



# **Sensing with Nanoelectromechanical Systems (NEMS)**

**Research Unit of Micro- and Nanosensors**

**Silvan Schmid, 2021-04-13**



# Nanomechanical sensing



# Nanomechanical sensing

## Equation of motion

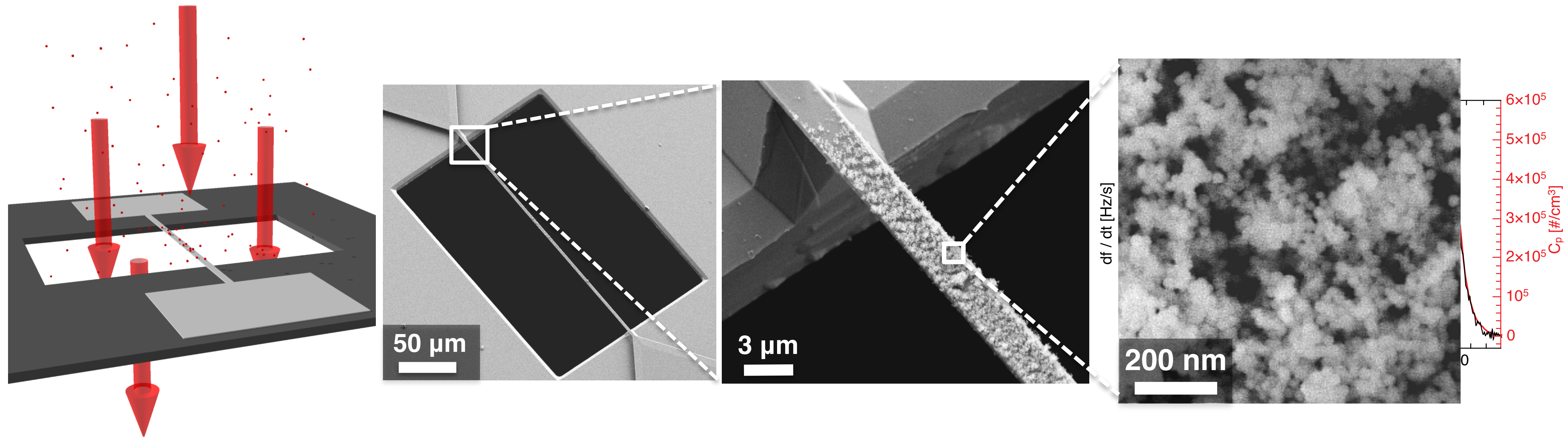
Mass

$$m \frac{\partial^2}{\partial t^2} x + c \frac{\partial}{\partial t} x + kx = F(t)$$



# NEMS Mass sensing

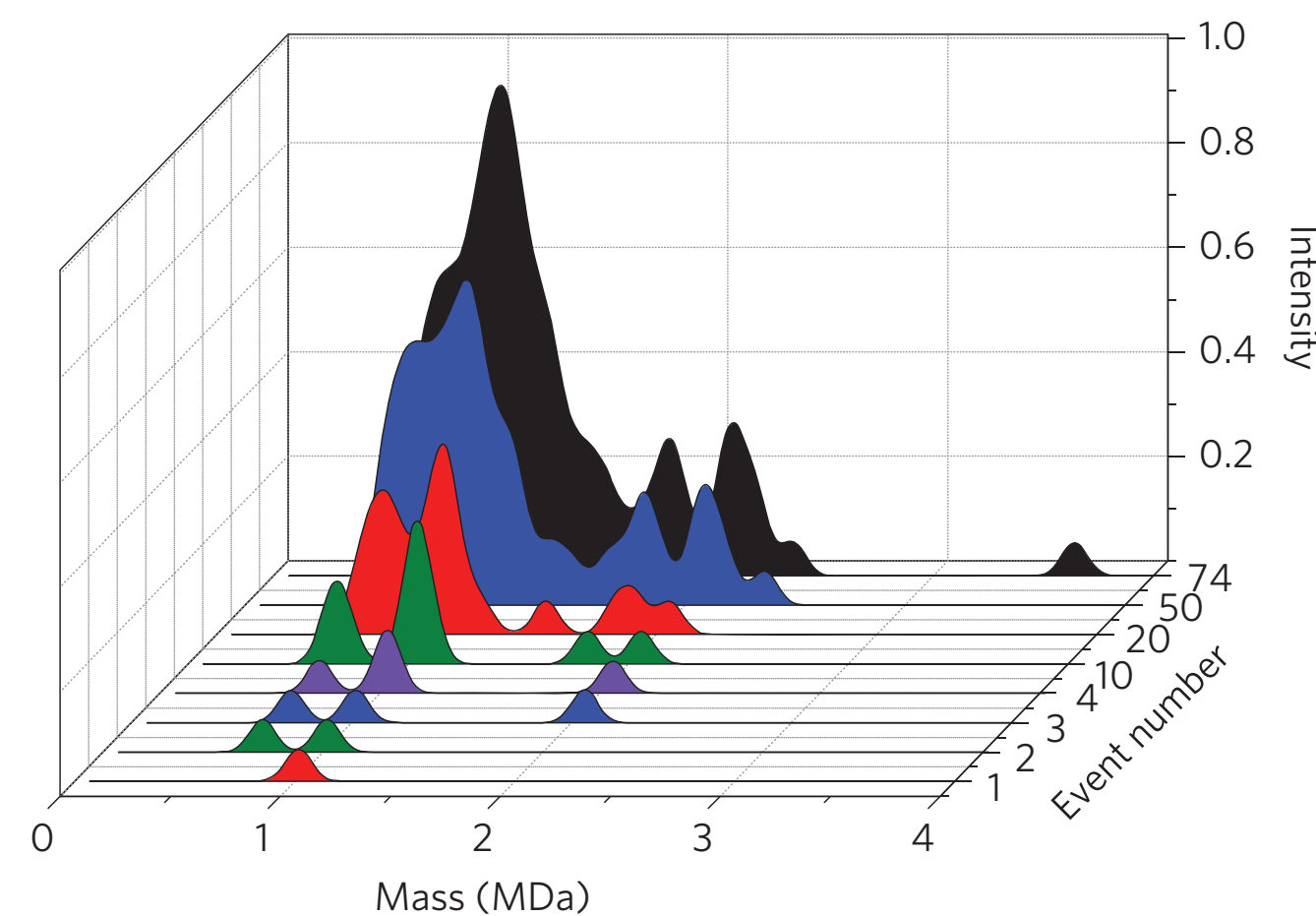
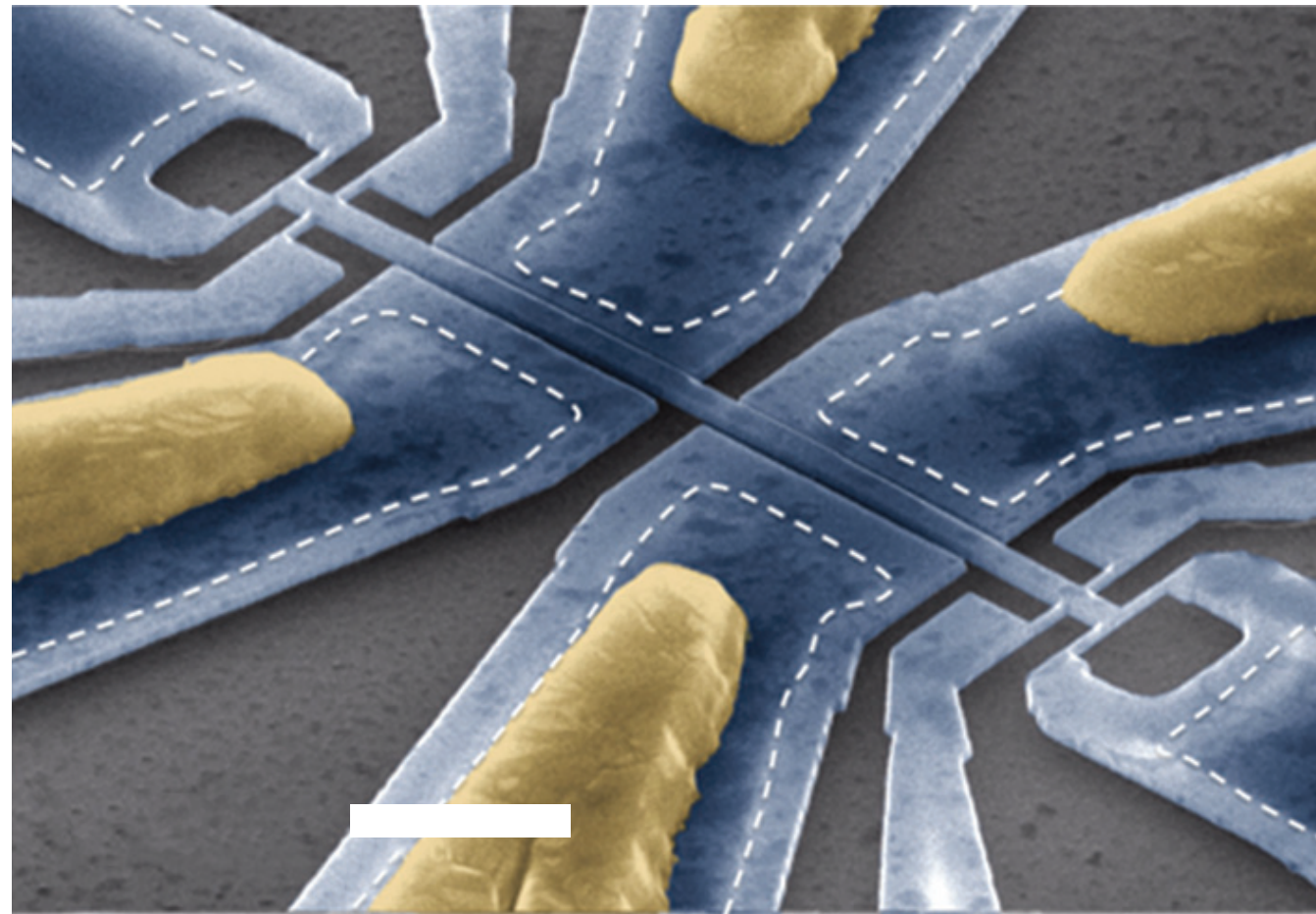
## Airborne nanoparticle mass concentration measurement



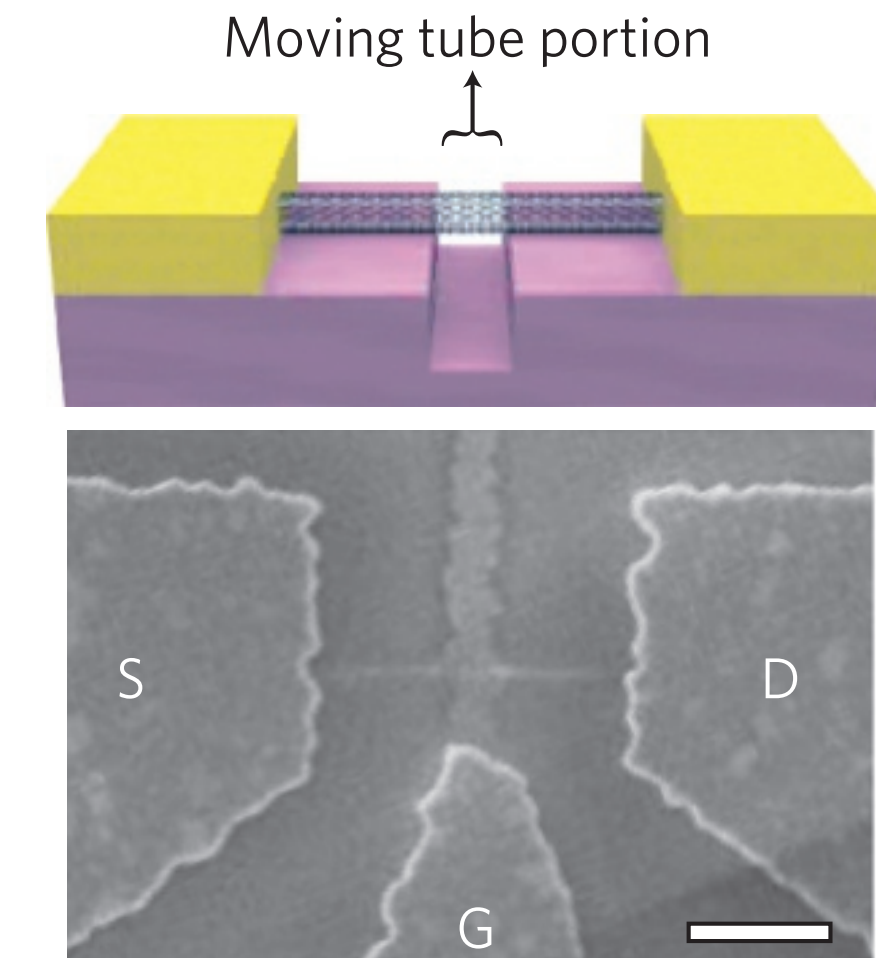


# NEMS Mass sensing

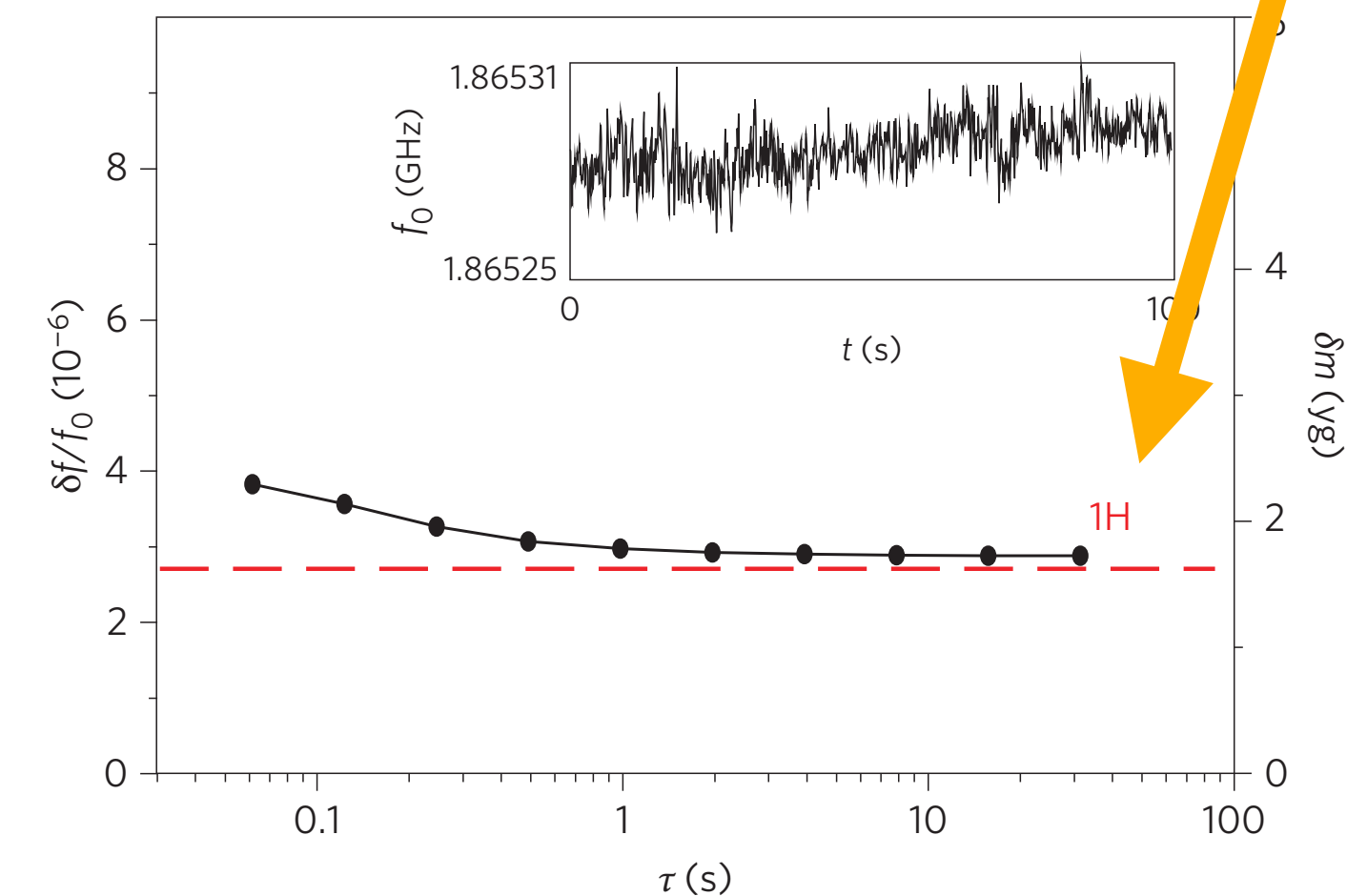
## From protein mass spectrometry to weighing of a proton



Hanay, M. S. et al. Nat. Nanotechnol. 7, 602–608 (2012).



Single-proton sensitivity



Chaste, J. et al. Nat. Nanotechnol. 7, 301–304 (2012).

# Nanomechanical sensing

## Equation of motion

Mass

$$m \frac{\partial^2}{\partial t^2} x + c \frac{\partial}{\partial t} x + kx = F(t)$$

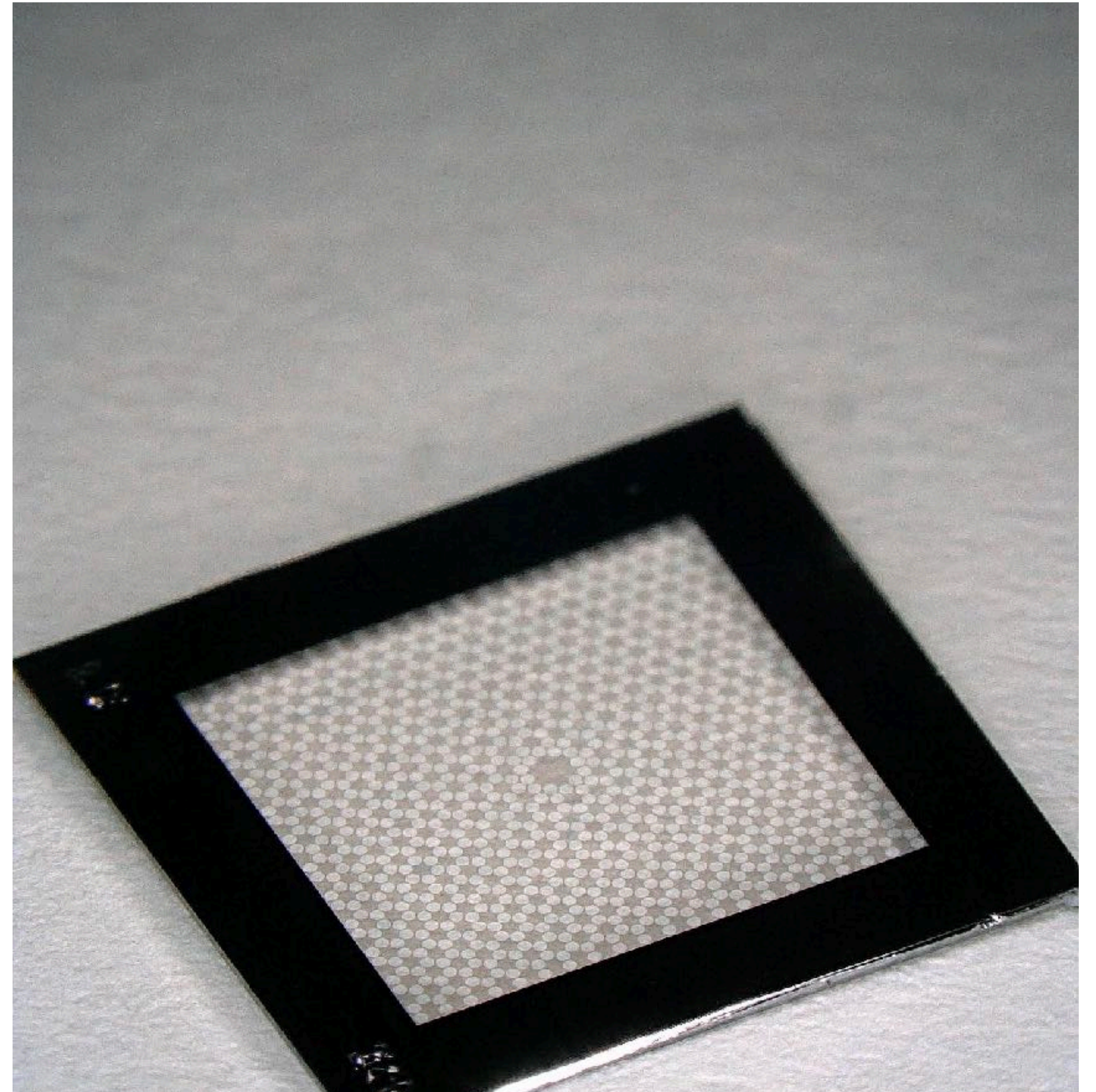
Energy loss



# Ultracoherent resonators

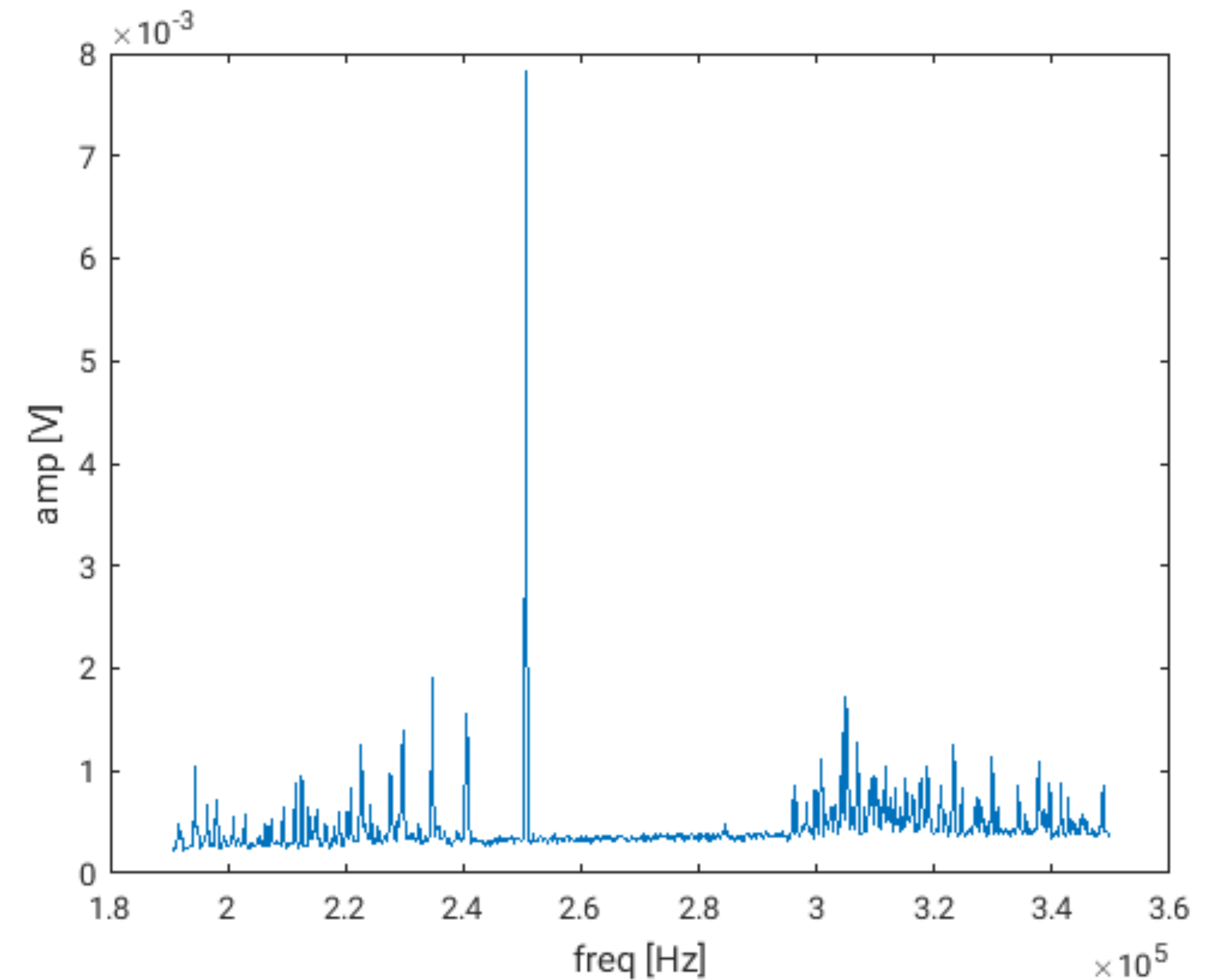
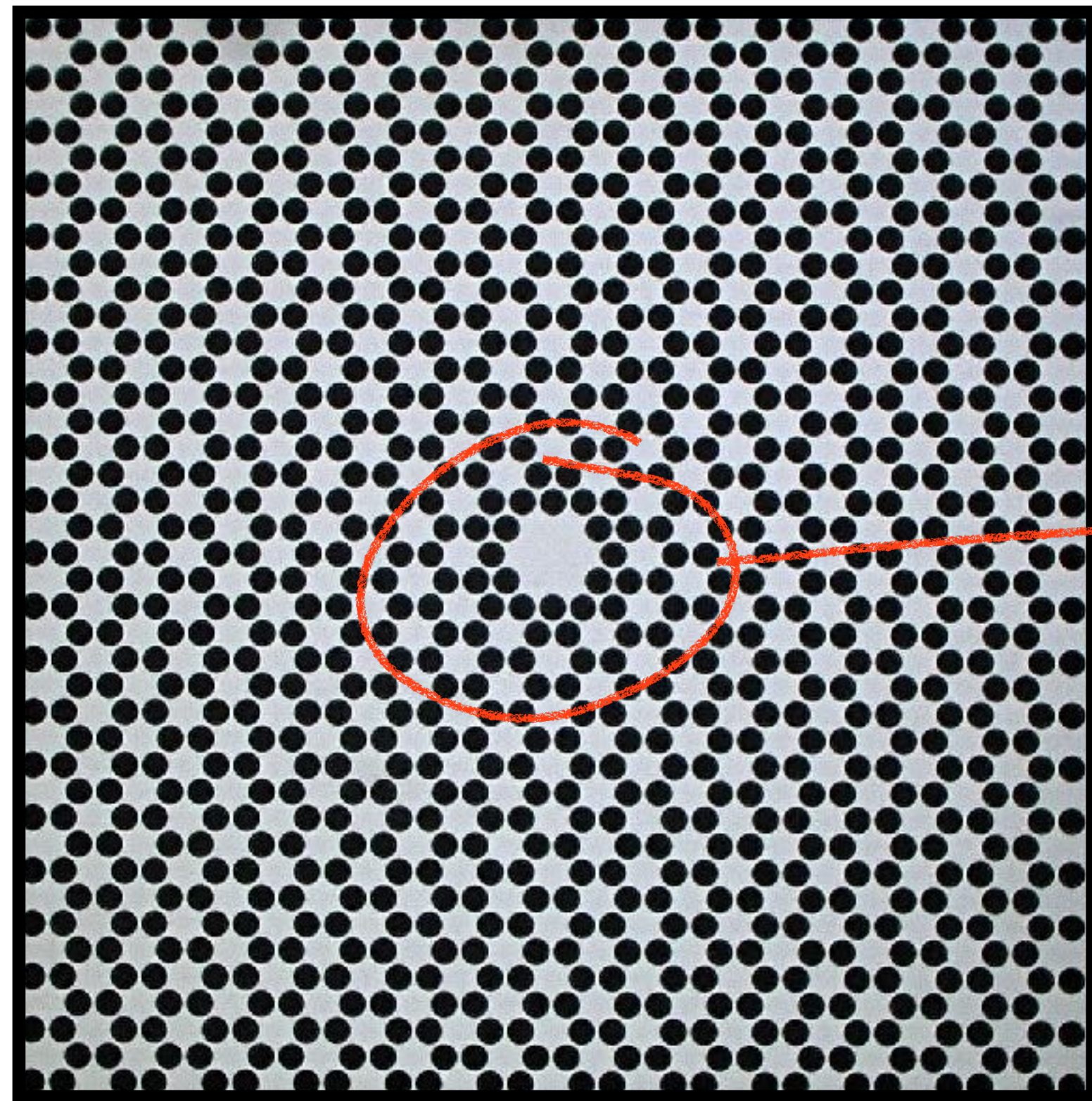
## By dissipation dilution

- Tools for metrology and fundamental research





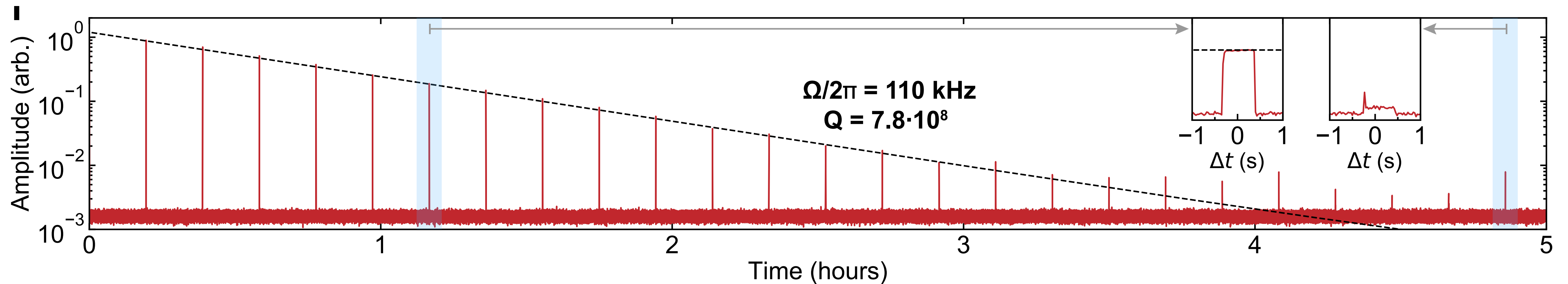
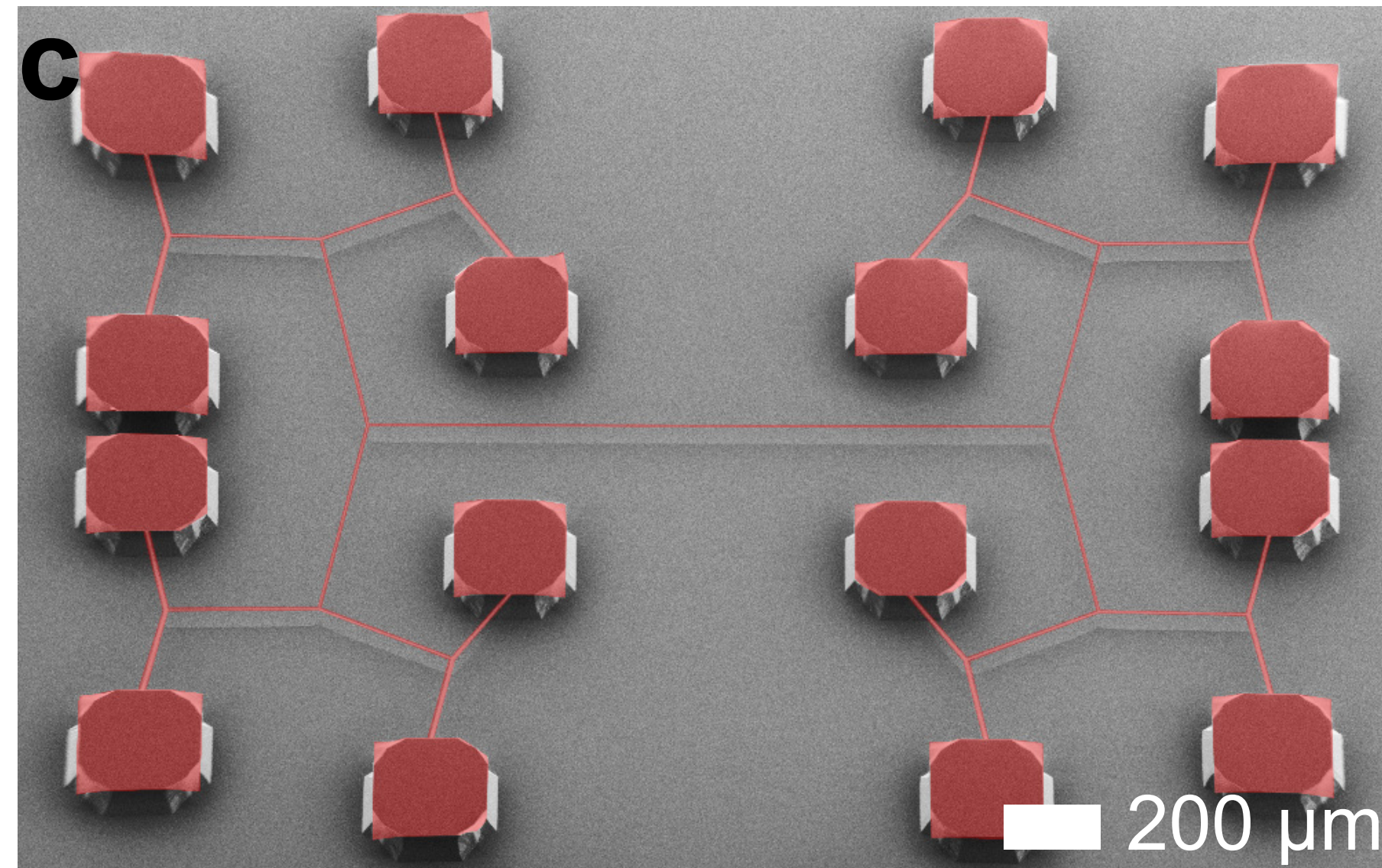
# Ultracoherent nanomechanical resonators



**Quality Factor = 300,000,000**



# Ultracoherent nanomechanical resonators



# Nanomechanical sensing

## Equation of motion

Mass

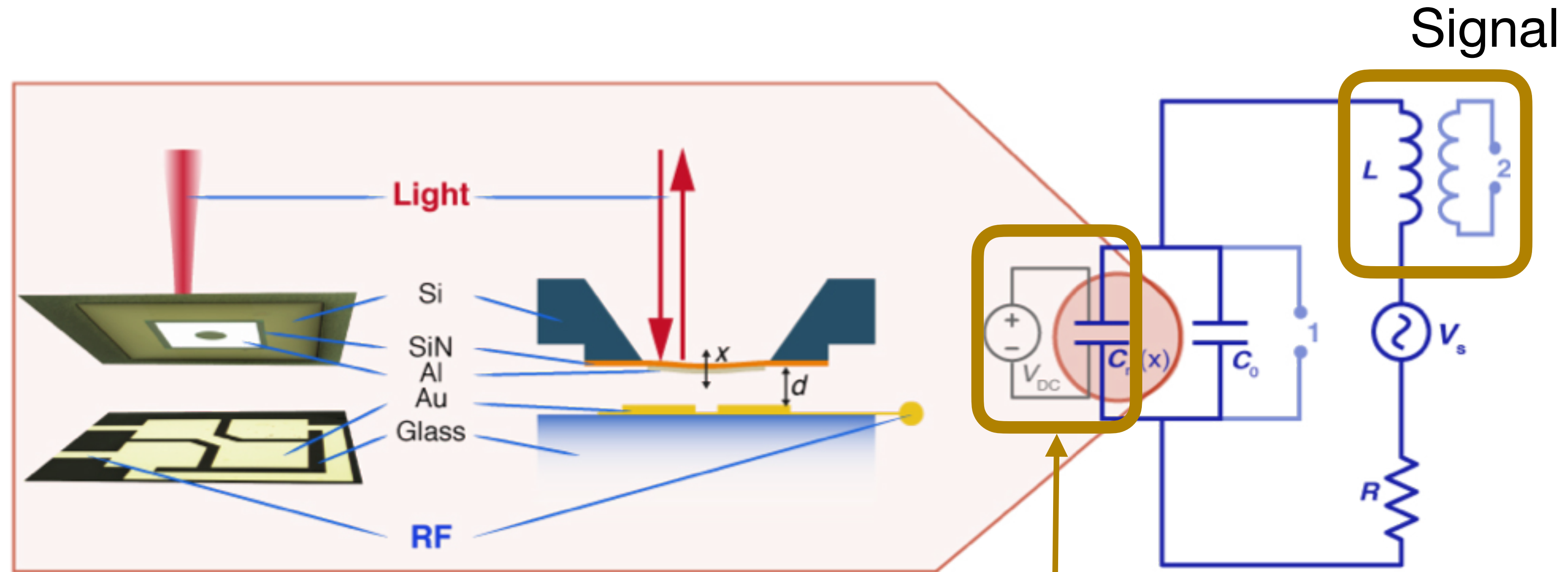
$$\boxed{m} \frac{\partial^2}{\partial t^2} x + \boxed{c} \frac{\partial}{\partial t} x + kx = \boxed{F}(t)$$

Energy loss

Force



# Radio to Optics Converter



Coupling by applying DC voltage

Noise level of nanomechanical transducer: **5 pV/Hz<sup>-1/2</sup>**

# Nanomechanical sensing

## Equation of motion

Mass

Spring constant (stiffness)

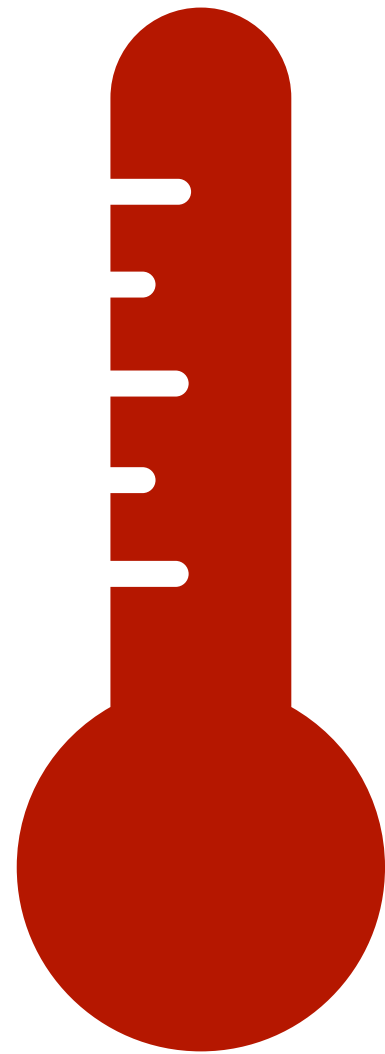
$$m \frac{\partial^2}{\partial t^2} x + c \frac{\partial}{\partial t} x + kx = F(t)$$

Energy loss

Force

# Nanomechanical sensing

## Temperature response

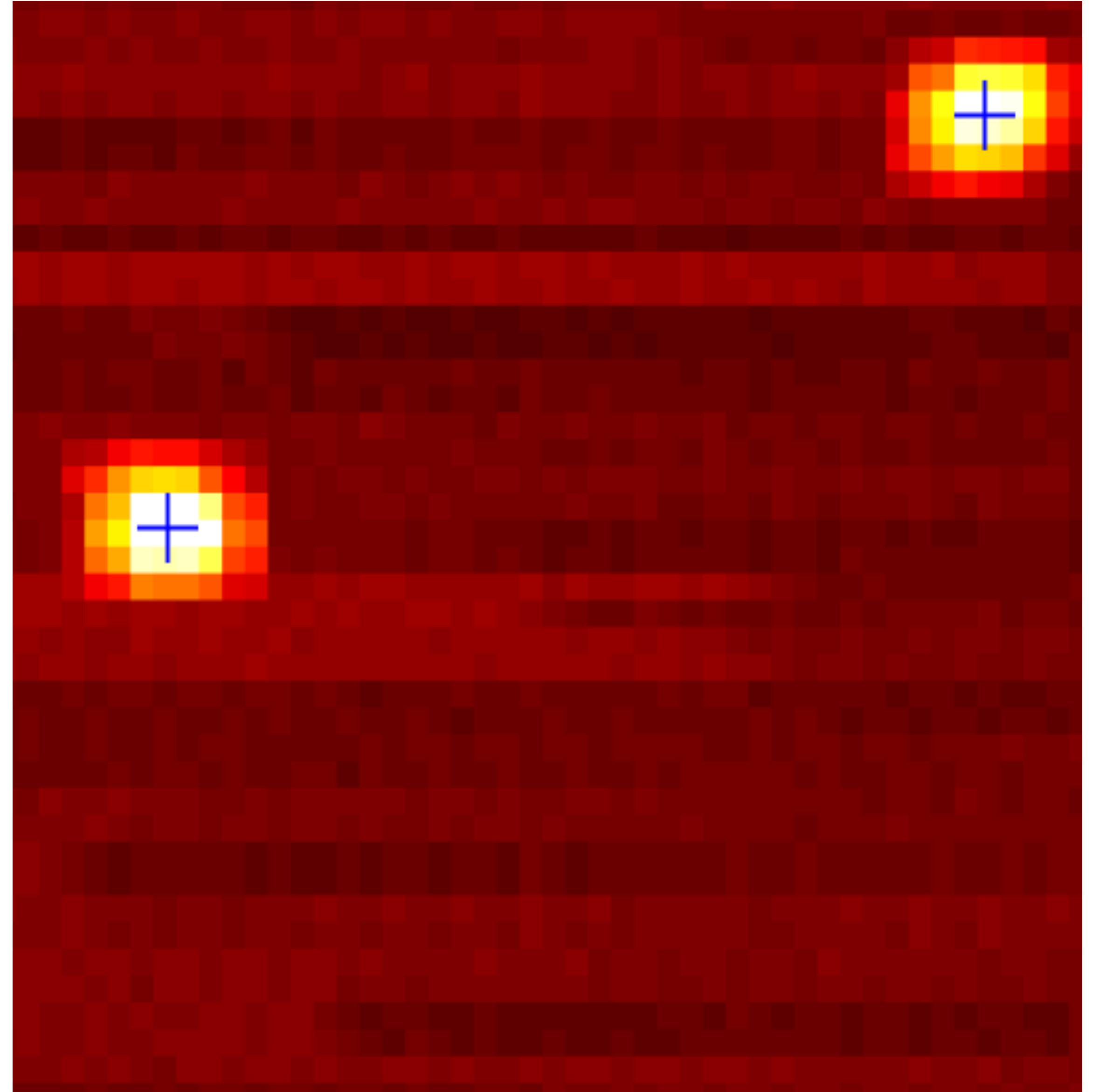


$$k(T)$$

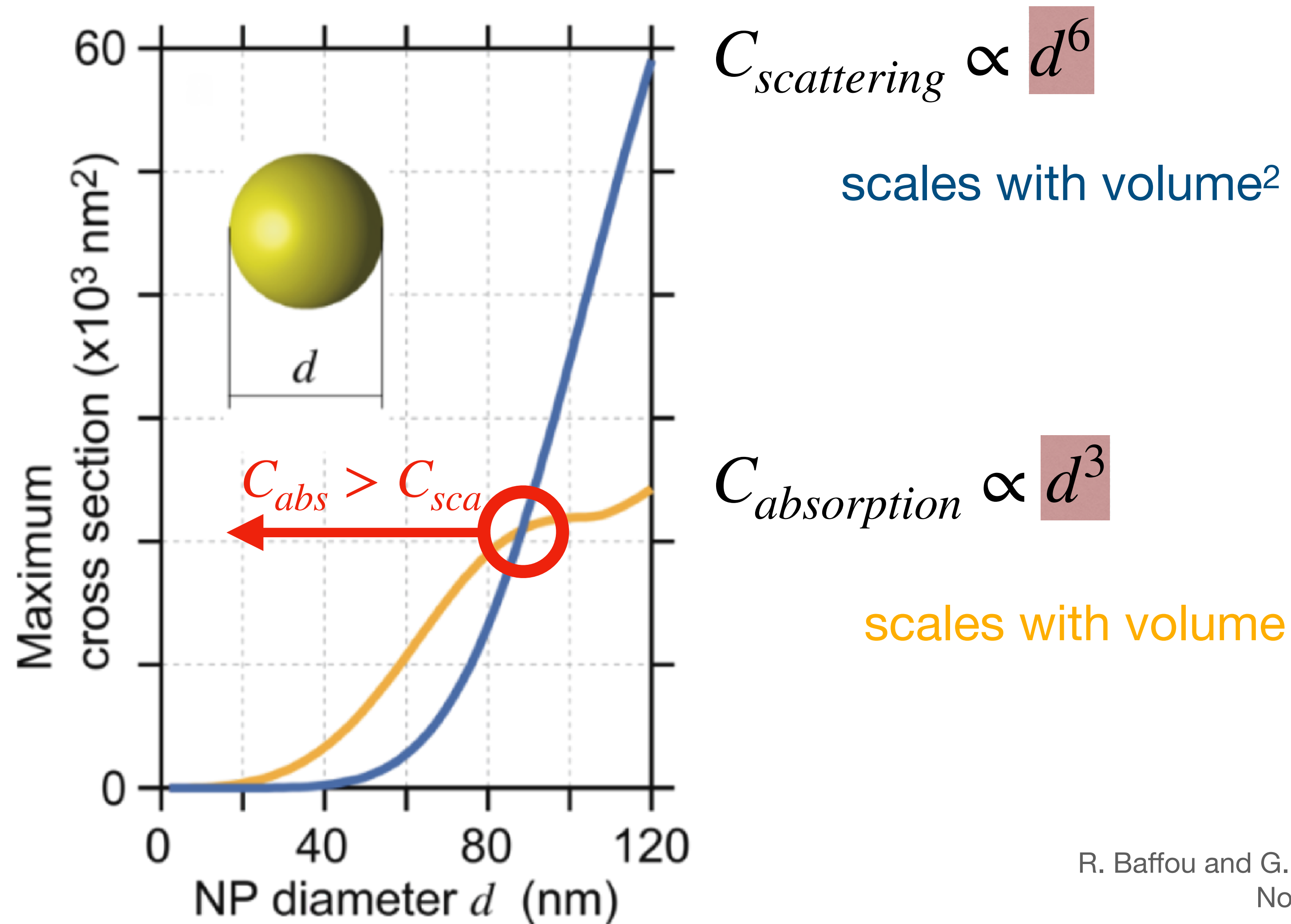


# Single-molecule imaging with NEMS photothermal sensing

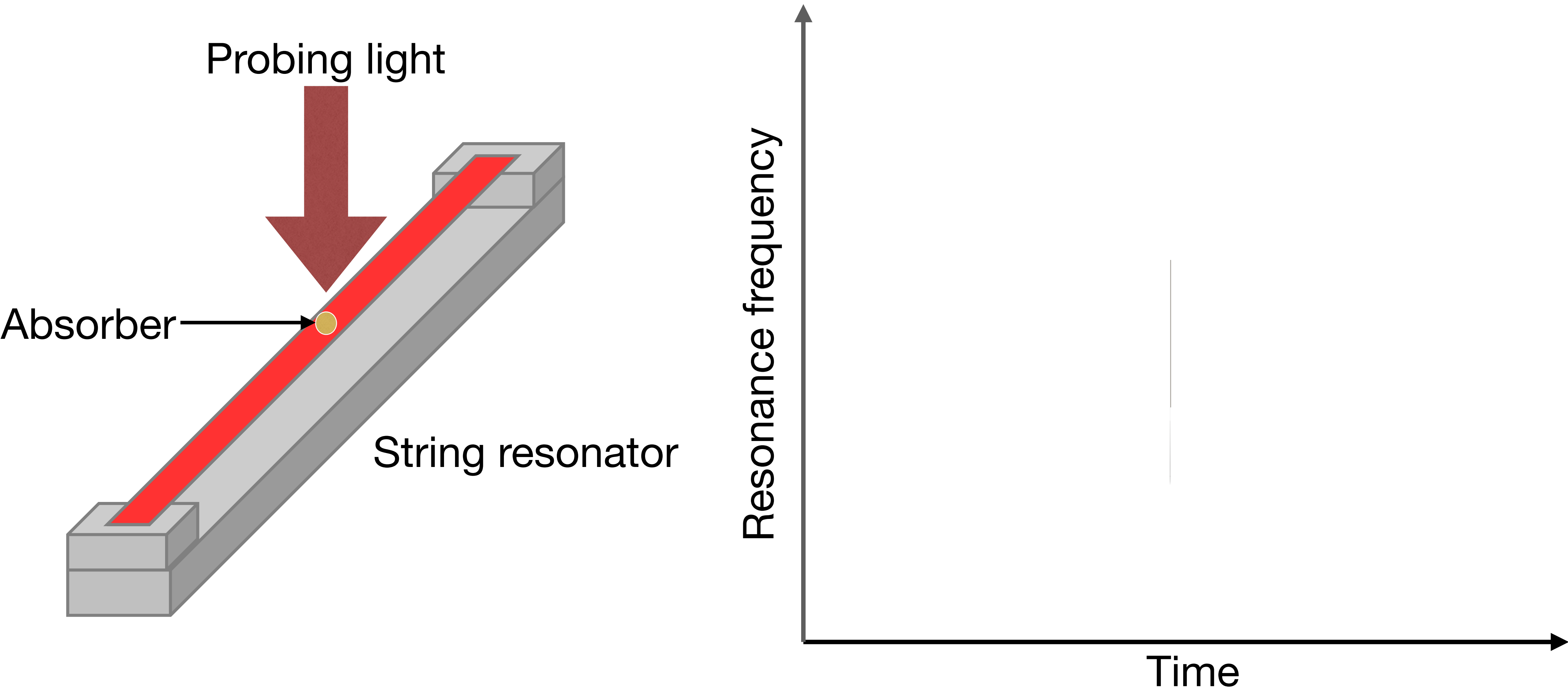
Collaboration with  
Biophysics Group at TU  
Wien



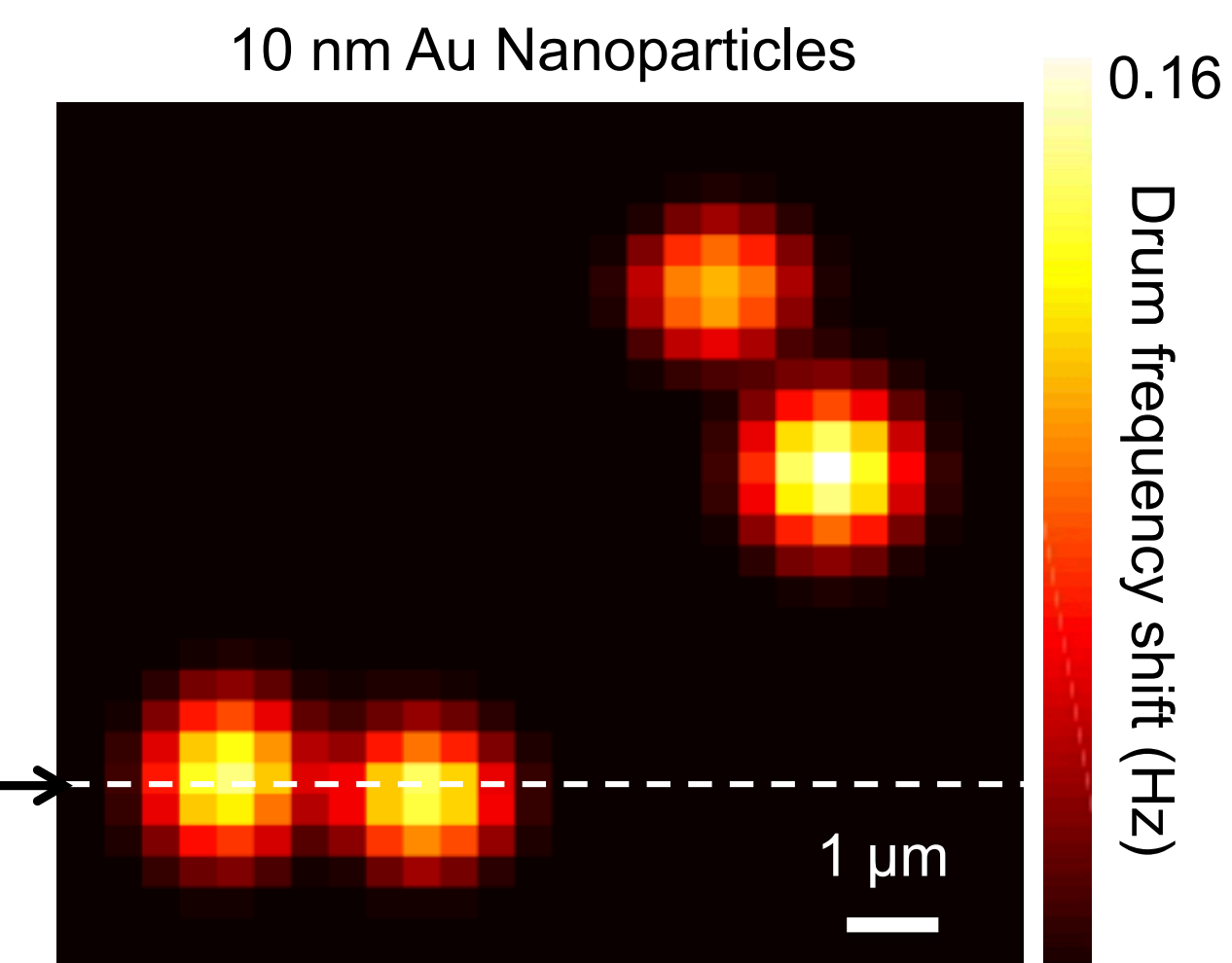
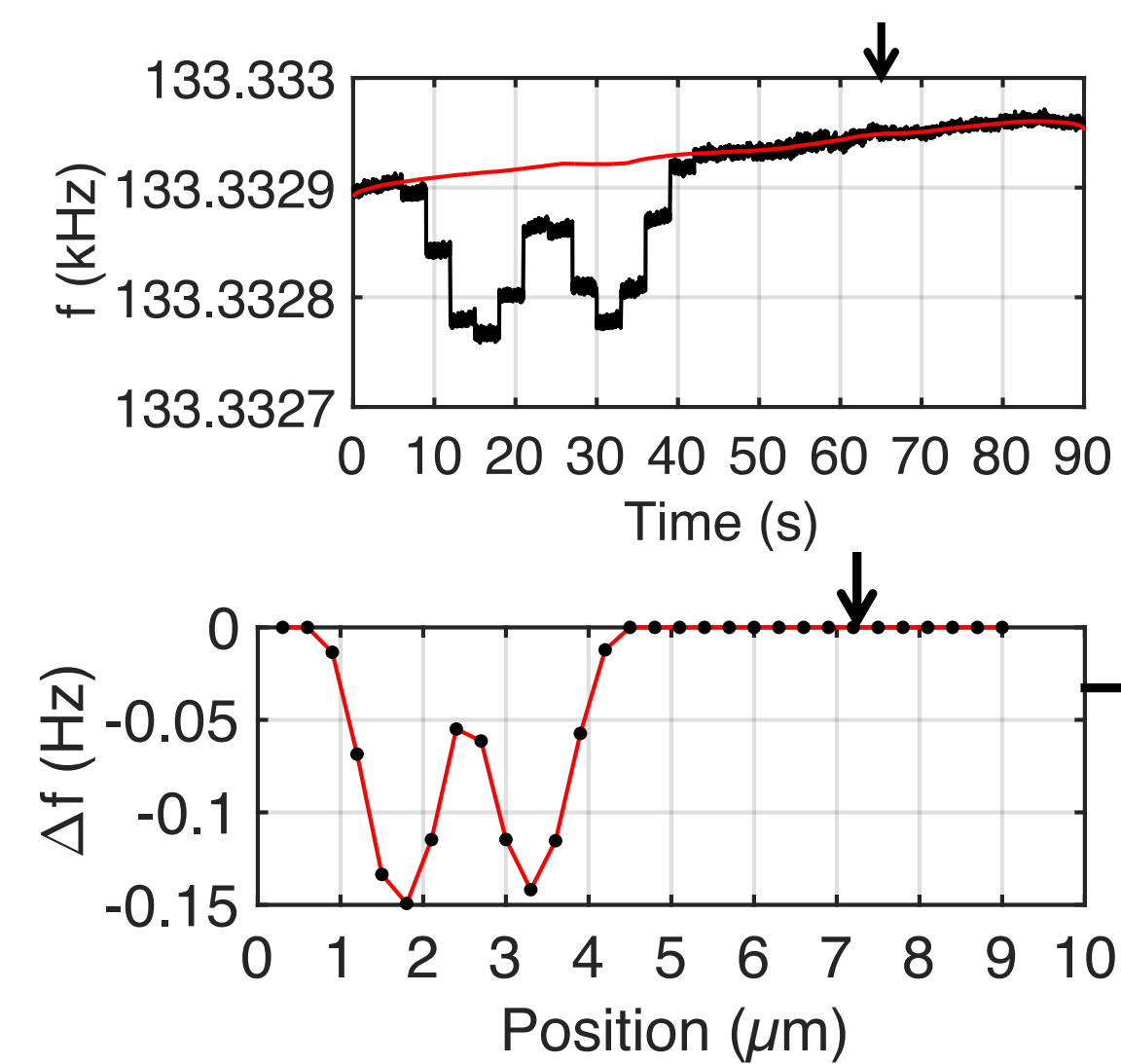
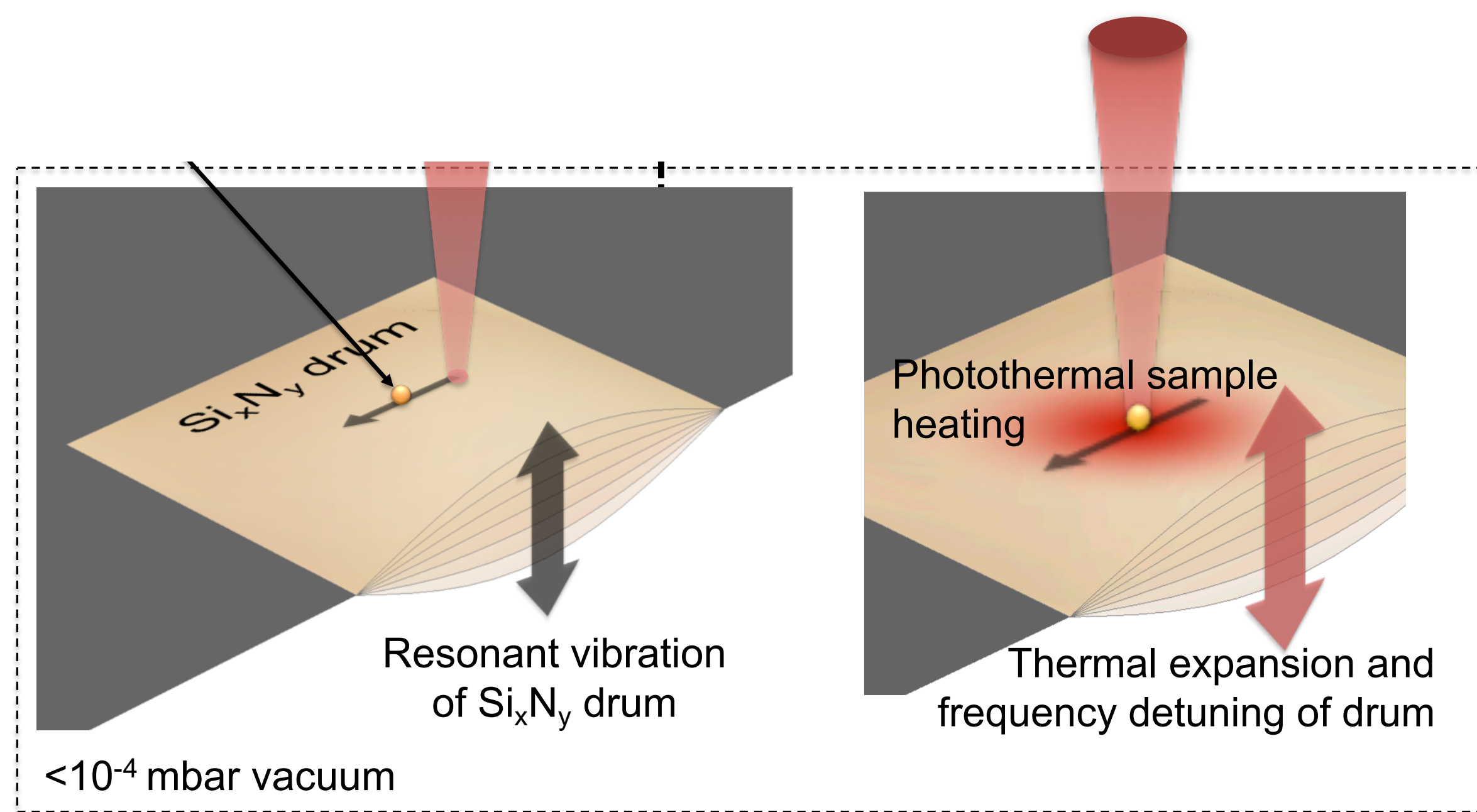
# Absorption vs scattering microscopy



# Photothermal sensing with a nano-optomechanical system



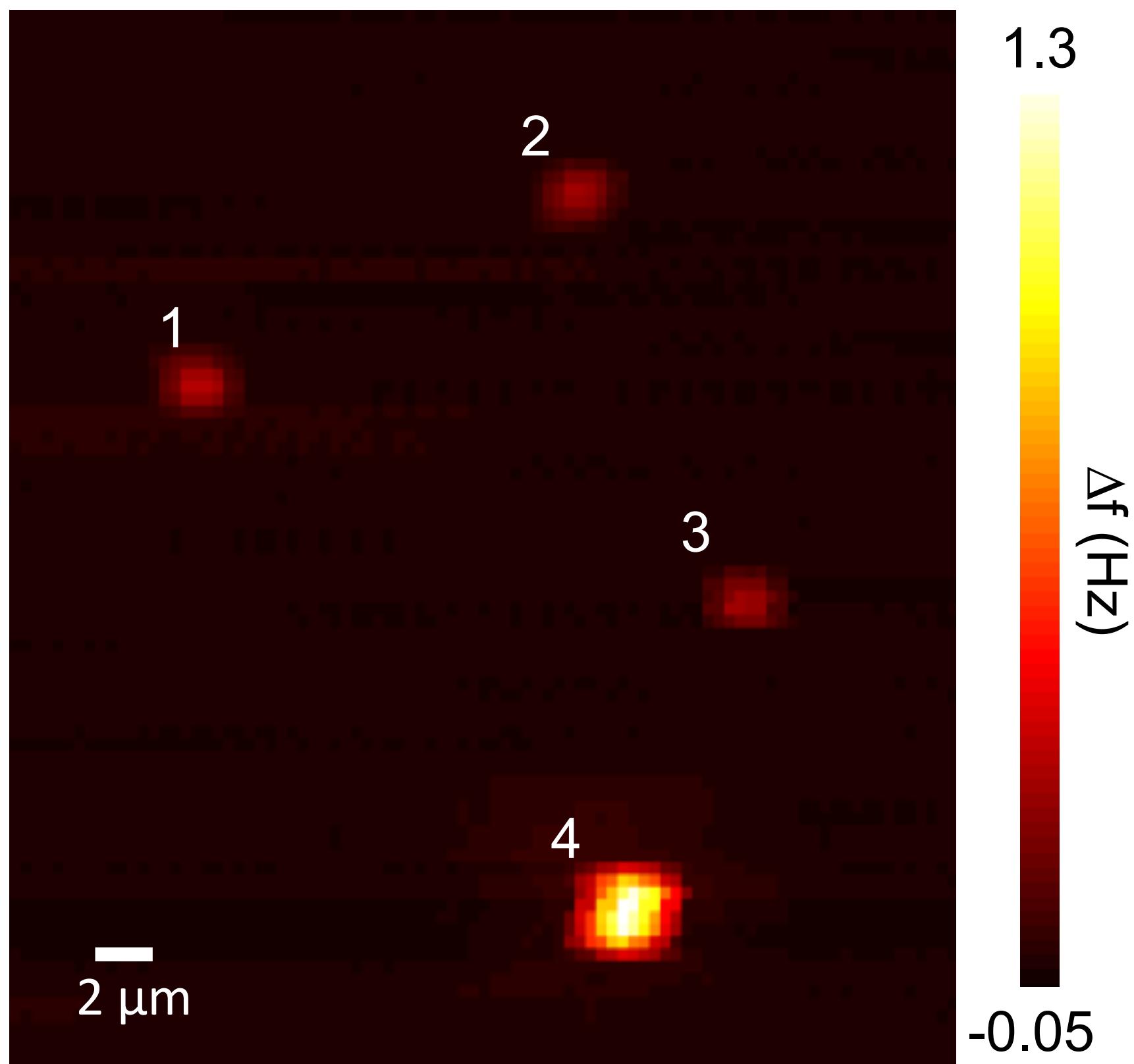




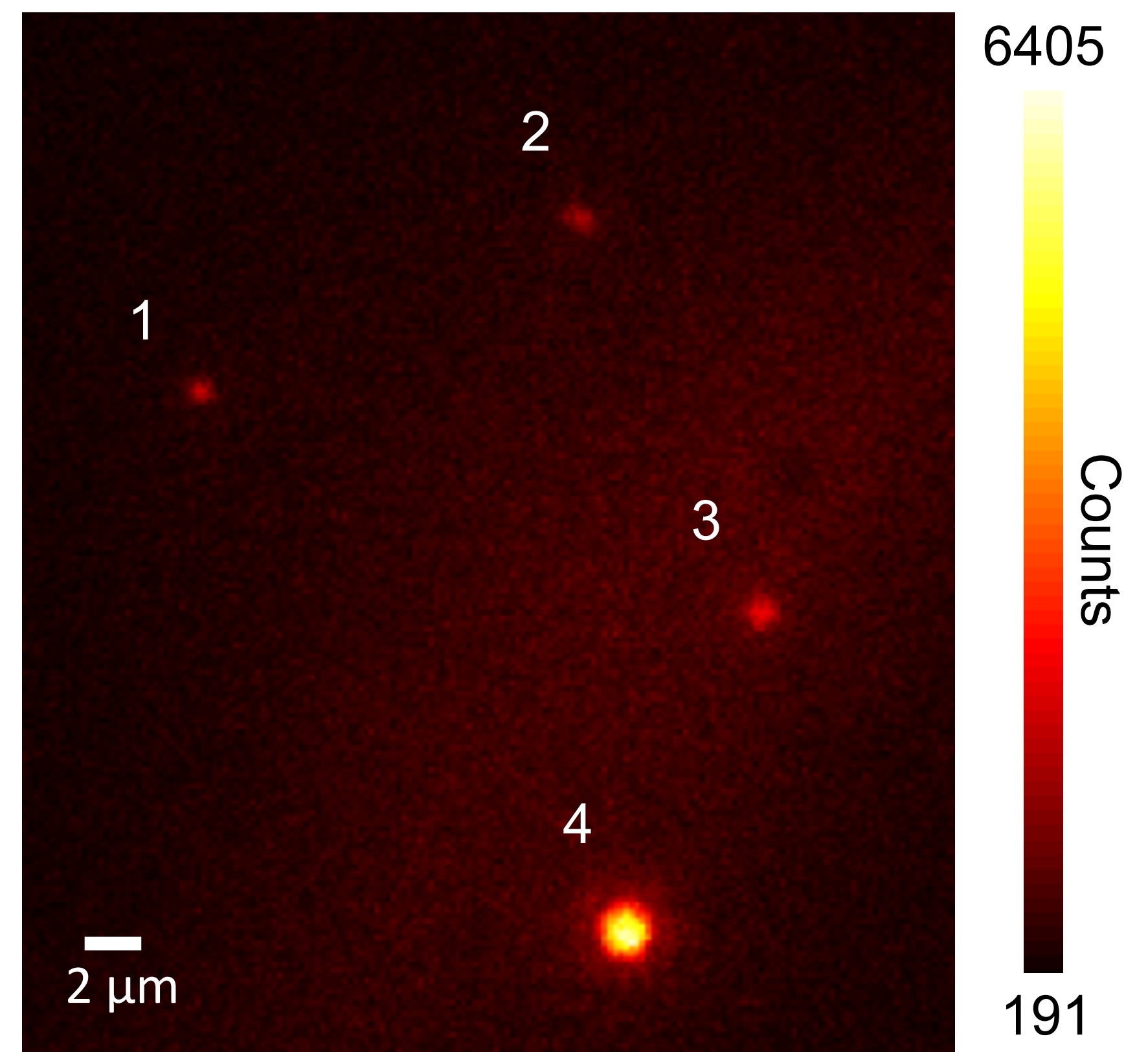
# Single-molecule imaging

## With nanomechanical silicon nitride drum

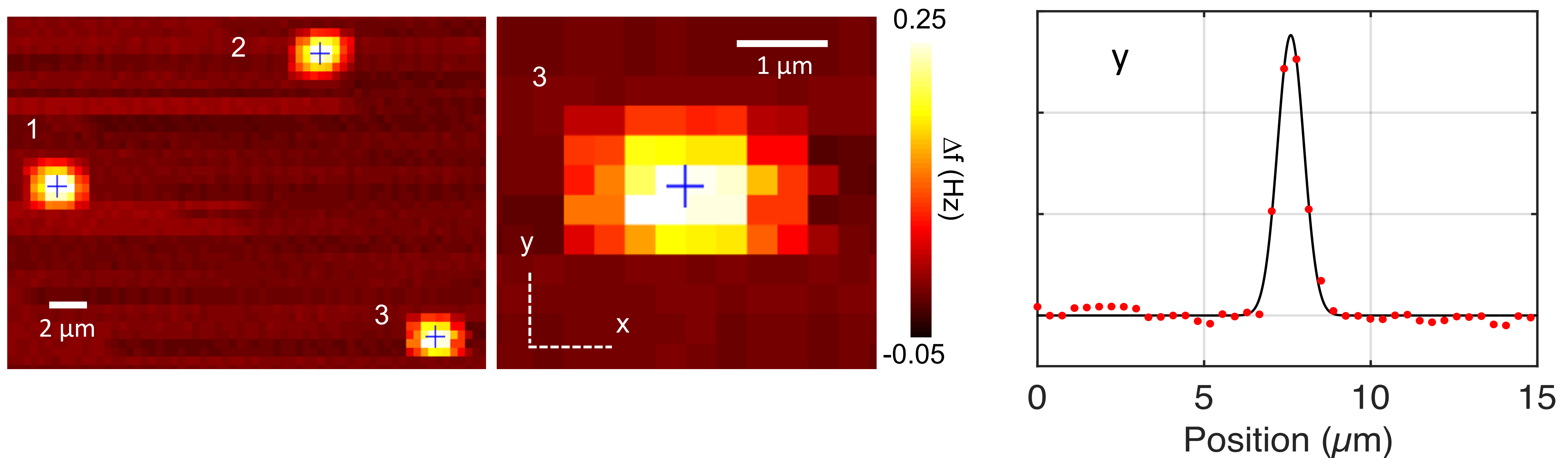
Photothermal microscopy



Fluorescence microscopy

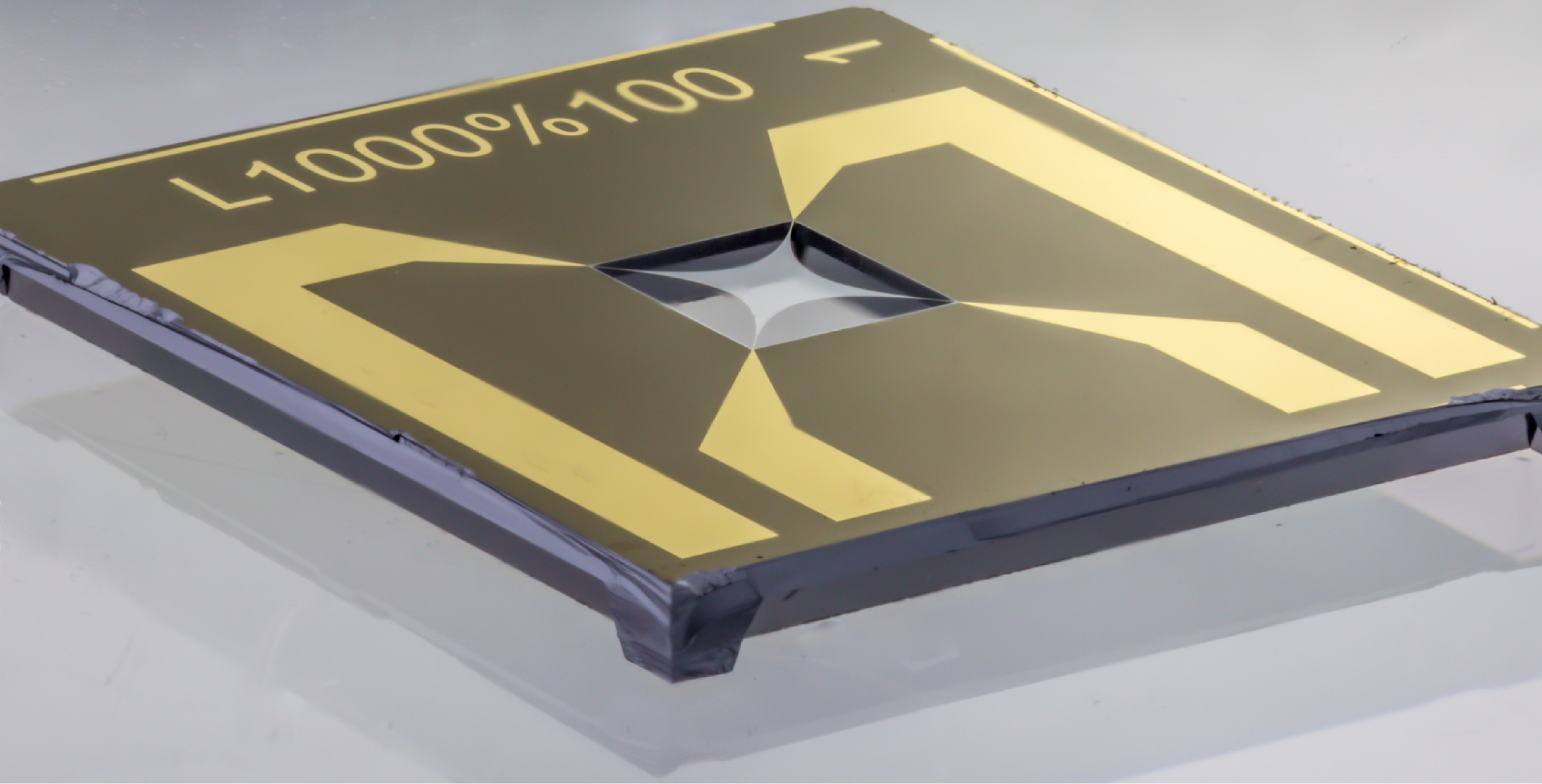


# Single-molecule signal-to-noise ratio



**SNR  $> 70$**

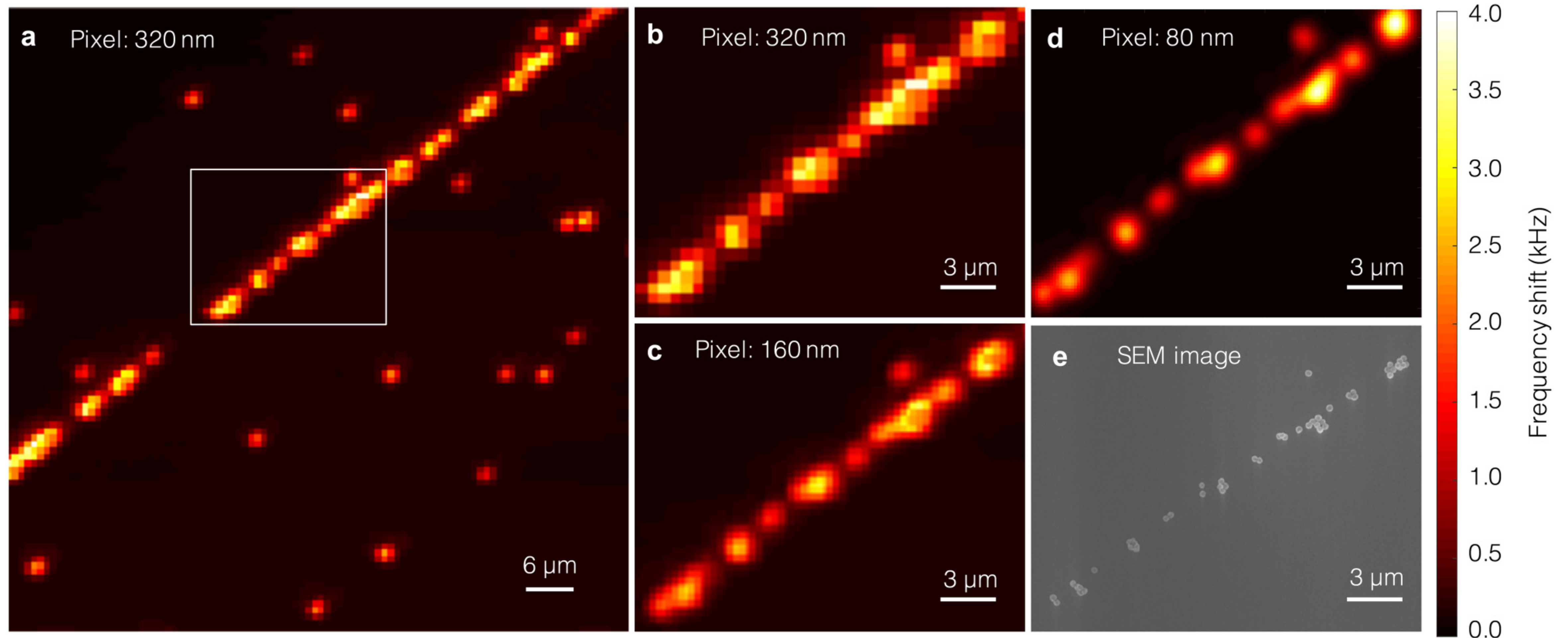






# Photothermal scanning microscopy

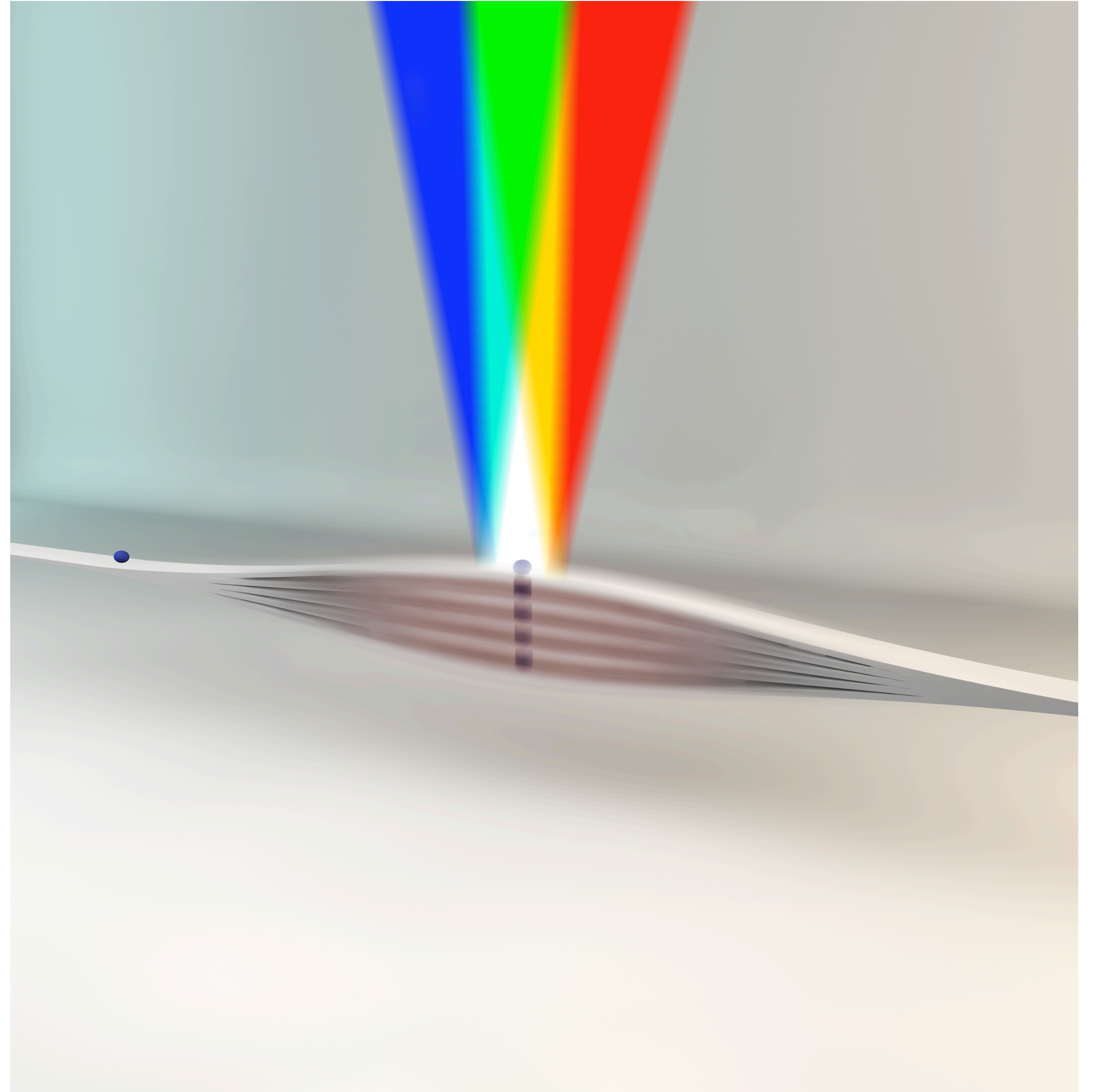
## With 80 nm pixel resolution





# Towards single-molecule absorption spectroscopy

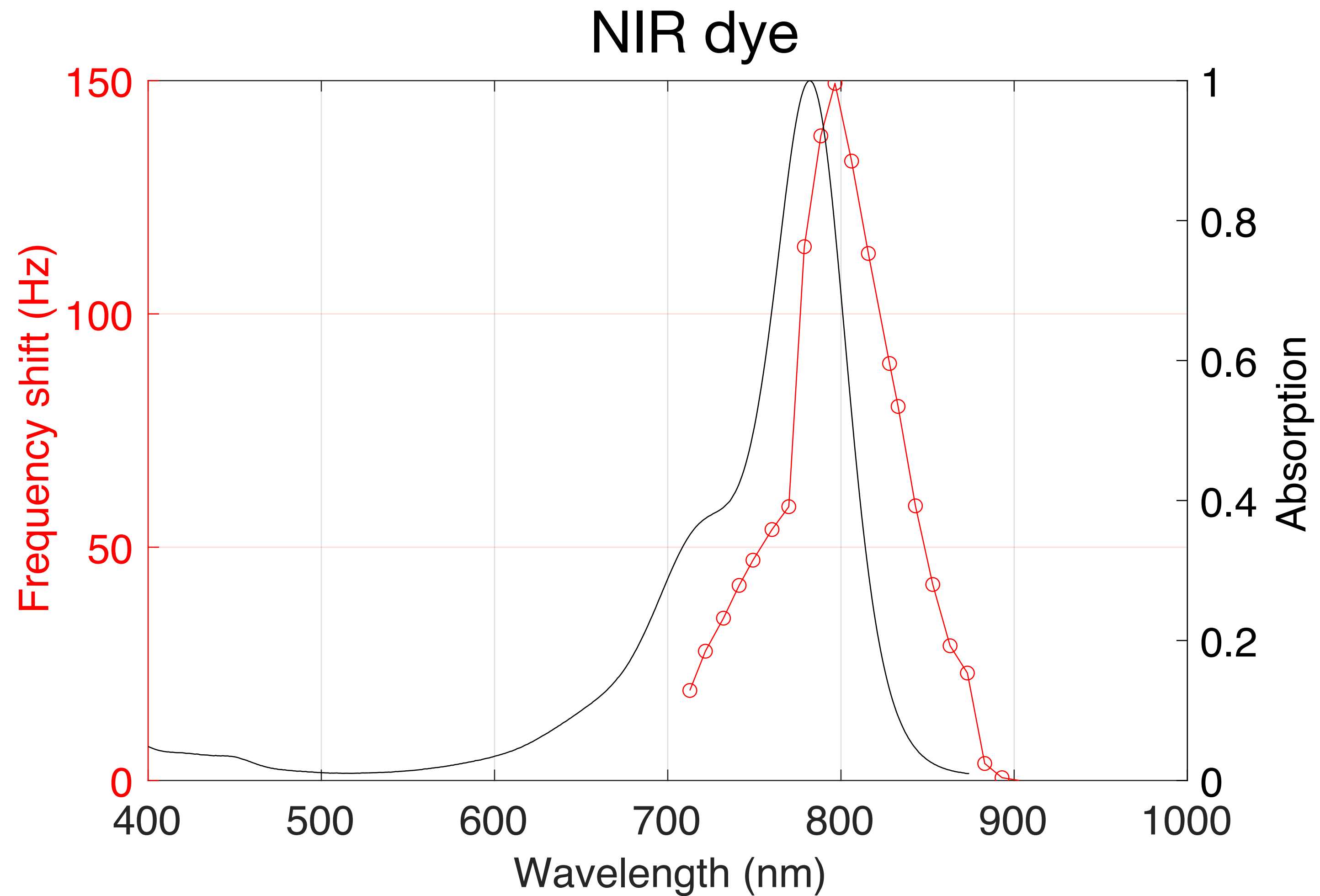
Tune wavelength of the probing light

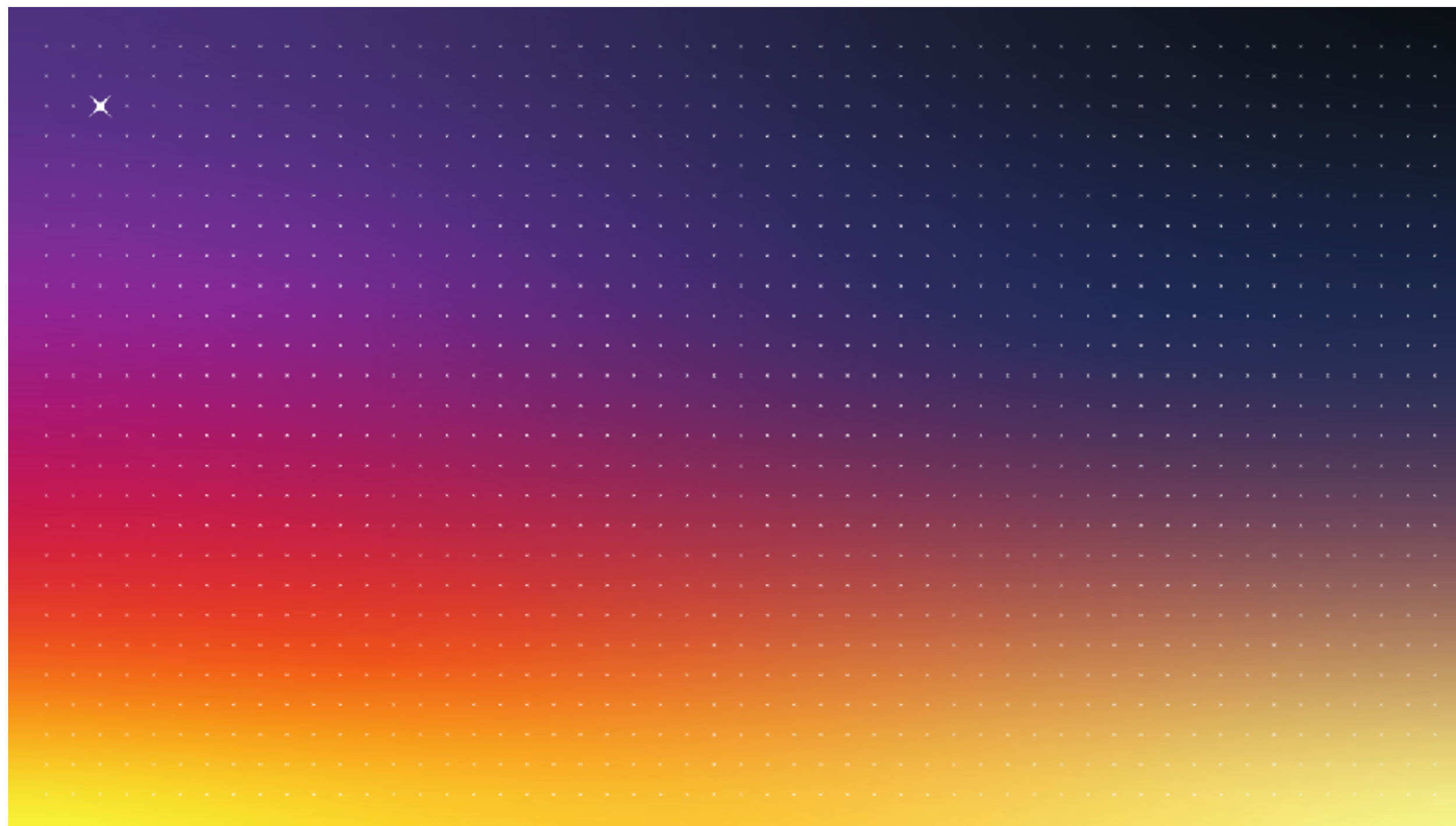




# Near IR spectroscopy

## With tuneable Ti:Sapphire laser





Dr. Josiane P. Lafleur (Analytical Chemist)

[www.invisible-light-labs.com](http://www.invisible-light-labs.com)