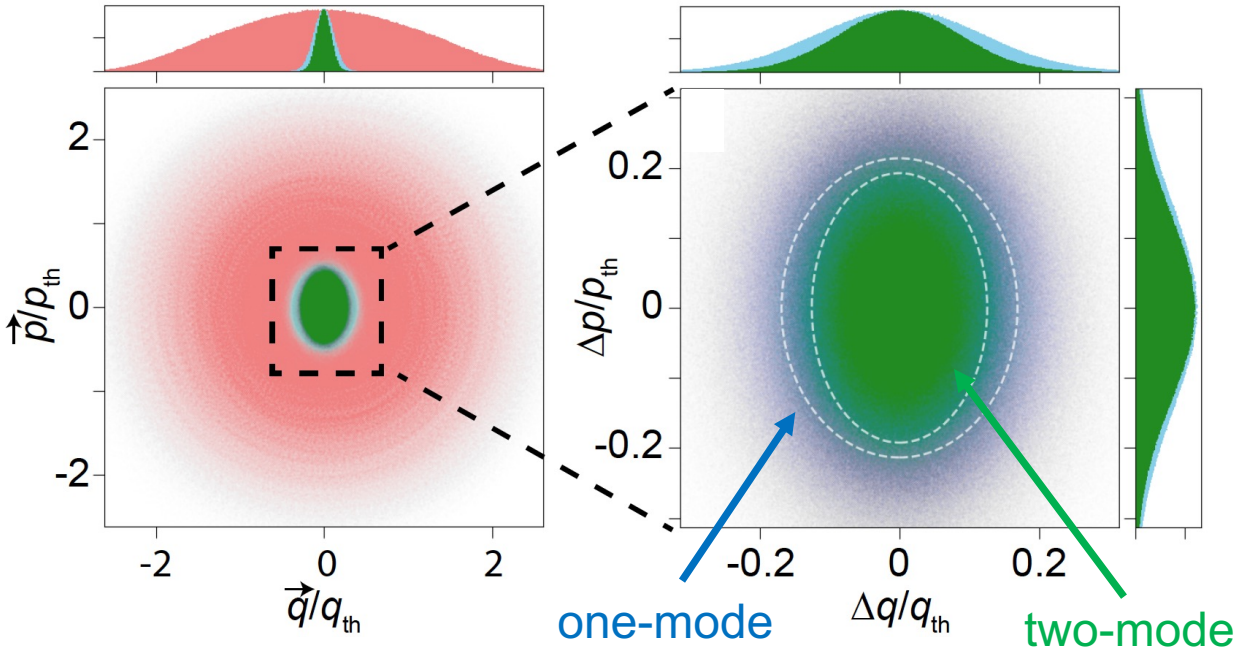
Meng *et al.* Science Advances **8** eabm7585 (2022)

State conditioning



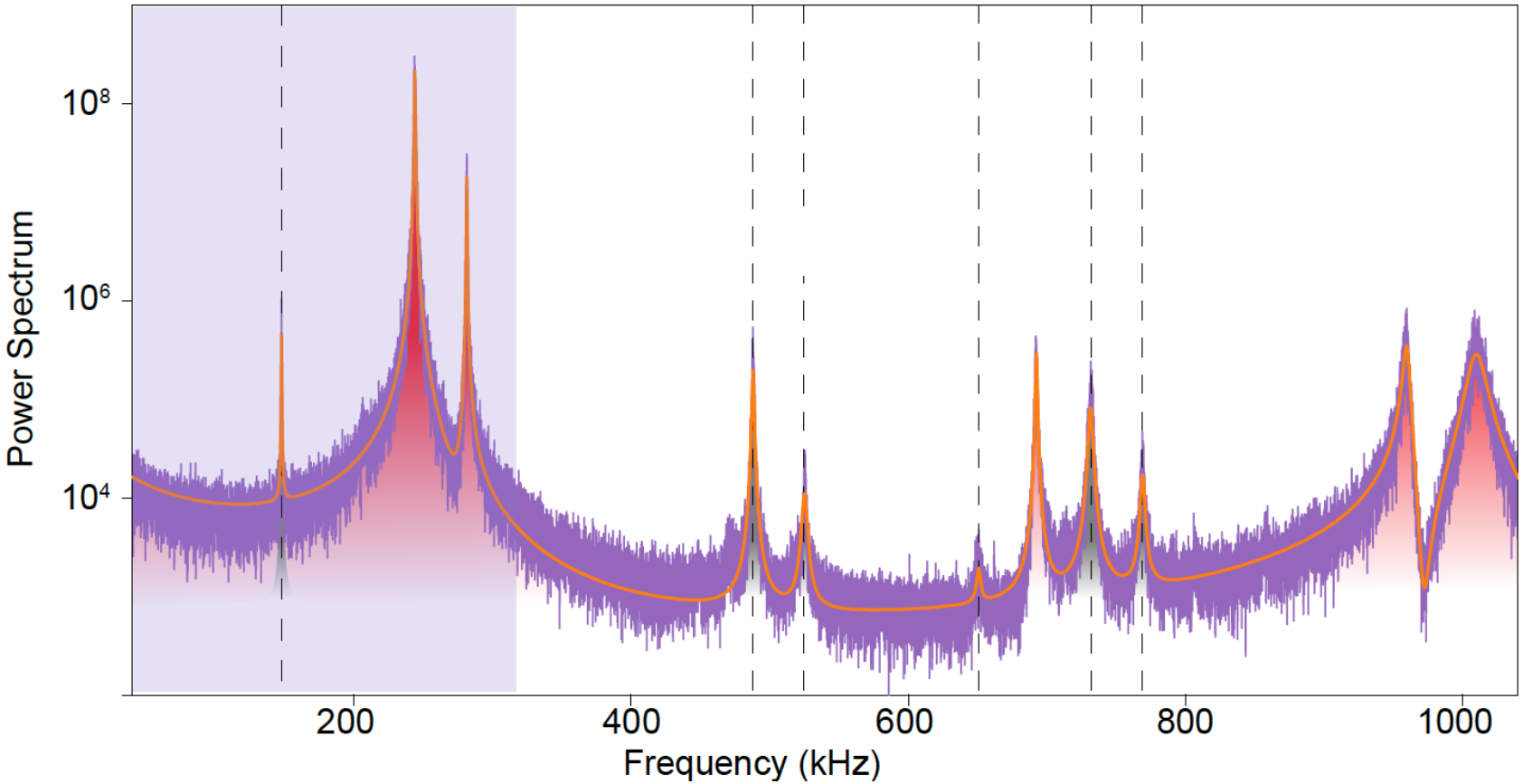
Meng *et al.* Science Advances **8** eabm7585 (2022)

State conditioning



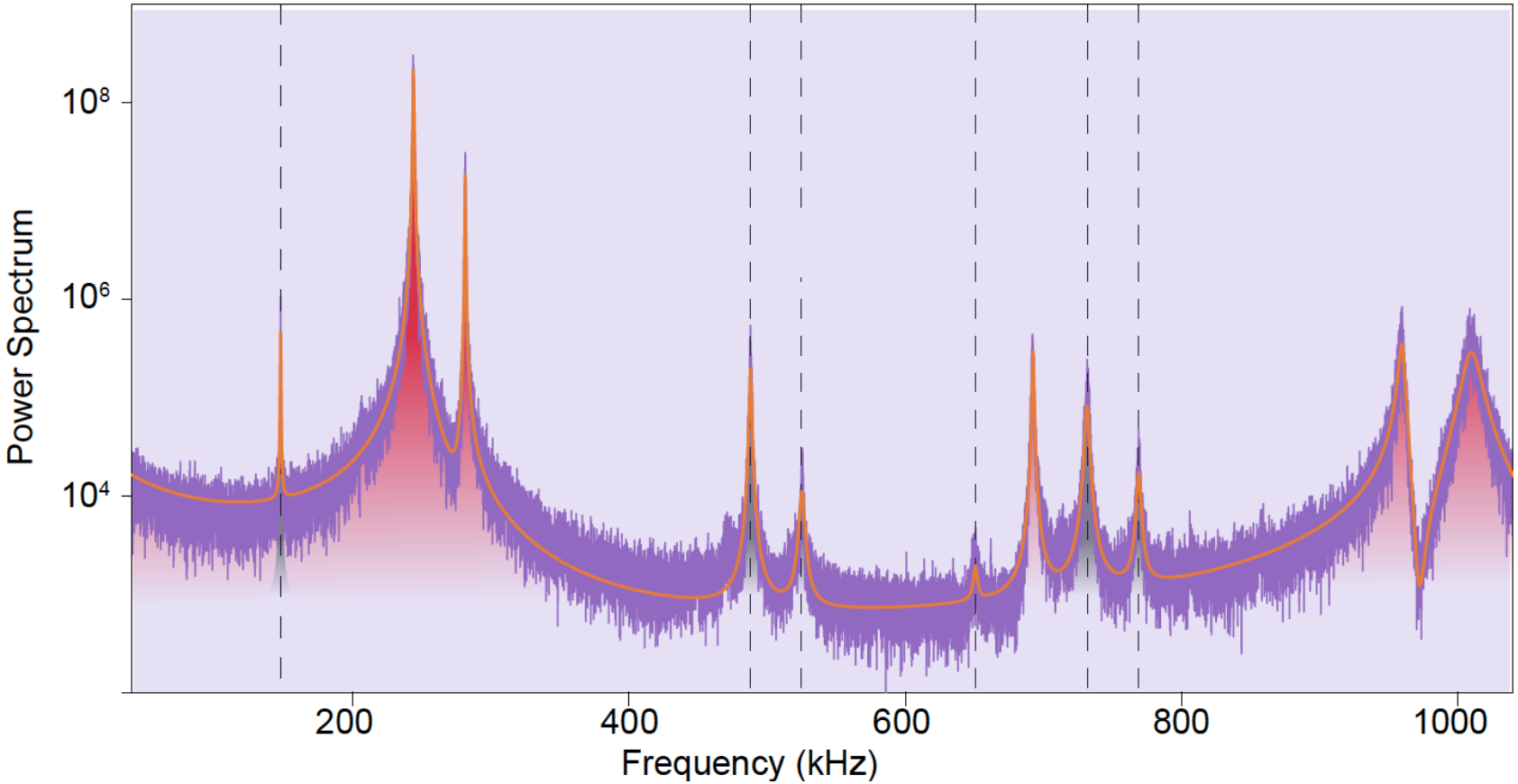
Meng *et al.* Science Advances **8** eabm7585 (2022)

Many mode state conditioning



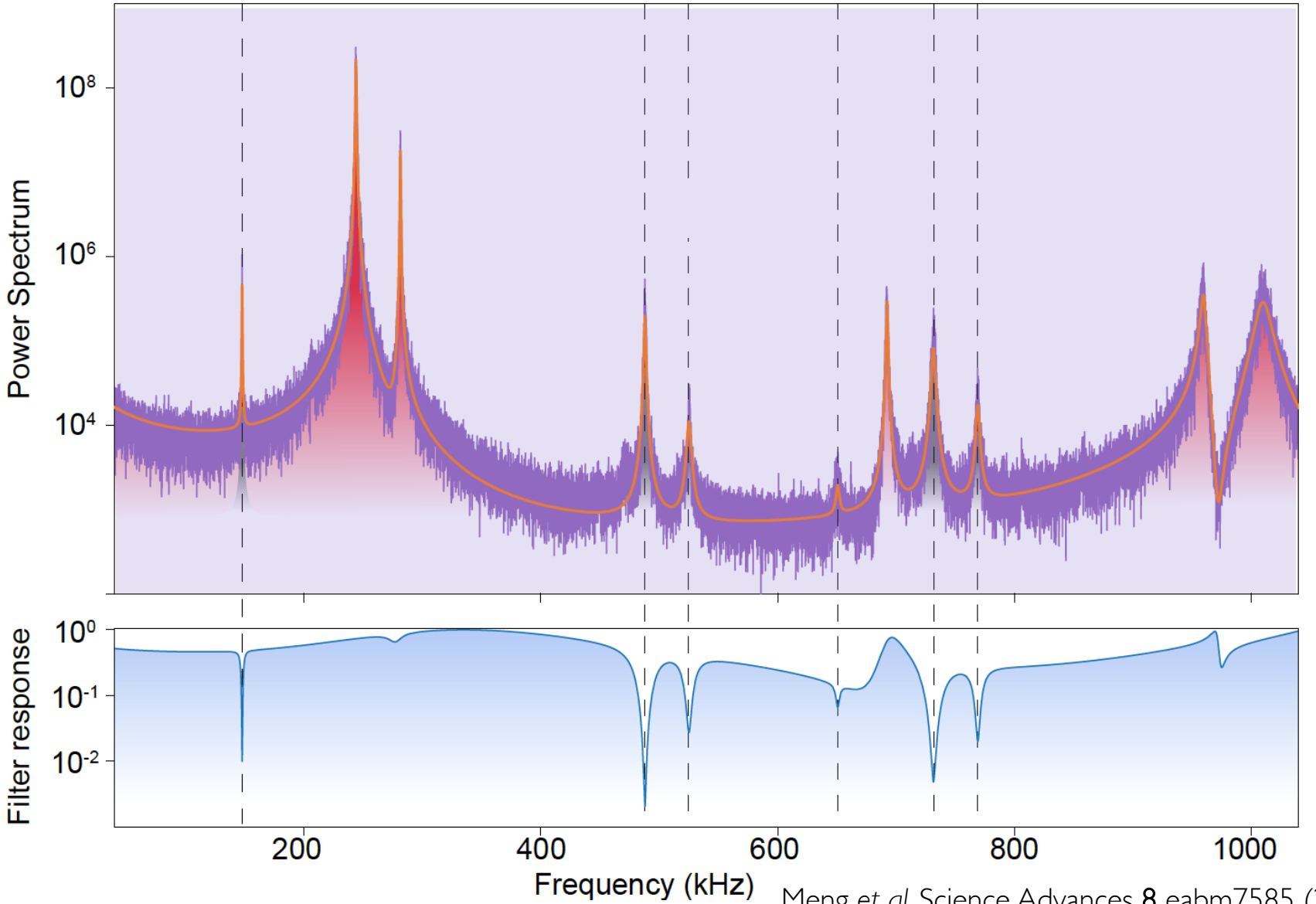
Meng *et al.* Science Advances **8** eabm7585 (2022)

Many mode state conditioning



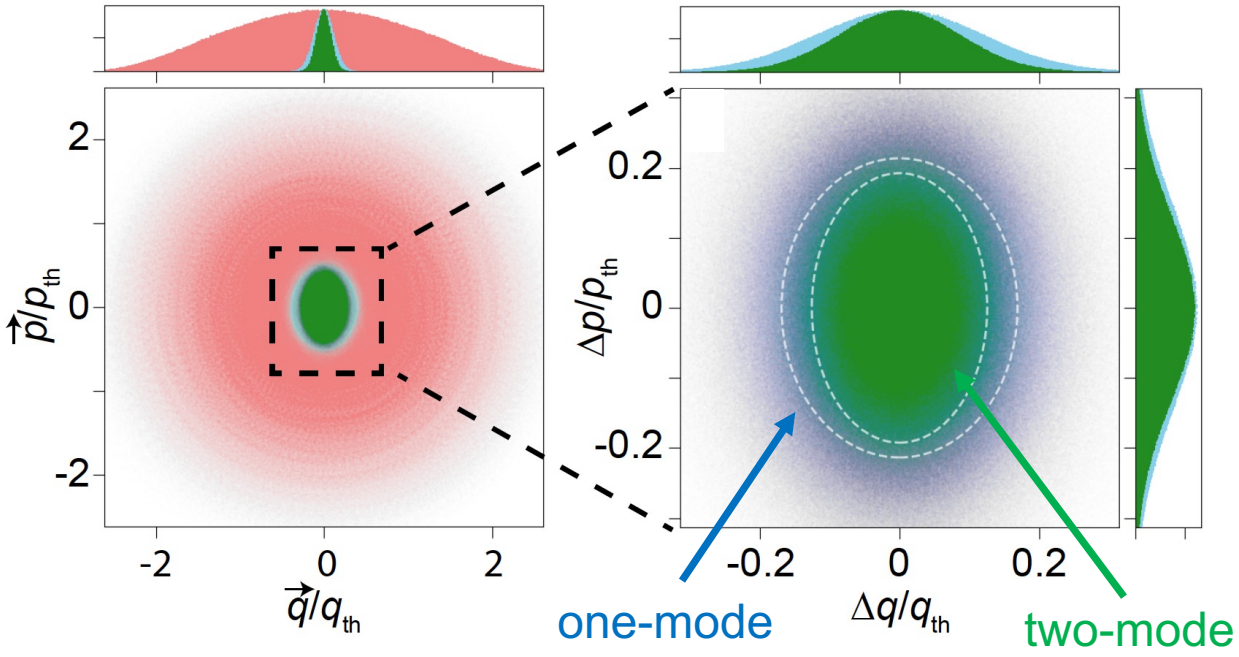
Meng *et al.* Science Advances **8** eabm7585 (2022)

Many mode state conditioning



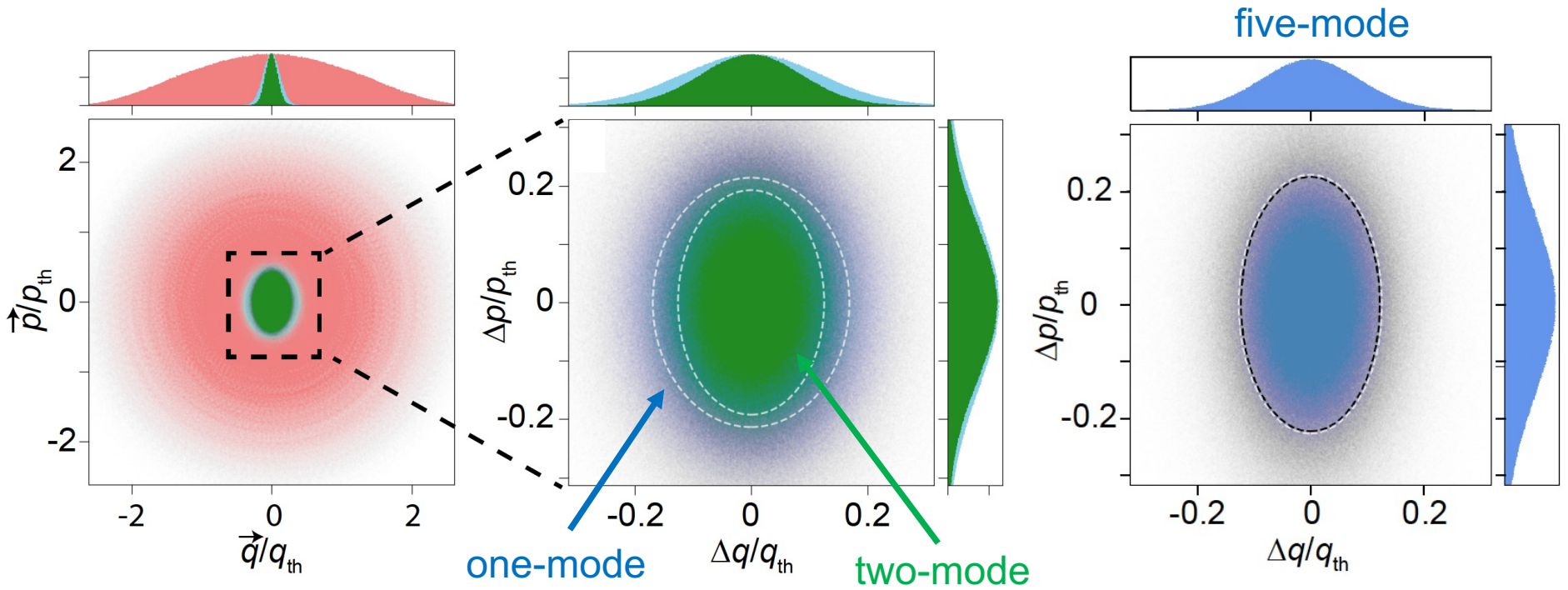
Meng *et al.* Science Advances **8** eabm7585 (2022)

Many mode state conditioning



Meng *et al.* Science Advances **8** eabm7585 (2022)

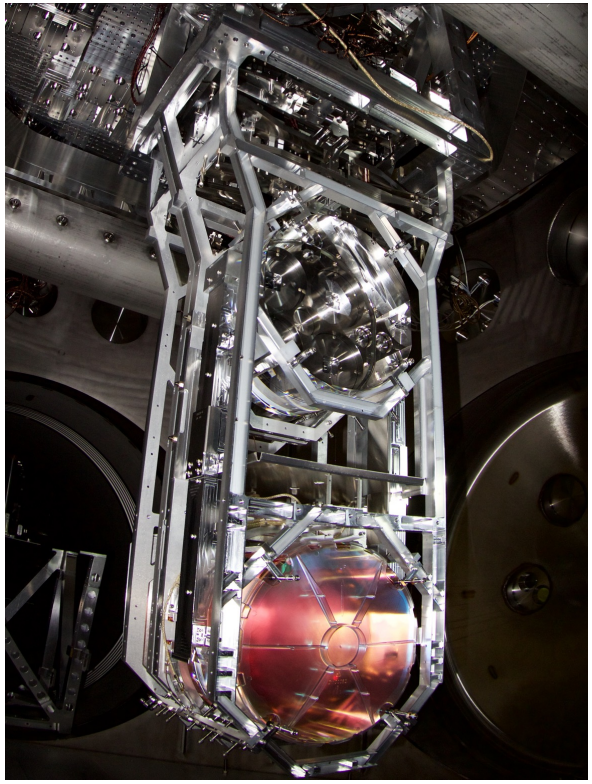
Many mode state conditioning



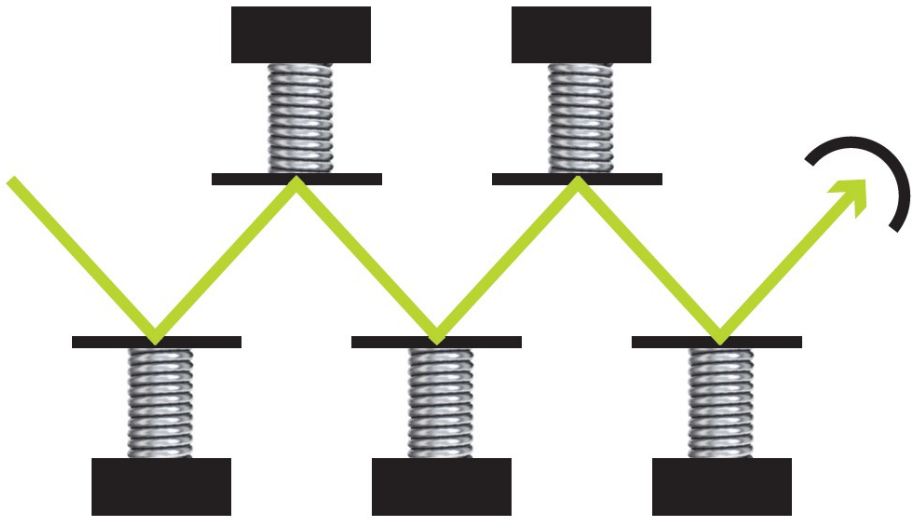
Meng *et al.* Science Advances **8** eabm7585 (2022)

How to do better?

Either employ a single very low frequency mechanical resonator



Or use a large array of near-identical resonators. Using **N** resonators reduces the required interaction strength by a factor of **N**.



Meng *et al.* Science Advances **8** eabm7585 (2022)

Entanglement via measurement

We predict **entanglement** is generated between sub-arrays of resonators when

$$C > \frac{n_{th}^2}{2N\eta}$$

Measurement and radiation pressure **correlate** momentum, while measurement **anti-correlates** position.

Meng *et al.* Science Advances **8** eabm7585 (2022)

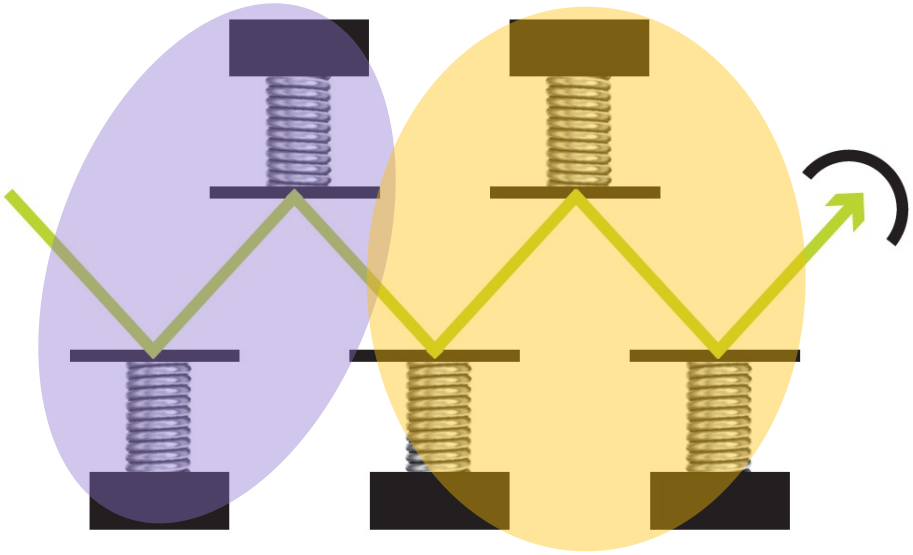
Entanglement via measurement

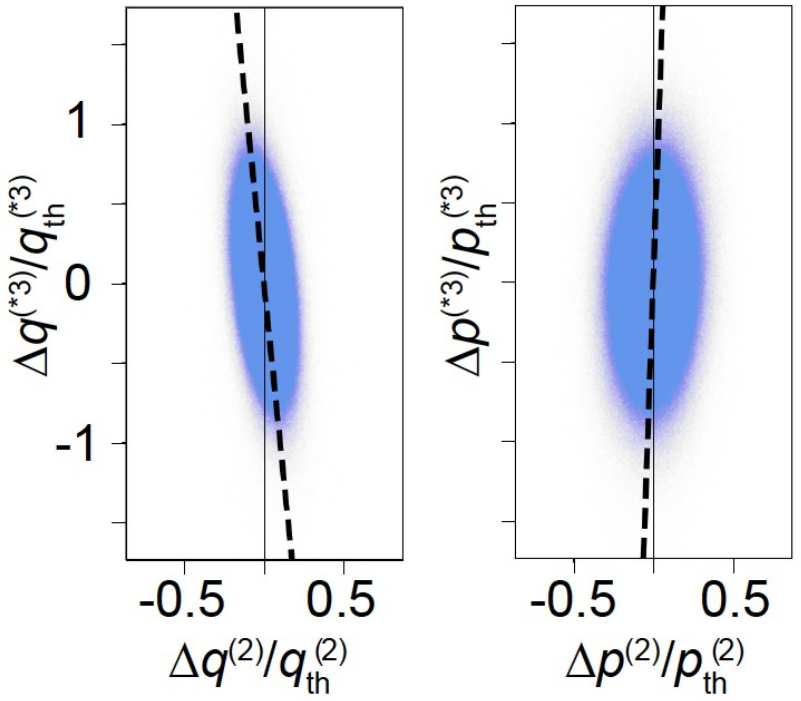
We predict **entanglement** is generated between sub-arrays of resonators when

$$C > \frac{n_{th}^2}{2N\eta}$$

Measurement and radiation pressure **correlate** momentum, while measurement **anti-correlates** position.

We observe the **classical** correlation generation of this kind.





Meng *et al.* Science Advances **8** eabm7585 (2022)

Conclusion

- Quantum/cavity optomechanics provide new approaches to study fundamental physics, build quantum technologies and precision sensors, and probe natural phenomena.
- A major challenge is the generation of non-classical states at room temperature.
- Here, we
  - Show theoretically that fast continuous measurements can achieve this, greatly relaxing the usual requirements for quantum control.
  - Experimentally validate this in the classical regime, generating thermomechanically squeezed states of a room temperature mechanical resonator
  - Achieve classical state preparation of multimode and structurally damped resonators, showing that both effects improve state preparation.
  - Observe the classical precursor to mechanical entanglement.

Interested in PhD/postdoc? w.bowen@uq.edu.au