Distance from equilibrium of a driven trapped NESS

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ABSTRACT

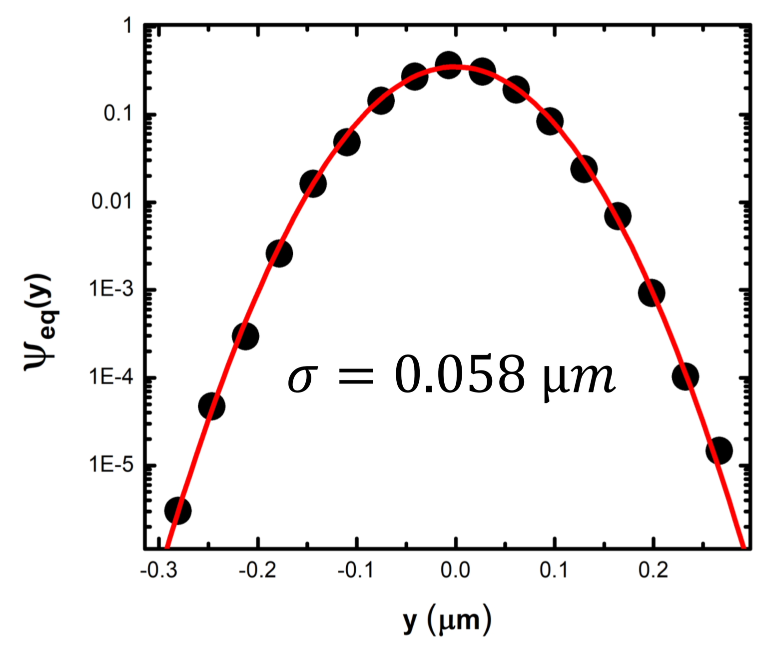
For driven systems, a detailed balance like (DBL) equation, K^*, was previously obtained. The DBL relation quantitatively defines how far a non-equilibrium steady state (NESS) is from equilibrium. Using an optical tweezer, a microscopic particle was held and driven with different velocities. The net drag force causes the particle to move away from its equilibrium position to a new one inducing a NESS. We will report K^* dependence on the driving velocity.

Motivation

- Investigate how far from equilibrium is the NESS of a particle dragged through a fluid with an optical trap.

$$K^* = ln\left[\frac{P_{ss}(x_b)}{P_{ss}(x_a)}\right] - ln\left[\frac{\Pi[x_a \to x_b, \Delta t]}{\Pi[x_b \to x_a, \Delta t]}\right]$$

Optical trap calibration



Stationary probability distribution of the measured position for a polystyrene bead of radius 1 μm in an optical trap.

$$\Psi_{eq}(y) = A\ exp\left(-\frac{1}{2}\frac{(y-y_c)^2}{\sigma^2}\right)$$

k_B – Boltzmann's constant
T – temperature
σ – standard deviation
y_c – center of the trap

- The optical trap stiffness is;

$$k_s = \frac{k_B T}{\sigma^2}$$

$$k_s \sim 1.60\ pN/\mu m$$

Methodology

Optical Tweezers

- Developed by Arthur Ashkin
- Utilizes the momentum of light in holding microscopic particles

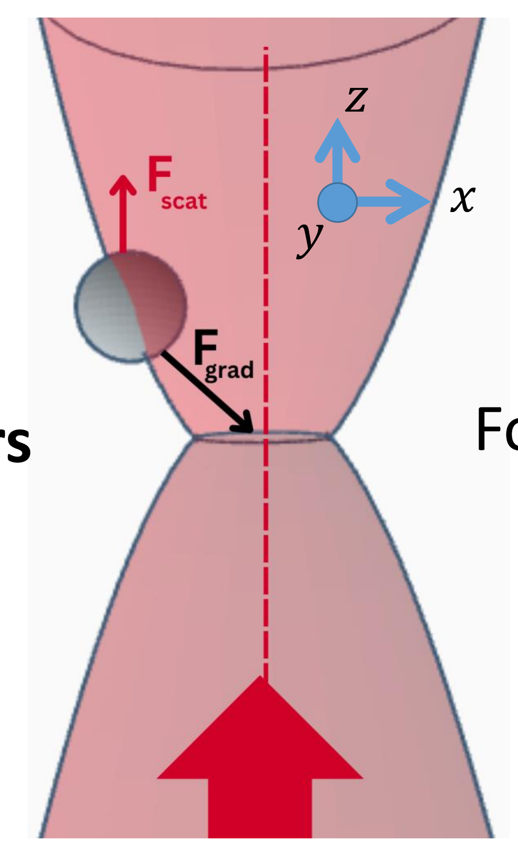
Forces in Optical Tweezers

- Gradient Force

$$\vec{F}_g \propto \nabla I(r)\hat{r}$$

- Scattering Force

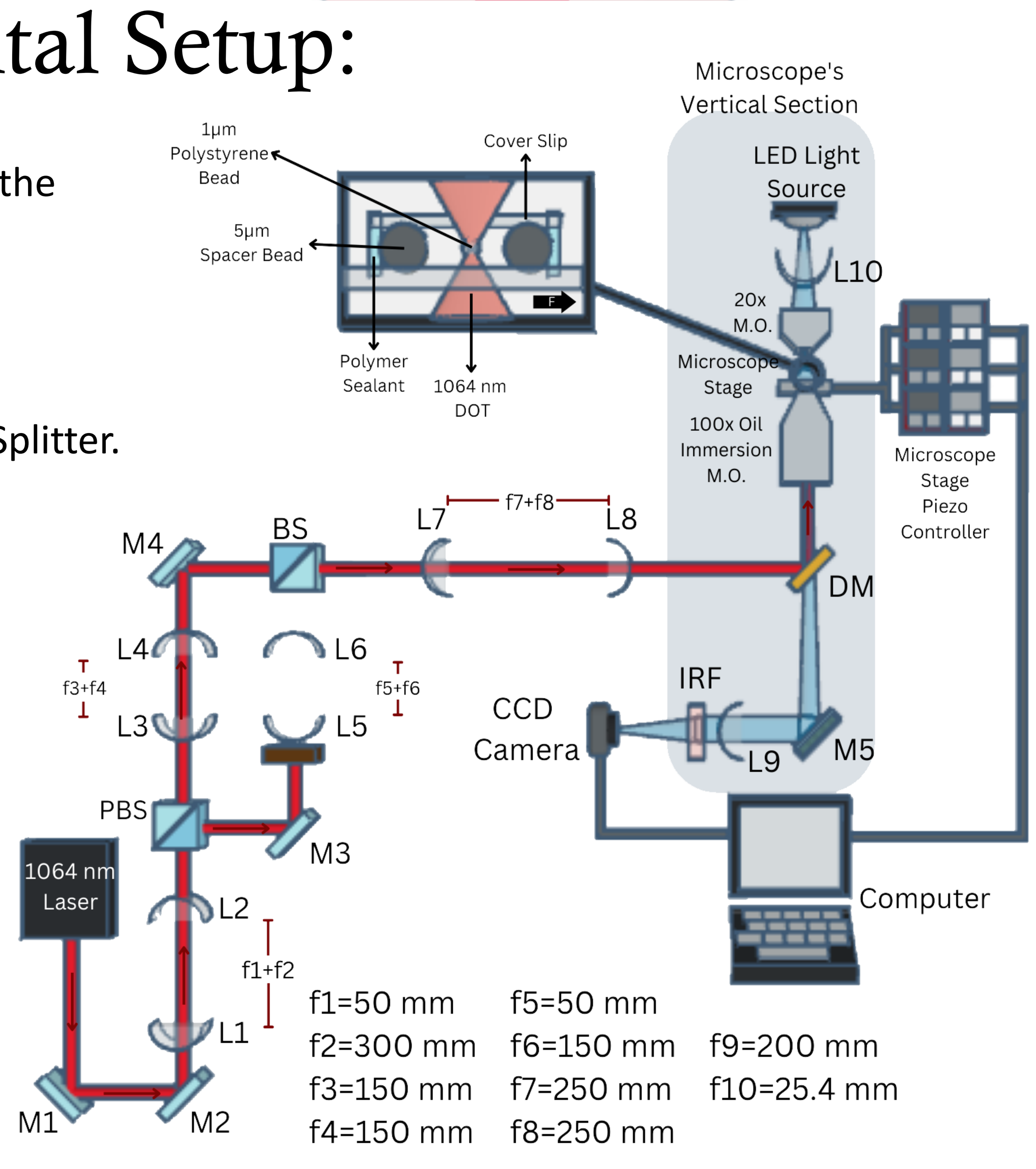
$$\vec{F}_s \propto I(r)\hat{z}$$

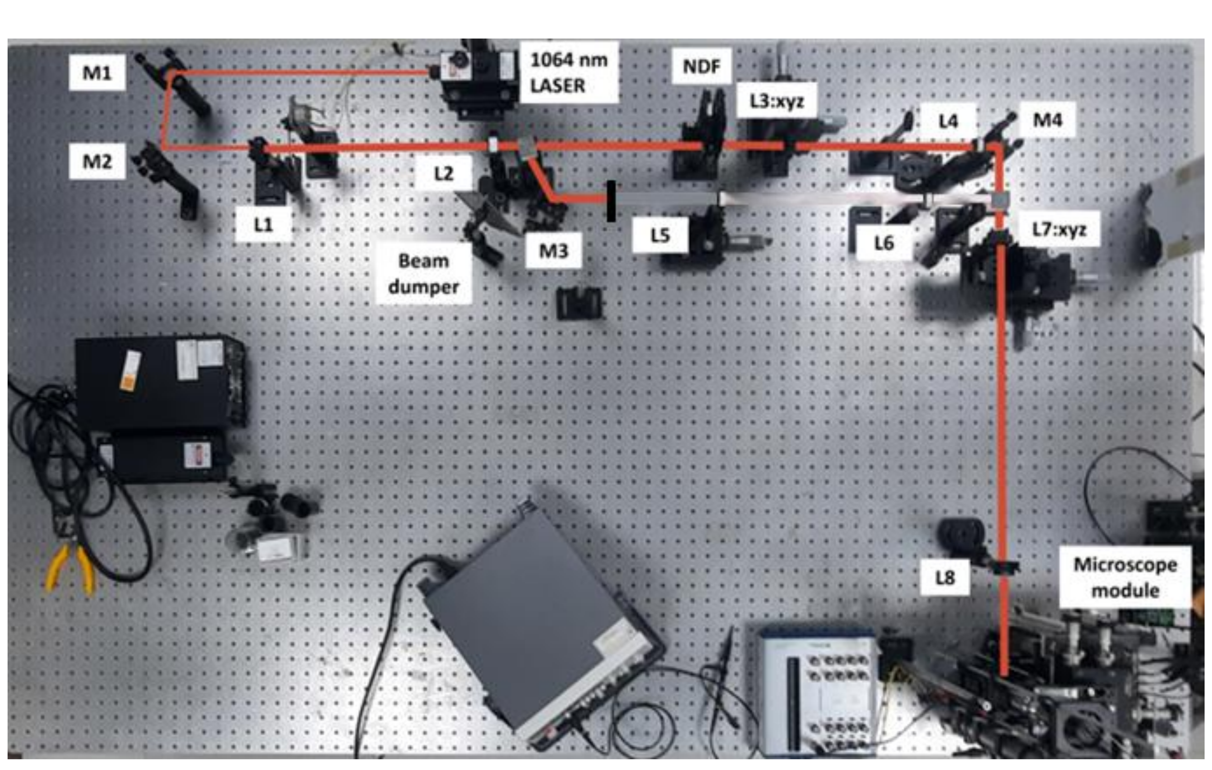


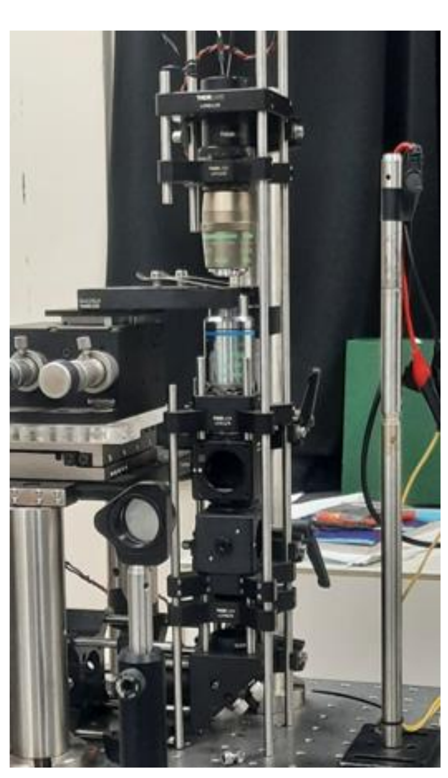
For a stable trap: $\vec{F}_g > \vec{F}_s$

Experimental Setup:

Schematic diagram of the Dual Optical Tweezer.
L: Lens.
f: focal length.
M: Mirror.
PBS: Polarizing Beam Splitter.
BS: Beam Splitter.
DM: Dichroic Mirror.
M.O. for Microscope Objective.
IRF: Infrared Filter.

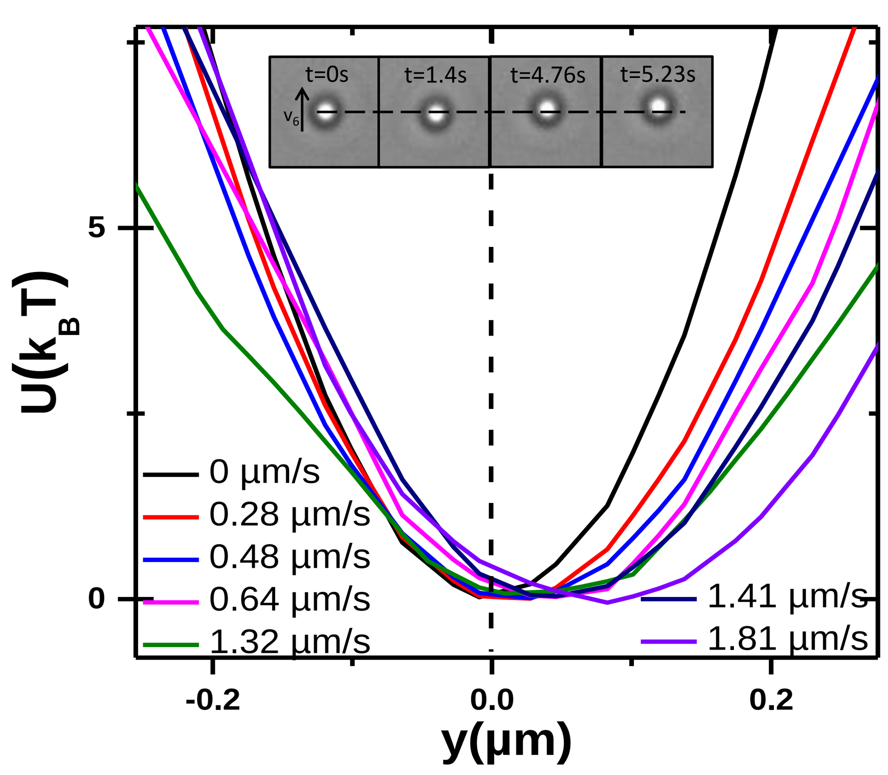




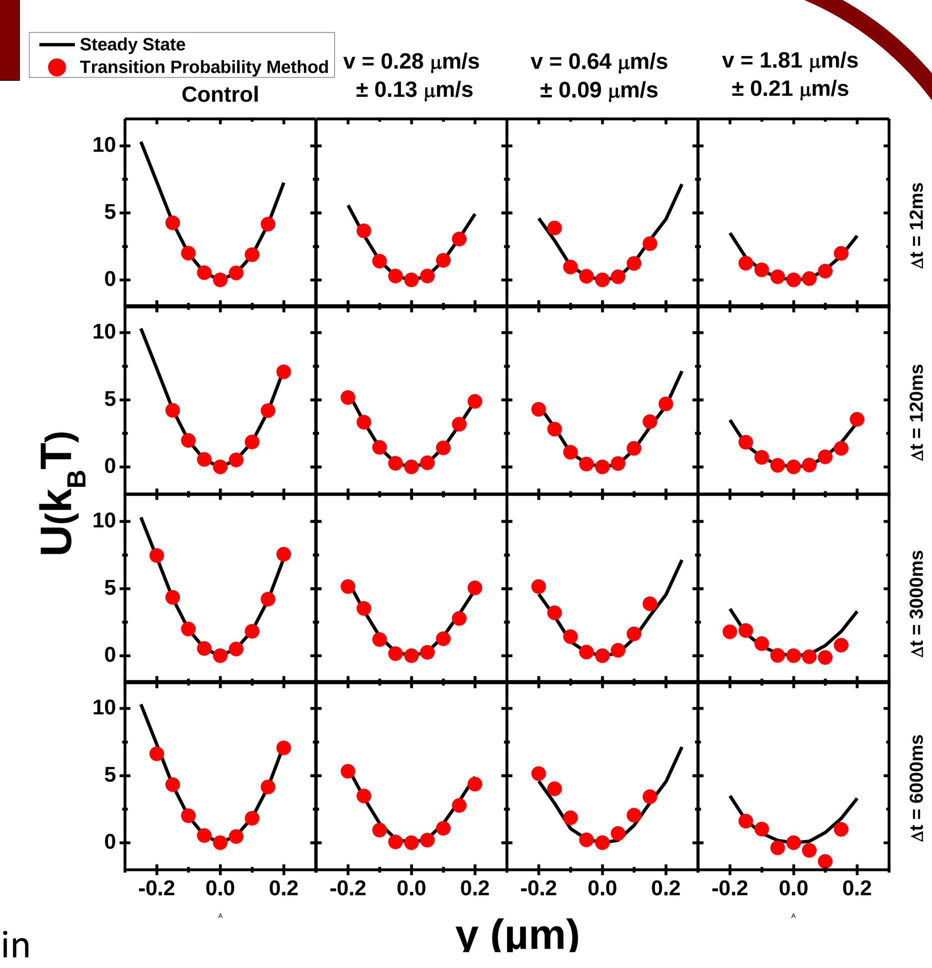


- Right image: Actual image of the experimental setup.
- Left image: Vertical Section of the microscope.

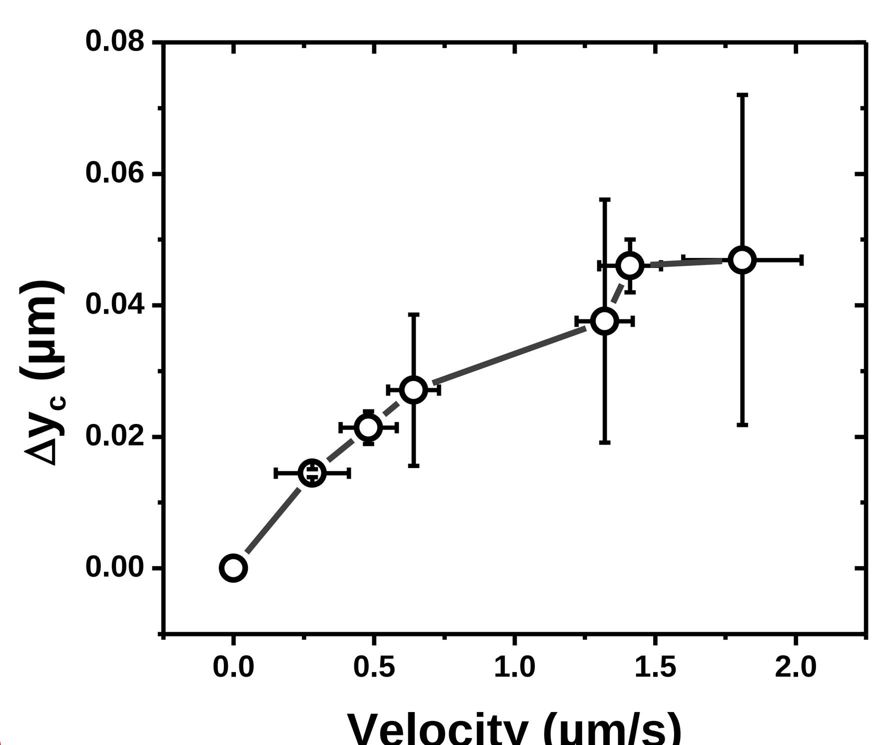
Initial Results



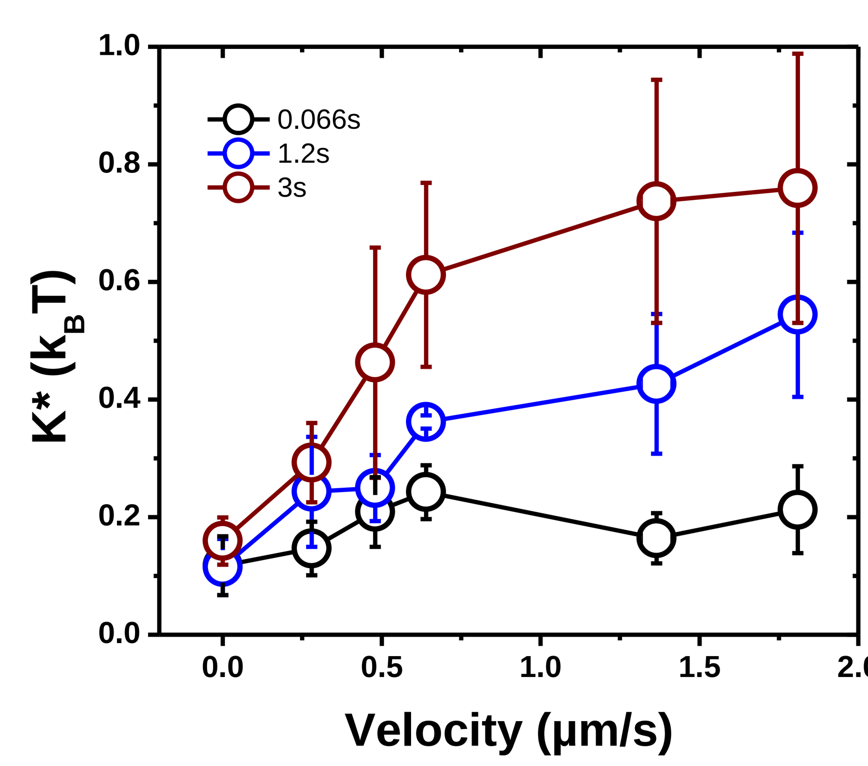
- Displays the shift of the center with the increase in velocity.
- Inset is a snippet from v = 1.81 μm/s.



- Shows how transition probability becomes inadequate for driven systems.



- Plot of the change of the center as a function of velocity.
- $\Delta y_c = |y_{cc} - y_{cv}|$, y_{cc} = center of control, y_{cv} = center for velocity v.



- Plot of K* as a function of velocity at different time lags.

Summary

- Increase in the driving velocity increases the shift of the center of the potential.
- The transition probability measured is unable to recreate the non-equilibrium potential especially at greater velocity and longer time lags.
- K* displays an increasing trend as velocity increases and shows a net increase in terms of magnitude as Δt increases.

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