Administrative details

- Today two paper presentations

On the menu today

Recap:

Decay rate engineering with optical antennas

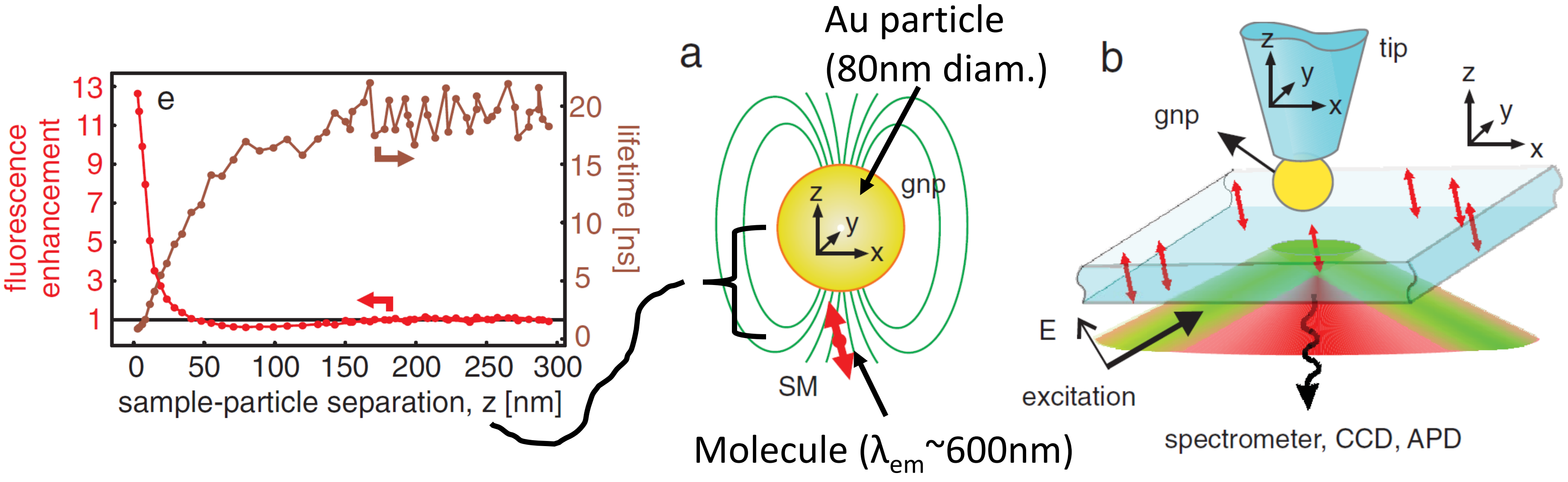
- The local density of optical states (LDOS)
- Optical antennas
  - Simple picture: dipole moment booster
  - Dipolar scattering theory and radiation damping
  - ➡ More detailed picture: LDOS of a dipolar scatterer

Coupled dipole model

Quantum efficiency

Optical antennas for LDOS engineering

Kühn et al., PRL 97, 017402 (2006)



Au particle (80nm diam.)

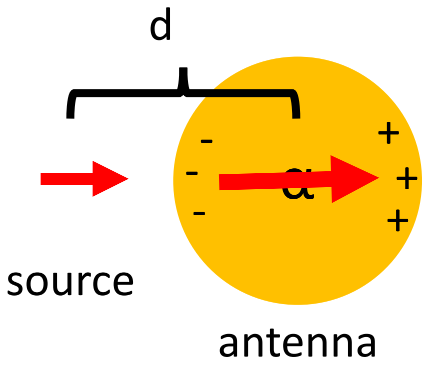
Molecule (λ_{em}~600nm)

- Metallic nanoparticles can act as “antennas” and boost decay rate of quantum emitters in their close proximity
- Effect confined to length scale of order λ/10

Optical antennas as dipole moment boosters

$$\boldsymbol{p}_{\text{ind}} = \alpha \boldsymbol{E}_s(\boldsymbol{r}_{\text{ant}})$$

$$\boldsymbol{E}_s \propto 1/d^3$$

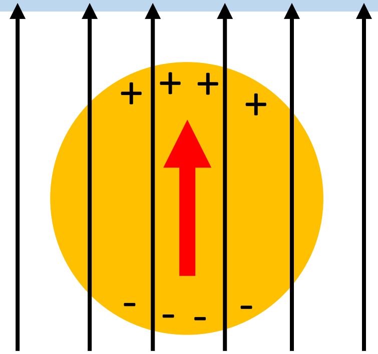


$$\boxed{P \propto |\boldsymbol{p}_{\text{ind}}|^2 \propto \frac{|\alpha|^2}{d^6}}$$

Optical antenna is a dipole moment booster!

The electrodynamic polarizability

$$\boxed{\boldsymbol{\alpha}_{\mathrm{eff}}^{-1} = \boldsymbol{\alpha}_0^{-1} - \mathrm{i}\,\mathrm{Im}\,\underline{\overleftrightarrow{\boldsymbol{G}}}(\boldsymbol{r}_0, \boldsymbol{r}_0)}$$



- This is a recipe to amend any electrostatic polarizability α_0 with a radiation damping term to ensure energy conservation
- Electrodynamic polarizability depends on position within photonic system
- Radiation correction is small for weak scatterers (small α_0)
- Radiation correction is significant for strong scatterers (large α_0)

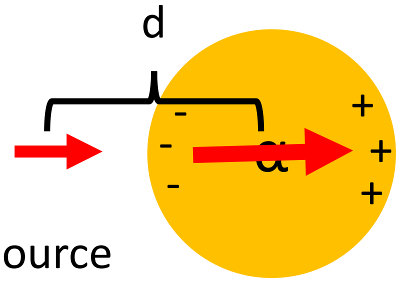
Radiation correction as a scattering series

Optical antennas – a cleaner derivation

Calculate rate enhancement via power enhancement

$$\boxed{\langle P\rangle = \frac{\omega}{2}\mathrm{Im}\left[\boldsymbol{p}^* \cdot \boldsymbol{E}(\boldsymbol{r}_0)\right]}$$

$$\boxed{\underline{\overleftrightarrow{\boldsymbol{G}}} = \omega^2\mu\mu_0\overleftrightarrow{\boldsymbol{G}}}$$



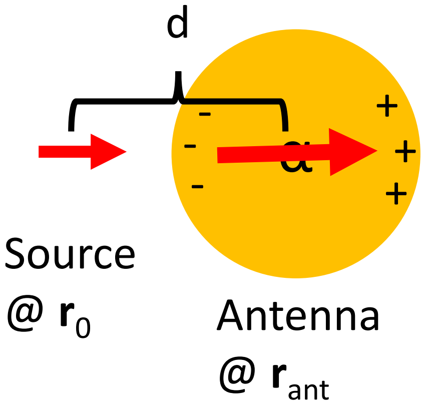
Source
@ $\mathbf{r}_0$

Antenna
@ $\mathbf{r}_{\mathrm{ant}}$

Optical antennas – a cleaner derivation

Calculated rate enhancement (equals power enhancement):

$$\boxed{\frac{P}{P_0} = 1 + \frac{A}{d^6}\,\frac{\operatorname{Im}\alpha}{\operatorname{Im}\underline{G}_0}}$$



- Rate enhancement goes with the imaginary part of polarizability
- Rate enhancement goes with inverse source-antenna distance d^{-6}

Wait a minute!
Didn't we say earlier that the enhancement for a strong antenna should go as $|\alpha|^2$?
True. But for a strong scatterer $\operatorname{Im}\alpha \propto |\alpha|^2$

Optical antennas …

- Modulate LDOS on sub-λ length scale
- Can boost decay rates of quantum emitters
- Can direct the emission of quantum emitters
- Rely on resonances in the polarizability of their constituents

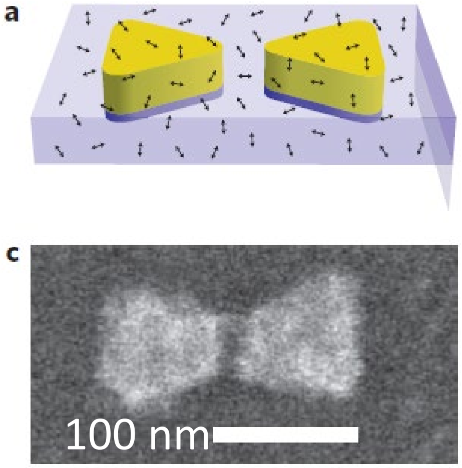
The polarizability of strong dipolar scatterers …

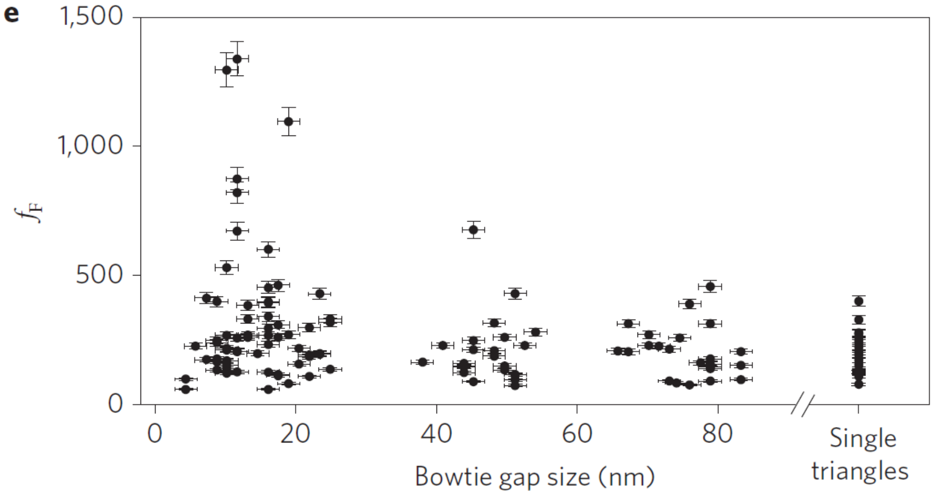
- has to take radiation effects into account
- depends on position within photonic system

The coupled-dipole model

The quantum efficiency and source brightness

Kinkhabwala et al., DOI: 10.1038/NPHOTON.2009.187





been enhanced by a factor of 1,340. **e**, Scatter plot of 129 SM fluorescence brightness enhancements, f_F, as a function of bowtie gap size. See Methods

Kühn et al., PRL 97, 017402 (2006)