# Optical Tweezers

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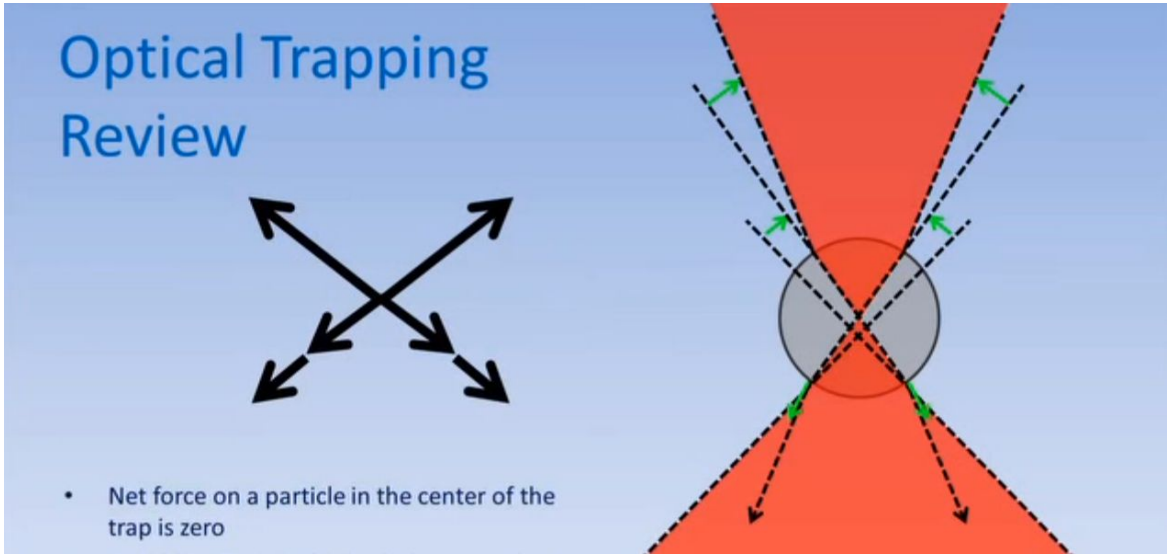
# Theory

- Photons carry momentum $E^2 = (m_0c^2)^2 + p^2c^2$
- Momentum is conserved in the trap

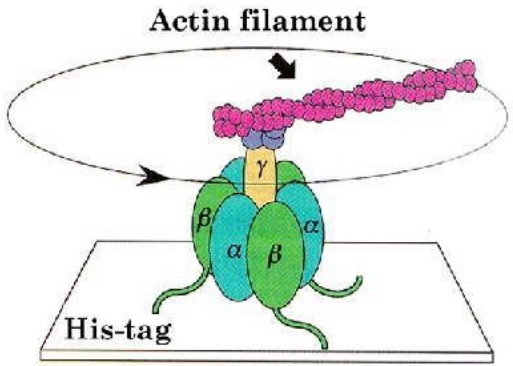


# Why use an optical trap?

- Capture and manipulate microscopic objects for testing and observation
- Non-contact and non-invasive

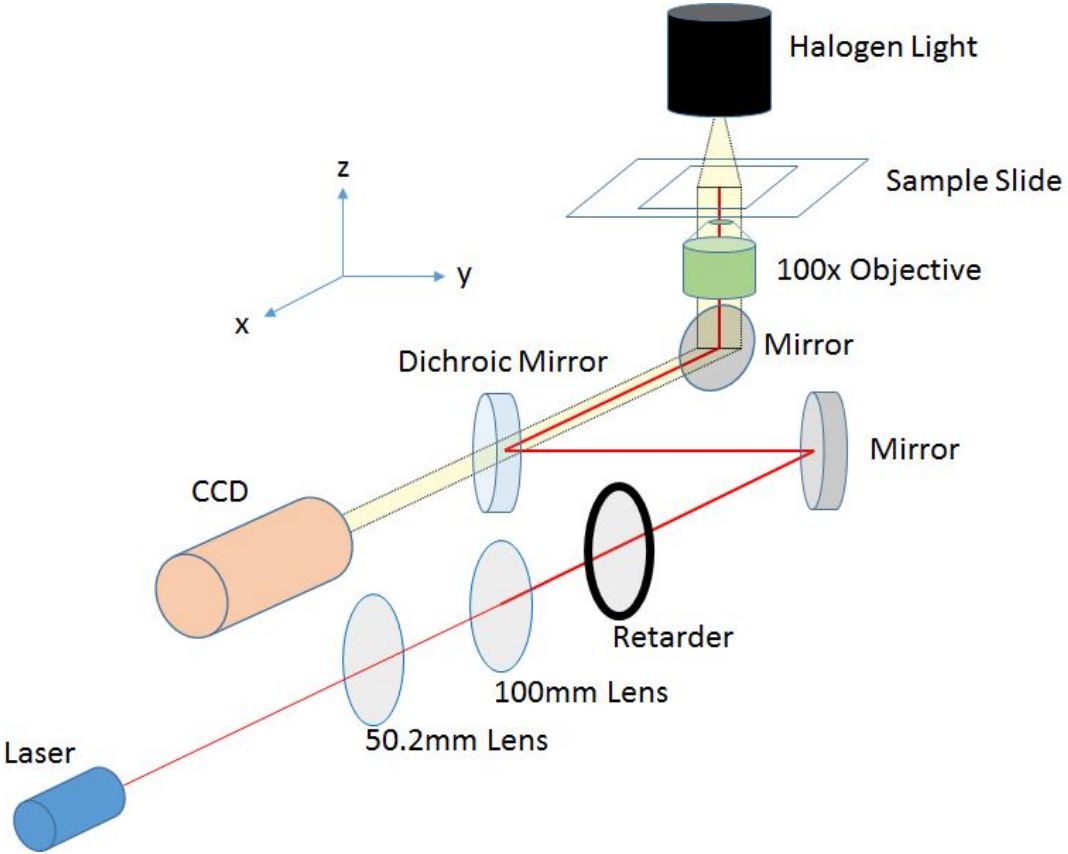
Applications:

- Laser Cooling
- Cell picking
- Protein motor analysis



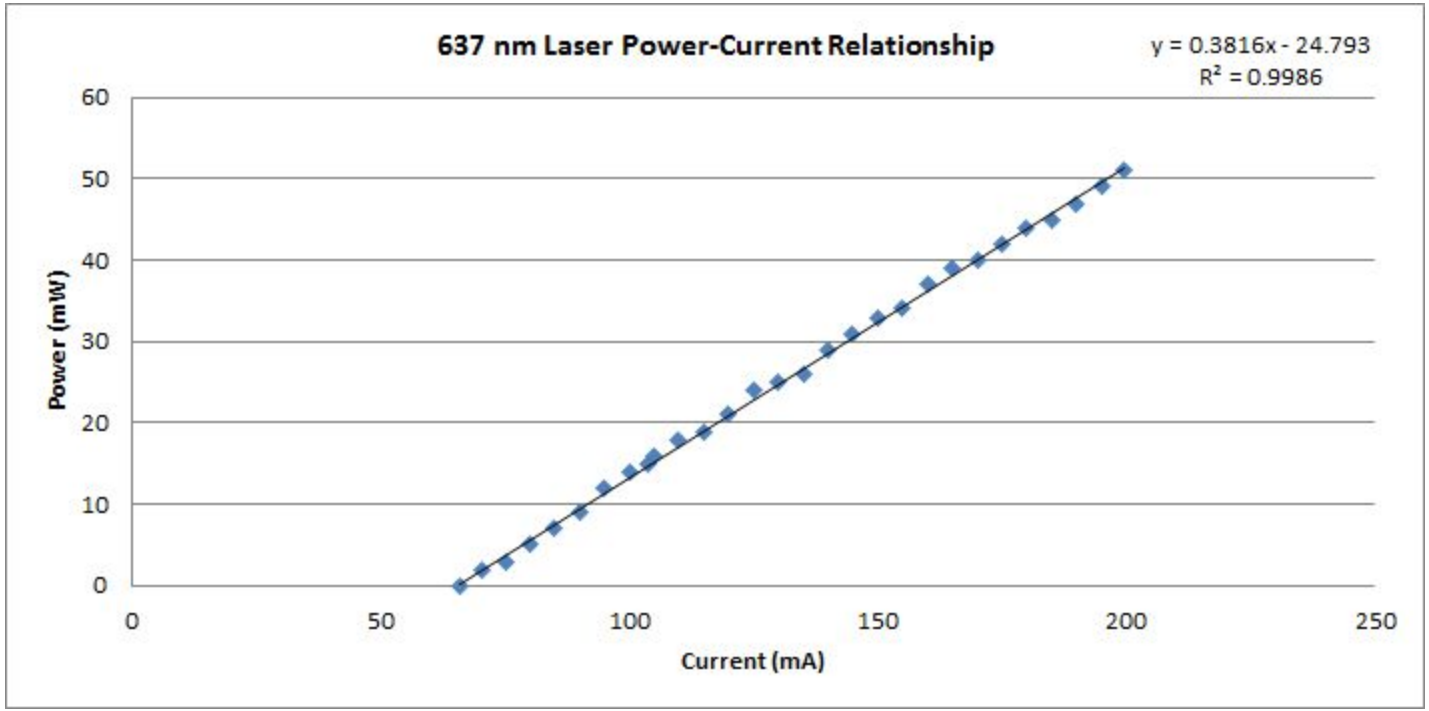

W. Junge, H. Lill & S. Engelbrecht
TIBS 22, 420 - 423 (1997)

# Experimental Setup



# Project Goals

- Measure power-current relationship of laser
- Determine trap strength using Brownian Motion
- Determine trapping force using Stoke’s Drag Force
- Add vortex phase plate to create a Laguerre-Gaussian beam
- Determine trapping force of LG beam
- Estimate the angular velocity exerted on trapped bead




Now we can analyze measurements as a function of power.

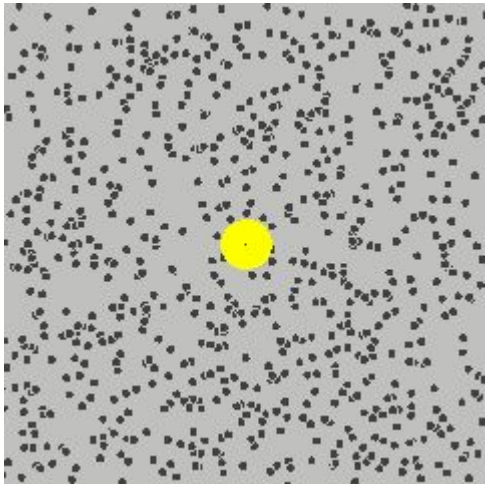
# Using Brownian Motion to Calculate Trap Strength

- *Brownian Motion*: random motion of particles due to collisions with atoms in a fluid excited by thermal energy
- Trapping force exhibits spring potential
- For low trapping forces:

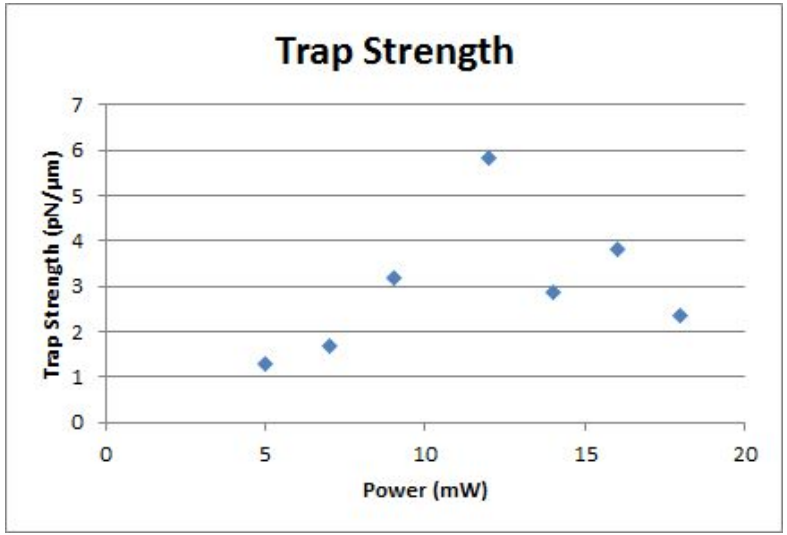
$$\frac{1}{2}(2)k_BT = \frac{1}{2}kx^2$$

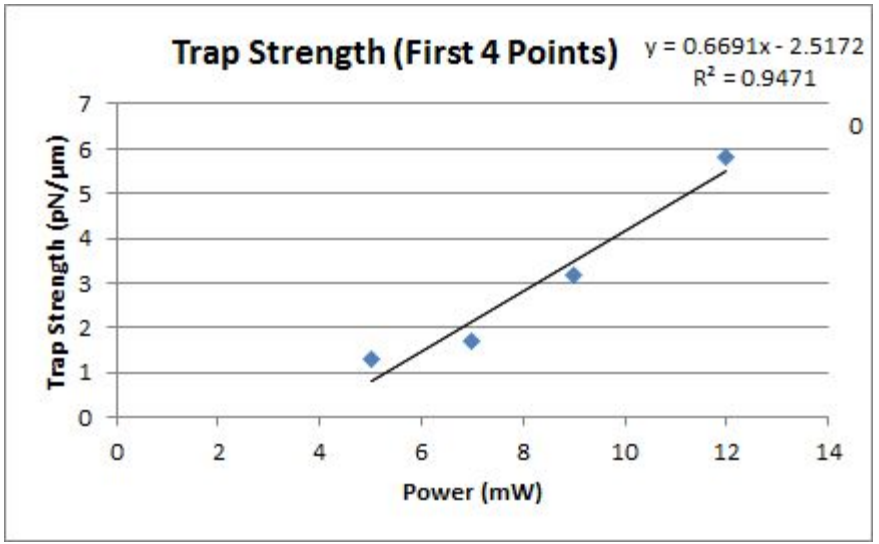
$$k = \frac{(2)k_BT}{x^2}$$

*k*: trap strength
$k_B$: Boltzmann constant
*T*: temperature
$x^2$: variance in position of the bead



# Brownian Motion Trap Strength Calculations




- Accurate for low laser powers
- Above ~13 mW, software cannot track bead

# Stoke’s Drag Force

- Motion of surrounding fluid causes drag known as Stoke’s Drag Force
- Added piezoelectric component to translation stage driven by sine curve
- Measure frequency at which $F_{trap} = F_{Stoke's}$

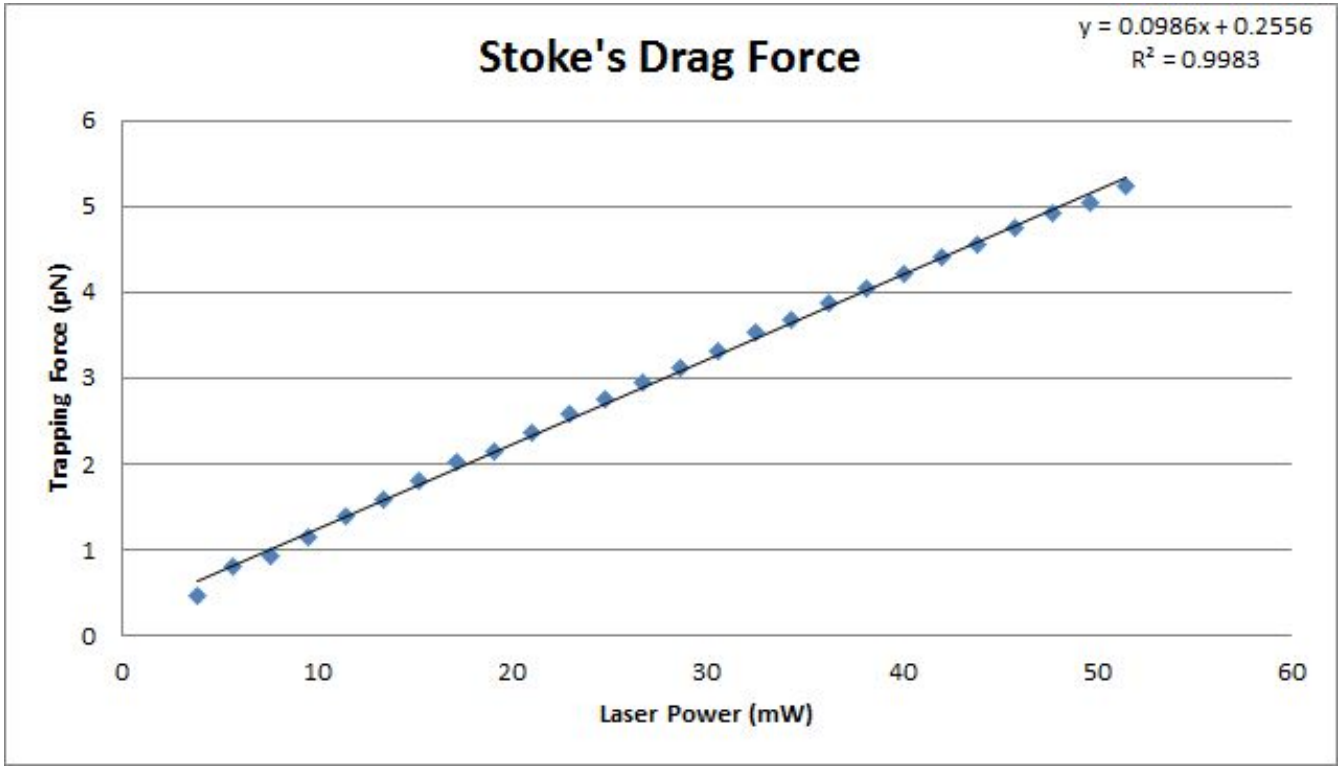
$$F_{trap} = 12\pi^2 \mu R A f_{escape}$$

$\mu$: viscosity of water (*8.9E-4 Pa*s*)

$R$: radius of trapped bead (*1.28 μm*)

$A$: amplitude of distance (*12.9 μm*)

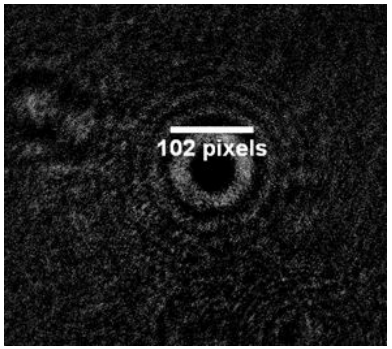
$f_{escape}$: frequency at which bead escapes the trap




The trapping force increases linearly with laser power output.

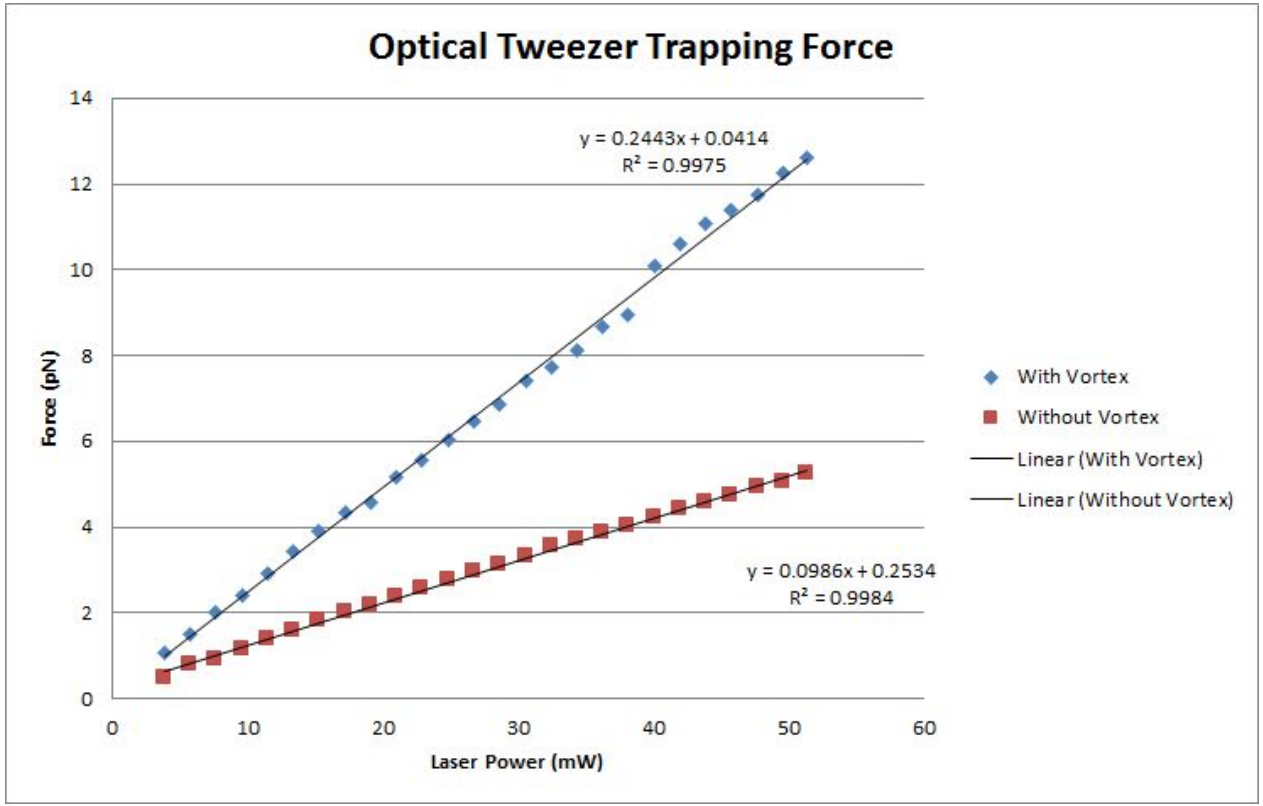
# Vortex Half-Wave Retarder

- Gradient of densities causes light to emerge with some angular momentum - Laguerre-Gaussian “donut” beam (m=1)
- Spot size: ~4.7 μm




Beam profile immediately after vortex phase plate

Negative of beam profile in sample plane




Trapping force **increased** by a factor of **2.2**

# Angular Momentum Estimate

- Trapped a rod-like bead (shown right)
- Using bead images, estimated that:

**1 Rotation = ~650 Frames**

- At 409.5 frames per second:

$$\omega_{OBJ} = 3.59 \text{ rad/s}$$

- Same order as theoretical calculations for a 1 μm radius spherical glass bead ($\omega_{OBJ} = 3.14$ *rad/s*)
- Decreasing power led to slower rotations

# Conclusion

By adding a vortex phase plate to optical tweezers system, we:

- Increased trapping force by factor of 2.2
- Spun rod-like glass bead at 3.59 radians per second
- Angular velocity increases as a function of power

*Further Research:*

- Beam manipulation with Spatial Light Modulator
  - Effect of pixel resolution error on trap strength
  - Hermite-Gaussian trapping beam
- Biological Research
  - Protein motor analysis
  - Cell picking