

Search for non-Newtonian gravity with optically levitated microspheres

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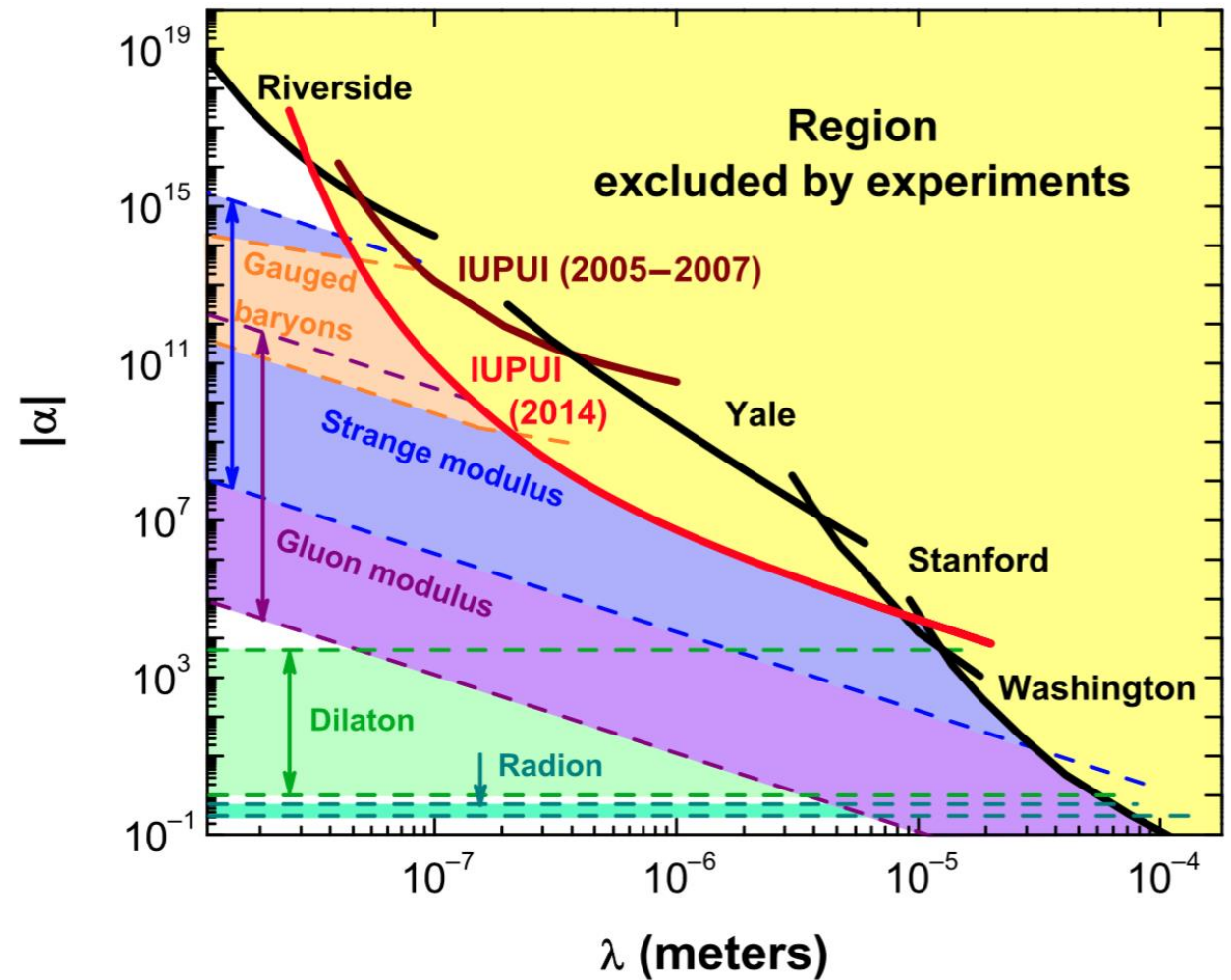
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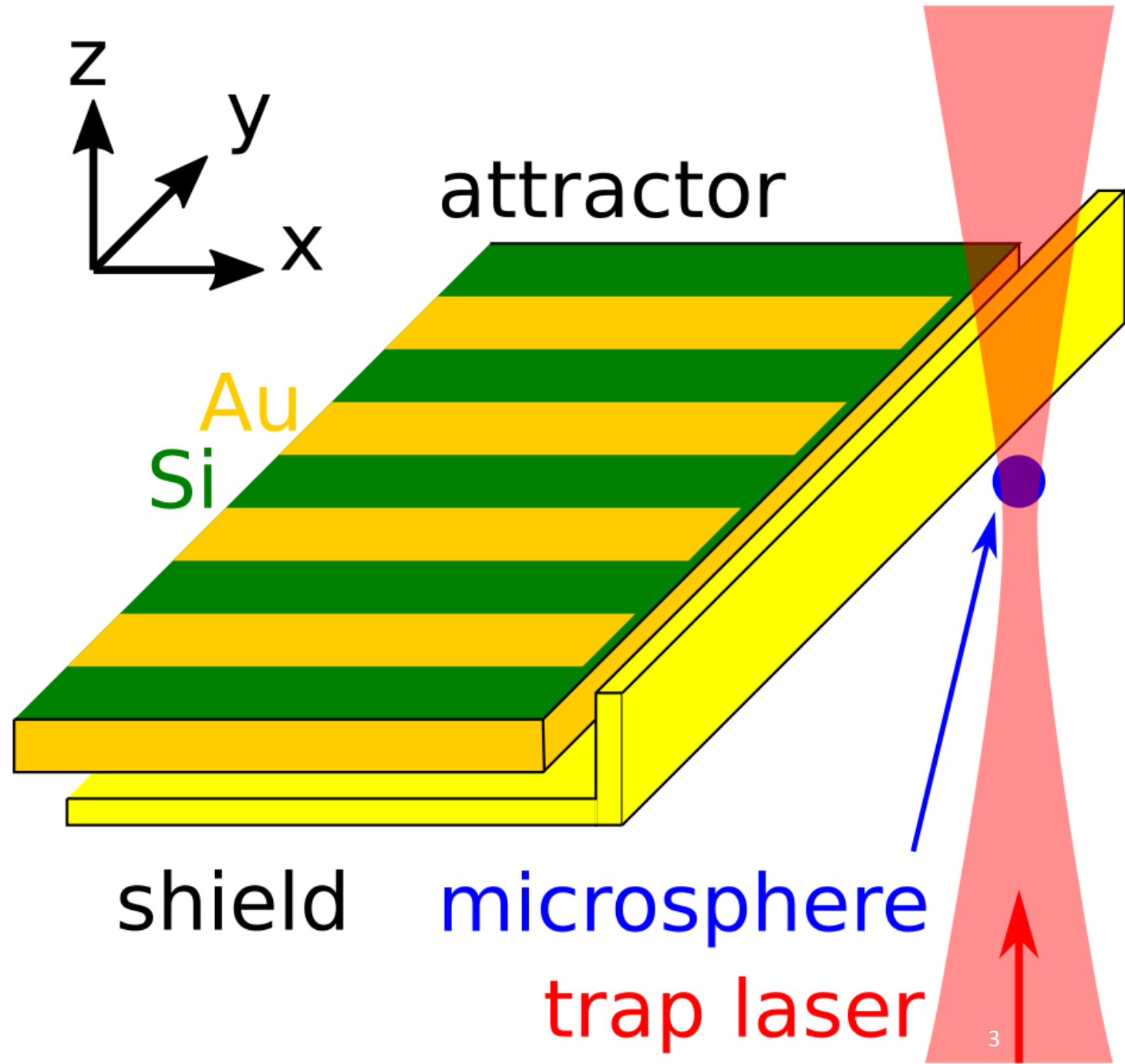
Modification of Newtonian gravity

- Many different motivations from the theory side
- Modified Newtonian gravity is traditionally modelled like

$$V(r) = -\frac{GMm}{r} (1 + \alpha e^{-r/\lambda})$$

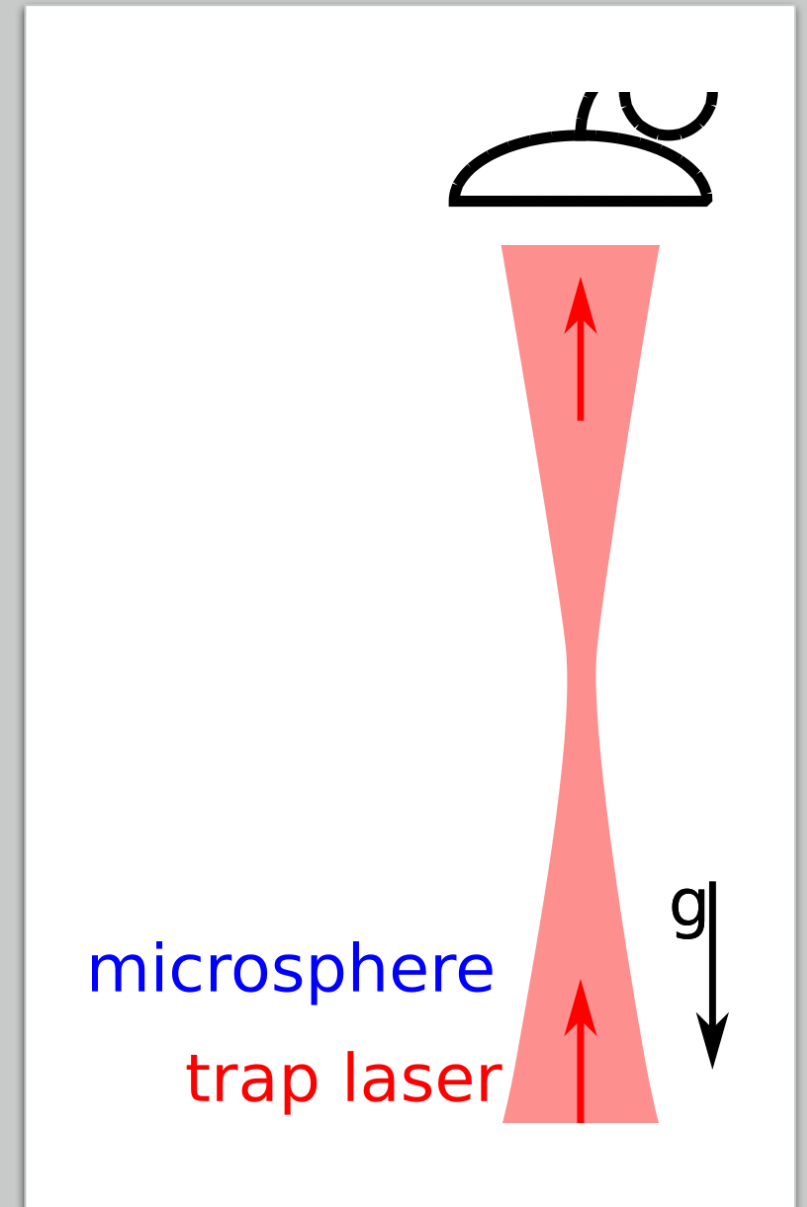


The experiment in one slide



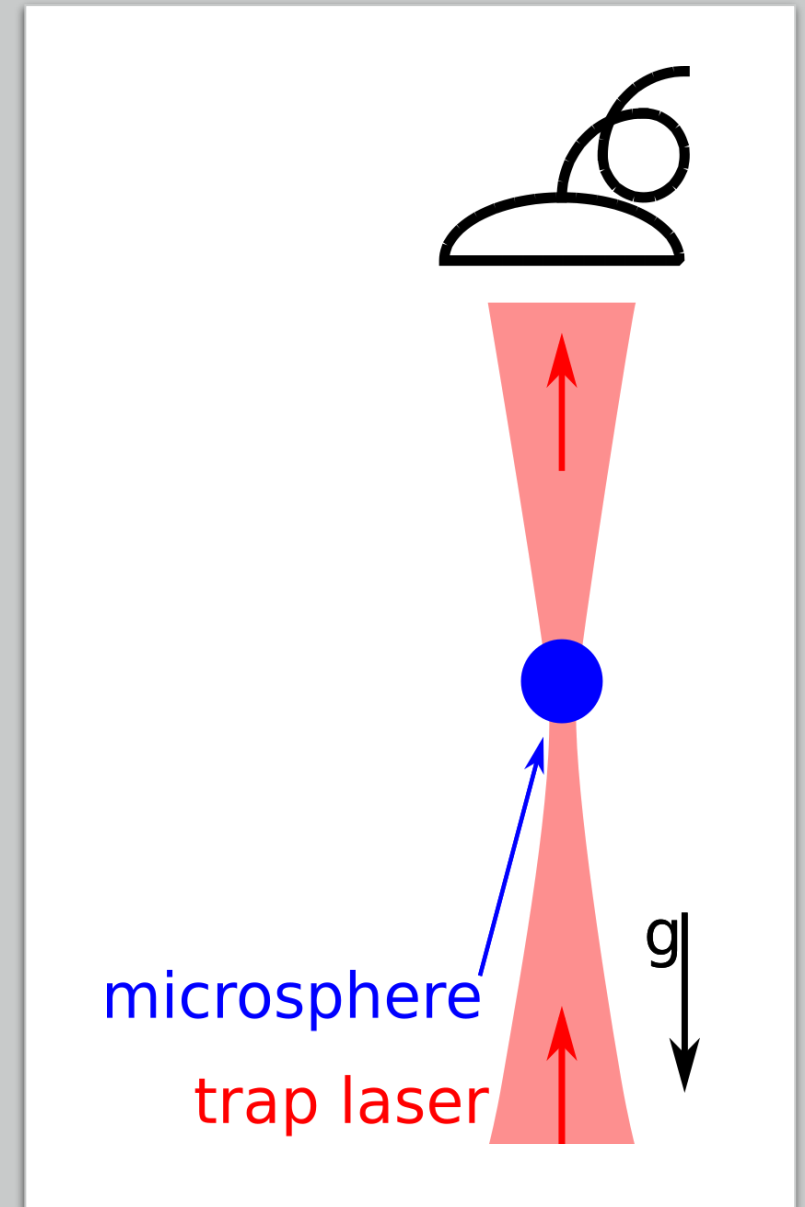
Detection principle

- Dielectric particles are attracted to the intense part of a laser beam



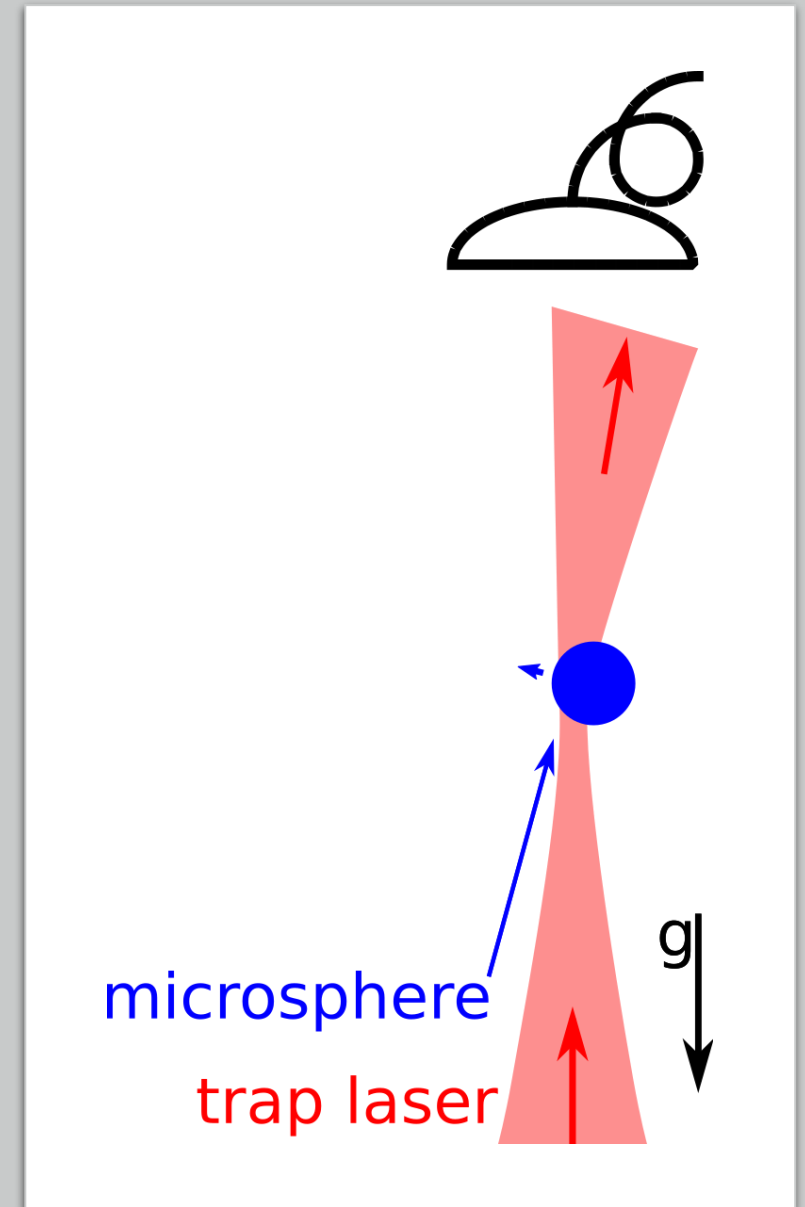
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- A laser beam propagating vertically-upward supports the particle against gravity



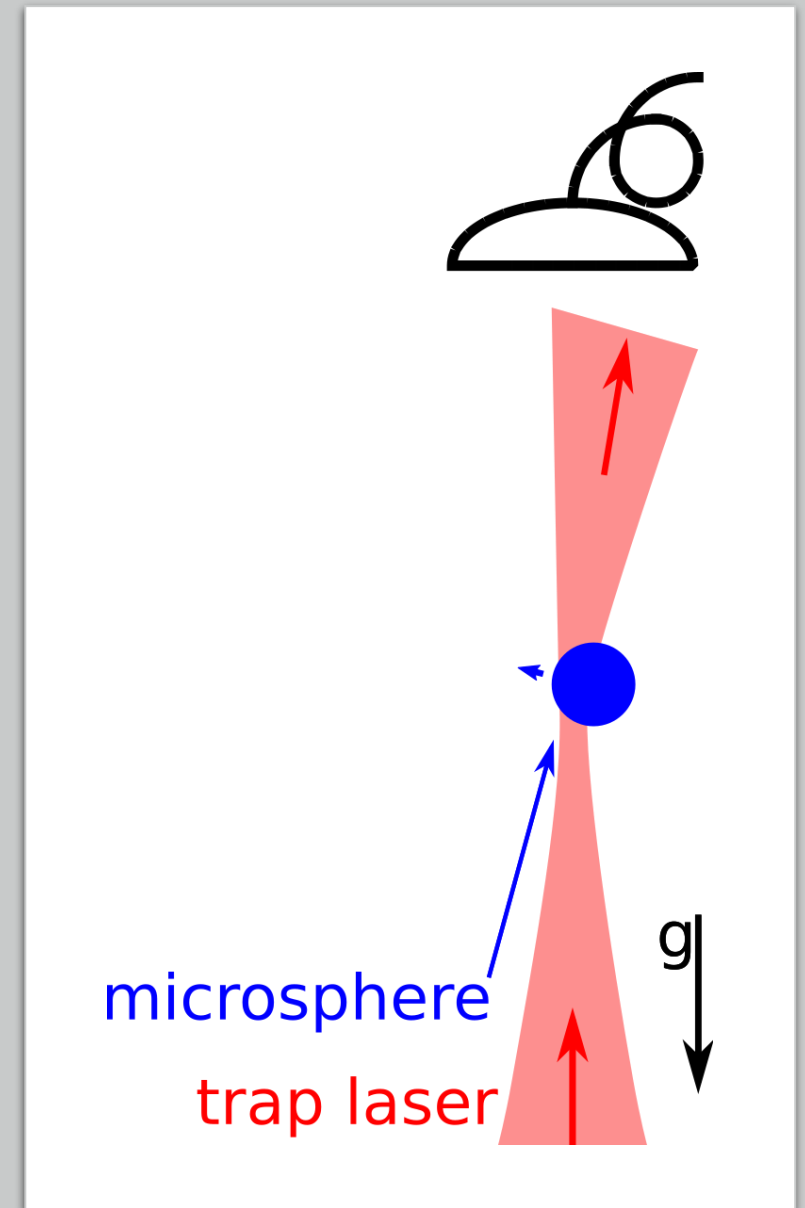
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⇒ trap is stable



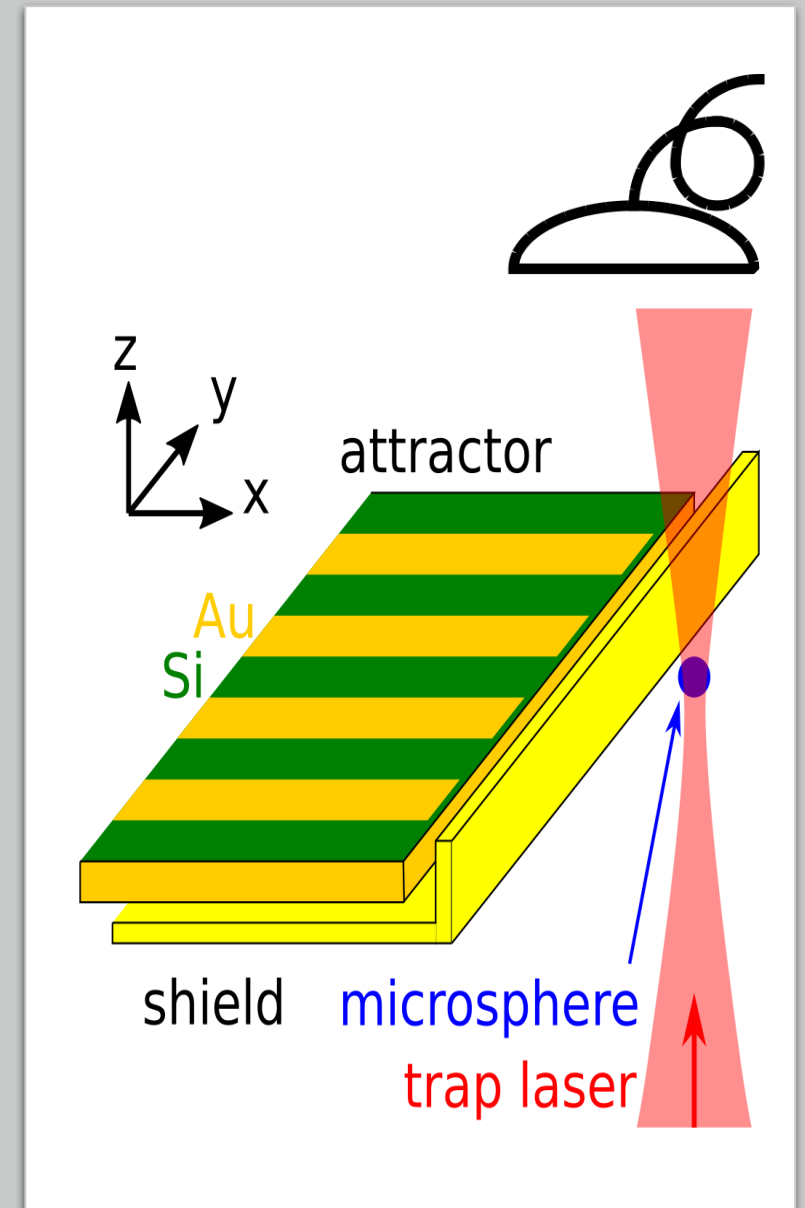
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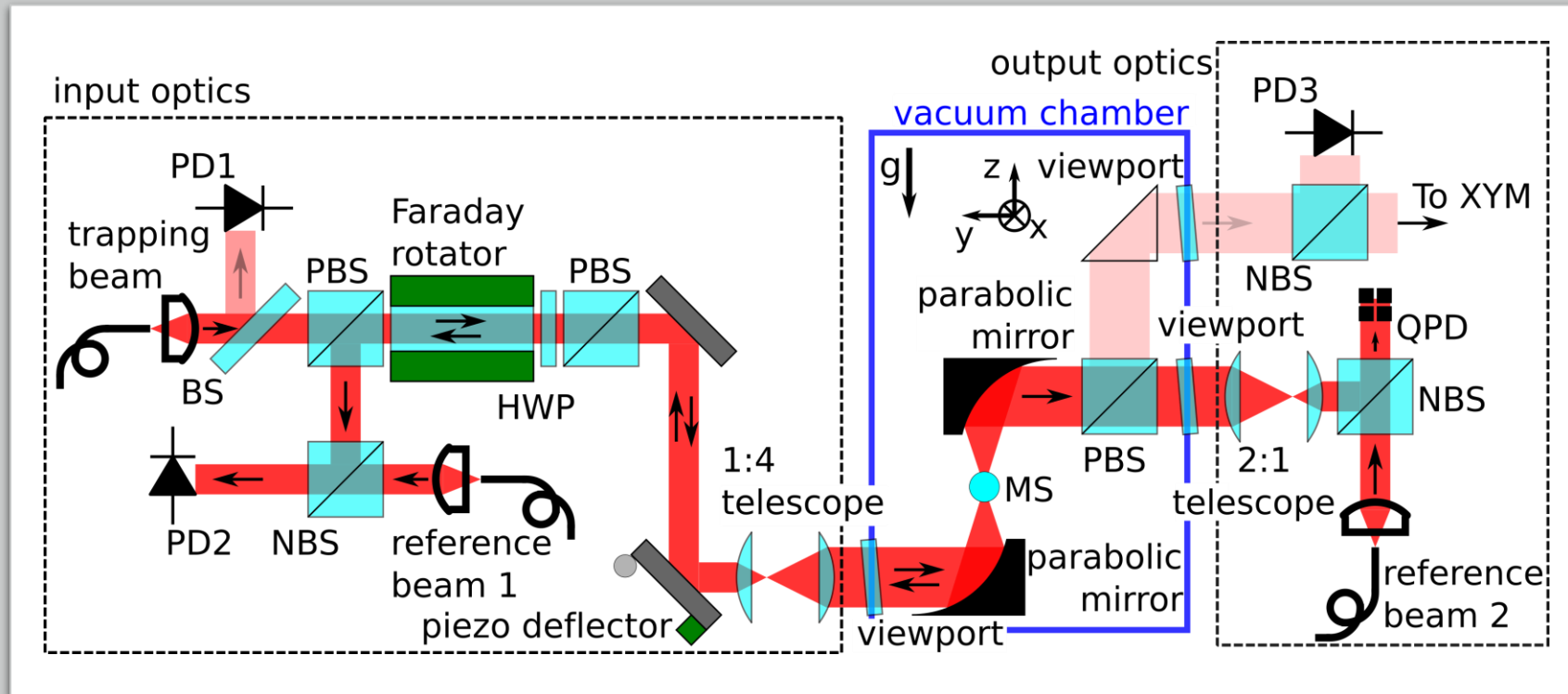
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- Measuring the output light turns this into a position/force sensor.
- An attractor is placed next to the sphere in order to generate gravitational attraction
- Shield is introduced to reduce electrostatic forces

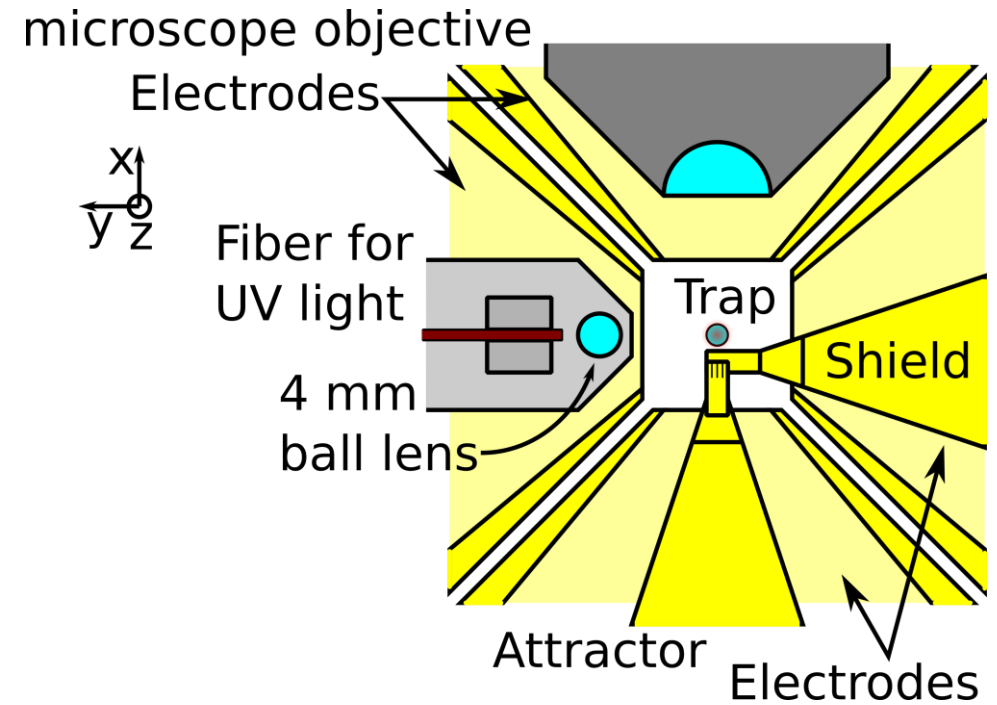
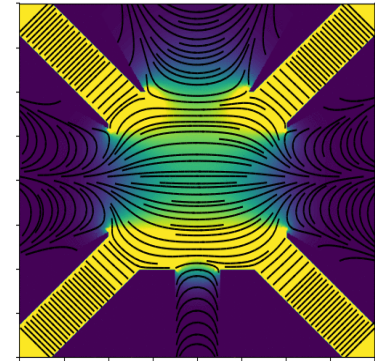
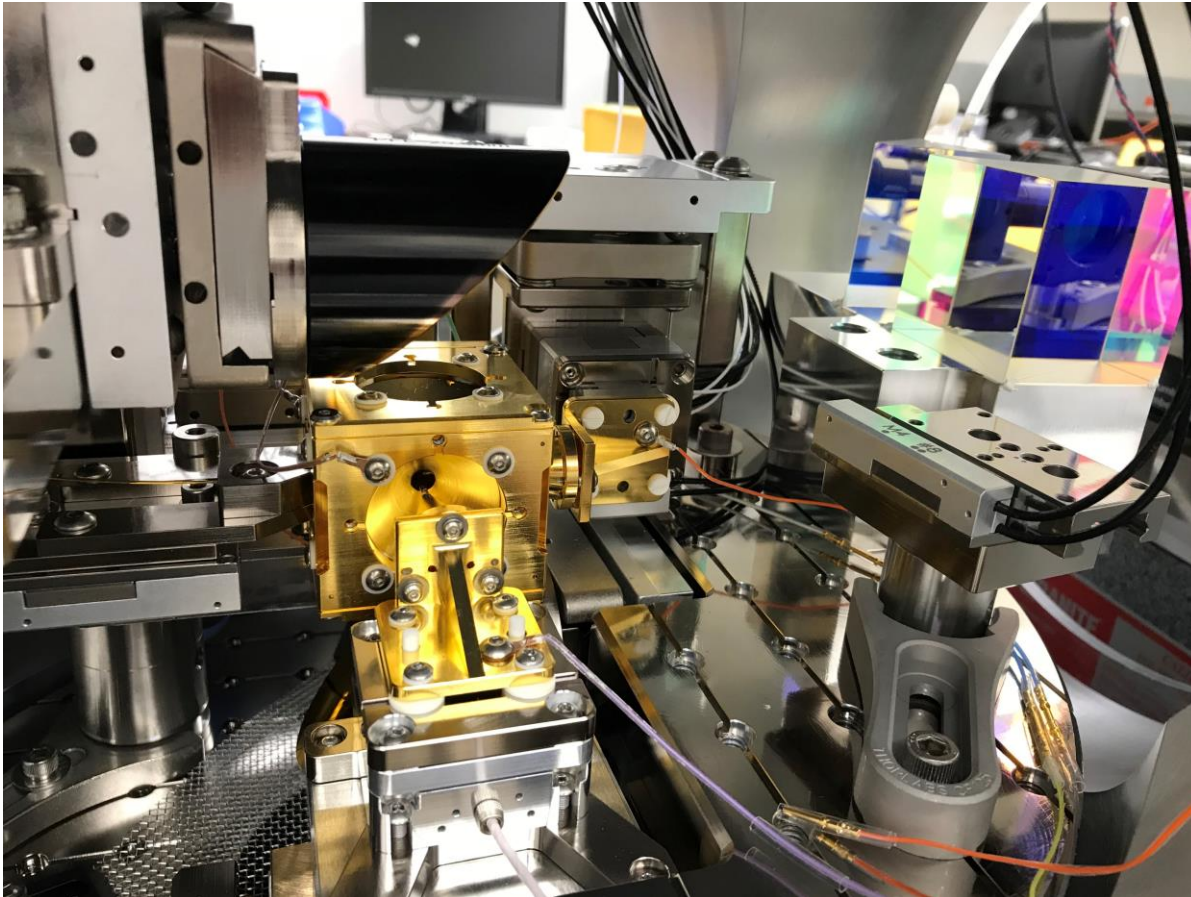




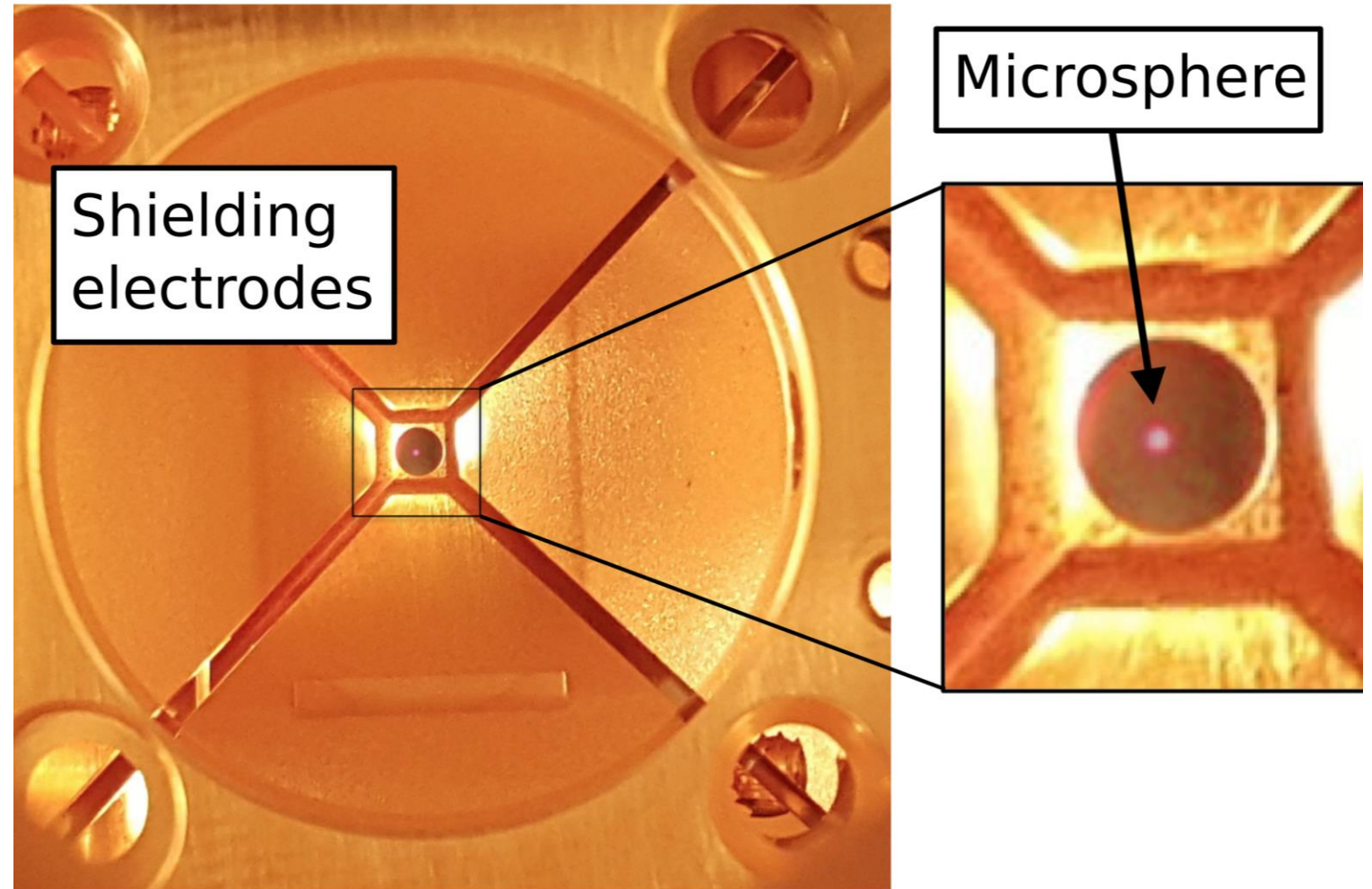
Detailed setup

- Vacuum in the chamber is 10^{-7} mbar
- Can trap $4.7 \mu\text{m}$ as well as $7.6 \mu\text{m}$ diameter microspheres
- Heterodyne detection method
- Active feedback cooling
- 3d position/sphere spin are recorded at 5kHz/20kHz
- Beam waist is $3.41 \mu\text{m}$

The vacuum chamber

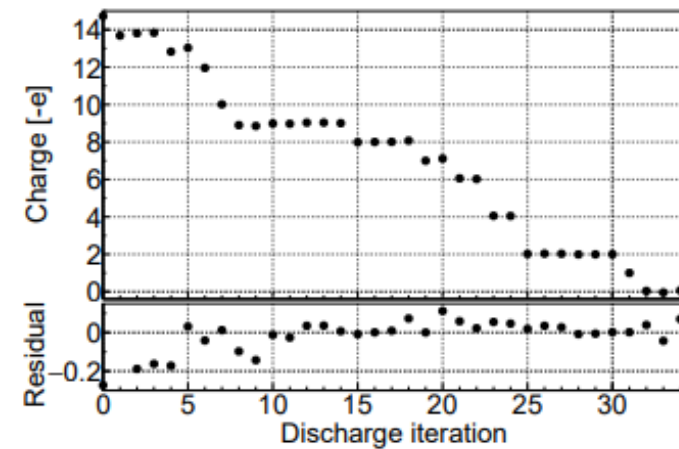
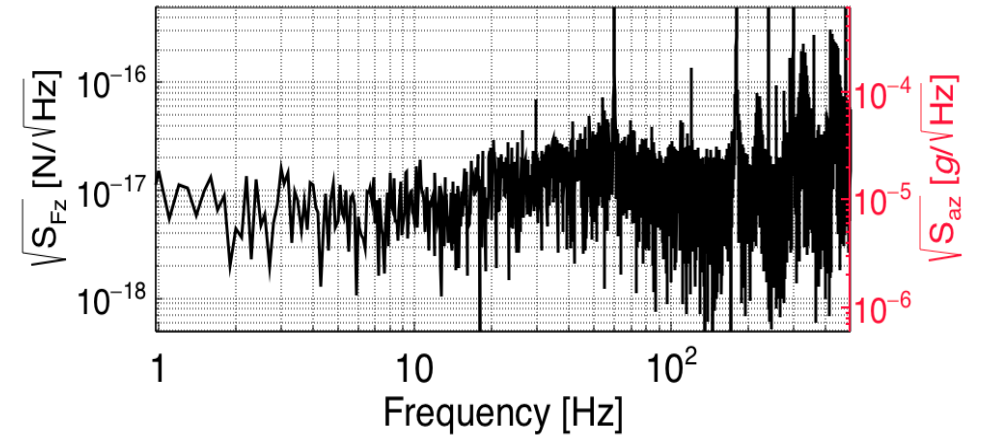


A trapped
microsphere



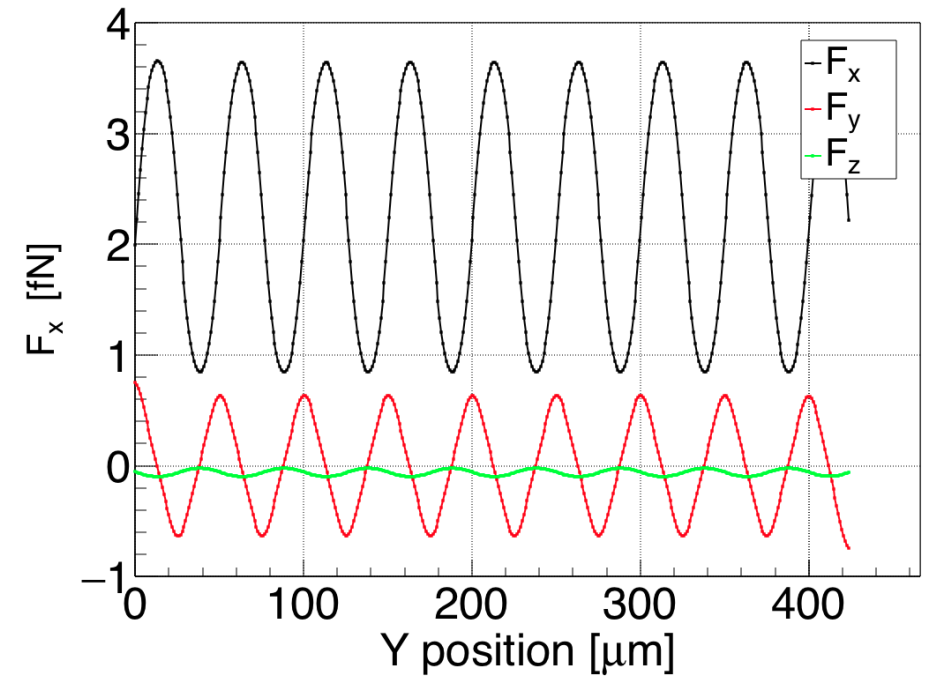
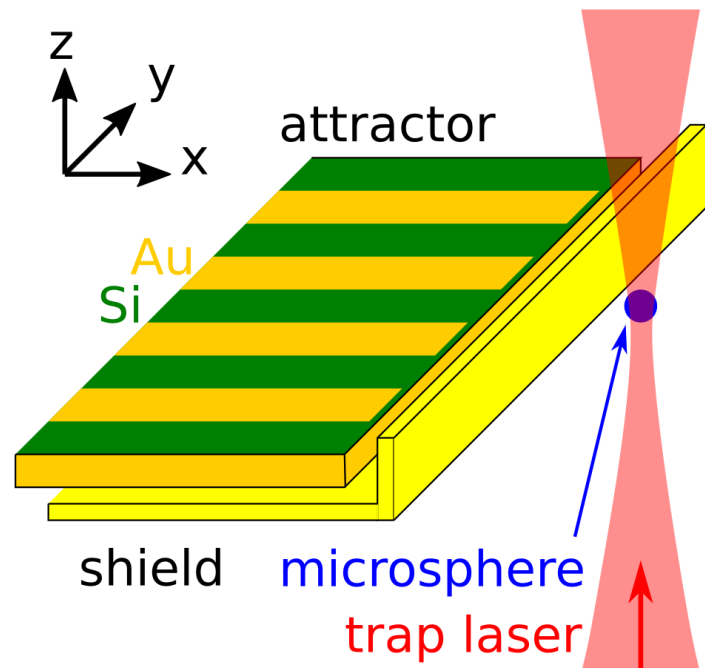
Force calibration and sensitivity

- Charge state of the sphere is controlled down to the single electron level
- This is used to perform force calibration on a sphere by sphere basis
- Response is stable to within 5%, and reproducible on the timescale of days
- Response is linear up to 500 e
- The noise floor is dominated by pointing fluctuations of the trapping and reference beams



Expected signal

- Simulated data for $d = 10 \mu\text{m}$, $\alpha = 10^{10}$, $\lambda = 5 \mu\text{m}$
- Position systematics are below $1 \mu\text{m}$
- Auxiliary microscopes are used for position estimation of relative position of the sphere as well

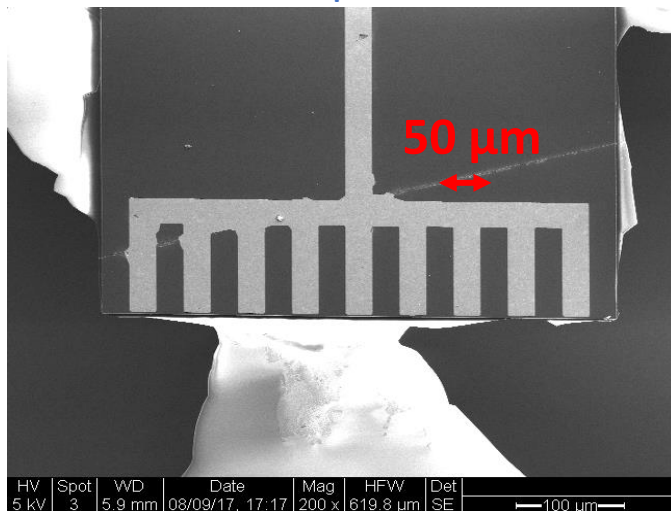


Nanofabrication

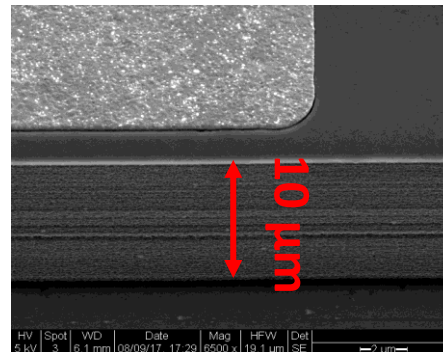
- Custom, in-house fabrication of attractor
 - Au-filled trenches in Si cantilever
- Both are gold coated
 - Minimize residual electrostatic interactions

Attractor

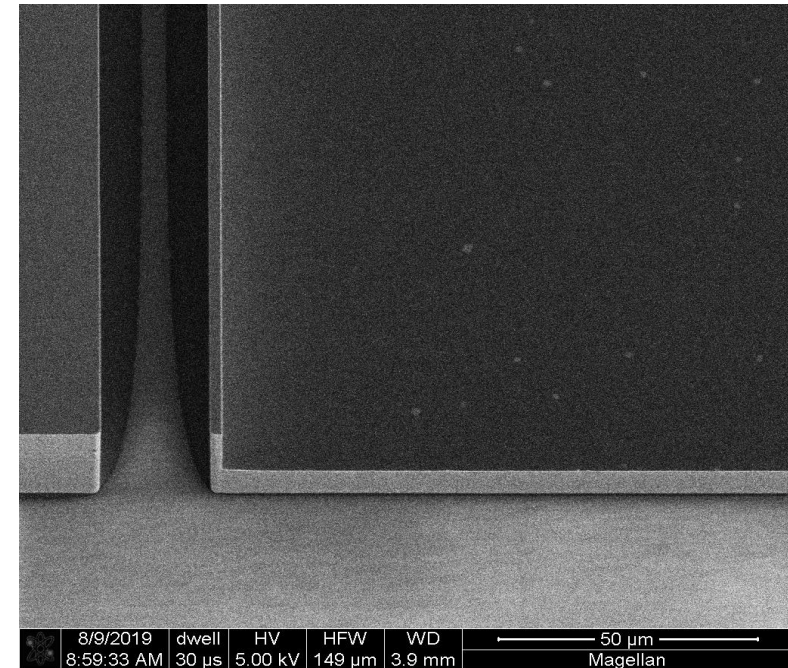
Top view



Side view



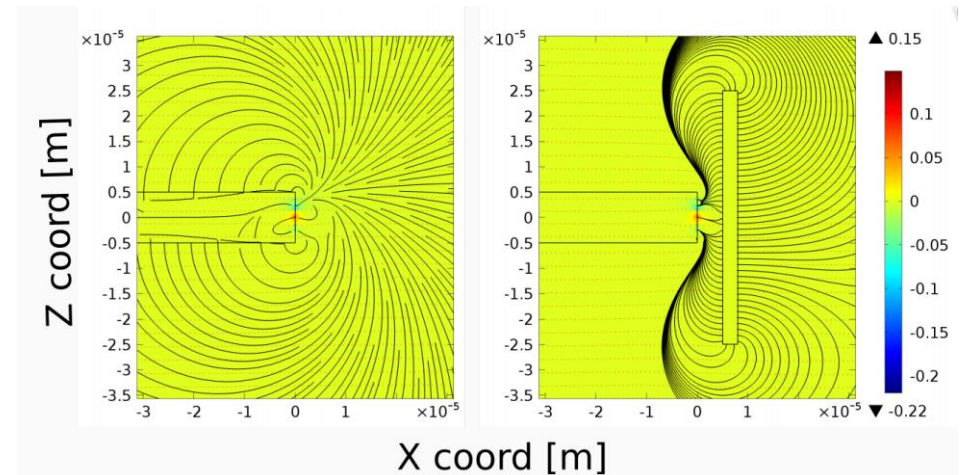
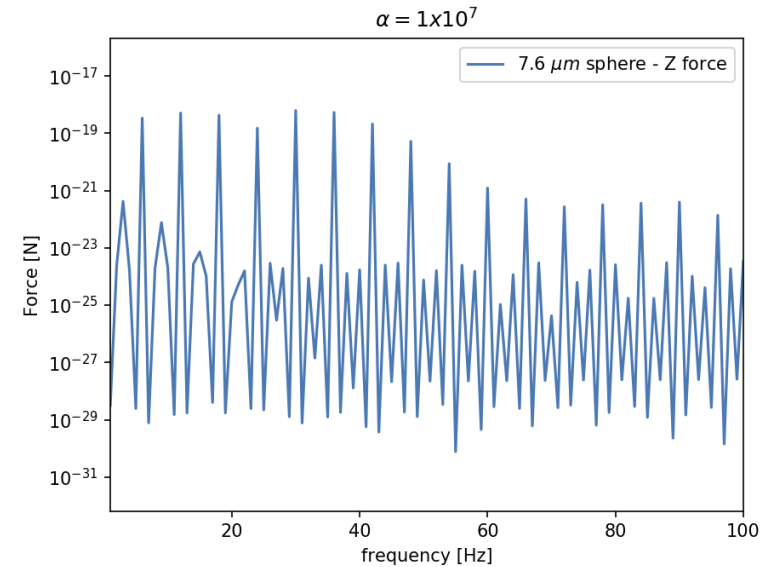
Shield



A taste of background mitigation

- Electrostatics
 - Neutral sphere
 - Sphere has EDM
 - Quasi-crystalline gold surface has micron scale grains with ~ 100 mV
- Scattered Light
 - Attractor clips the beam
 - Stray light
- Mitigation
 - Drive attractor along density modulation at f_0 , and observe correlated force at $f_0, 2f_0, 3f_0, \dots$
 - Shield

7/28/2020



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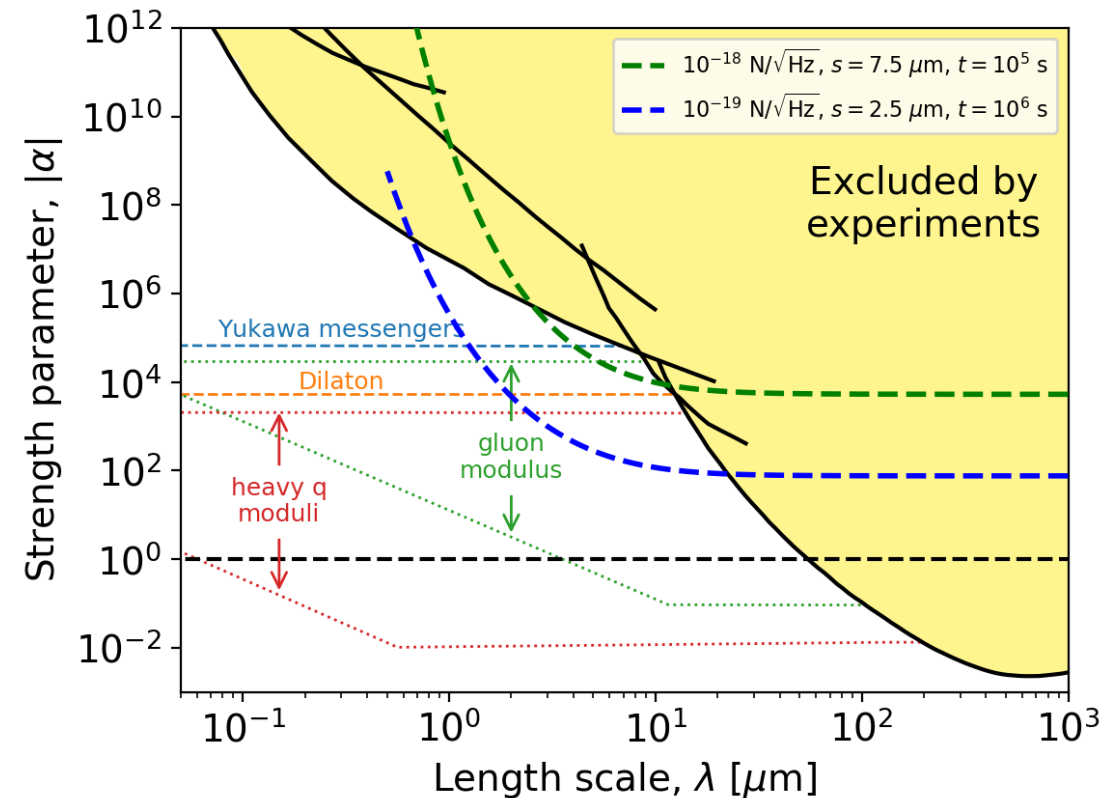
Conclusion and Outlook

Conclusion

- An apparatus to search for non-Newtonian gravity with optically-levitated microsphere had been built and characterized
- Performance of the force measurement is characterized, showing the sensitivity of $<10^{-17} \text{ N}/\sqrt{\text{Hz}}$

Outlook

- Certain amount of the data is taken, and analysis is ongoing
- With planned upgrades to stabilize the system and suppress noise level, we expect to suppress backgrounds sufficiently for a first competitive measurement.



Acknowledgment

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