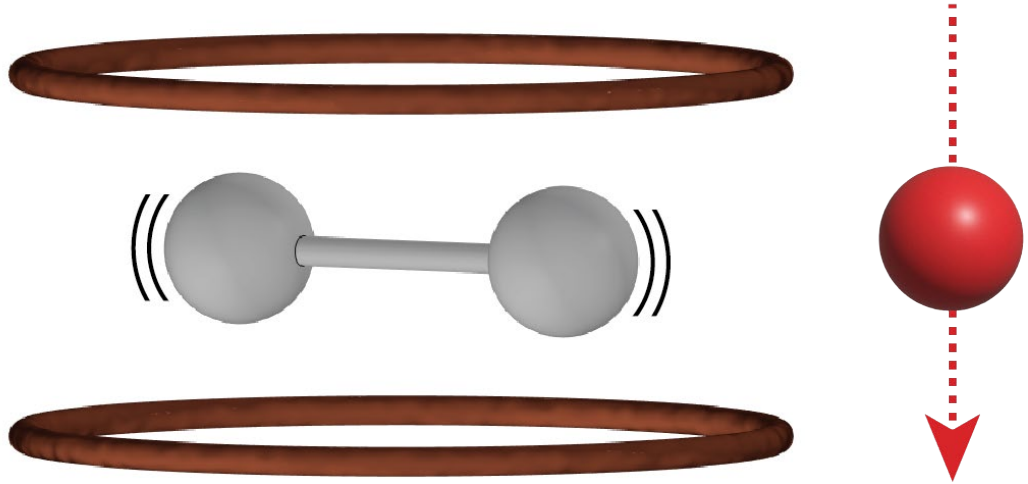
Gravitational search for dark matter using mechanical sensors



Gerard Higgins

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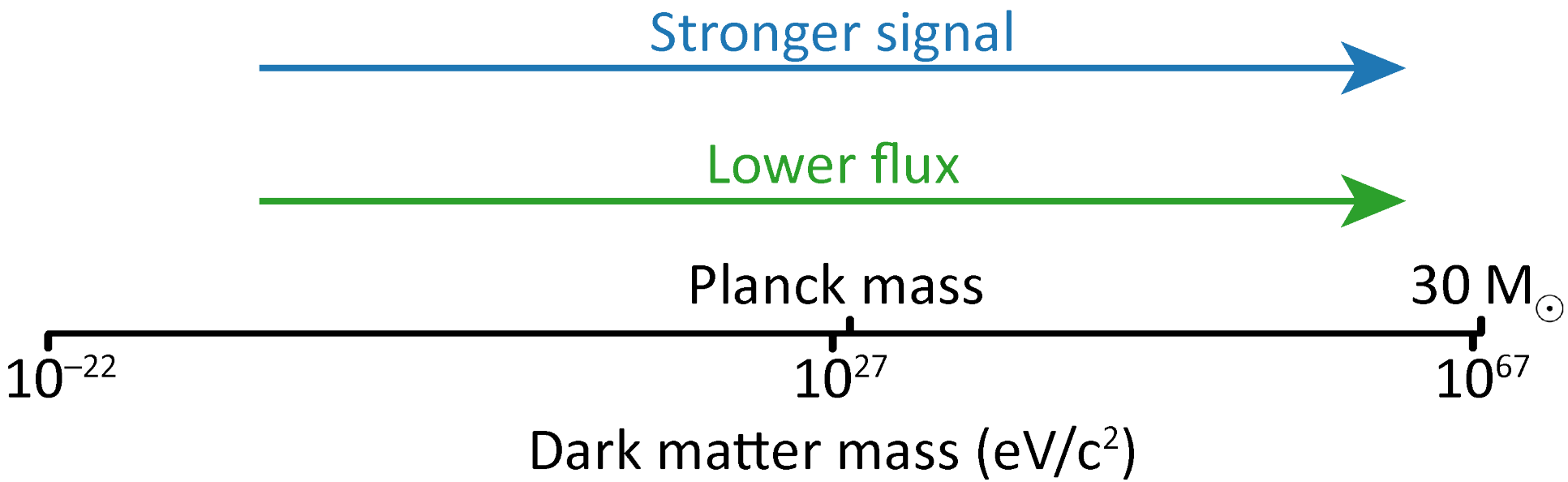
Vienna, Austria

YOUNGST@RS 18/11/2024

Can we hunt for dark matter via gravity in the lab?

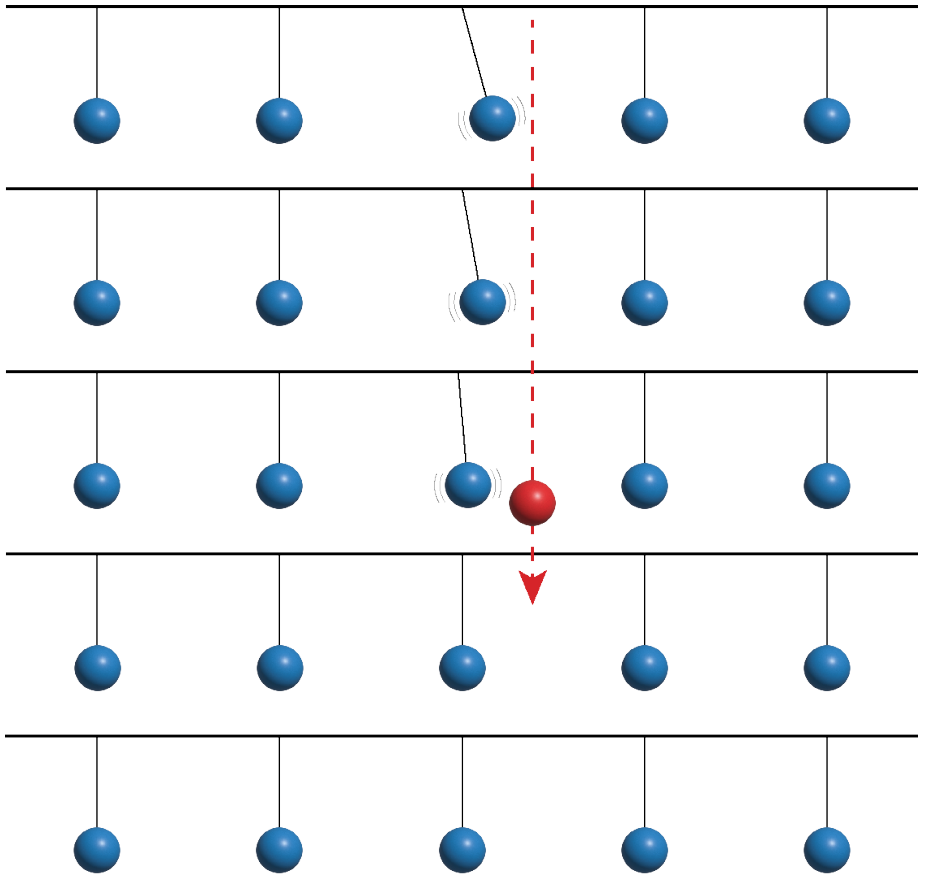


1 Planck-mass particle m^{-2} $year^{-1}$, Planck mass $= \sqrt{\hbar c/G} \cong 22\ \mu g$

D Carney et al., Proposal for gravitational direct detection of dark matter, Phys Rev D (2020)
The Windchime Collaboration, Snowmass 2021 White Paper: The Windchime Project, arXiv:2203.07242 (2022)

Windchime idea

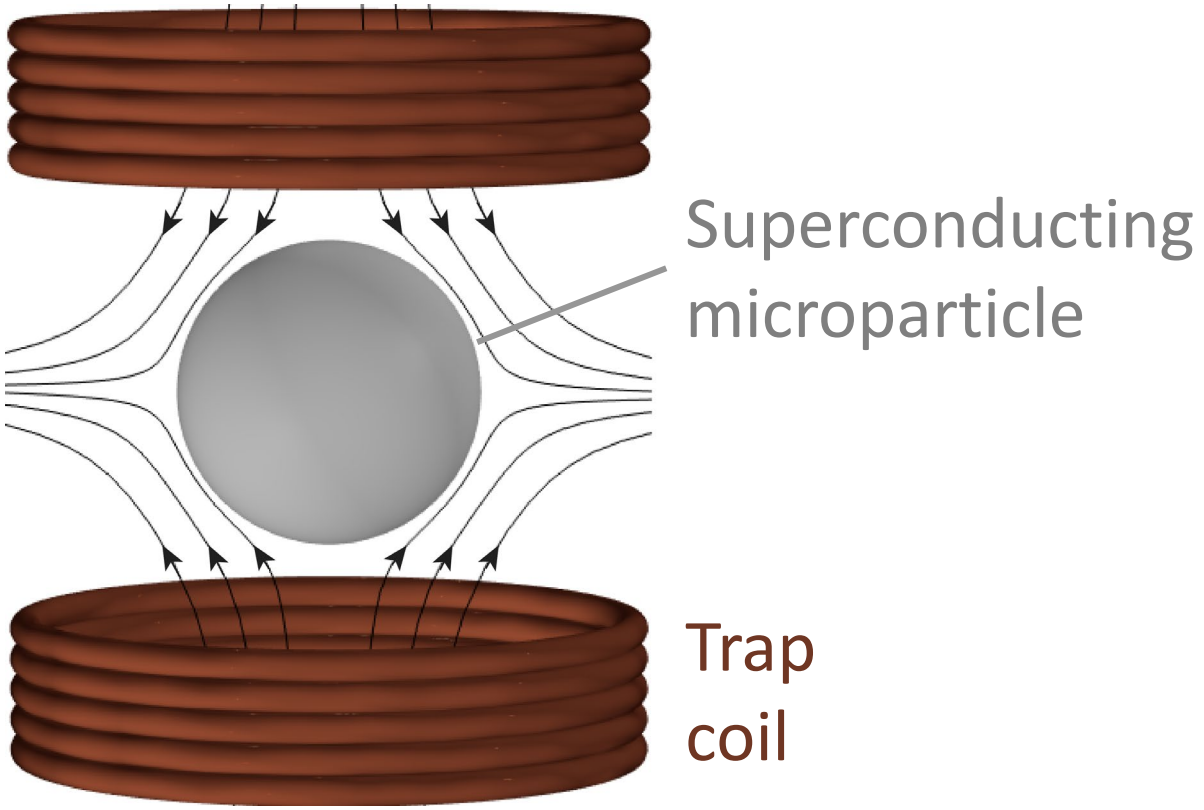
- Array of gram-scale mechanical sensors
- 3D meter-scale array
- Densely packed, spacing ~1 cm
- Highly isolated from surroundings
- Precise readout, 30-60 dB beyond SQL



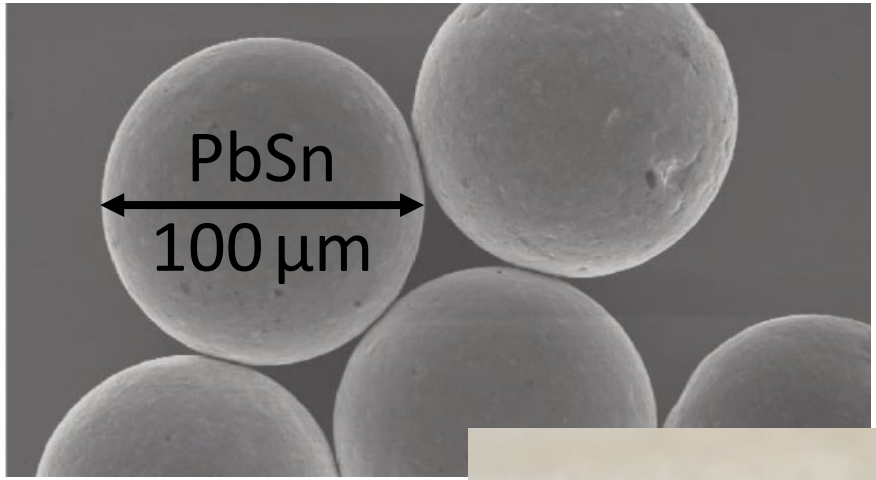
D Carney et al., Proposal for gravitational direct detection of dark matter, Phys Rev D (2020)
The Windchime Collaboration, Snowmass 2021 White Paper: The Windchime Project, arXiv:2203.07242 (2022)

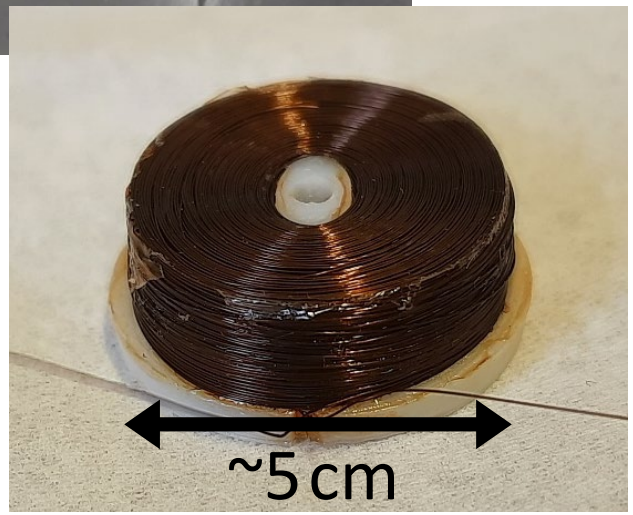
Magnetically-levitated superconductors

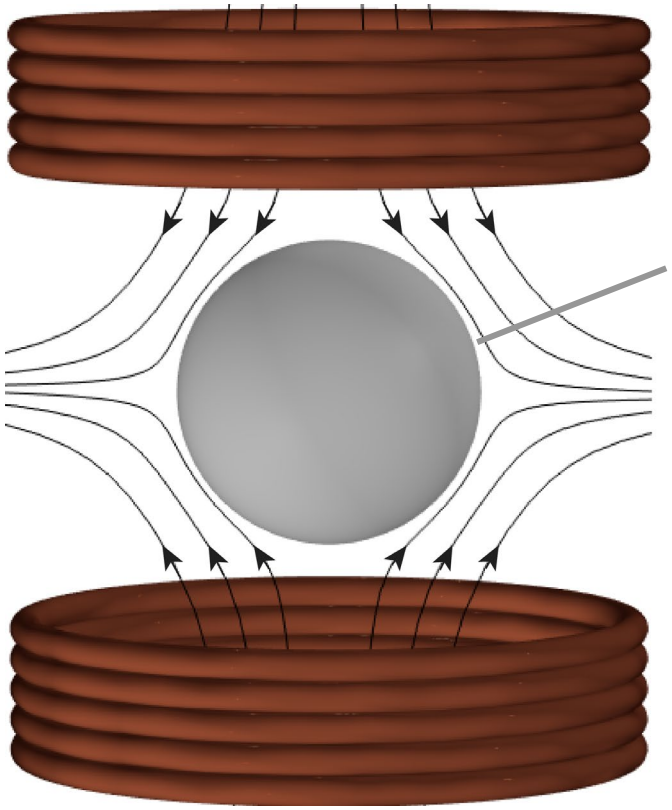
- Gravimeters
  J Goodkind, Rev Sci Instrum (1999)
- Gravity gradiometers
  CE Griggs et al, Phys Rev Applied (2017)
- Probe quantum physics using large masses
  O Romero-Isart et al, Phys Rev Lett (2012)



Trap microparticle in magnetic field minimum







Superconducting microparticle

Trap coil

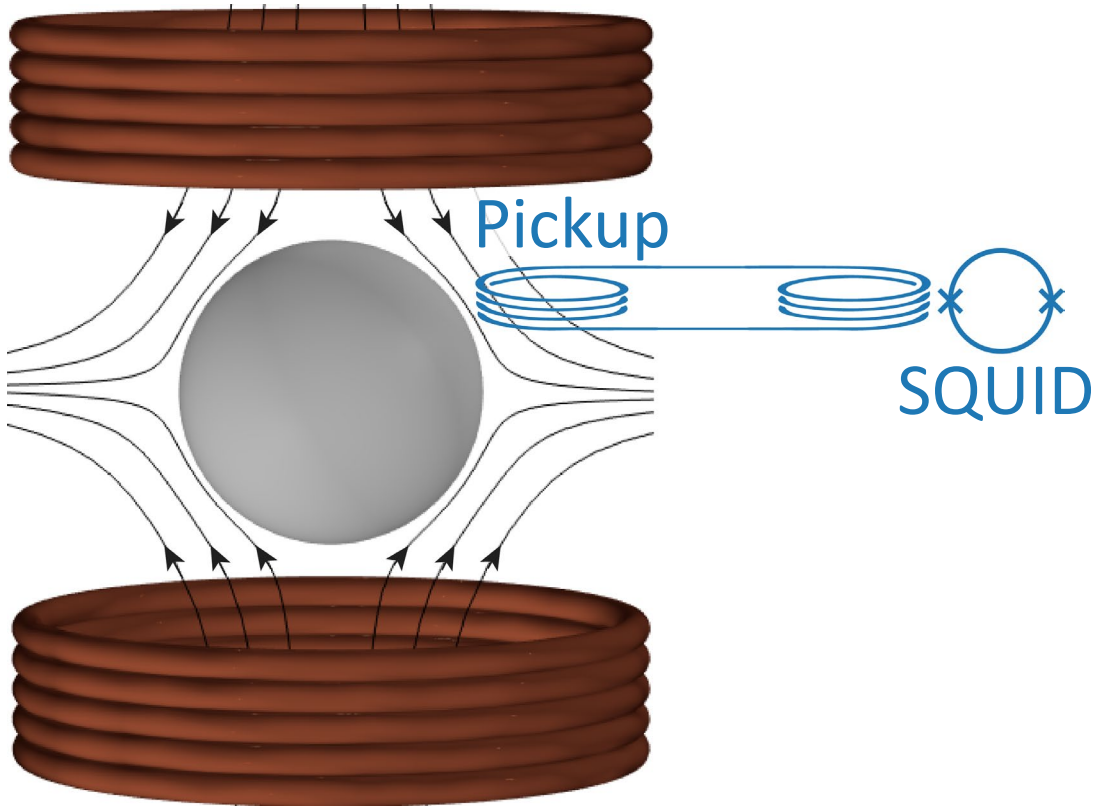
J Hofer, R Gross, G Higgins et al., Phys Rev Lett (2023)
P Schmidt, R Claessen, G Higgins et al., Phys Rev Appl (2024)

M Gutierrez Latorre, G Higgins et al., Phys Rev Appl (2023)
M Gutierrez Latorre, …, G Higgins, W Wieczorek, IEEE Trans Appl Supercond (2022)

Precise readout of superconductor motion

Precise readout using superconducting quantum circuits

→ Potential for sensing beyond SQL



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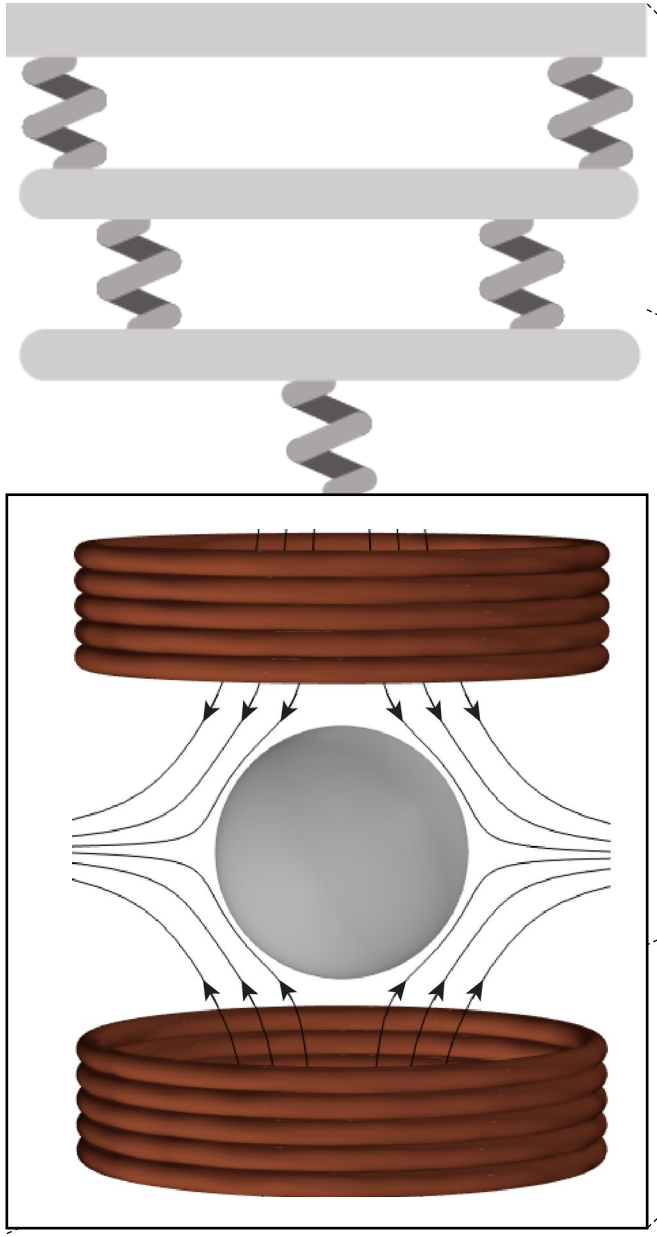
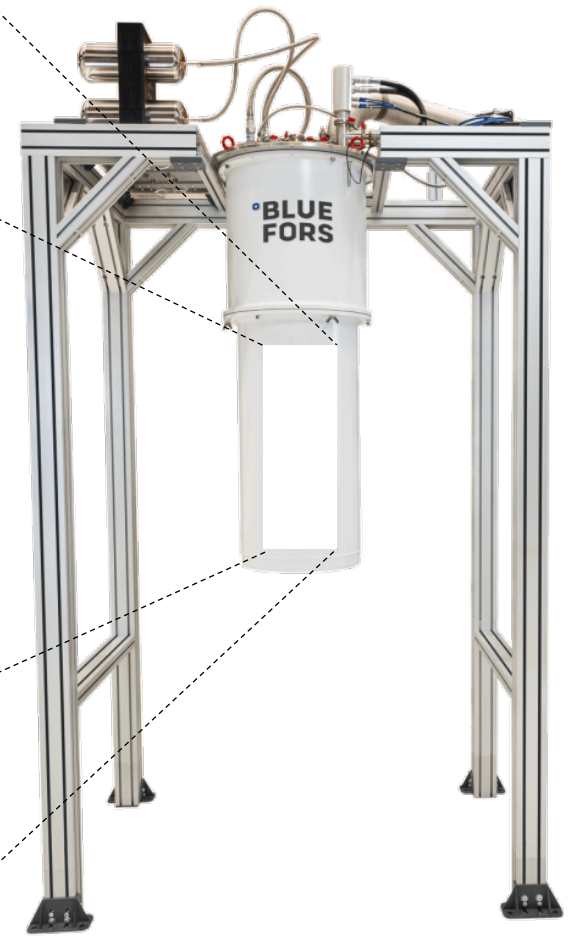
M Gutierrez Latorre, …, G Higgins, W Wieczorek, IEEE Trans Appl Supercond (2022)

Ultralow noise

- Levitation
- Ultrahigh vacuum
- mK temperatures
- Magnetic shielding
- Vibration isolation





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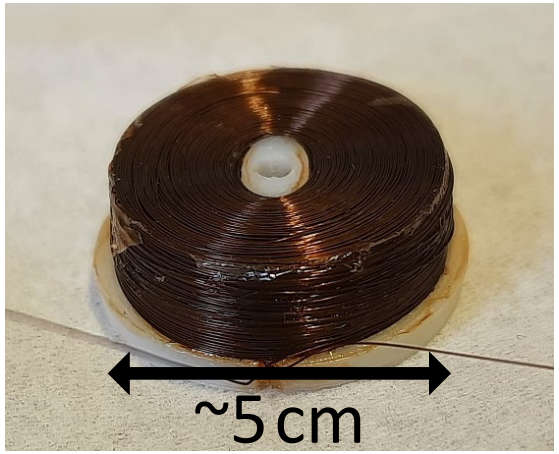
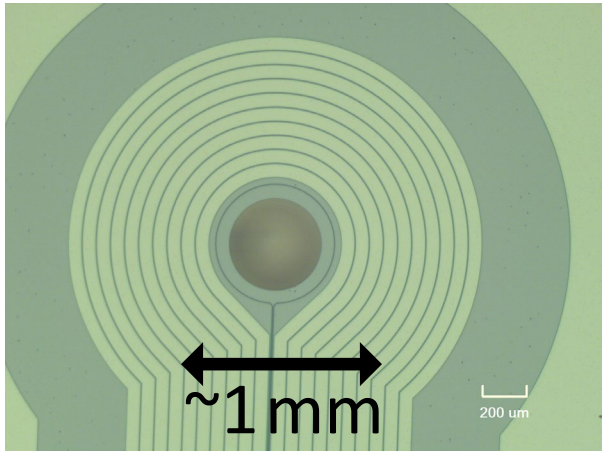
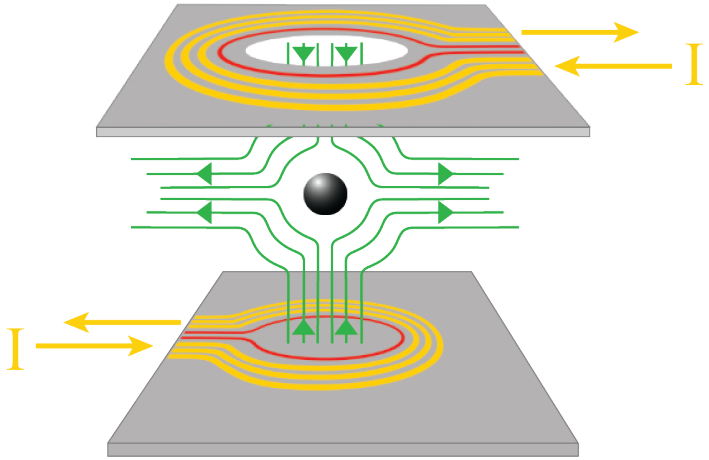
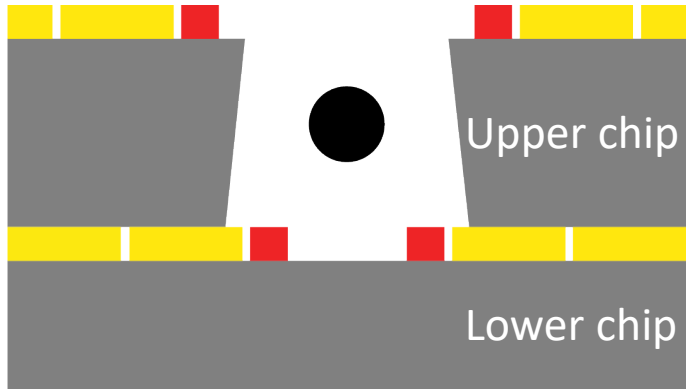
Miniaturization









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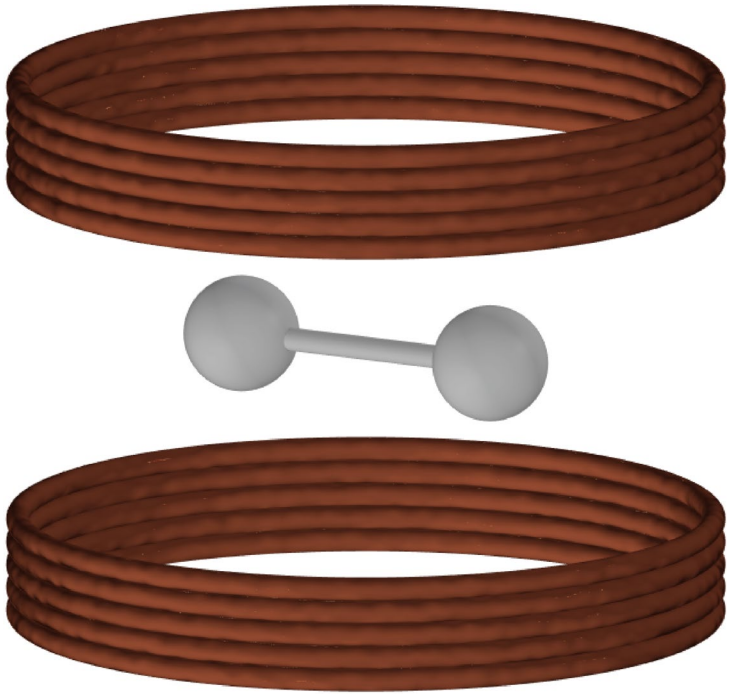
Levitated superconductors enable unprecedented sensitivities

Trap gram-scale superconductors

- Dumbbells & hollow spheres



Precise readout

- Close to standard quantum limit

Ultralow noise

- Reduce thermal coupling by 10^3
- Mitigate vibrational noise

Levitated superconductors enable unprecedented sensitivities

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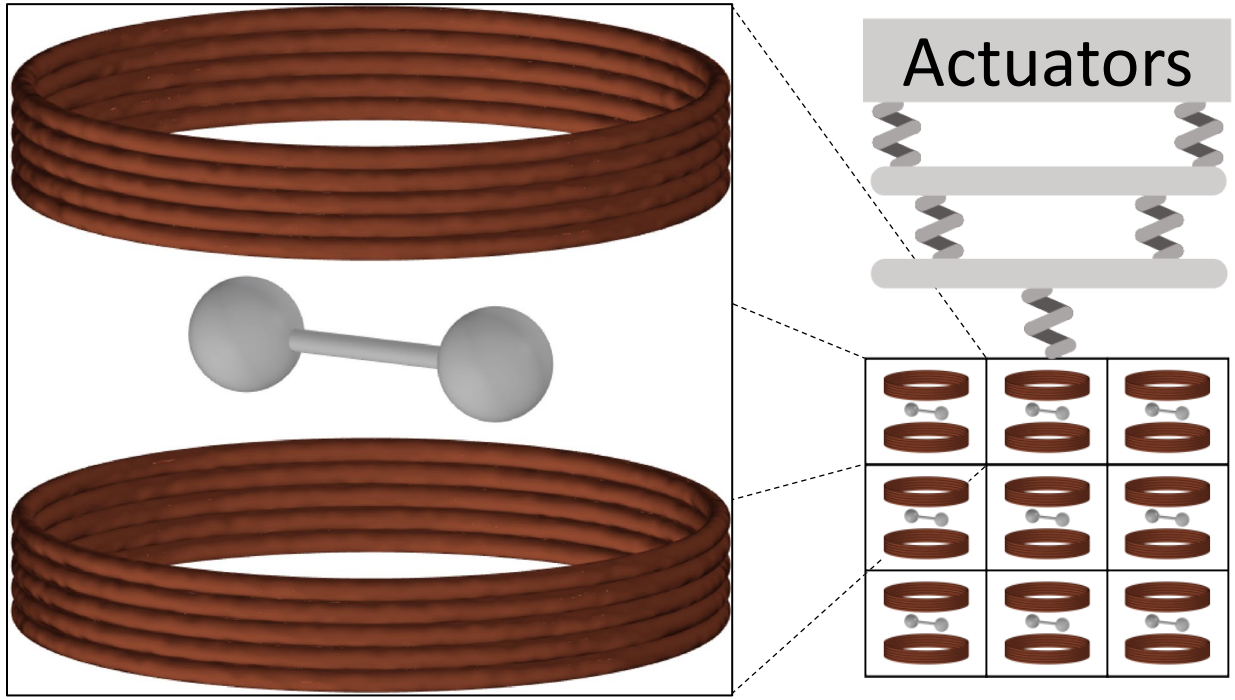
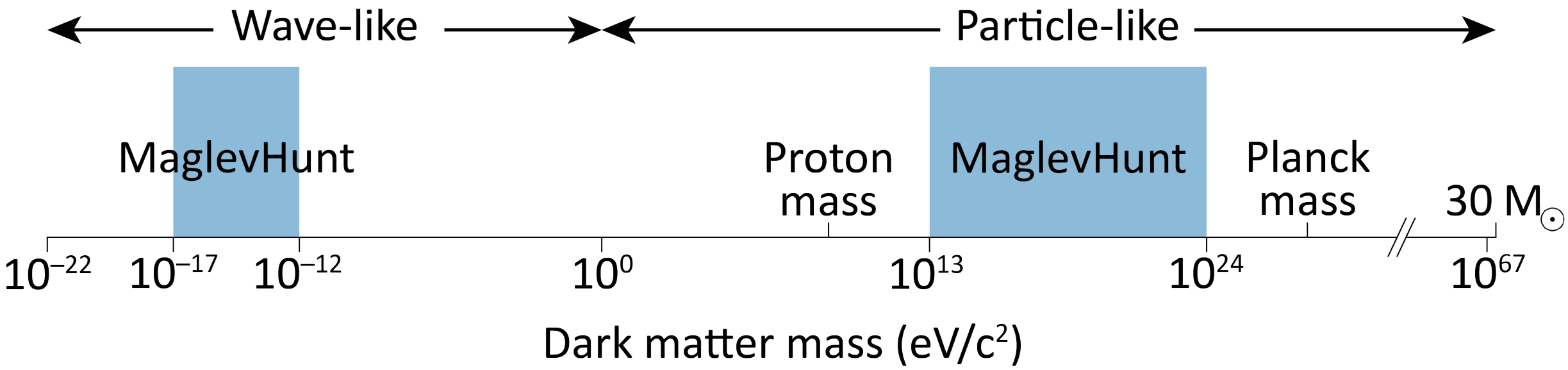
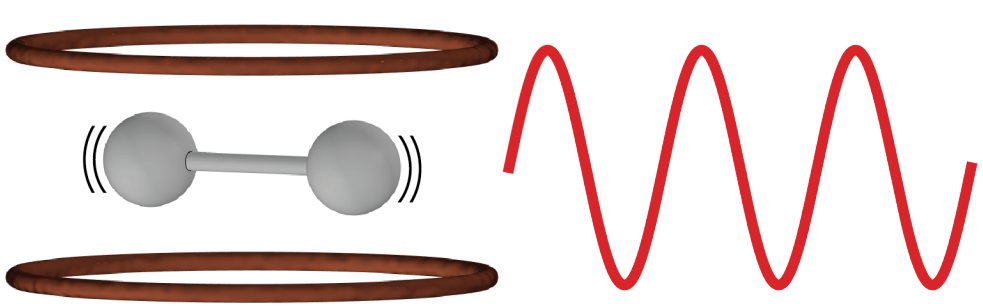
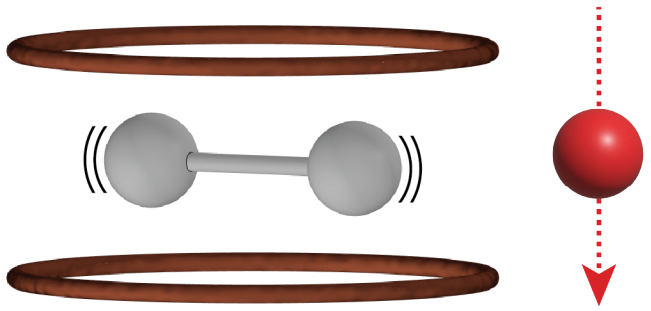


Hunt for dark matter using levitated superconductors

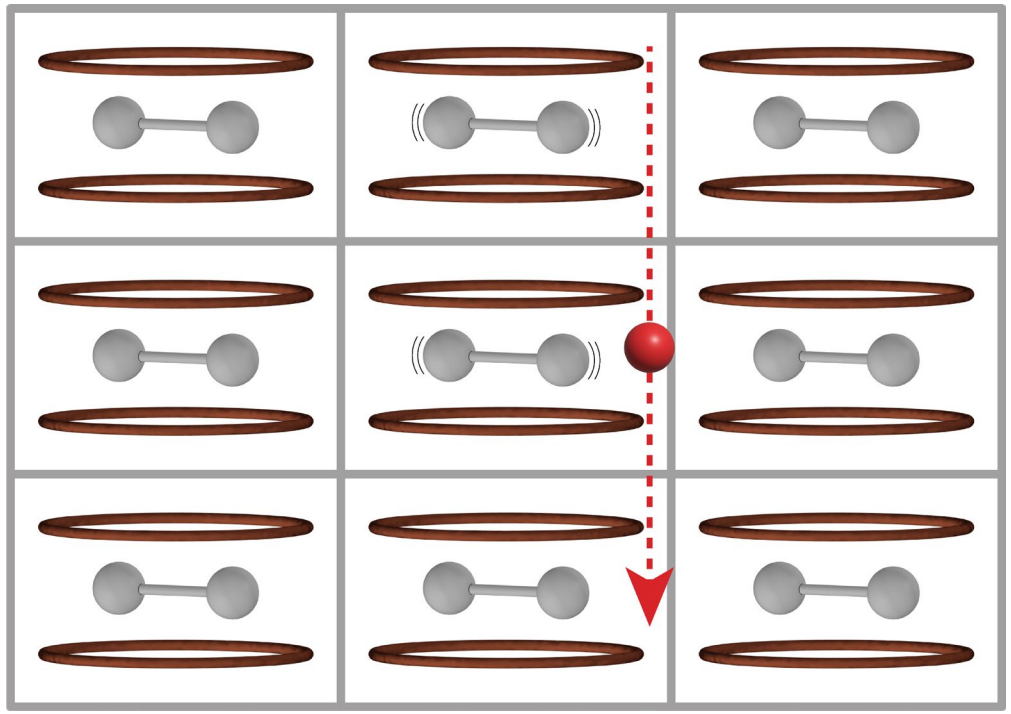






Outlook

- Develop leading mechanical sensors
- Hunt for dark matter
- Lay groundwork for gravity-based search



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