HARVARD
School of Engineering and Applied Sciences

Measurement of sub-Femtonewton Optical Forces in Fluid

High-precision measurements at the thermal limit using a Brownian probe

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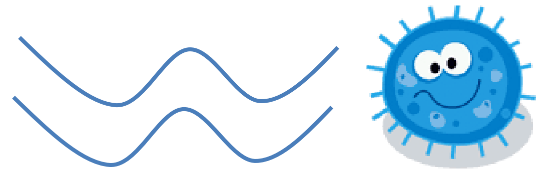
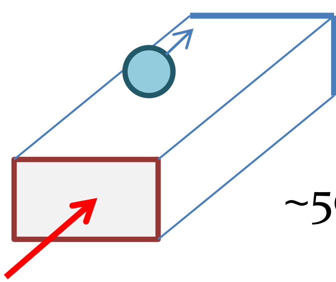
what's 1 fN?

optical force of sunlight on single cell

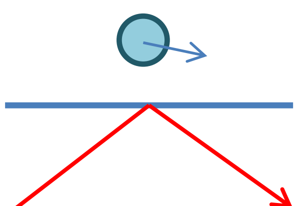


drag on bacterium moving through water



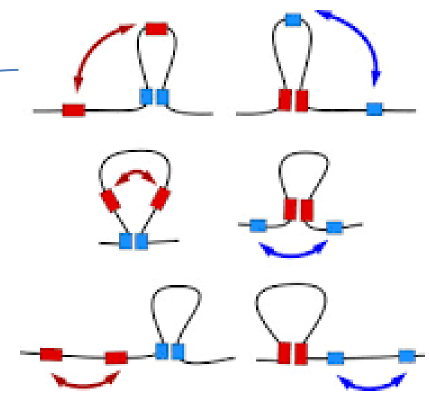
~50 fN

~10 fN



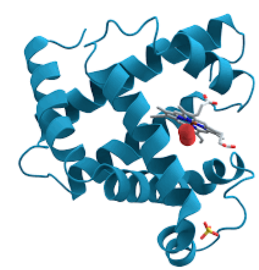
Forces in Optics

Forces in Biology



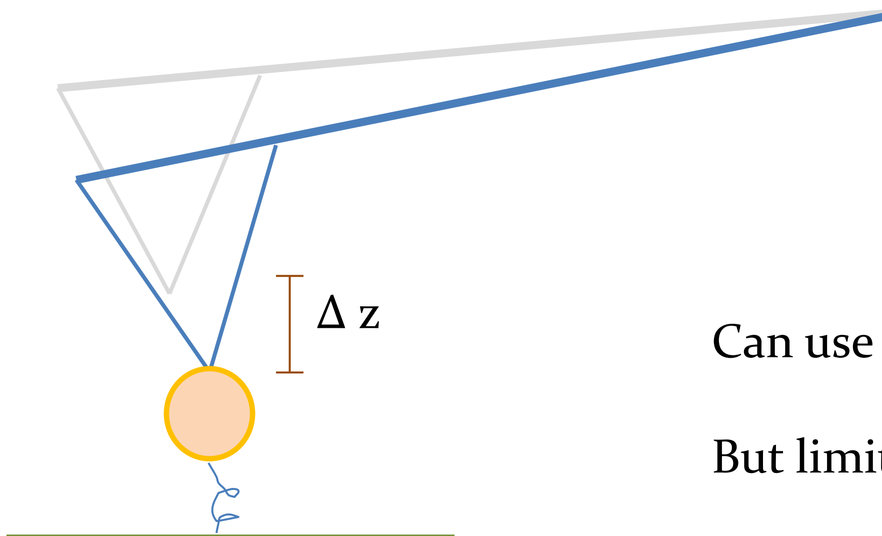
< 100 fN

Hfsp.org



~ 20 fN

AFM is the most commonly used instrument for performing force spectroscopy, but its sensitivity, especially in fluid, is limited



$$F = -K\Delta Z$$

Can use more compliant cantilever

But limited by thermal noise

Force Sensitivity: ~ 0.1-1 pN

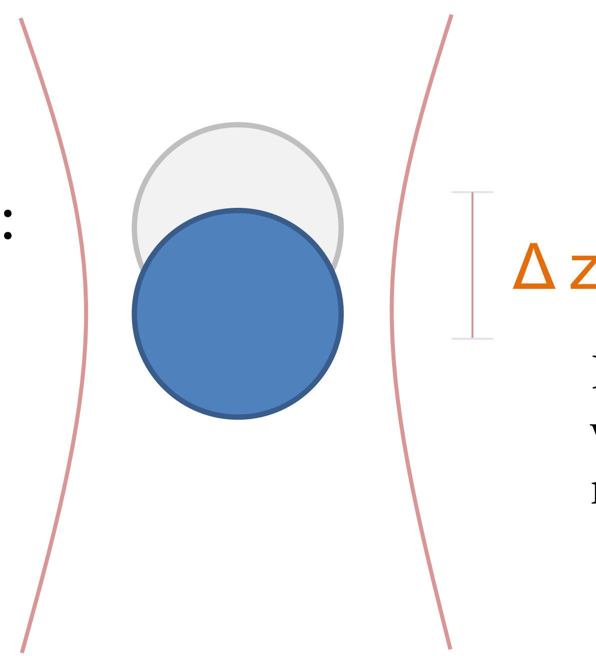
Thermal fluctuations is a dominant noise source at these scales

$$S_F^{th} = 2\gamma k T$$

Fluctuation-dissipation theorem:
Thermal noise scales with drag

Drag in liquid many times drag in air

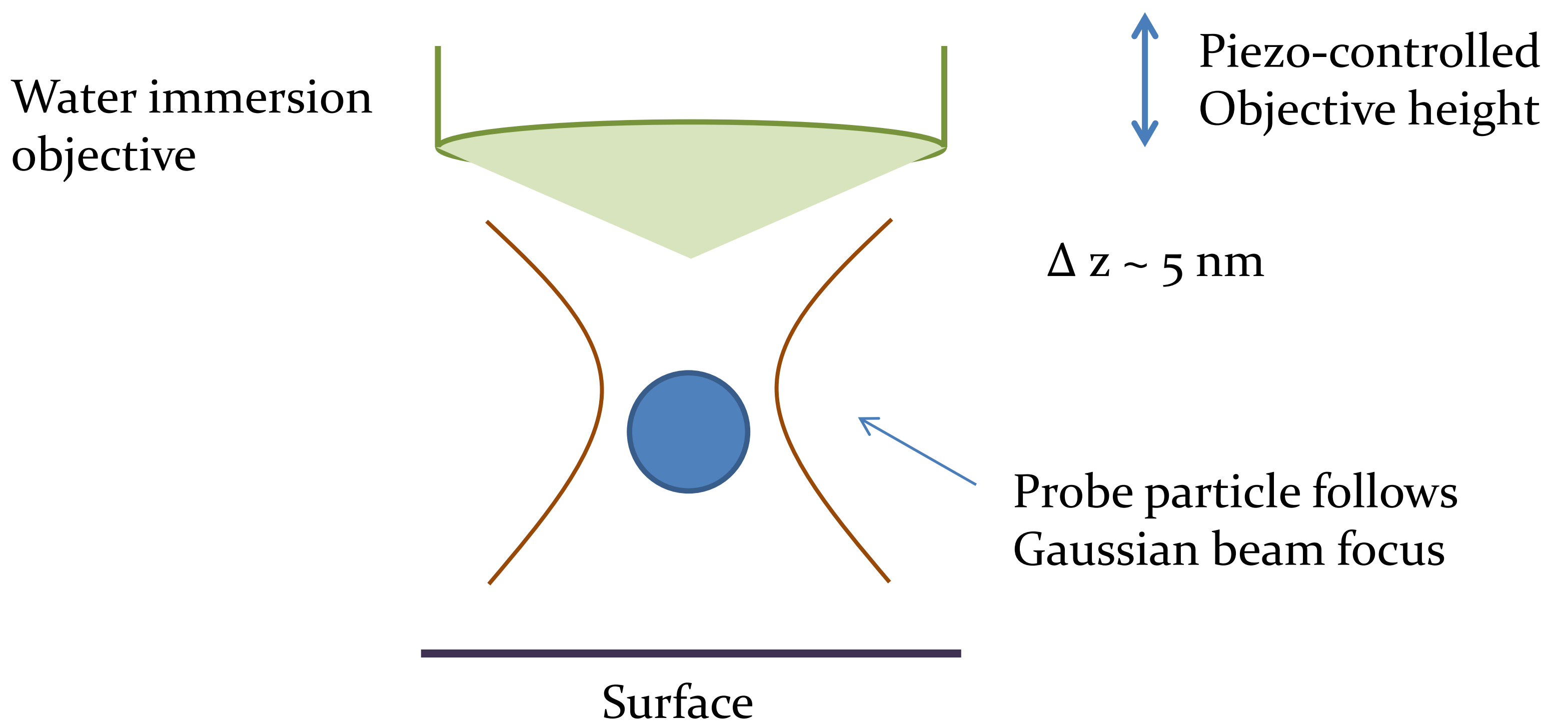
1. Reduce the thermal limit:



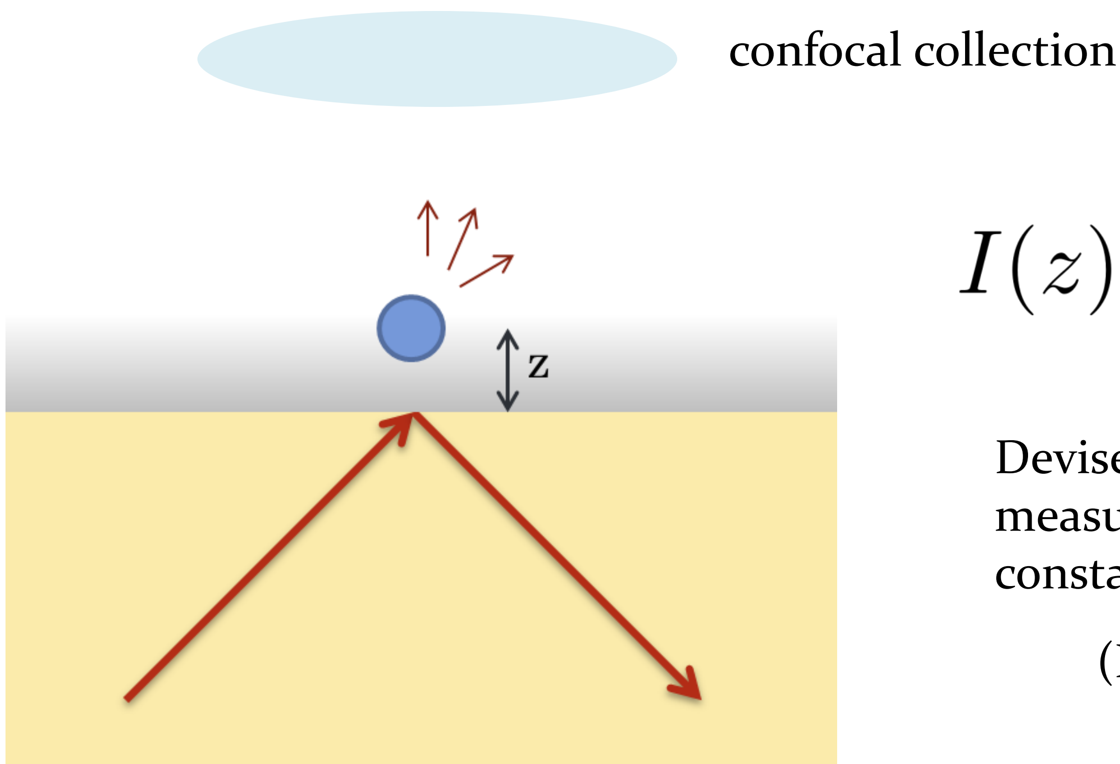
Replace AFM cantilever with optically trapped microsphere (PFM)

D. Prieve
E-L Florin

2. Scan focus of optical tweezer to precisely position trapped bead



3. Use light scattered from an evanescent wave to track particle position at ~ 1 ms time scale



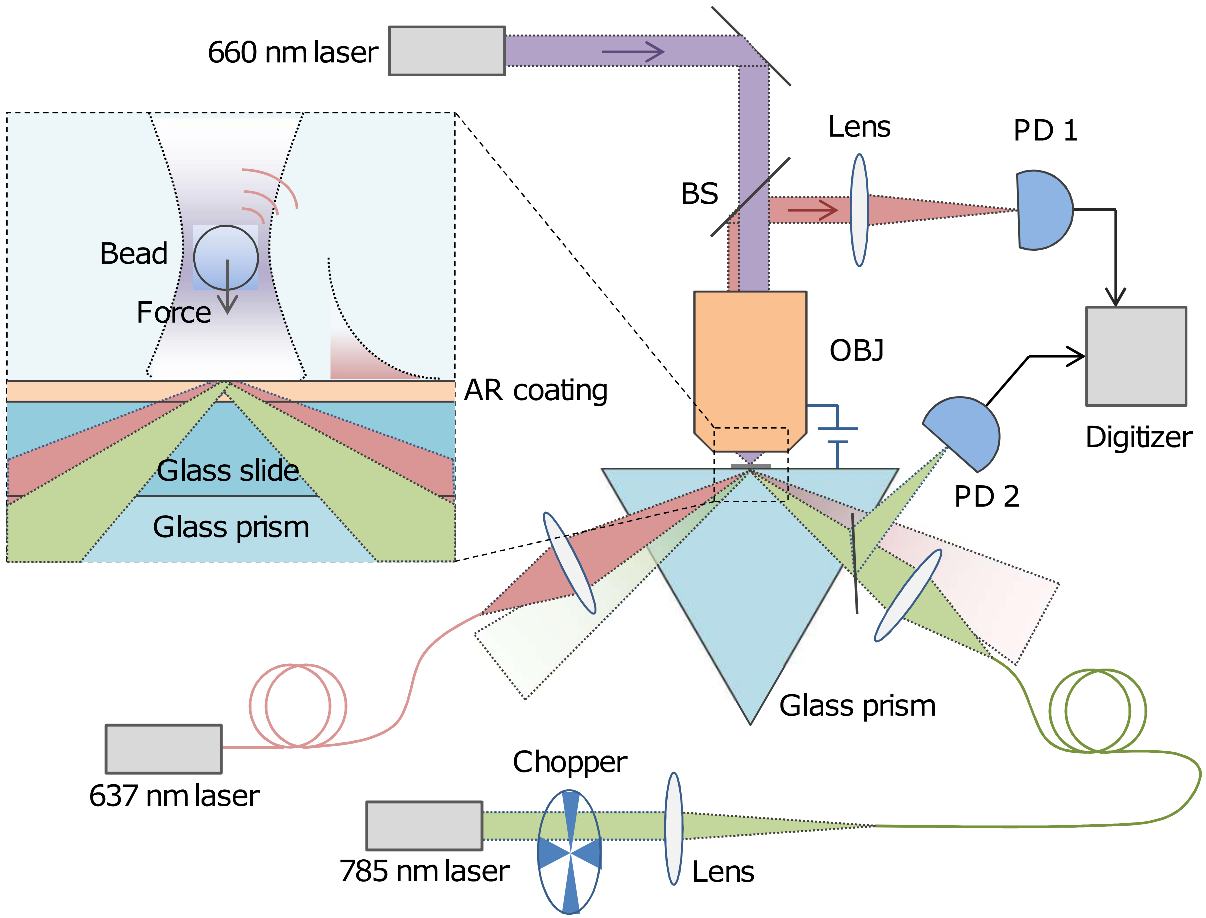
$$I(z) = I_0 e^{-\beta z} + C$$

Devised method to directly measure each calibration constant:

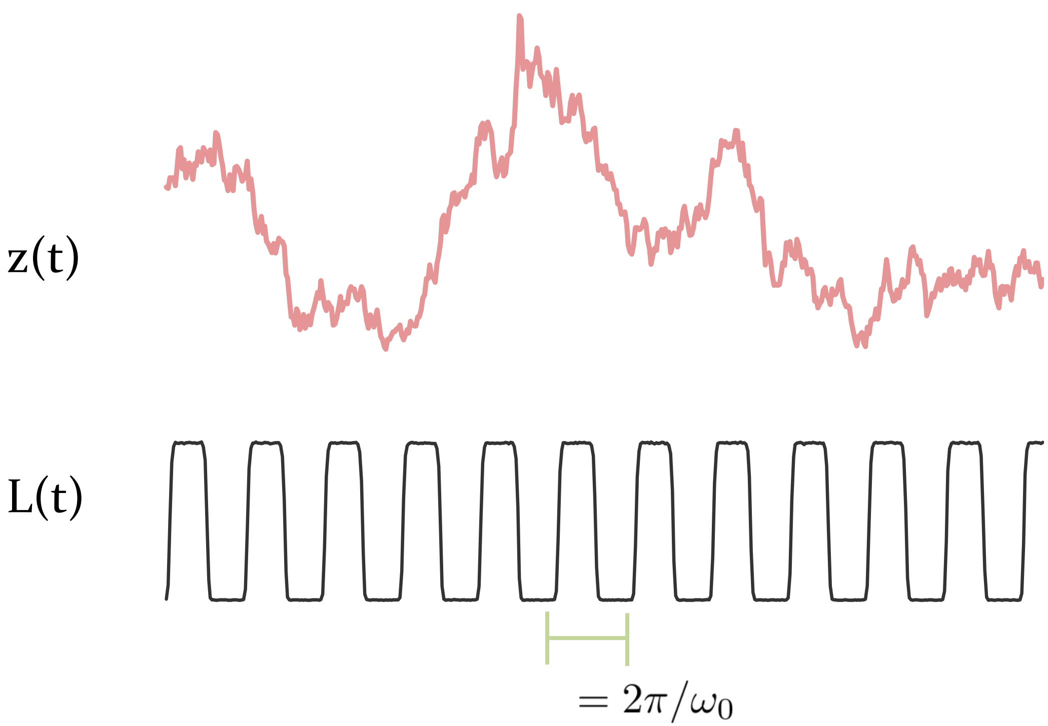
(Liu, L. (2014). PNAS)

(Prieve, et al)

4. Use another totally internally reflected beam to generate attractive gradient optical force



5. Modulate optical force with chopper and use lock-in detection to extract response amplitude & phase



$$\tilde{z}_{tot}(\omega) = \tilde{z}_B(\omega) + \tilde{z}_{ext}(\omega)$$

noise

Response Amplitude: $\left|\tilde{z}_{ext}(\omega_0)\right|$

Response Phase: $\mathrm{Arg}[\tilde{z}_{ext}(\omega_0)]$

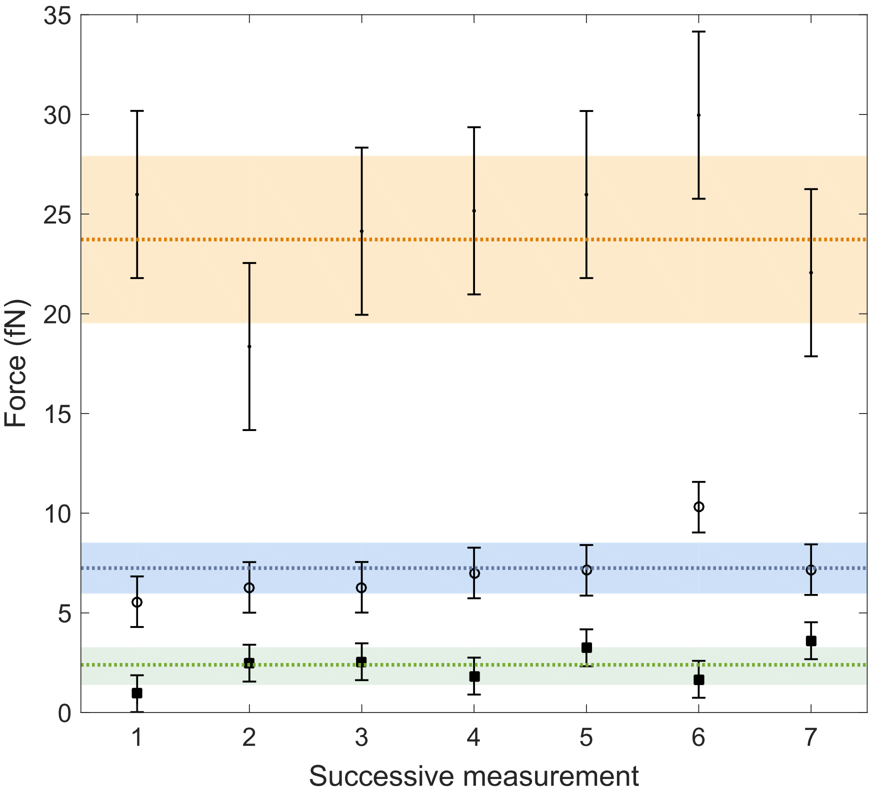
Avoid 1/f noise, avoid noise peaks

Etc.

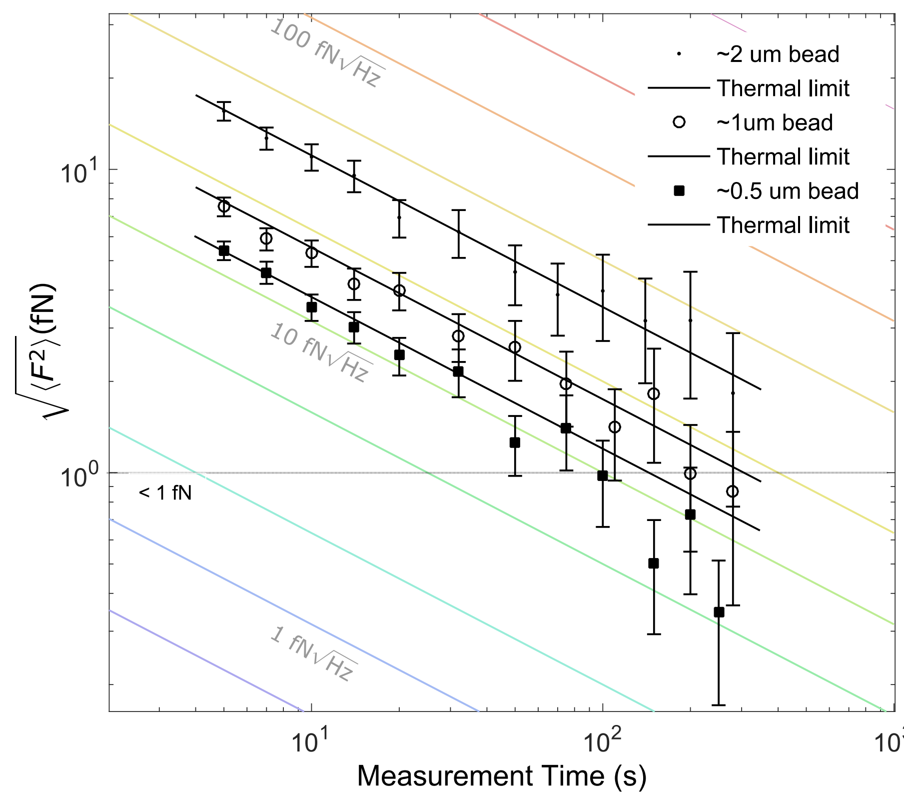
For more details:

Liu, L., Kheifets, S., Ginis, V., & Capasso, F. (2016). PRL

Measured noise agrees with thermal limit predictions

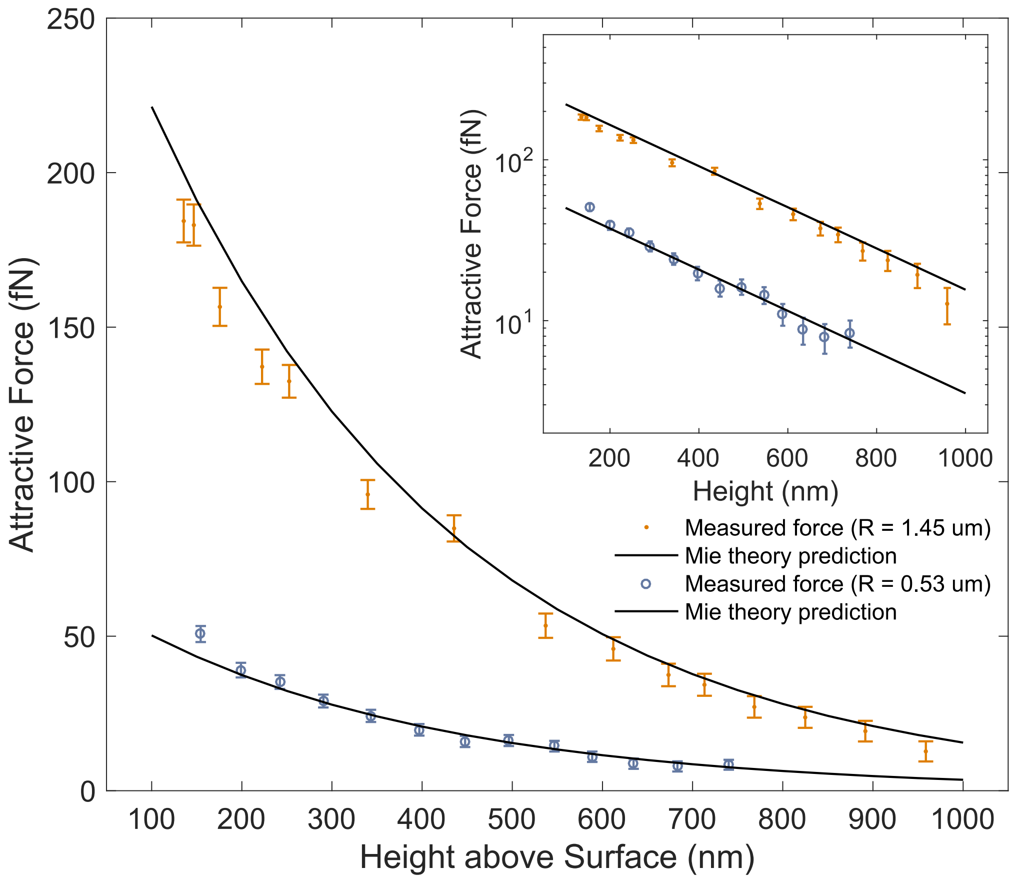


(a)



(b)

Measured F(z) agrees quantitatively with Mie Theory predictions

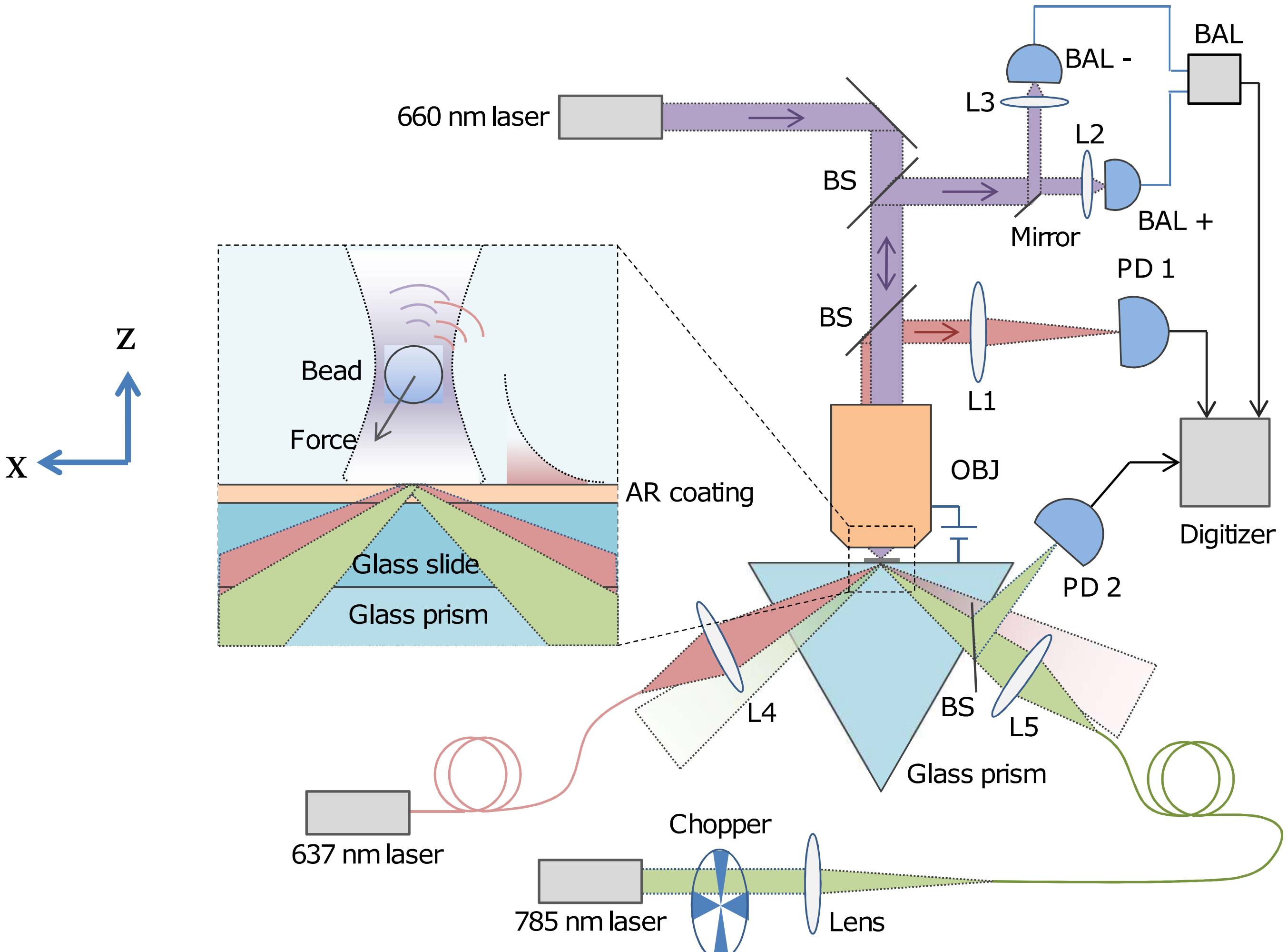


Summary

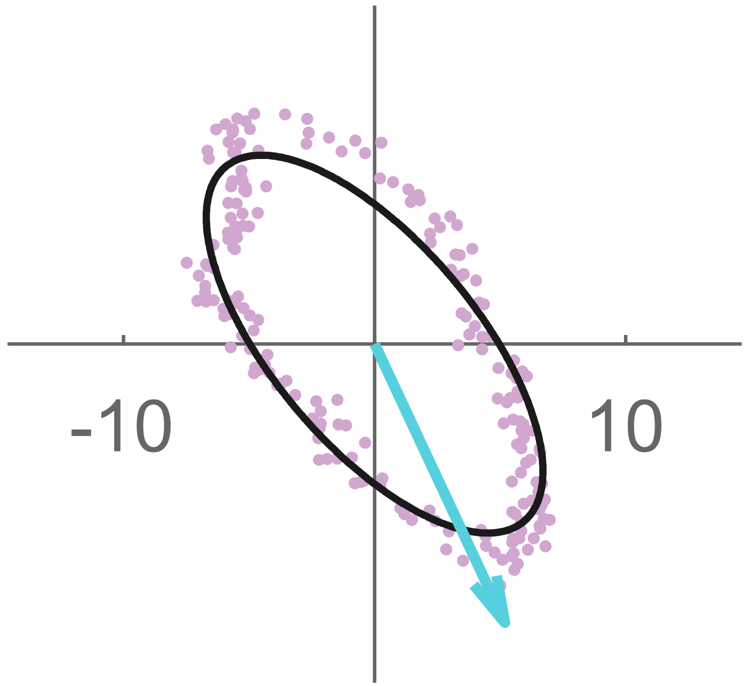
- > 100x improvement in sensitivity (N/sqrt(Hz)) over previous methods (including PFM and AFM methods)

- First quantitative confirmation of Mie theory for forces from evanescent field.

For continuing work we added another dimension of detection



Discovered some interesting dynamics due to near-surface anisotropy



Paper in progess,
come talk to me!