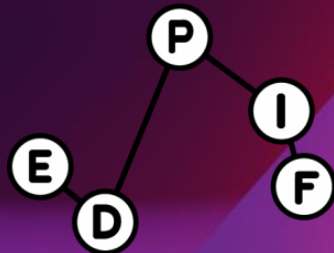


Optomechanics for nanoparticle mass sensing

Louis Waquier

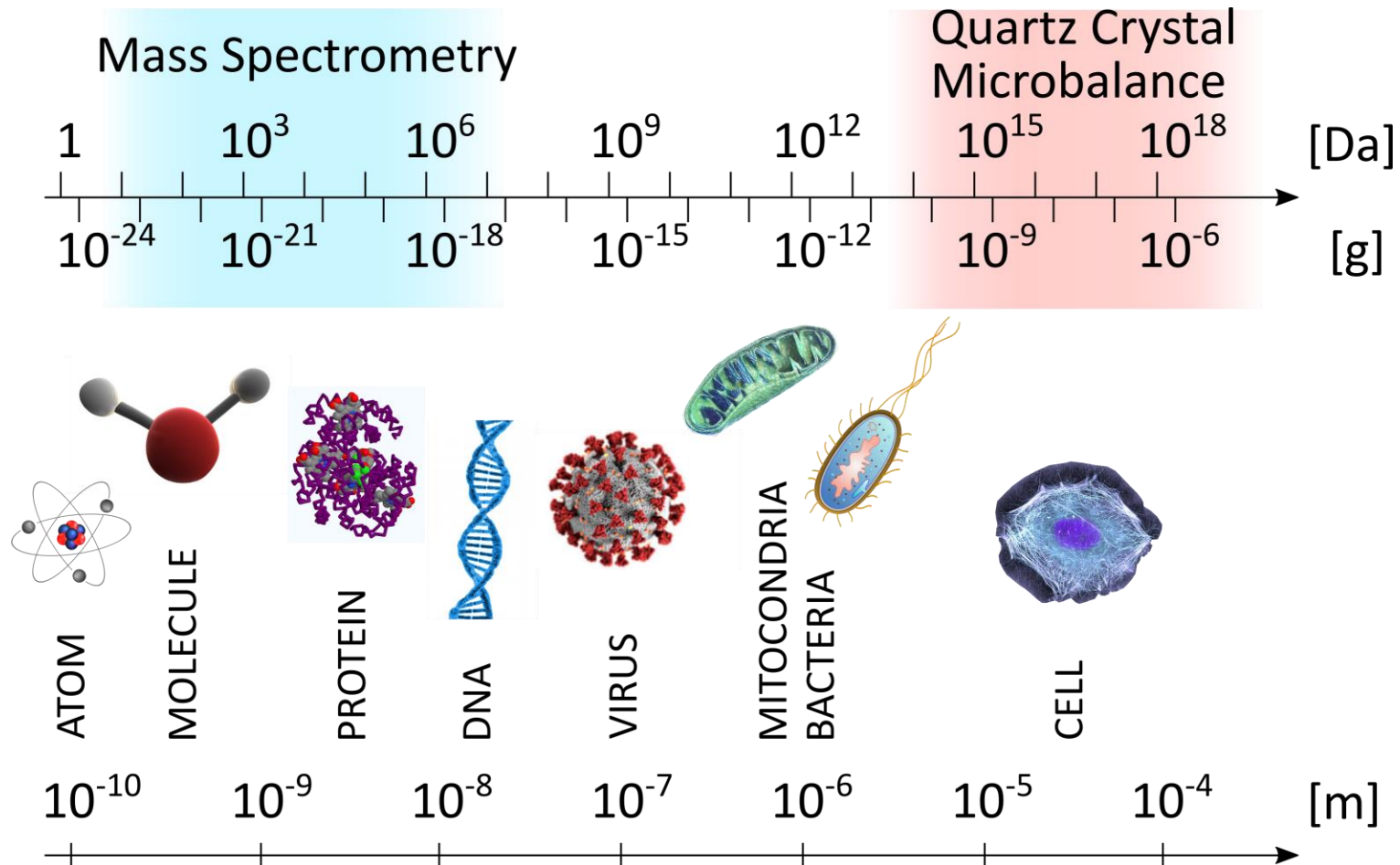
Laboratoire Matériaux et
Phénomènes Quantiques MPQ



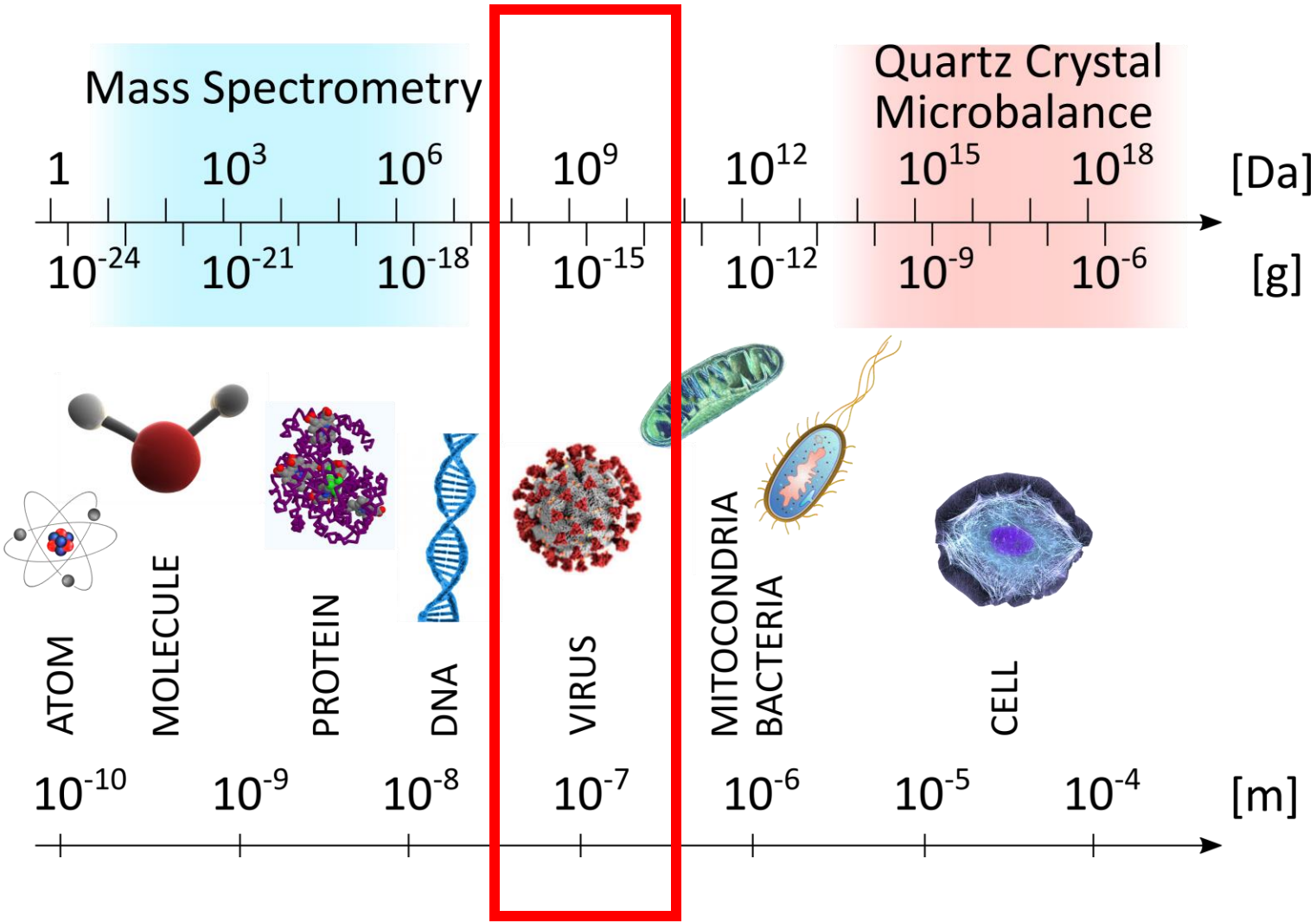
Université
Paris Cité



Weighing biological objects

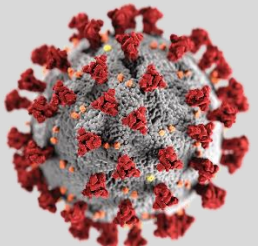


Mass & Elasticity = Virus fingerprint



ID Card

Sars-COV-2



Diameter 100 nm
 Mass 0.5 fg
 Stiffness ~ 1 GPa

Target sensitivity down to 30 attograms !



Target sensitivity down to 30 attograms !



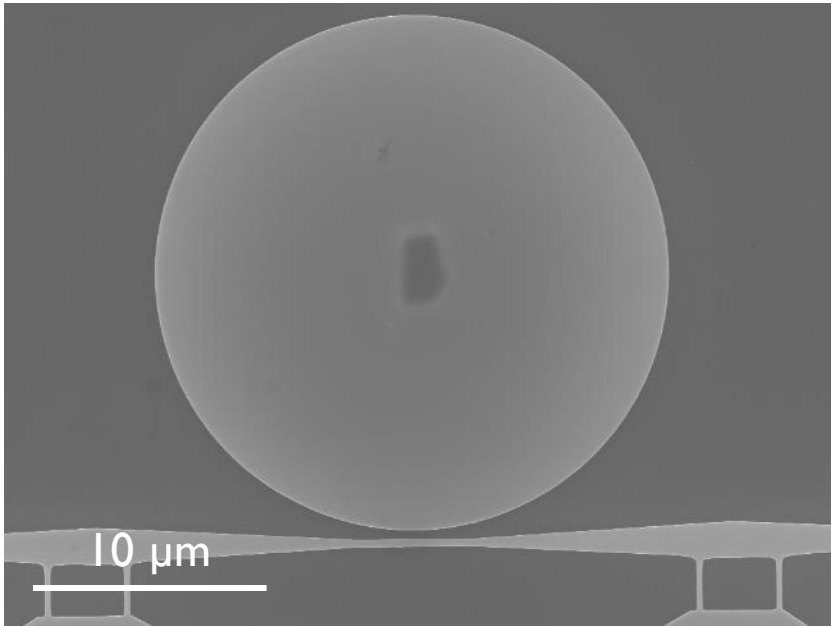
Target sensitivity down to 30 attograms !



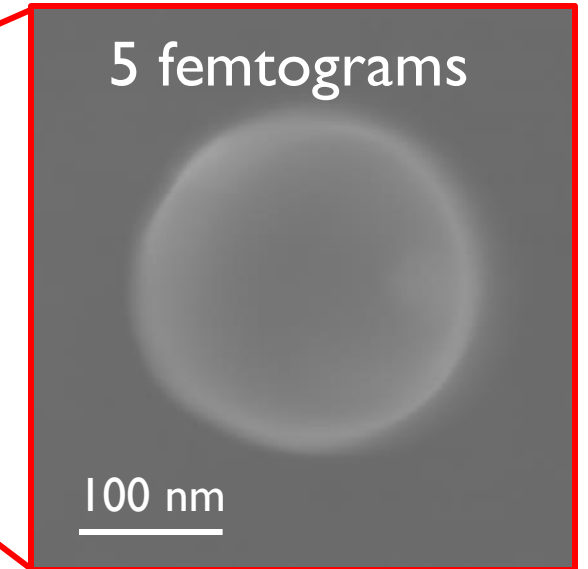
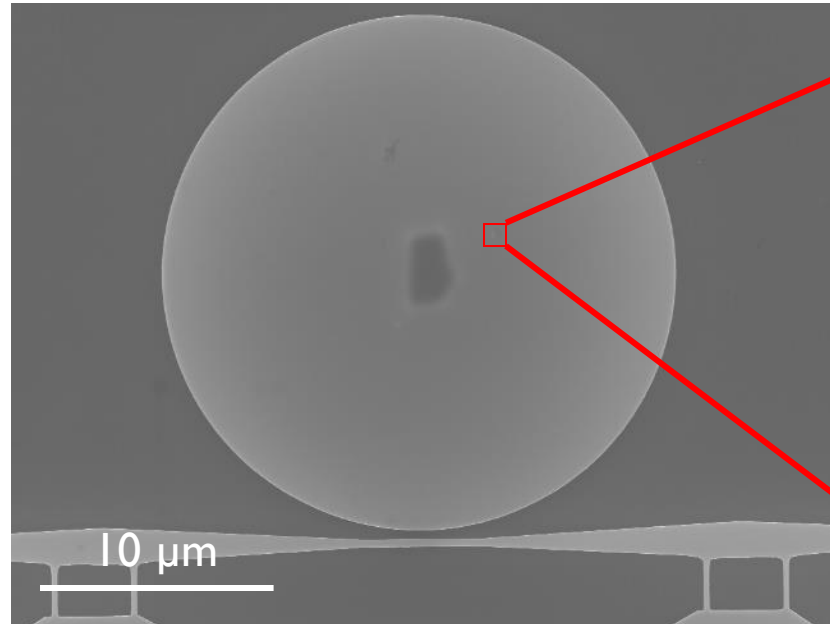
Target sensitivity down to 30 attograms !



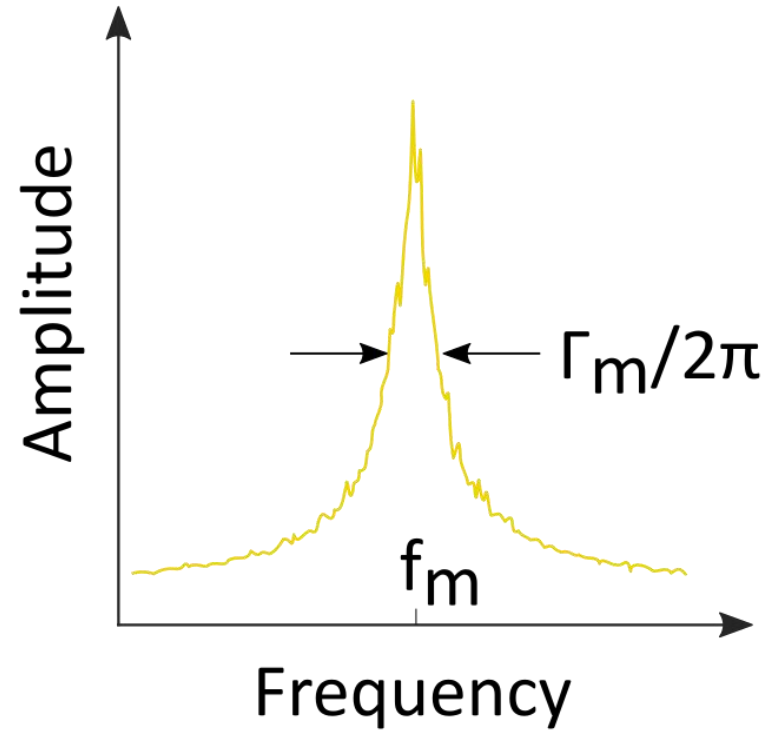
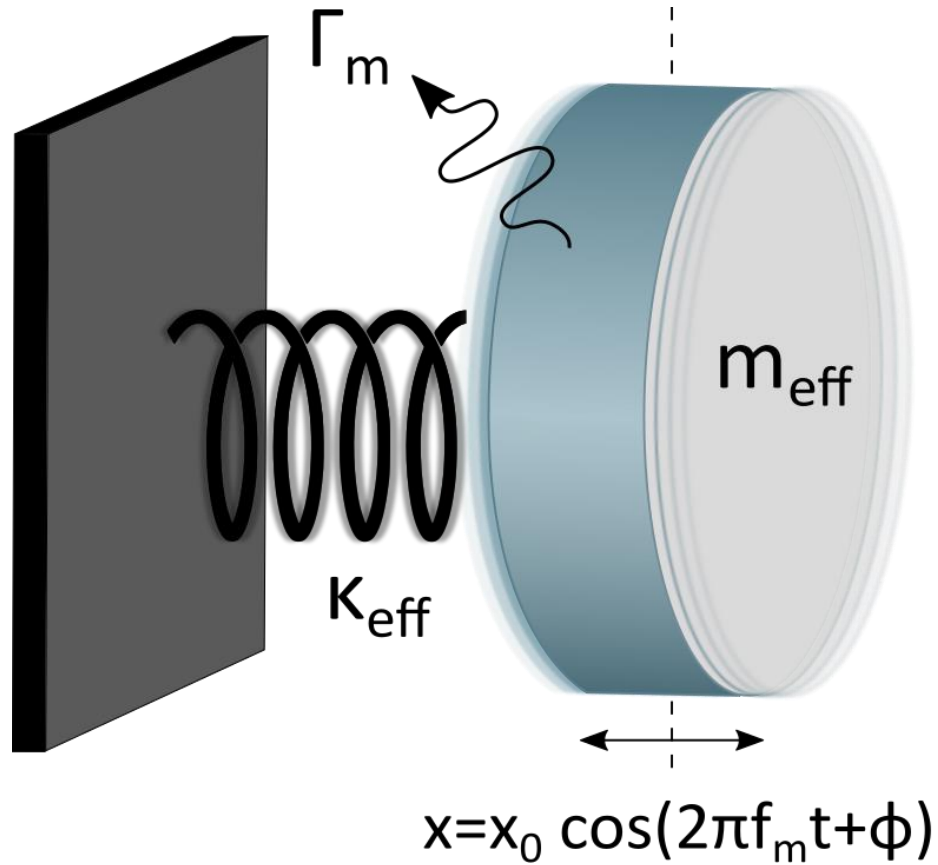
Target sensitivity down to 30 attograms !



Target sensitivity down to 30 attograms !

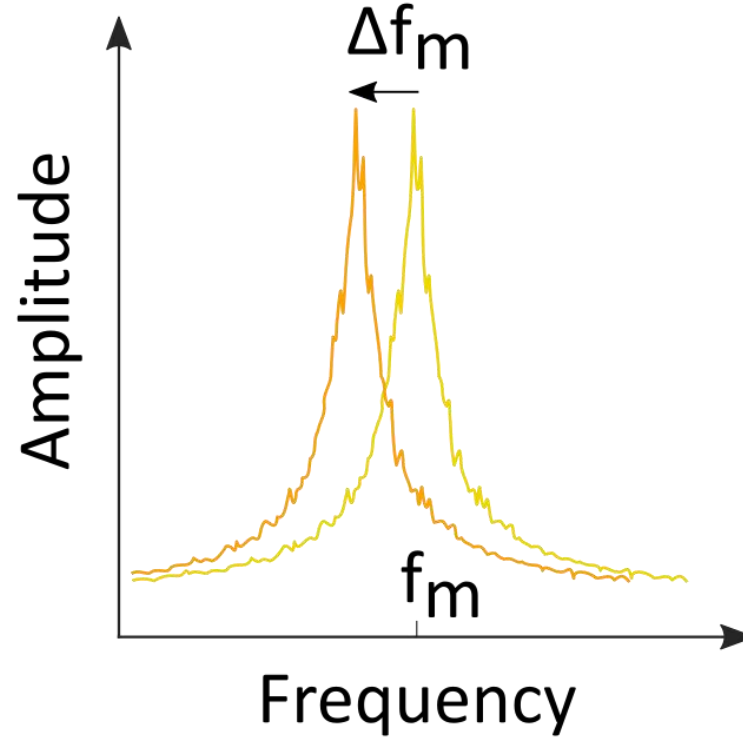
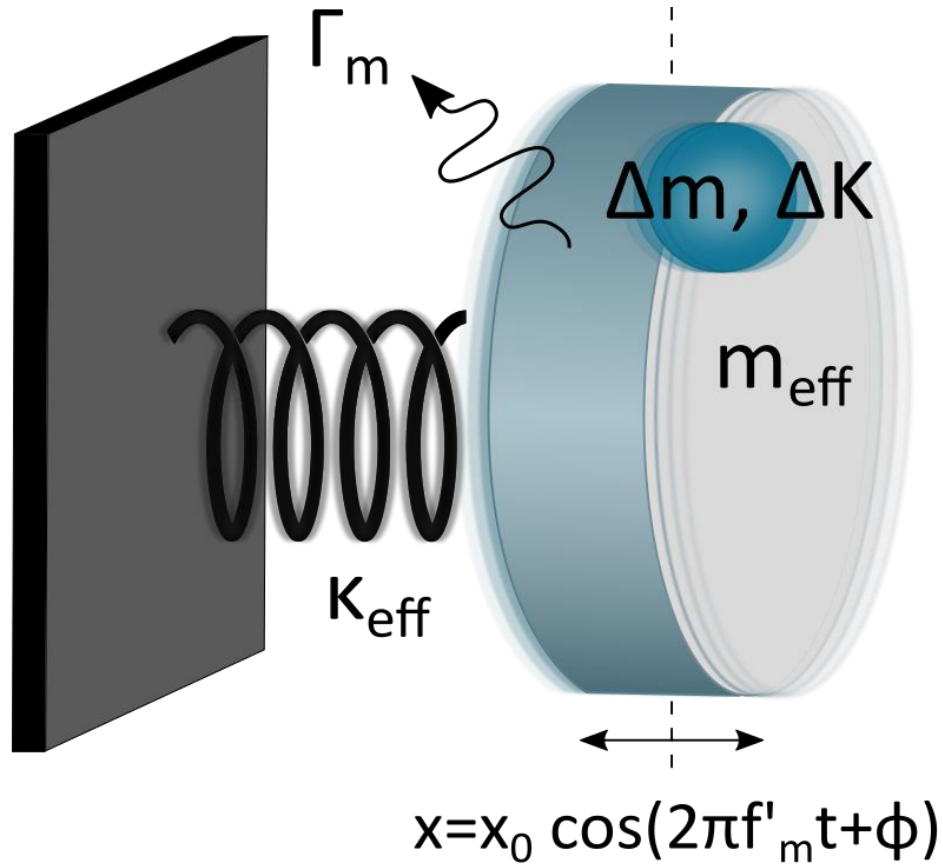


A mechanical resonator is a mass sensor



$$f_m = \sqrt{\frac{K_{eff}}{m_{eff}}}$$

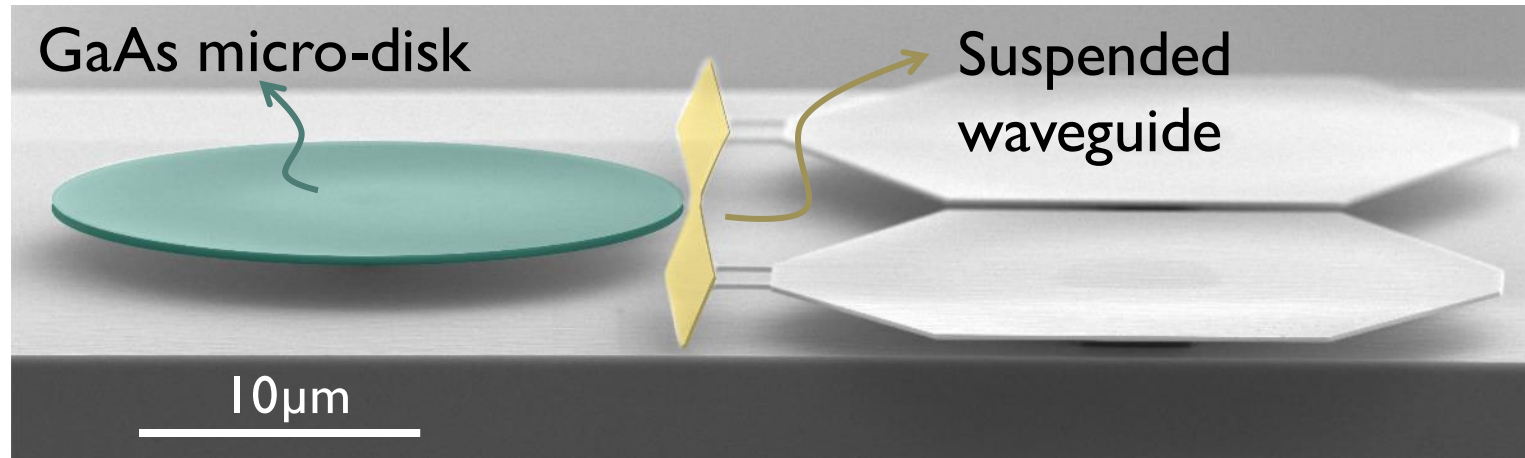
A mechanical resonator is a mass sensor



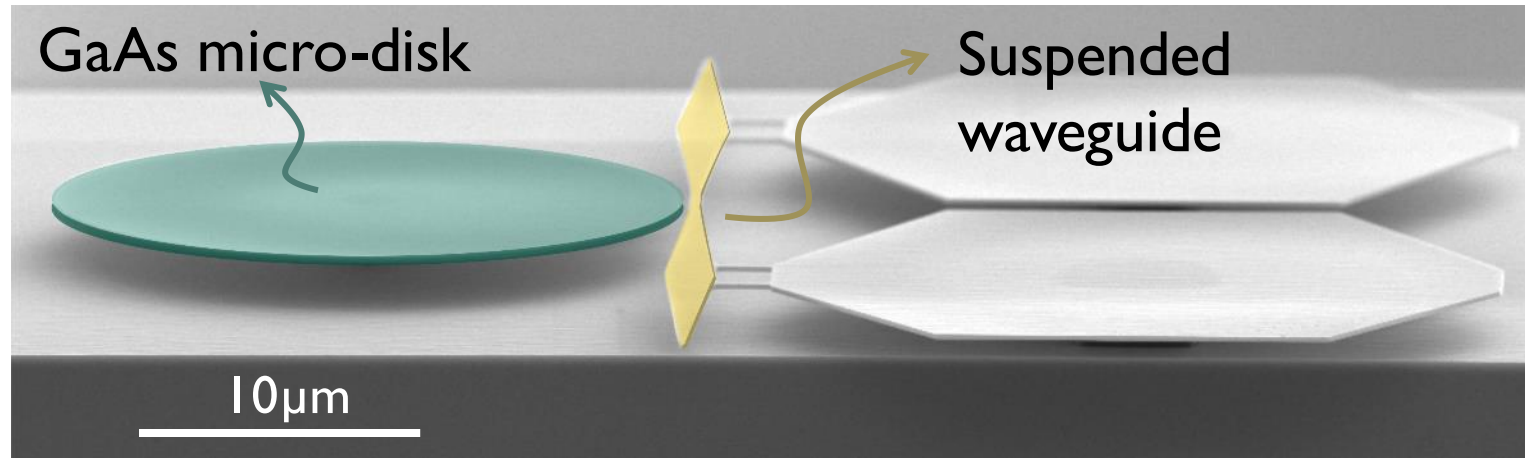
$$f'_m = \sqrt{\frac{K_{eff} + \Delta K}{m_{eff} + \Delta m}}$$

$$\frac{\Delta f_m}{f_m} = -\frac{1}{2} \frac{\Delta m}{m_{eff}} |x_{norm}|^2$$

A coupling between light and mechanical motion

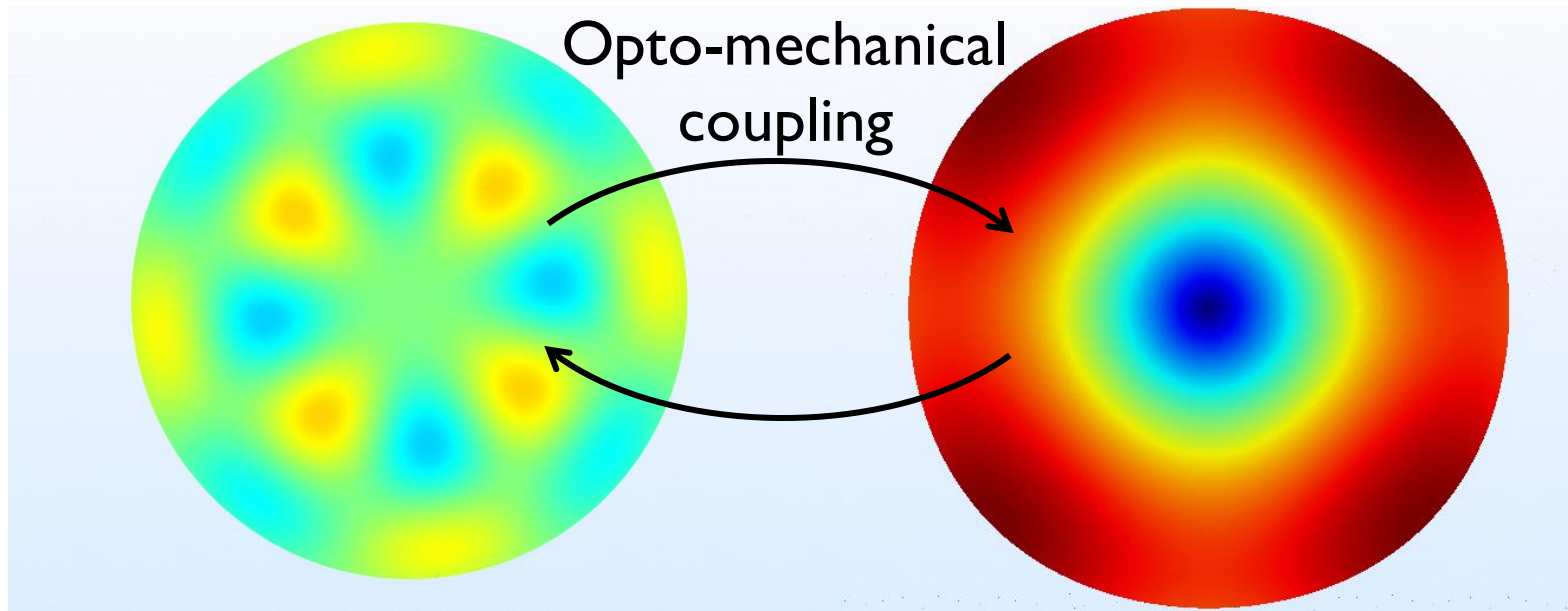


A coupling between light and mechanical motion



Optics

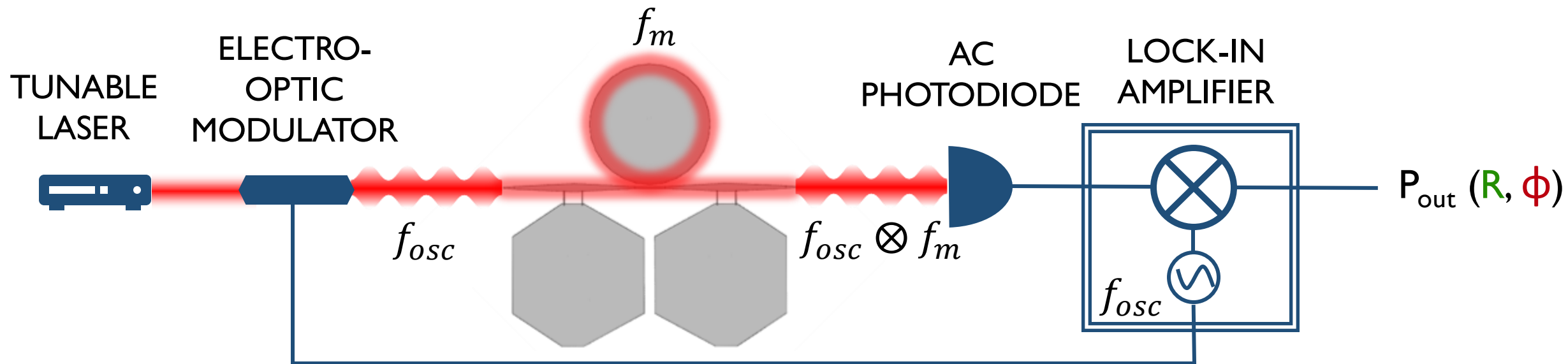
Whispering Gallery Mode (WGM)



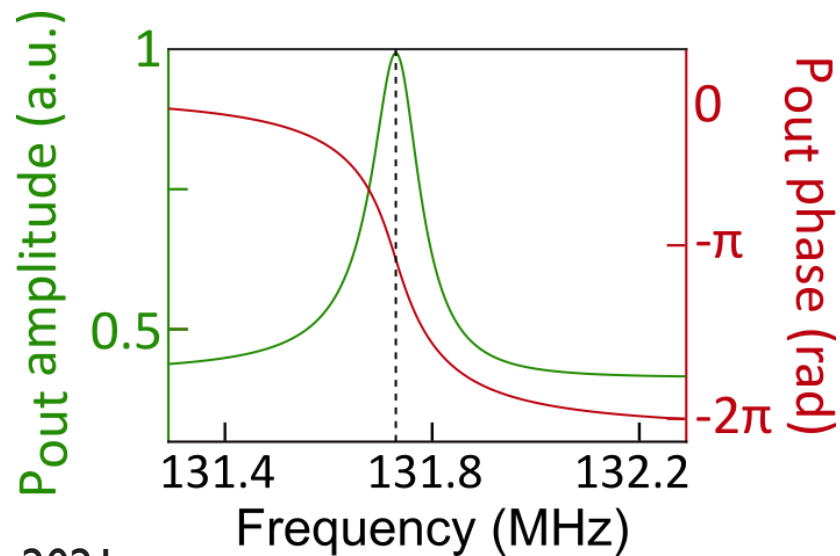
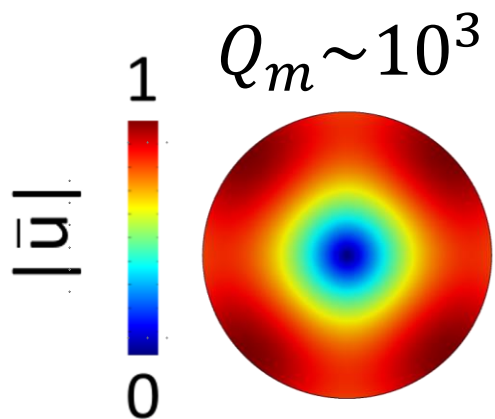
Mechanics

Radial Breathing Mode (RBM)

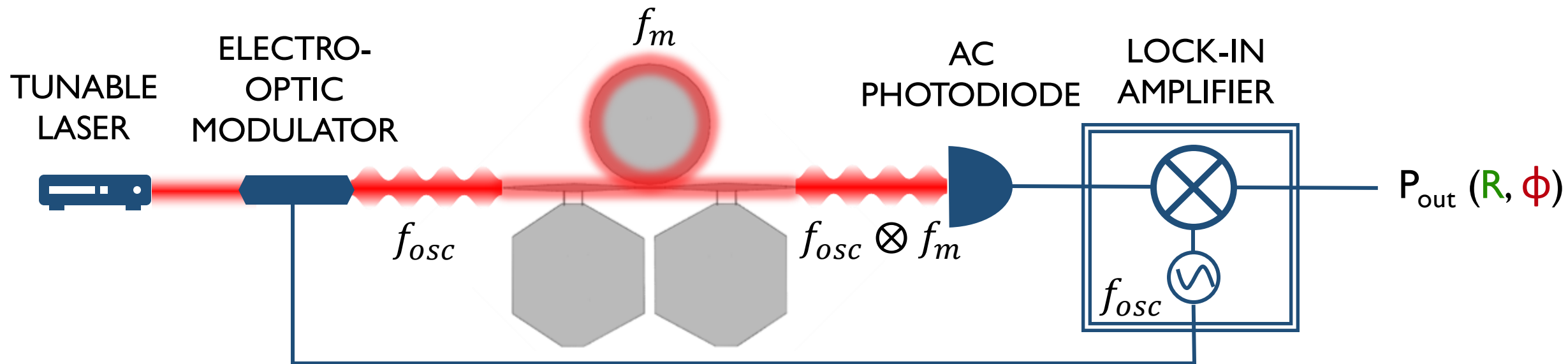
Mechanical motion is **driven** and **detected** by light



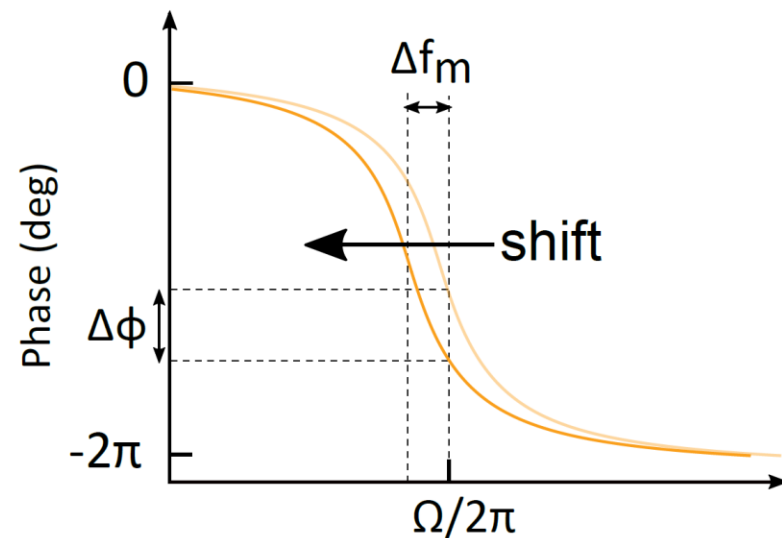
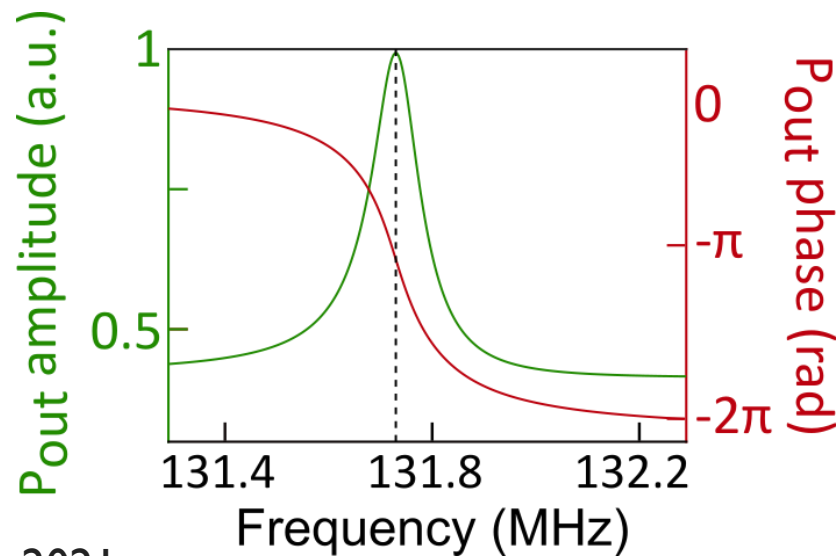
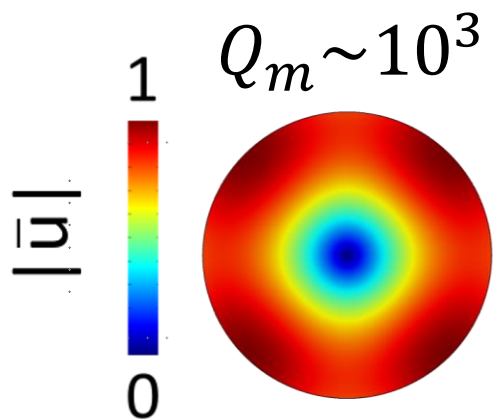
Mechanical RBM



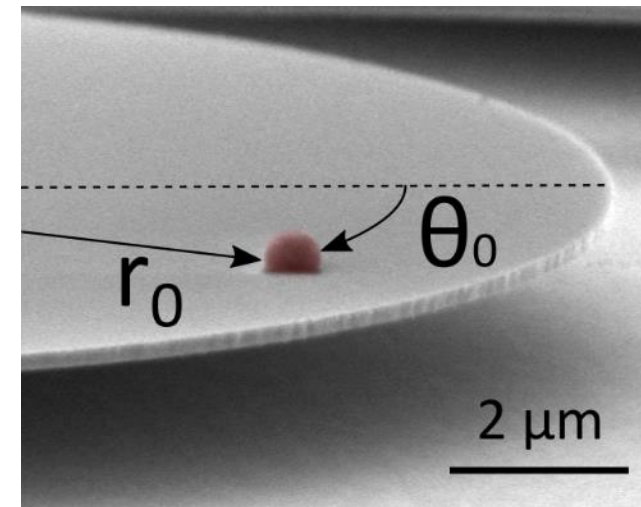
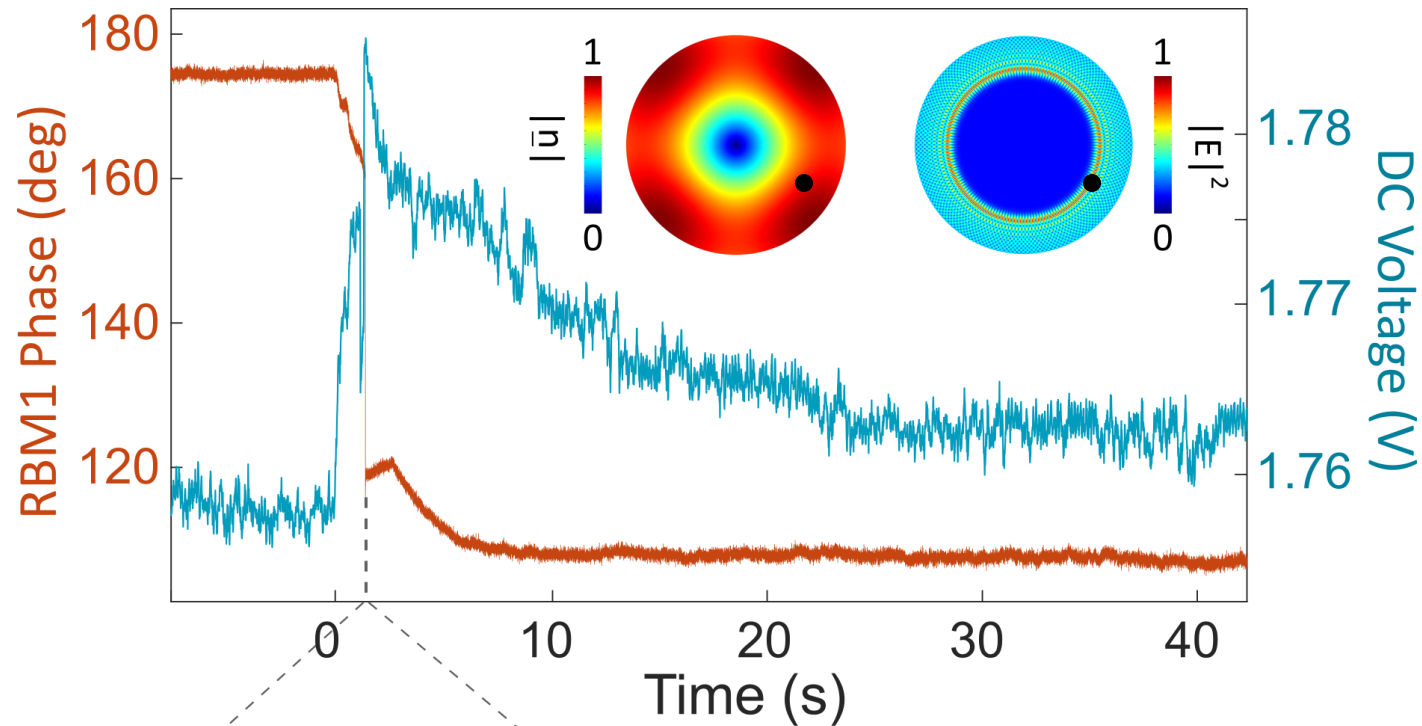
Mechanical motion is **driven** and **detected** by light



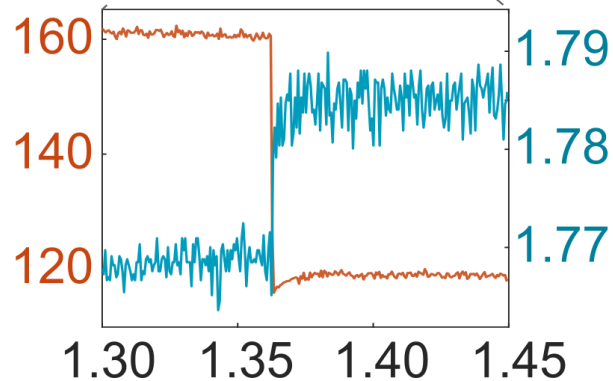
Mechanical RBM



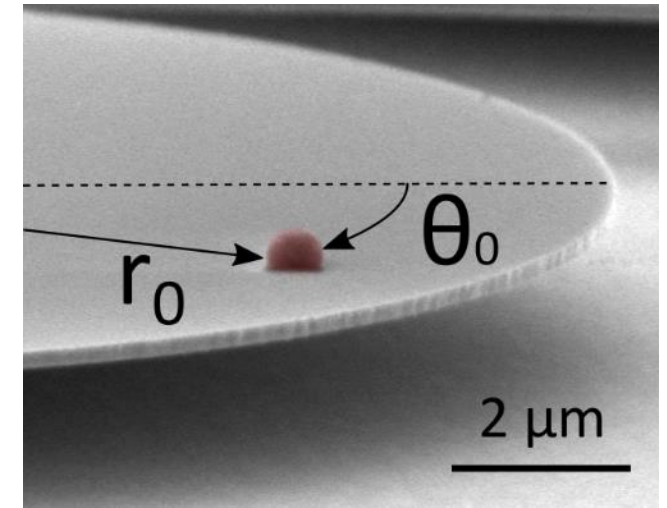
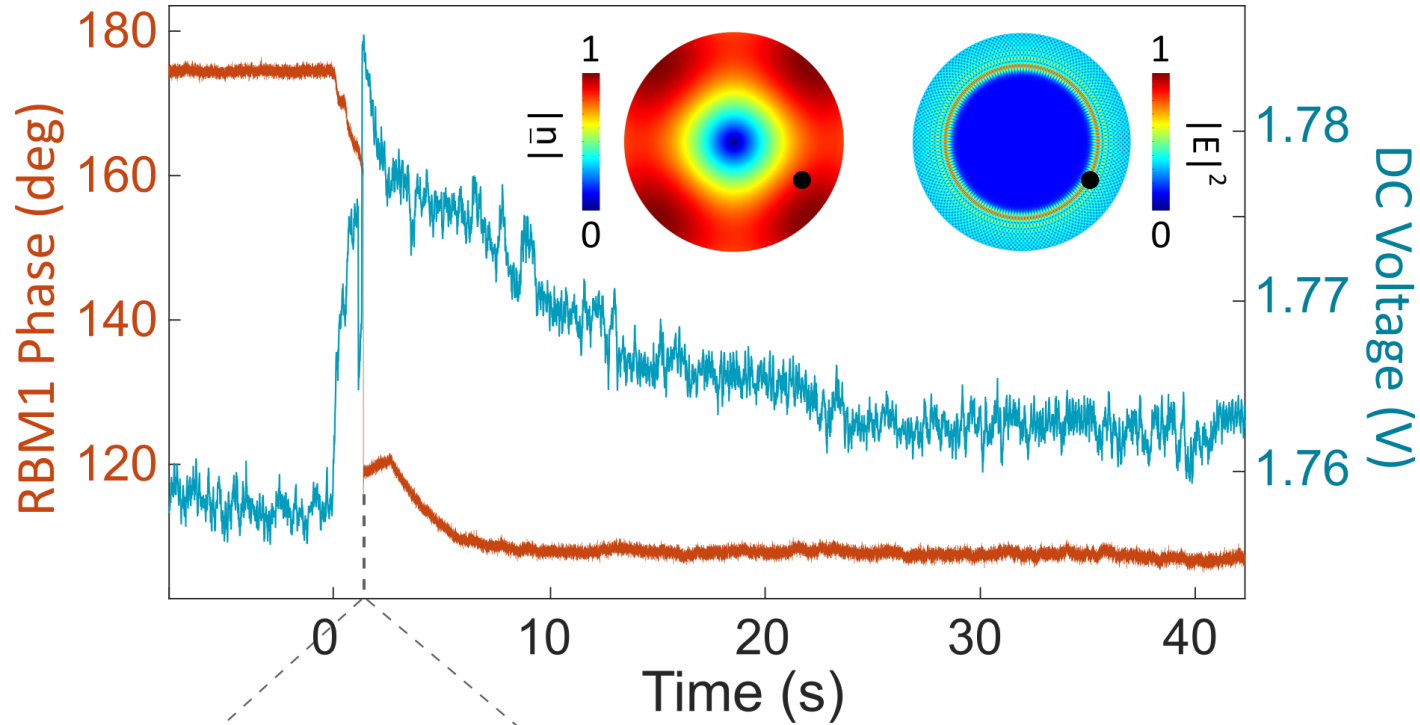
When a nanoparticle lands on the disk...



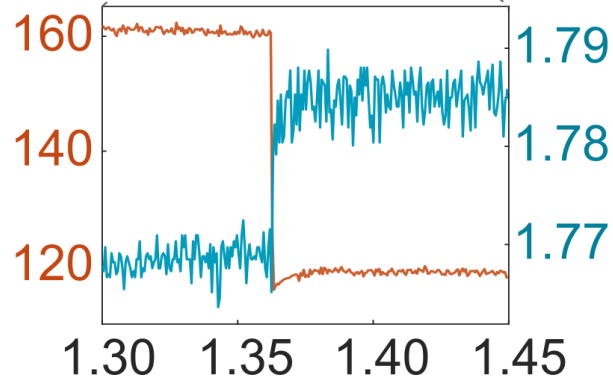
Latex nanoparticle
300 nm nominal diameter, 15 fg



When a nanoparticle lands on the disk...

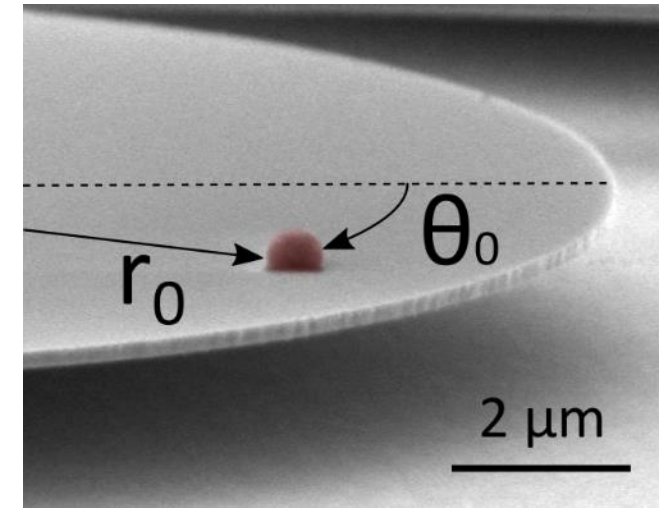
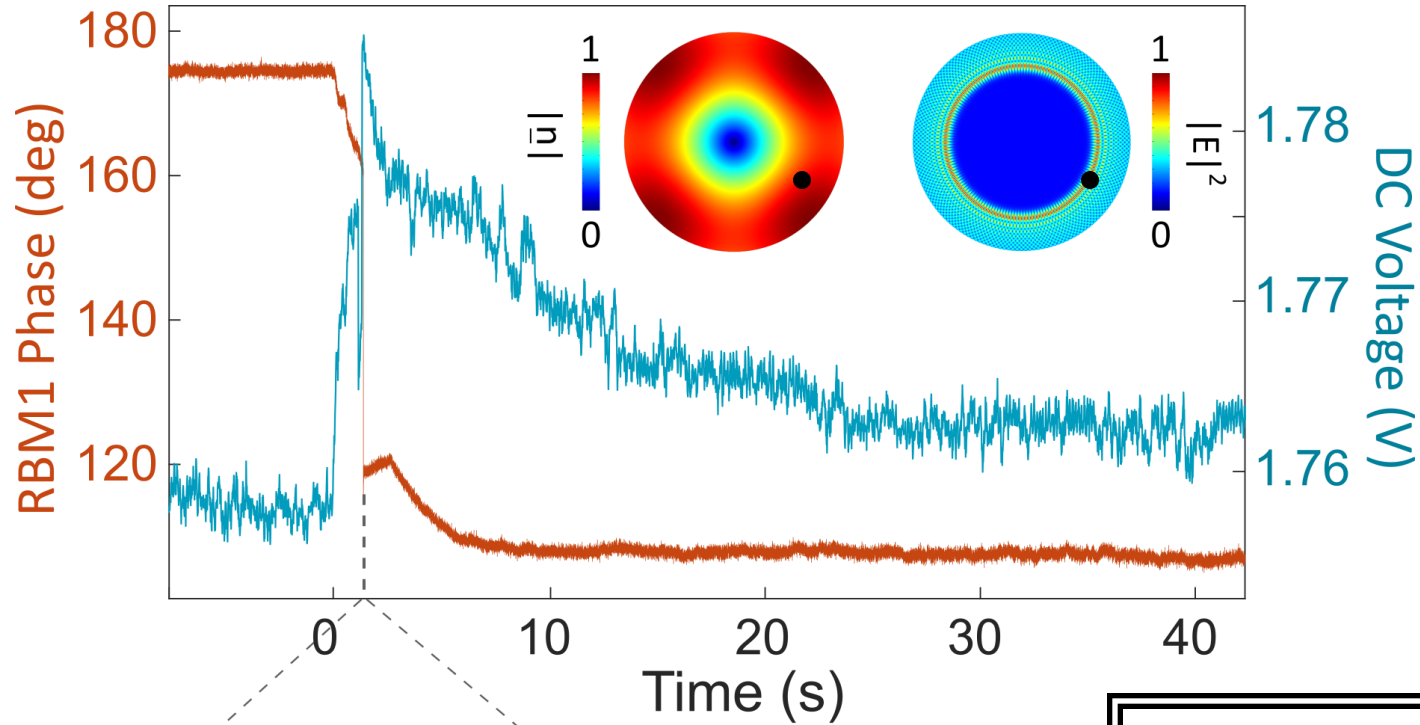


Latex nanoparticle
300 nm nominal diameter, 15 fg



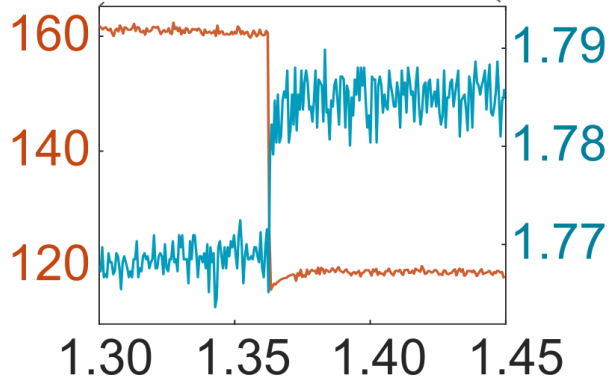
$$\longrightarrow \frac{\Delta f_m}{f_m} = -31.5 \text{ ppm}$$

When a nanoparticle lands on the disk...



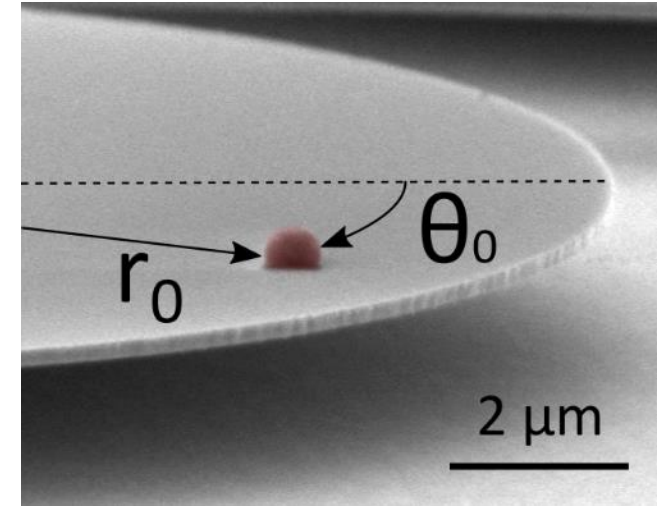
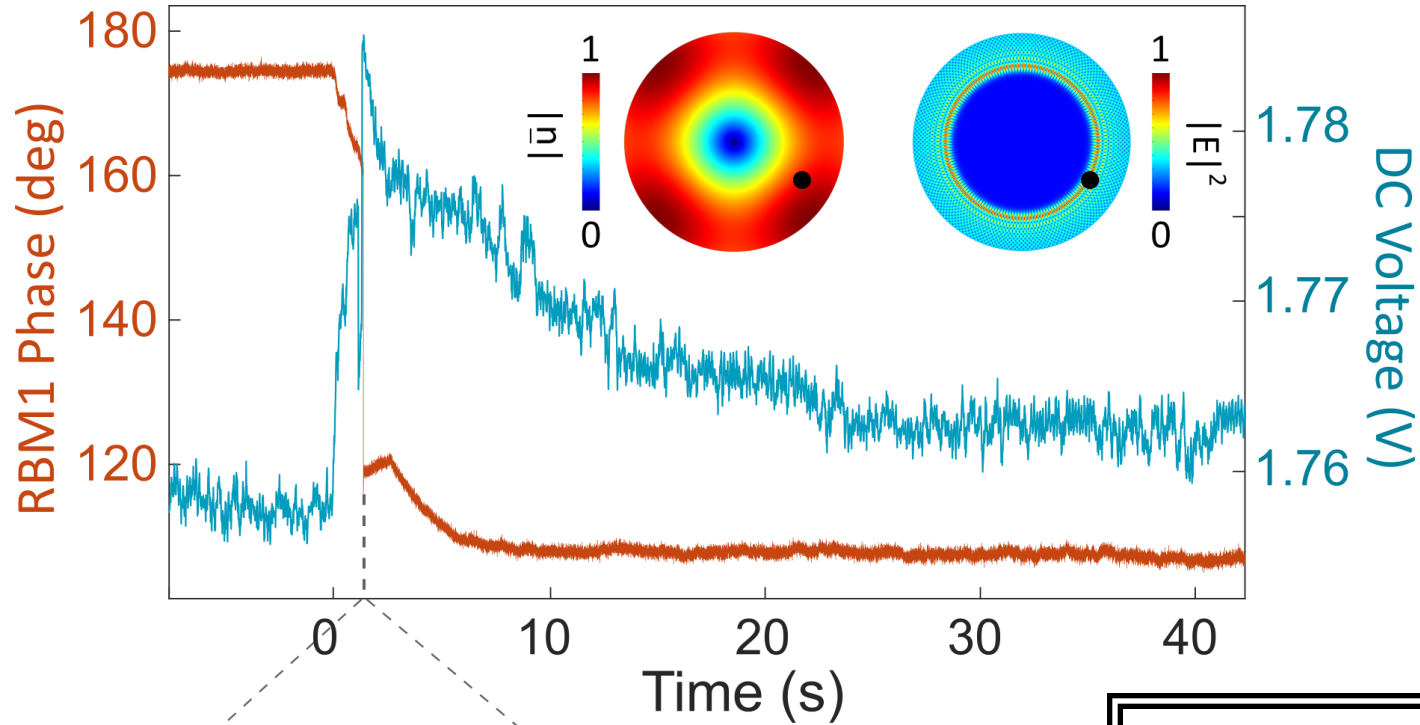
Latex nanoparticle
300 nm nominal diameter, 15 fg

$$\frac{\Delta f_m}{f_m} = -\frac{1}{2} \frac{m_{NP}}{m_{disk}} |u(r_0, \theta_0)|^2$$



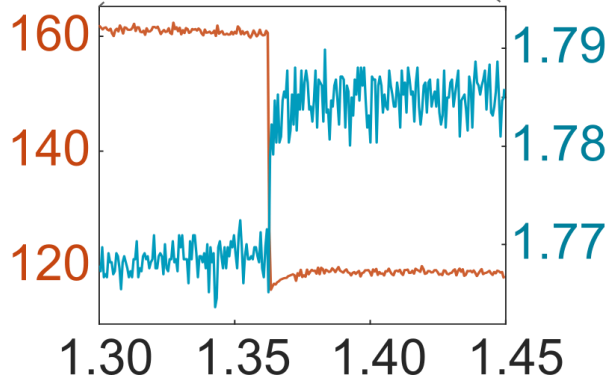
→ $\frac{\Delta f_m}{f_m} = -31.5 \text{ ppm}$

When a nanoparticle lands on the disk...



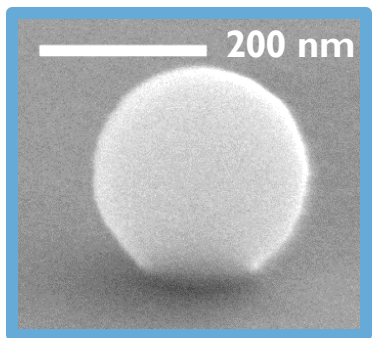
Latex nanoparticle
300 nm nominal diameter, 15 fg

$$\frac{\Delta f_m}{f_m} = -\frac{1}{2} \frac{m_{NP}}{m_{disk}} |u(r_0, \theta_0)|^2$$

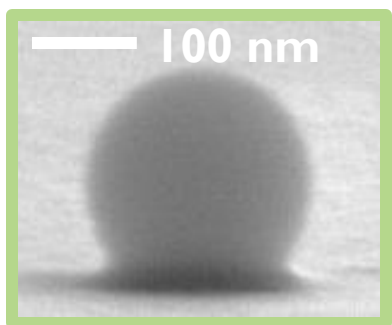


$$\longrightarrow \frac{\Delta f_m}{f_m} = -31.5 \text{ ppm} \longrightarrow m_{NP} = 22.4 \text{ fg}$$

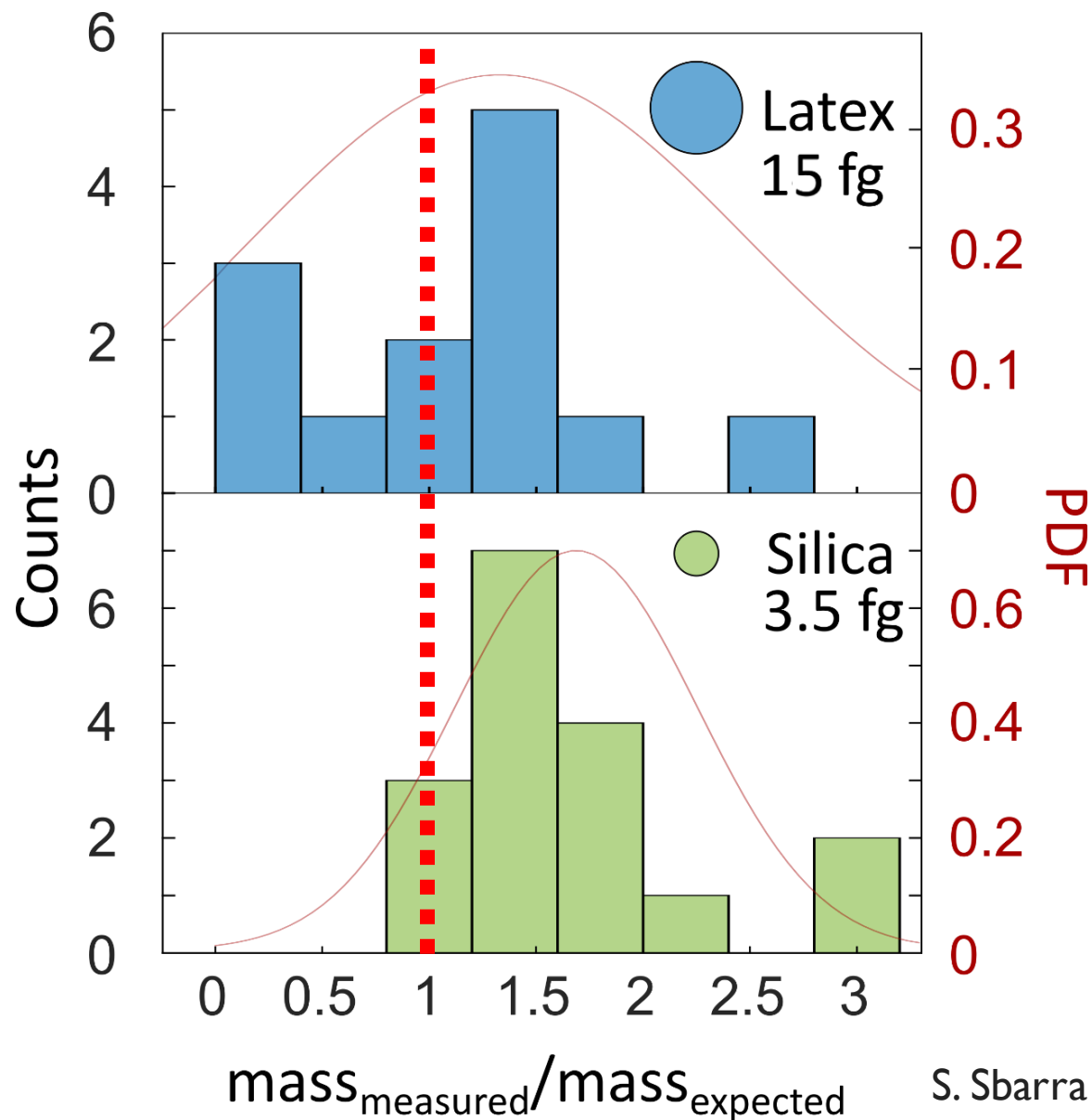
What about the reproducibility ?



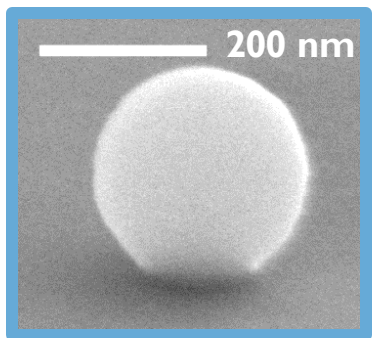
Latex
300 nm diam.



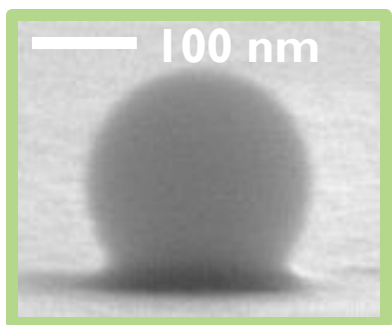
Silica
150 nm diam.



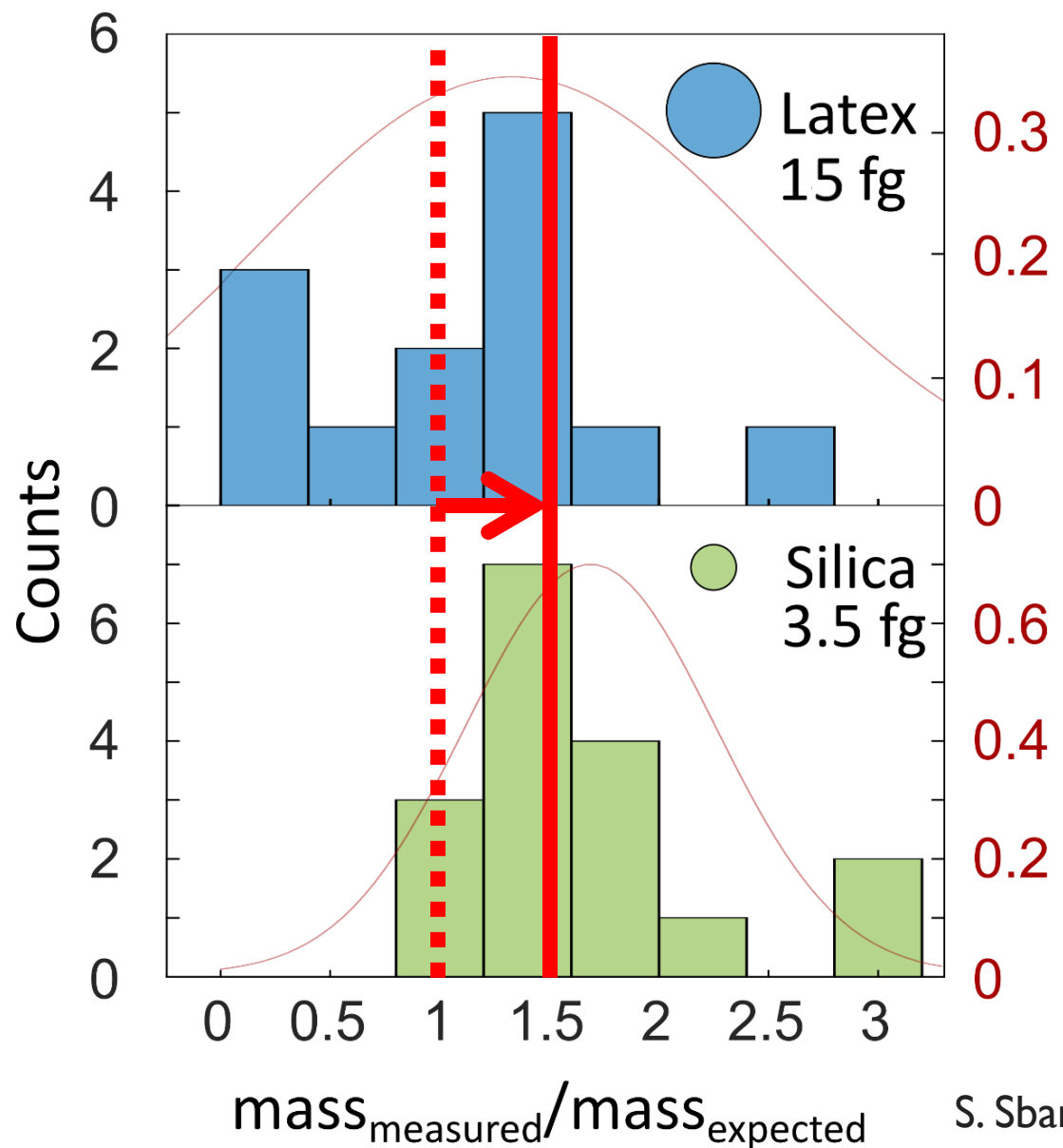
Measured mass seems overestimated by ~ 50%



Latex
300 nm diam.



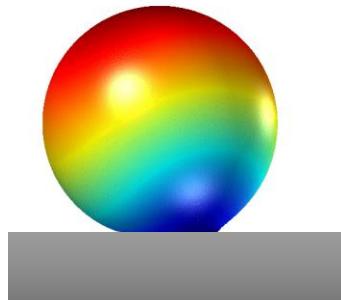
Silica
150 nm diam.



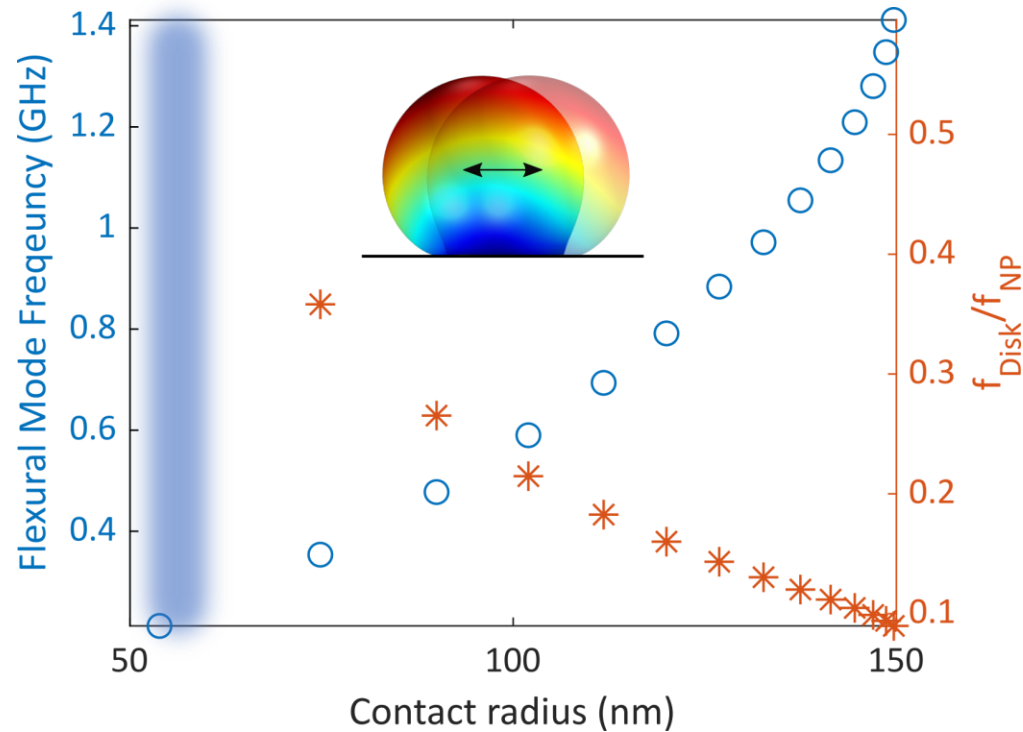
Sources of **deviation**

- Residual liquid meniscus
- For Latex NP : Mechanical coupling between disk and nanoparticle vibrations

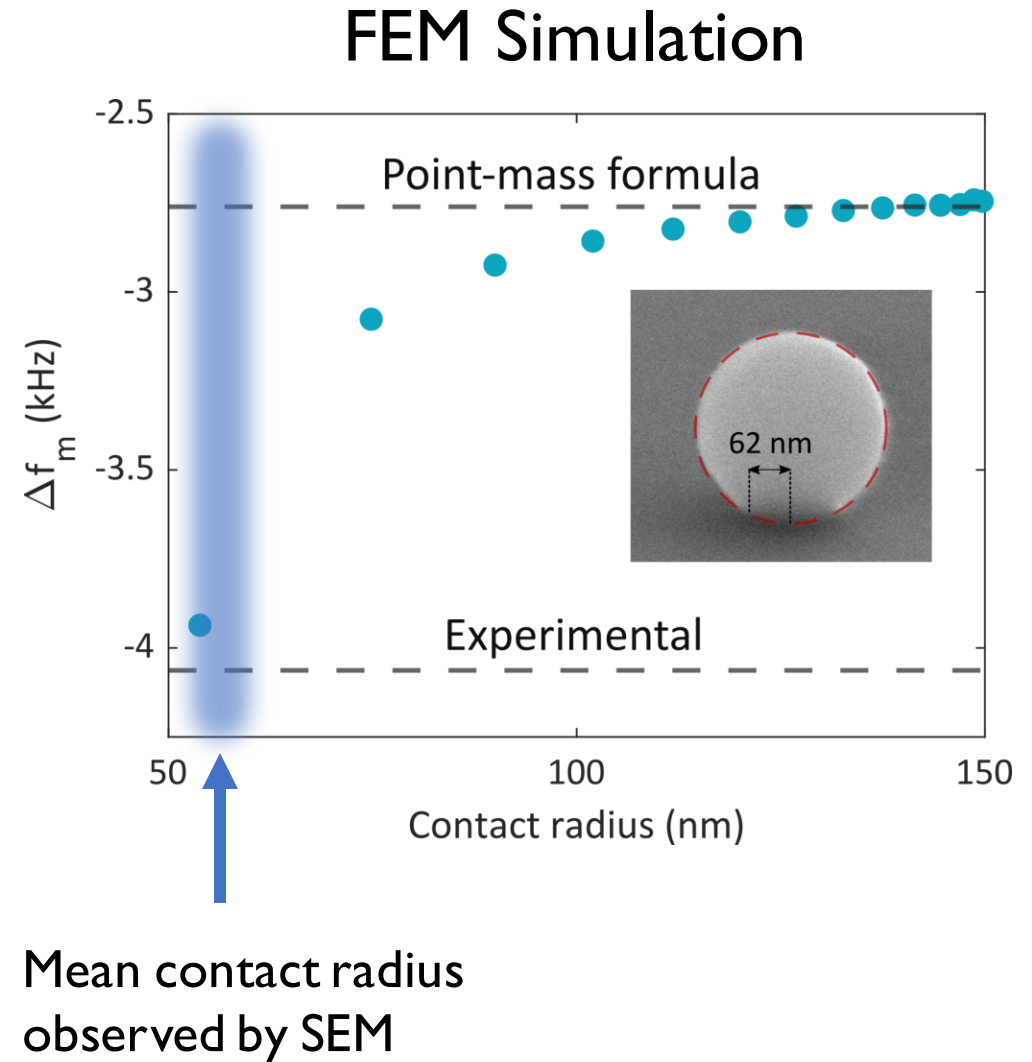
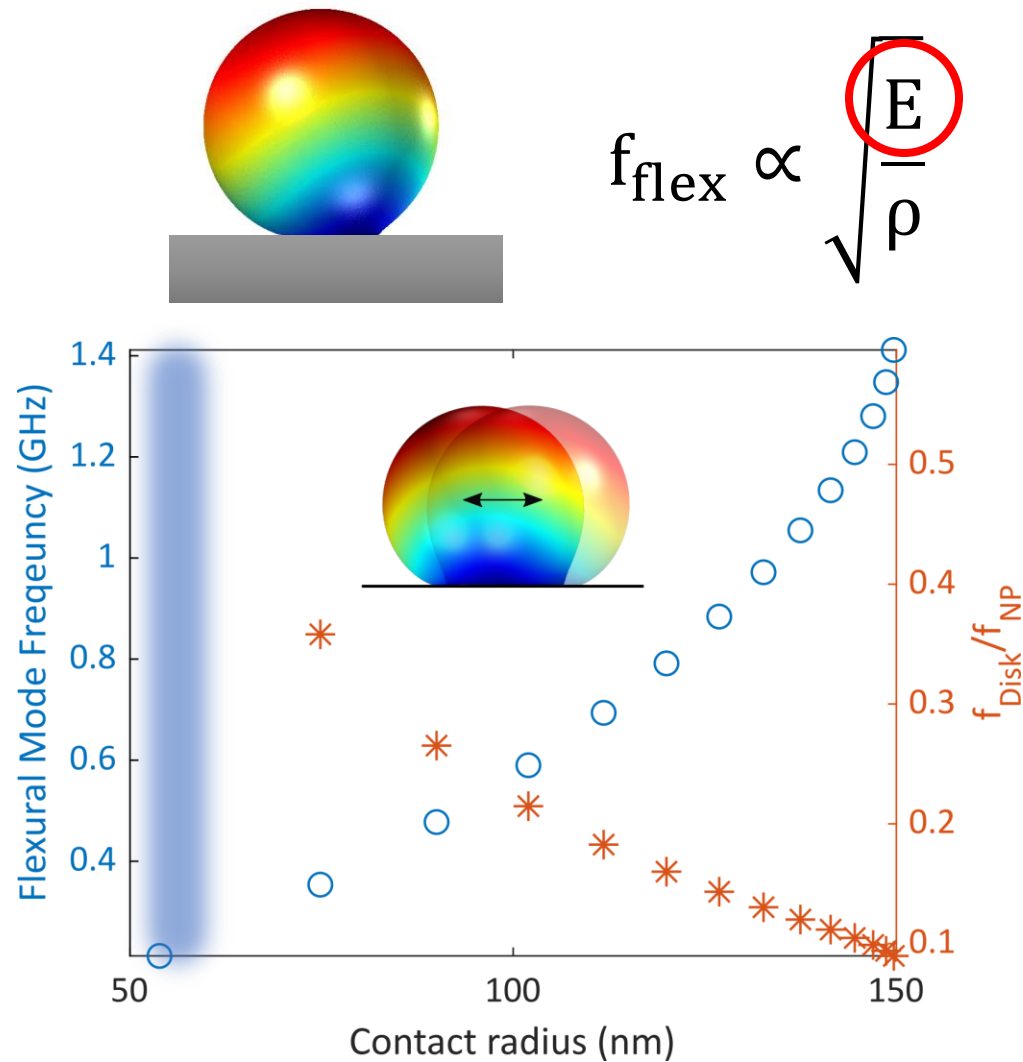
A coupling between the particle and the disk



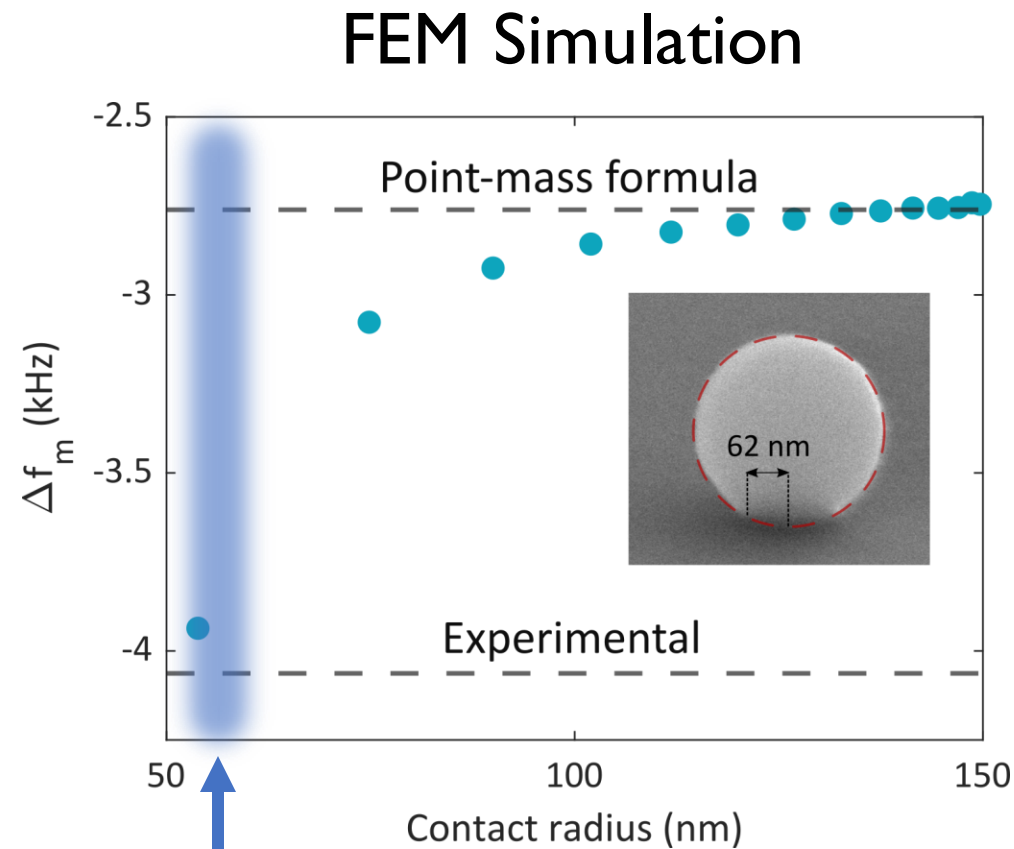
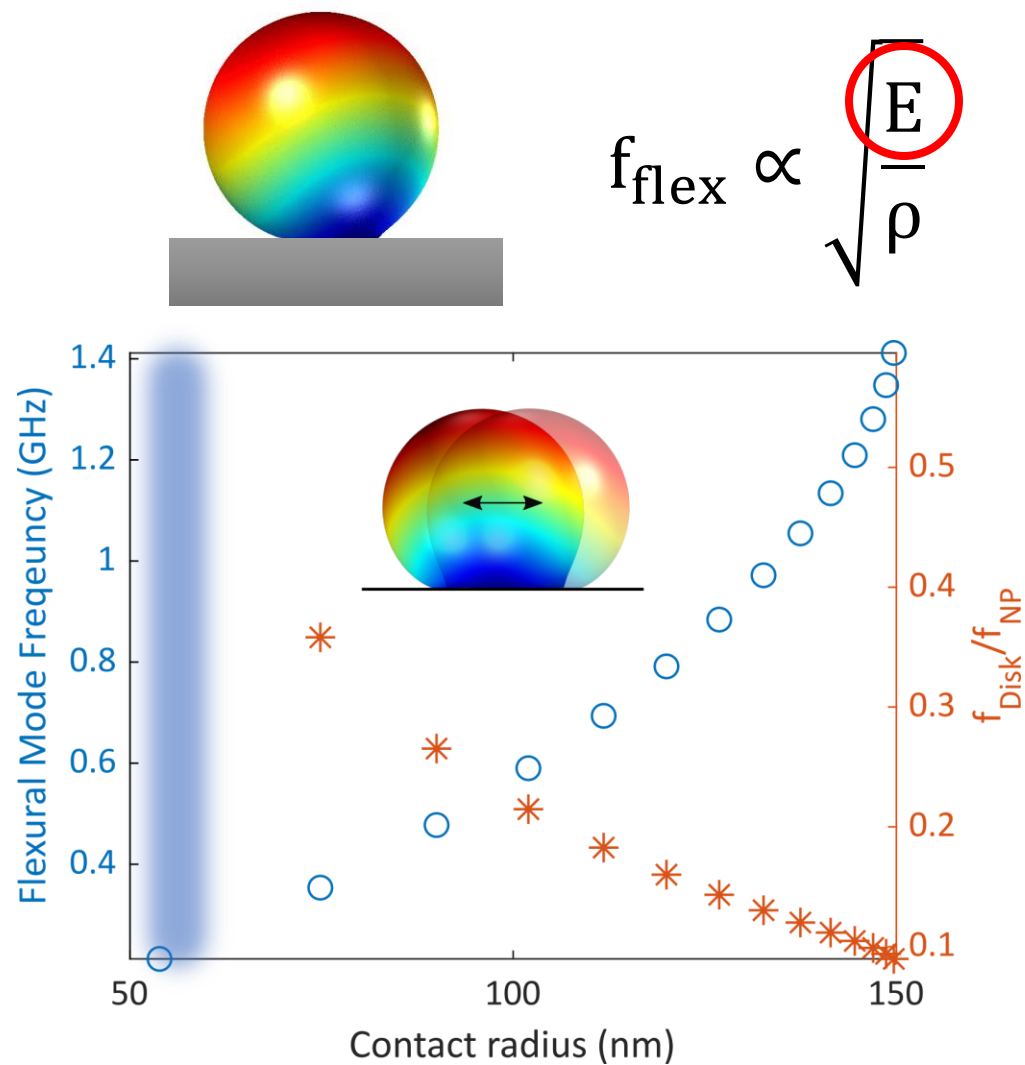
$$f_{\text{flex}} \propto \sqrt{\frac{E}{\rho}}$$



A coupling between the particle and the disk



A coupling between the particle and the disk

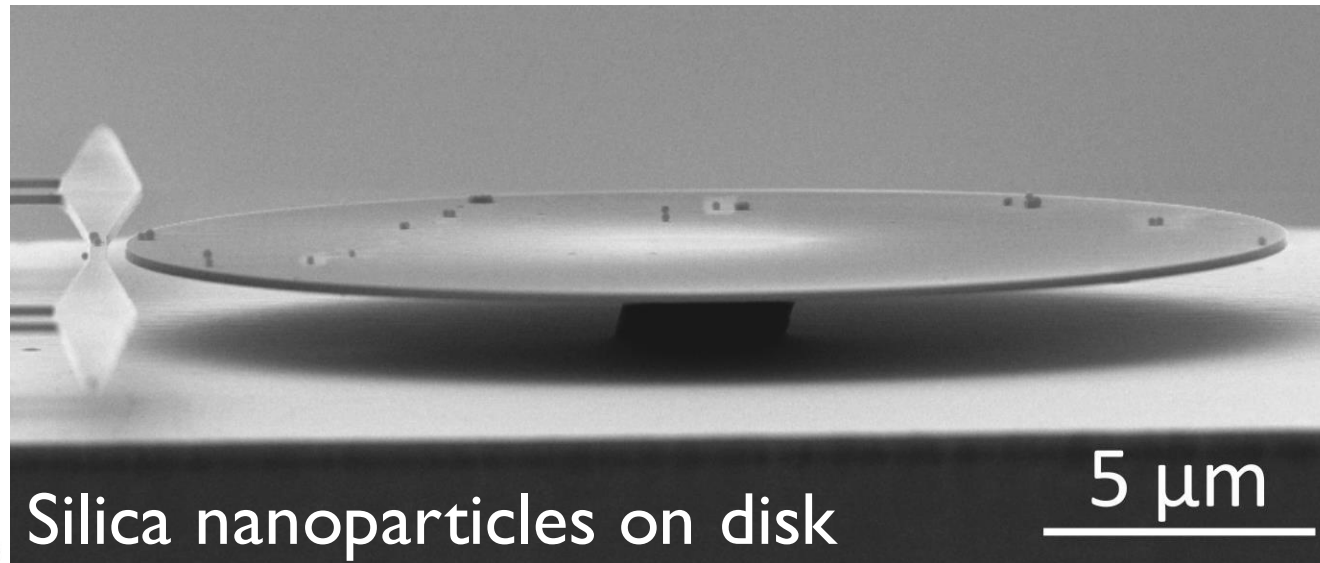


Mean contact radius
observed by SEM

$E = 2.7 \pm 0.6$ GPa
ref. value 3 GPa at 100 MHz

To keep in mind

- **Dual optical and mechanical** nano-sensing with **ultra-high sensitivity**



Viruscan

 European Commission |  Horizon 2020
European Union funding
for Research & Innovation

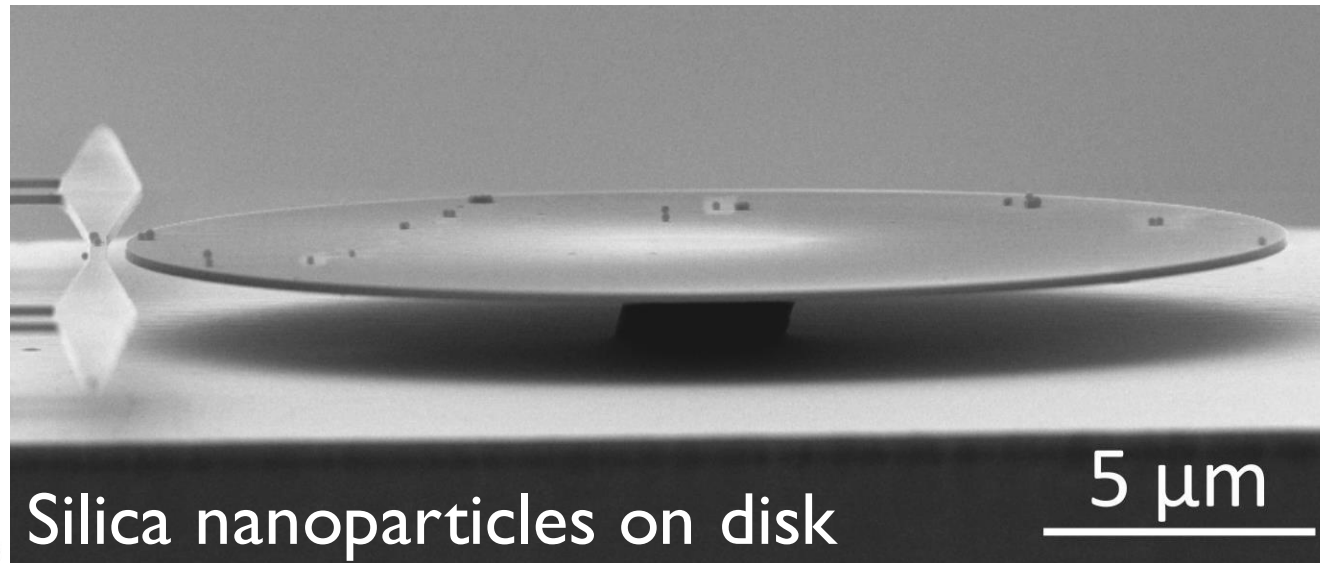


European Research Council
Established by the European Commission

S. Sbarra, L. Waquier, S. Suffit, A. Lemaître, and I. Favero. *Nano Letters*, 22(2), 710-715 (2022).

To keep in mind

- **Dual optical and mechanical** nano-sensing with **ultra-high sensitivity**
- **Multi mechanical mode sensing** of nano-object **in real-time**



Viruscan

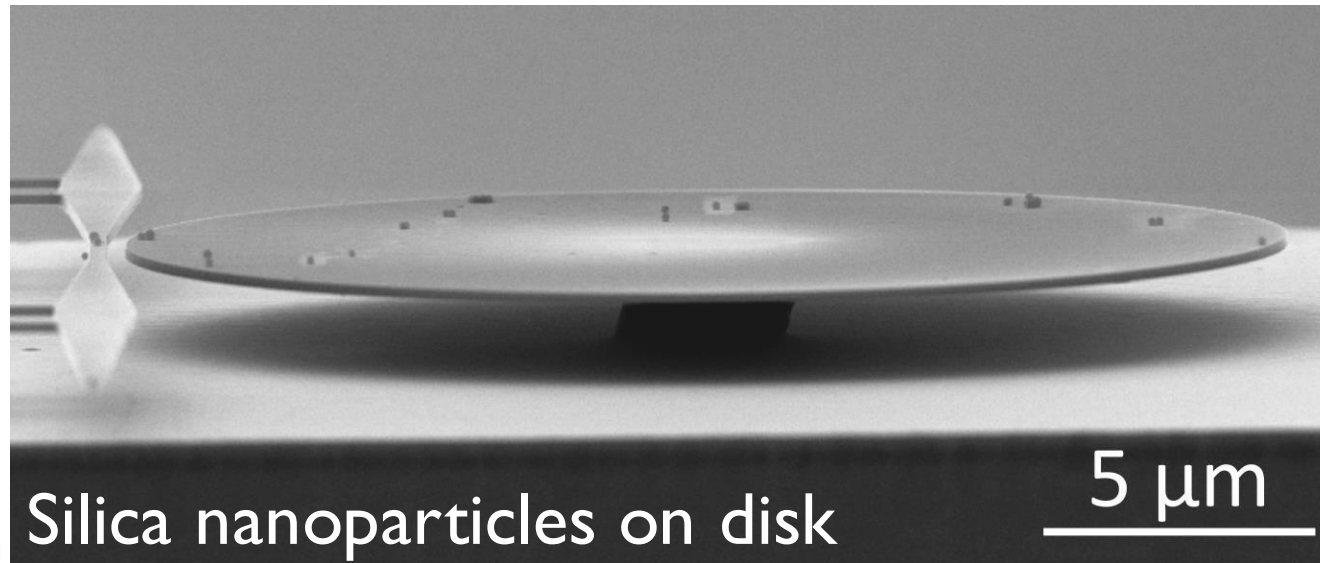


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S. Sbarra, L. Waquier, S. Suffit, A. Lemaître, and I. Favero. *Nano Letters*, 22(2), 710-715 (2022).

To keep in mind

- **Dual optical and mechanical** nano-sensing with **ultra-high sensitivity**
- **Multi mechanical mode sensing** of nano-object **in real-time**
- Analysis of signals provides the **mass** and **elasticity** of the nano-object



Viruscan

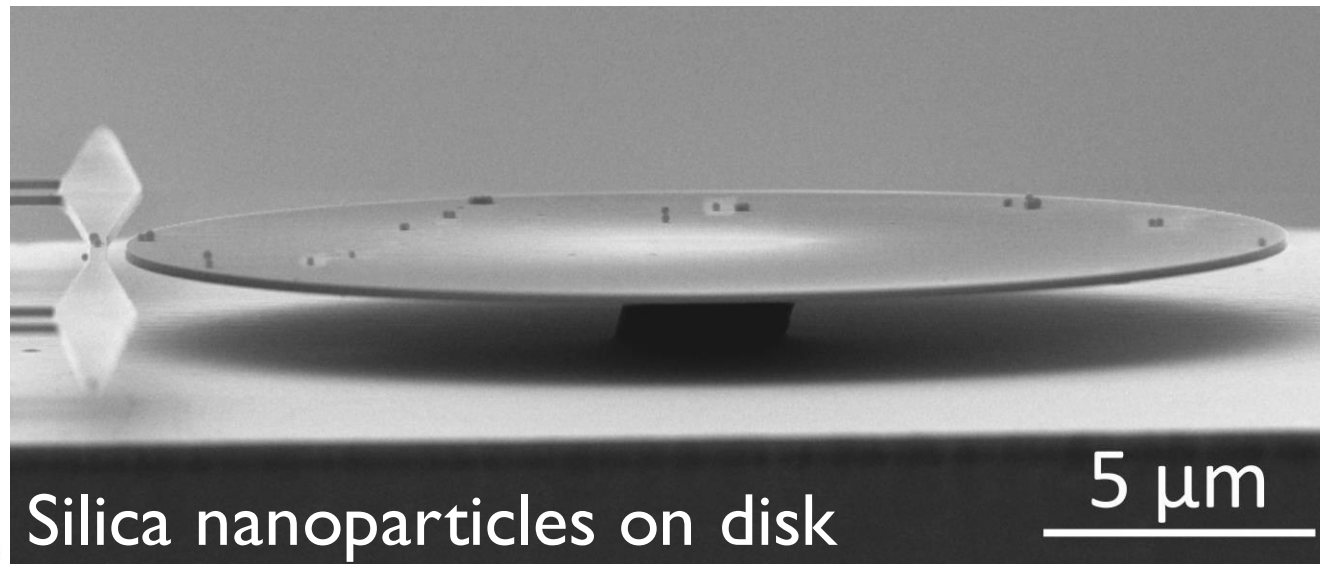


European Research Council
Established by the European Commission

S. Sbarra, L. Waquier, S. Suffit, A. Lemaître, and I. Favero. *Nano Letters*, 22(2), 710-715 (2022).

To keep in mind

- **Dual optical and mechanical** nano-sensing with **ultra-high sensitivity**
- **Multi mechanical mode sensing** of nano-object **in real-time**
- Analysis of signals provides the **mass** and **elasticity** of the nano-object
- Preparing the ground for **optomechanical virus sensing** with a dedicated instrument



Viruscan



European Research Council
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S. Sbarra, L. Waquier, S. Suffit, A. Lemaître, and I. Favero. *Nano Letters*, 22(2), 710-715 (2022).

To keep

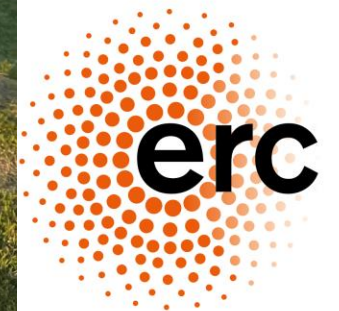
- **Dual optical** sensing with
- **Multi mech** nano-object



the **mass** and
ct

otomechanical
ated instrument

Virusco



European Research Council
financed by the European Commission

S. Sbarra, L. Waquier, S. Suffit, A. Lemaître, and I. Favero. *Nano Letters*, 22(2), 710-715 (2022).

To keep

- **Dual optical** sensing with
- **Multi mech** nano-object



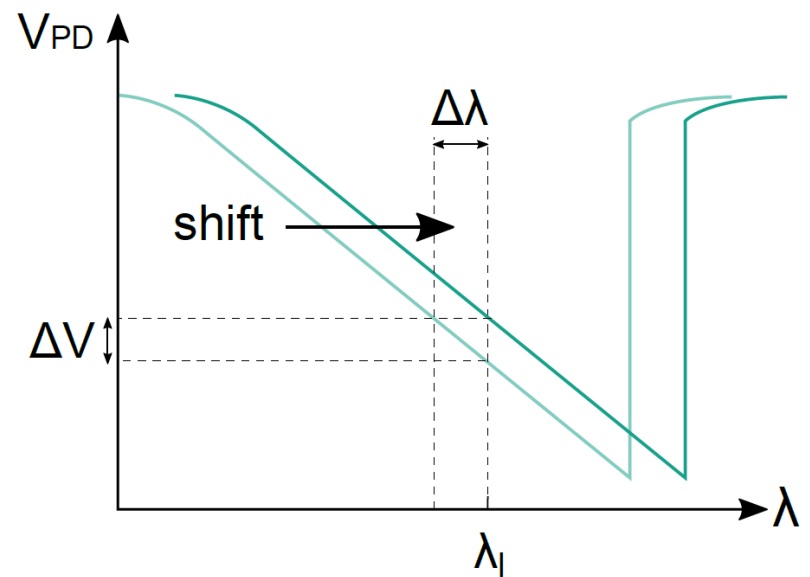
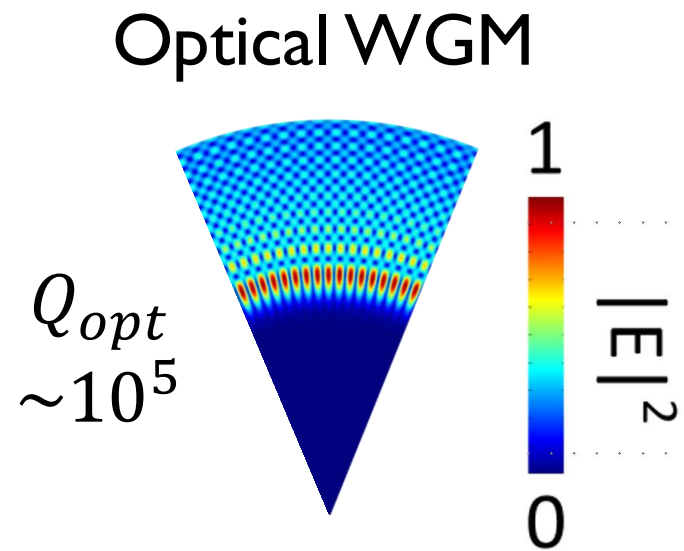
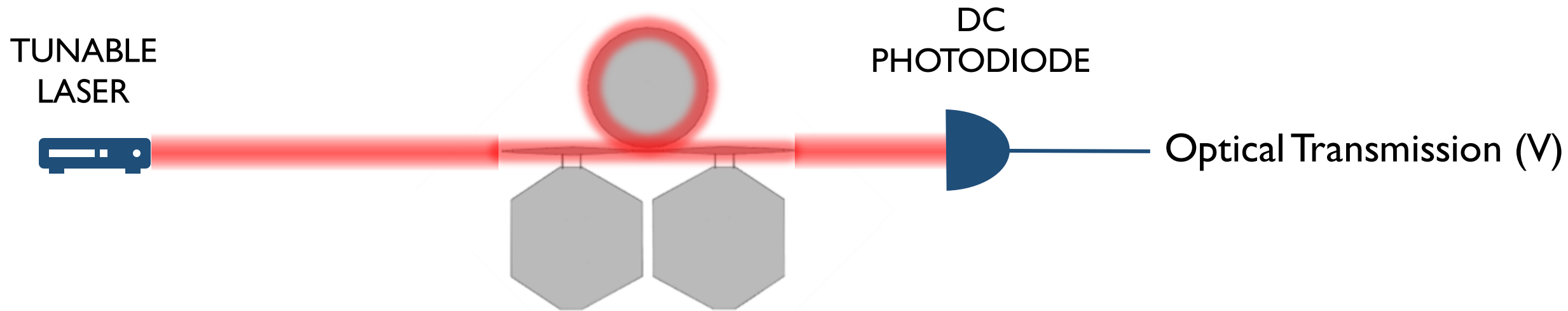
Viru



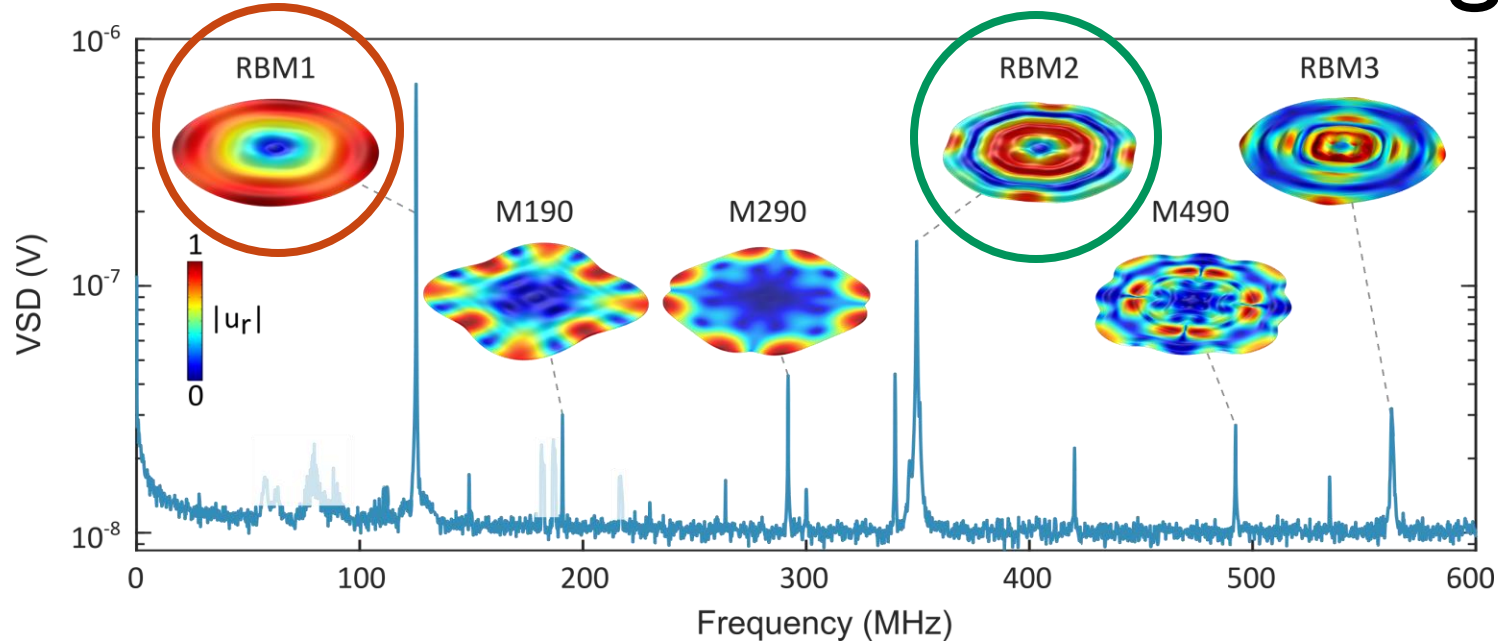
European Research Council
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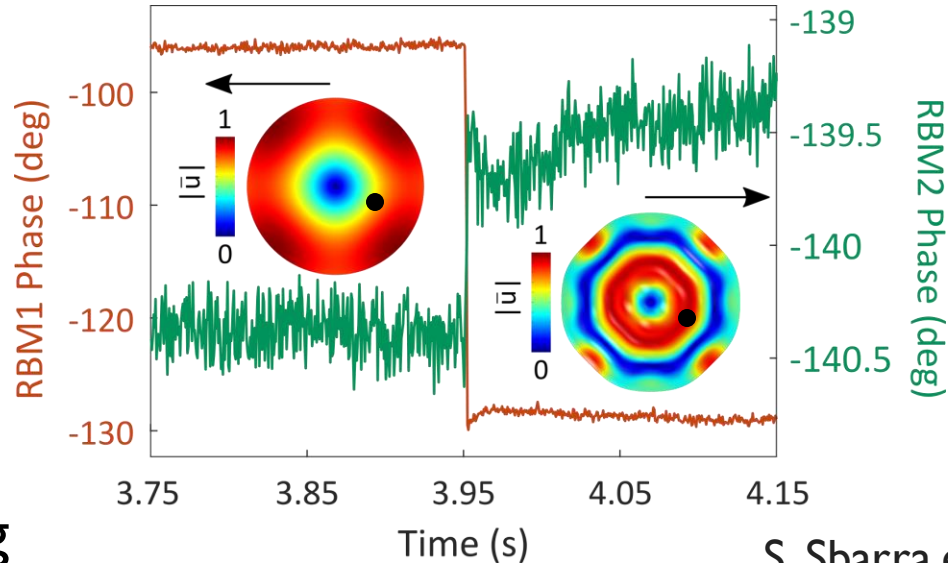
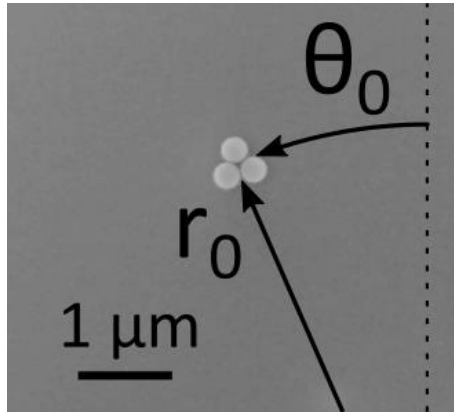
Optical resonance shift for sensing



Multi mechanical mode sensing



$$\frac{\Delta f_m}{f_m} = -\frac{1}{2} \frac{m_{NP}}{m_{disk}} |u(r_0, \theta_0)|^2$$

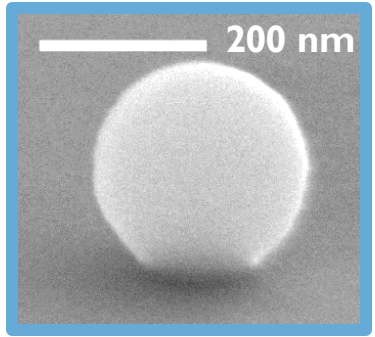


RBM 1 49.8 fg (+12%)

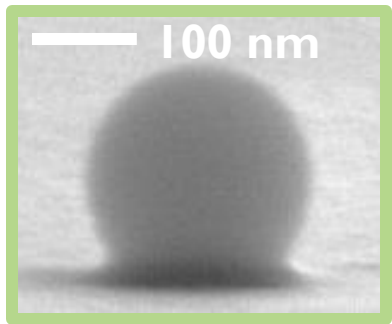
RBM 2 26.1 fg (-41%)

Cluster of 3 Latex NP: 44.4 fg

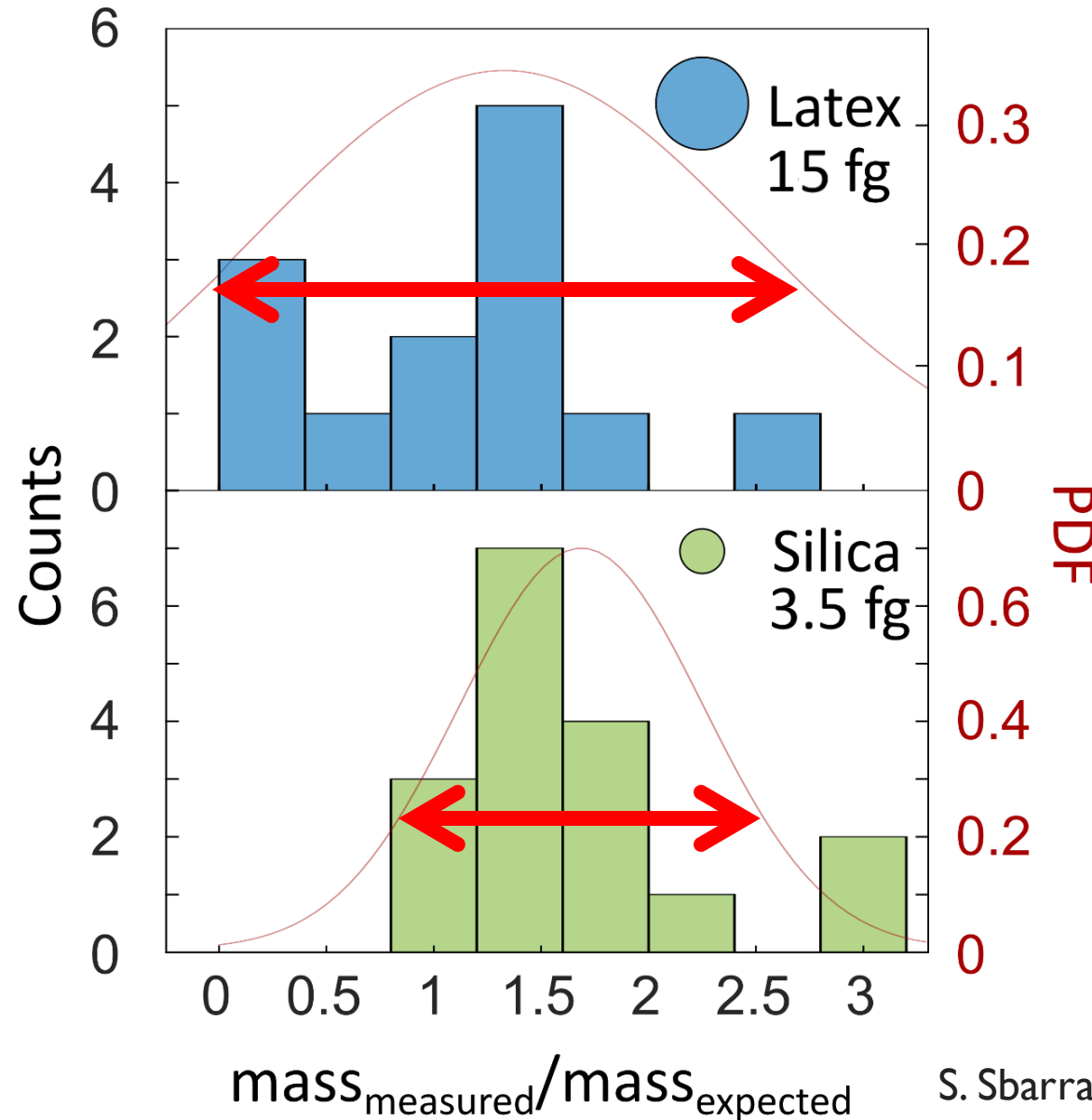
Statistics on nanoparticle mass measurement



Latex
300 nm diam.



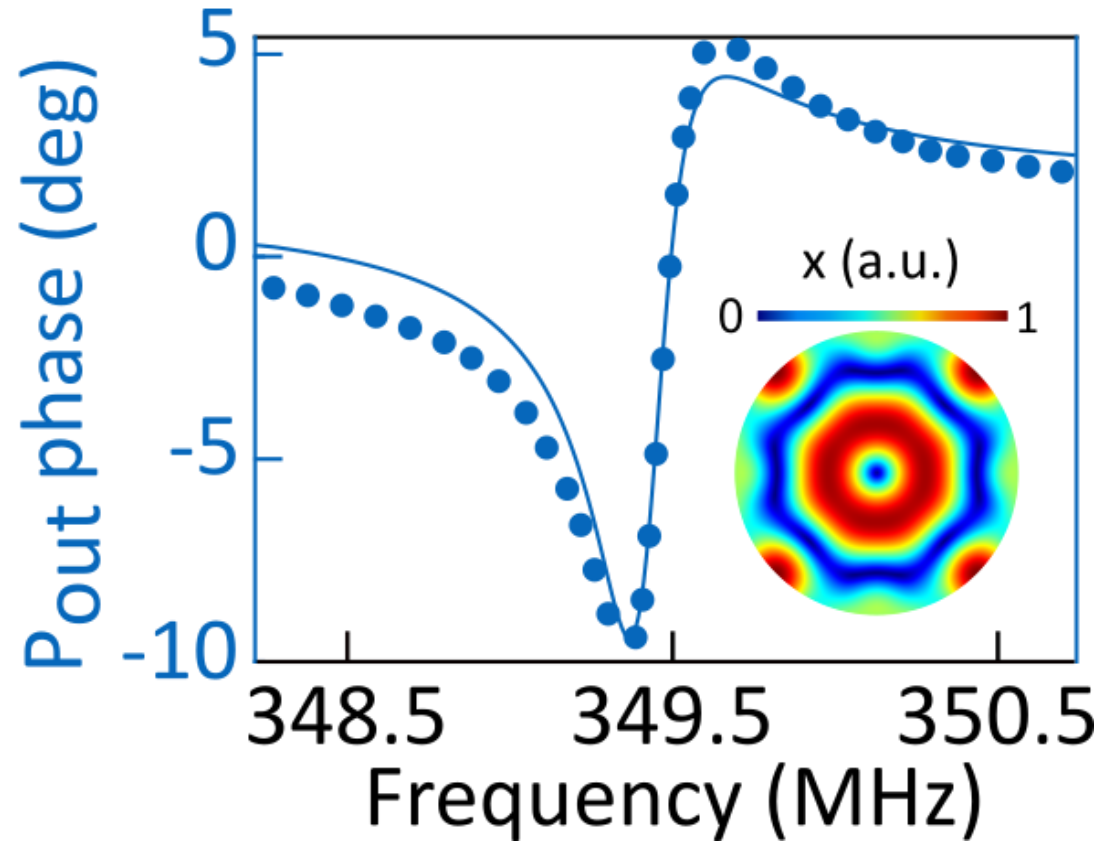
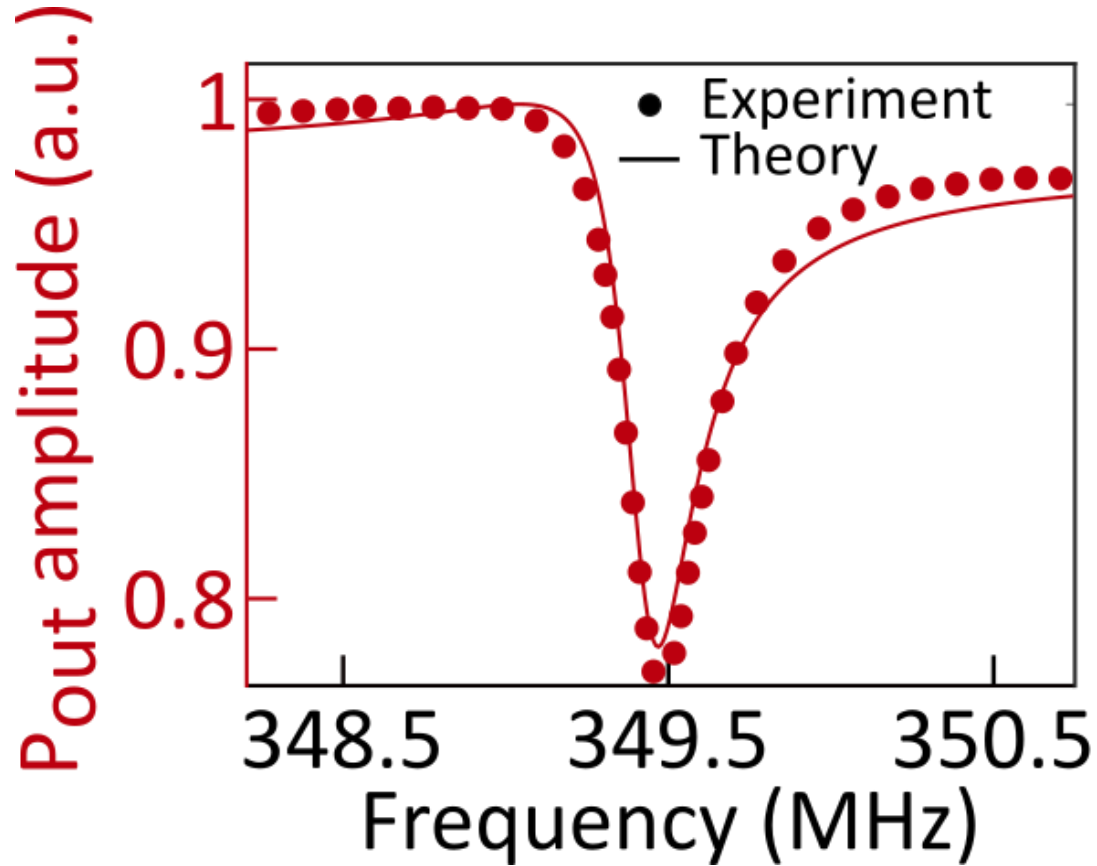
Silica
150 nm diam.



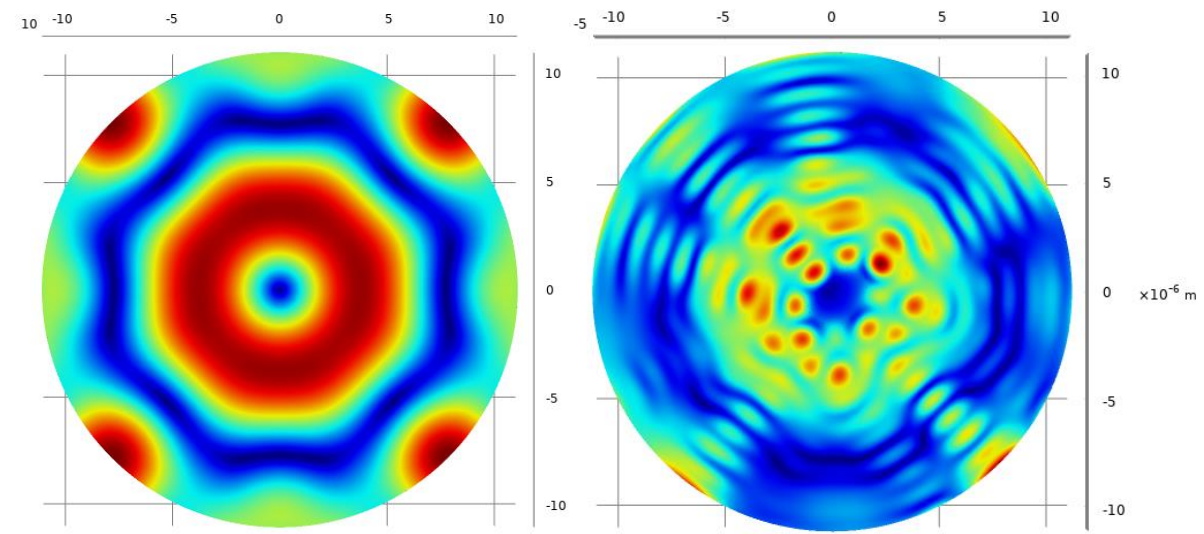
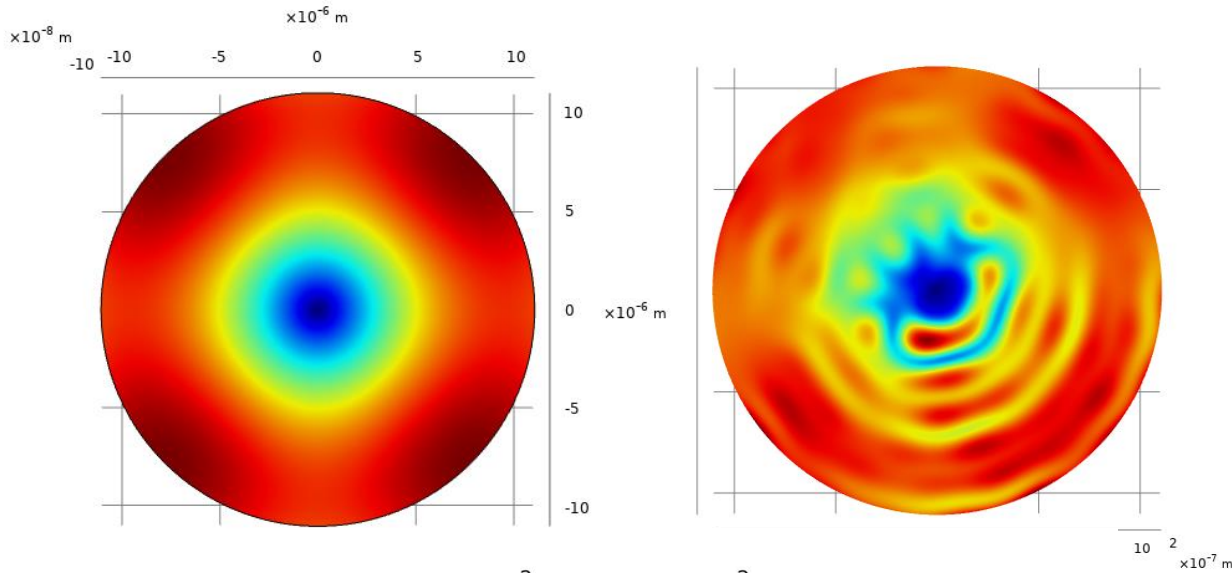
Sources of dispersion

- $\pm 20\%$ Mist: error on phase-frequency slope
- $\pm 20\%$ Mechanical mode deformation induced by pedestal
- Particle density and dimension

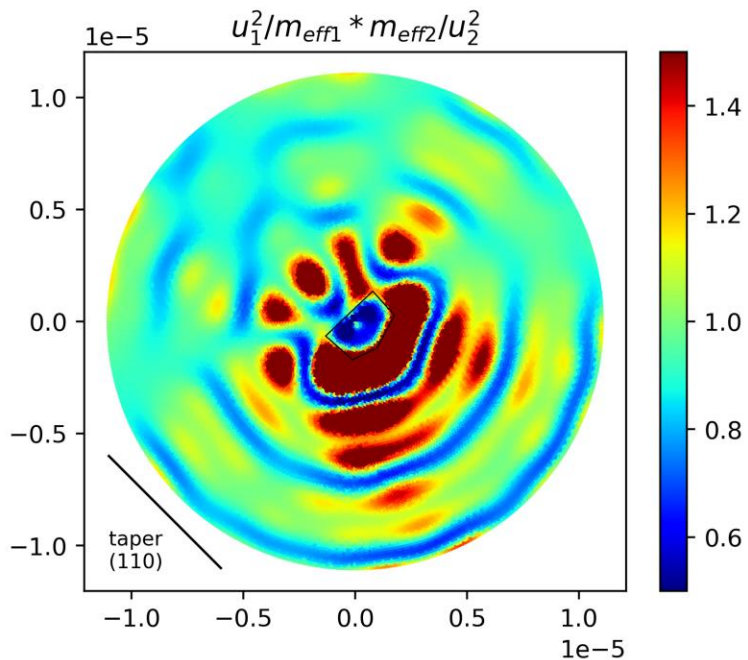
Phase-Frequency characteristic of RBM2



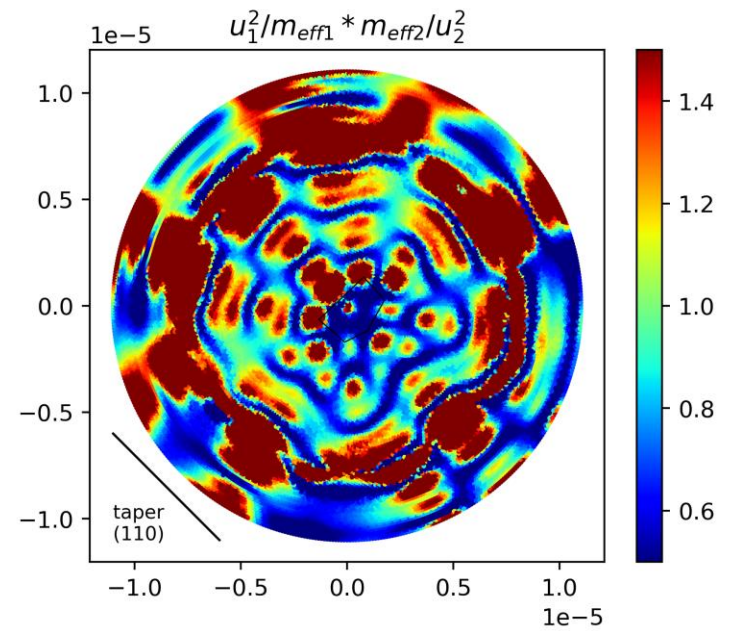
Pedestal anisotropy deformed the mode profile



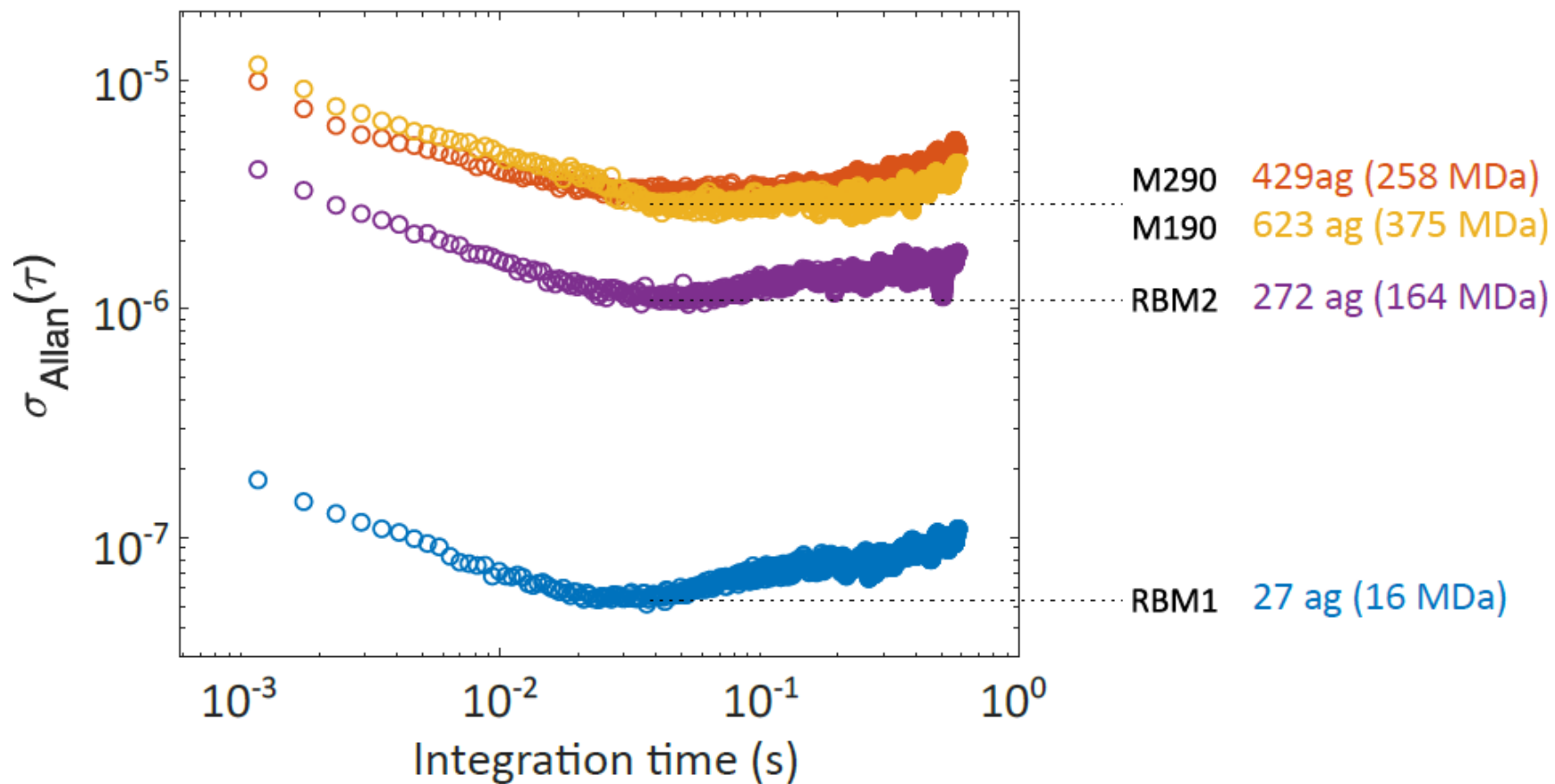
RBM I



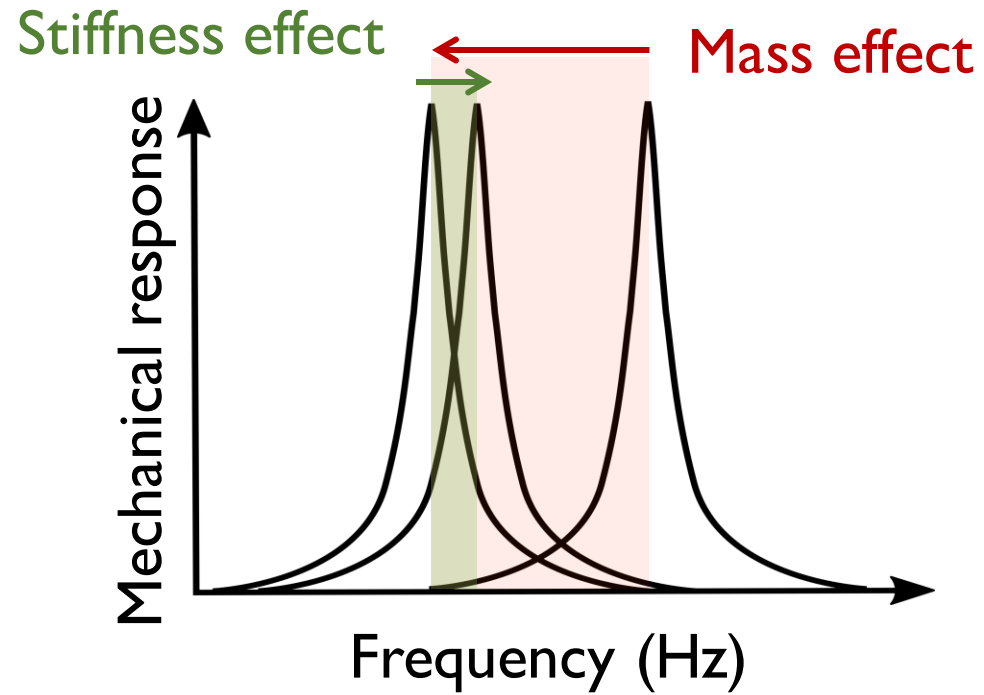
RBM 2



Sensitivity of several mechanical modes



Elasticity can be measured



$$\frac{\delta f}{f} = -\frac{1}{2} \frac{m_{NP}}{m_{eff}} |u(\mathbf{r}_0)|^2 + \varepsilon \times |u''(\mathbf{r}_0)|^2 \times \frac{E_{NP} V_{NP}}{E_{GaAs} V_{eff}}$$