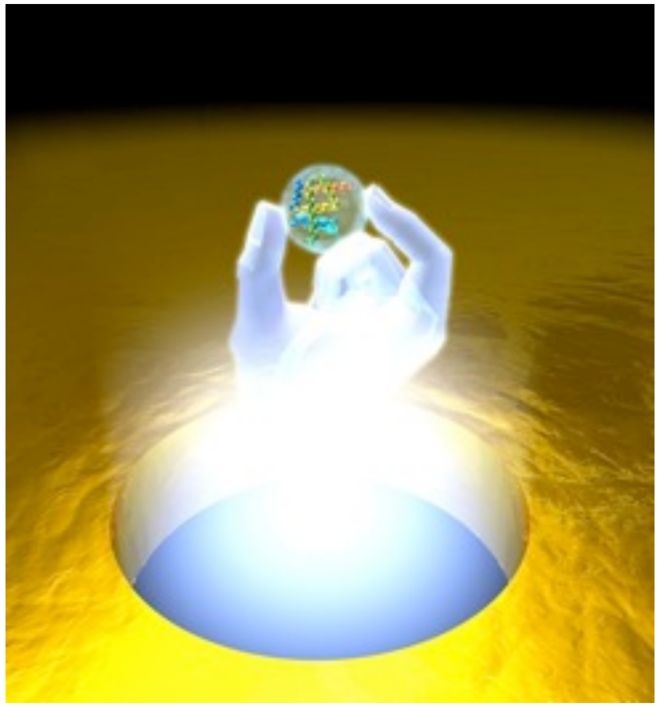
BioPlasmonics:
Developing novel nanotools for biosciences & medicine



Romain Quidant

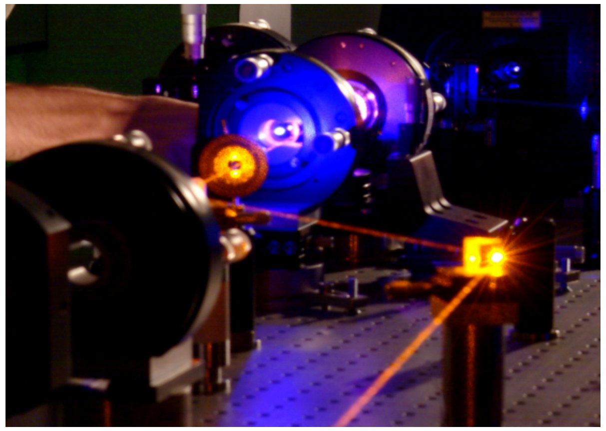
ICFO-Institut de Ciencies Fotòniques &
ICREA-Institució Catalana de Recerca i Estudis Avançats

ICFO Institut de Ciències Fotòniques

*iCrea INSTITUCIÓ CATALANA DE RECERCA I ESTUDIS AVANÇATS

ICFO - The Institute of Photonic Sciences

Advancing the limits of scientific and technological knowledge in optical sciences



A few figures...

- **250 people** (200 researchers)
- **20 groups** (15 senior and 5 junior)
- **14000 square meter**s (250 clean room)

ICFO - The Institute of Photonic Sciences

Advancing the limits of scientific and technological knowledge in optical sciences

For more details please visit: www.icfo.es

BIO PHOTONICS

Optical Tweezers; Plasmonics Oncology; Nano-Surgery & Neuro-Photonics; Chemically Selective Imaging; Sensors; Lab-on-a-Chip; Single-Molecule Photonics; Ultrafast Microscopy; Cell Spectroscopy.

QUANTUM OPTICS

Quantum Information Processing & Communication; Quantum Cryptography; Quantum Imaging & Metrology; Coherent Control & Quantum Biology; Single-Atom Photonics; Quantum Dynamics.

NONLINEAR OPTICS

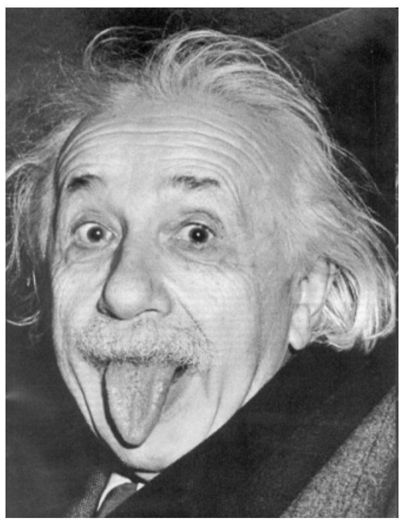
All-Optical Photonic Devices; Frequency Conversion and OPOs; Photonic Crystals; Ultrafast & Atto-Optics; Tunable Lasers; Electro & Acousto-Optic Devices; Fiber & Integrated Sensors; Photonics Clean-Tech.

NANO PHOTONICS

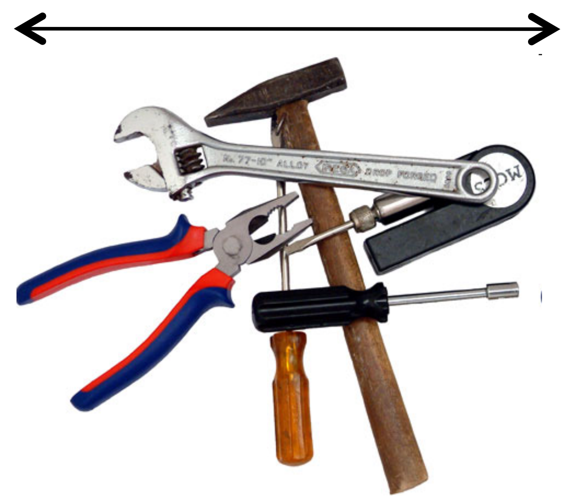
Nano-Photonic Devices; Organic LEDs; Light Harvesting; Solar Cells; Plasmonics; Molecular NanoPhotonics; Nano-Optical Tweezers; Nano-Optical Manipulation on a Chip; Nano-Antennas; Nano-Cavities.

PROVIDING NOVEL NANOTOOLS TO MEDICAL DOCTORS

Physicist



10 – 100 nm



Medical doctor

- Earlier and more reliable diagnosis

- More efficient & less-invasive therapies

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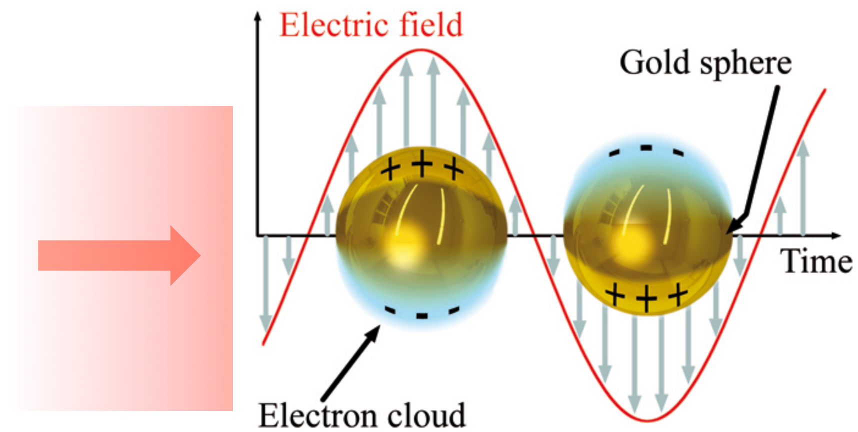
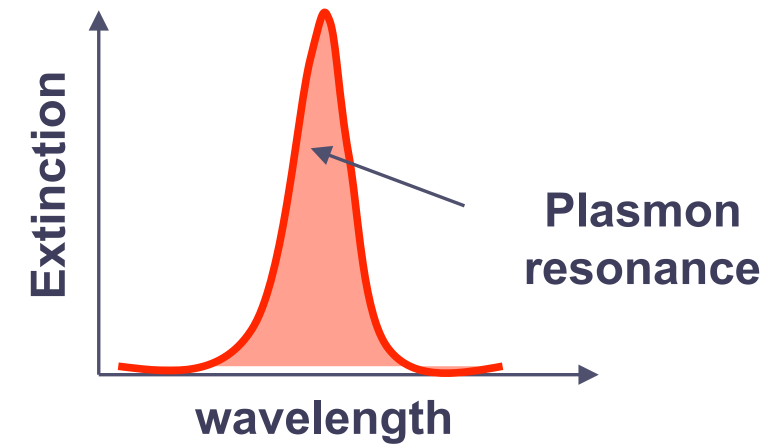
The protagonist? A gold nanoparticle

GOLD NANOPATICLE

10-100nm

LOCALIZED SURFACE PLASMONS





Enhanced Scattering → **Nano-source of light**

Enhanced Absorption → **Nano-source of heat**

Outline

Part 1- Plasmon nano-optics for sensing and trapping - wed 9.45 am

Part 2 -ThermoPlasmonics:using metallic NP as heat nanosources - Thur 9.00 am

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Outline

- Part 1-

Plasmon nano-optics for sensing and trapping:

Towards an integrated plasmon-based analytical platform
for early cancer diagnosis

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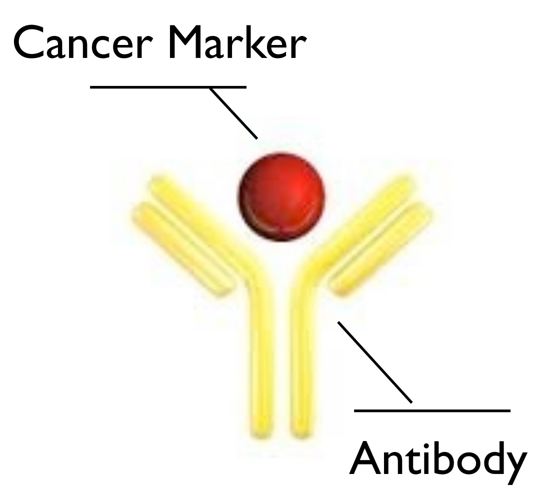
FROM THE MACRO- TO THE NANO-SCALE

- ✔ Cancer is usually diagnosed based on the detection of a **macroscopic** tumor

An example: Breast cancer

- Screening through Mammograms and MRI
- Diagnostic through biopsy (taking a piece of tissue and inspect it below the microscope)

- ✔ **Earlier detection** could be achieved by detecting low concentration of **cancer markers** over-expressed at the membrane of cancer cells or in blood.



Cancer Marker detection must combine:

- High sensitivity and specificity
- Label-less
- Parallel assays
- Cost effective

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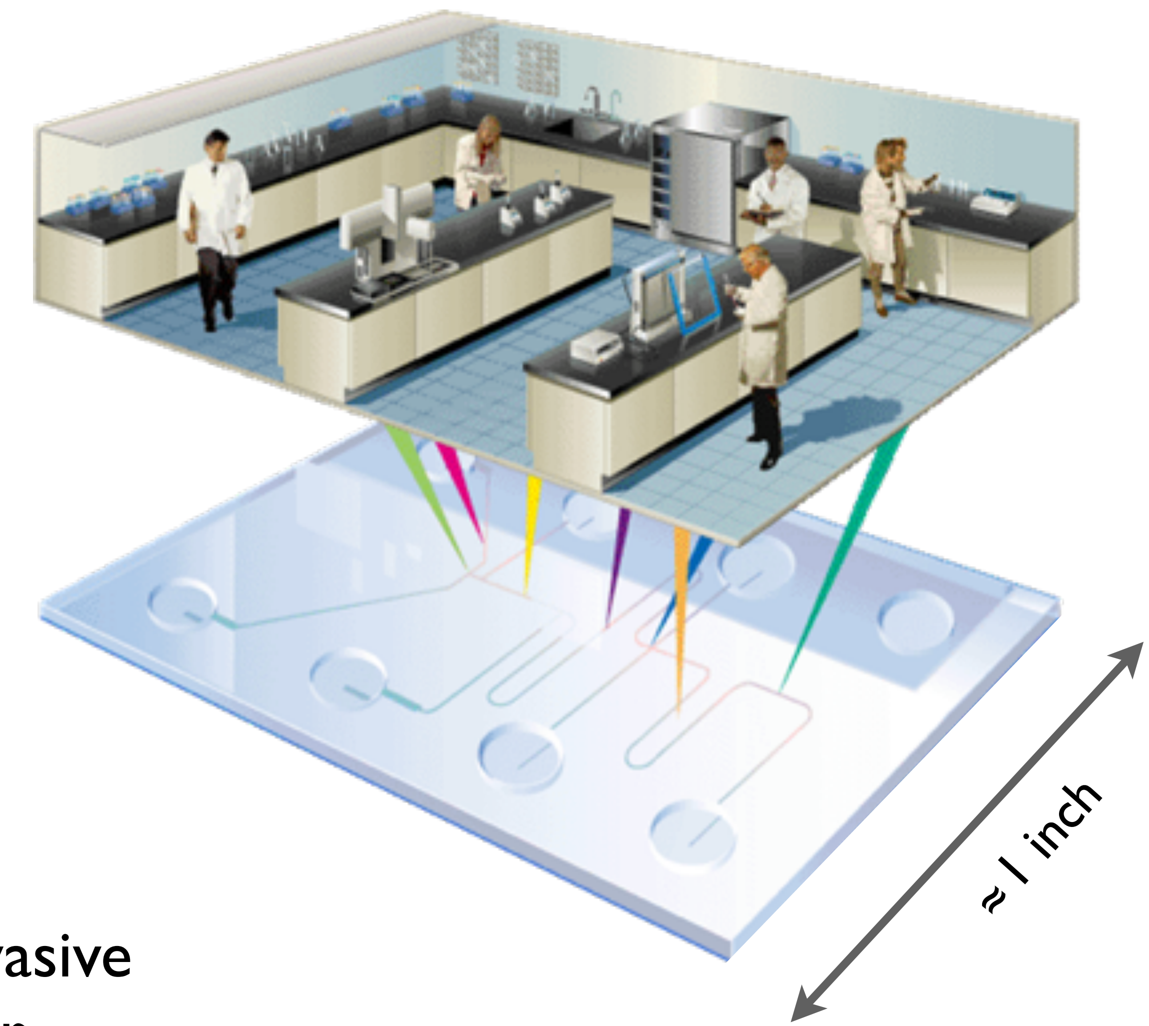
LAB-ON-A-CHIP

Honey, I shrinked the lab....



But it is now...

- Less invasive
- Cheaper
- Transportable
- More sensitive

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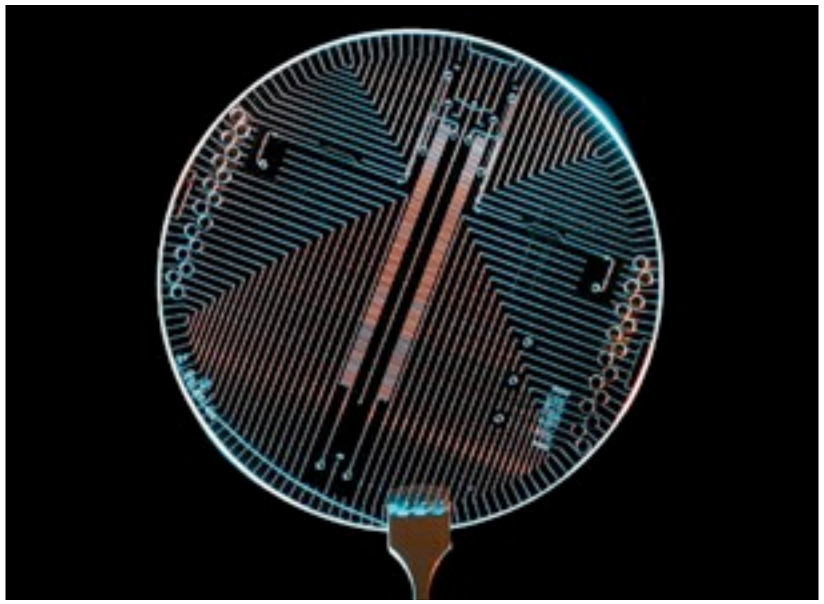
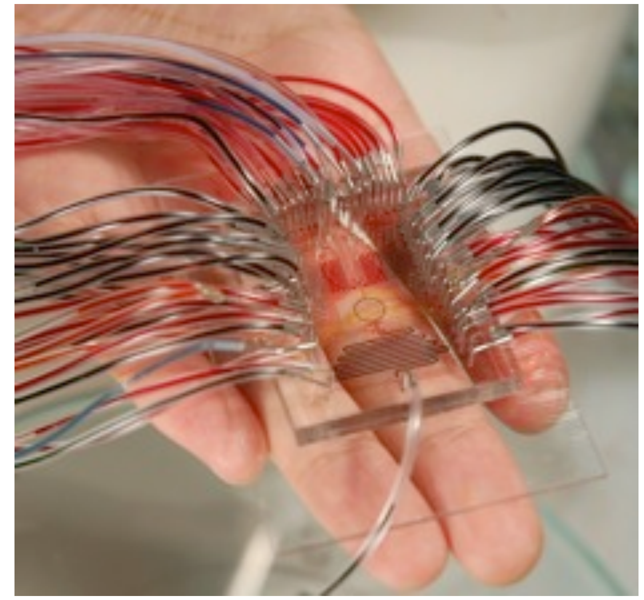
MICROFLUIDICS: THE WALL OF THE LABORATORY

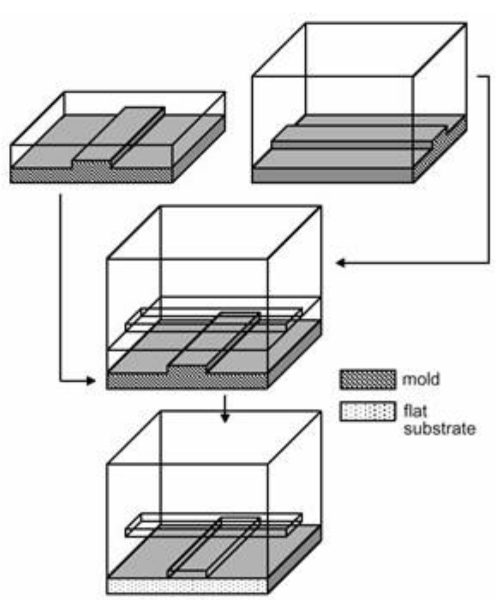
The corridors and the lab space...

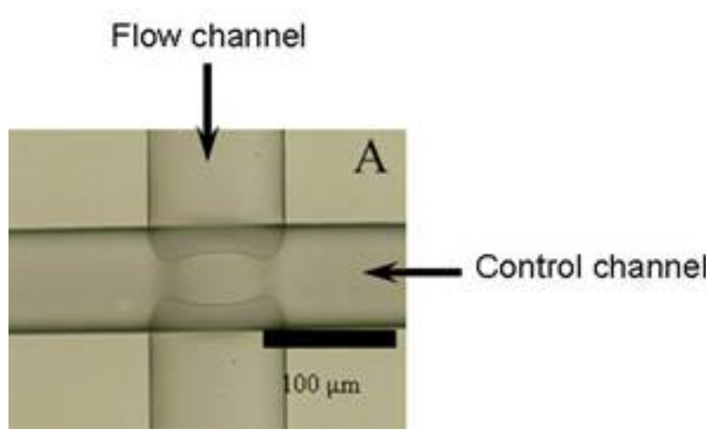




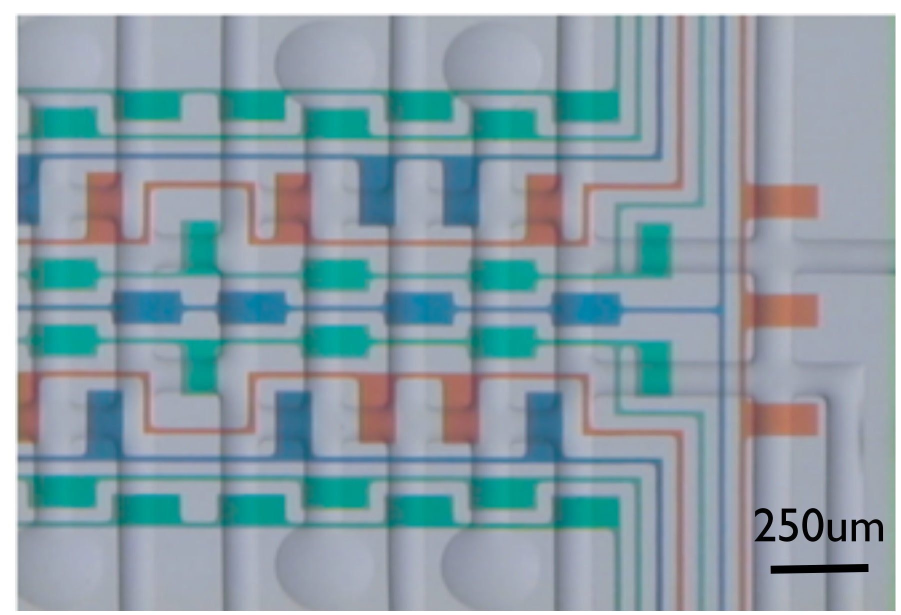
- Small fluid volumes (nl, pl)
- Cheap
- Transparent

Please close the door when leaving...





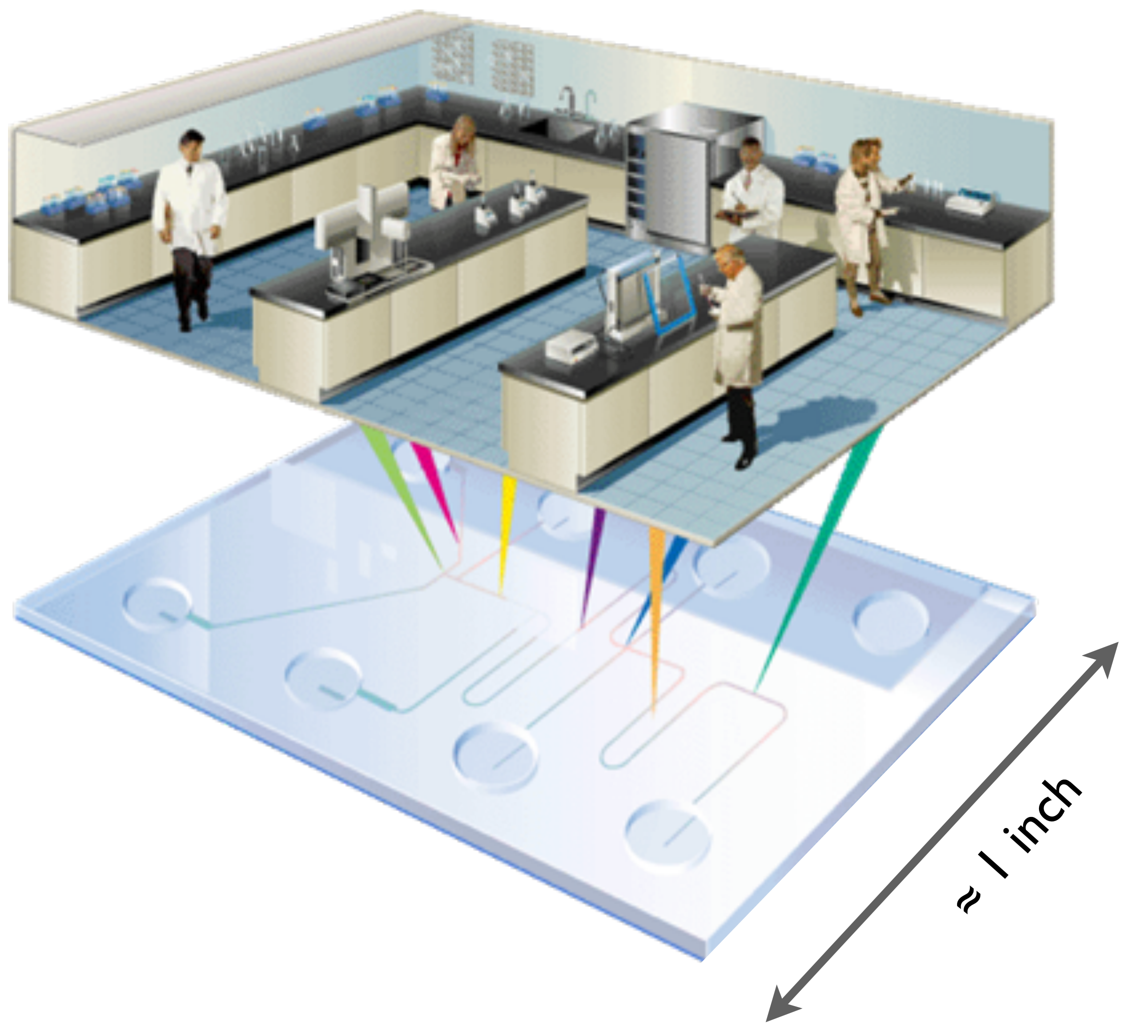
The Quake's valve



Courtesy of S. Maerkl

LAB-ON-A-CHIP

Honey, I shrinked the lab....



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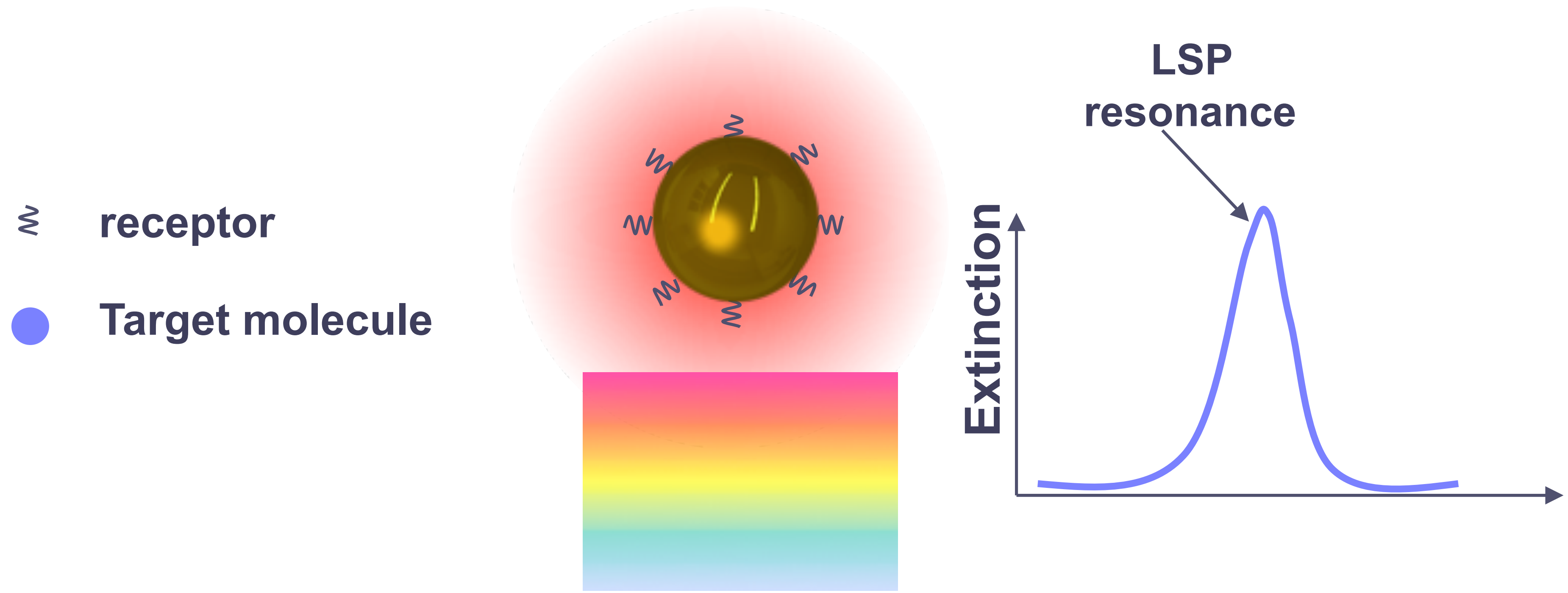
LSPR-sensing (Resonance shift sensing)

LSP resonance are highly sensitive to a small change of the dielectric surrounding

$$\alpha(\omega) = 4\pi\varepsilon_{ref} a^3 \frac{\varepsilon_{metal}(\omega) - \varepsilon_{ref}}{\varepsilon_{metal}(\omega) + 2\varepsilon_{ref}}$$



By monitoring Δλ one gets a direct information about the number of binding events occurring at the particle surface

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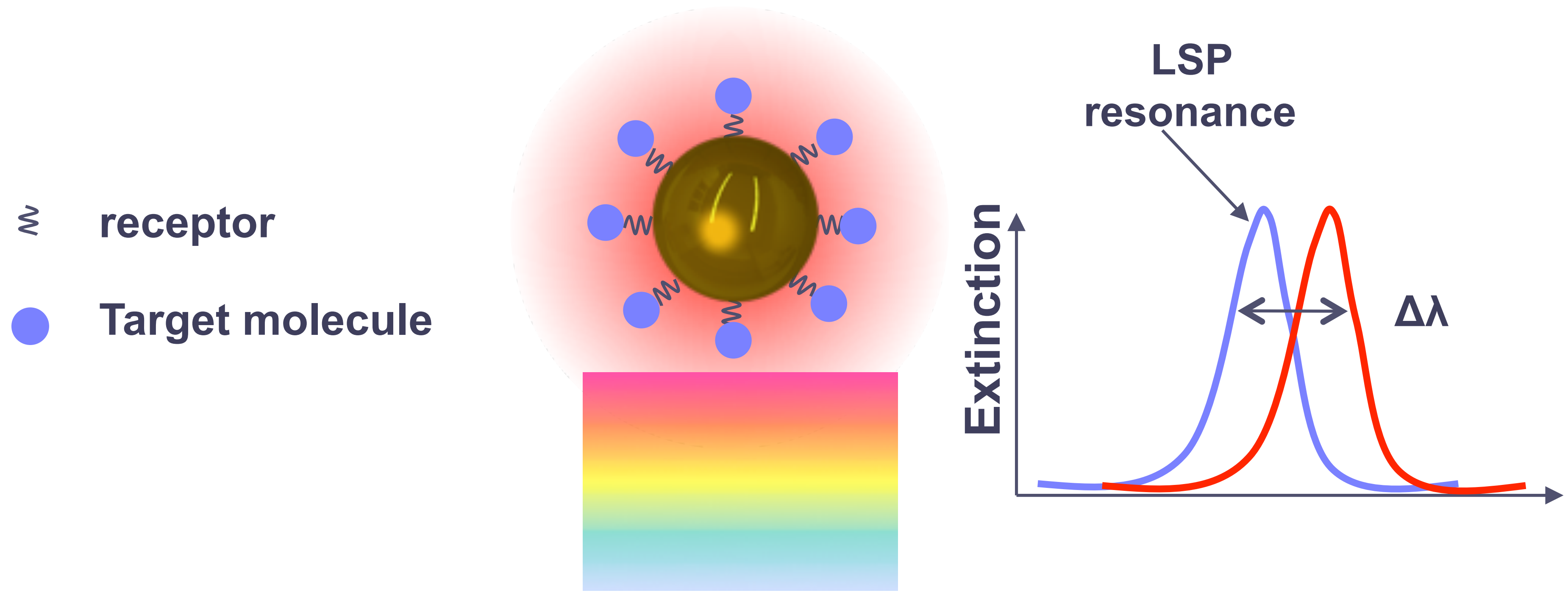
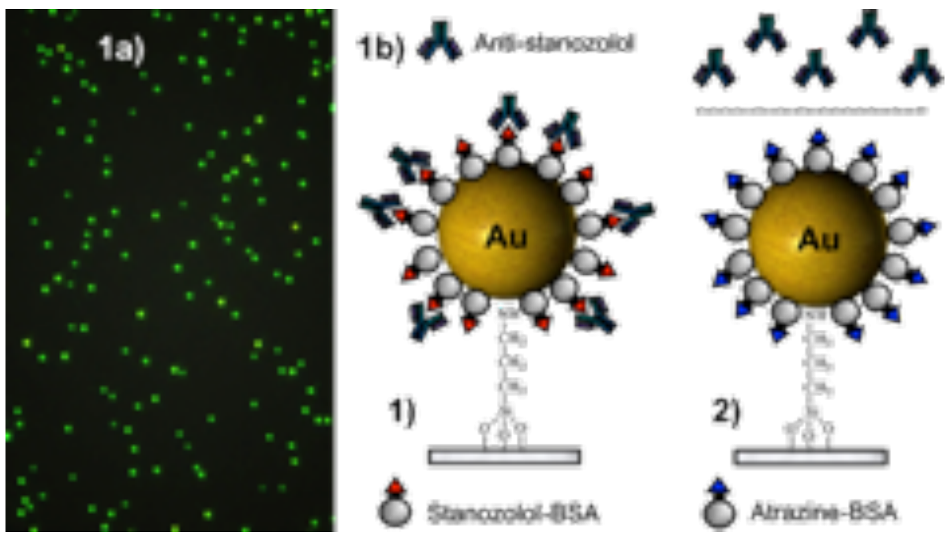
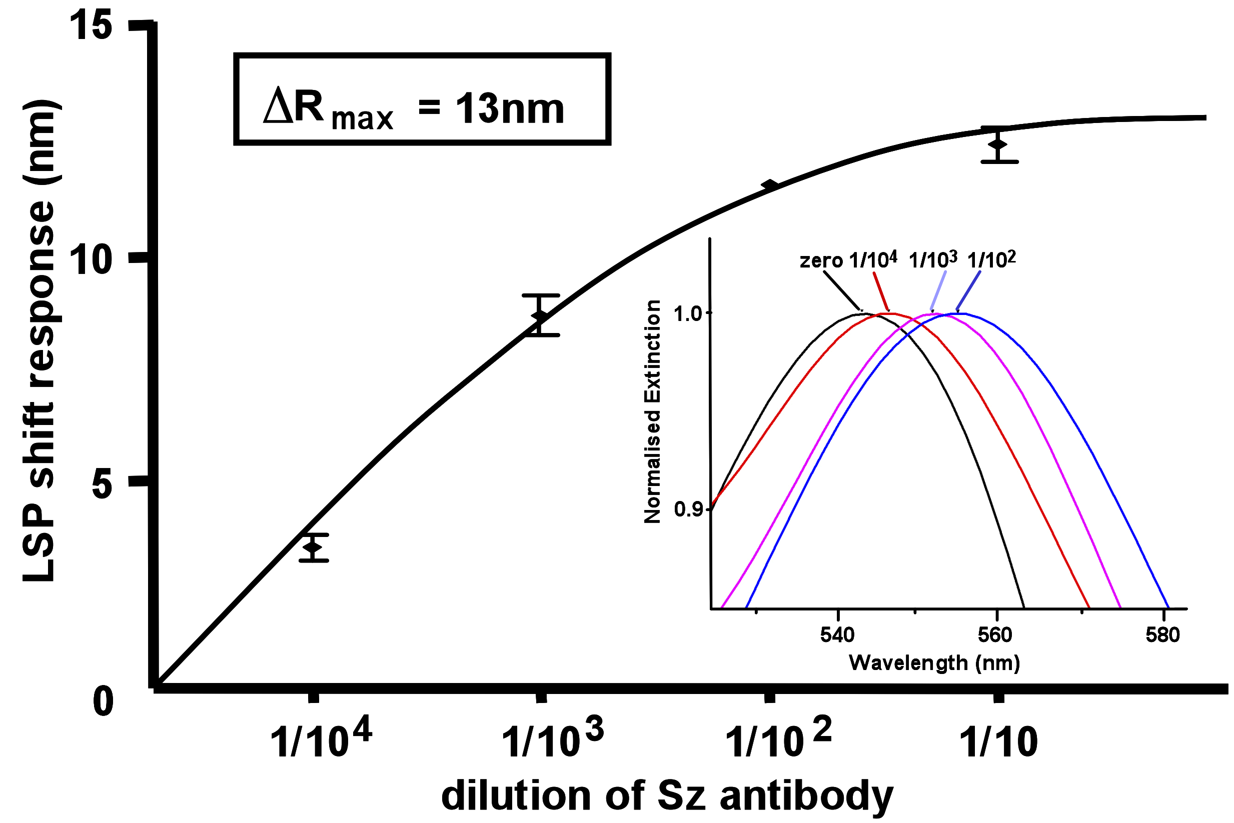


By monitoring Δλ one gets a direct information about the number of binding events occurring at the particle surface

LSPR sensing with randomly arranged gold colloids





✓ **Only 0.6 nm (4% of max shift) of non-specific binding**

✓ **Sensitivity in the nM range (higher sensitivity is expected with patterned samples)**

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M. Kreuzer, R. Quidant, G. Badenes, P. Marco, Biosensors & Bioelectronics, vol **21**, 1345 (2006)

What dictates the Sensitivity of an optical sensor?

LSP resonance are highly sensitive to a small change of the dielectric surrounding

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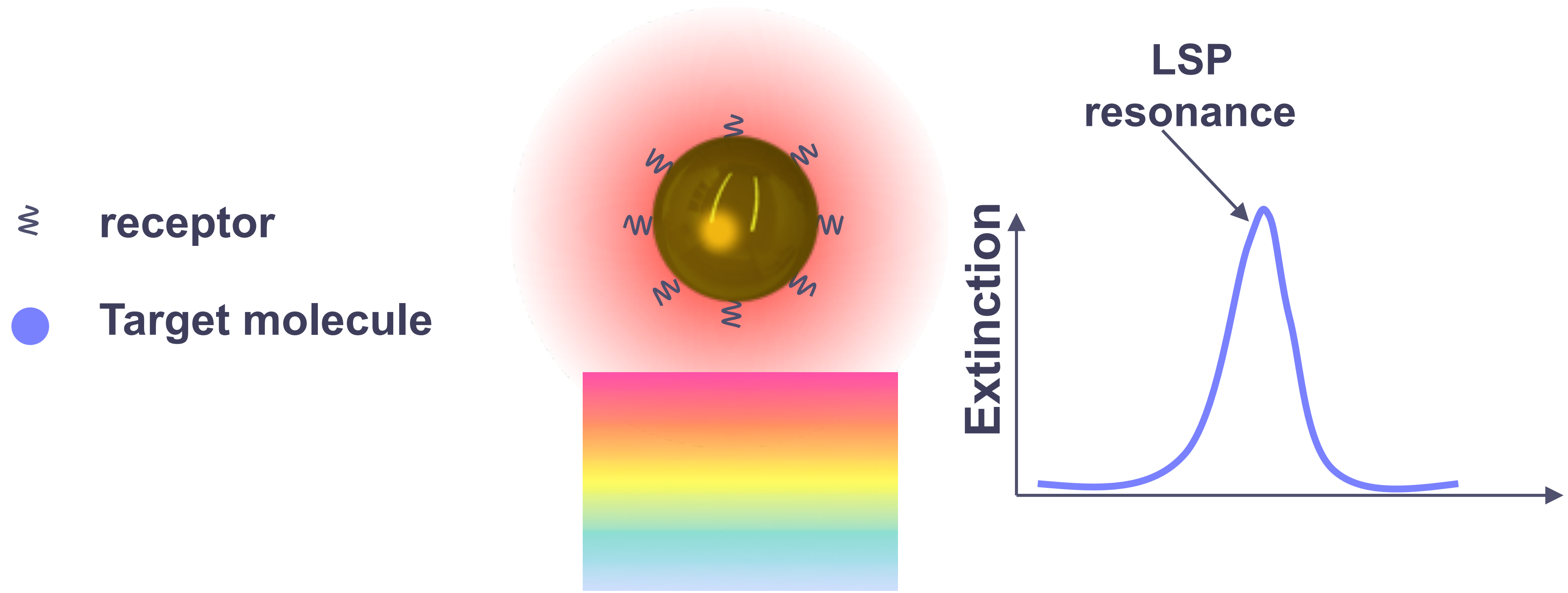

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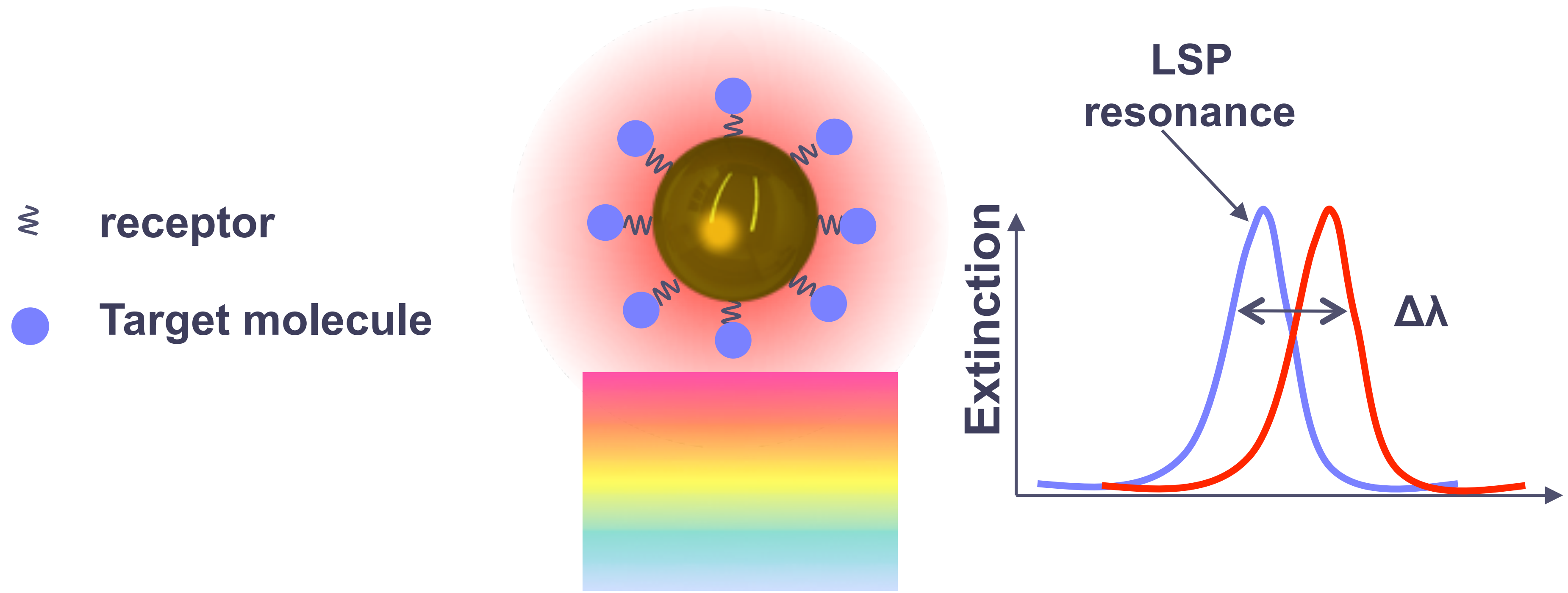
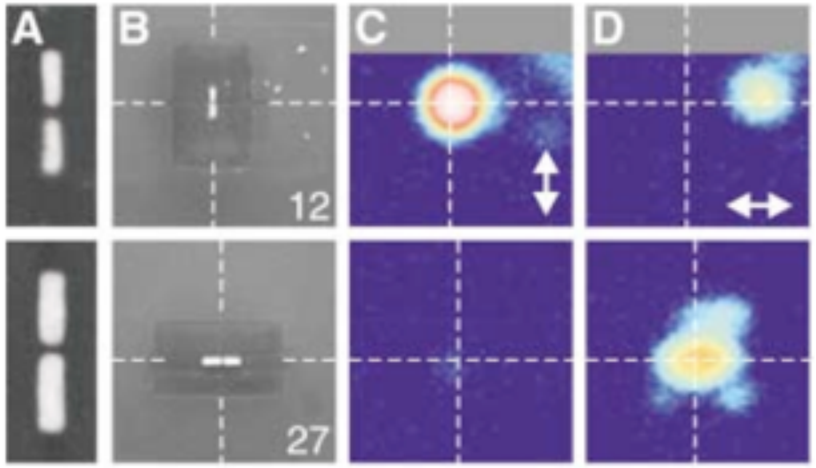


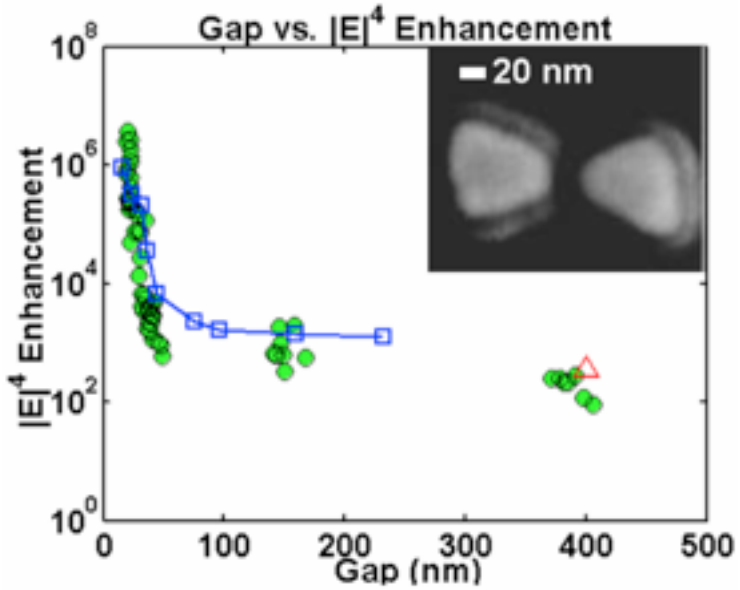
By monitoring Δλ one gets a direct information about the number of binding events occurring at the particle surface

From Radiowave to Optical antennas...

RW Half-wave
dipole antenna



P. Muhlschlegel et al, Science **308**, 1607 (2005)



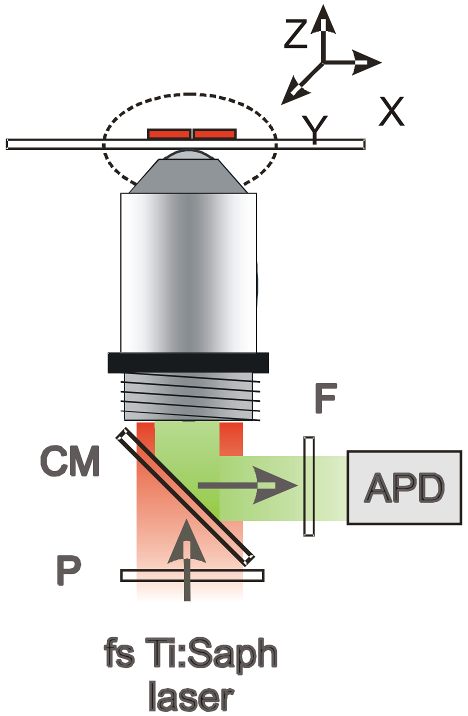
P. J. Schuck et al, Phys. Rev. Lett. 94, 017402 (2005)

Optical Gap Antenna

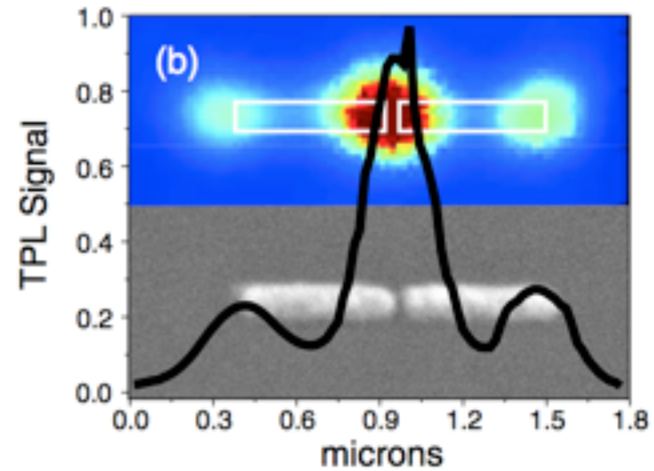
Petru Ghenuche

Sudhir Cherruku-lappurath

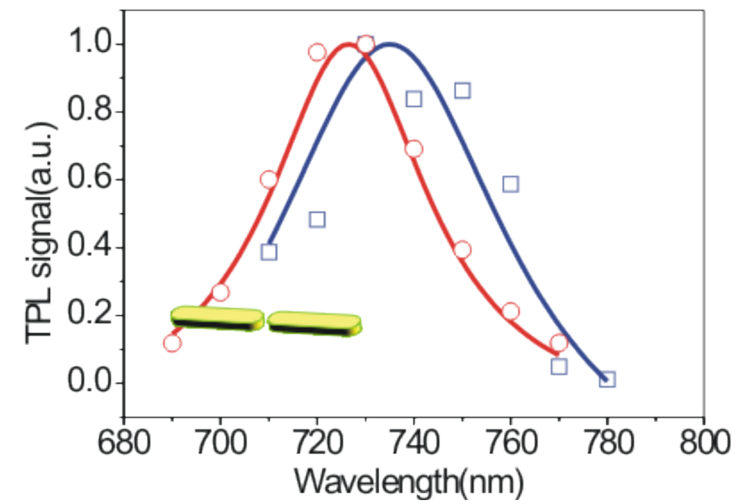
Two photon Lluminescence in gold (TPL)



TPL map at resonance

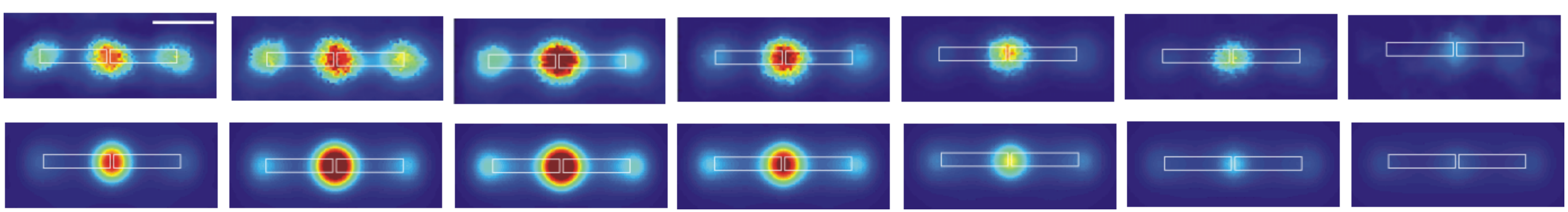


Near field Spectroscopy in the gap



Wavelength (nm)

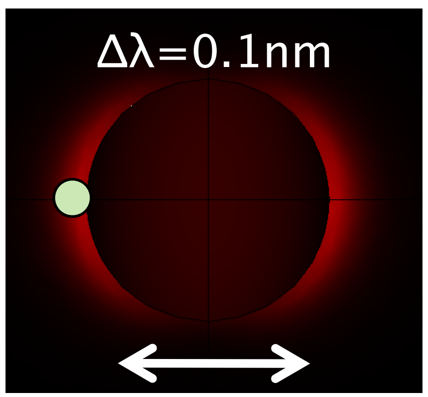
710 720 730 740 750 760 770

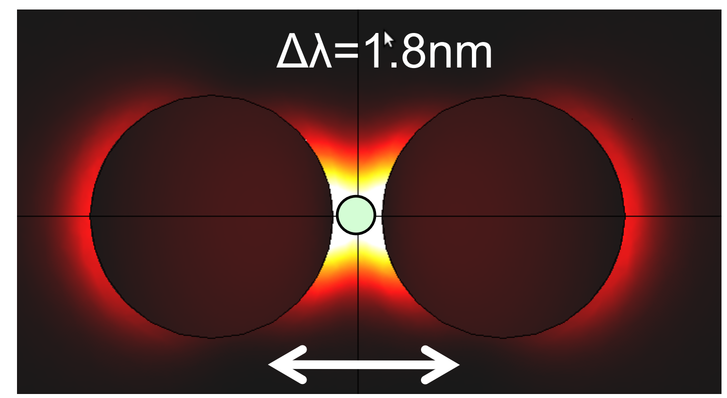


P. Ghenuche et al, Phys. Rev. Lett. **101**, 116805 (2008)

Shaping plasmonic modes for higher sensitivity

The sensitivity of a plasmonic sensor is mostly governed by spatial overlap between the plasmonic mode and the analyte





8nm dielectric sphere (n=1.5)

Low spatial overlap → small resonance shift

high spatial overlap → increased resonance shift

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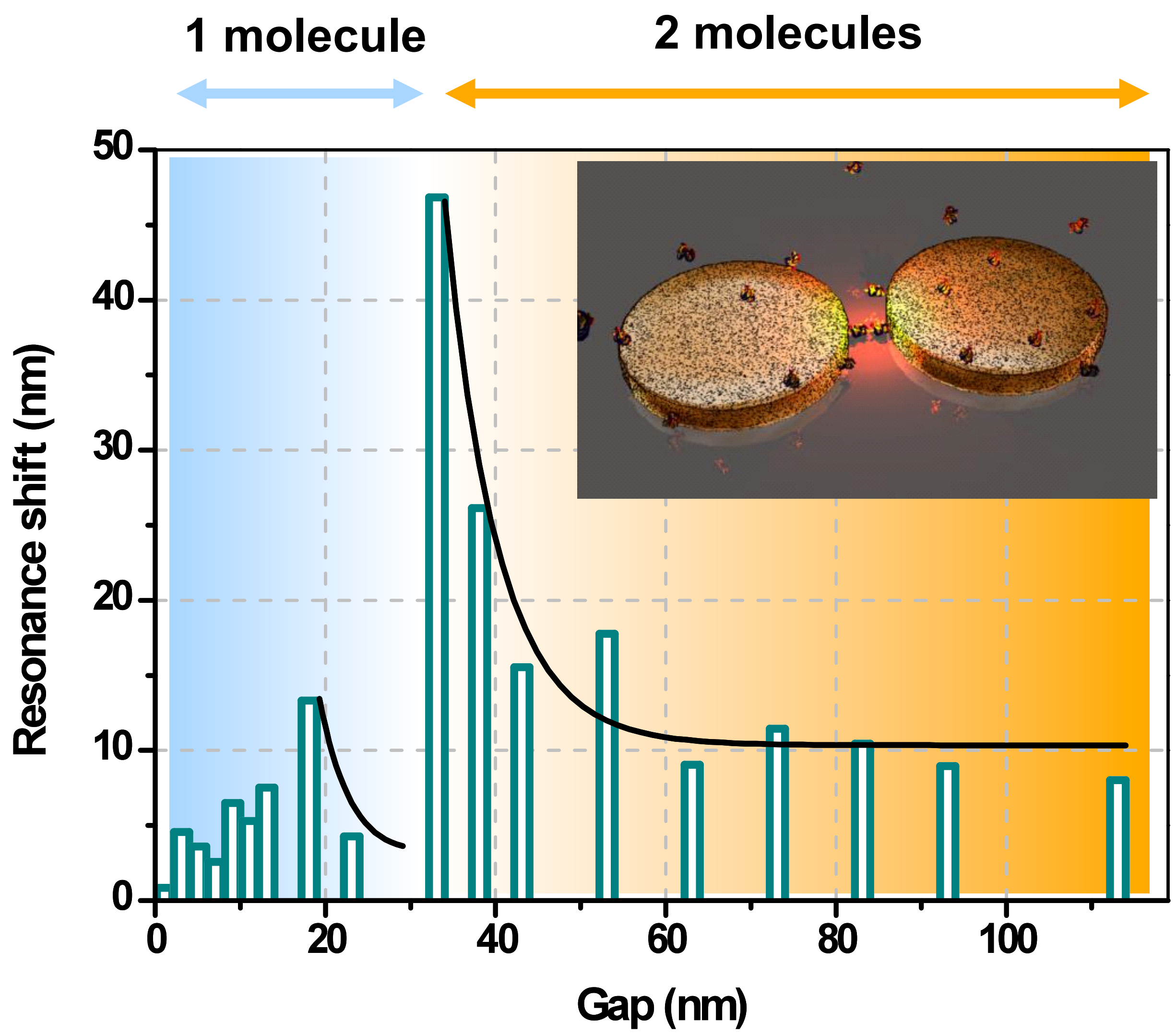
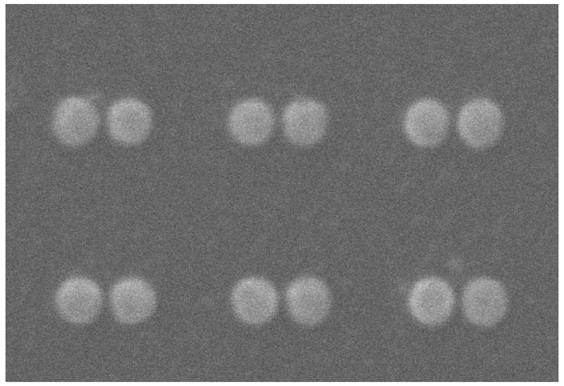
S. Enoch, R. Quidant, G. Badenes Opt. Express **12**, 3422-3427 (2004)

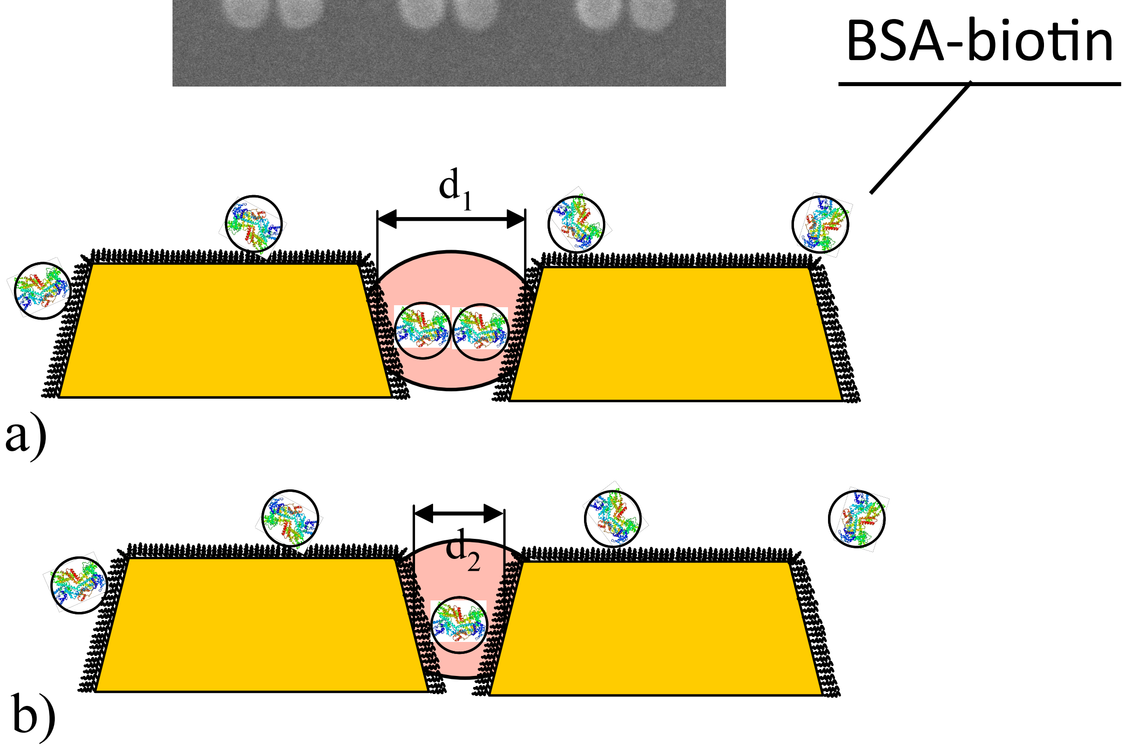
Enhanced molecular detection in plasmonic dimers

Srdjan Acimovic

Mark Kreuzer







S. Aćimović et al, ACS Nano **3**, 1231-1237 (2009)

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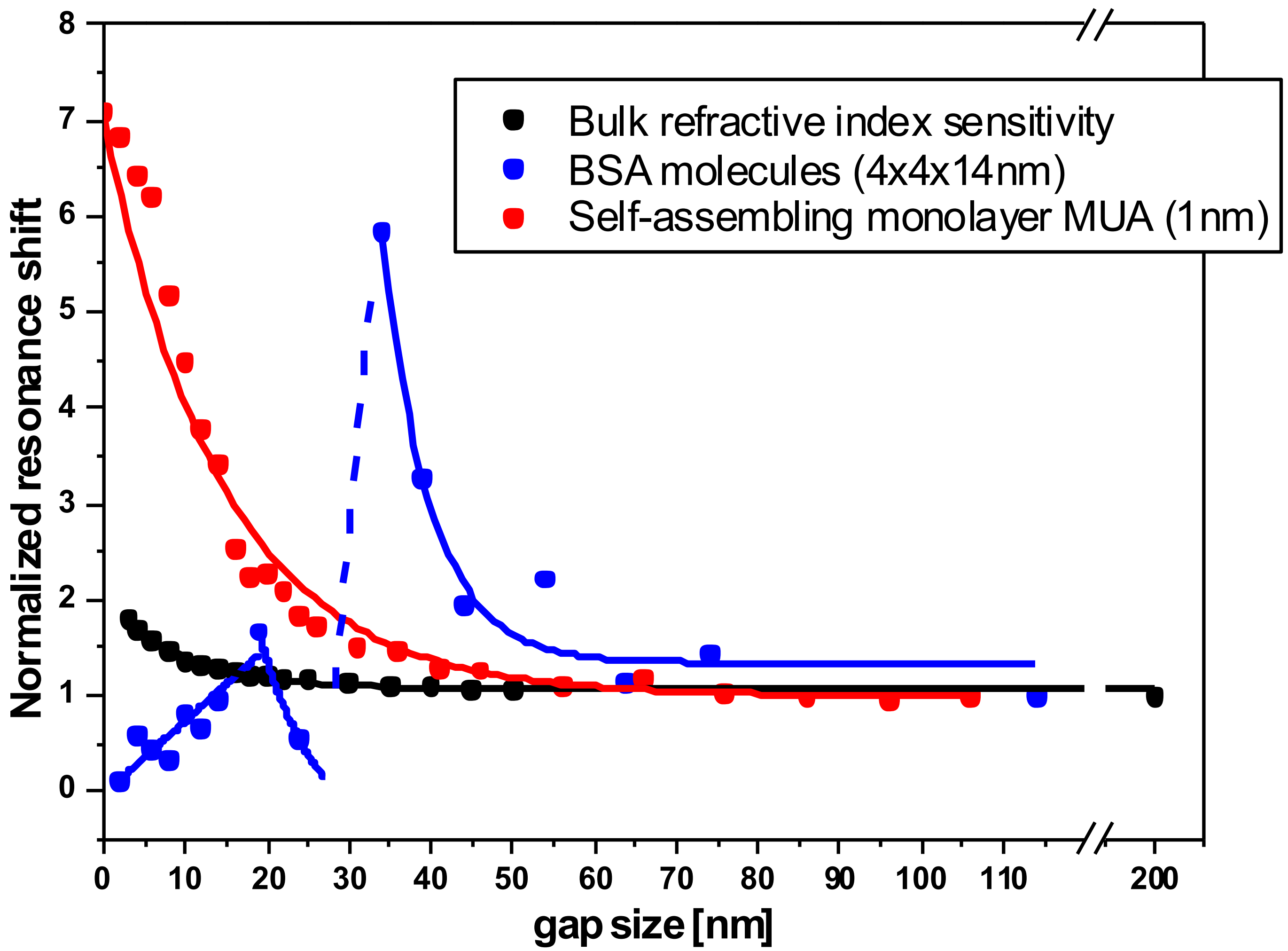
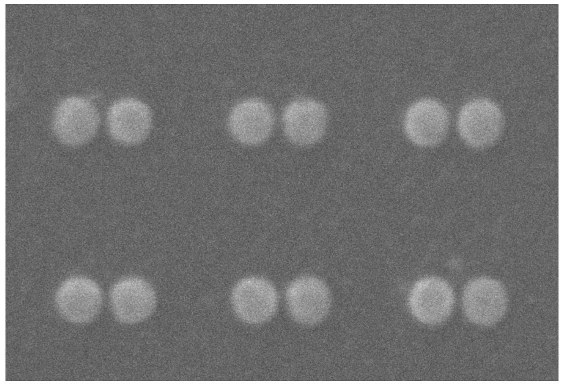
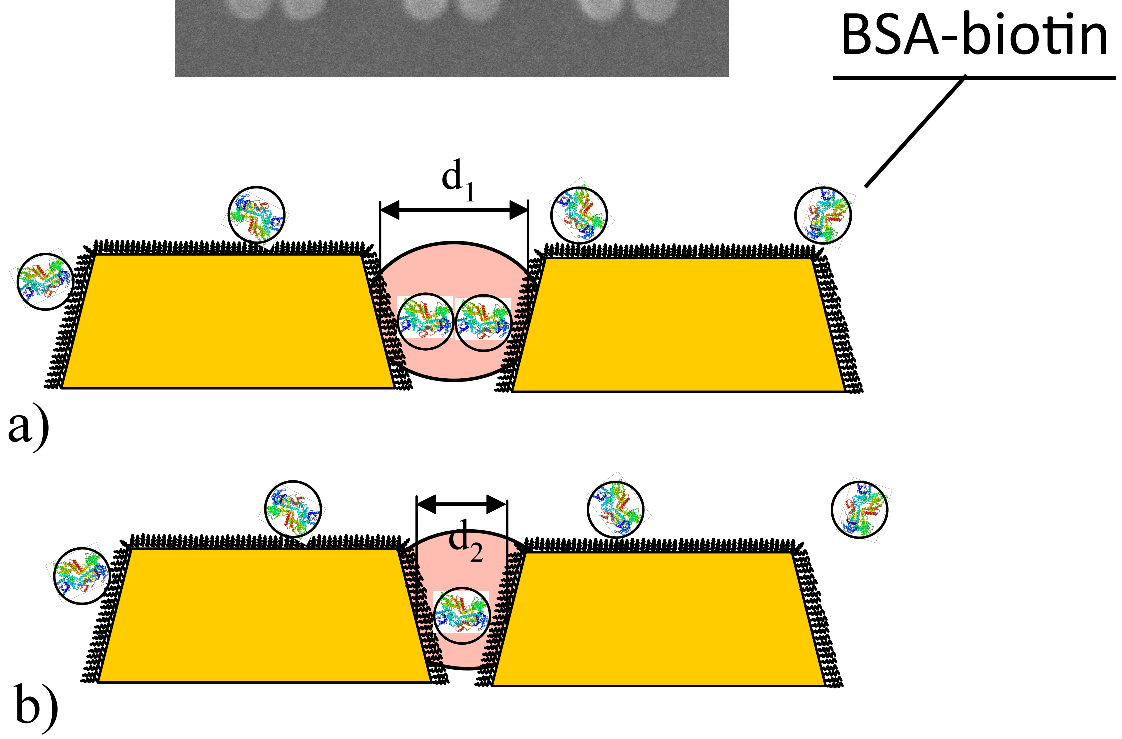
Influence of the size of the target molecule

Srdjan Acimovic

Mark Kreuzer







S. Aćimović et al, ACS Nano **3**, 1231-1237 (2009)

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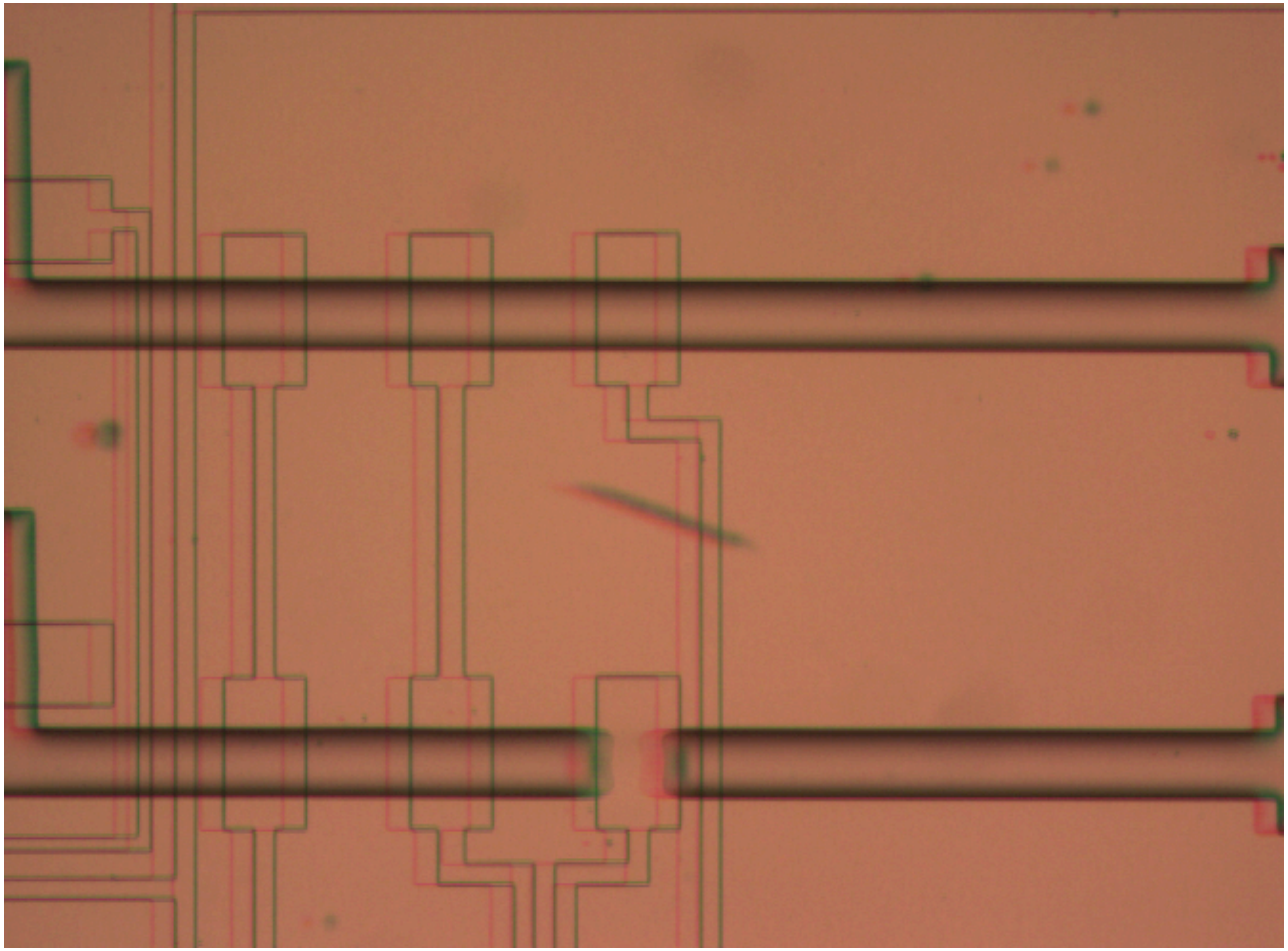
A short Lab tour



Srdjan Acimovic

Mark Kreuzer

Maria Ale Ortega

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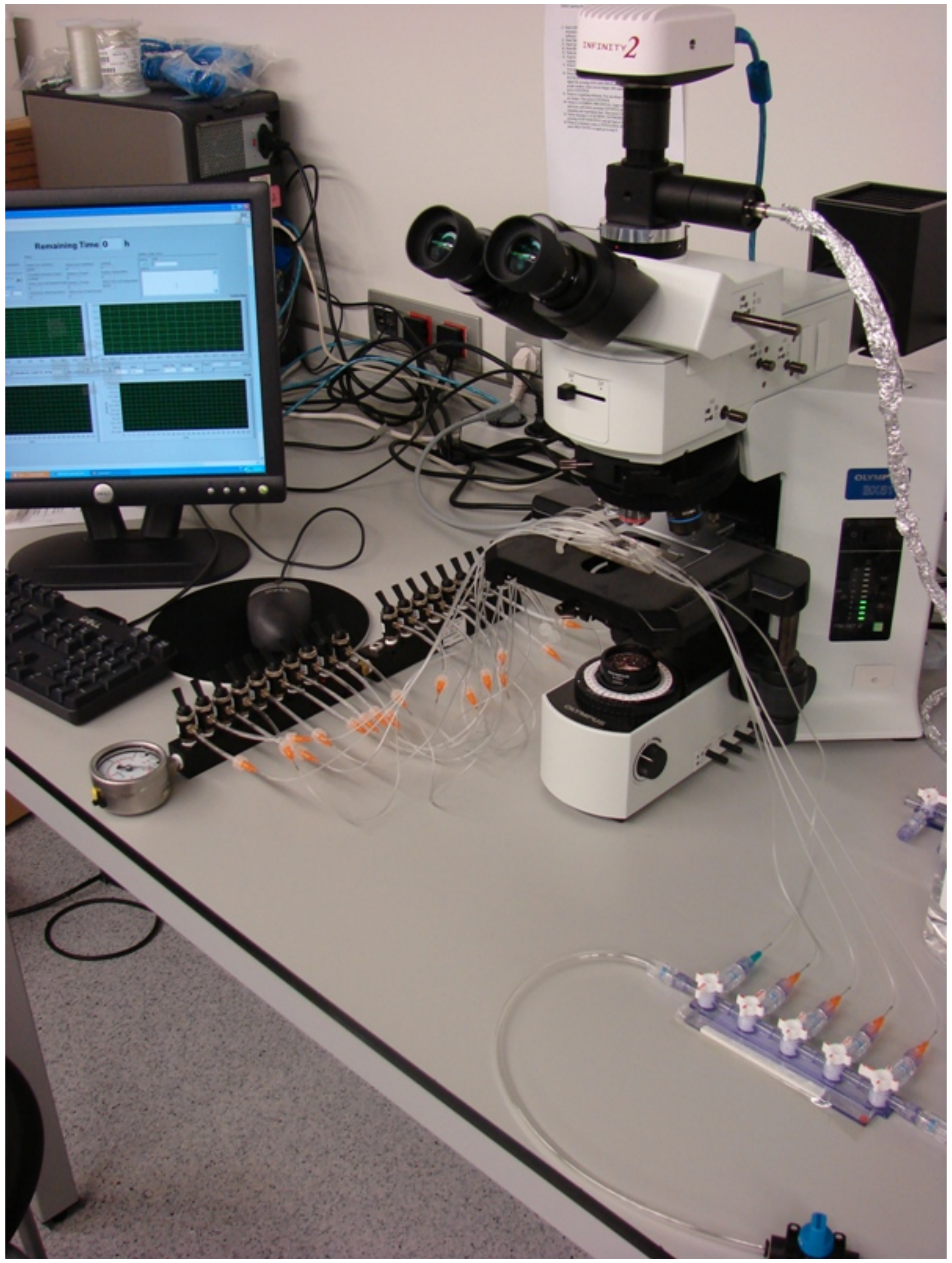
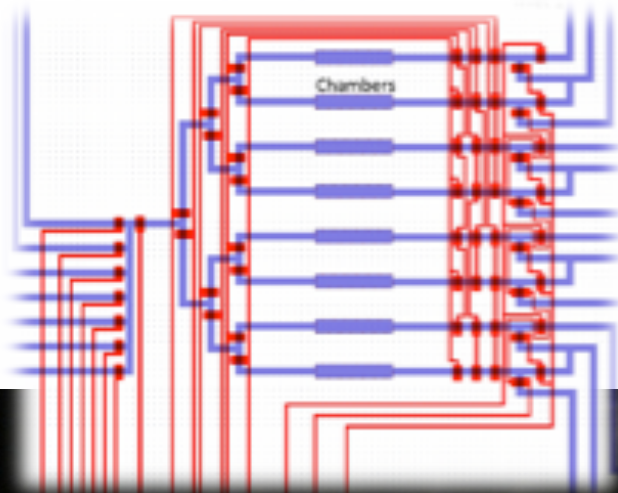
Real time monitoring of LSP shift

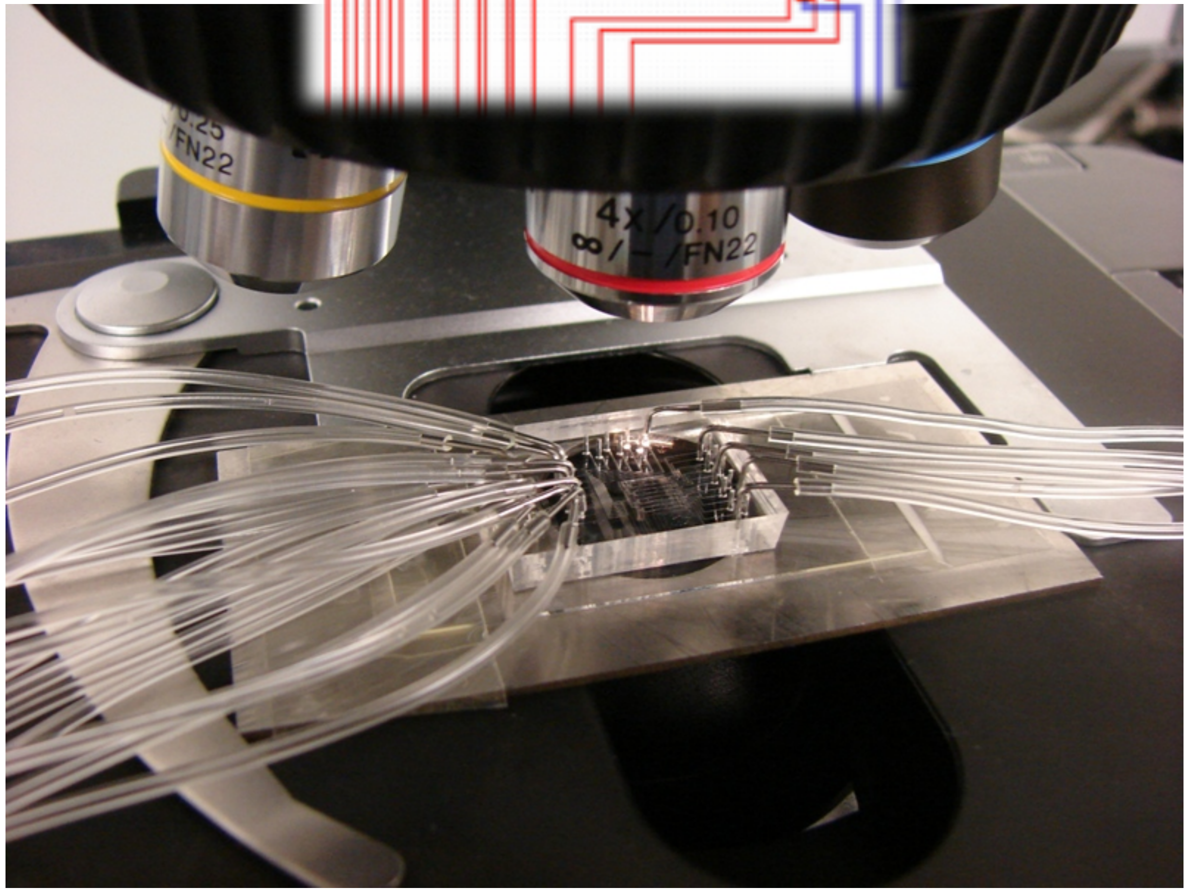
Srdjan Acimovic

Mark Kreuzer

Maria Ale Ortega







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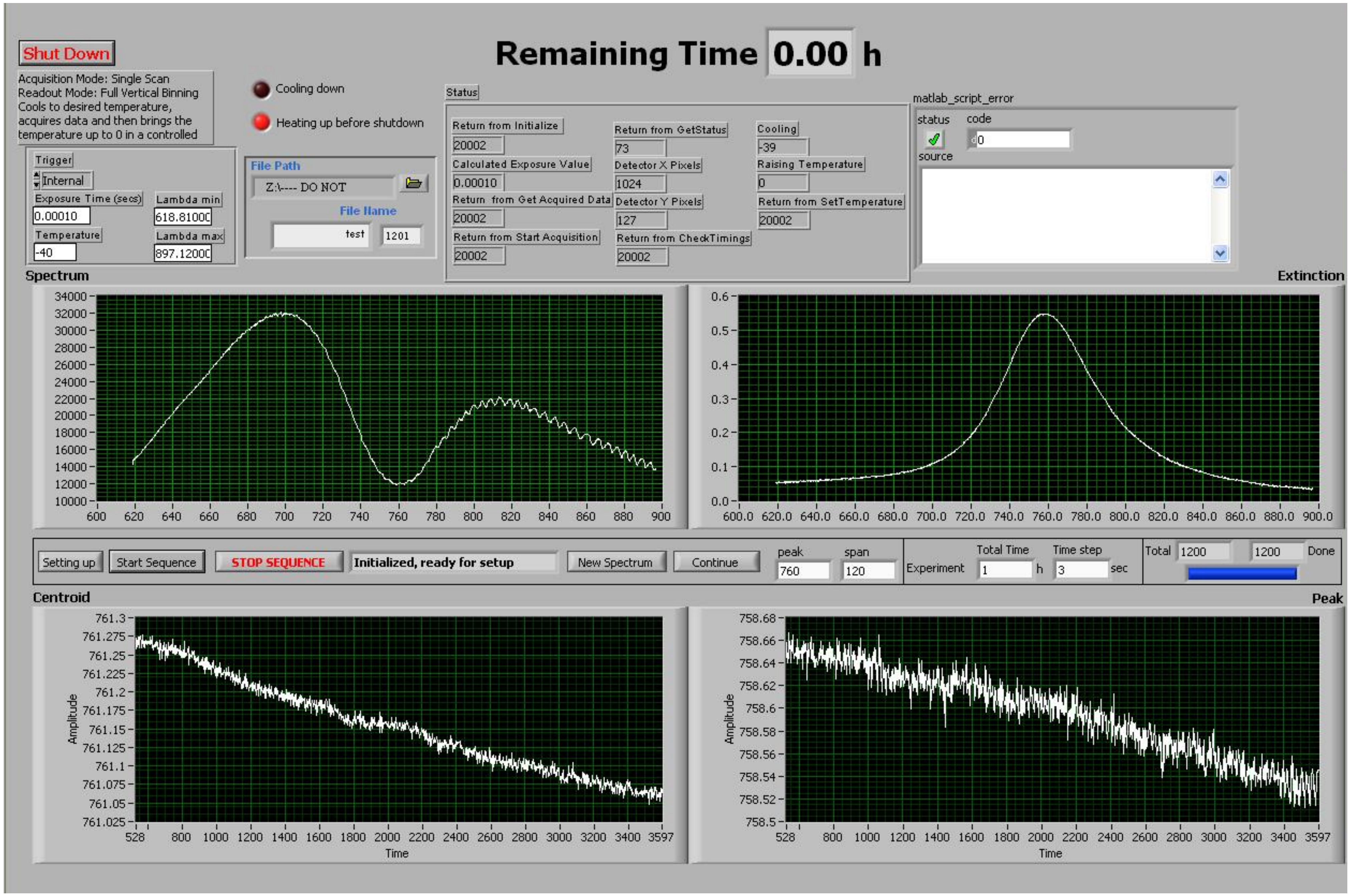

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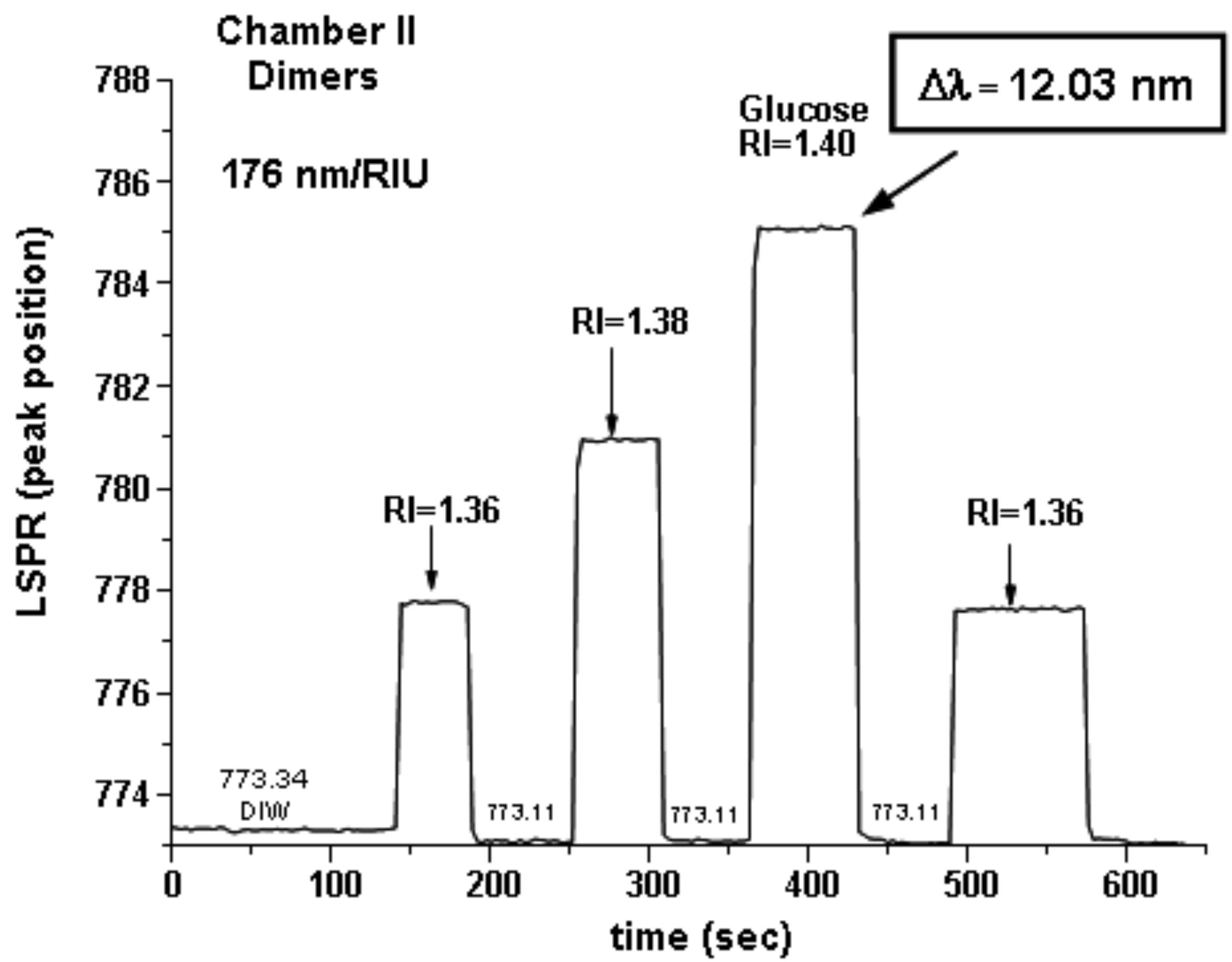
Buk refractive index sensing



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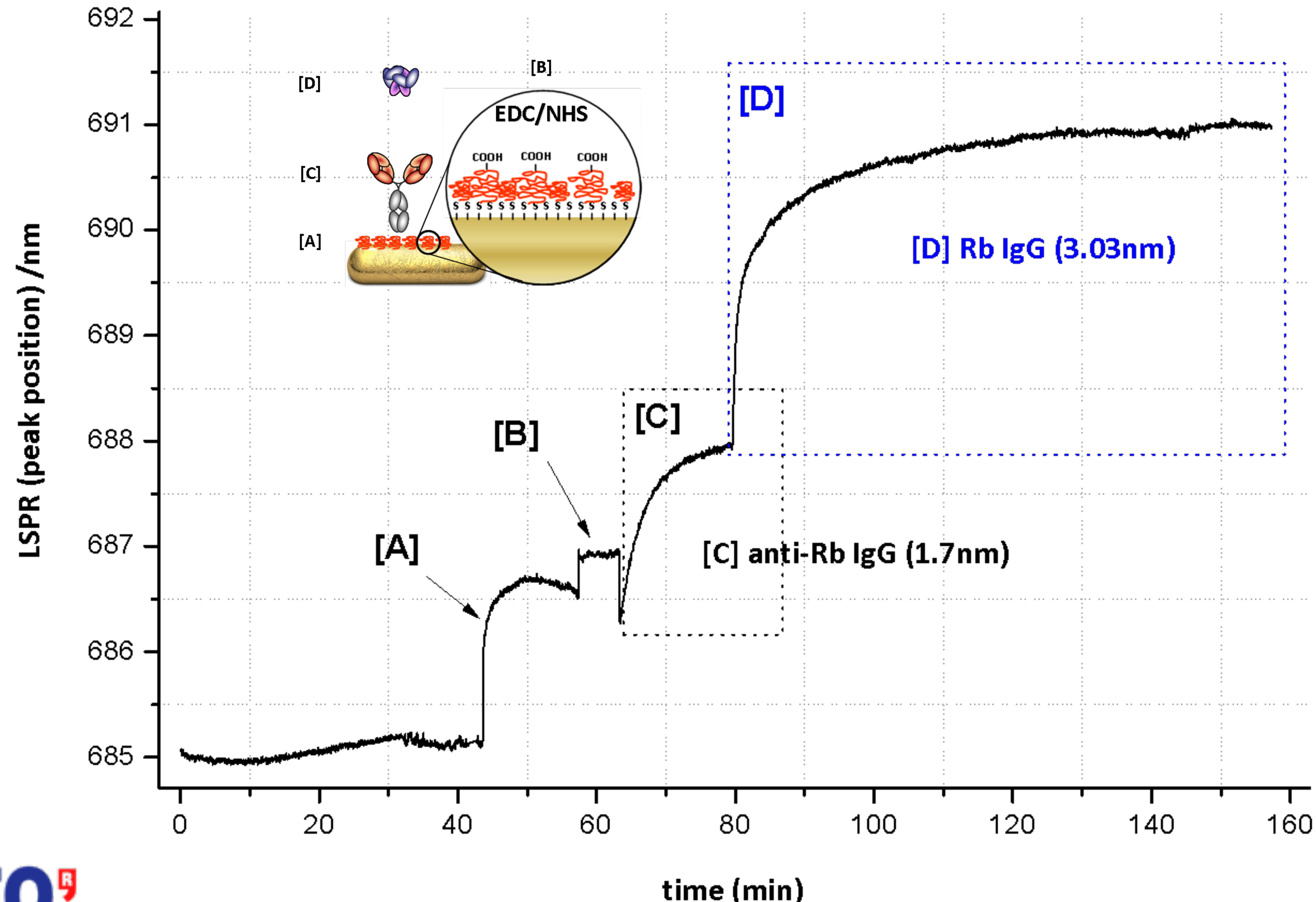
IgG detection in a microfluidic chip



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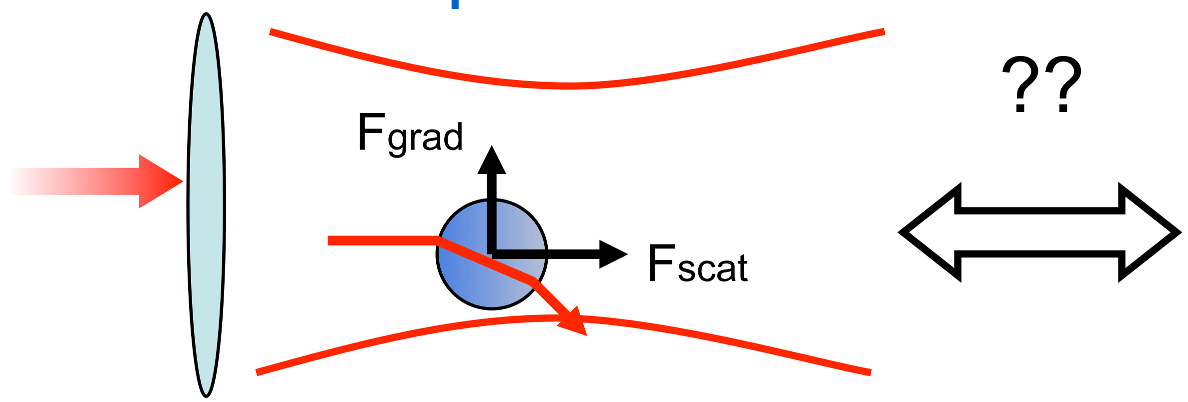
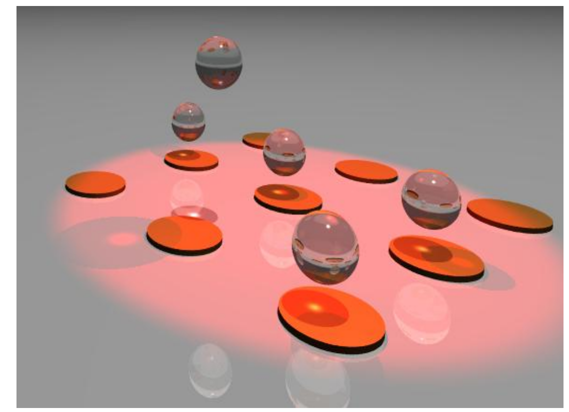
Surface Plasmon-based trapping

3D Optical tweezers



2D SP tweezers



Maurizio
Righini

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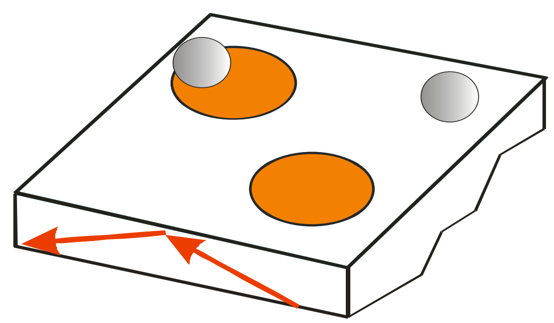
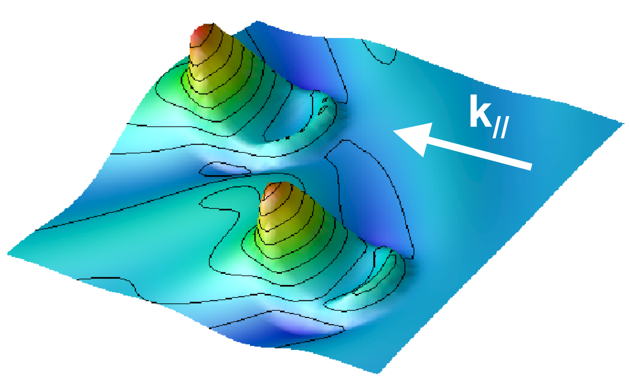
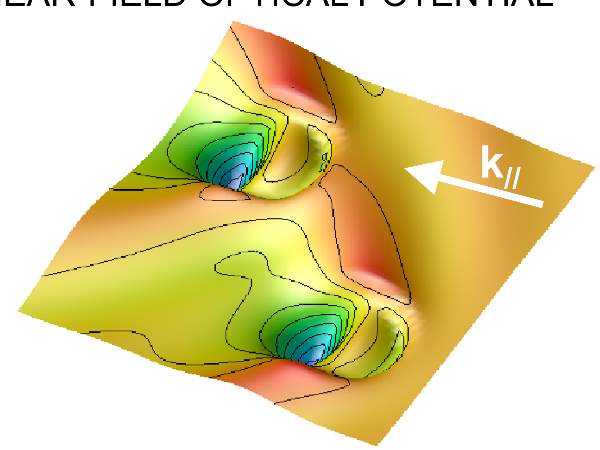


ELECTRIC NEAR-FIELD INTENSITY



NEAR-FIELD OPTICAL POTENTIAL



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Quidant et al, Optics Letters 30, 1009-1011 (2005)

Parallel trapping of micro-object with SP traps

Maurizio Righini

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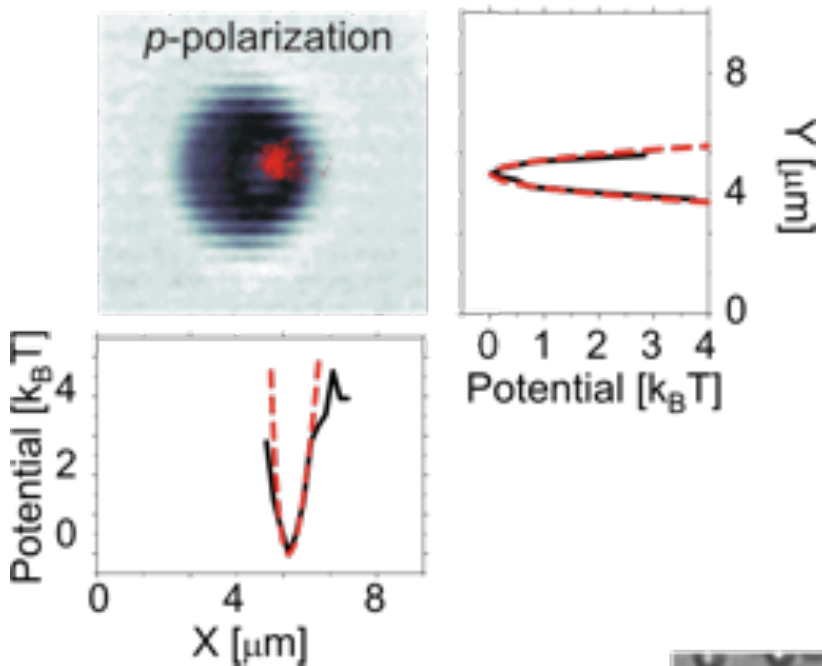
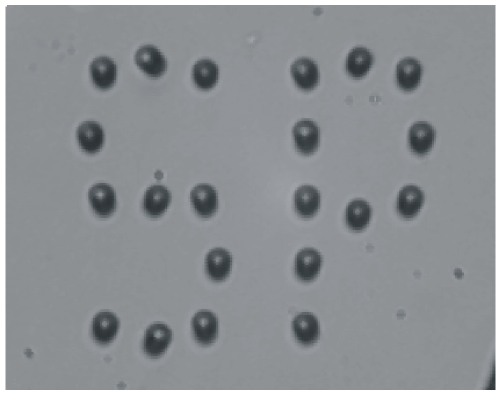
SP TRAP FEATURES

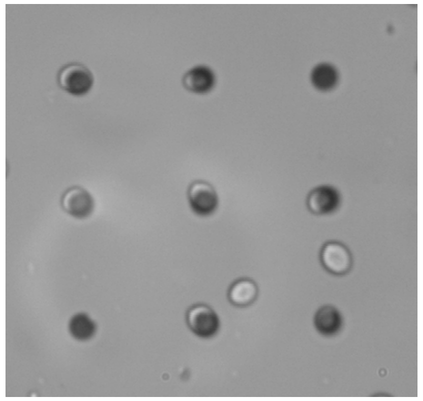


PARALLEL TRAPPING

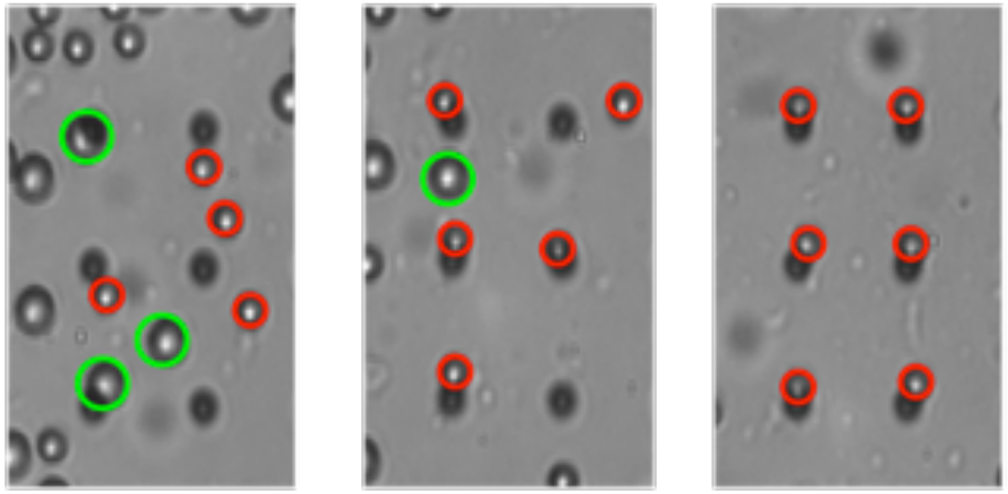
3.5 microns PS beads



Yeast cells



SELECTIVE SP TRAPPING



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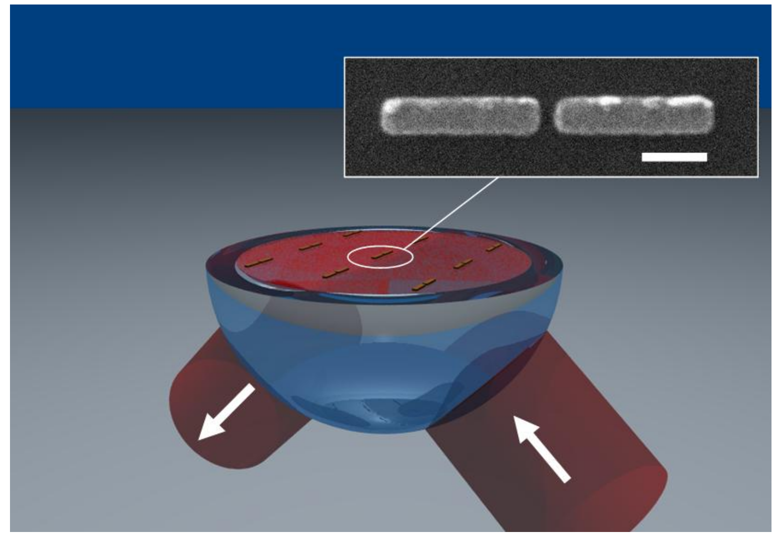
M. Righini et al, Nature Physics **3**, 477 (2007)

M. Righini et al, Phys. Rev. Lett **100,** 183604 (2008)

Trapping 200 nm PS beads with optical gap antennas



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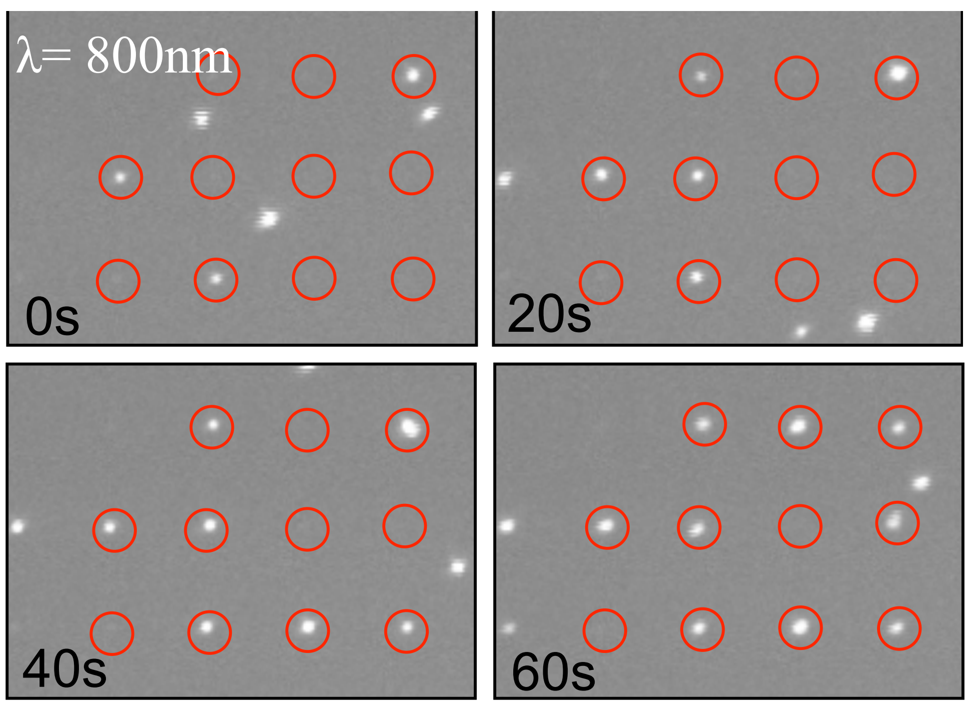
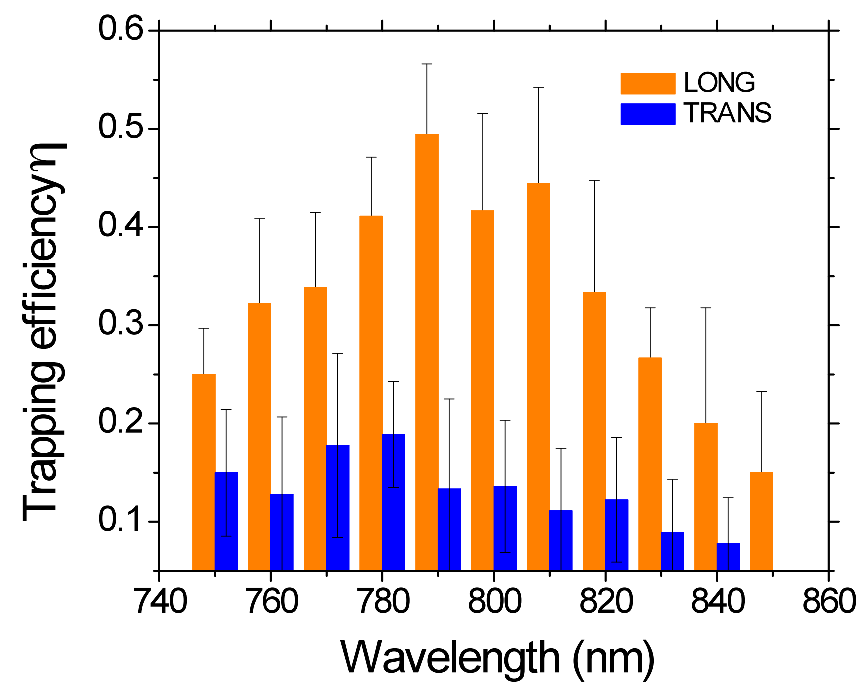


Trapping efficiency vs wavelength



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M. Righini et al, NanoLetters **9**, 3387–3391 (2009)

Trapping and alignment of E-coli bacteria

Maurizio Righini

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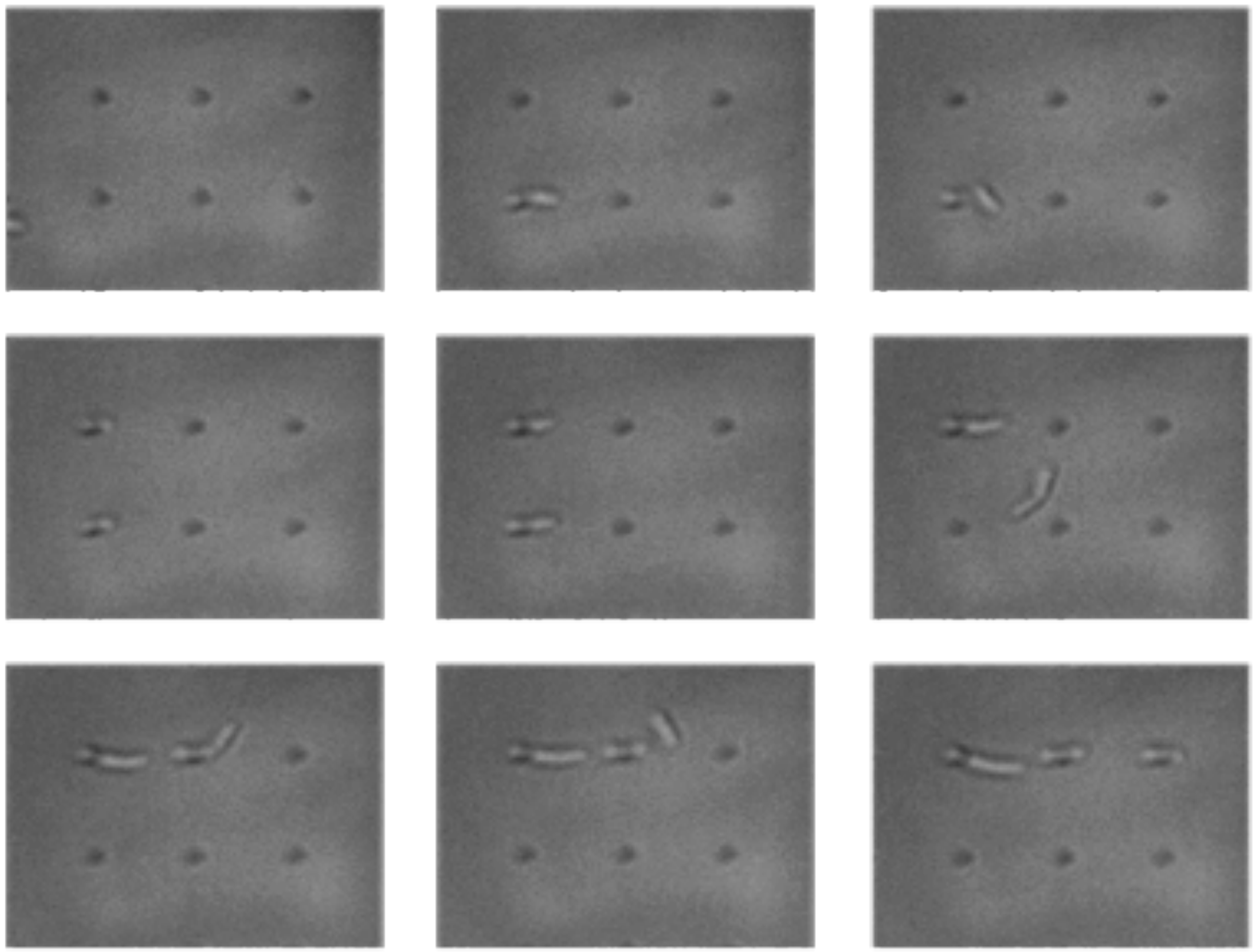

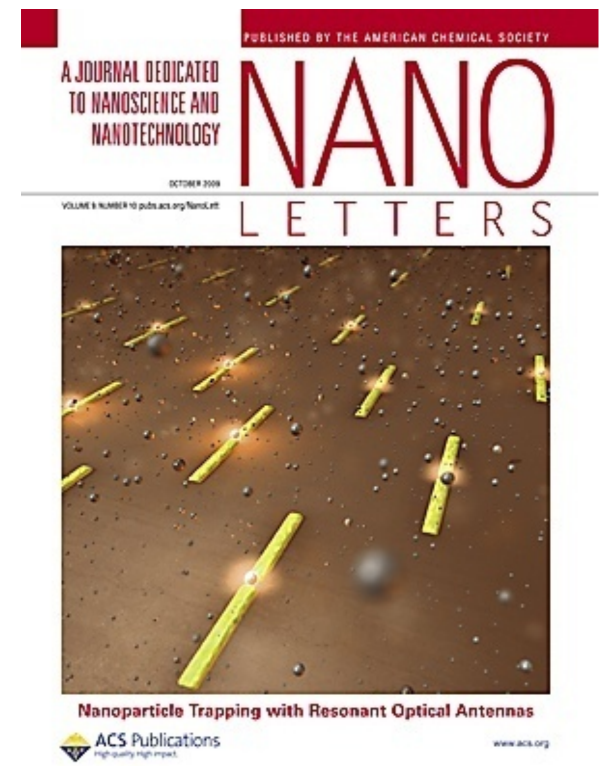

- Division time ~ 60 min both for the trapped and untrapped bacteria
- Estimated local intensity experienced by the trapped bacteria is 10 times below the damage threshold $10^{10} W.m^{-2}$

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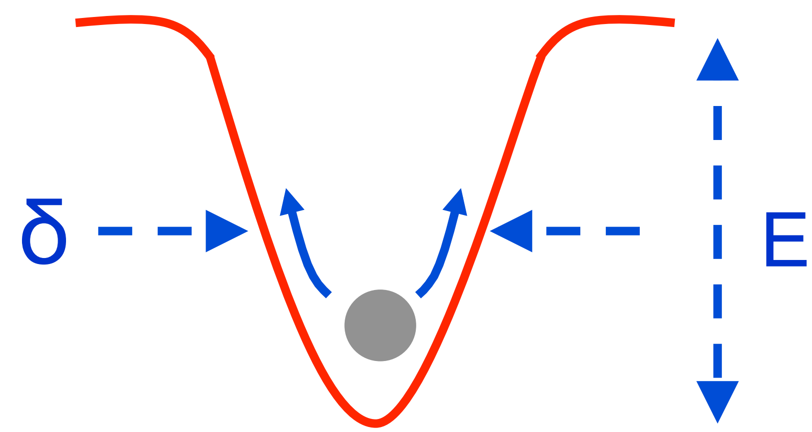
M. Righini et al, NanoLetters **9**, 3387–3391 (2009)

Where is the limit?

When downsizing the size of the trapped specimen ...

↘ Optical gradient force (R*3)

$$\mathbf{F}_{gradient} = \frac{2\pi n_m R^3}{c}\left(\frac{m^2-1}{m^2+2}\right)\nabla I$$



↗ Brownian motion (1/R)

$$\langle x^2(t)\rangle = \frac{2k_BT}{6\pi\eta R}|t|$$

Increasing the trapping efficiency requires ...

Increasing the trap Confinement (↓ δ) = Concentrating light Fields down to the sub-λ scale	&	Increasing the Potential depth (↑E) = Increasing the local Field intensity within the trap Risks of photo-damage

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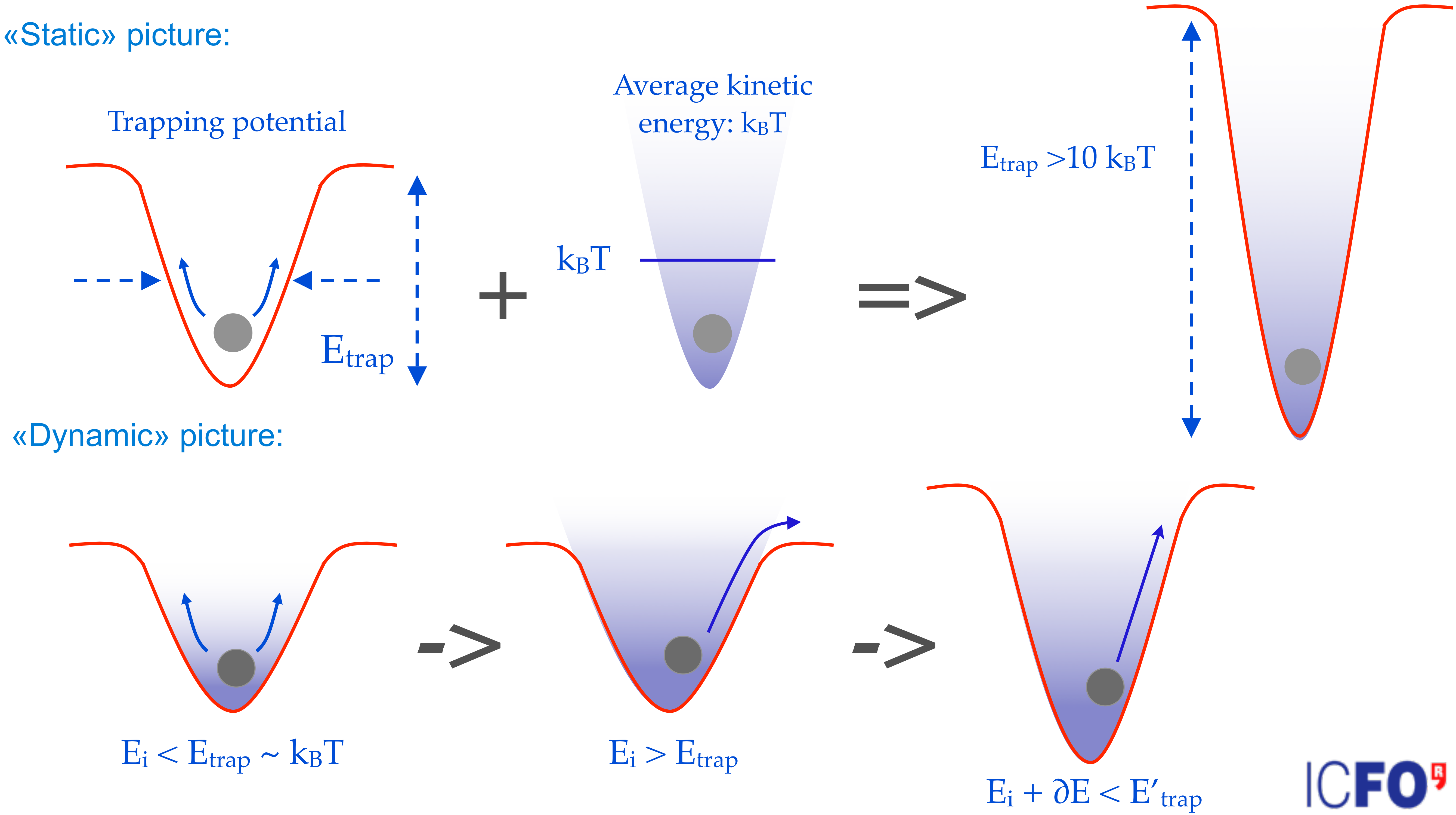
Relaxing the trapping conditions using a dynamic trap



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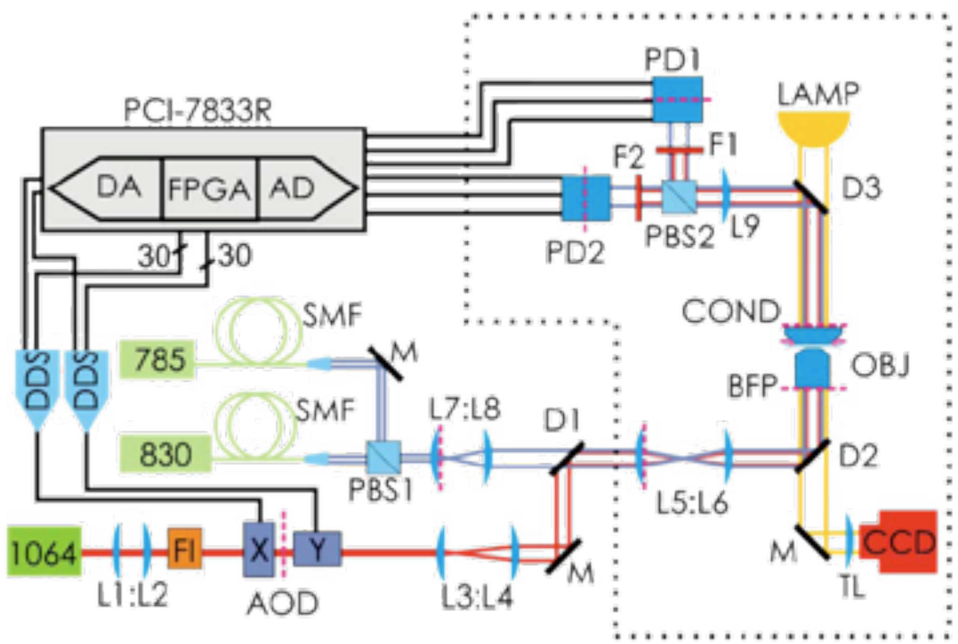
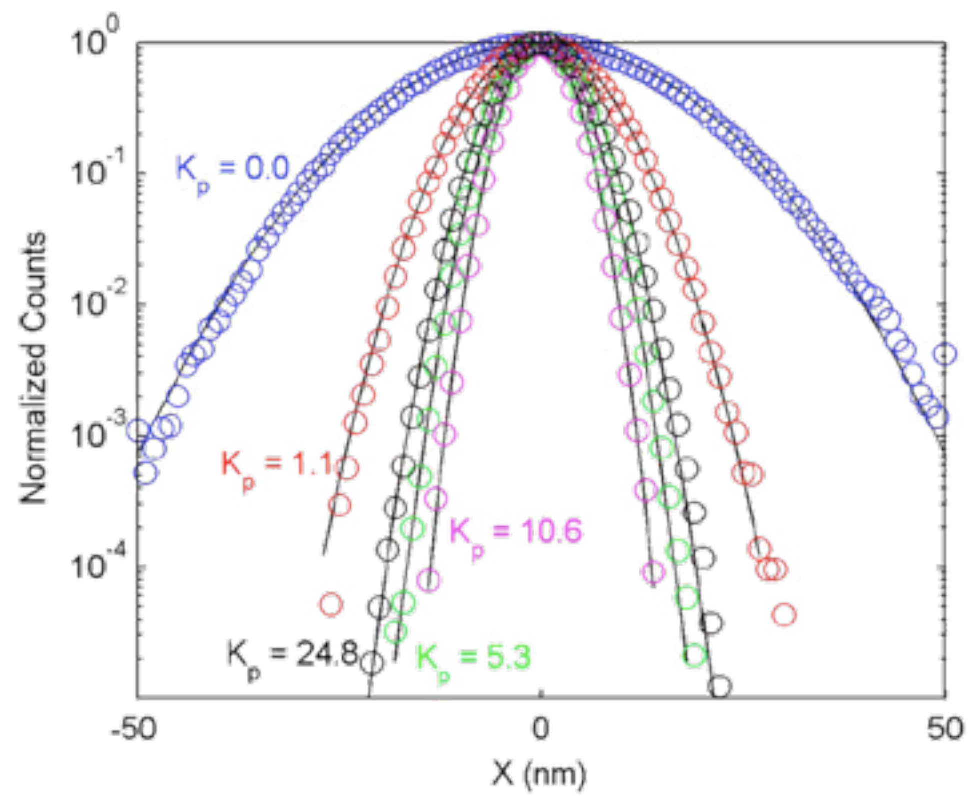
Relaxing the trapping conditions using a dynamic trap

«Static» picture:

Average kinetic

«Dy





Wallin, A. E., et al, Stiffer optical tweezers thourgh real-time feedback control. *Appl. Phys. Lett.* **92**, 224104 (2008).

$E_i < E_{trap} \sim k_B T$

$E_i > E_{trap}$

$E_i + \partial E < E'_{trap}$

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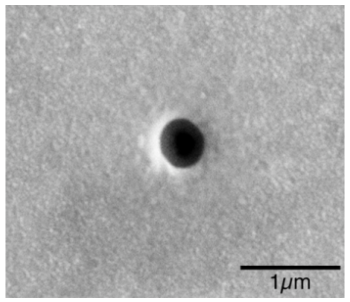
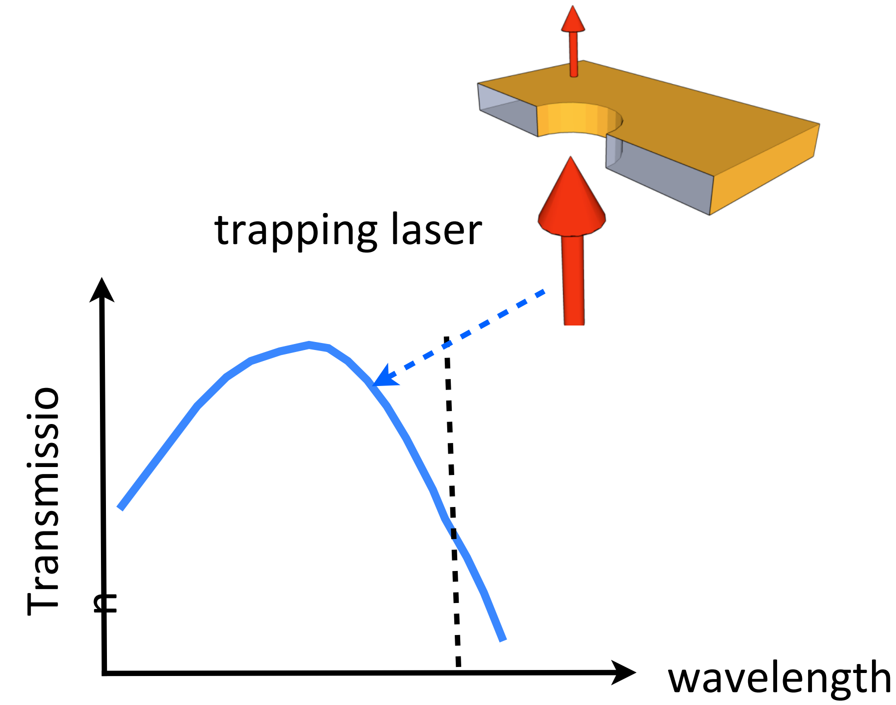
Self-Induced Back-Action (SIBA) Trapping in metallic nanoapertures

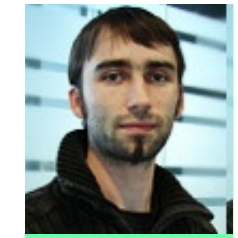
Single nano-aperture:
310 nm diameter, 100 nm thick gold layer



Trapping with a nano-hole:

Okamoto et al (1999)
Kwak et al (2004)





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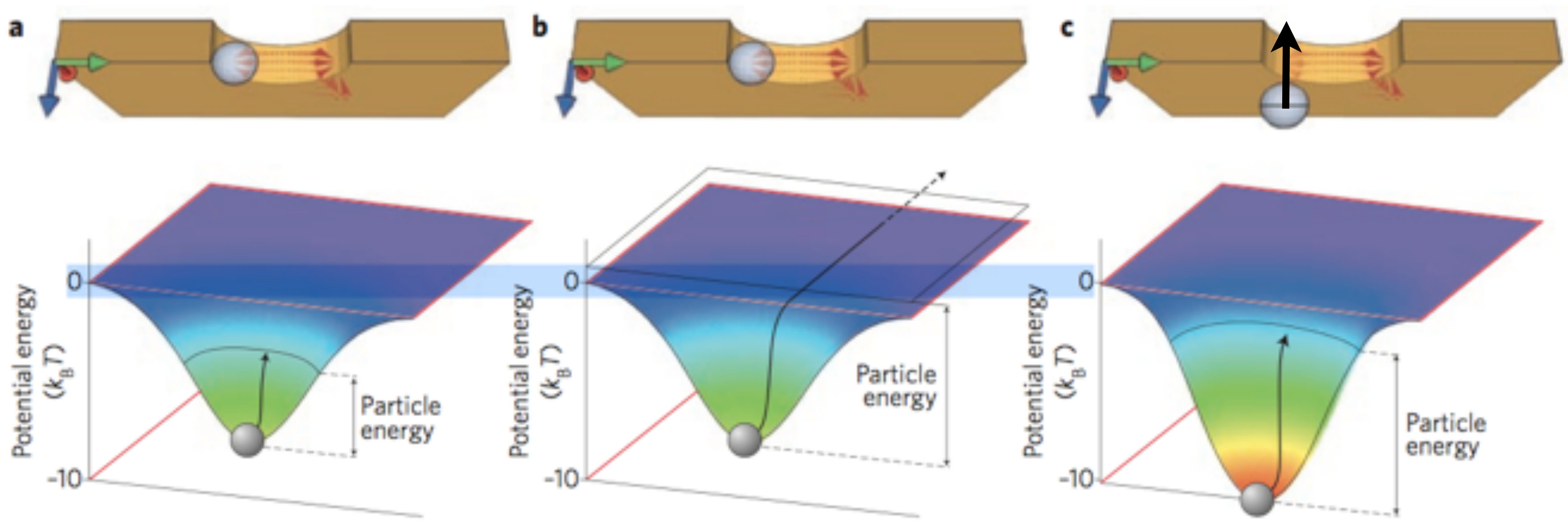
Juan
now @Sydney



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In the SIBA approach, trapping not only relies on the gradient force but is assisted by the change in the momentum of transmitted photons

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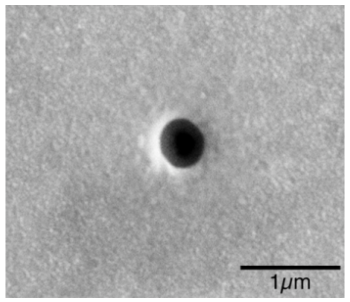

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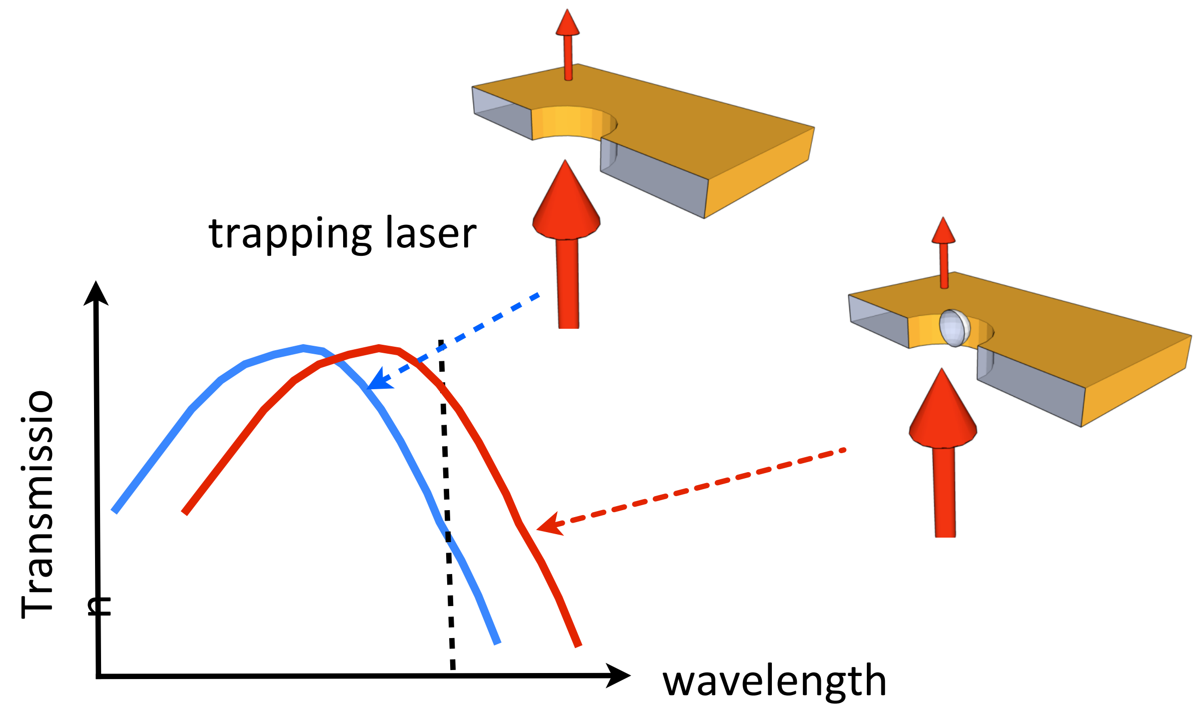

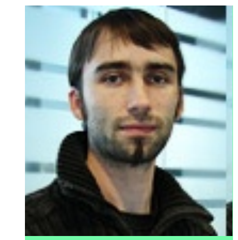

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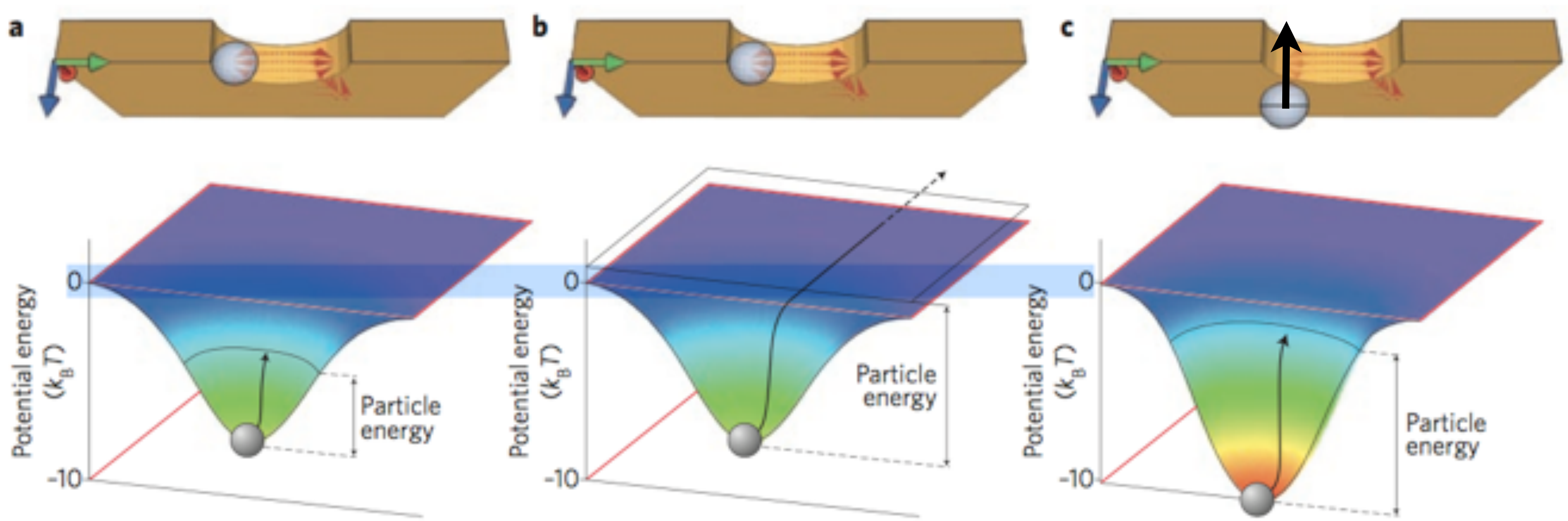

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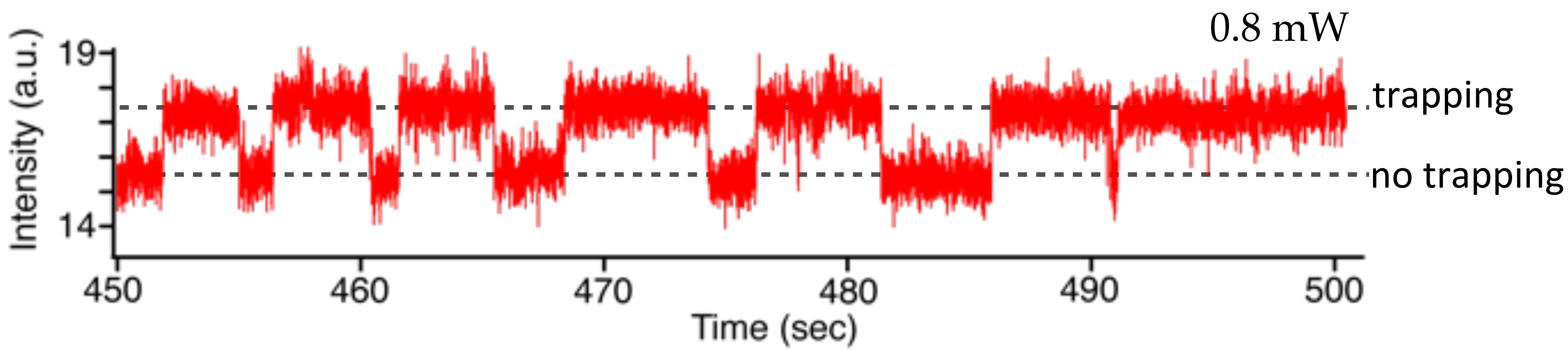
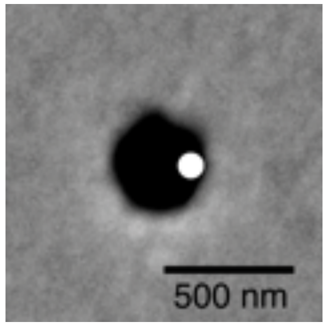
In the SIBA approach, trapping not only relies on the gradient force but is assisted by the change in the momentum of transmitted photons

SIBA Trapping of 100nm and 50 nm PS beads in spherical nanoapertures

Mathieu Juan now @Sydney

Trapping of **100 nm PS beads**:
0.8 mW for ~ 4 sec average trapping time





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M. L. Juan et al, Nature Physics 5, 915-919 (2009)

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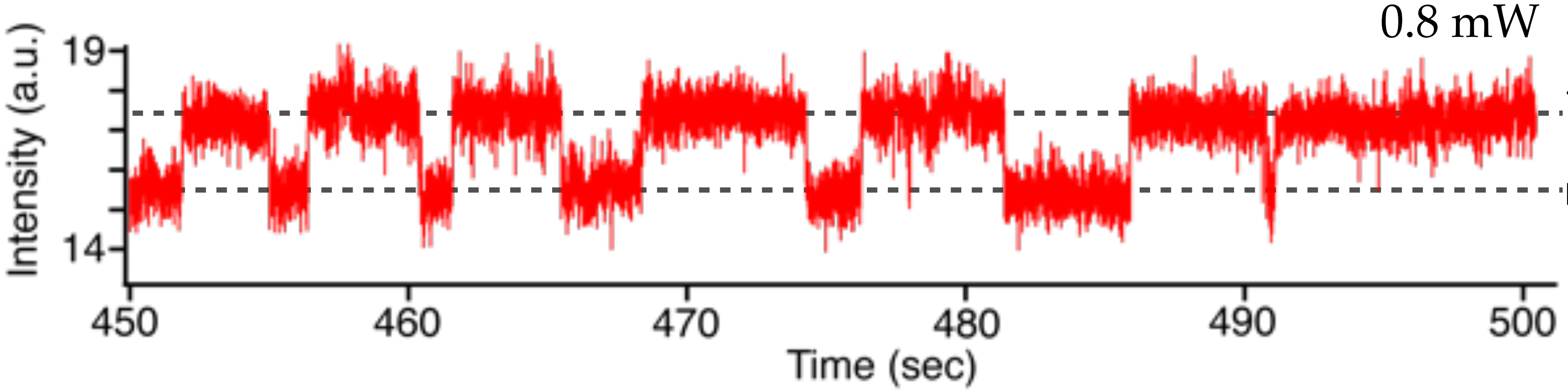
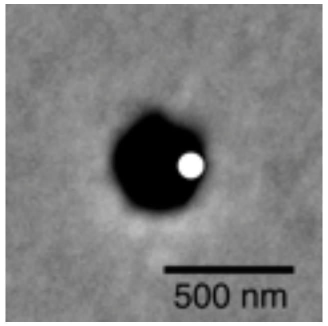
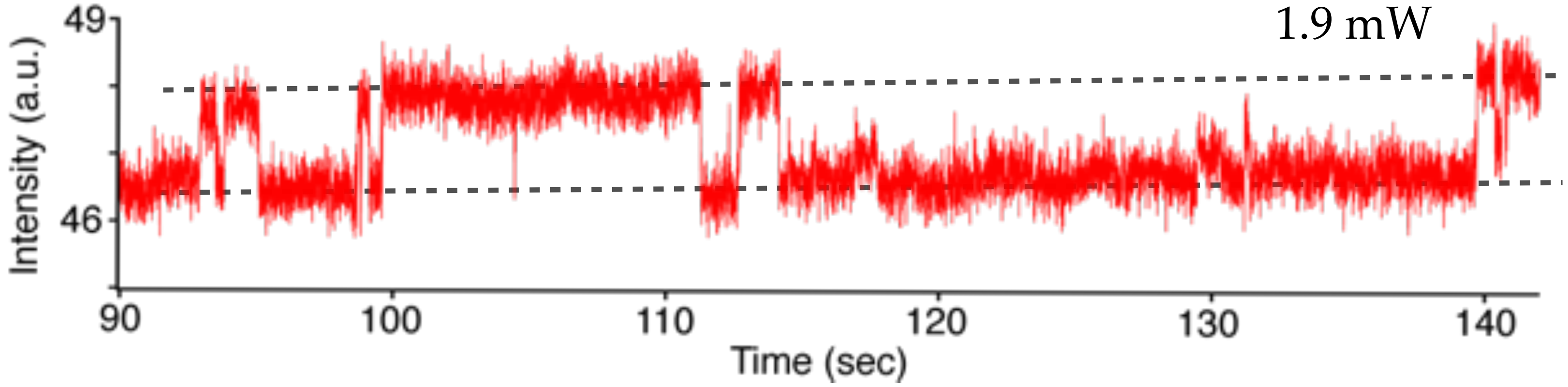
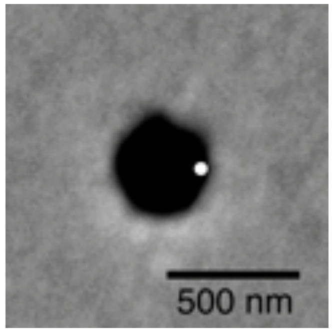




Trapping of **50 nm PS beads**:
1.9 mW for ~ 5 sec average trapping time





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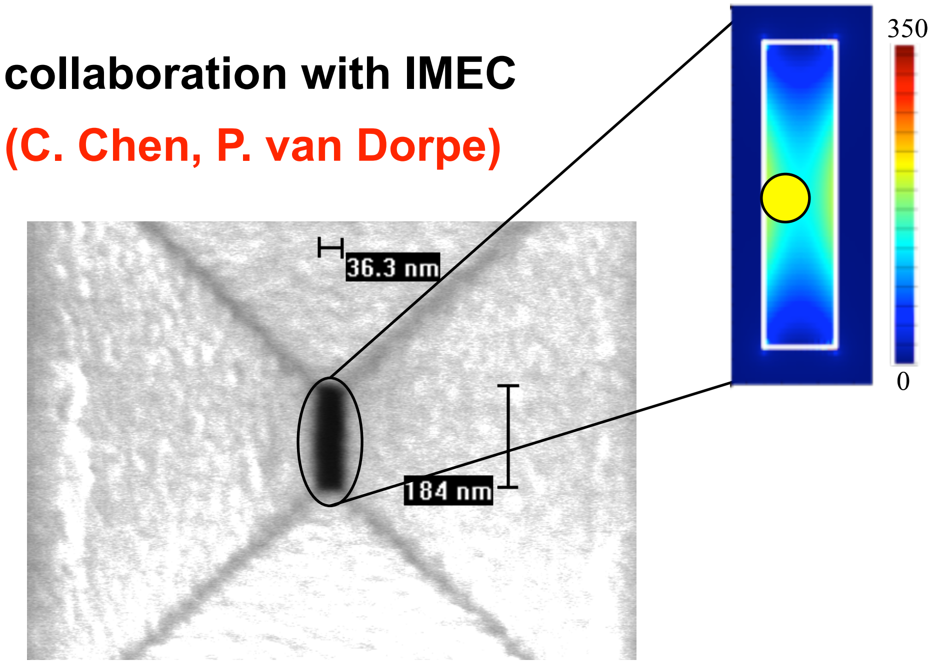
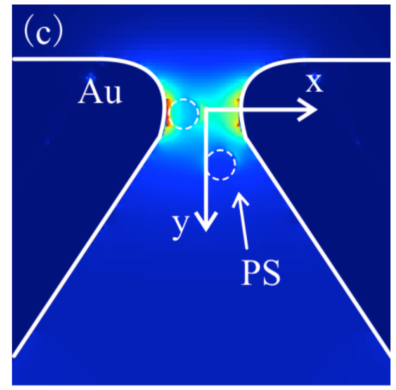
M. L. Juan et al, Nature Physics 5, 915-919 (2009)

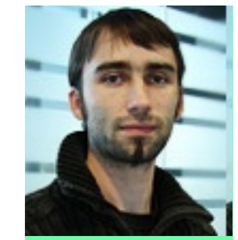
Improving SIBA trapping through mode engineering

In collaboration with IMEC

(C. Chen, P. van Dorpe)







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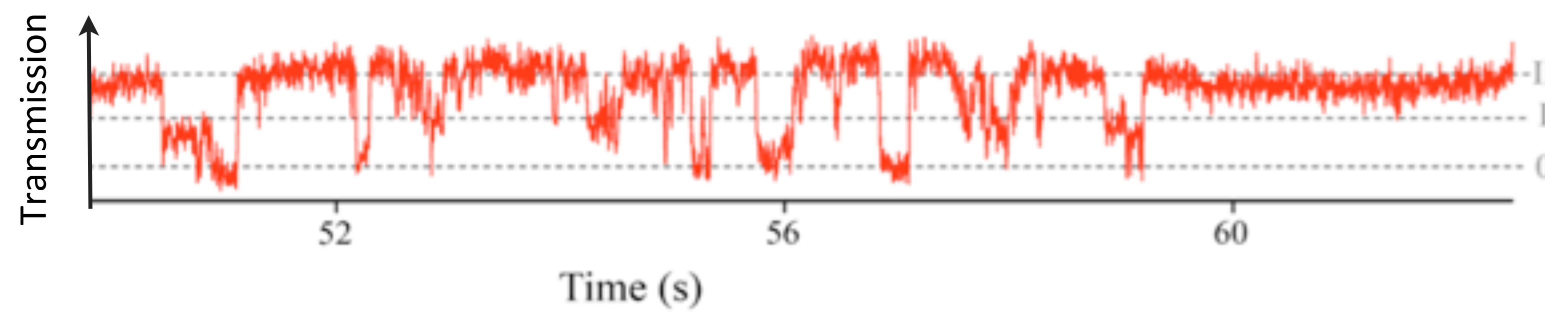
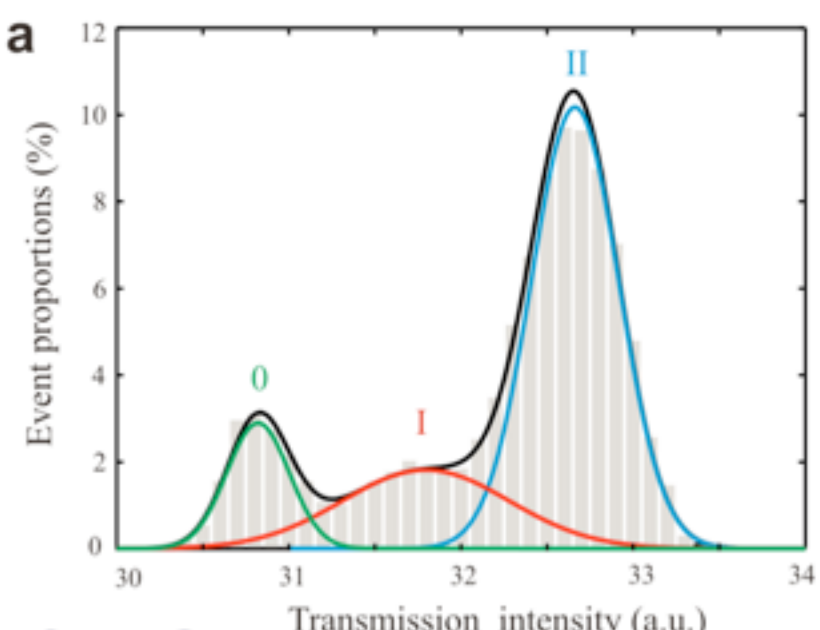
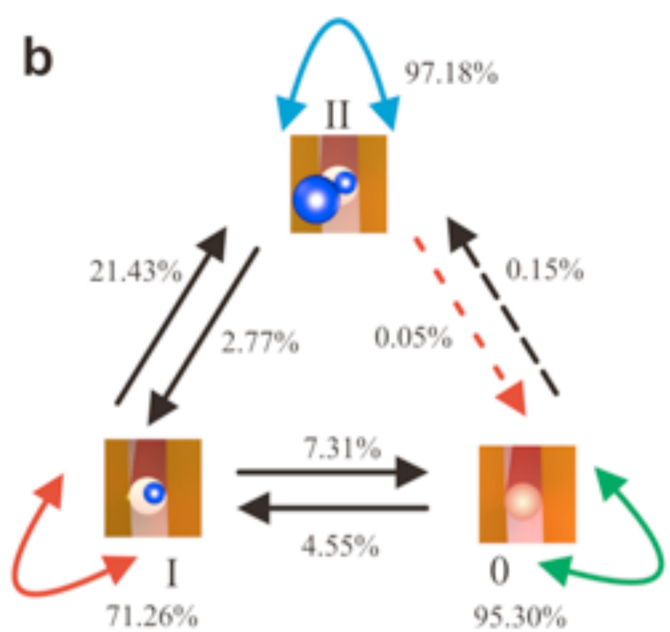
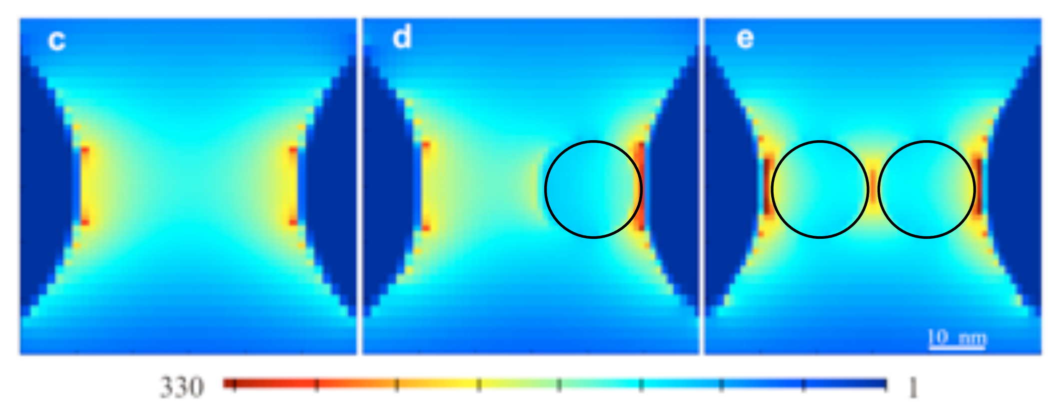
Trapping of **20nm** PS beads









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C. Chen, M. L. Juan et al, Nano Lett. **12**, 125-132 (2012)

Plasmon nano-optical tweezers

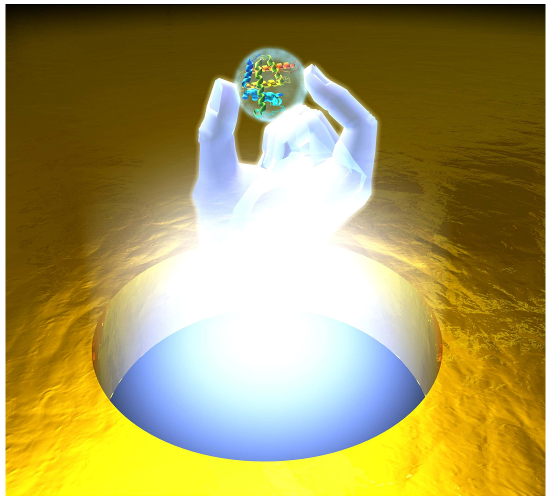
nature photonics FOCUS | REVIEW ARTICLES
PUBLISHED ONLINE: 31 MAY 2011 | DOI: 10.1038/NPHOTON.2011.56

Plasmon nano-optical tweezers

Mathieu L. Juan[1], Maurizio Righini[1] and Romain Quidant[1,2]

Conventional optical tweezers, formed at the diffraction-limited focus of a laser beam, have become a powerful and flexible tool for manipulating micrometre-sized objects. Extending optical trapping down to the nanometre scale would open unprecedented opportunities in many fields of science, where such nano-optical tweezers would allow the ultra-accurate positioning of single nano-objects. Among the possible strategies, the ability of metallic nanostructures to control light at the subwavelength scale can be exploited to engineer such nano-optical traps. This Review summarizes the recent advances in the emerging field of plasmon-based optical trapping and discusses the details of plasmon tweezers along with their potential applications to bioscience and quantum optics.

Nature Photonics 5, 349–356 (2011)



Towards single protein trapping??

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Surface Plasmon Early Detection of Circulating Heat Shock Proteins & Tumor Cells (SPEDOC)

OBJECTIVE

Combining the last advances of plasmon nano-optics (sensing, tweezers, SERS) microfluidics and oncology to develop a new integrated platform for early stage cancer diagnosis and treatment monitoring

PARTNERS

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INSERM - Institut National de la Sante et de la Recherche Medicale
EPFL - Ecole Polytechnique Federale de Lausanne
COSINGO - Image Optic Spain S.L.
ICFO - Institute of Photonic Sciences (Coordinator)

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SEVENTH FRAMEWORK PROGRAMME

Initiated the 1st of January 2010

THE PLASMON NANOOPTICS GROUP@ICFO

romain.quidant@icfo.es

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spedoc

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GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

Fundació Privada CELLEX

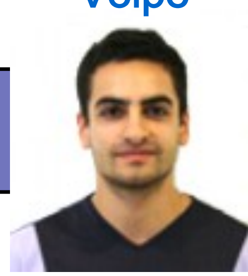
icrea Institució Catalana de Recerca i Estudis Avançats

The Plasmon Nano-Optics Group @ ICFO.es

Openings for both postdocs and PhDs !

PhD students

Giorgio Volpe



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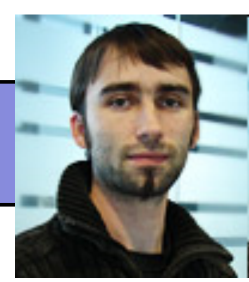

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Christopher Galloway

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Sebastian Thompson