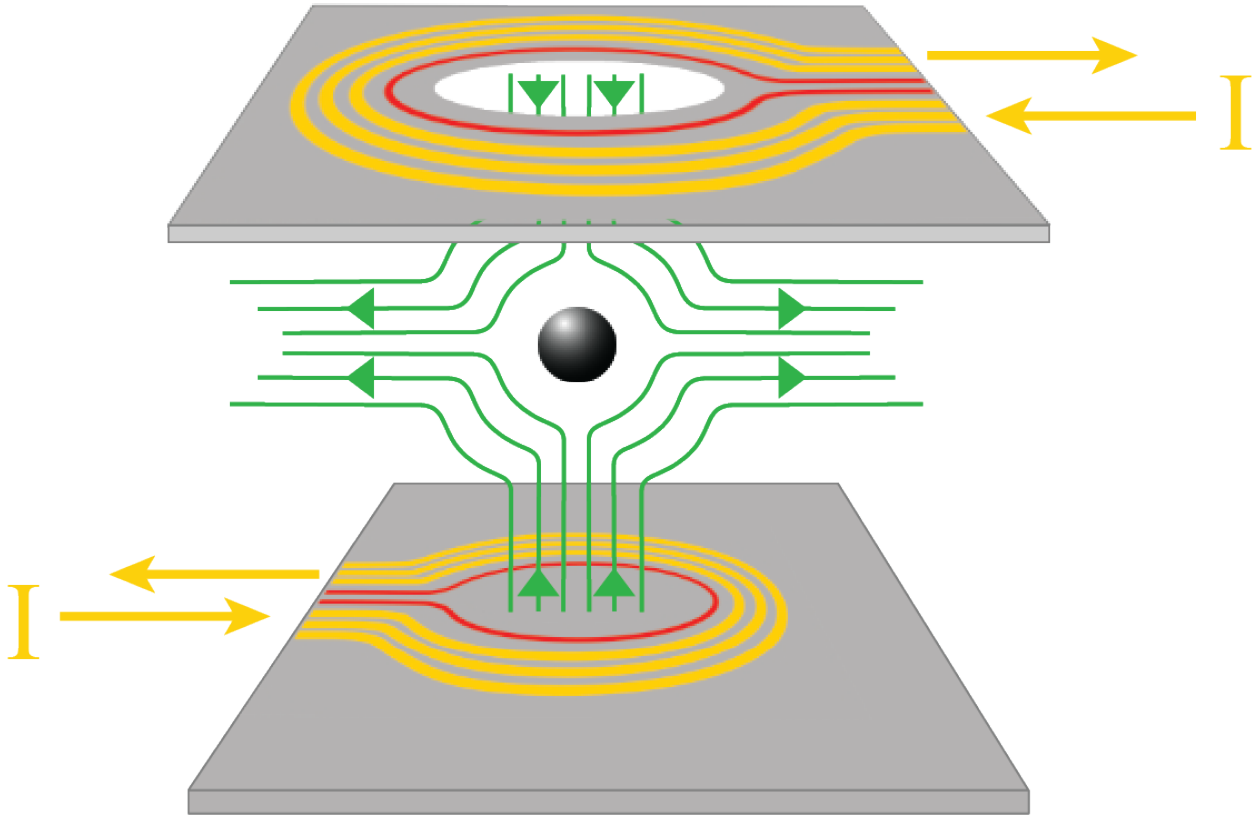
Chip-based magnetically-levitated superconducting microspheres



Gerard Higgins

Trento, 1st August 2023

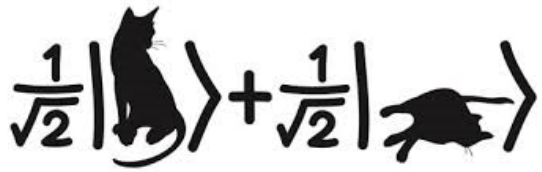
CHALMERS UNIVERSITY OF TECHNOLOGY

IQI Vienna

Quantum control of massive mechanical oscillators

Motivation

- Tests of quantum mechanics
  - Collapse models
  - Quantum gravity
- Force and acceleration sensors



Requirements

- Measurement close to (or beyond) the standard quantum limit
- Excellent isolation from the environment
- High mass

Optically-levitated nano/microparticles

- Ground state cooling

Electric/magnetic levitation

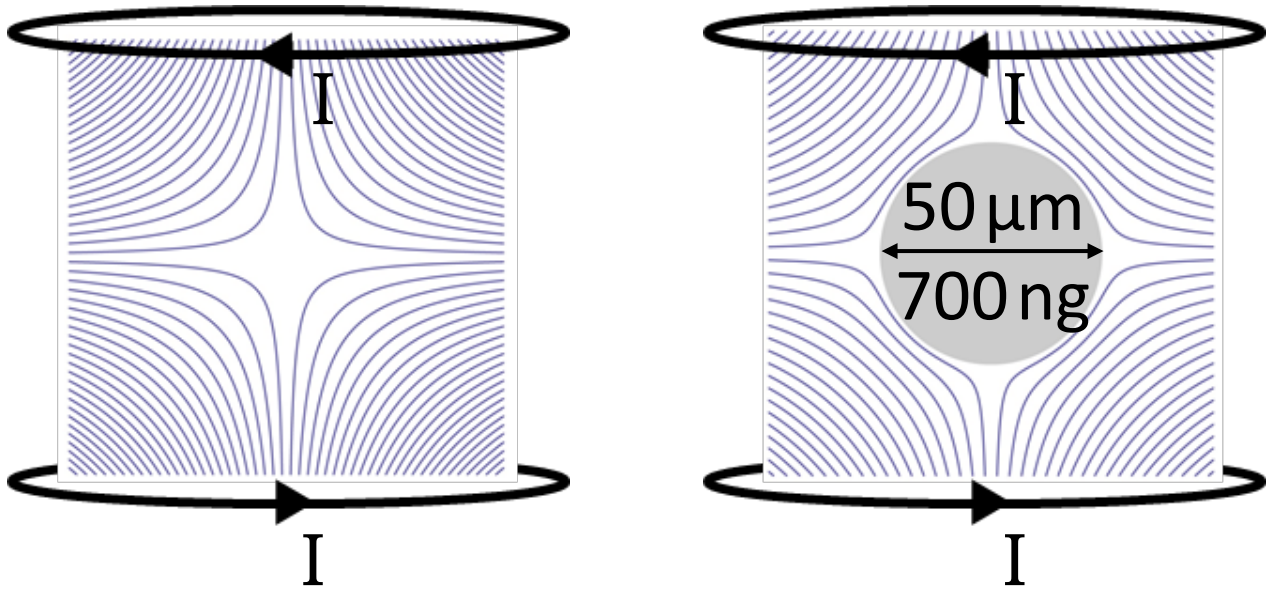
- Avoid optical recoil → low dissipation rates
- Higher masses

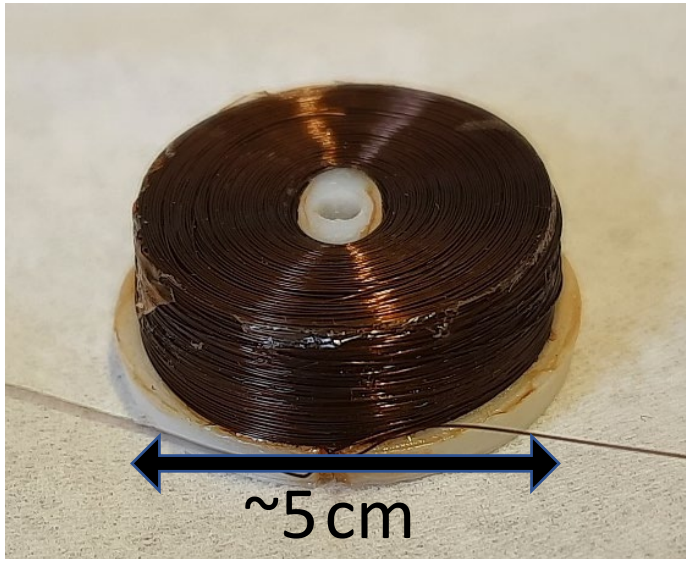
Levitation of diamagnets, superconductors

- No permanent charge/moment → low dissipation rates

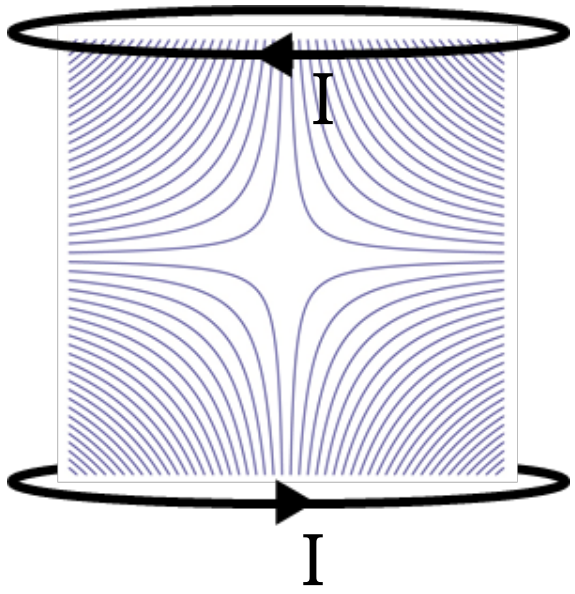
Romero-Isart et al., Phys Rev Lett 109 147205 (2012)

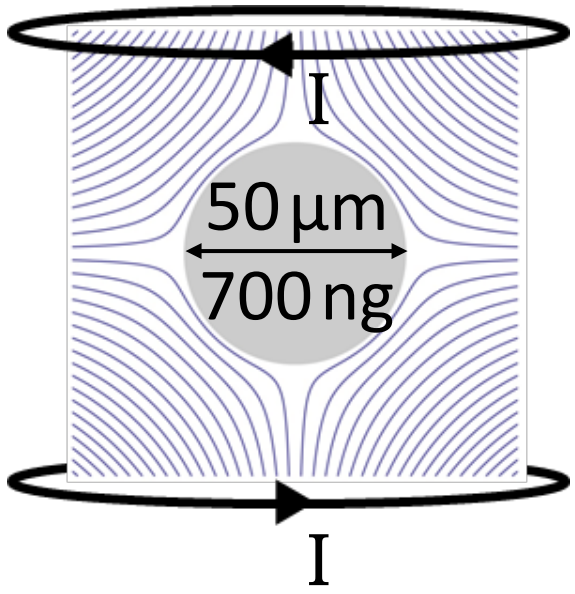
Cirio et al., Phys Rev Lett 109 147206 (2012)

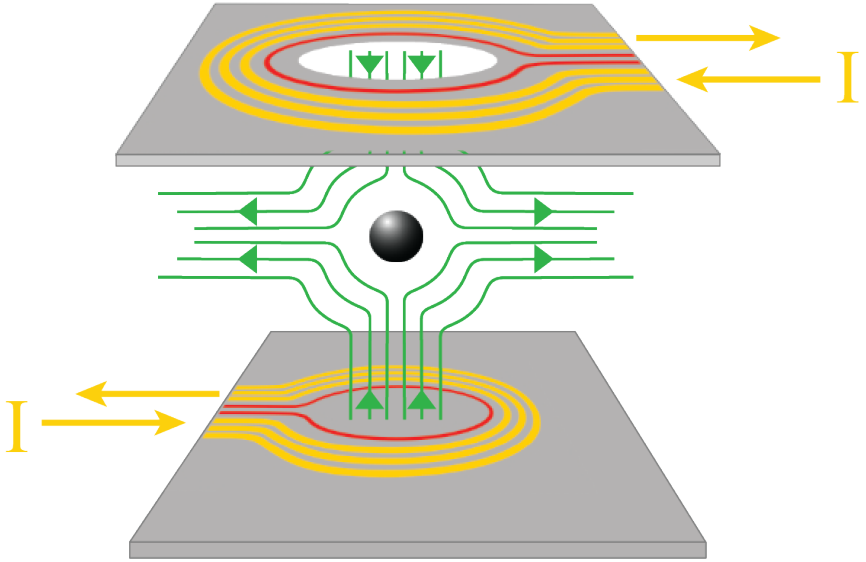


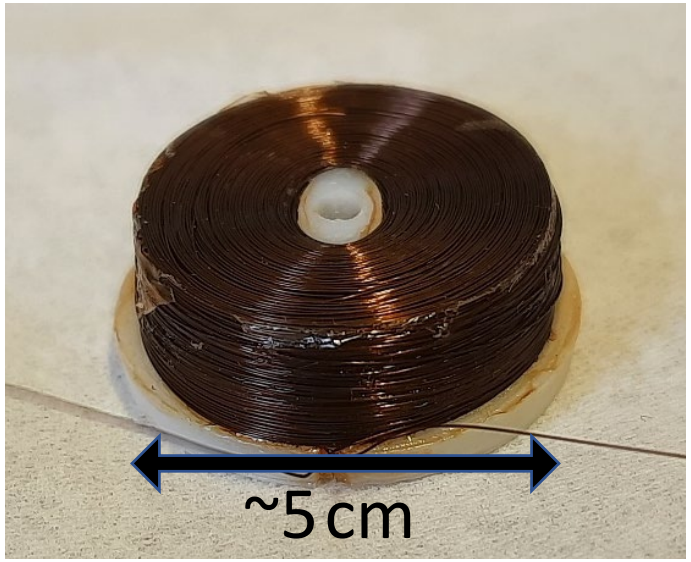


Hofer et al., Phys Rev Lett 131 043603 (2023)

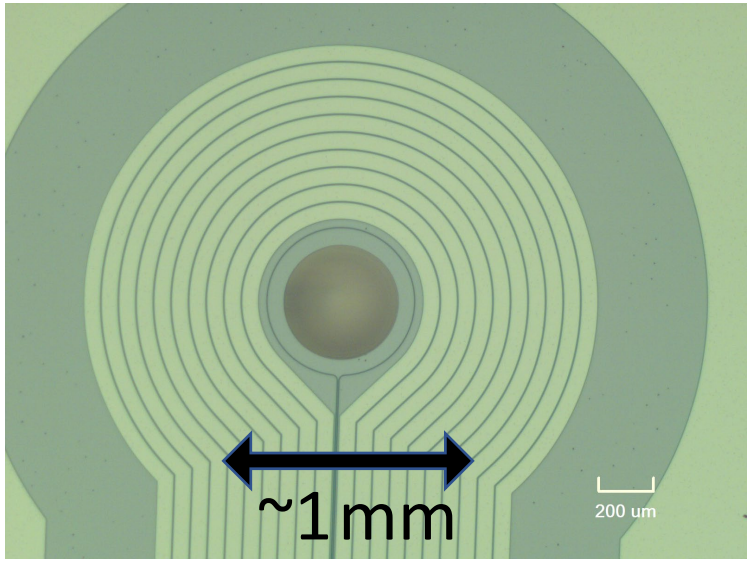


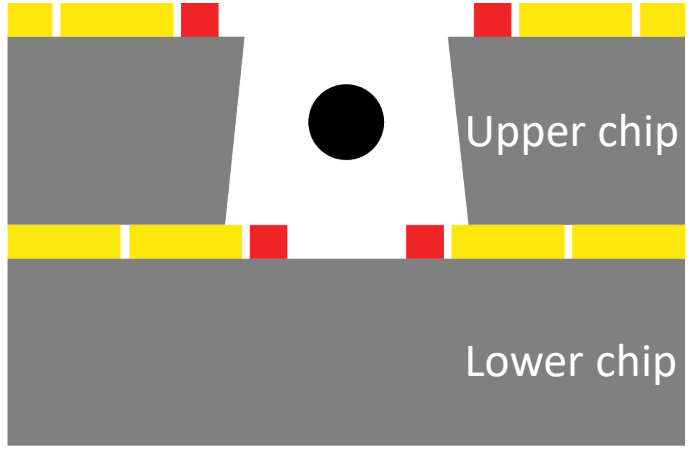






Hofer et al., Phys Rev Lett 131 043603 (2023)

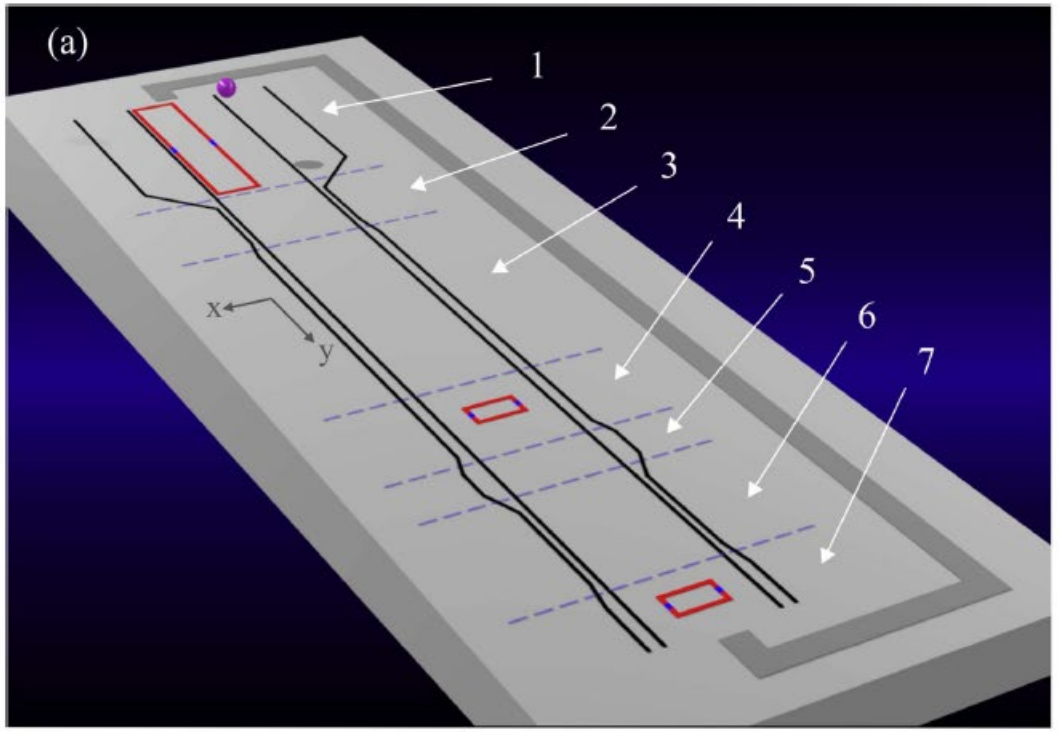


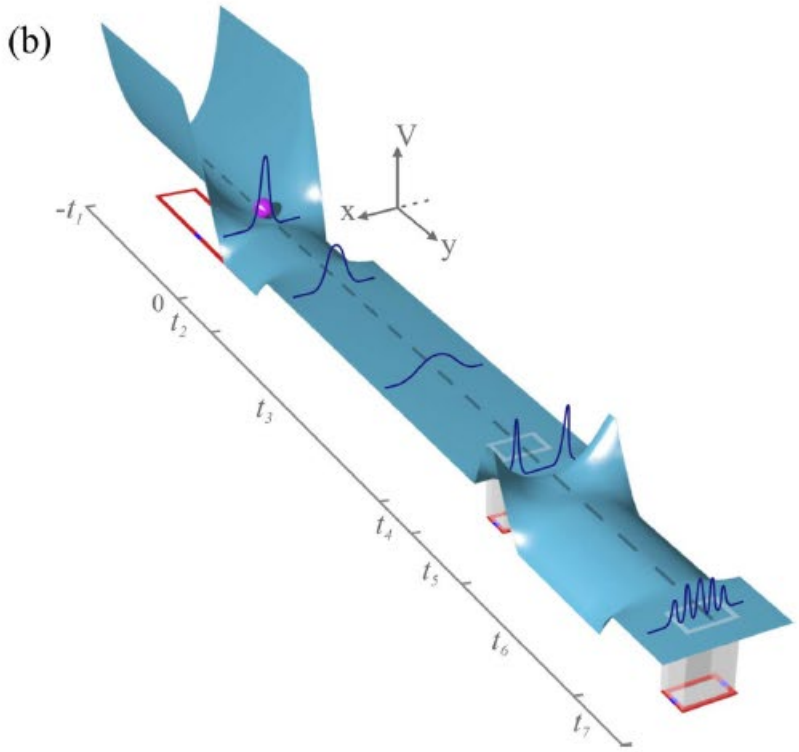


Gutierrez-Latorre et al., Phys Rev Applied 19 054047 (2023)

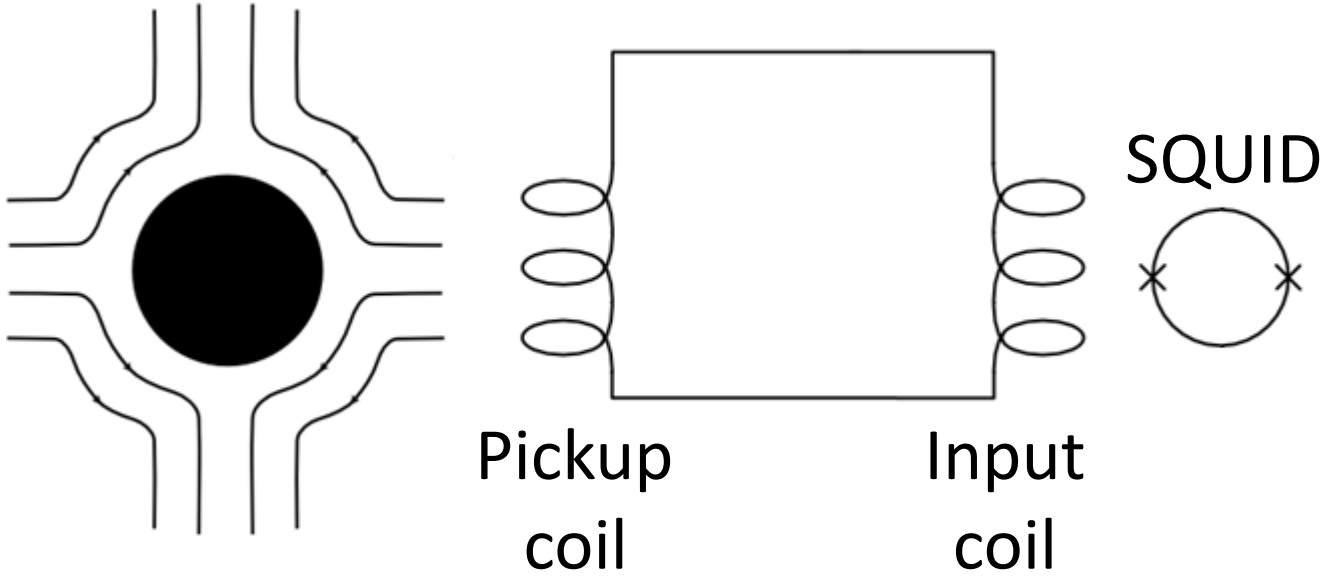
Gutierrez-Latorre et al., IEEE Trans Appl Supercond 32 1800305 (2022)

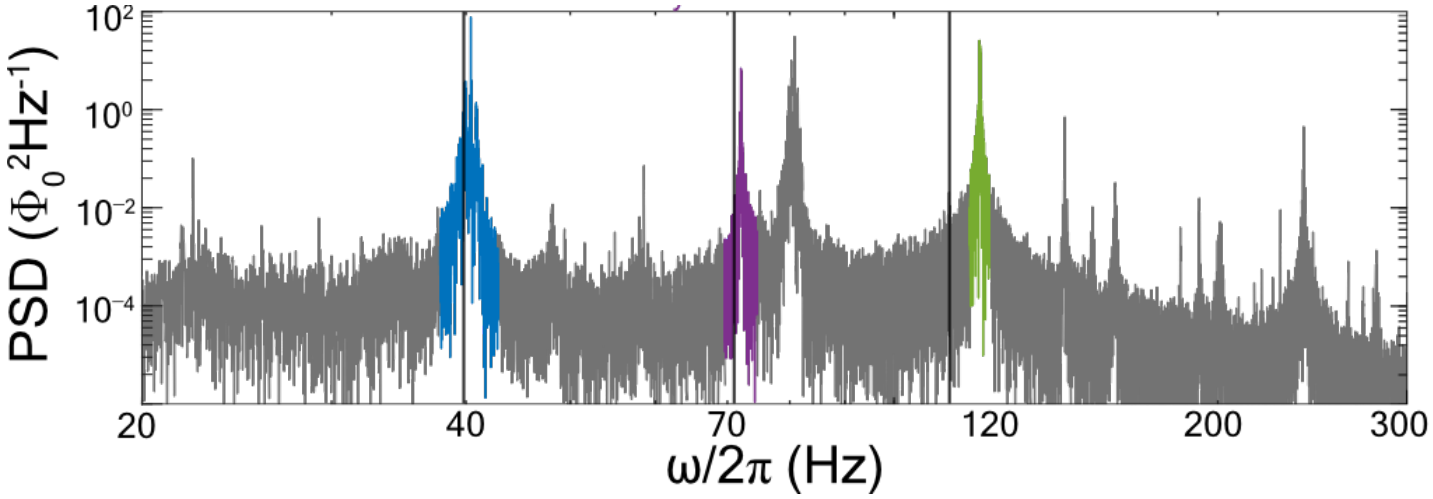
Magnetic skatepark

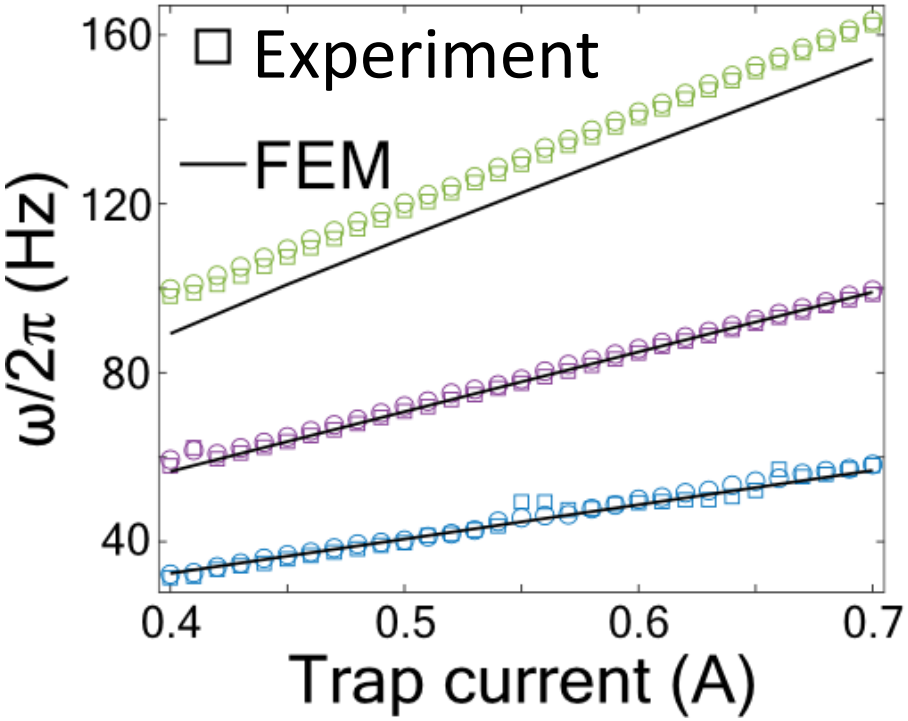




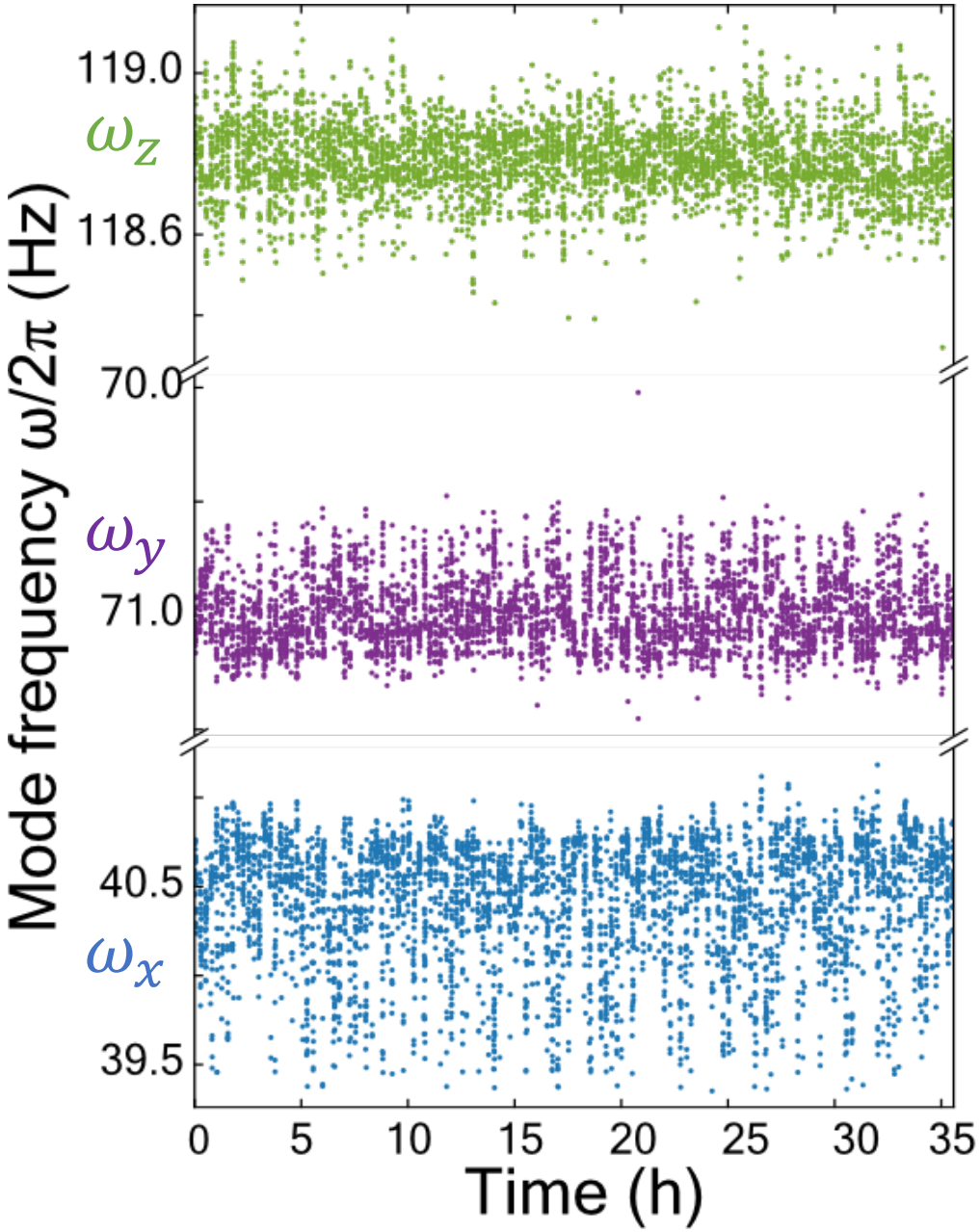
Pino et al., Quantum Sci. Technol. 3 025001 (2018)

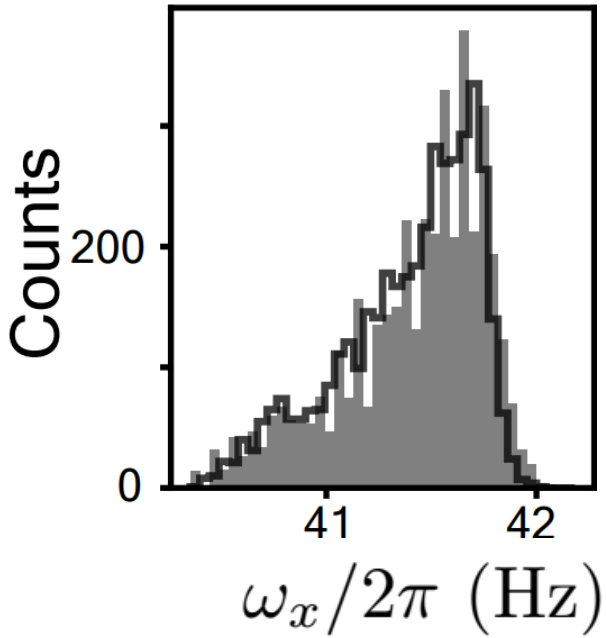




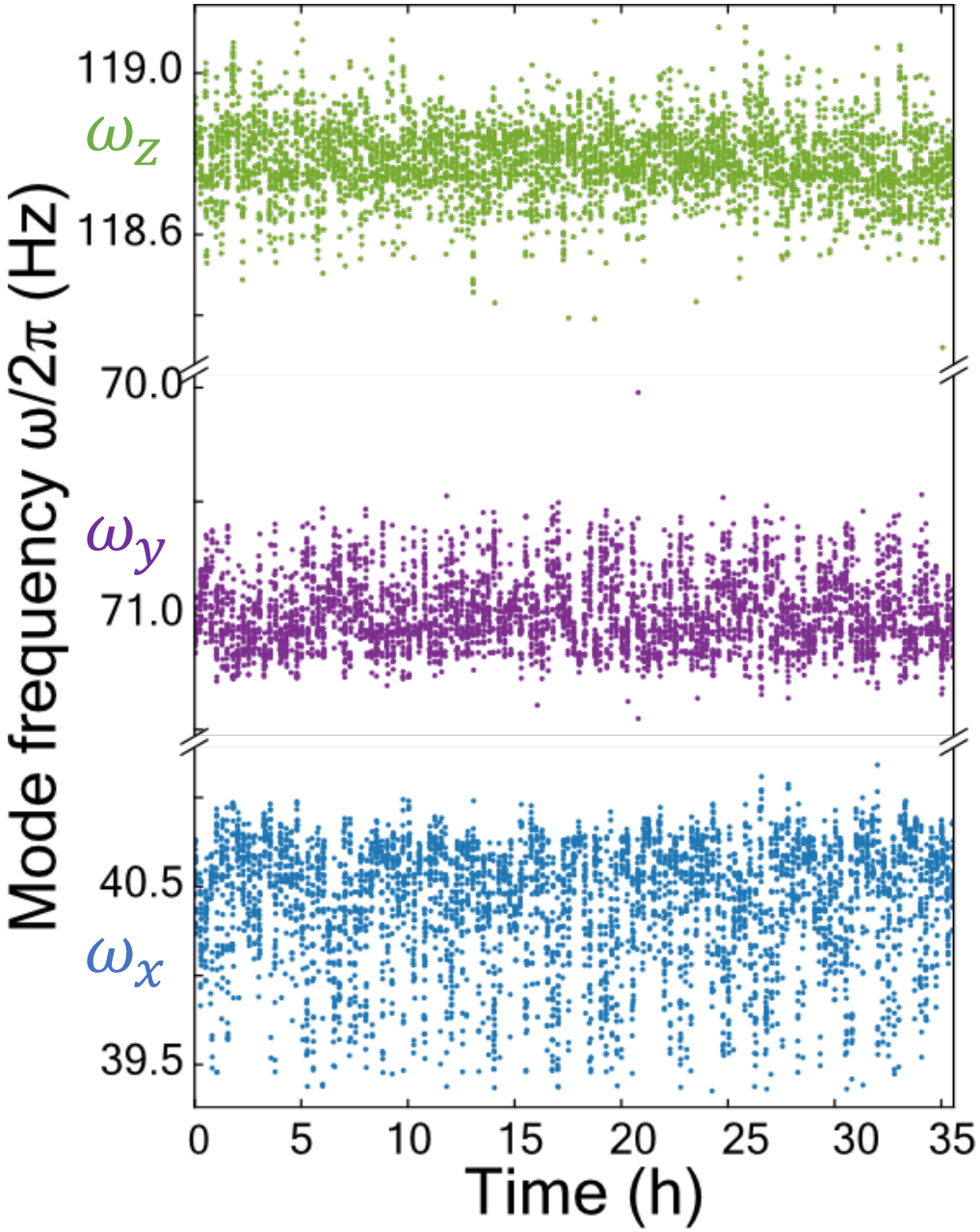


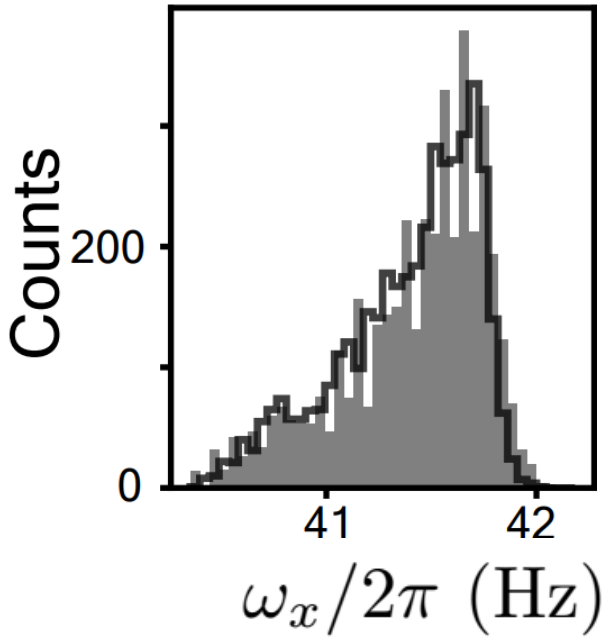
Gutierrez-Latorre et al., Phys Rev Applied 19 054047 (2023)

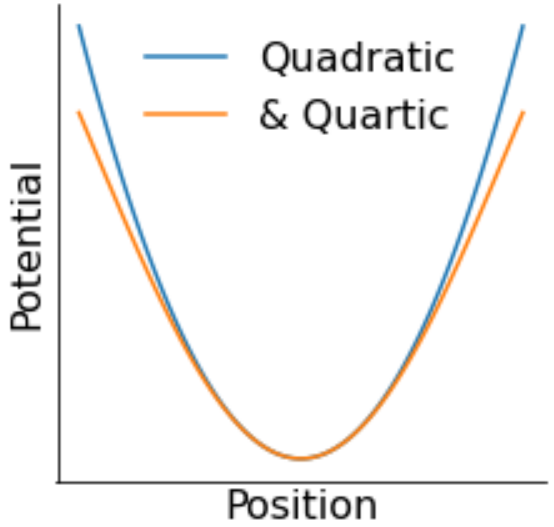


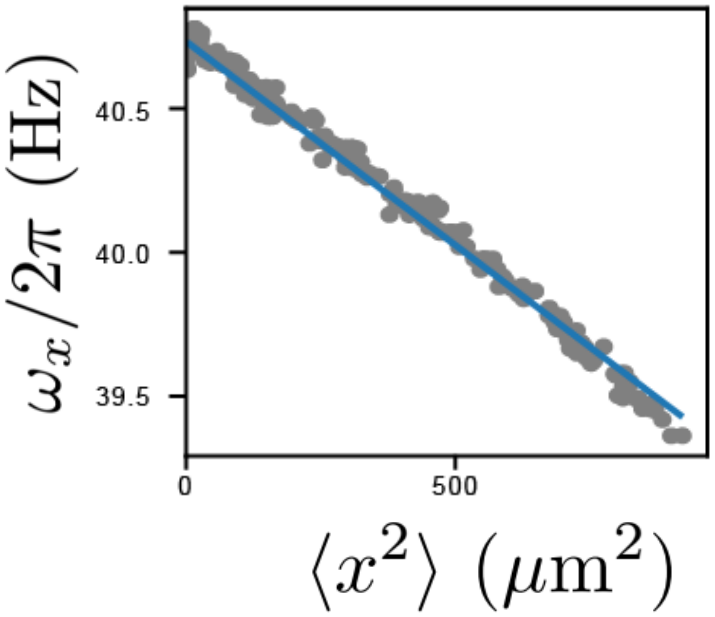


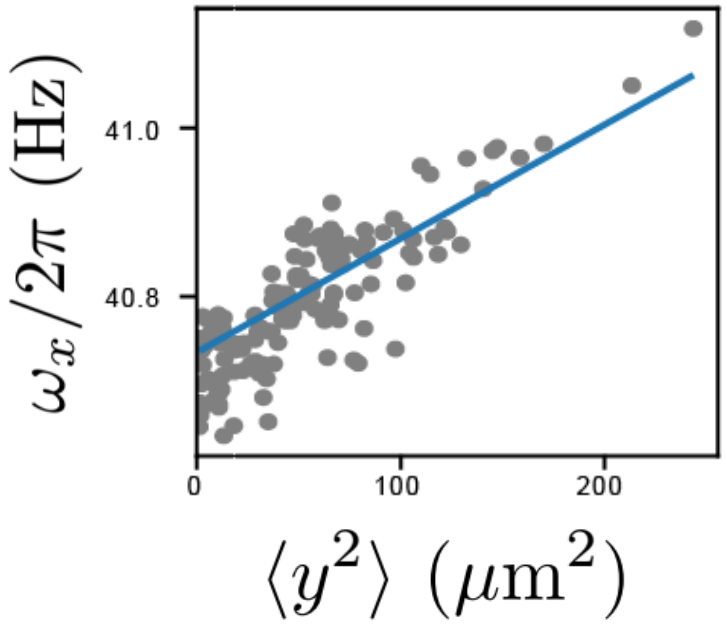
Gutierrez-Latorre et al., Phys Rev Applied 19 054047 (2023)



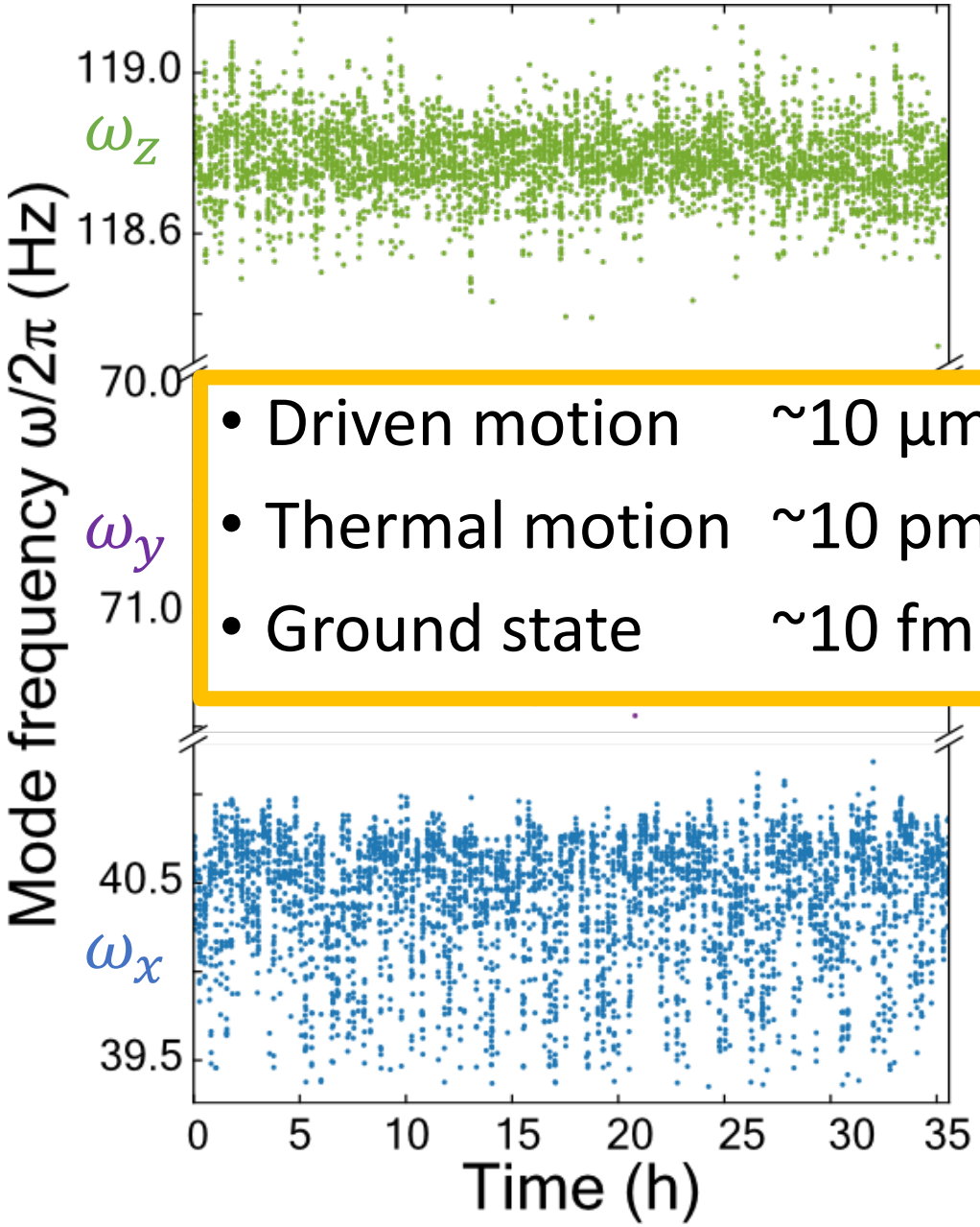




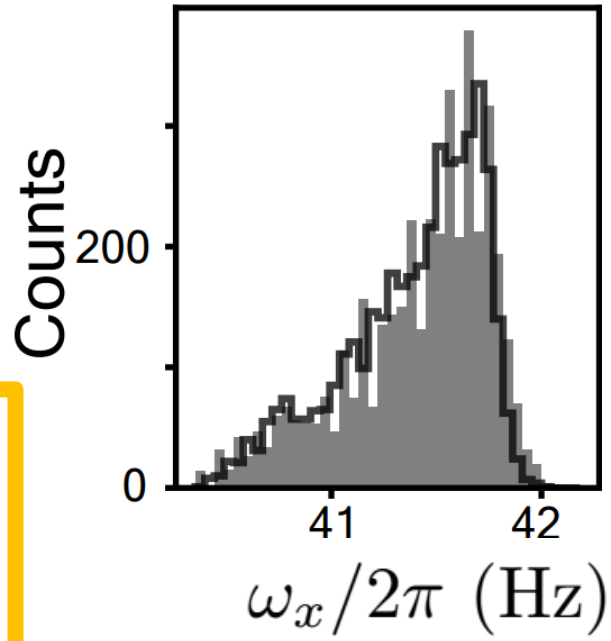


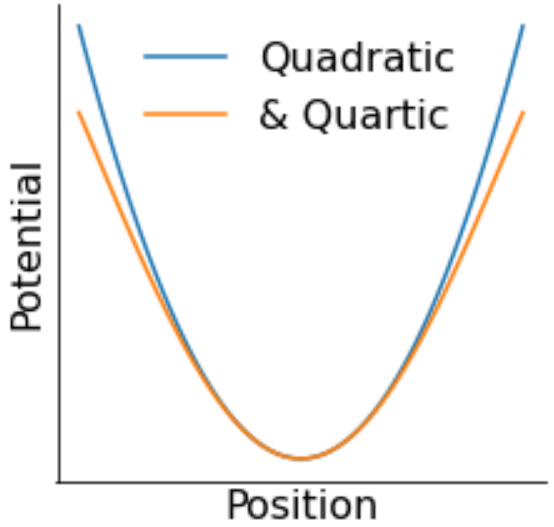


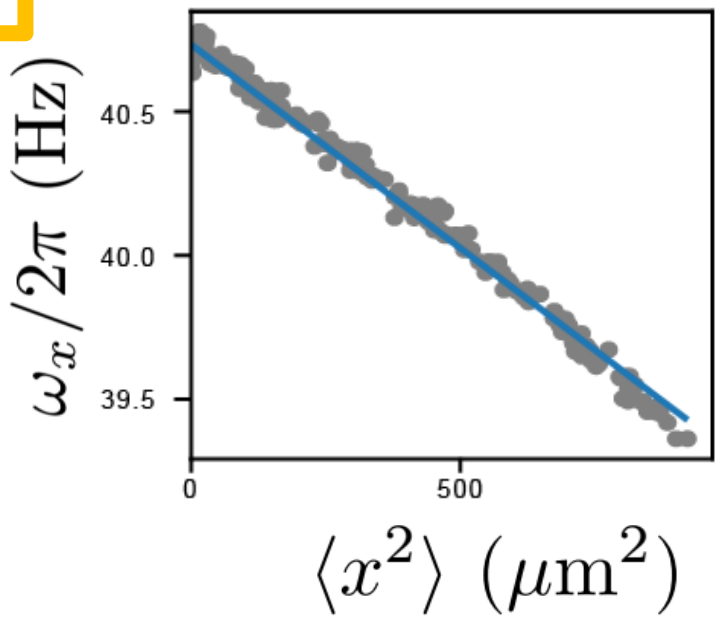
Gutierrez-Latorre et al., Phys Rev Applied 19 054047 (2023)

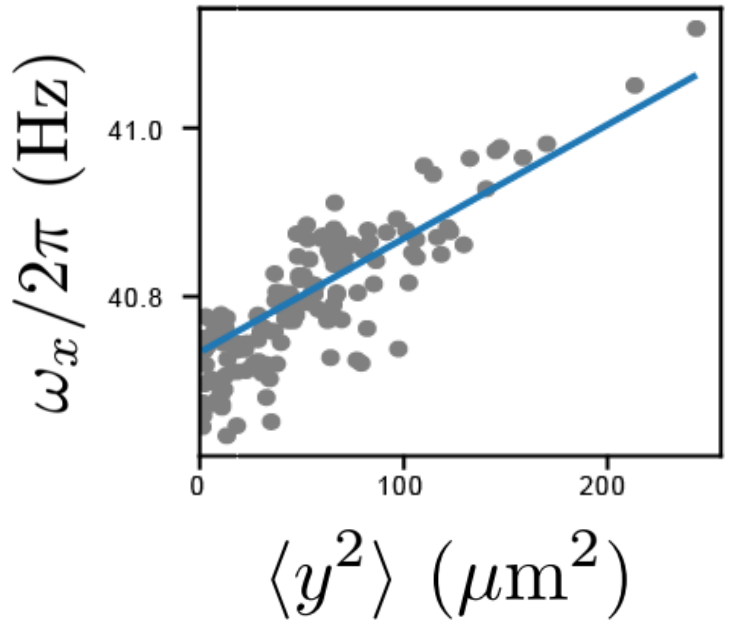


- Driven motion ~10 μm
- Thermal motion ~10 pm
- Ground state ~10 fm

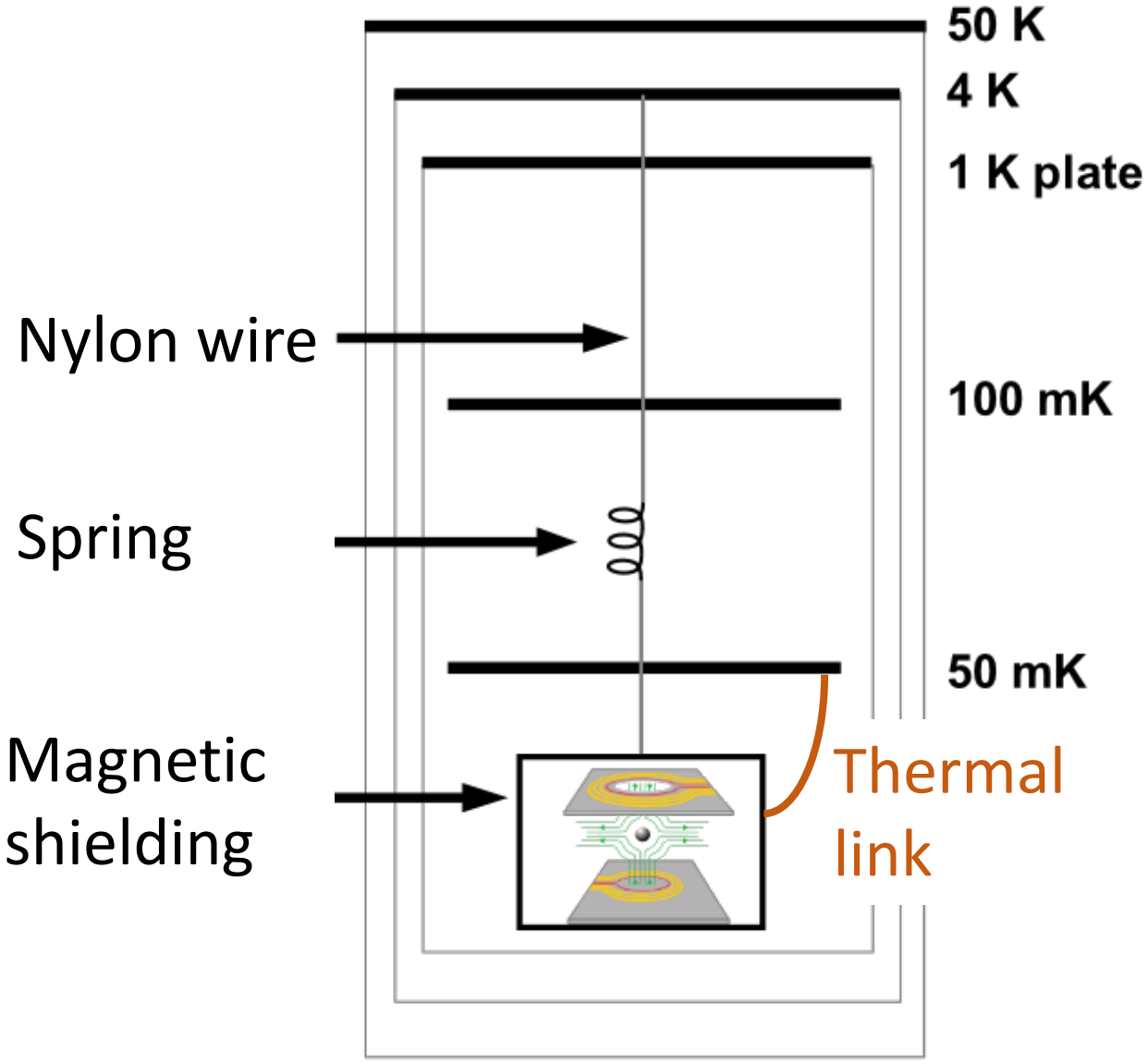








Gutierrez-Latorre et al., Phys Rev Applied 19 054047 (2023)

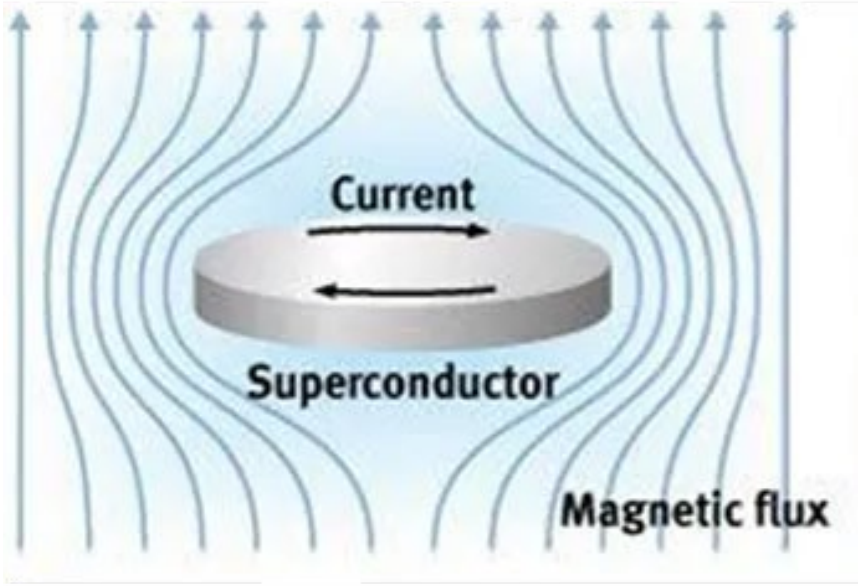


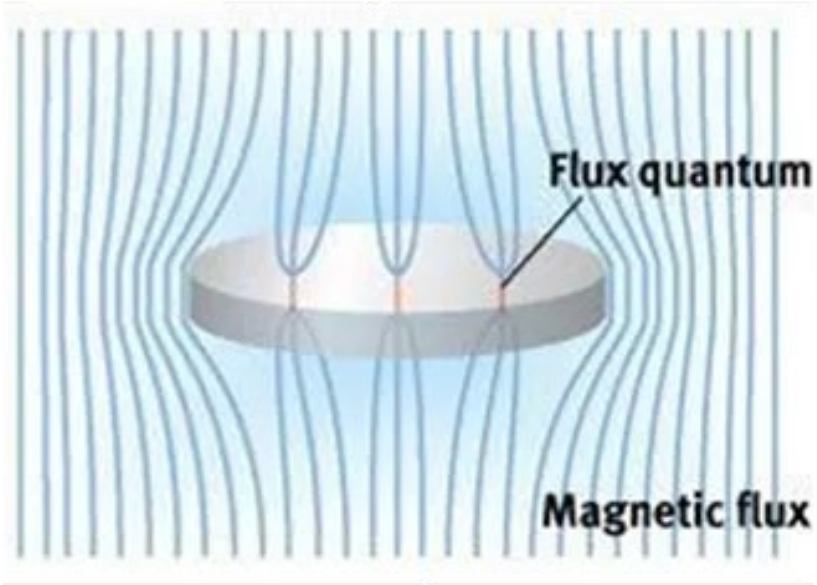
Q improvement

5,000 → 100,000

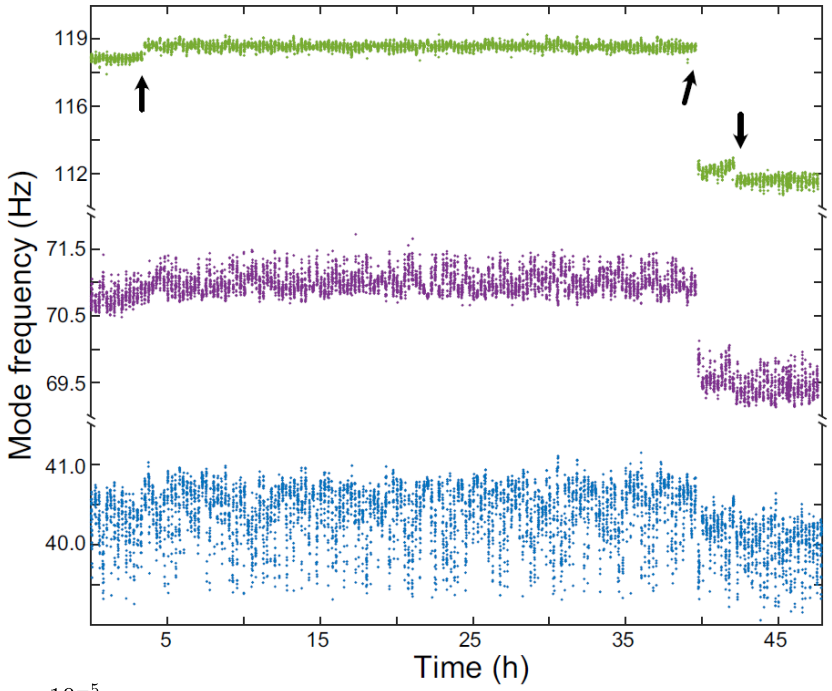
Dissipation

- Temperature ~50mK in a dilution refrigerator
- Eddy current damping – probably limiting in Gothenburg ($Q \sim 10^5$)
- Flux creep – probably limiting in Vienna ($Q = 3 \times 10^7$)

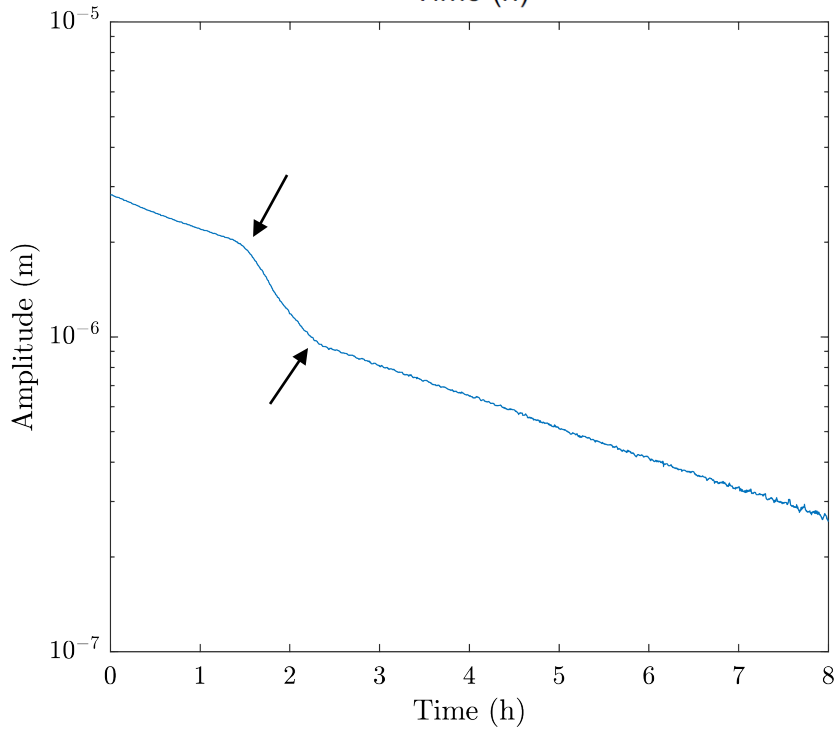




Dissipation caused by flux creep:
Brandt, Appl Phys Lett 53 1554 (1988)

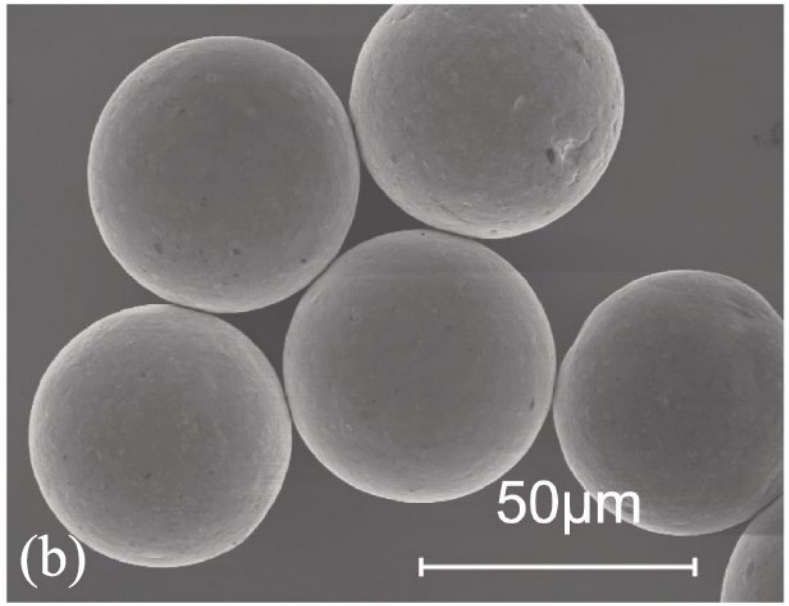


Gutierrez-Latorre et al.,
Phys Rev Applied
19 054047 (2023)

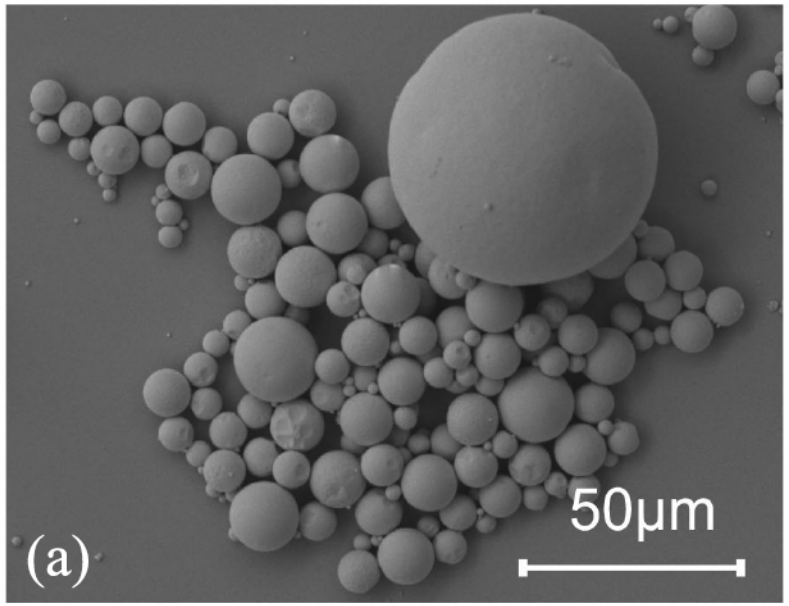


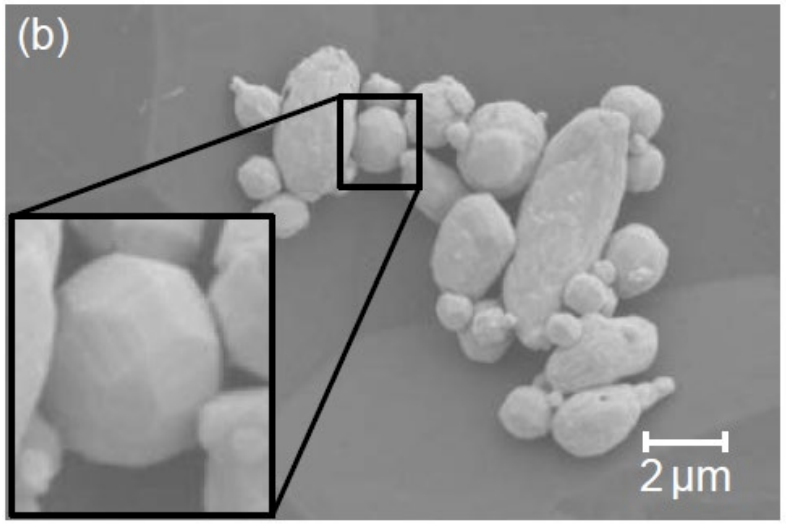
Hofer et al.,
Phys Rev Lett
131 043603 (2023)

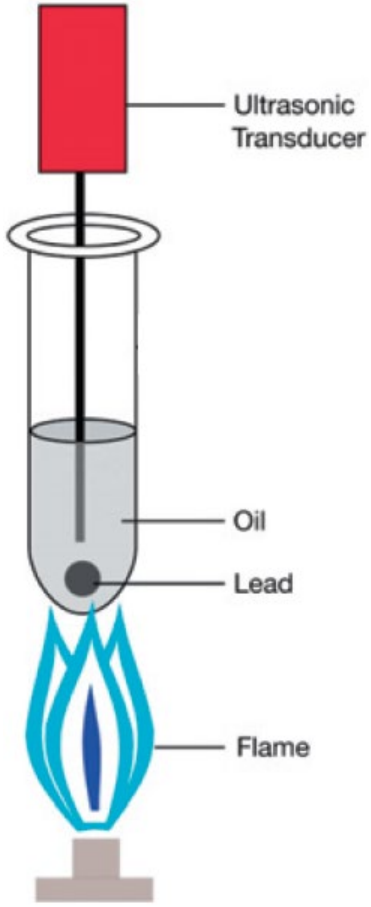
PbSn (solder)



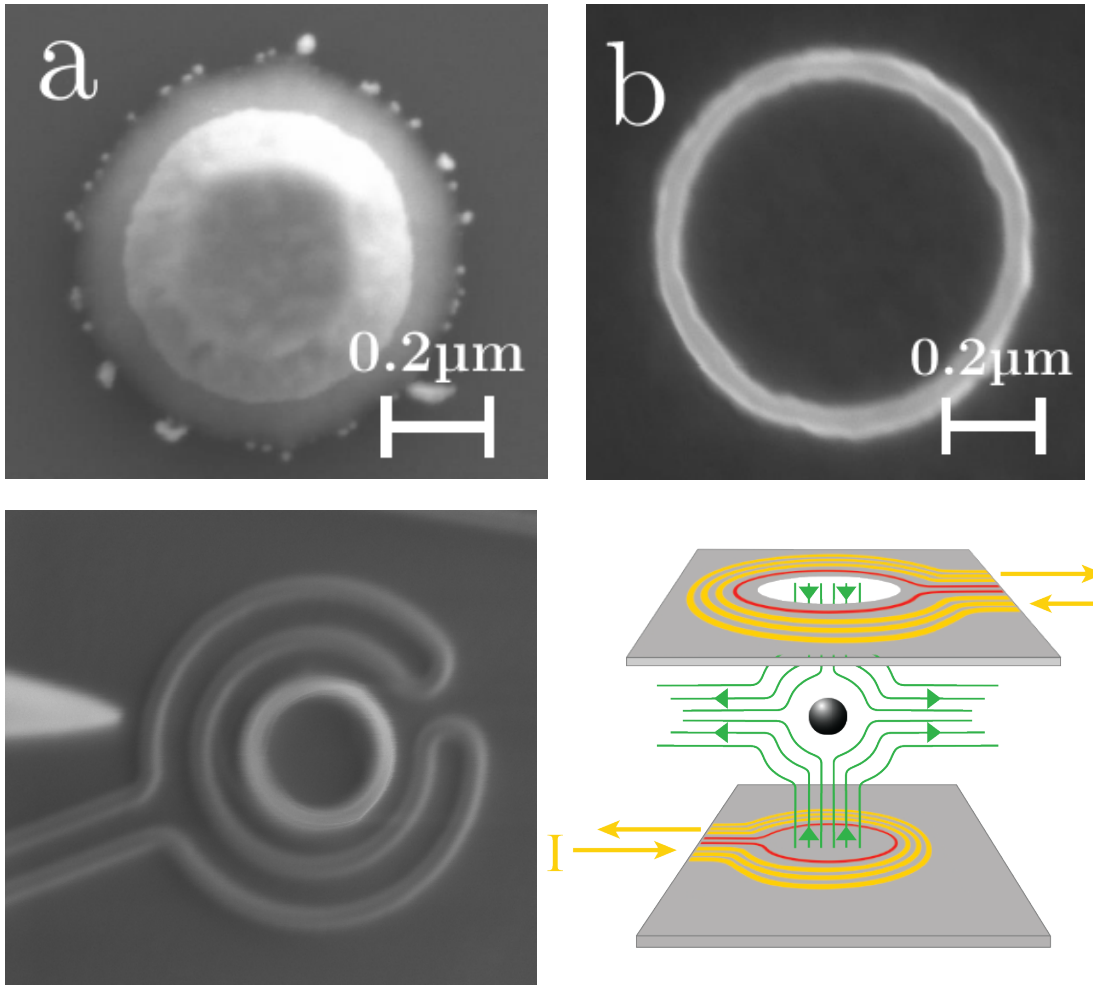
Pure Pb



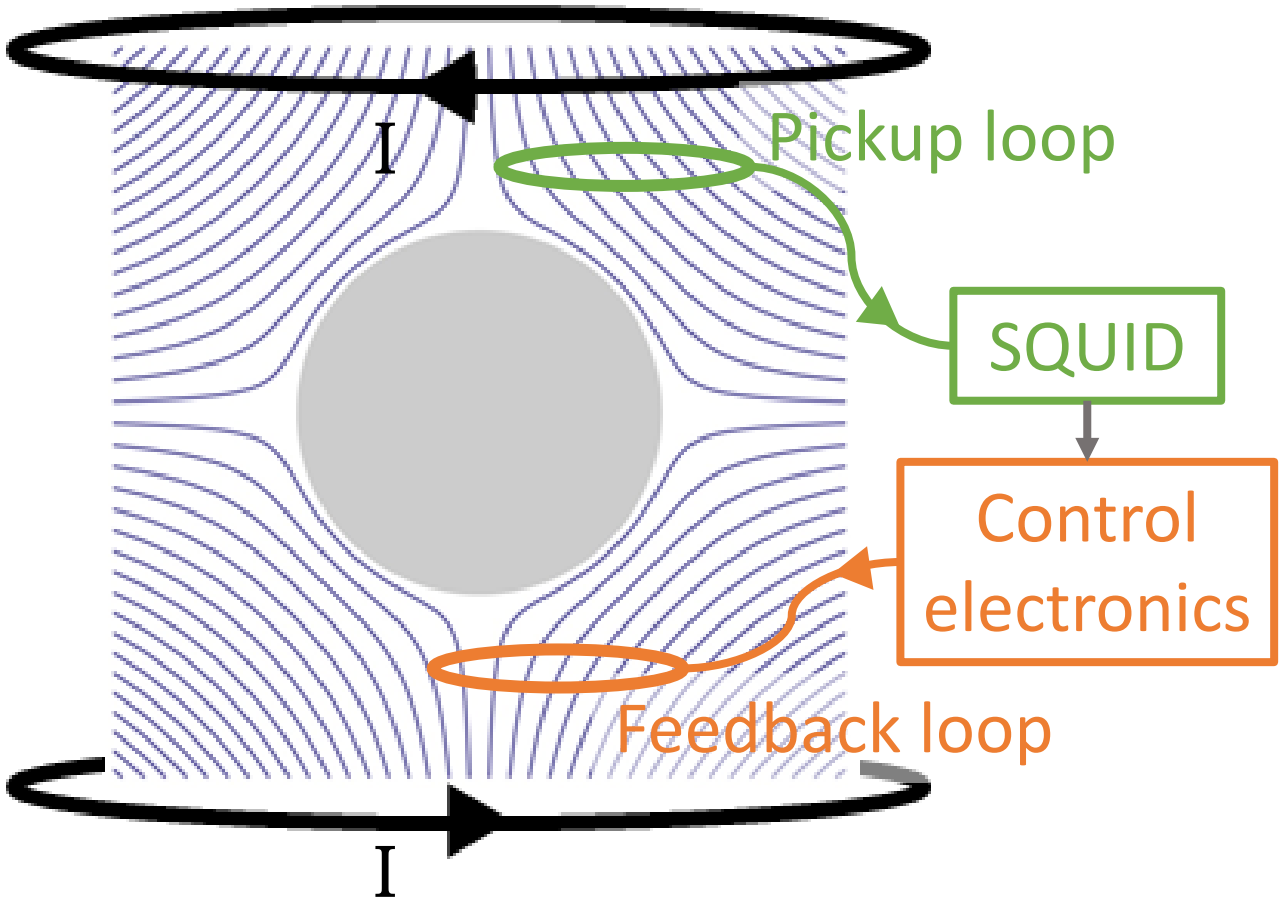


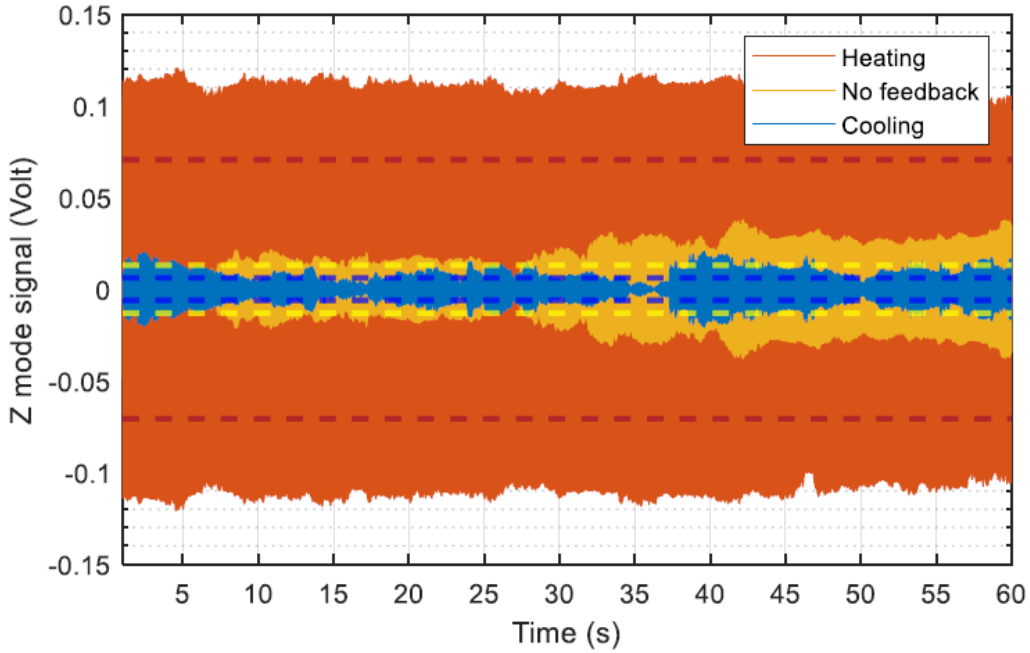


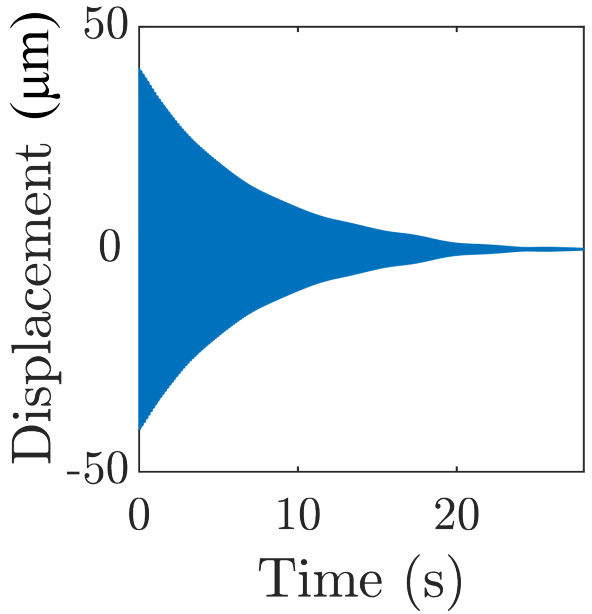
Ultrasonic cavitation
Friedman et al., J. Mater. Res. Technol. 25, 633 (2010)



Gutierrez Latorre et al., Supercond Sci Technol 33 105002 (2020)
Navau et al., Phys Rev B 103 174436 (2021)

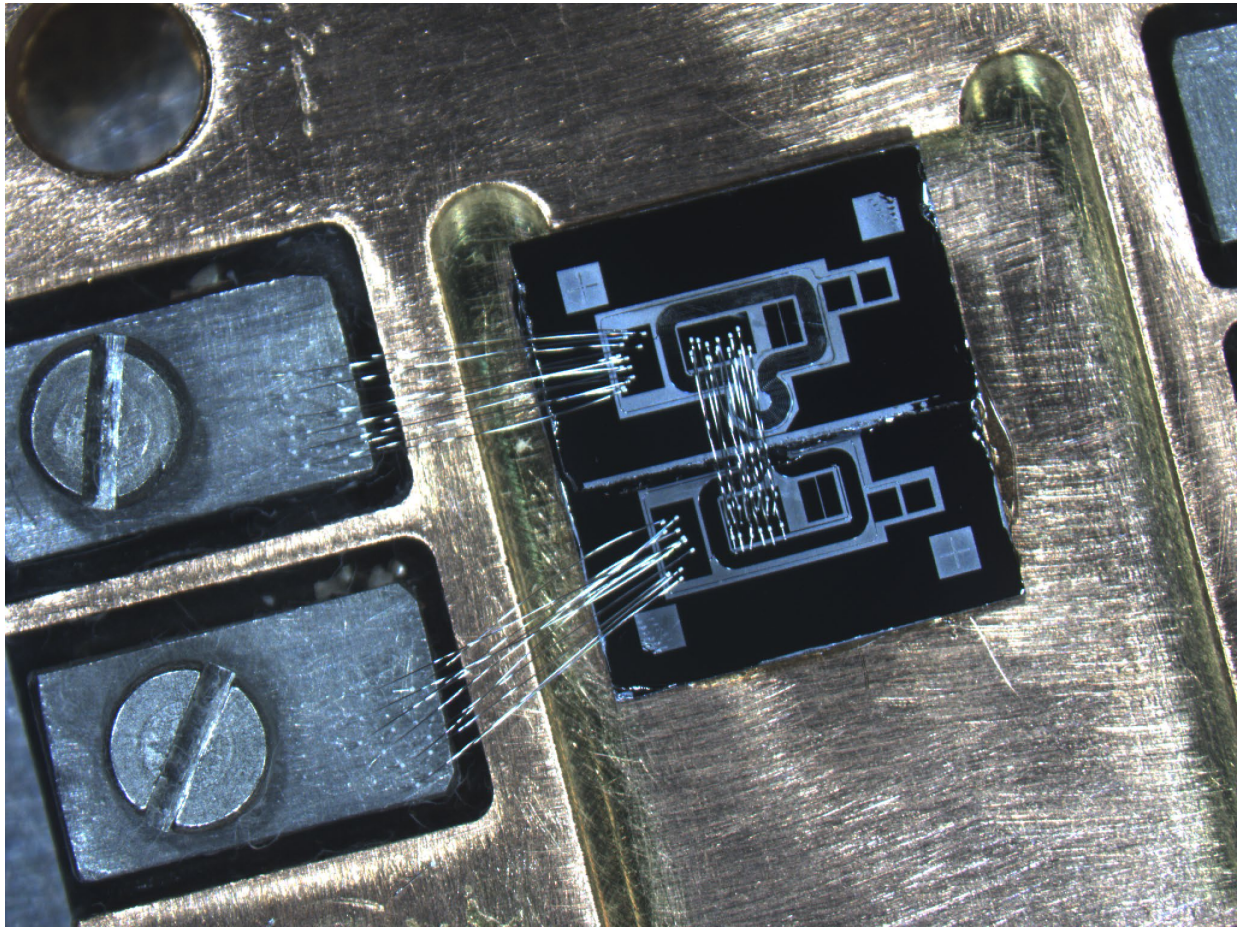






Hofer et al., Phys Rev Lett 131 043603 (2023)

Niobium wire bonds → Aluminium bonds

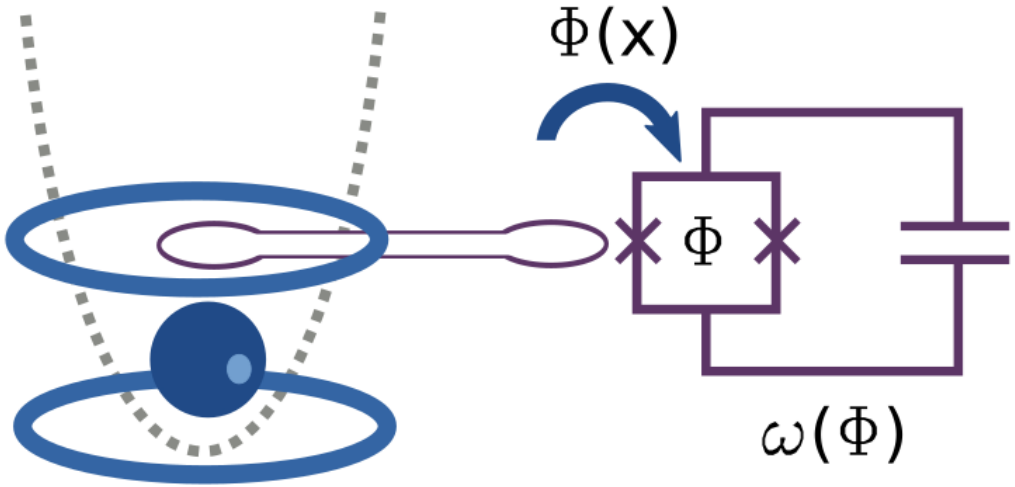


Next steps

- Improve vibration isolation
- Improve quality factor → Particle material
  → Magnetic shielding
- Increase signal → Pickup placement
  → Flux transfer efficiency
- Decrease noise → Magnetic shielding
  → Read-out using flux-tunable resonator

Levitated particle

Superconducting circuit



Resonator → read-out and cooling

Qubit → non-Gaussian states

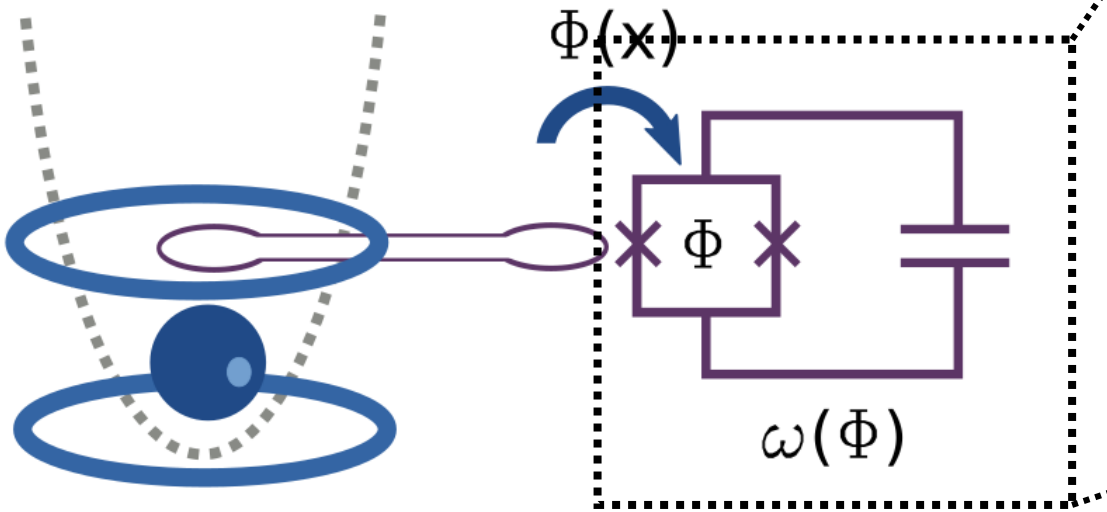
Cavity optomechanical control techniques!

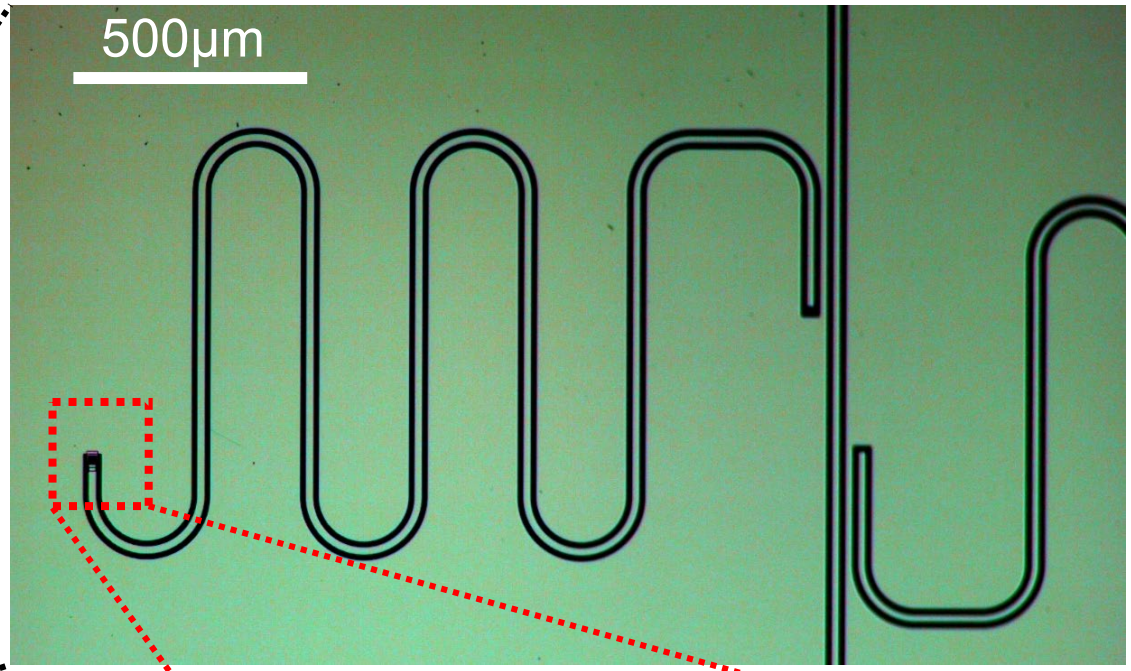
Zoepfl et al., Phys Rev Lett 125, 023601 (2020)

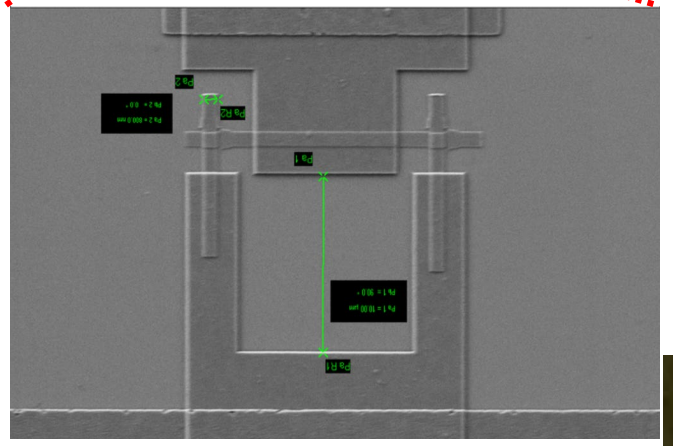
Schmidt et al., Commun Phys 3, 233 (2020)

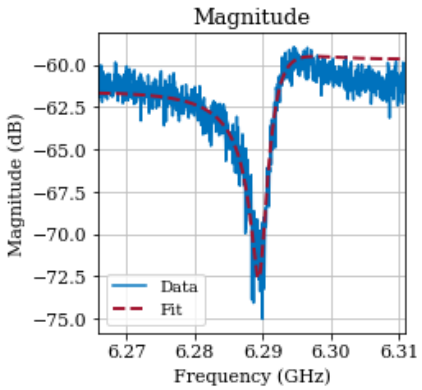
Levitated particle

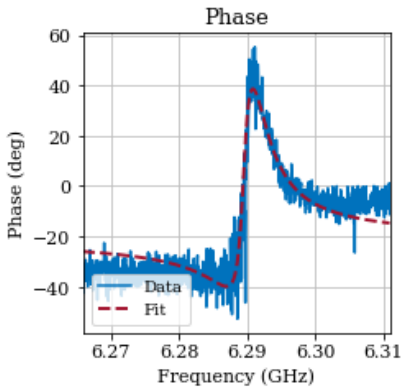
Superconducting circuit









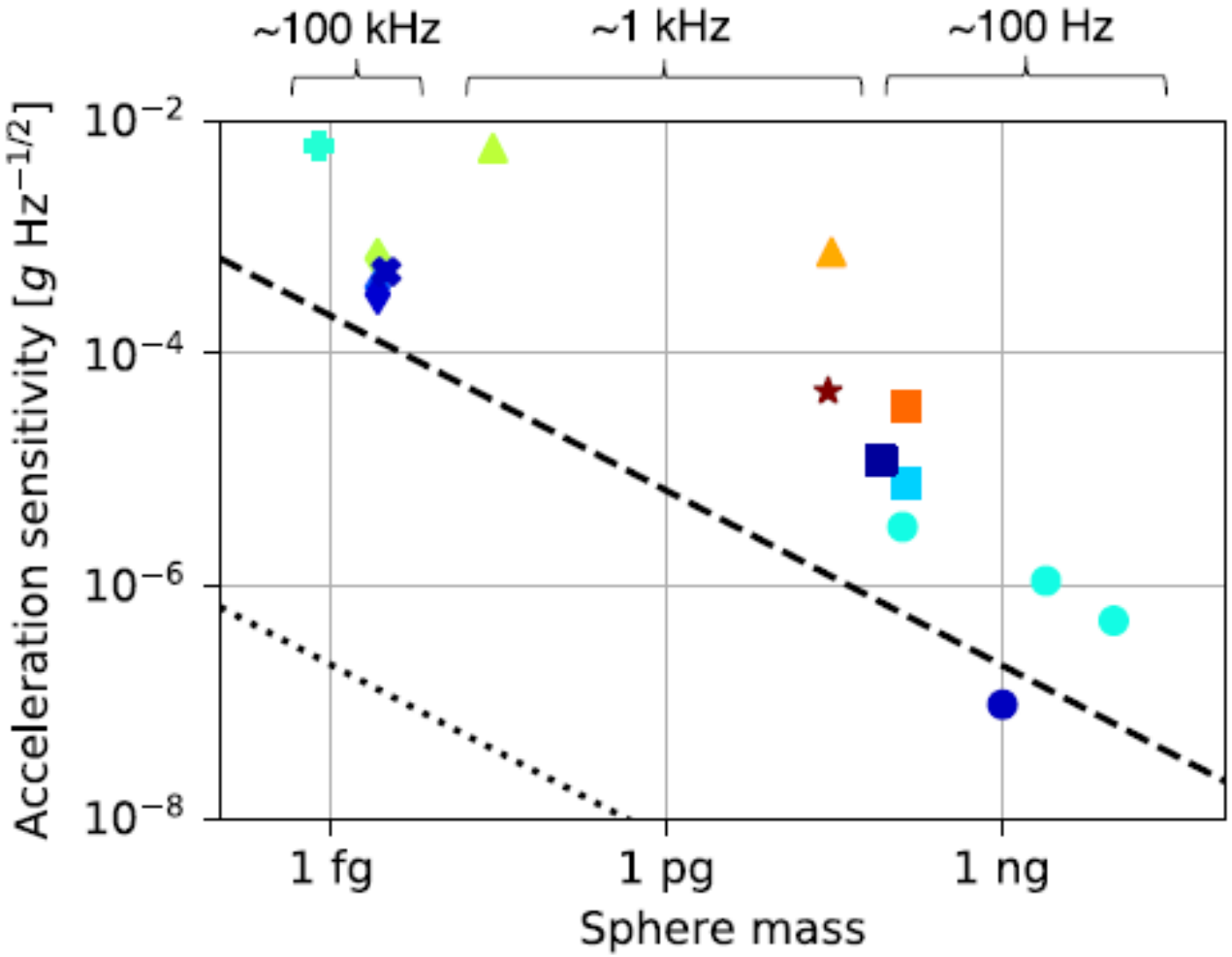


Zoepfl et al., Phys Rev Lett 125, 023601 (2020)

Schmidt et al., Commun Phys 3, 233 (2020)

see Rémi Claessen's poster

Acceleration sensitivity

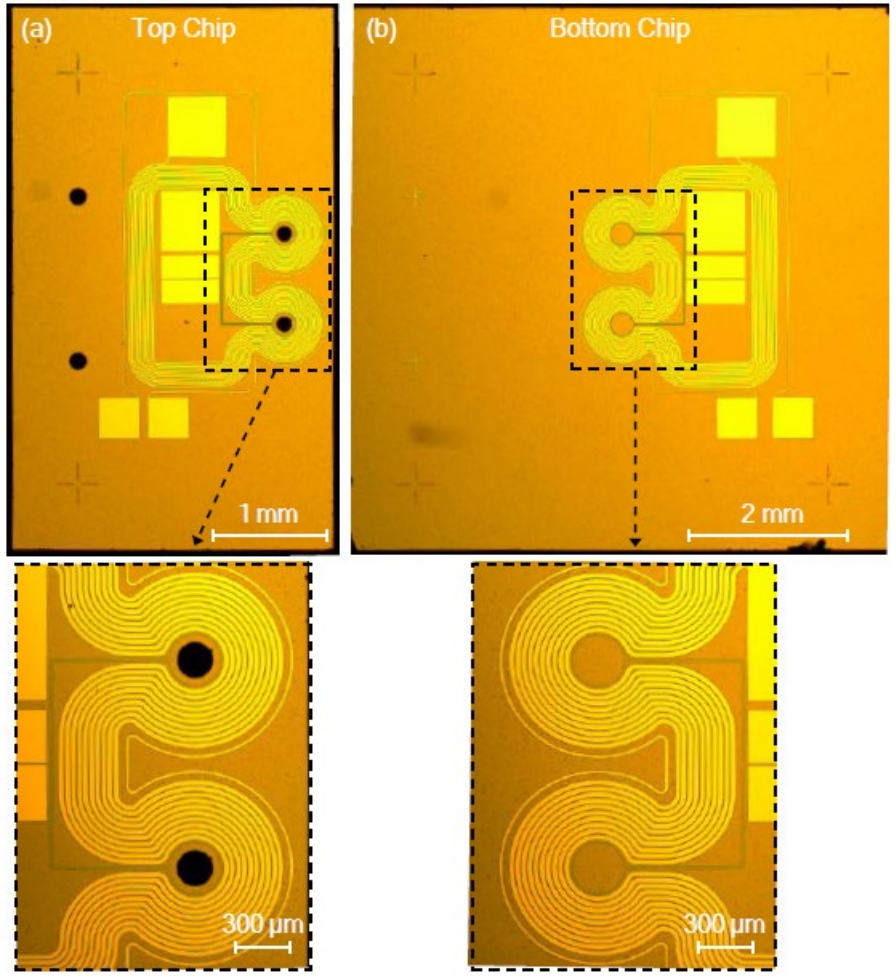


✖ 700ng, $10^{-8}\mathrm{g}/\sqrt{\mathrm{Hz}}$

✖ 5µg, $10^{-10}\mathrm{g}/\sqrt{\mathrm{Hz}}$

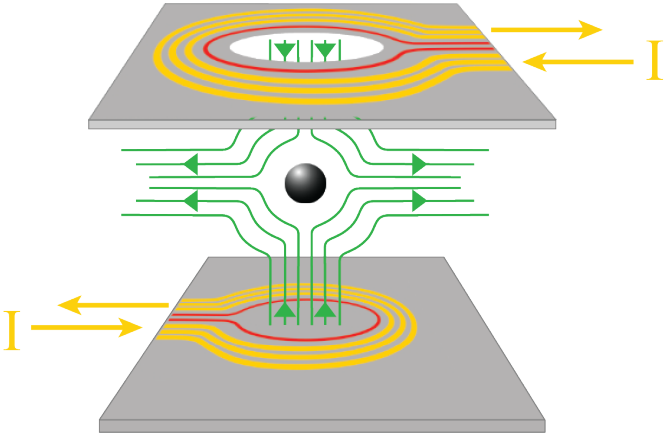
Moore et al., Searching for new physics using optically levitated sensors, Quantum Sci Technol (2021)

Two particles in adjacent traps



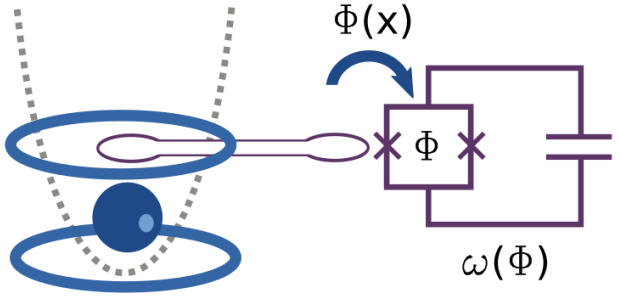
Summary

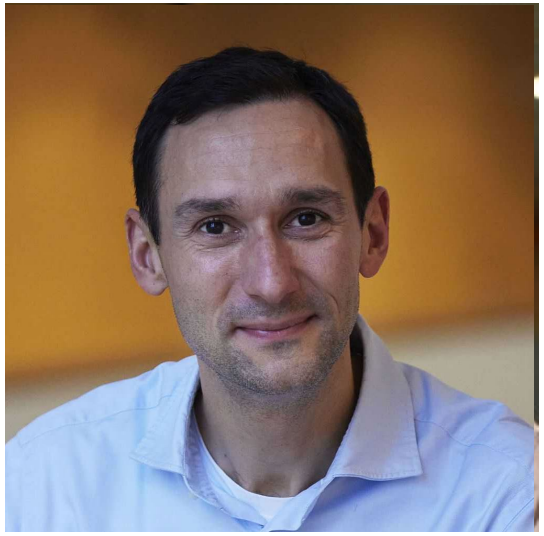
- Superconducting microparticles stably levitated in chip-based traps
- Integrated readout



Future

- Ground-state cooling
- Quantum state generation
- Entangle multiple particles on chip





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