

# **Optically Trapped Gold Nanoparticle Enables Listening at the Microscale**

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# Applications of the Optical Tweezer

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A Standard tool widely used in biology, physics, chemistry, and material science

- i) Noninvasively manipulating micro- and nano-objects in space and arranging on substrate
- ii) Applying precisely adjustable forces and torques
- iii) Measuring forces at the scale of a single molecule

+ Exploring & demonstrating an ultrasensitive sound detection scheme  
based on motion analysis of a three-dimensionally optically trapped nanoparticle

# Scheme

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## **Brownian Motion**

Stochastic collisions with solvent molecules  
-> random drifting of the particle

Interaction with 3D potential well (Trap beam)

Obtaining trap beam  
parameter

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graph LR; A["Brownian Motion<br/>Stochastic collisions with solvent molecules<br/>-> random drifting of the particle"] --> D["Obtaining trap beam<br/>parameter"]; B["Interaction with 3D potential well (Trap beam)"] --> D;
```

# Scheme

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## Brownian Motion

Stochastic collisions with solvent molecules  
-> random drifting of the particle

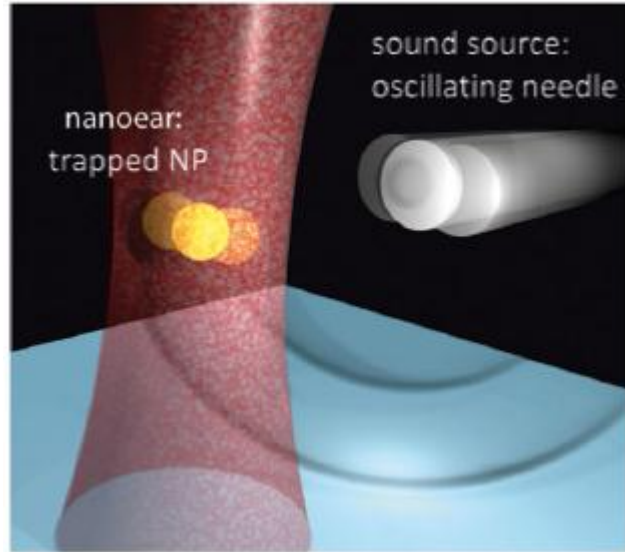
Interaction with 3D potential well (Trap beam)

Non-equilibrium fluctuation of particle's  
environment  
(acoustic wave, local solvent flow)

Readout?

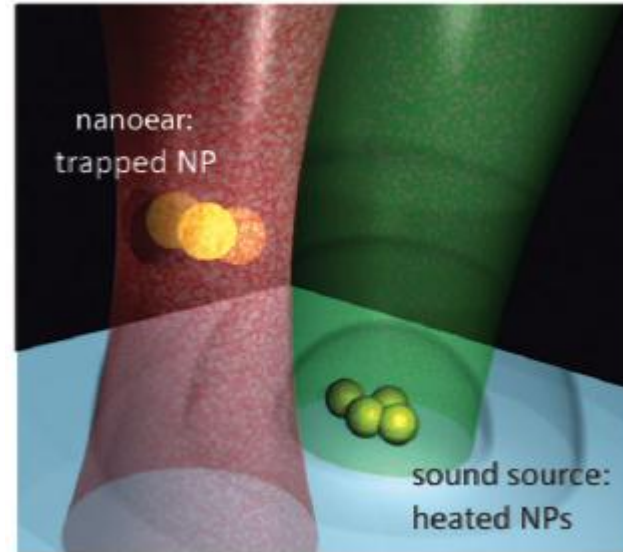
```
graph LR; A["Brownian Motion<br/>Stochastic collisions with solvent molecules<br/>-> random drifting of the particle"] --- B; C["Interaction with 3D potential well (Trap beam)"] --- B; D["Non-equilibrium fluctuation of particle's<br/>environment<br/>(acoustic wave, local solvent flow)"] --- B; B --> E["Readout?"]
```

# Scheme



Macroscopic sound source

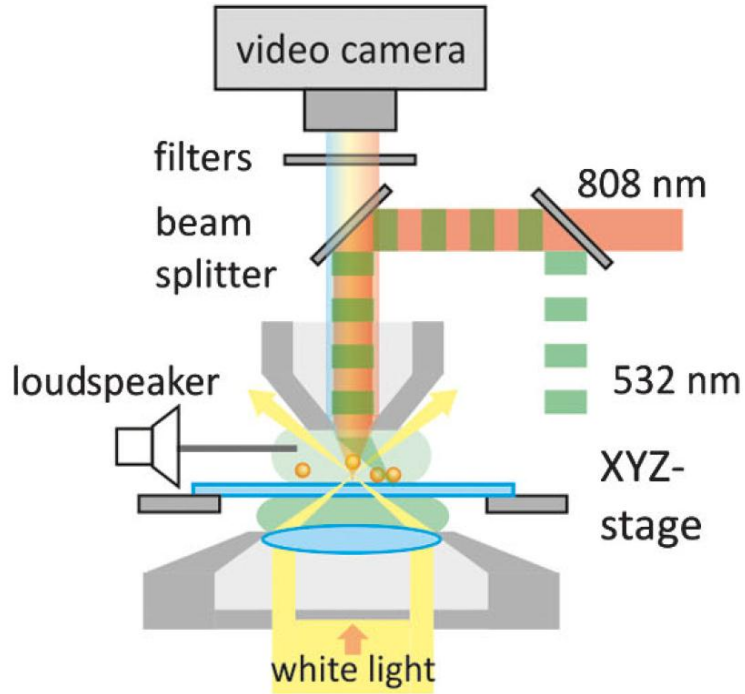
Tungsten needle glued on a  
loudspeaker



Microscopic sound source

Aggregated Au NPs  
(plasmonically heated by an  
laser beam)

# Setup

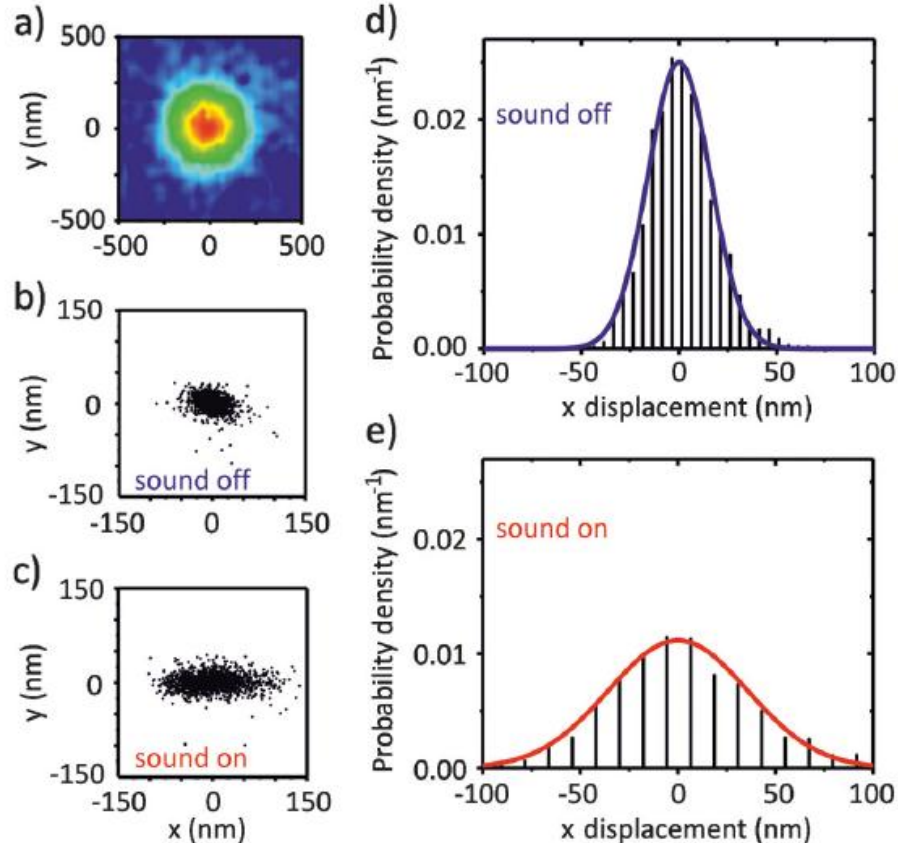
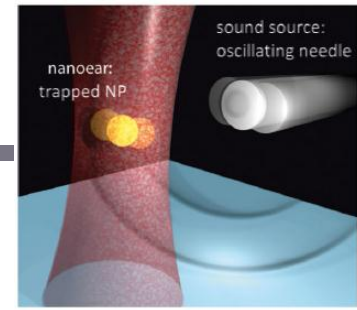


Trapping beam : Ti:Sapphire laser (CW 808 nm)  
Acoustic wave generation : CW 532 nm

100x/NA1.0/water immersion lens  
-> 3.5 $\mu$ m focal plane

EOS 500D 50 frame/sec

# Result : macroscopic sound source

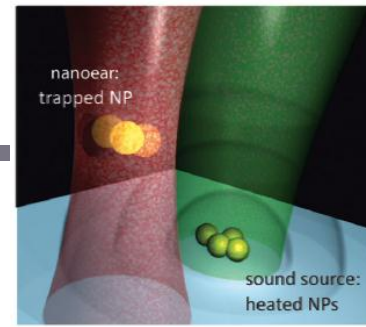


60 nm Au nano ptl  
300 Hz sound source  
30s (1500 frames)  
Localization accuracy  $\sim 1.5$  nm

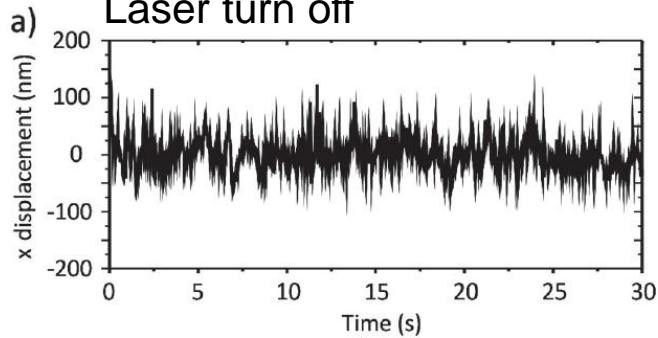
The direction of sound propagation was shown

**Sensitivity ?**

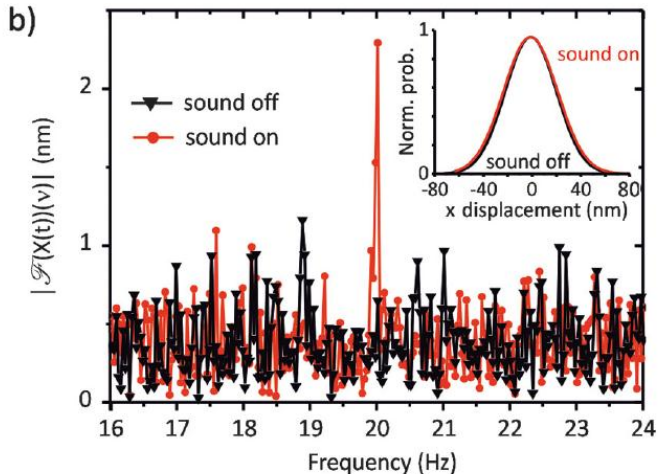
# Result : microscopic sound source



Laser turn off



Aggregated Au nanoptls on substrate  
Optothermal heating (green laser 30 mW)  
11  $\mu\text{m}$  distance between focal point & substrate



$\sigma_{\text{off}} : 21.5 \pm 0.4 \text{ nm}$

$\sigma_{\text{on}} : 22.1 \pm 0.5 \text{ nm}$

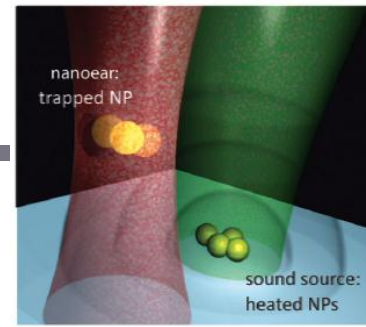
20 Hz sound is detected by Fourier Transformation

Heat transfer from the aggregate ( $10^{-20}\text{K}$ )

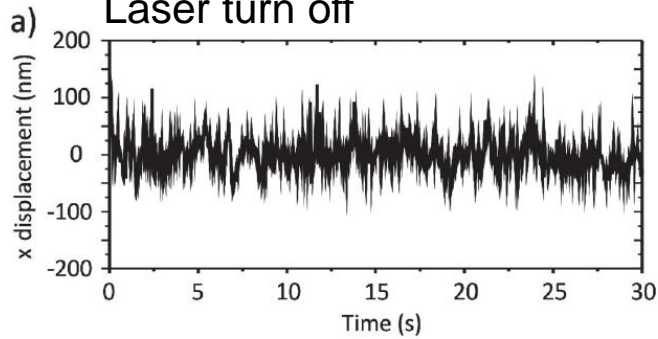
Radiation pressure forces exerted on the trapped nanoparticle by light scattered by the aggregate (0.04fN)  
: negligible



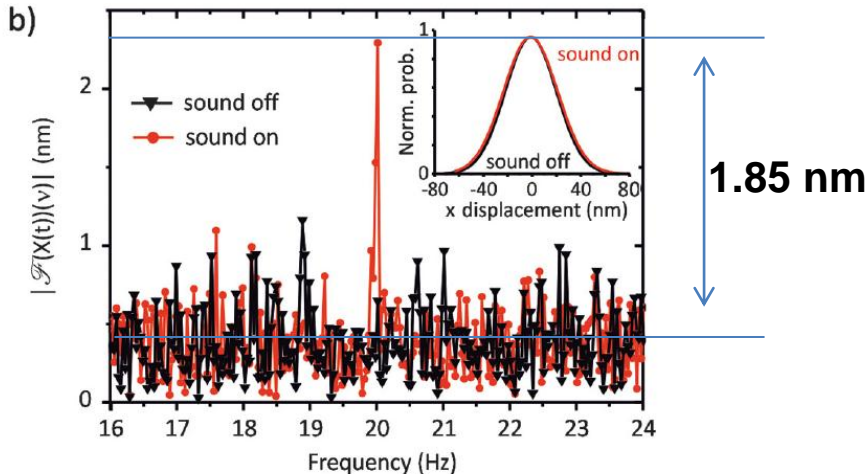
# Result : microscopic sound source



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Aggregated Au nanoptls on substrate  
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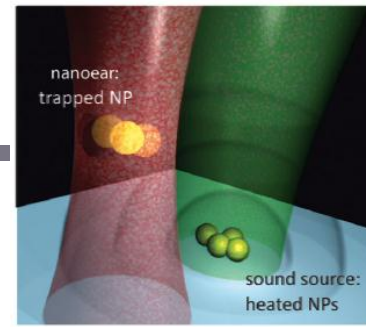
$$P(x) = P_0 e^{-x^2/2\sigma^2}$$

$$\kappa = k_B T / \sigma^2 \sim (170 \pm 6) \text{ aN} / \text{nm} / \text{mW}$$

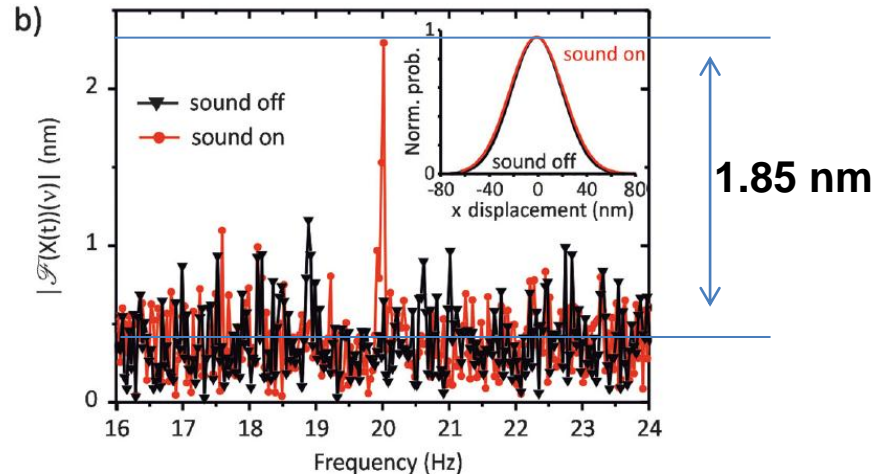
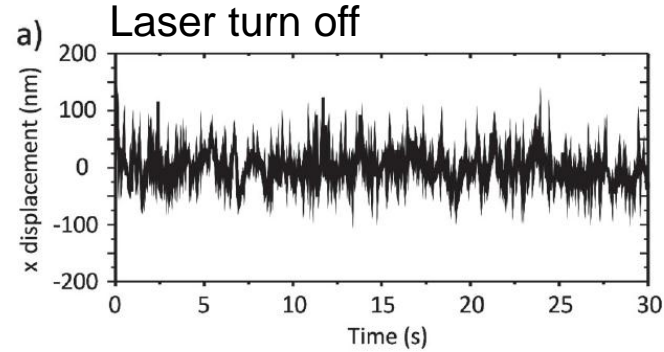
$$E(x) = x^2 \kappa / 2$$

$$E_{\text{transferred}} = \frac{1}{2} \left( \frac{A}{\sigma} \right)^2 k_B T \approx 90 \mu\text{eV}$$

# Result : microscopic sound source



Aggregated Au nanoptls on substrate  
Optothermal heating (green laser 30 mW)  
11  $\mu\text{m}$  distance between focal point & substrate



$$P_{avg} = \frac{1}{2} c \rho v_{max}^2 \pi r^2$$

$$\kappa x_{max} = 6\pi\eta r v_{max}$$

$$P_{detected} = \frac{1}{2\pi} c \rho \left( \frac{\kappa x_{max}}{6\eta} \right)^2$$

$$L_W = -58\text{dB}$$

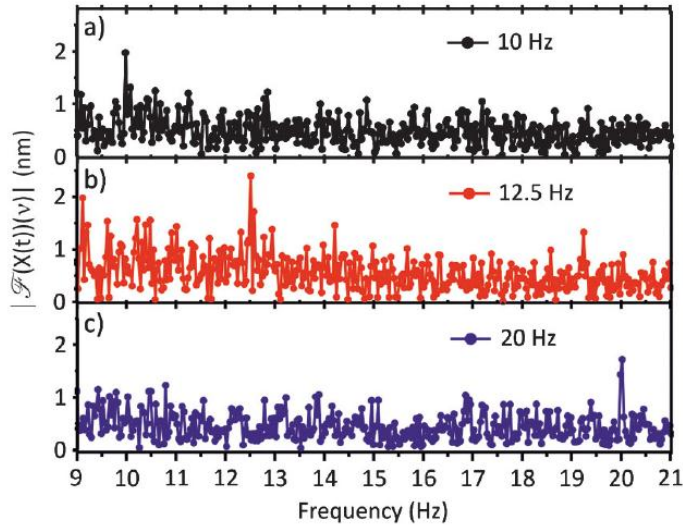
$$L_{emp} = 20\text{dB}$$

$$L_{hear} = 0\text{dB}$$

Empty room

Human ear limitation

# Result : microscopic sound source



Thin gold stripped (thickness 75 nm) deposited on a substrate

Optothermal heating

## Comment

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The motion of the nanoparticle in the direction orthogonal to this connecting line is found not to be affected by the sound

: **longitudinal** nature of acoustic wave

: determining direction