Optical Tweezers

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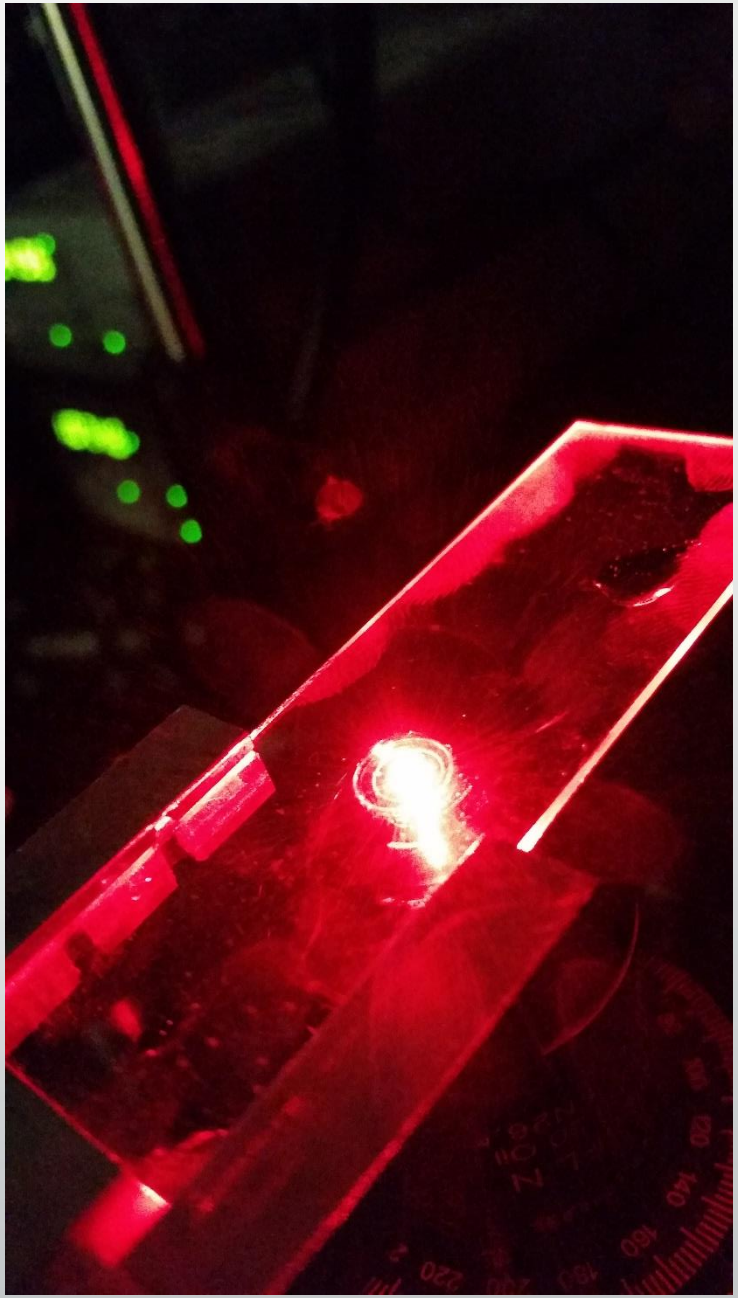
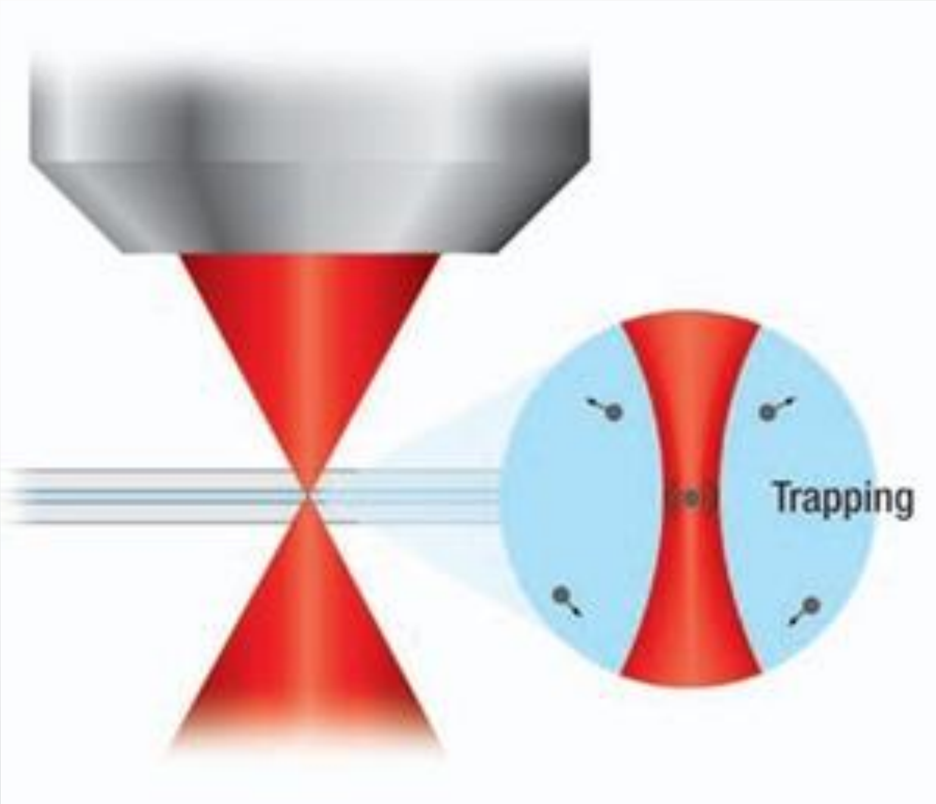


History

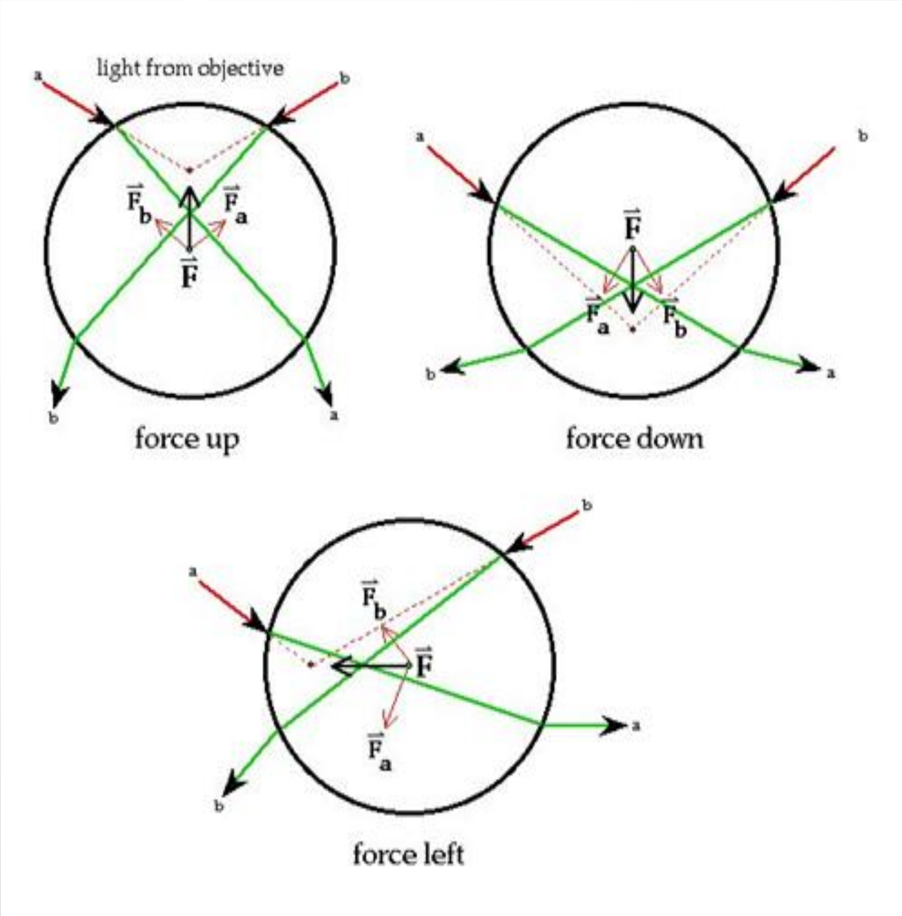
- First observed in Belle Labs- 1970
- Cooling and trapping neutral atoms- 1997 Nobel Prize
- Force spectroscopy on biological motors



http://www.thorlabs.de/NewGroupPage9.cfm?ObjectGroup_ID=3959

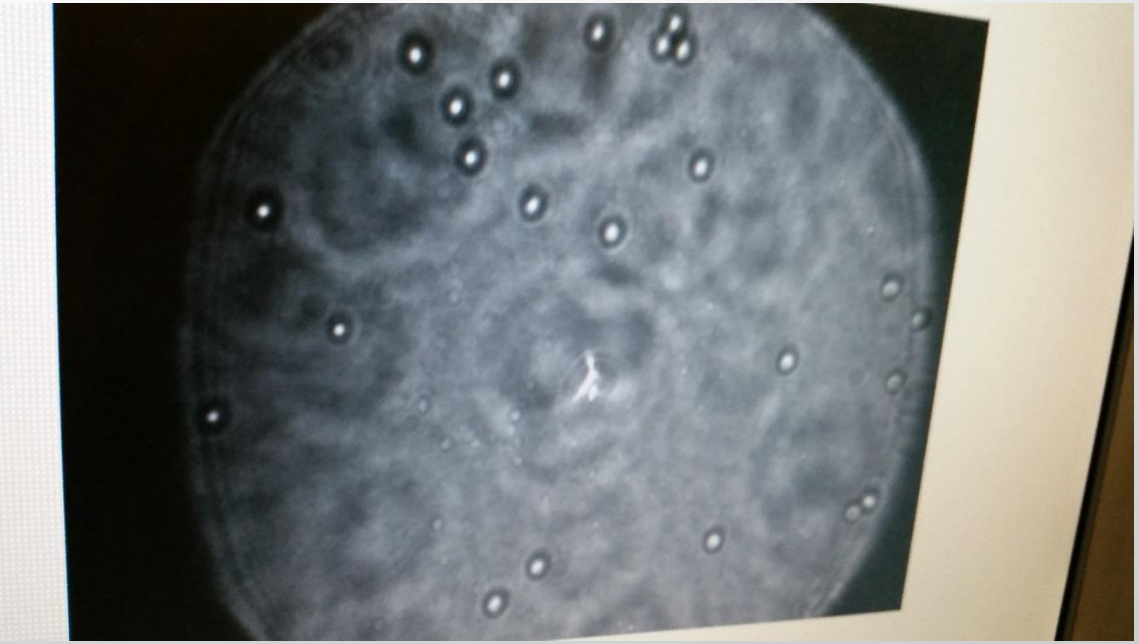
Theory

- Conservation of momentum between photons and particle
- Gradient force and radiation pressure
- Highly dependent on index of refraction mismatch, and NA of the microscope objective



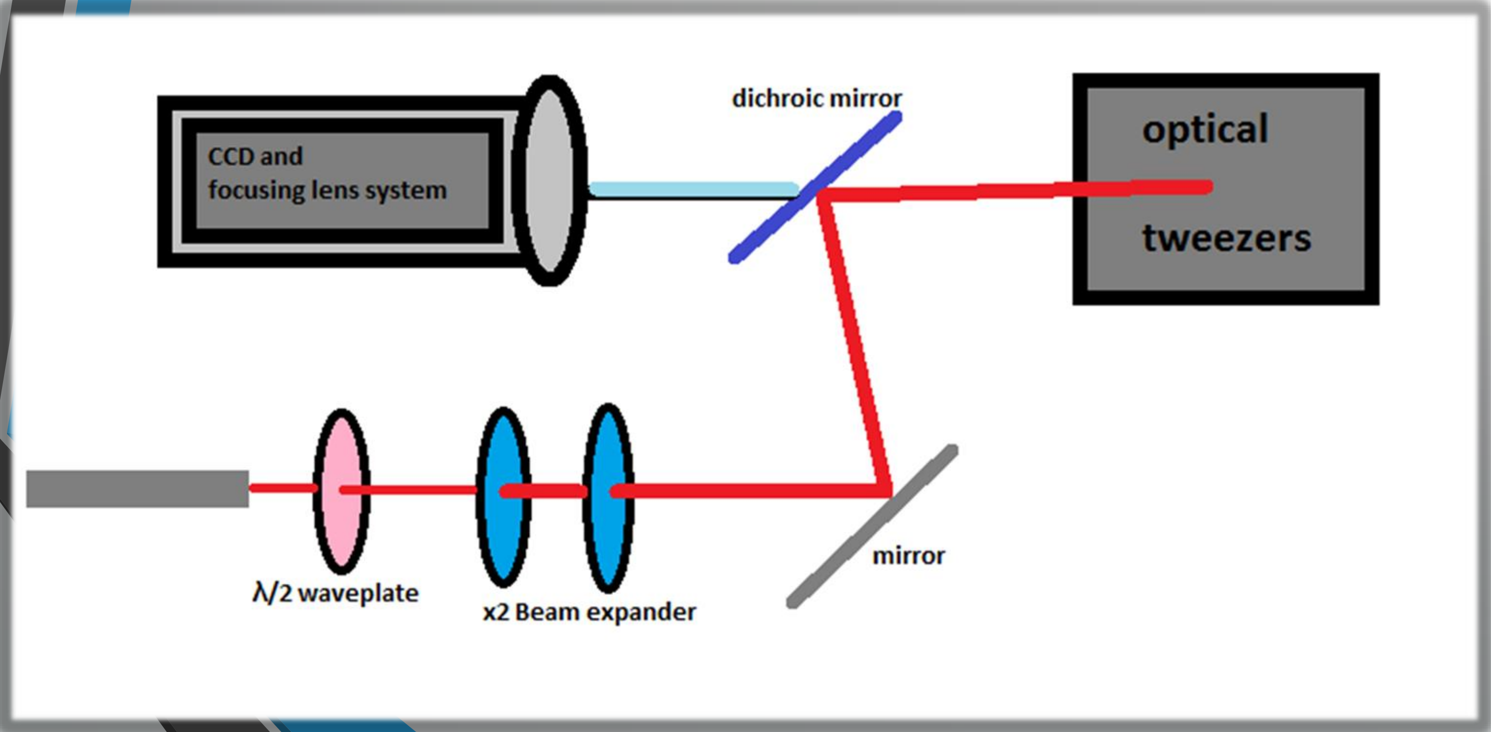
Goals

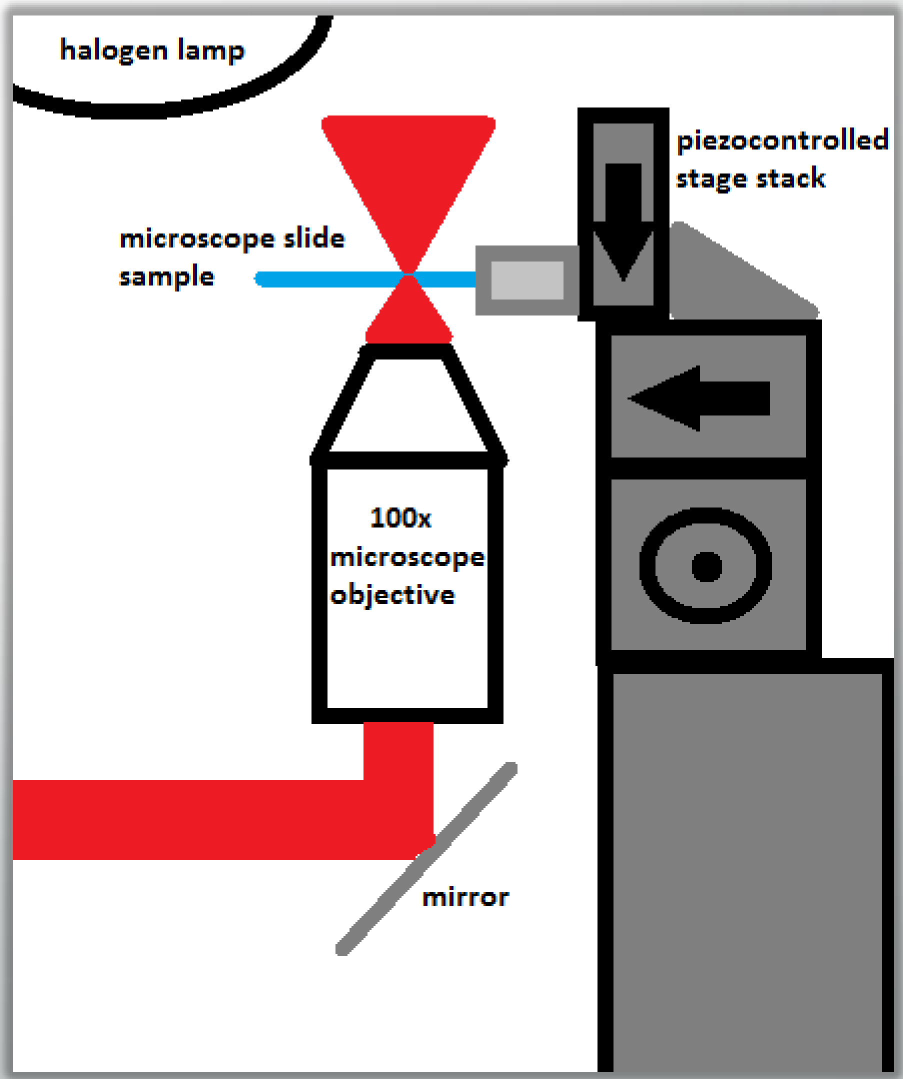
- Trap and image 2.56 µm silica beads with 637 nm diode laser
- Conduct force calibrations to determine relationship between trapping force and laser power
- Install 980 nm laser to conduct biological measurements



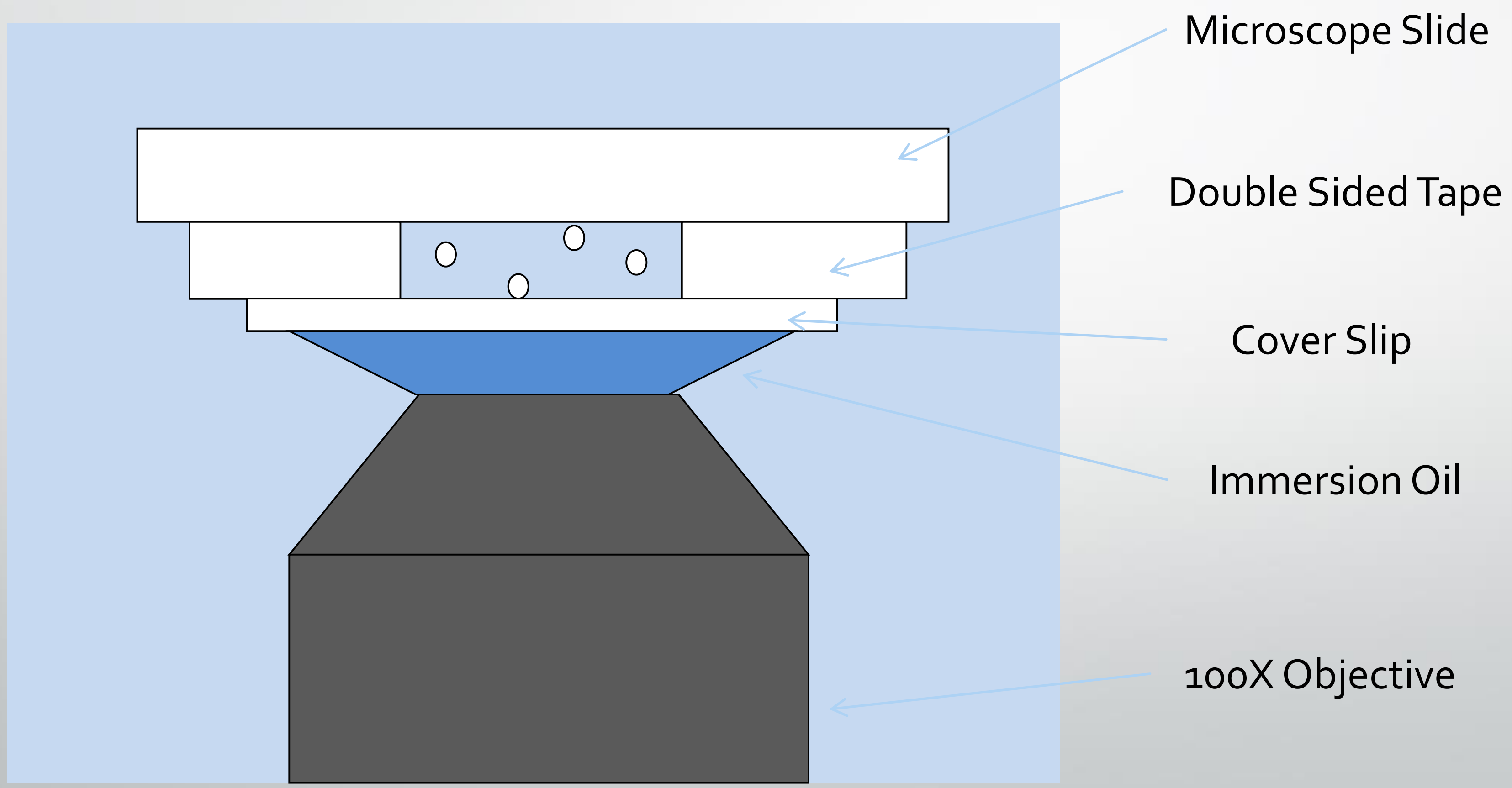
Set Up

Source: 637 nm fiber coupled laser diode, 980 nm fiber laser (temperature controllers, laser diode current controllers)

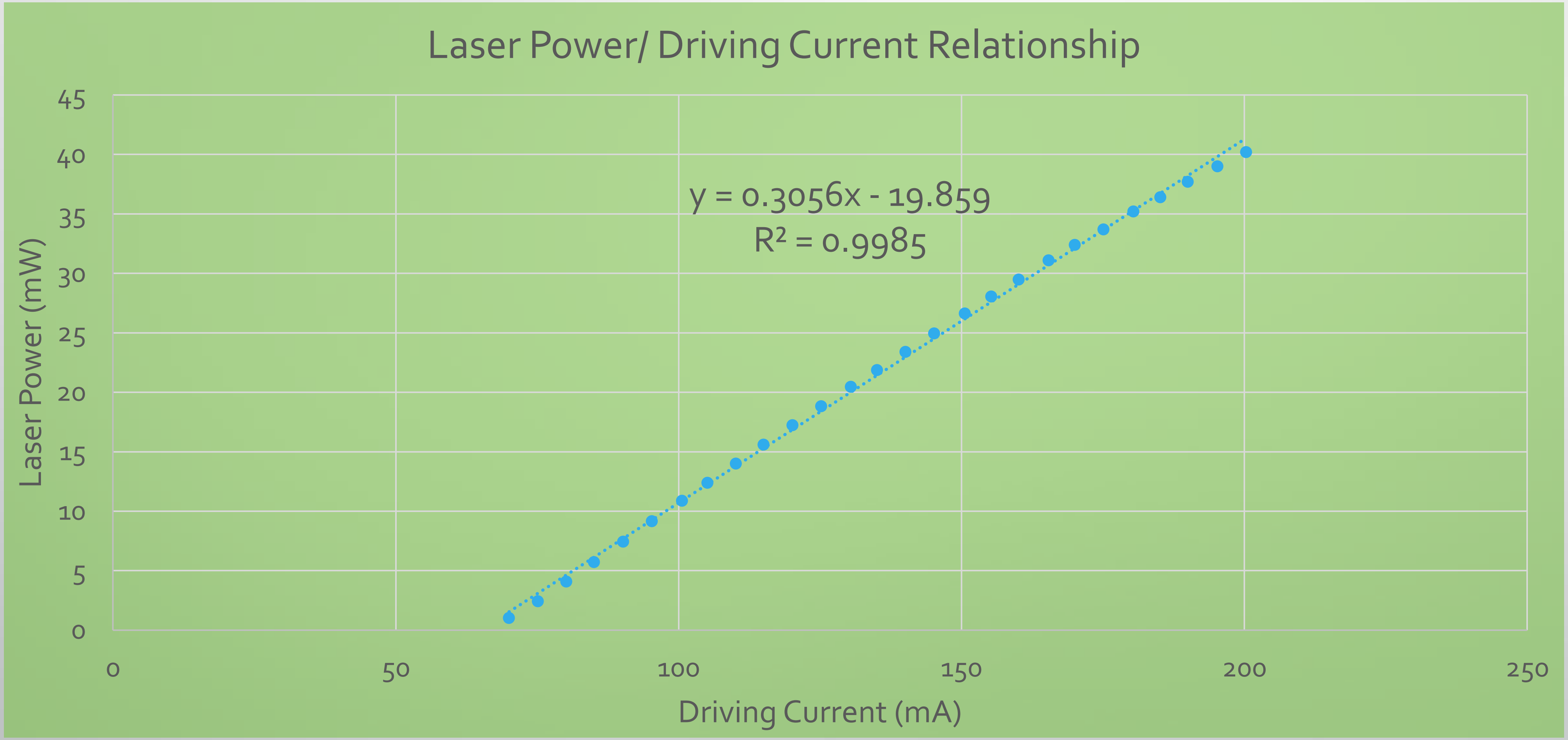




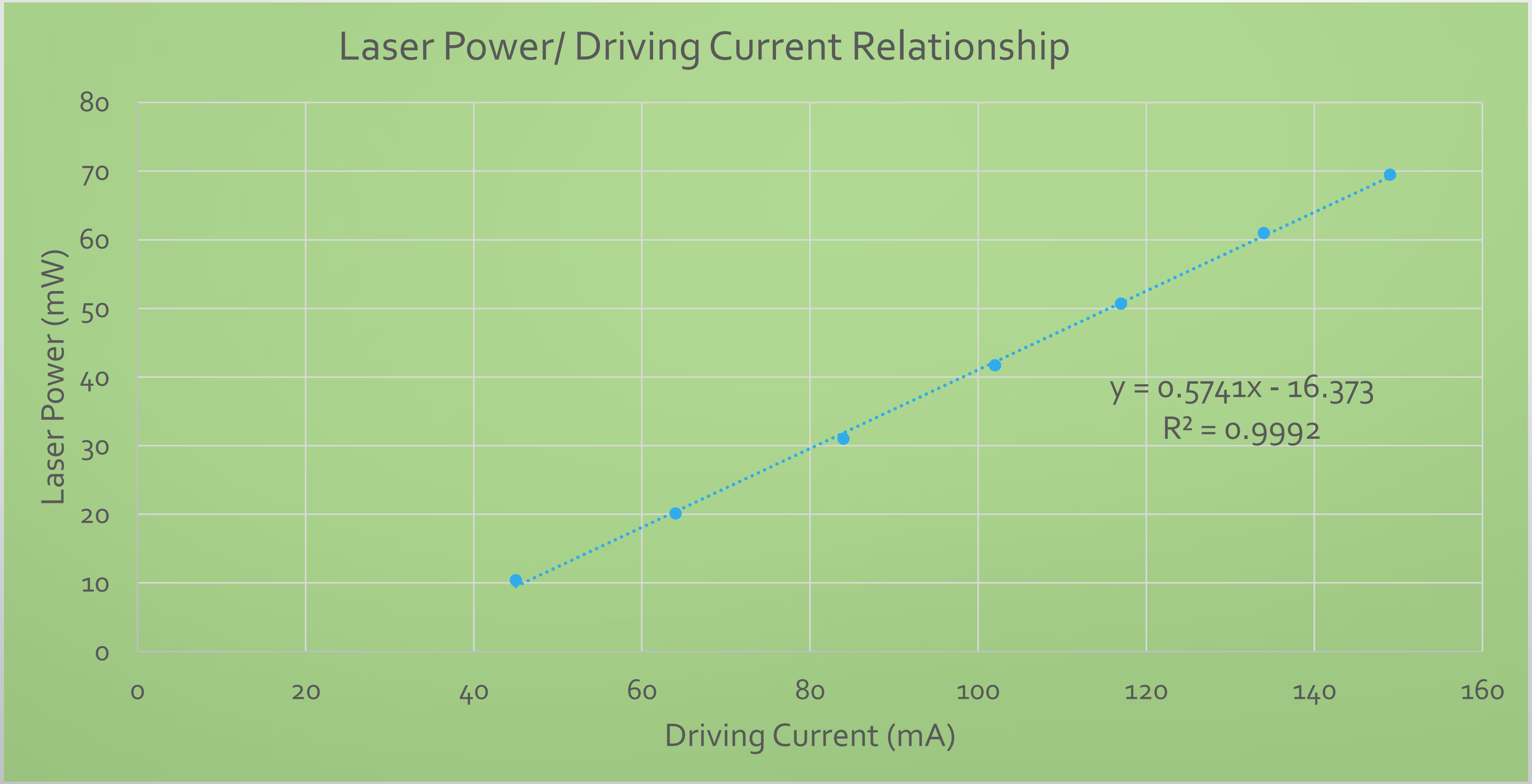
Slide Preparation



Laser Characterization- 637 nm



Laser Characterization- 980 nm



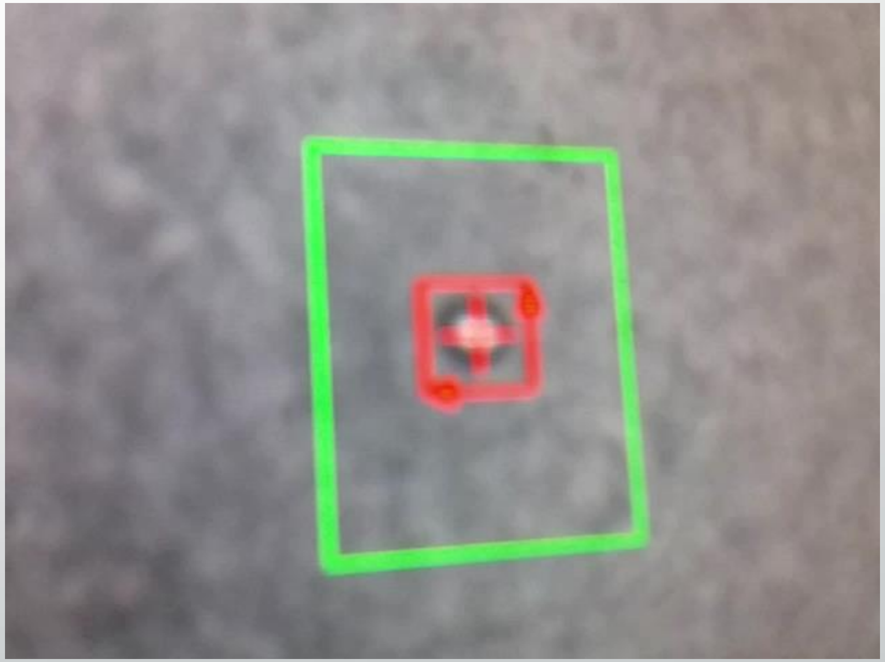
Equipartition Force Calibration (Brownian Motion)

- Equipartition Theorem relates temperature and kinetic energy of particles

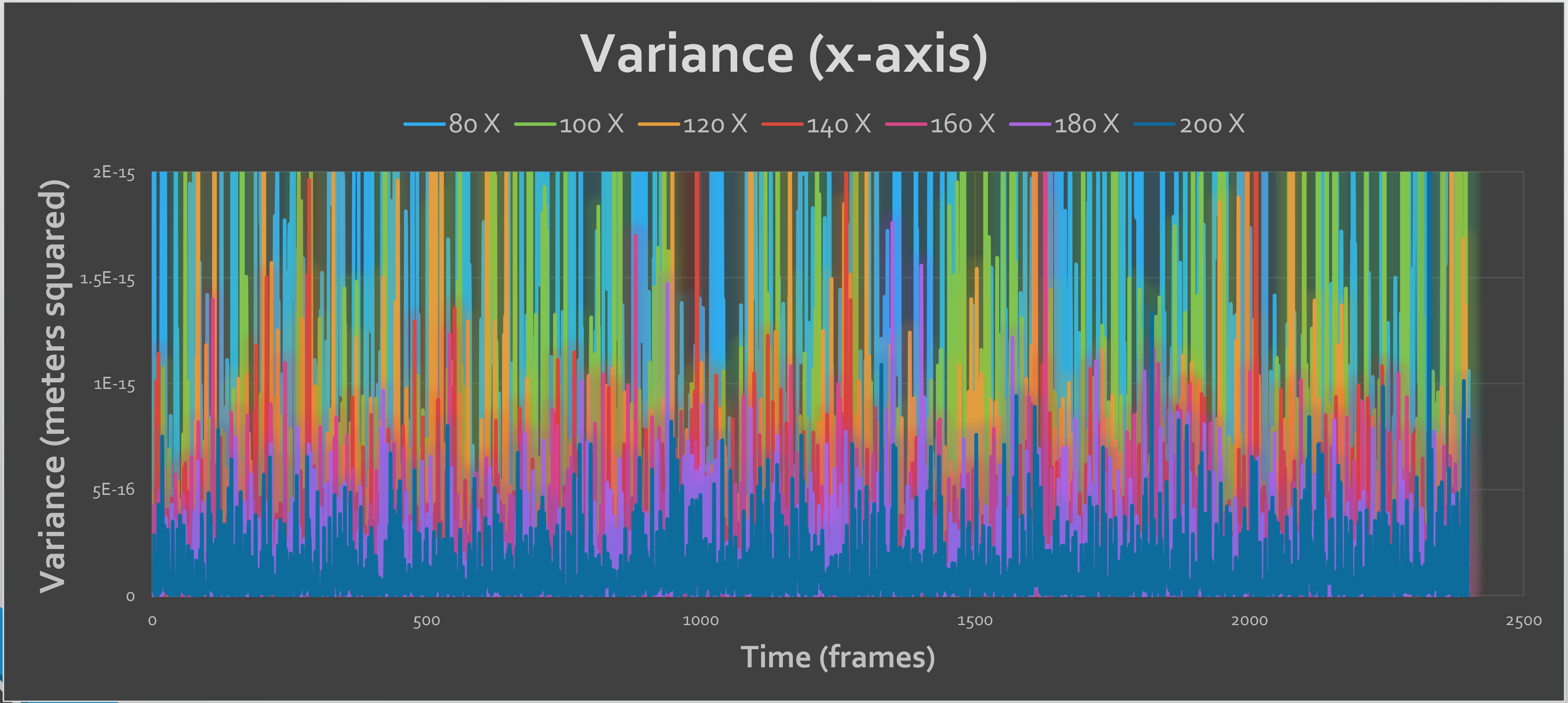
$$\frac{1}{2}k_BT = \frac{1}{2}k < x^2 >$$

- k = characteristic spring constant
- $< x^2 >$= average variance where

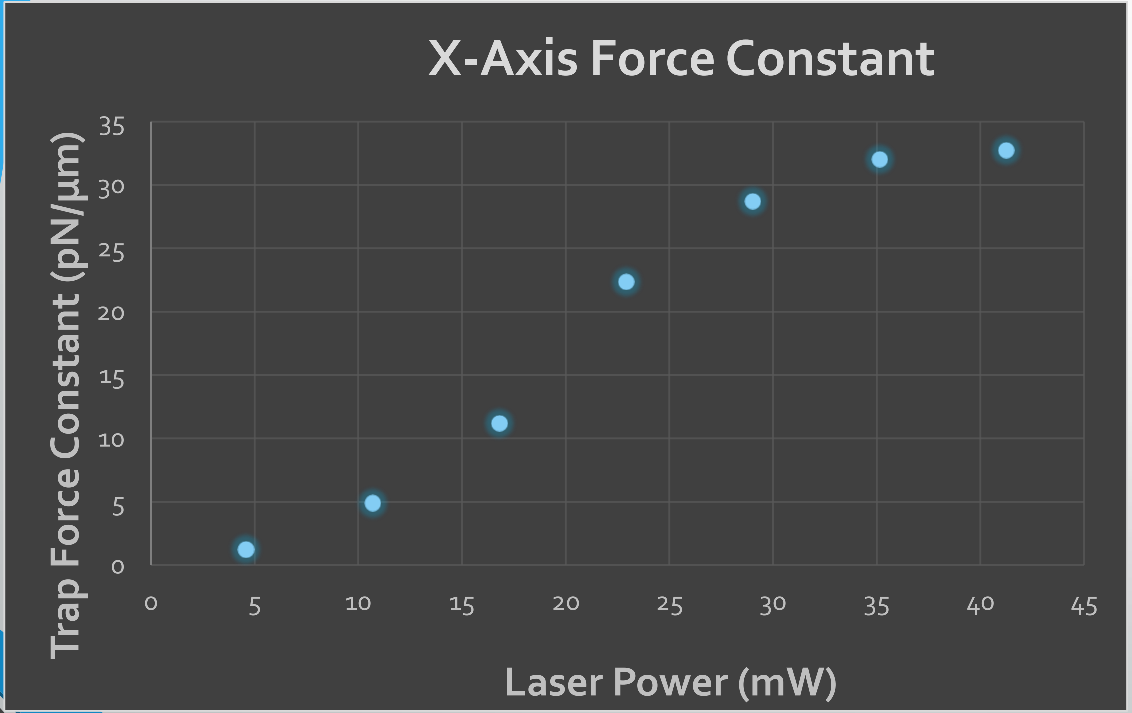
variance =$\sum_i (x_{avg} - x_i)^2$



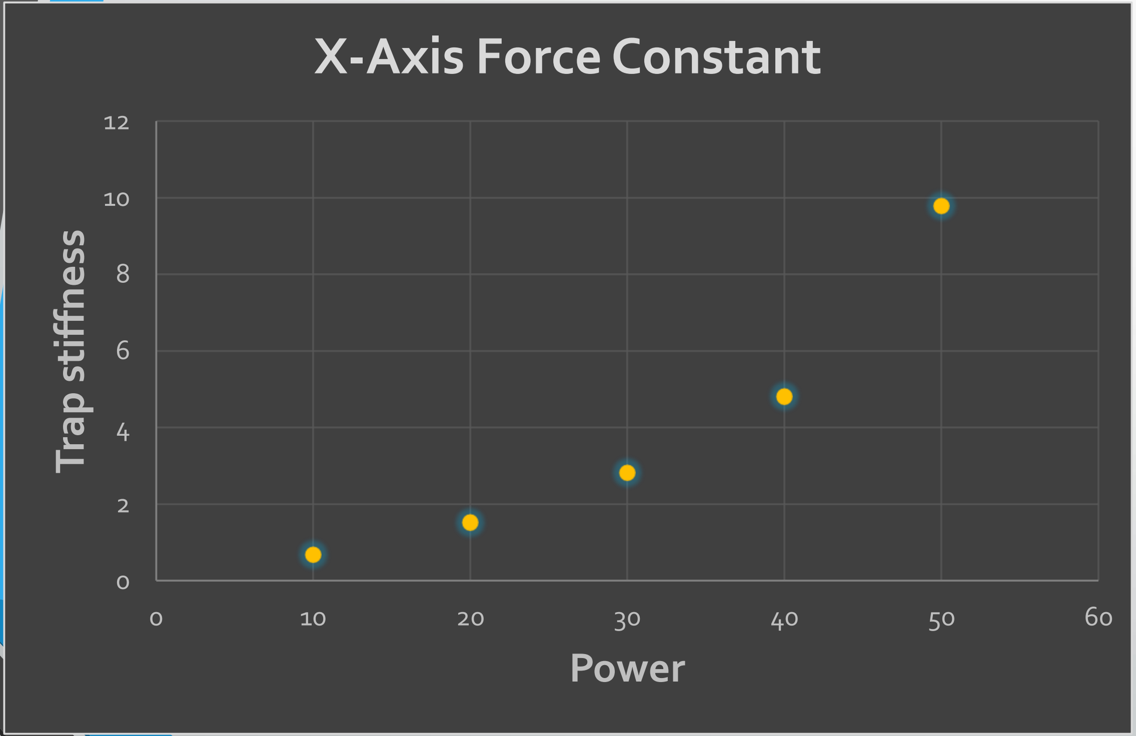
Equipartition Force Calibration (Brownian Motion)

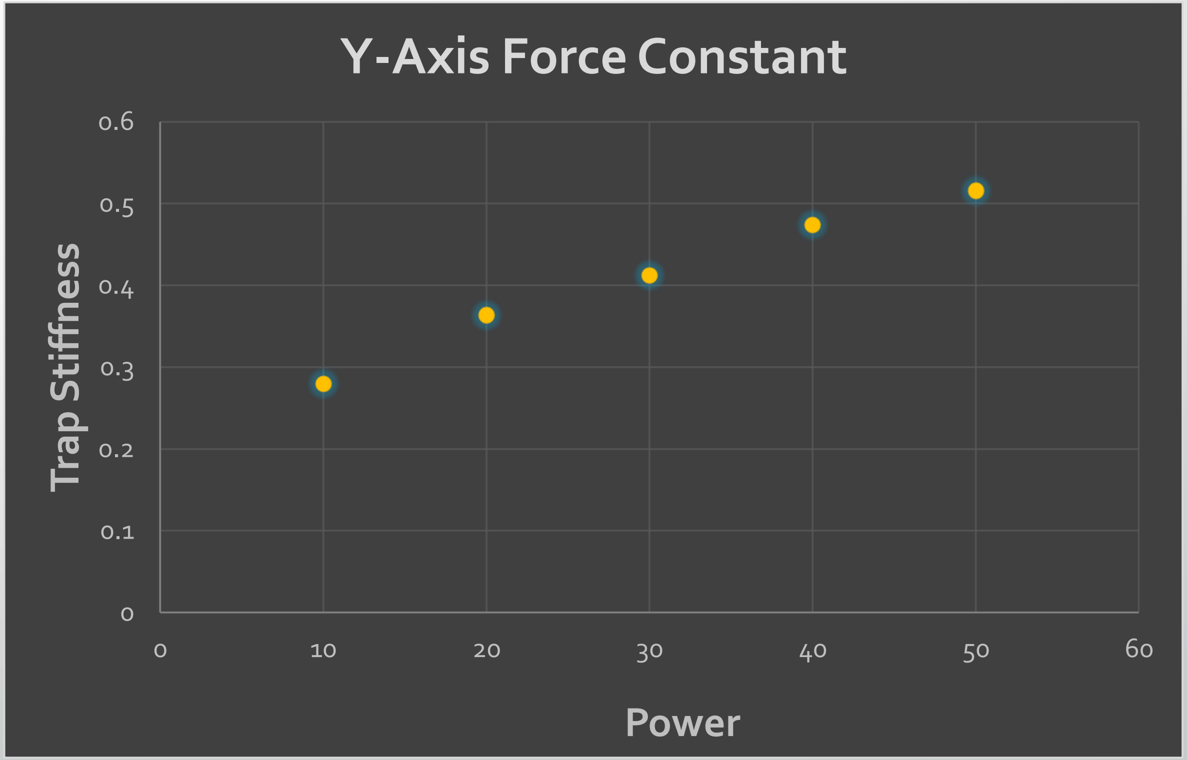


Equipartition Force Calibration-637 nm (Brownian Motion)



Equipartition Force Calibration- 980 nm (Brownian Motion)





Stokes Drag Force

Knowing a particles size and velocity, as well as the fluid's dynamic viscosity, the drag force experienced by the particle can be determined :

$$F_d = 6\pi\mu R v_s$$

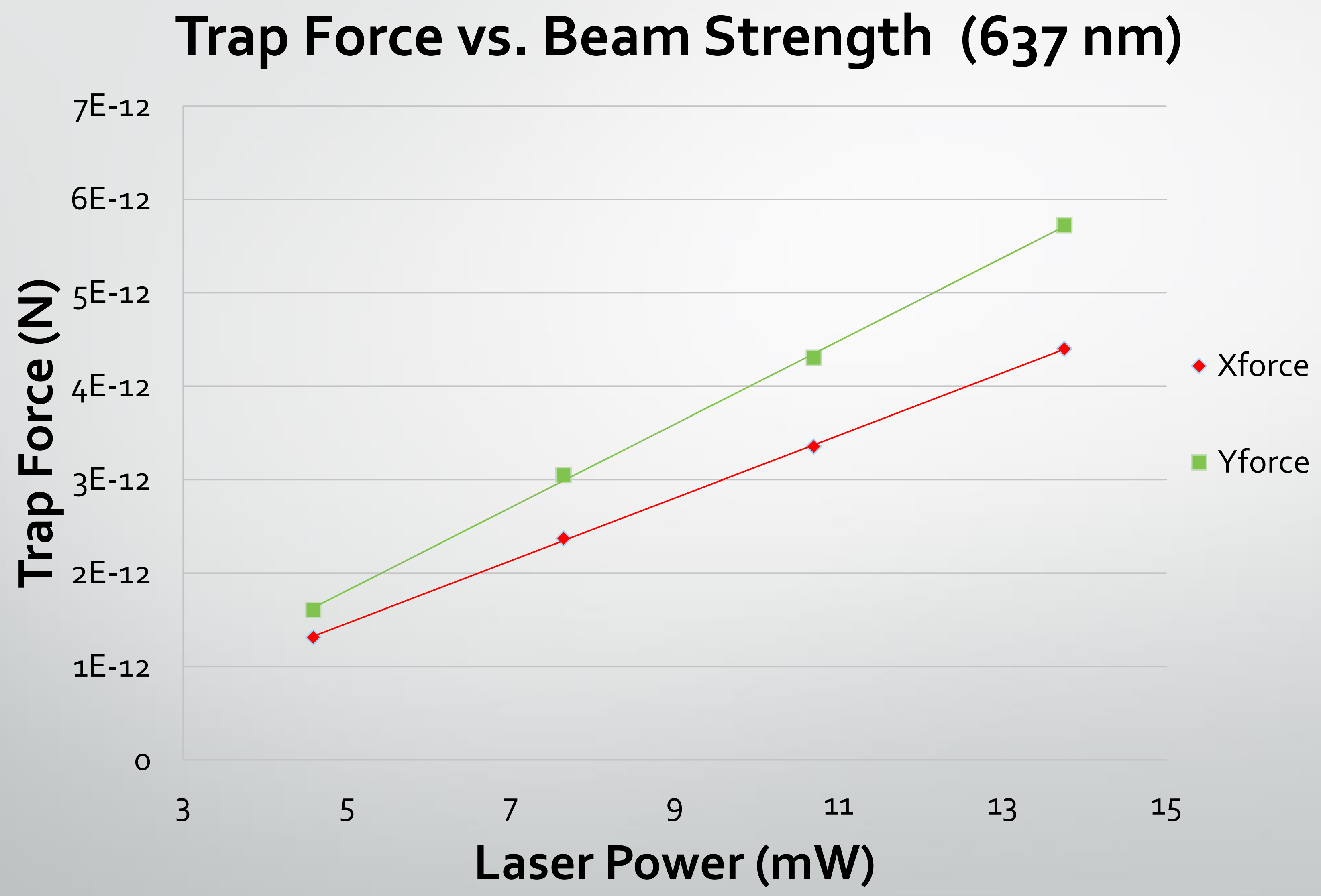
Stokes law assumes laminar flow, spherical particles, homogenous liquid and no particle interference

Method

- Electronically drive the microscope slide at known sinusoidal frequencies and observe when the microsphere exits the trap.
- Convert frequency f to max velocity of slide
- Calculate trap force with Stoke's Law
- Perform in x and y directions

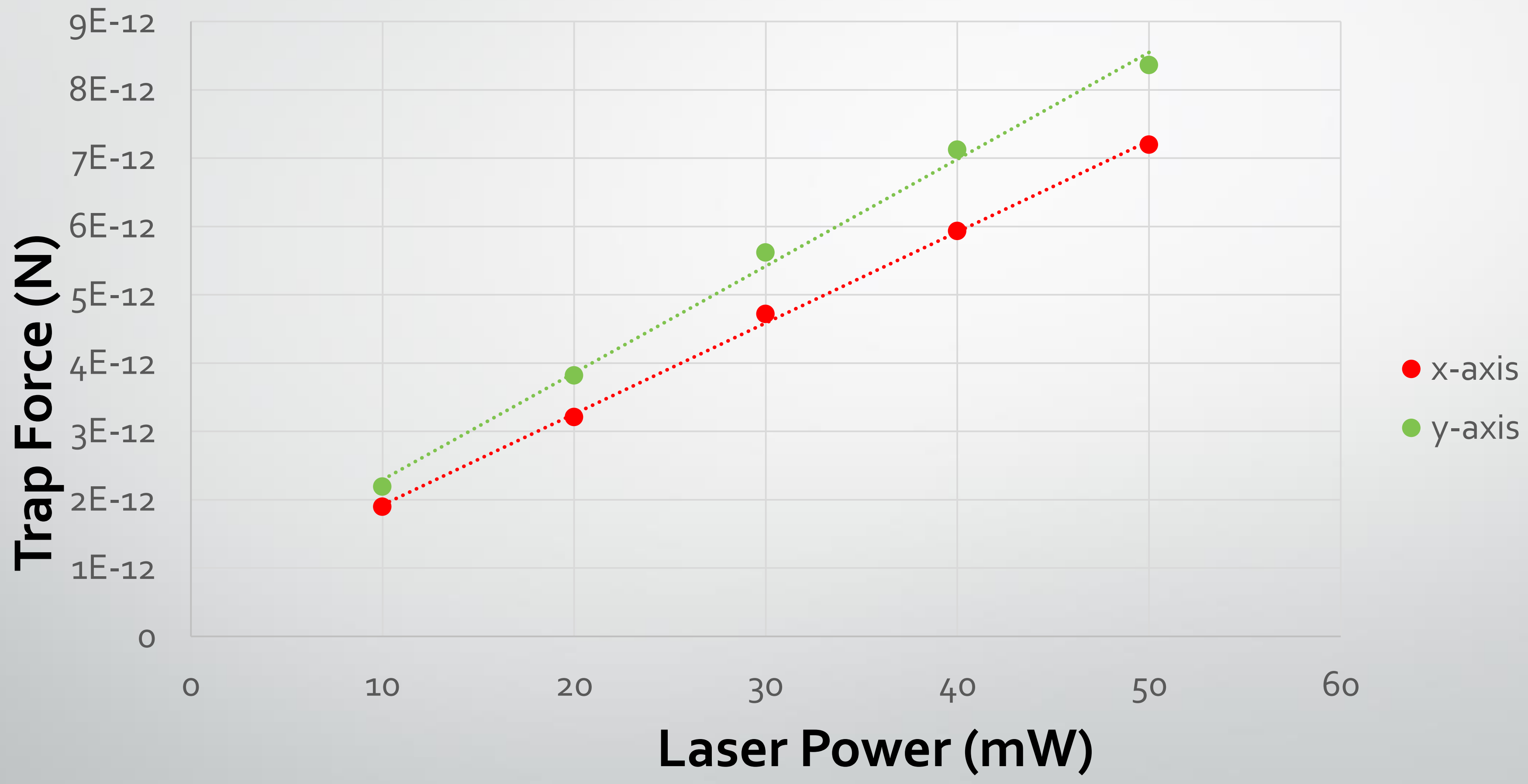
- $x = A sin(\omega t)$
- $v = \omega A cos(\omega t)$
- $v_{max} = \omega A$
- $v_{max} = 2\pi f A$
- $F_d = 12\pi^2 \mu R f \mathrm{A}$

Stoke's Force Calibration

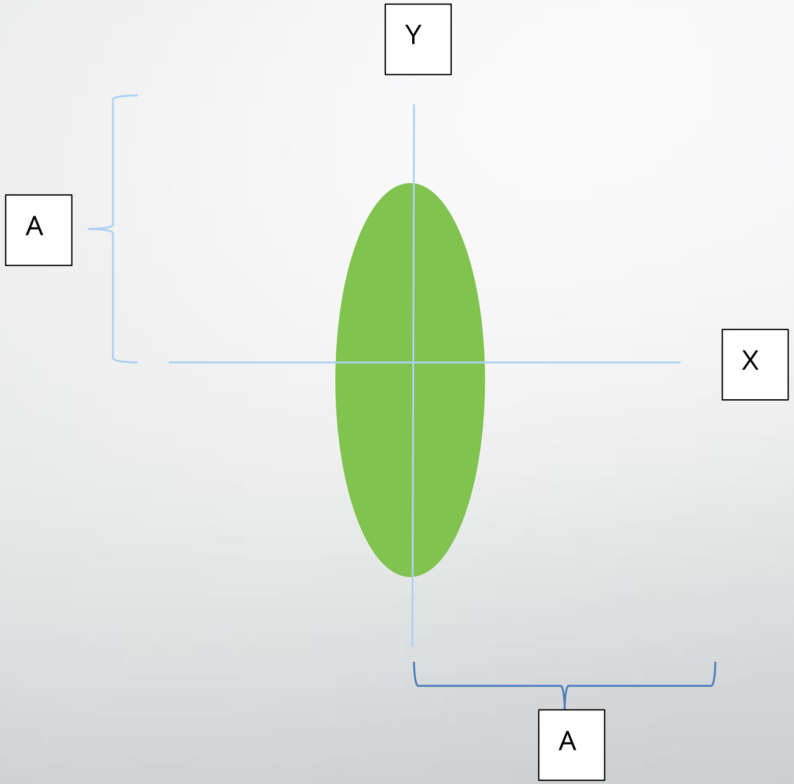


Trap Force vs. Beam Strength (637 nm)
7E-12
6E-12
5E-12
4E-12
3E-12
2E-12
1E-12
0
3
5
7
9
11
13
15
Trap Force (N)
Laser Power (mW)
Xforce
Yforce

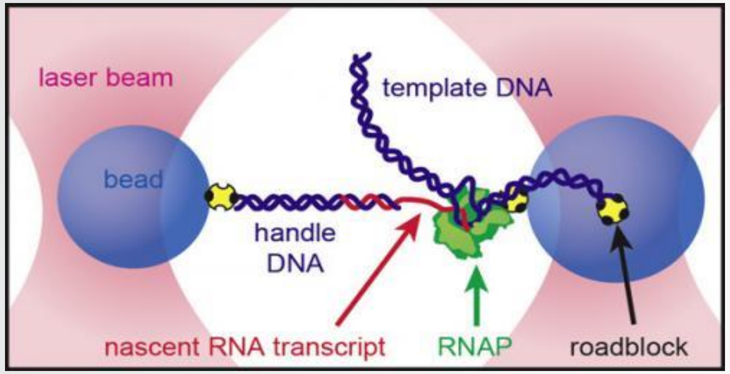
Trap Force vs Beam Strength (980 nm)



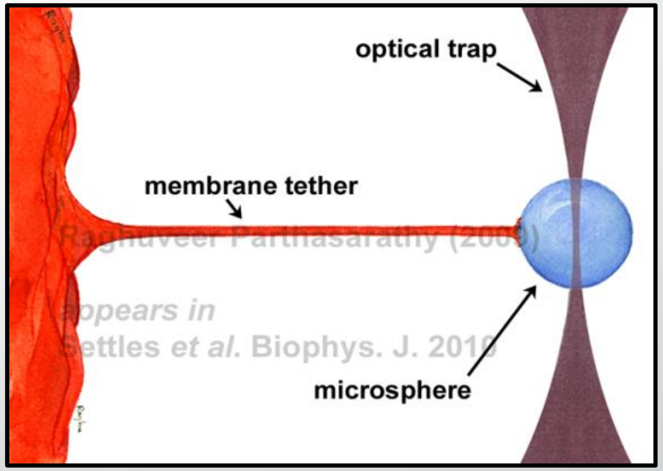
Possible Explanation



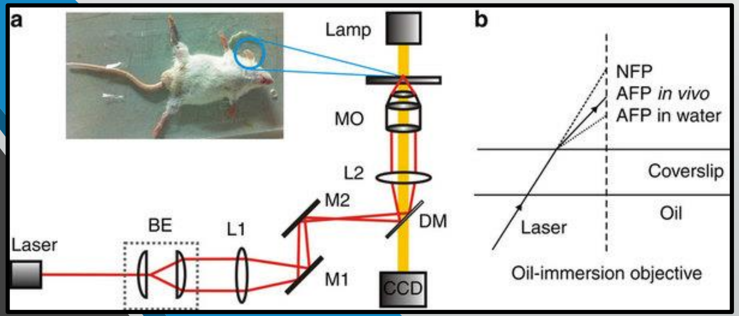
Biophysical Applications of Optical Tweezers



Unfolding single strands of RNA by binding RNA polymerase to adjacent microspheres, and increasing distance between spheres



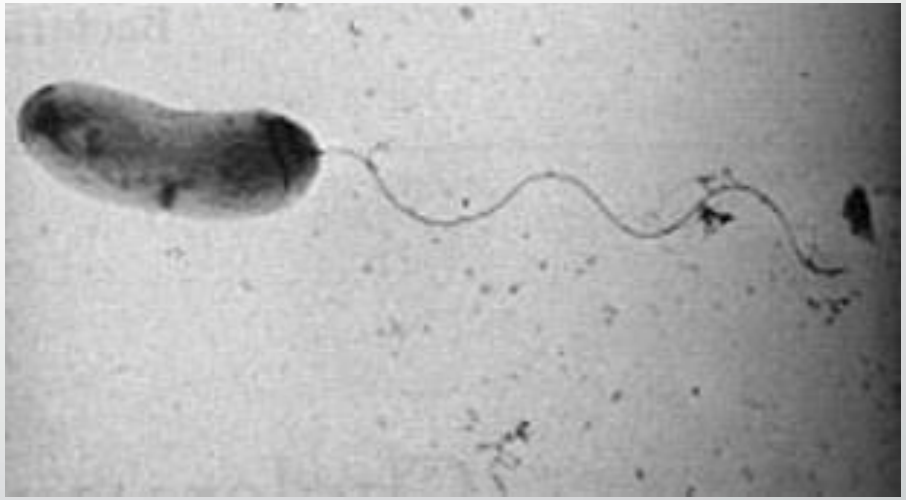
Illustrating membrane mechanics of intracellular trafficking with experiments that construct, deform, and observe membranes interacting with trafficking proteins.



Trapping Red blood cells in living organisms to measure cell living cell dynamics in vivo

Biological Measurements

- Vibrio cholerae
  - Moves with single flagellum at speeds up to 50 microns per second
  - Trapped bacteria escaped trap at forces of 1 to 5 picoNewtons
  - Credit to Dr. Raghuveer Parthasarathy



https://microbewiki.kenyon.edu/index.php/Vibrio_cholerae