PHY 4803L Presentation
Optical Tweezers

Mitchell Kelly Junhao Zhang

April 25, 2023

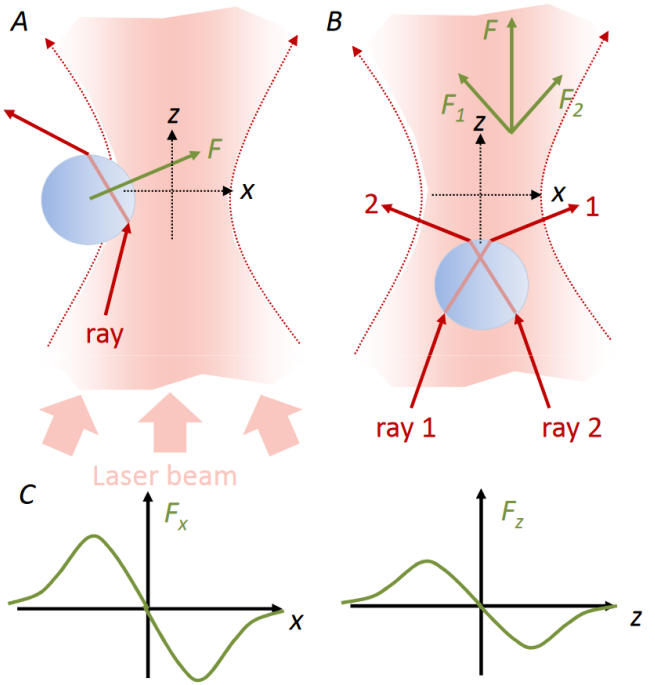
Theory

1. Photon scattering from the laser creates two forces
   - a gradient restoring force towards laser focus obeying Hooke's Law,
   - a weak scattering force in the beam direction.
2. The molecules of the solution propagate randomly, which creates a collision force on the particle

$$F_c(t) = F_{\text{drag}}(t) + F_{\text{Brownian}}(t).$$

3. Because the Brownian force is a randomly fluctuating function of time, it's easiest to find the Fourier Transform of the function in the form of

$$P_F(f) = \frac{\tilde{F}(f)\tilde{F}^*(f)}{\tau}.$$



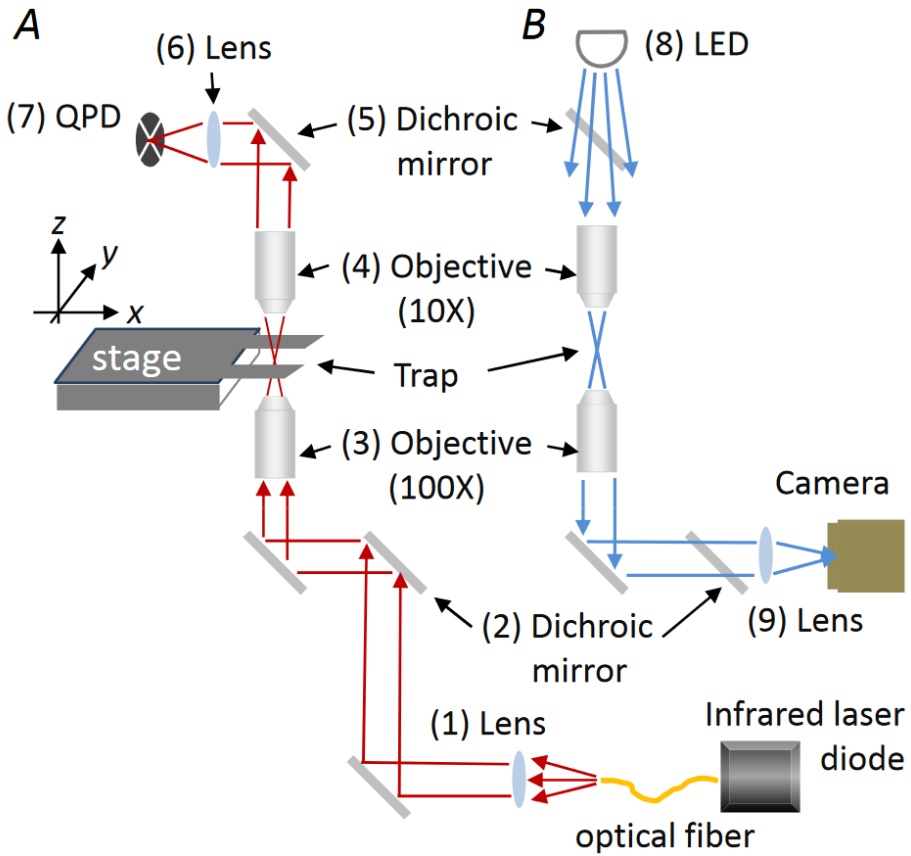
The force diagrams of a particle in the force gradient, offset A) in the x-axis, and B) in the z-axis.

Apparatus

1. The quadrant photodiode detector (QPD) uses four photodiodes to detect the position of the particle and produces voltage linear to the particle displacement in the form of

$$V = \beta x.$$

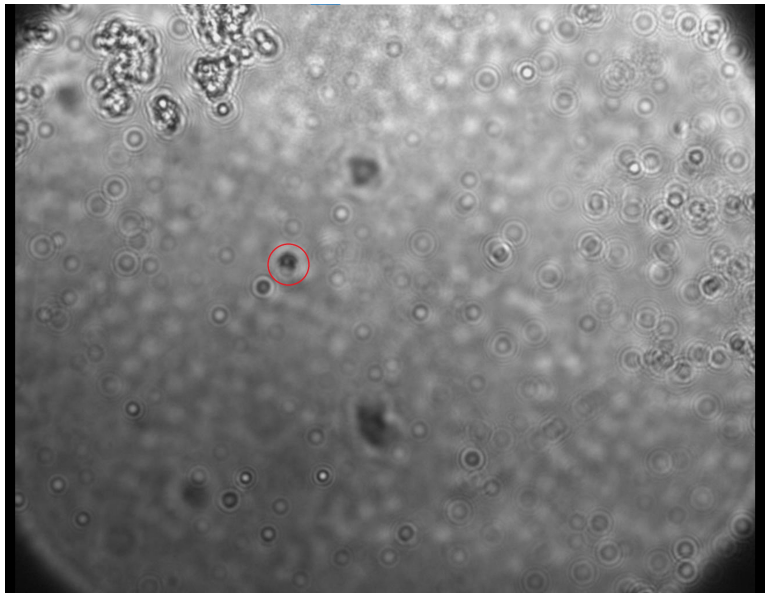
2. The stage is controlled by piezos in the three axes, where precise movements are made using strain feedback, since the piezos have strong hysteresis and its voltage is not linear with displacement.



The A) infrared and B) visible light path in the experimental apparatus.

Sample Sphere Preparation

1. A 1:225,000 dilution (1:150^2 and 1:10) was performed using deionized water (DI) or 1M NaCl with 1.2 µm Silica sphere stock solution
   - 1:225,000 DI dilution for trapped sphere analysis
   - 1:150 DI and 1:1500 1M NaCl dilutions for stuck sphere experiments
   - Vortex mixing before each subsequent dilution
2. Ibidi Slide
   - Insertion
   - Oil immersion
   - Microscope Focus



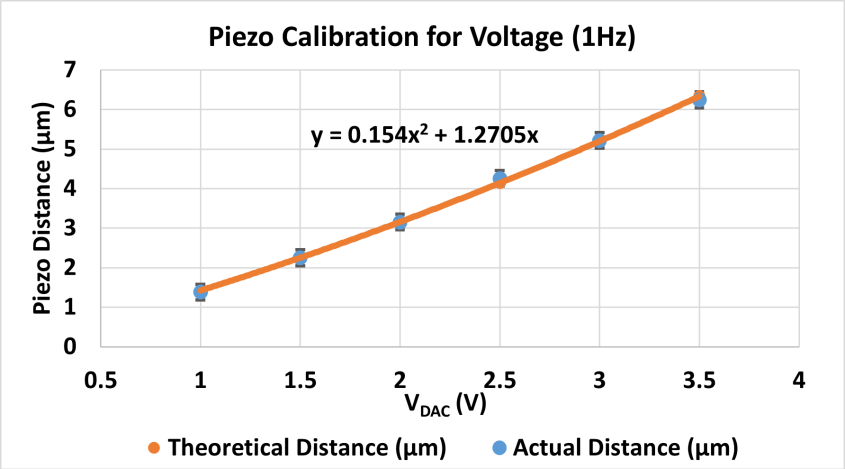
Silica Sphere Trapping Video: Movement from bottom to top of Ibidi channel.
`https://youtu.be/LRHb7kd4cMs`

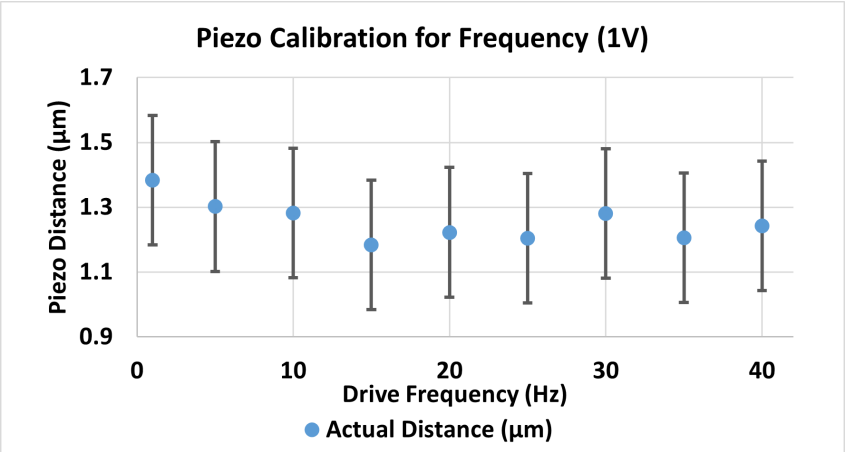
Piezo Calibration

1. Tweezers Program sinusoidally oscillates slide with known frequency and amplitude in the x-axis.
   - Voltage: $1 \rightarrow 3.5$ V
   - Frequency: $1 \rightarrow 40$ Hz
2. V_{DAC} Fitting Equation:

$$A = a_1 V_{\text{DAC}} + a_2 V_{\text{DAC}}^2$$

3. There is no frequency dependence on the piezo distance, within the error bounds.



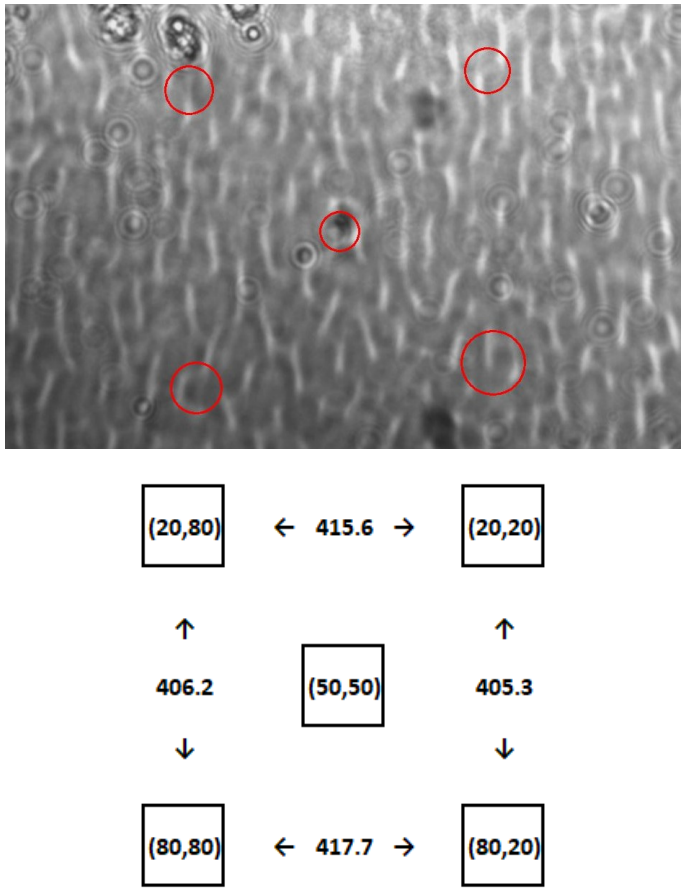


Voltage and frequency dependence of piezo drive.

QPD Calibration

1. The raster program runs using the parameter piezo strain percentage, which must be calibrated to actual distance.
2. Using the pixel distance at $\pm 30\%$ strain, we found the following conversion of μm traveled per % of strain of a stuck sphere:

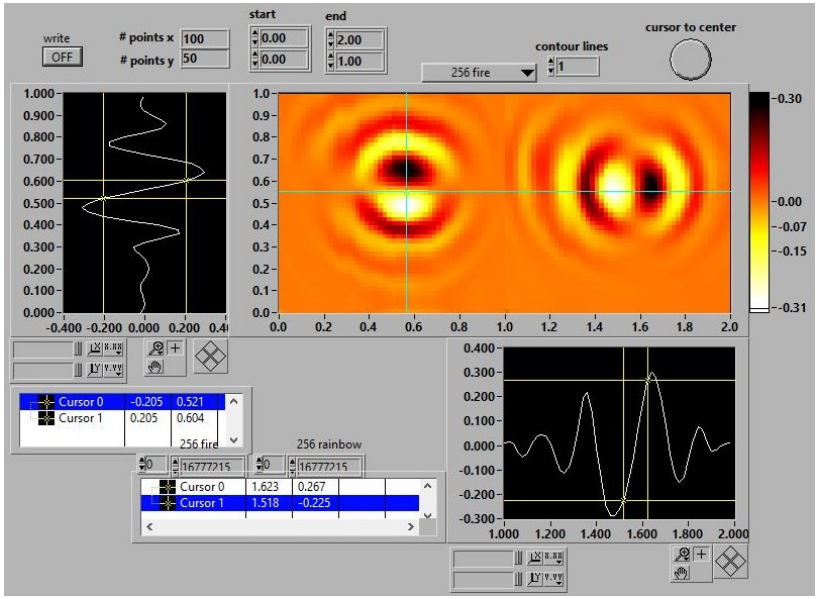
Axis	μm/% strain	% Error
x	0.833	1.70%
y	0.812	1.73%



Pixel distance between various strain inputs.

QPD Raster Scan

1. The program scans the $\pm 15\%$ strain range, and measures the QPD voltage at each point.
2. To find the detector constant β in each axis, we look at slices in each axis and find the slope in the linear regime.
3. We looked at the detector constants at 60 mW vs. 30 mW laser power, and also at the top and bottom of the Ibidi channel.

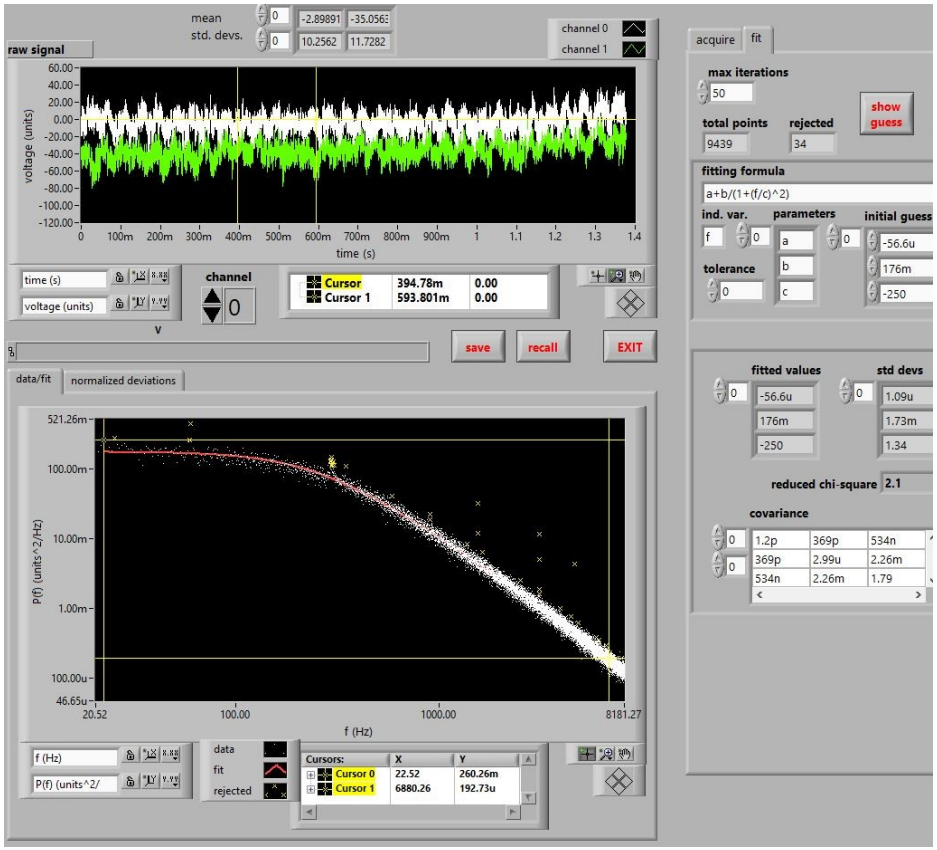


QPD Raster scan of the silica sphere at the top of the channel.

Power	Position	β in x	β in y
30mW	Middle	32.5 ± 7.1	22.4 ± 4.9
60mW	Top	173.2 ± 20.3	178.0 ± 20.9
	Middle	122.7 ± 14.4	118.8 ± 13.9
	Bottom	65.9 ± 7.7	64.8 ± 7.6

Full Trap Experiment

1. Using a trapped sphere, we can calculate various parameters regarding the tweezers system:
   - Detector constant β
   - Drag Coefficient γ
   - Trap stiffness k
2. Driving the stage at 23.25 Hz, we oscillate the sample at an amplitude of 0.1 µm and fit the power spectrum to the known model for Brownian motion.

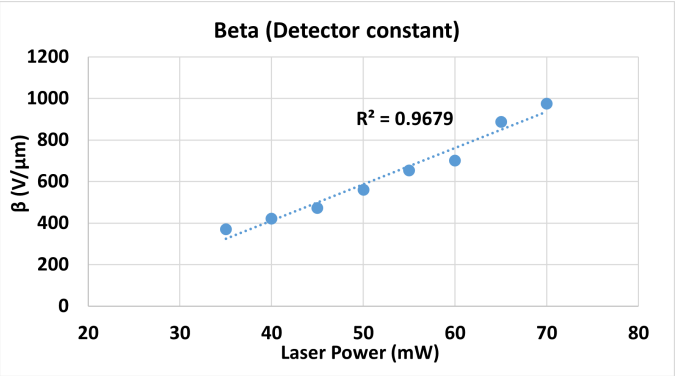


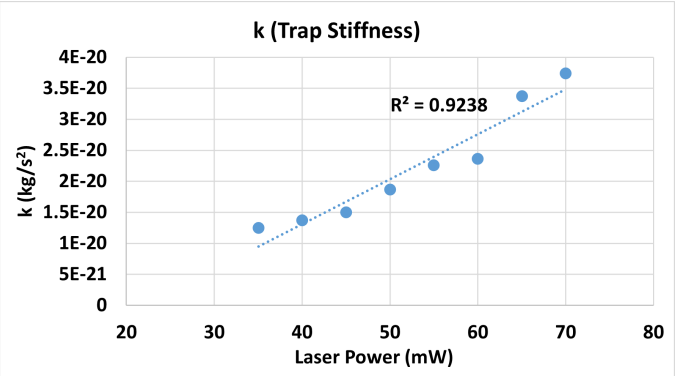
PSD analysis software showing the power spectrum and the fitting parameters.

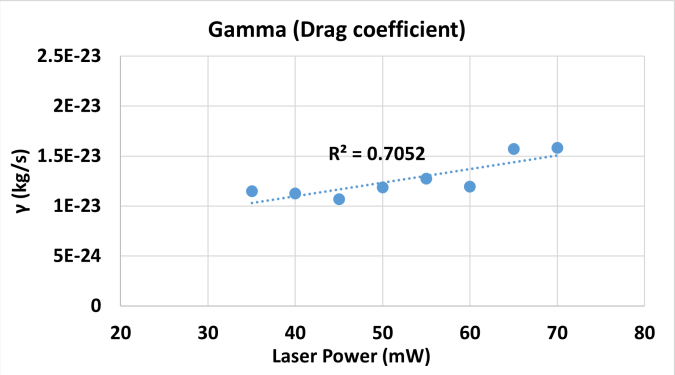
Full Trap Results

1. The detector constant β increases with laser power, since the QPD's voltage is linear to the total amount of light.
2. The trap strength k also increases with laser power, as photons of higher energy increase the change in momentum the gradient force can provide.
3. The drag coefficient γ is constant in terms of laser power by the Einstein-Stokes formula:

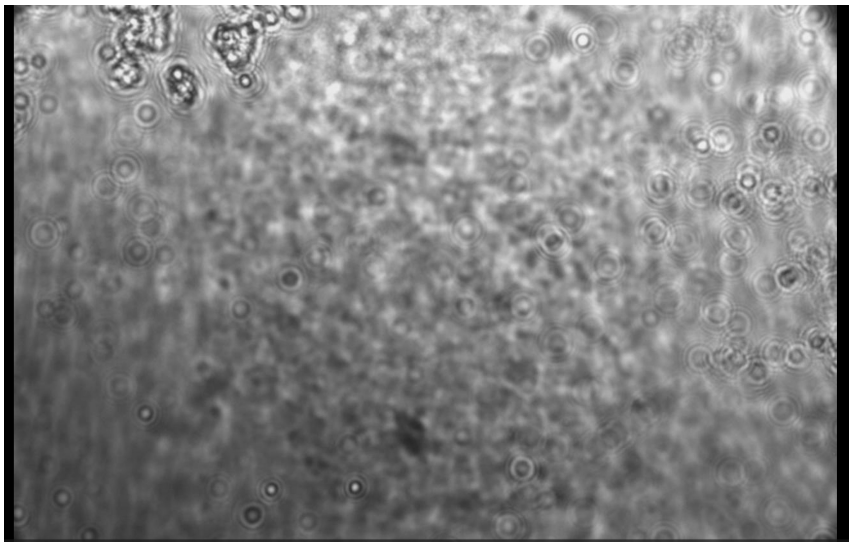
$$\gamma = 6\pi\eta a.$$



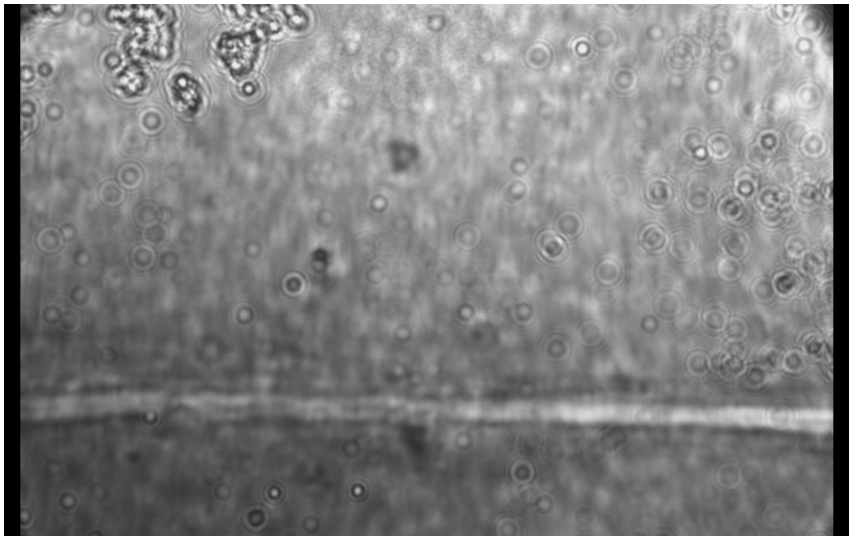




Vesicle Transport in an Onion



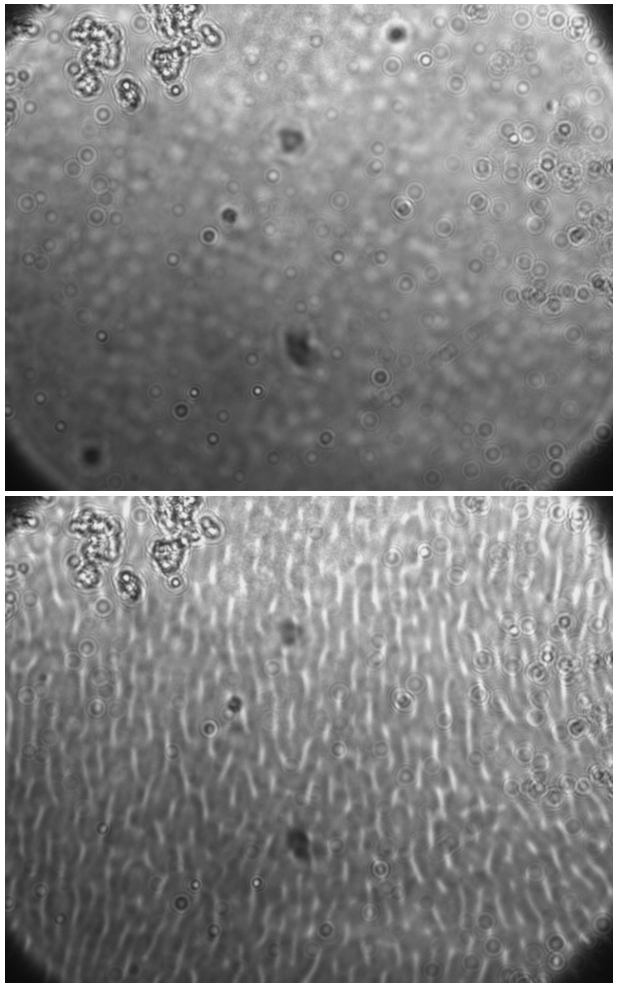
Nucleus of an onion epidermal cell.



Onion Vesicle Trapping Video:
Vesicles stretched from cell wall recoil back upon release.
`https://youtu.be/VEFr9Jnouig`

Problems

1. Bacterial Contamination
   - DI diluted solution acted like 1M NaCl.
   - Bacterial Growth likely occurred over weekend.
   - Solved by performing a dilution with new solution.
2. Microscope Lens Streaks
   - Reminiscent of Astigmatism and light.
   - Became more apparent (i.e. dots to streaks).



References

R. DeSerio.
Optical tweezers.
https://www.phys.ufl.edu/courses/phy4803L/group_IV/optical_tweezers/OT.pdf, 2020.
Phy 4803L, Department of Physics, University of Florida.