Controlling photon emitters on nanometer & femtosecond scale

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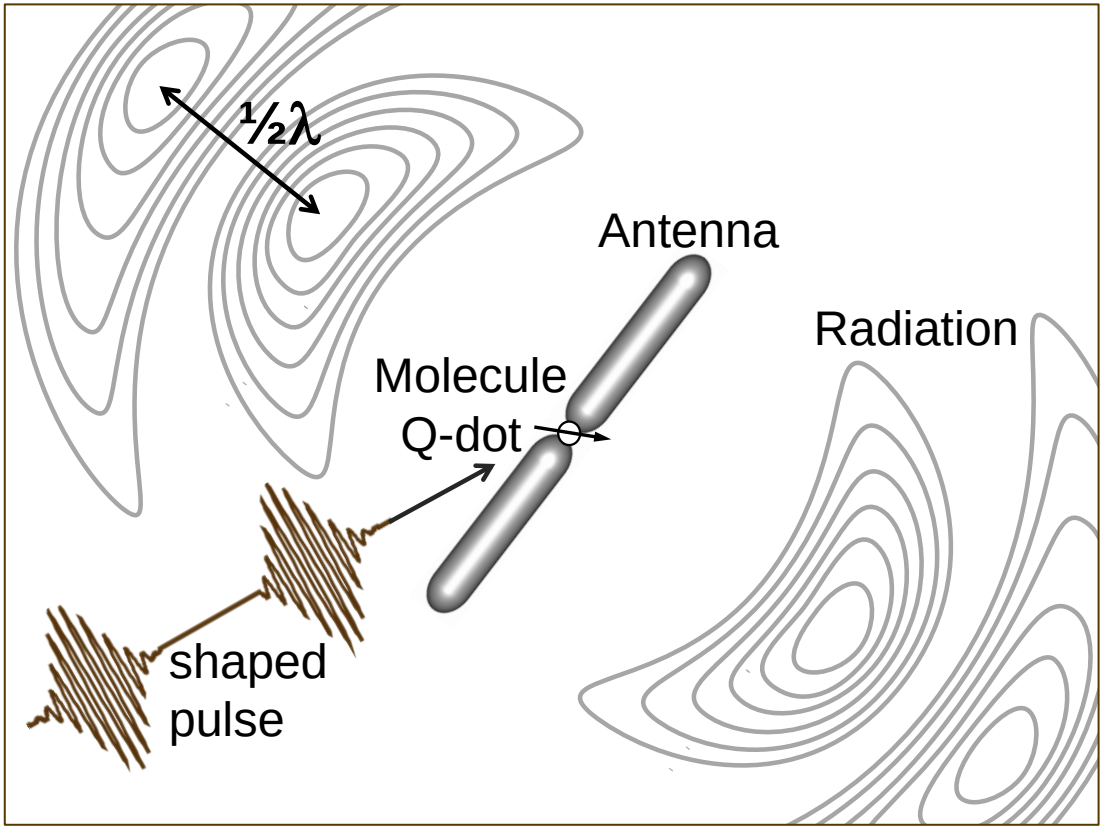
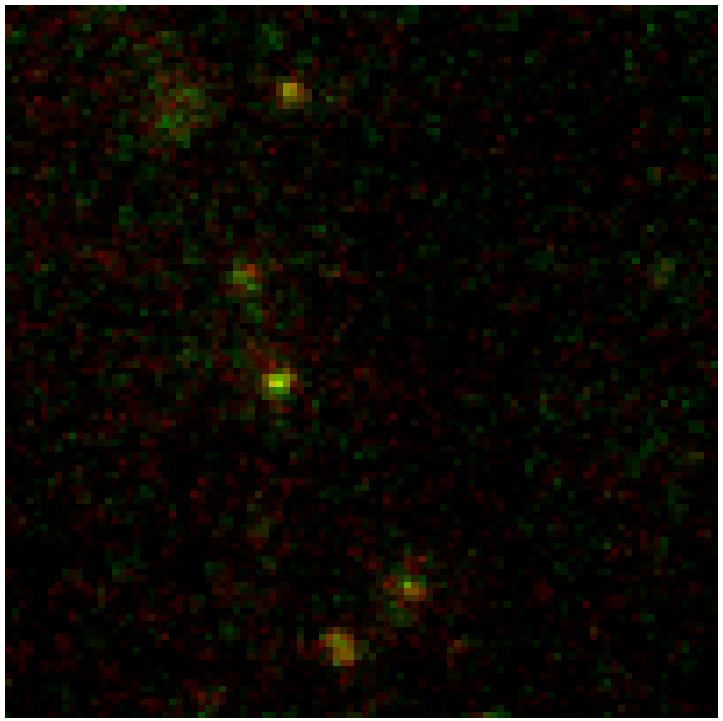
NanoPhotonics: where “*fs*” and “*nm*” meet

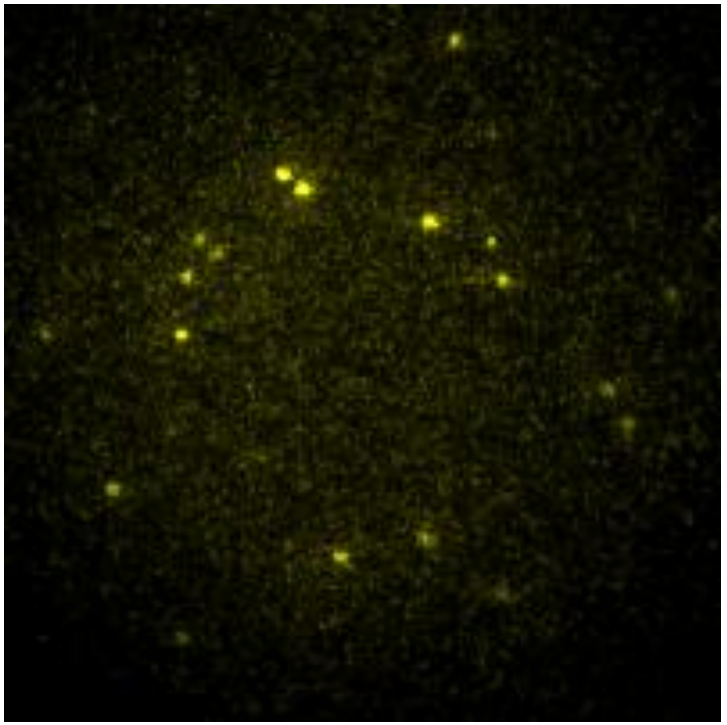
[fs] phase controlled excitation of single molecules
“Single Molecule Coherent Control”



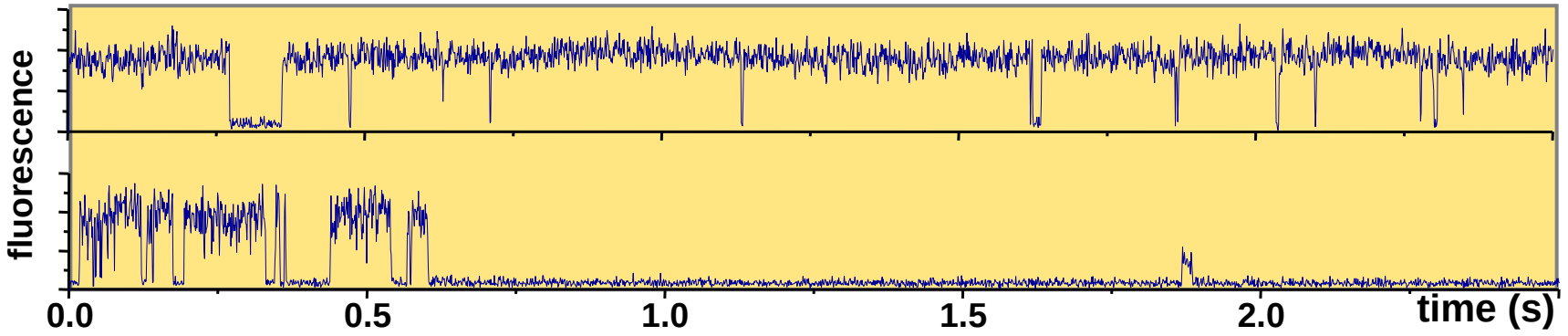
[nm] phase controlled driving of a nano-antenna
“Coherent control of antennas”

Detection of single molecule dynamics





30 x 30 μm², 100 ms/frame



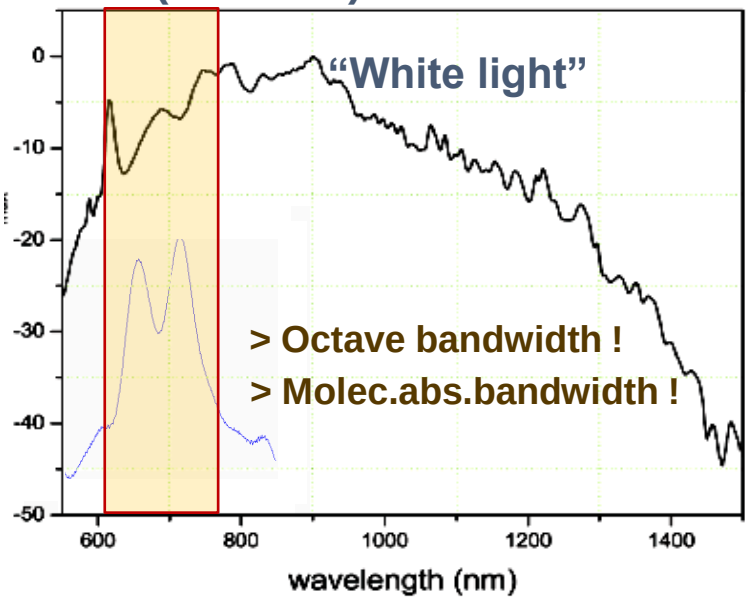
Diffusion, rotation, blinking, bleaching: hours, sec, ms, μs…..

Tools for ultrafast (fs) phase controlled excitation

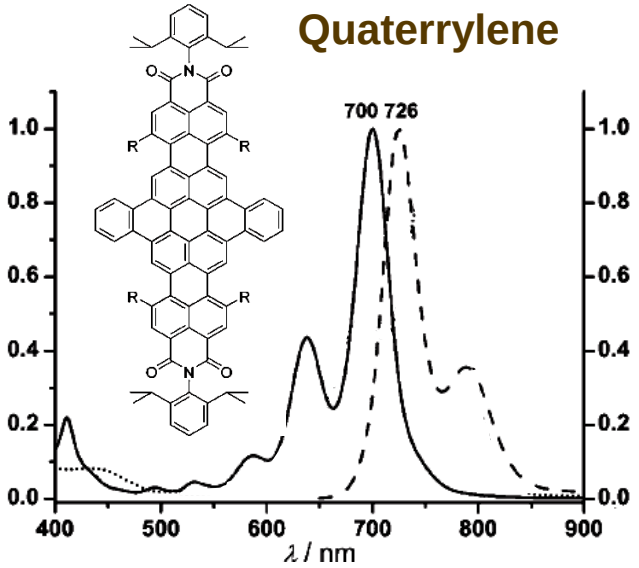
Ultrafast laser
7 fs pulse length

Menlo systems

Broad (coherent) excitation bandwidth

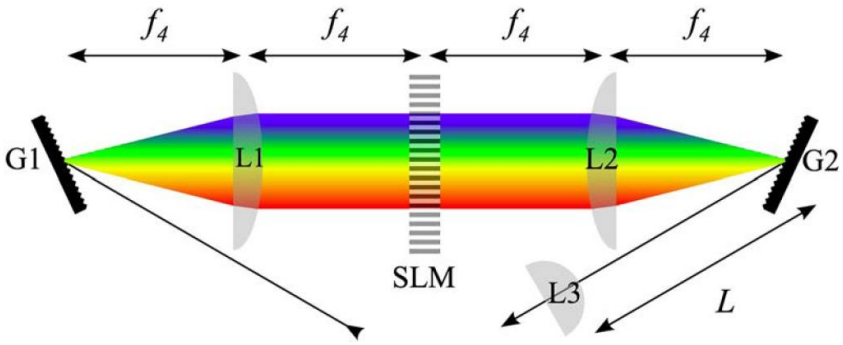


Molecule
Quaterrylene



Yuri Avlasevich, Klaus Mullen,
Chem. Eur. J. **13**, 6555 – 6561 (2007).

Pulse shaper

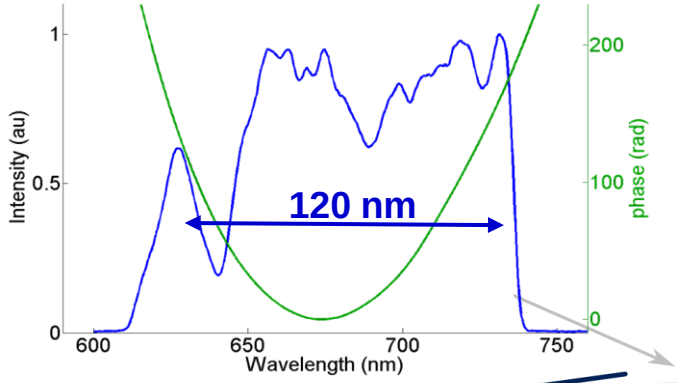


Single Molecule microscope

In-focus spectral phase control and compensation

Broad band excitation in visible: 610 – 730 nm, 14 fs

Diffraction limited, 1.3NA objective

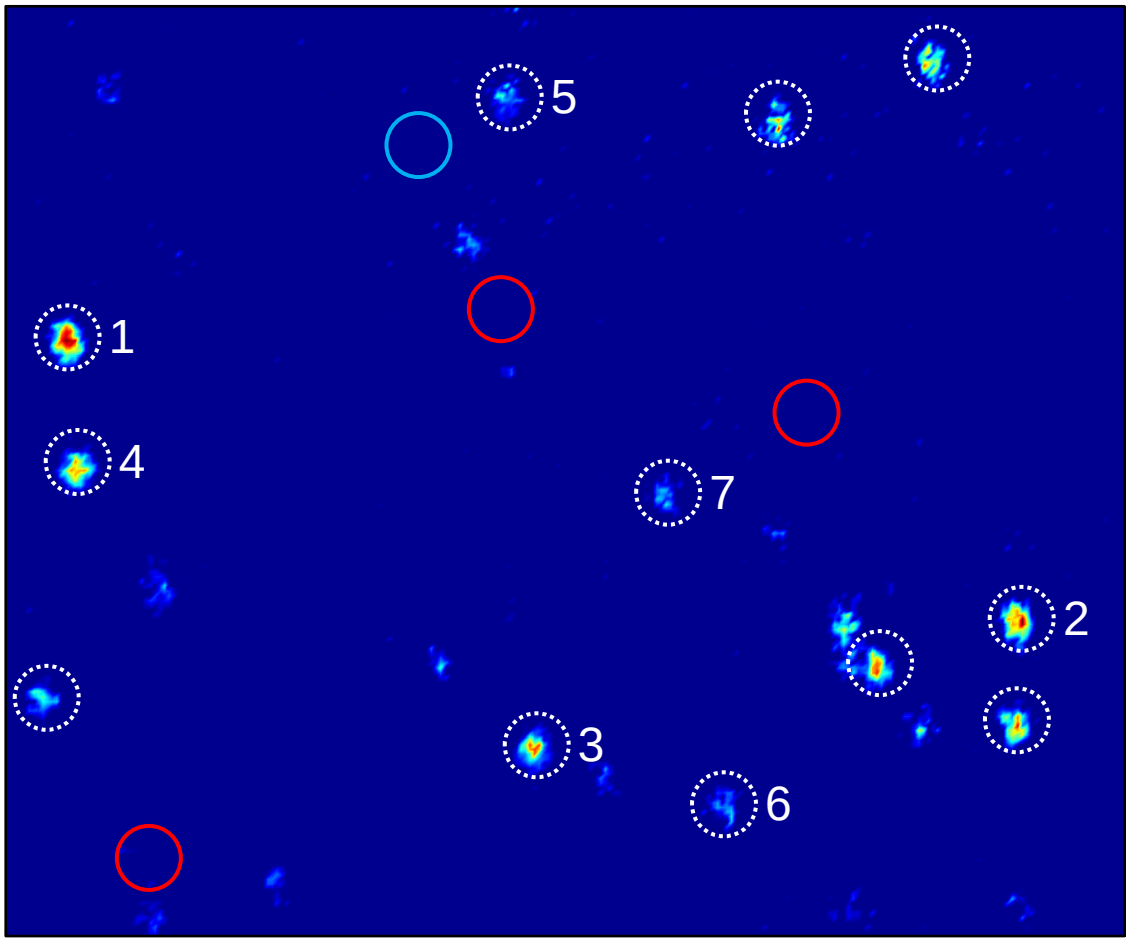


Dispersion Compensation ~ 8000 fs²

MIIPS - Multiphoton Intrapulse Interference Phase Scan

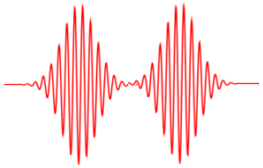
V. V. Lozovoy, I. Pastirk, M. Dantus, Multiphoton intrapulse interference, Optics Letters 29, 775-777 (2004).

Beyond the ensemble



Delay

21 fs

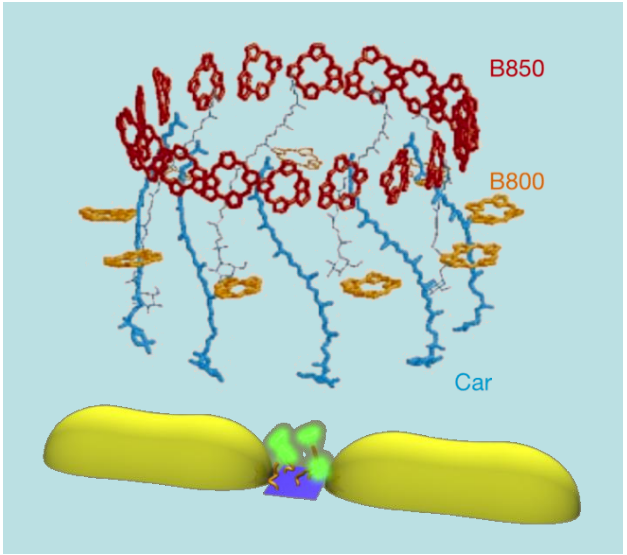


bleaching

blinking

heterogeneity

- First phase controlled excitation of a Single Molecule
- At room temperature, on large molecules
- Single Molecular vibrational wavepacket, ~ 35 fs period
- Single Molecular wavepacket group velocity
- Starting phase differs between molecules: heterogeneity
- Decoherence time 20 - 50 fs



Outlook

- Multiphoton excitation
- Coupled systems, energy transfer
- Biosystems....

What's NANO about antennas ?

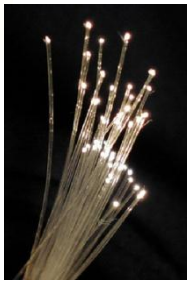
Near-field, sub-λ ⟵ **λ** ⟶ **Far field, many λ**

Optics on nanoscale

atoms, molecules << λ

Lenses, mirrors, fibers,...

>>> λ



¿ Optical NanoAntennas ?

Optics, visible

500 THz (10^{14} Hz)

λ = 400 – 800 nm

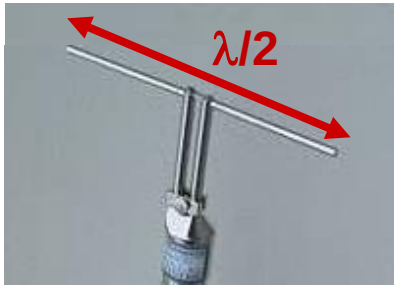
period ~ **2 fs**

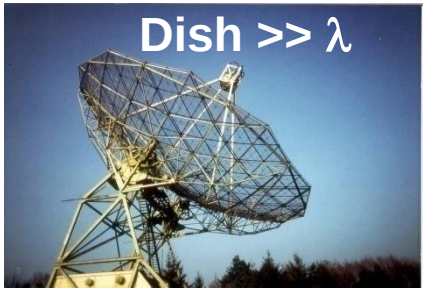
10^8 x

Radio frequency

kHz-MHz

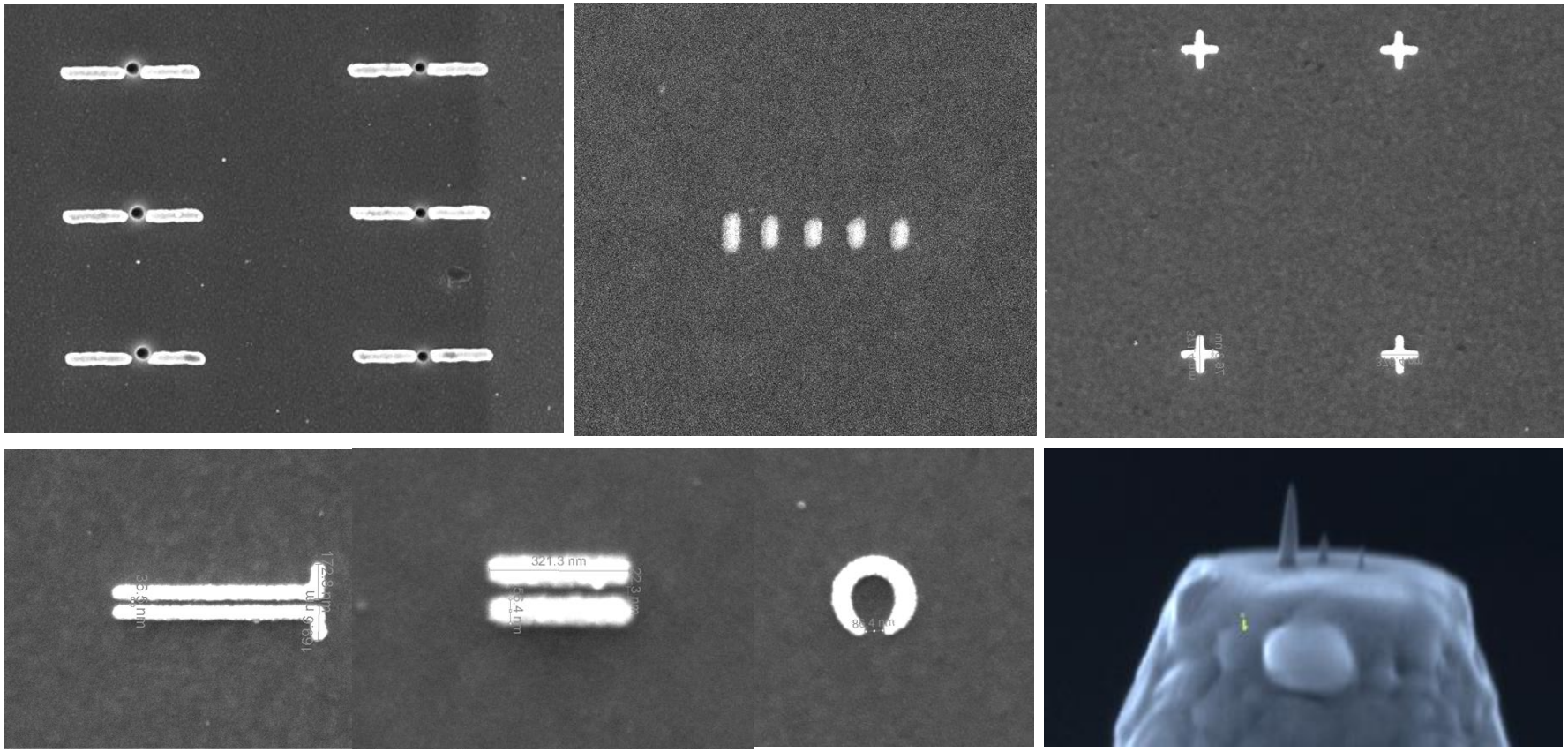
λ=1 m @ 300MHz





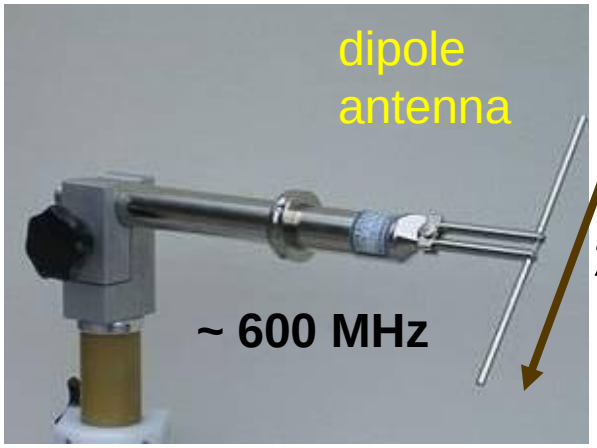
Transducer near – far field

Optical Nano-antennas

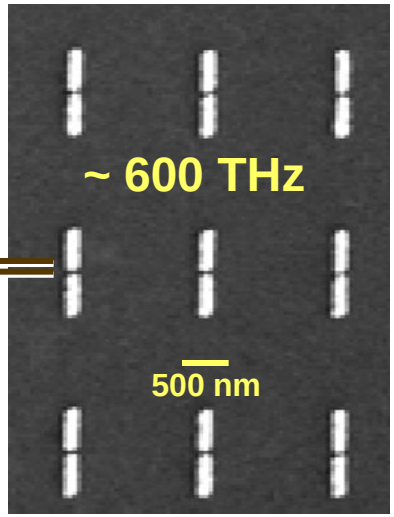


E-beam lithography, focussed ion beam milling

¿ Driving Antennas at optical frequencies ?

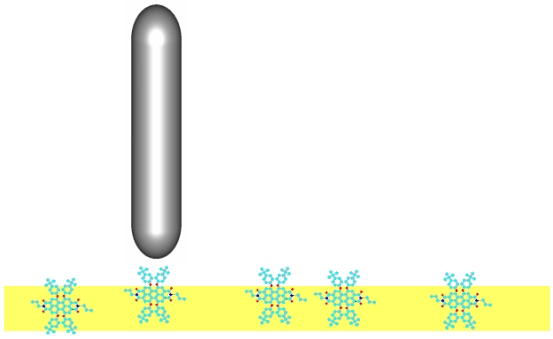


Far field



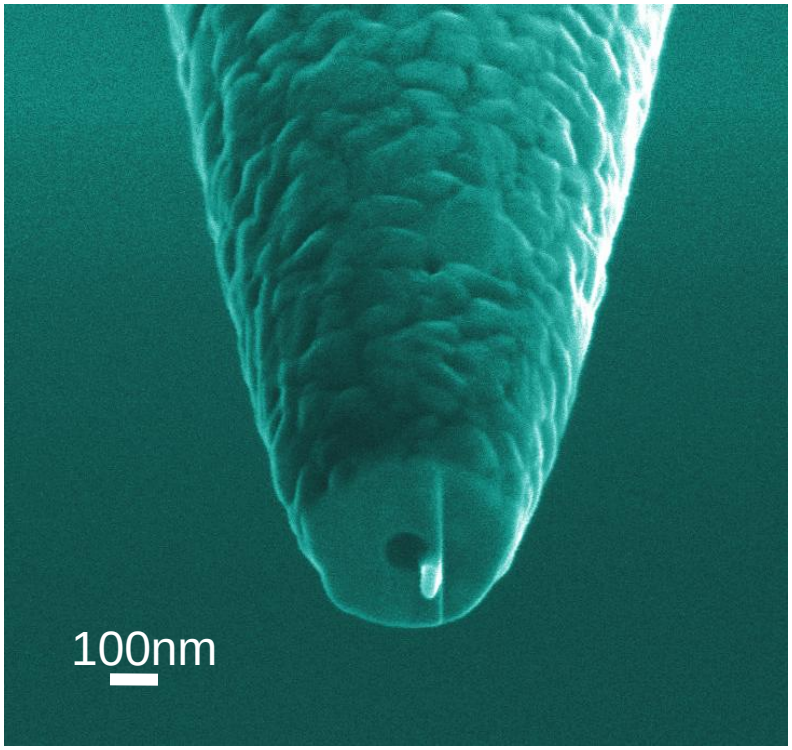
?

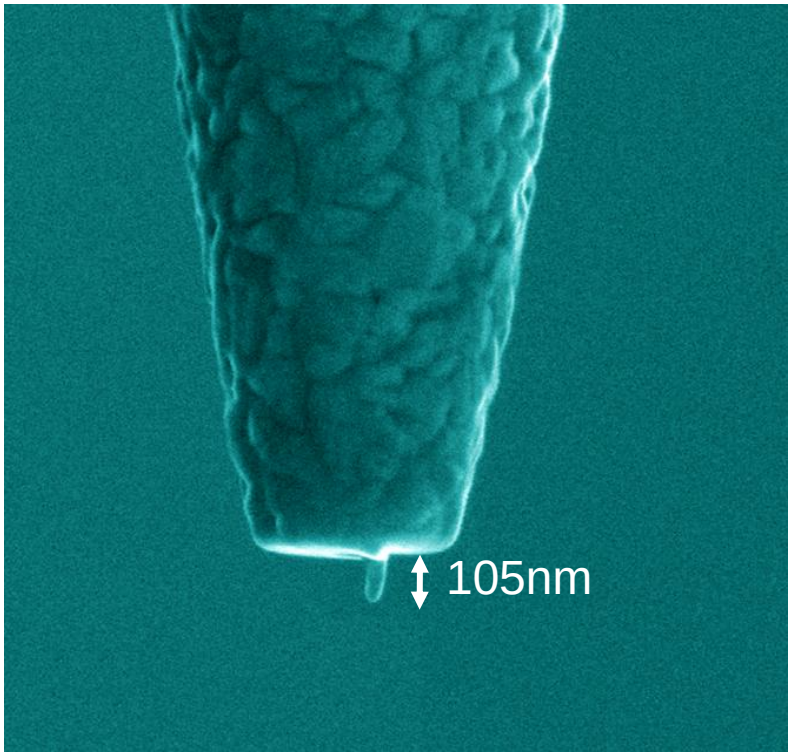
Nano-antennas
on surface

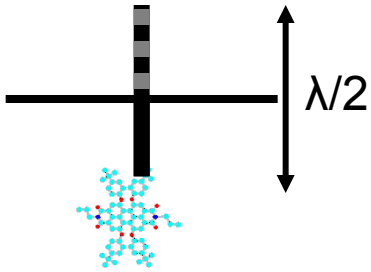


Antenna probe

A resonant nano-antenna light source



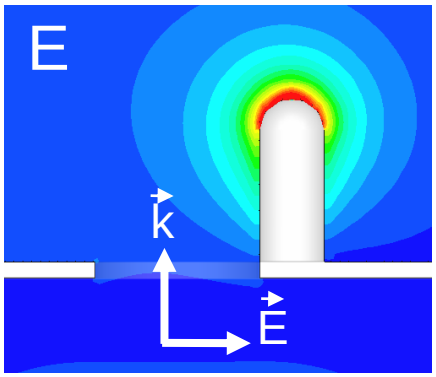


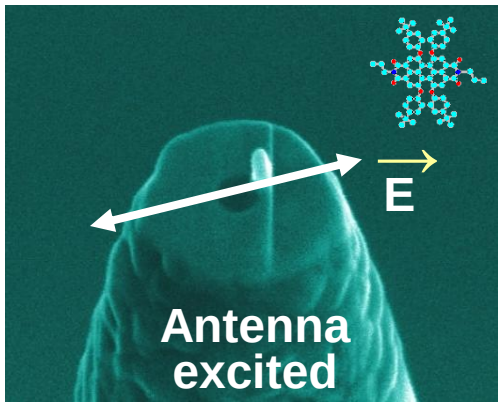


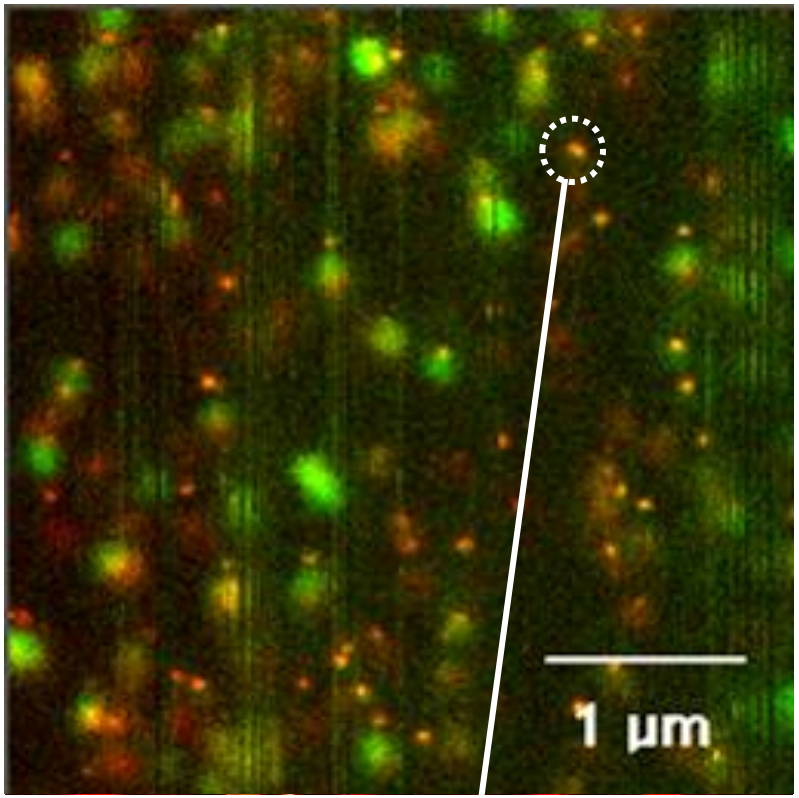
Dipole → Monopole antenna (λ/4)

Taminiau *et al*, *Nano Letters* **7**, 28 (2007); Frey *et al*, *Phys. Rev. Lett.* **93**, 200801 (2004)

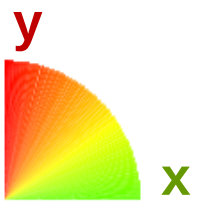
The antenna field is localized within 25 nm

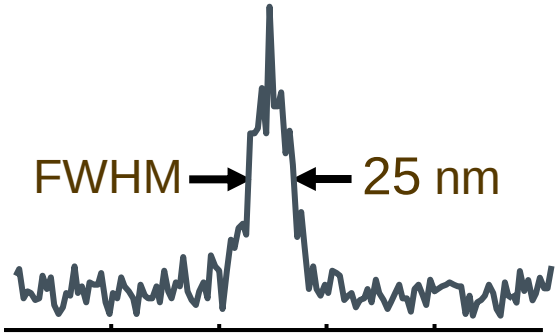


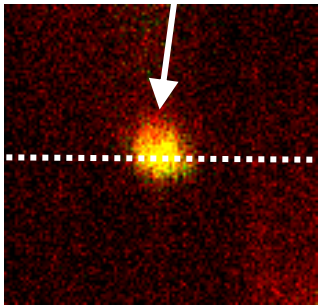




single fluorescent molecules



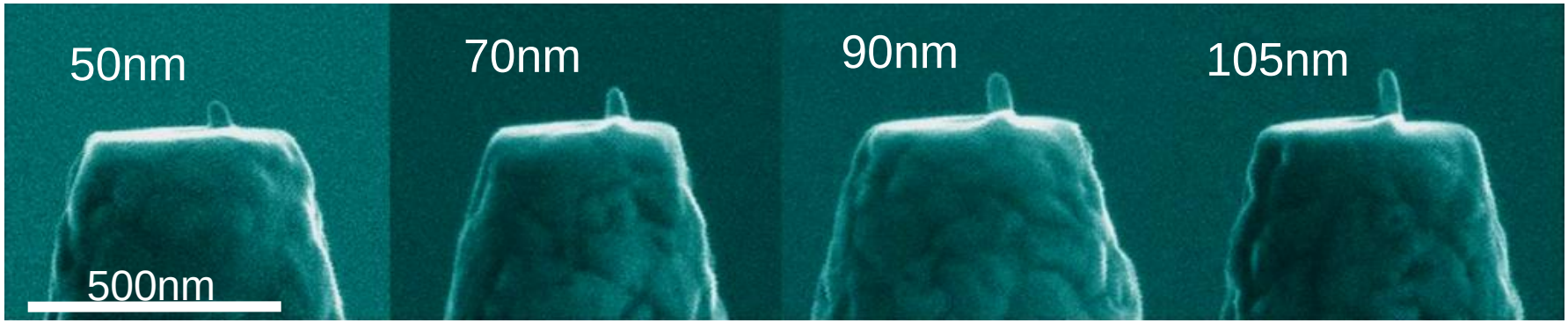




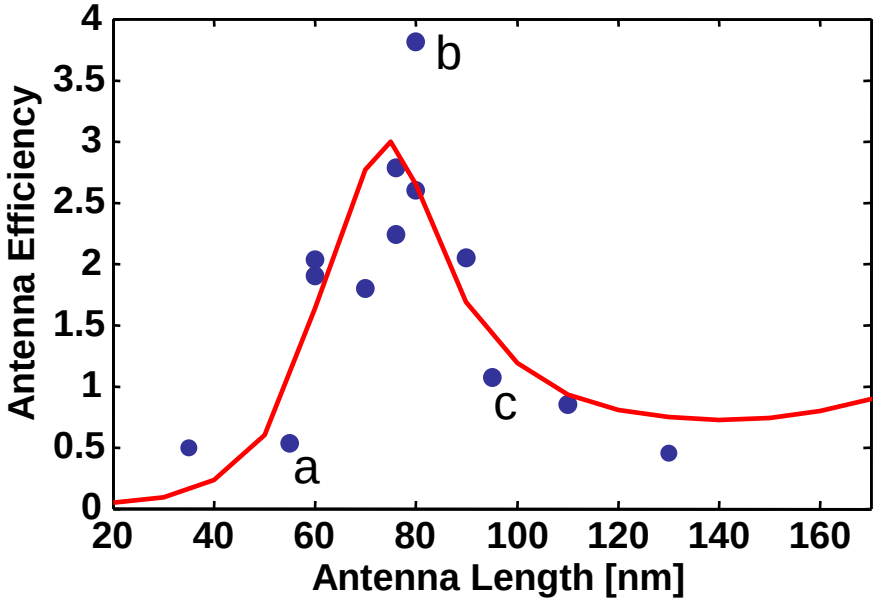
~10% of diffraction limit

Taminiau, Moerland, Segerink, Kuipers, van Hulst, *Nano Letters* **7**, 28 (2007)

Tweaking the antenna resonance



Fabricated antenna lengths 30 to 170 nm, radius ~20 nm



Antenna "Efficiency":
Antenna signal / Aperture signal

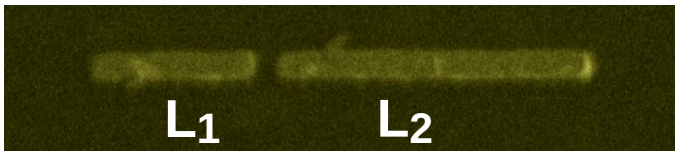
Monopole resonance for ~ 80 nm length Al (λ=514 nm)

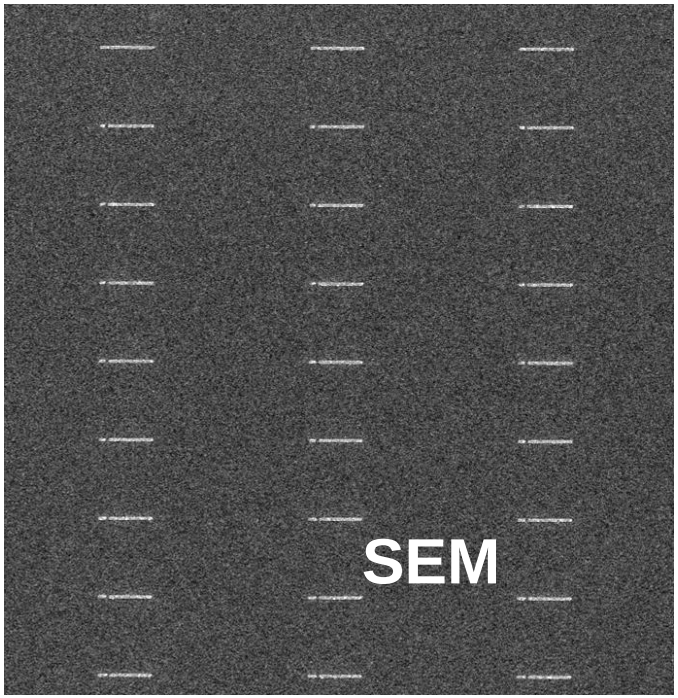
Limited quality factor ~4

Sharper antennas ??

Taminiau *et al, IEEE Trans. Antennas & Propagation* **55**, 3010 (2007)

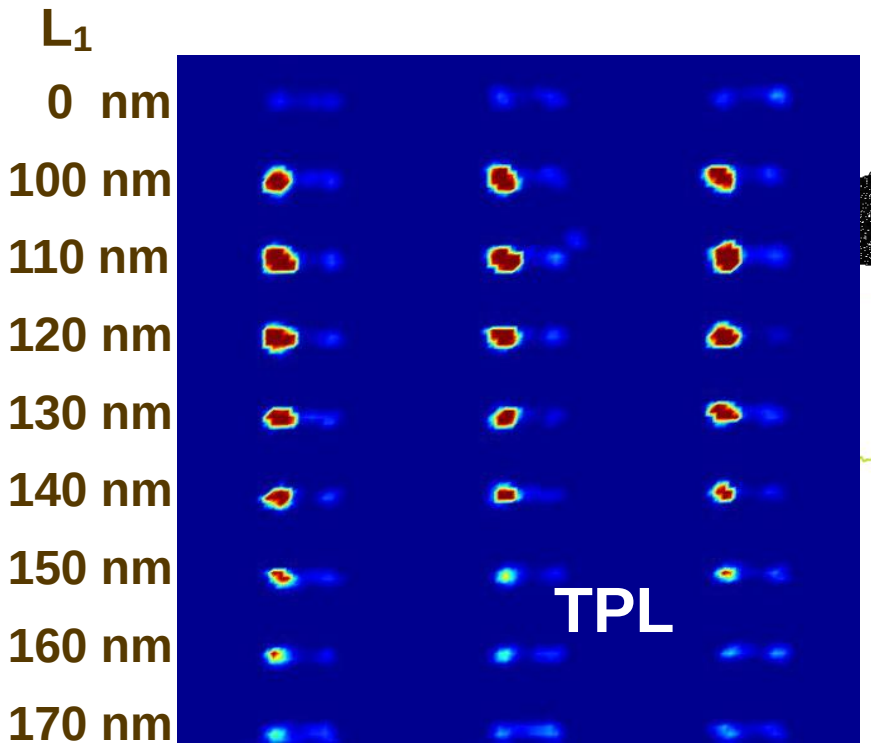
λ/2 dipole resonance and antenna length

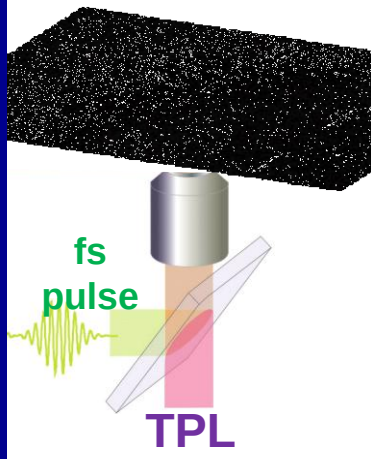




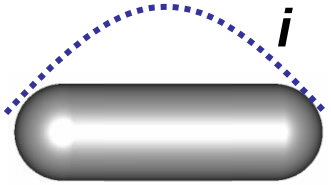
10 μm

Au on glass, 50 nm height, 50 nm width

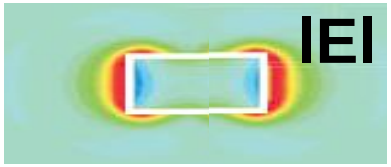




λ/2 dipole resonance for Au bar of L = 110 - 120 nm, at <λ> = 750 nm, i.e. λ_{eff} ~ 225 nm

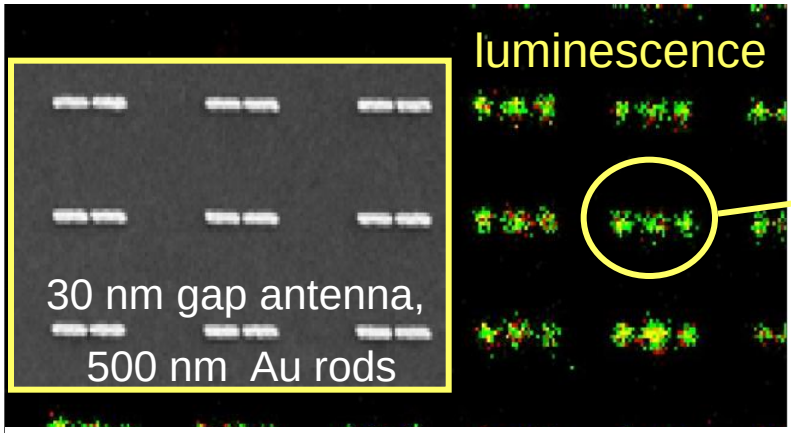


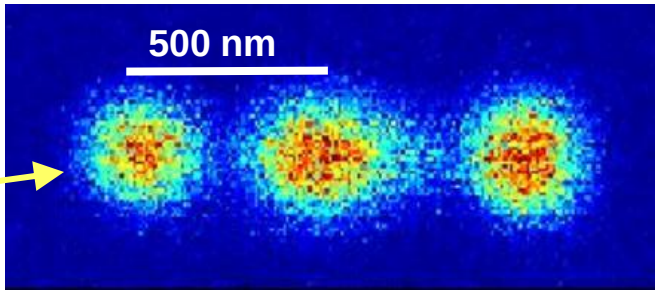
j = 1

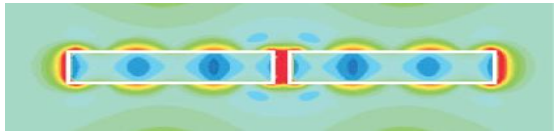


Data: Daan Brinks, Marta Castro-Lopez

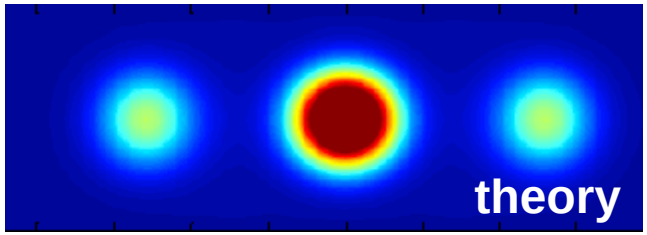
Multipole and gap resonances of symmetric antenna



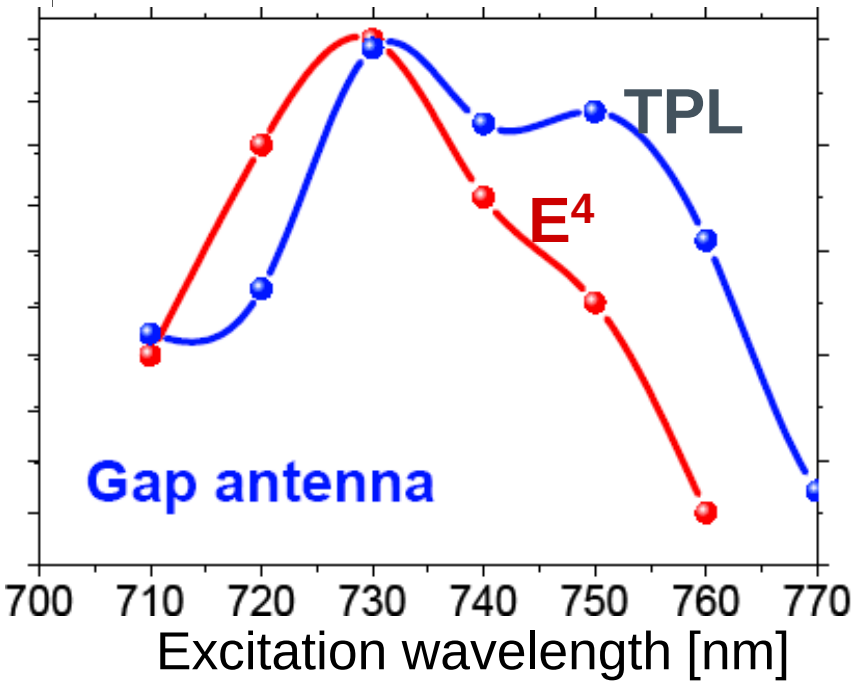


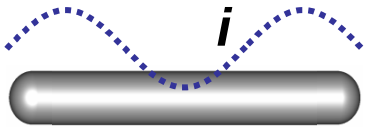


3λ/2 mode,
λ_{eff} ~ 200 nm



E^4
200 nm
convolution



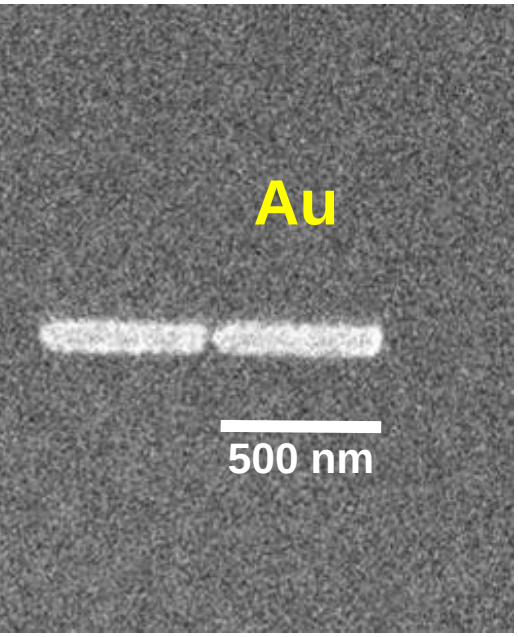


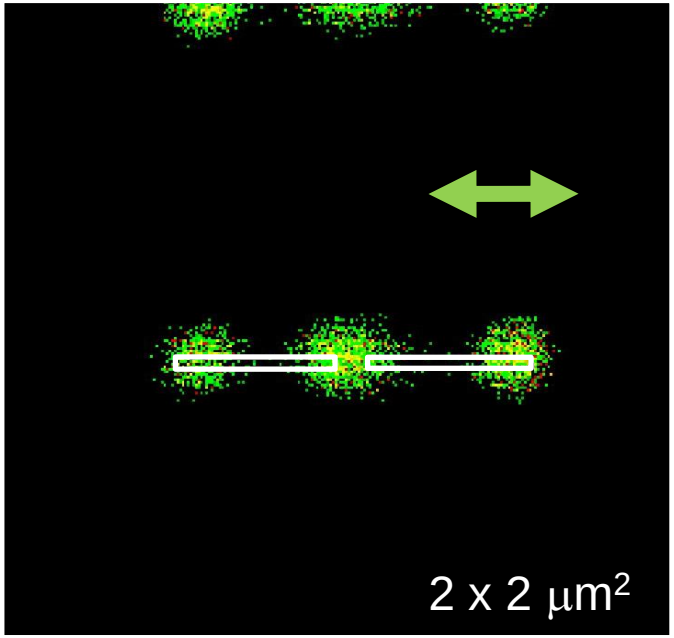
j = 3

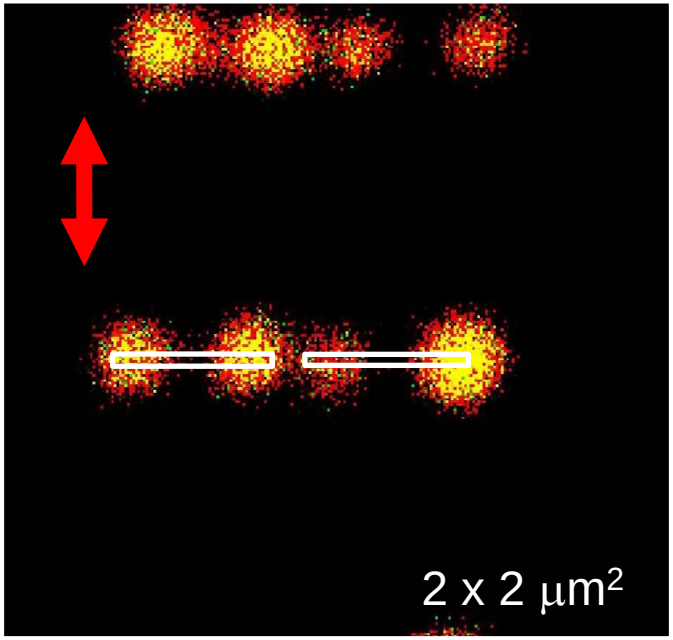
3/2 λ resonance for Au bar of L = 500 nm, at λ = 730 nm

Ghenuche, Cherukulappurath, Taminiau, van Hulst, Quidant, *PRL* **101,** 116805 (2008)

The effect of polarization

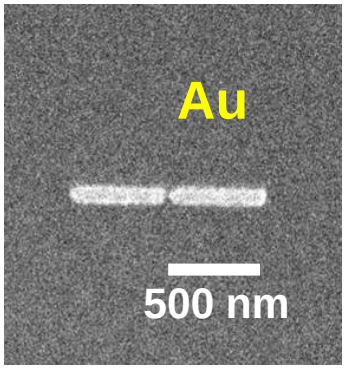


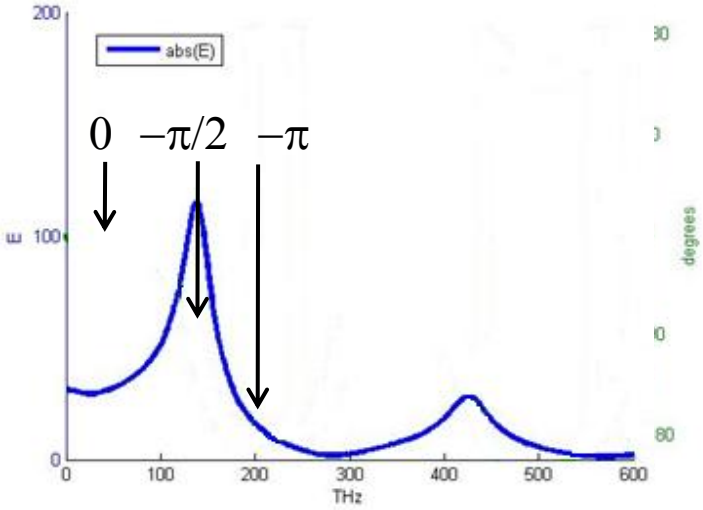




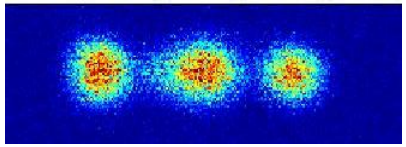
Data: Daan Brinks

The phase of the antenna resonance





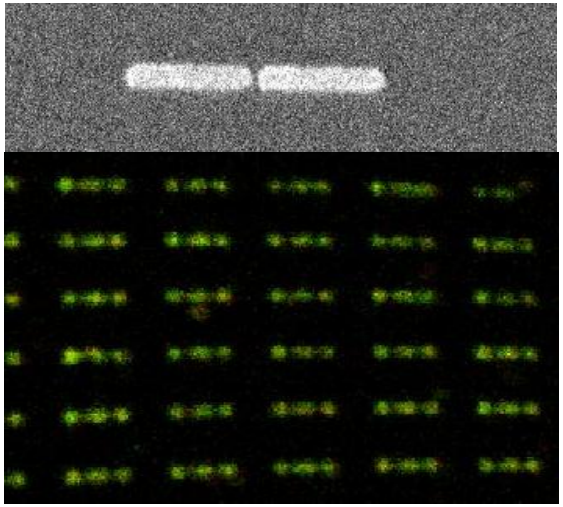
Phase?

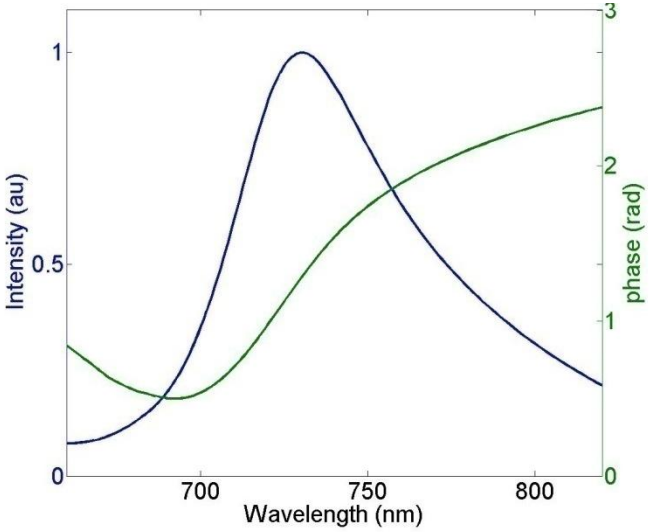


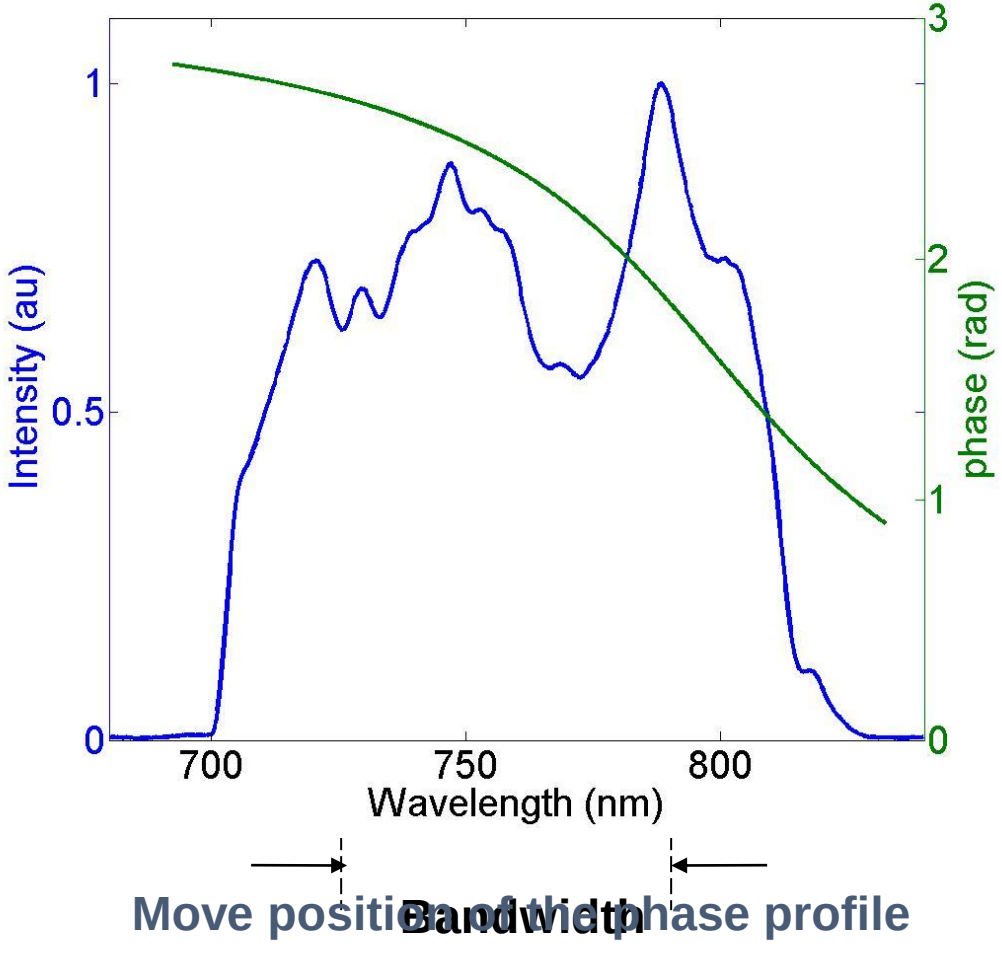
Phase controlled driving of nanoantenna?

Spatial response?

Broad band excitation







Move position of the phase profile

Calculation Tim Taminiau, Finite Integration (Microwave Studio)

- Pulse phase compensates antenna dispersion
- Shifting phase profile maps antenna resonance
- Phase controlled switching of antenna hotspots

Outlook

- Antenna coupled to single quantum system
- Controlled local excitation of molecules
- Control of single photon emission (direction, decay time)

Players at ICFO

LMU
CeNS


Fernando Stefani


Daan Brinks


Tim Taminiau


Lars Neumann


Alberto Gonzalez-Curto


Martin Kuttge


Dominique Heinis


Florian Kulzer


Richard Hildner


Marta Castro-Lopez


Salvatore Minissale


Riccardo Sapienza

NanoLight.es

Bio-Light-Touch

Körber-STIFTUNG
Forum für Impulse

photonics 4 life

SEVENTH FRAMEWORK PROGRAMME
Laserlab Europe

MICINN-Consolider-Ingenio

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MINISTERIO DE CIENCIA E INNOVACIÓN
Plan Nacional de I+D+I
2008 - 2011

Plasmo-nano-devices

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Muchas gracias
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