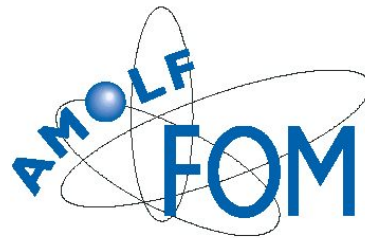


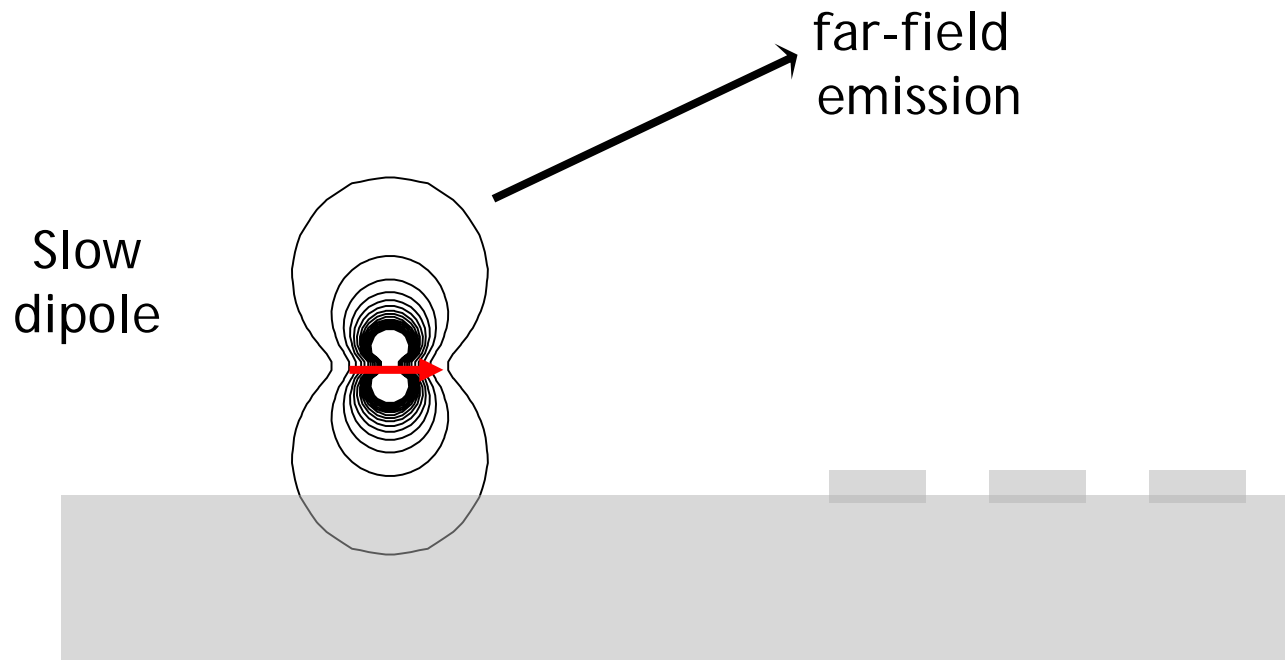
Turning slow emitters into fast emitters using surface plasmons

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FOM Institute AMOLF
Amsterdam, The Netherlands



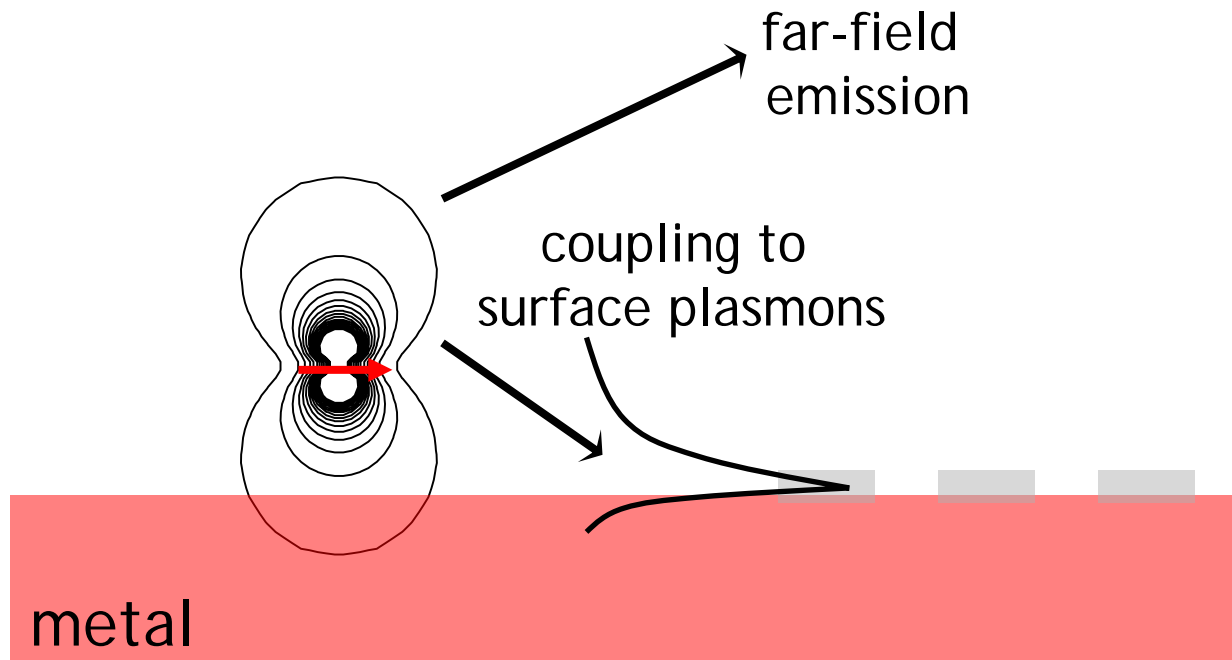
A slow emitter (Er: $\tau = 1-10$ ms, Si QD: $\tau = 10-100$ μ s):

- has low emission power
- can not be modulated fast
- is sensitive to non-radiative processes

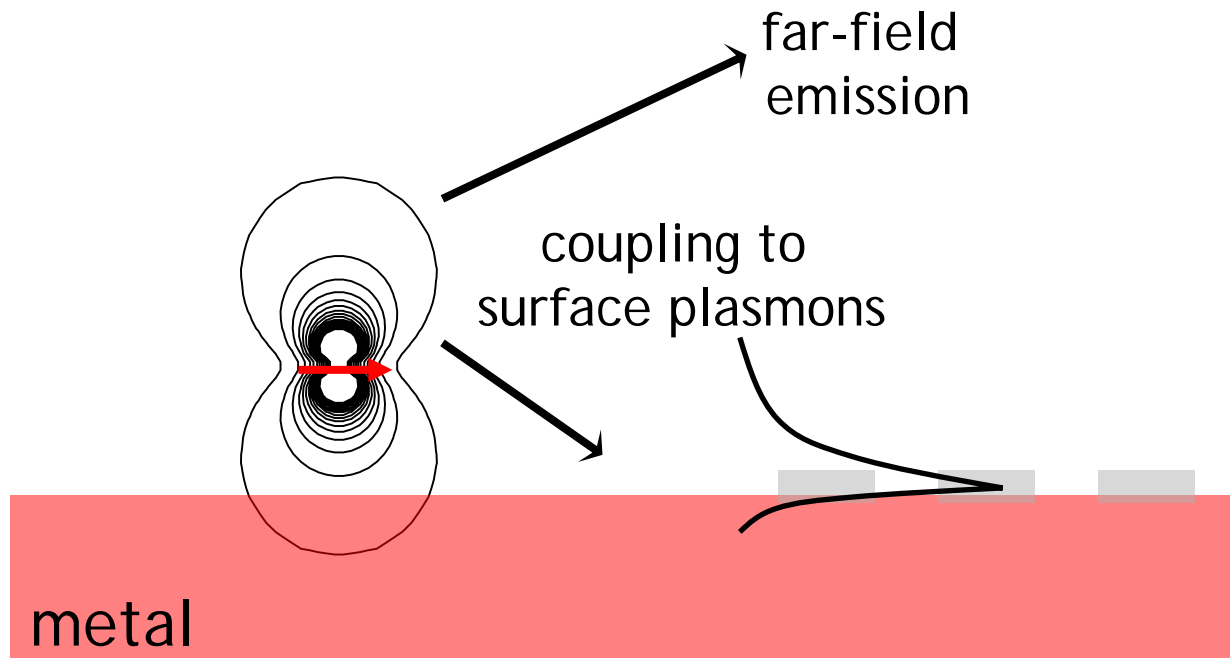


Dipole near a metal-dielectric interface:

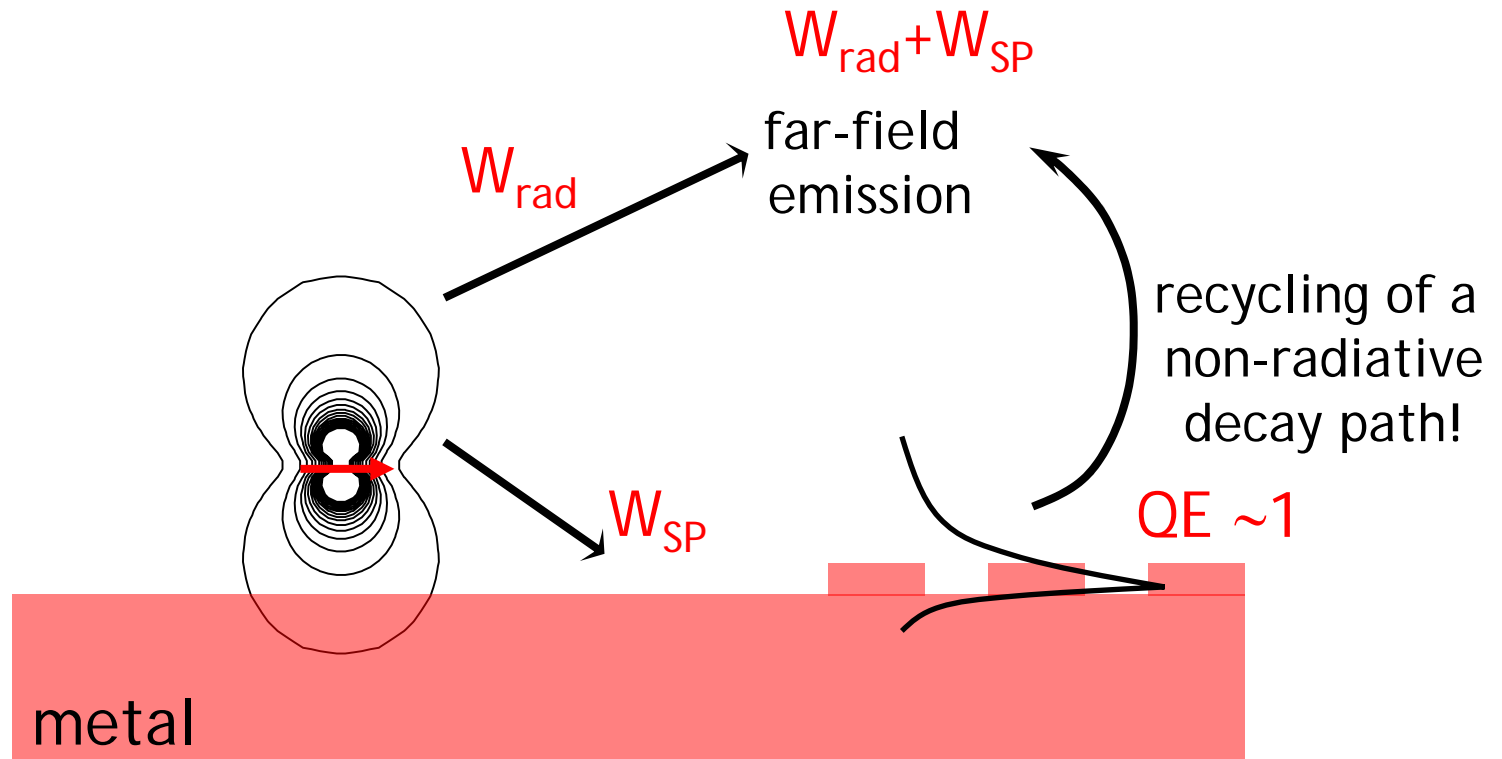
- generates a surface plasmon
- thus **adding a quenching path**: lifetime decreases



Surface plasmon propagates along
metal-dielectric interface: $L_p = 10 \mu\text{m} - 10 \text{mm}$



Surface plasmon **radiates** out into the far field
using a grating to resolve the momentum mismatch

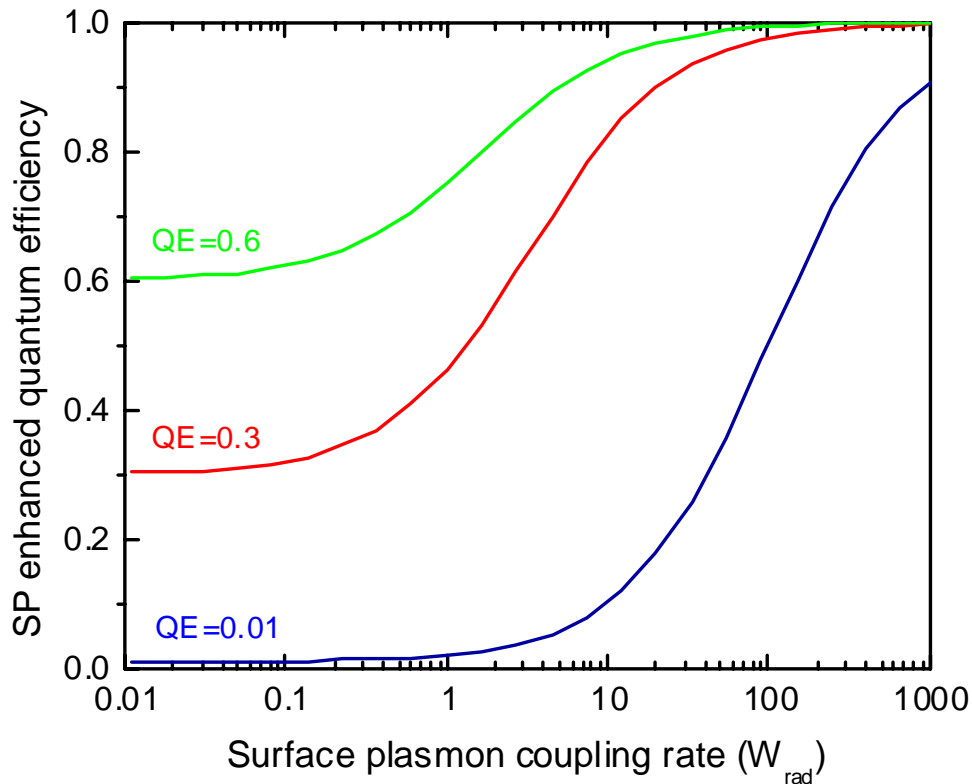


Turn the "non-radiative" plasmon into a far-field photon:
Slow emitter becomes a fast emitter: $W = W_{\text{rad}} + W_{\text{SP}}$

An inefficient emitter becomes an efficient emitter !

$$QE = \frac{W_{rad}}{W_{rad} + W_{nr}}$$

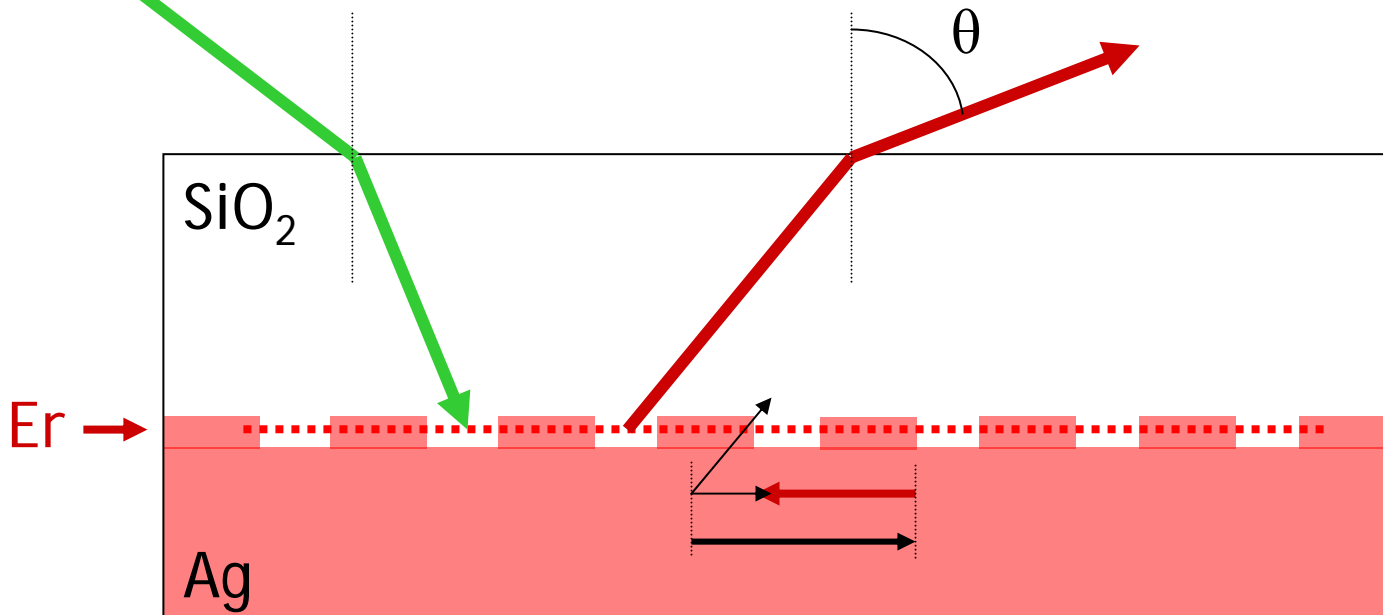
$$QE = \frac{W_{rad} + W_{SP}}{W_{rad} + W_{SP} + W_{nr}}$$



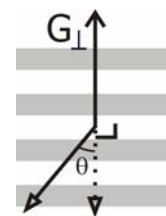
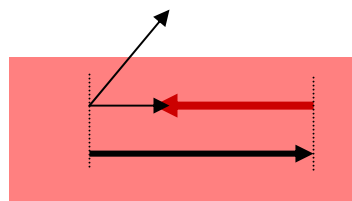
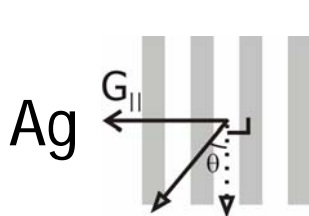
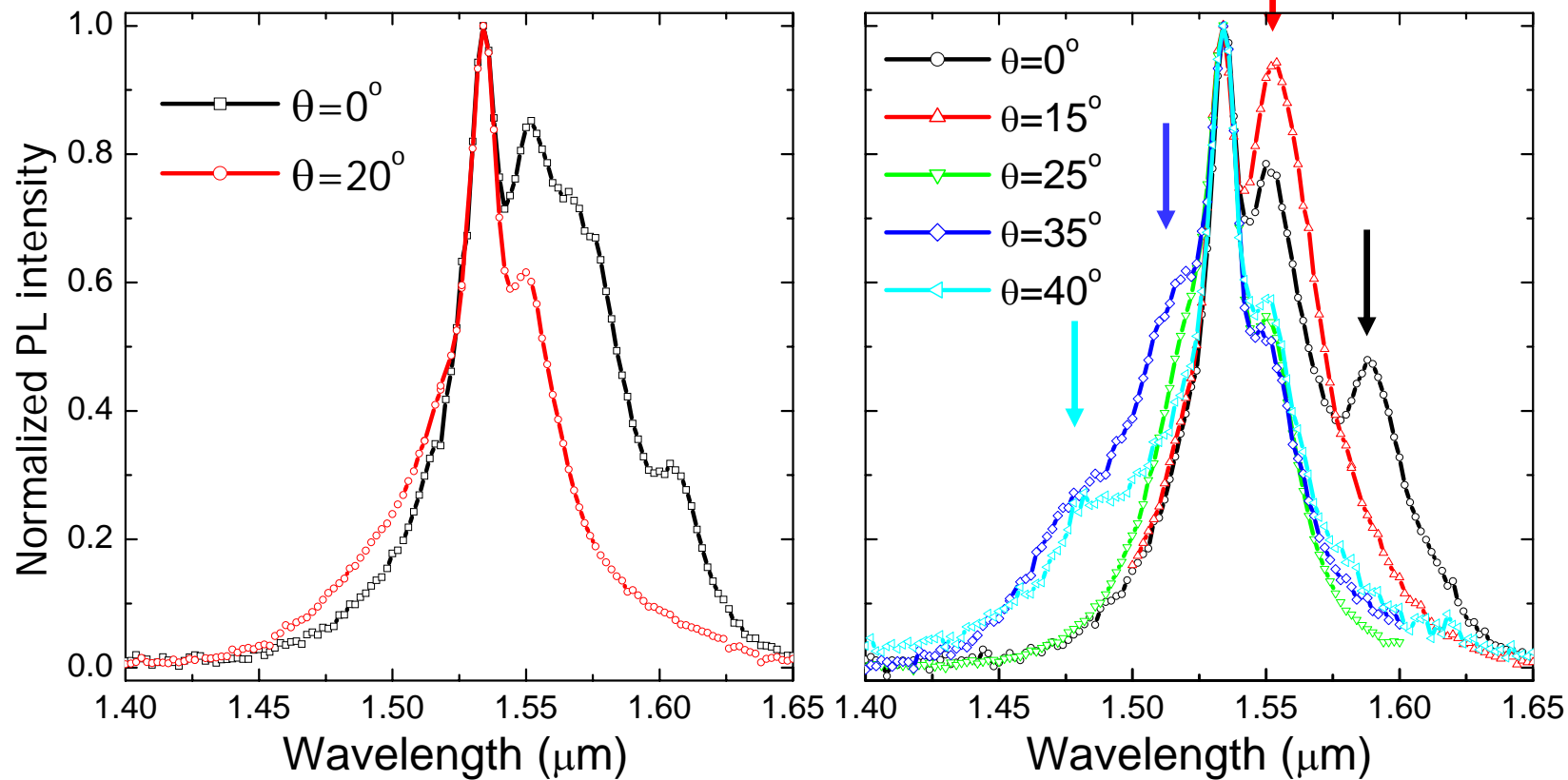
- Erbium ions implanted in silica glass substrate
- Grating etched in silica
- Ag film deposited

Herasil glass - 250 μm thick
350 keV Er, $1.2 \times 10^{15} \text{ cm}^{-2}$, 77 K
Thermal anneal 800 $^{\circ}\text{C}$, 1 hr
e-beam lithography, dry etching
grating: $p=1070 \pm 1 \text{ nm}$, $d=230 \text{ nm}$
Ag sputter evaporation ($t=300 \text{ nm}$)

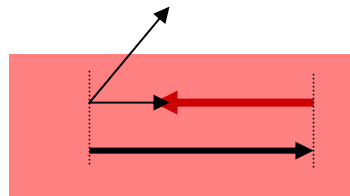
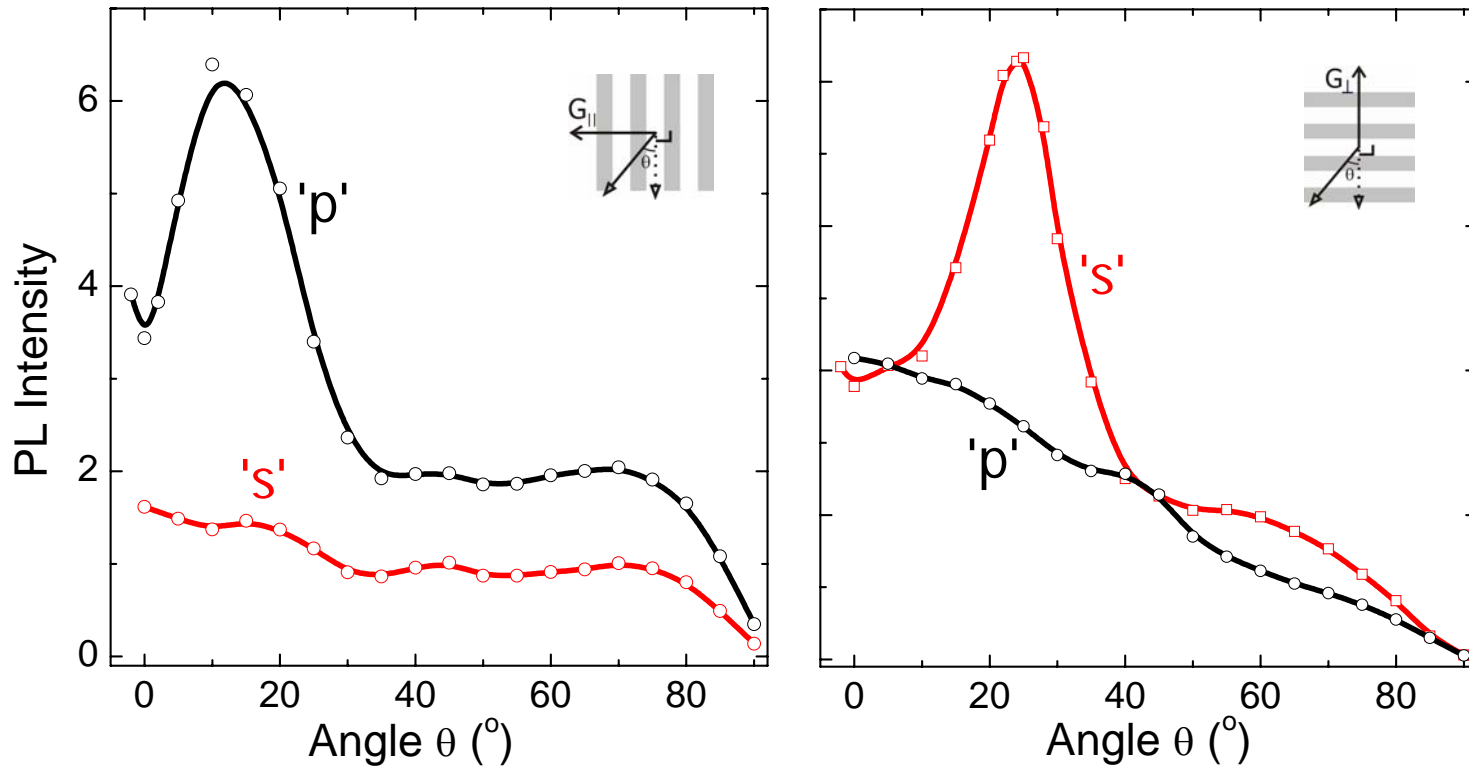
$\lambda_{\text{pump}}=488 \text{ nm}$



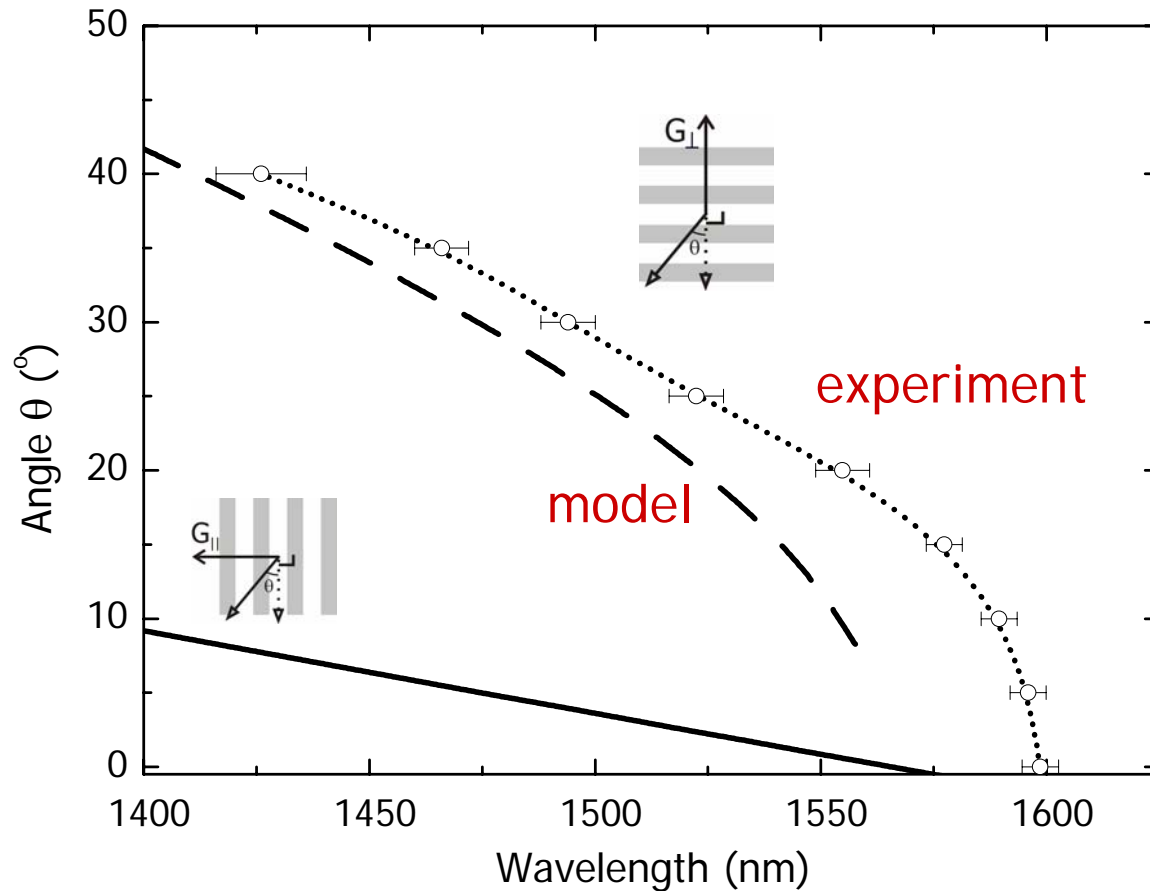
PL spectra for different angles



PL intensity as a function of angle ($\lambda=1534$ nm)

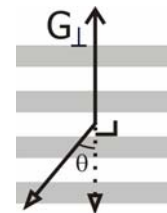
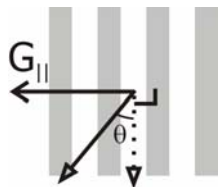
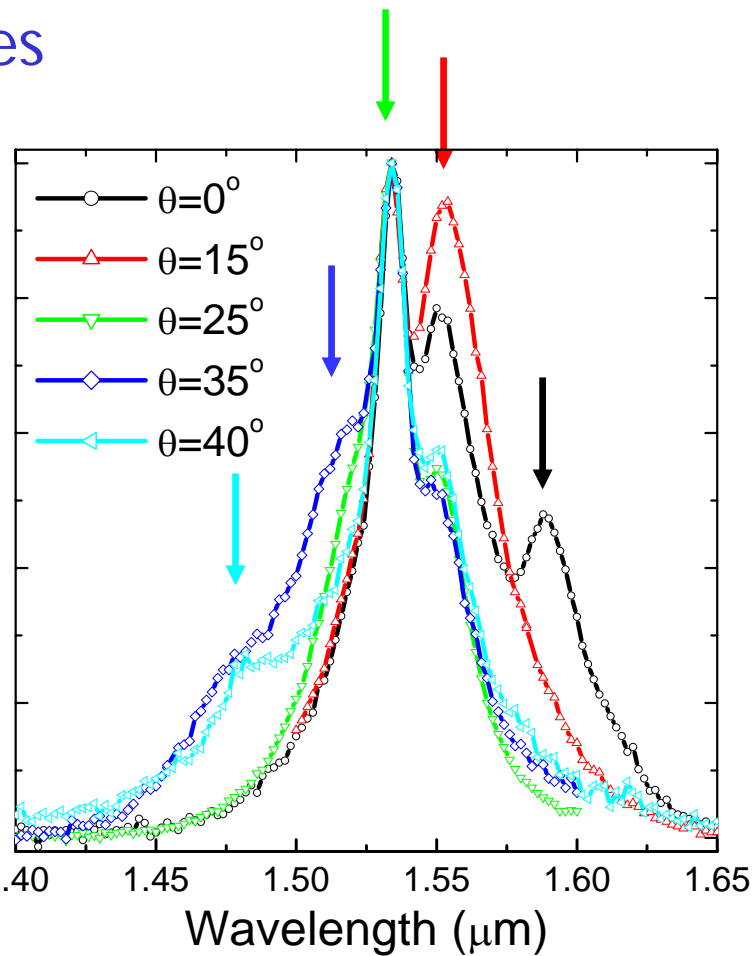
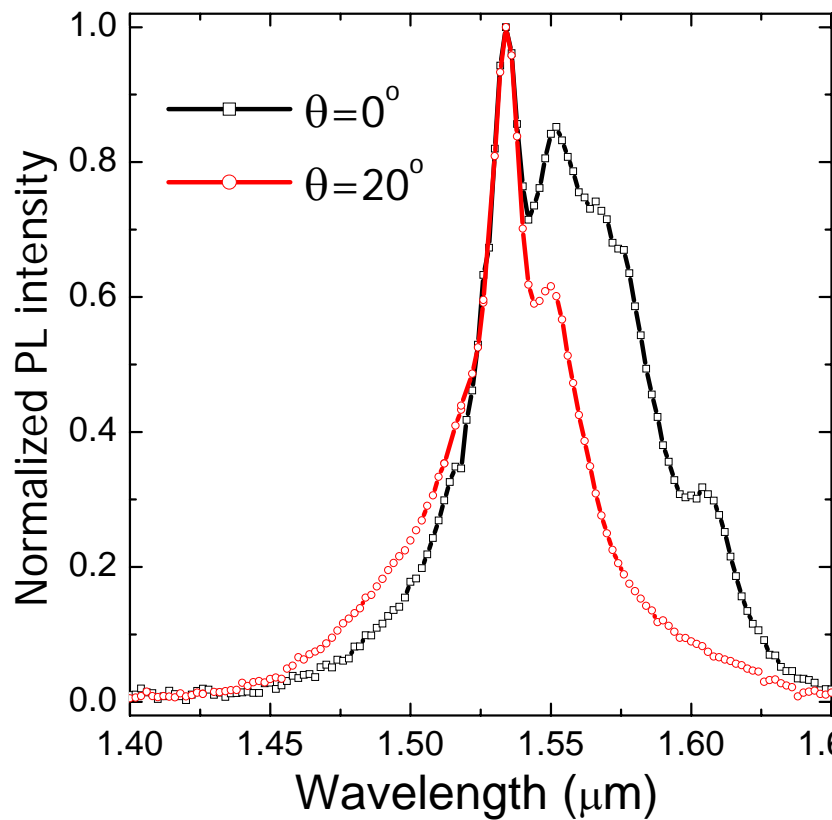


Observation angle of enhanced PL for each wavelength

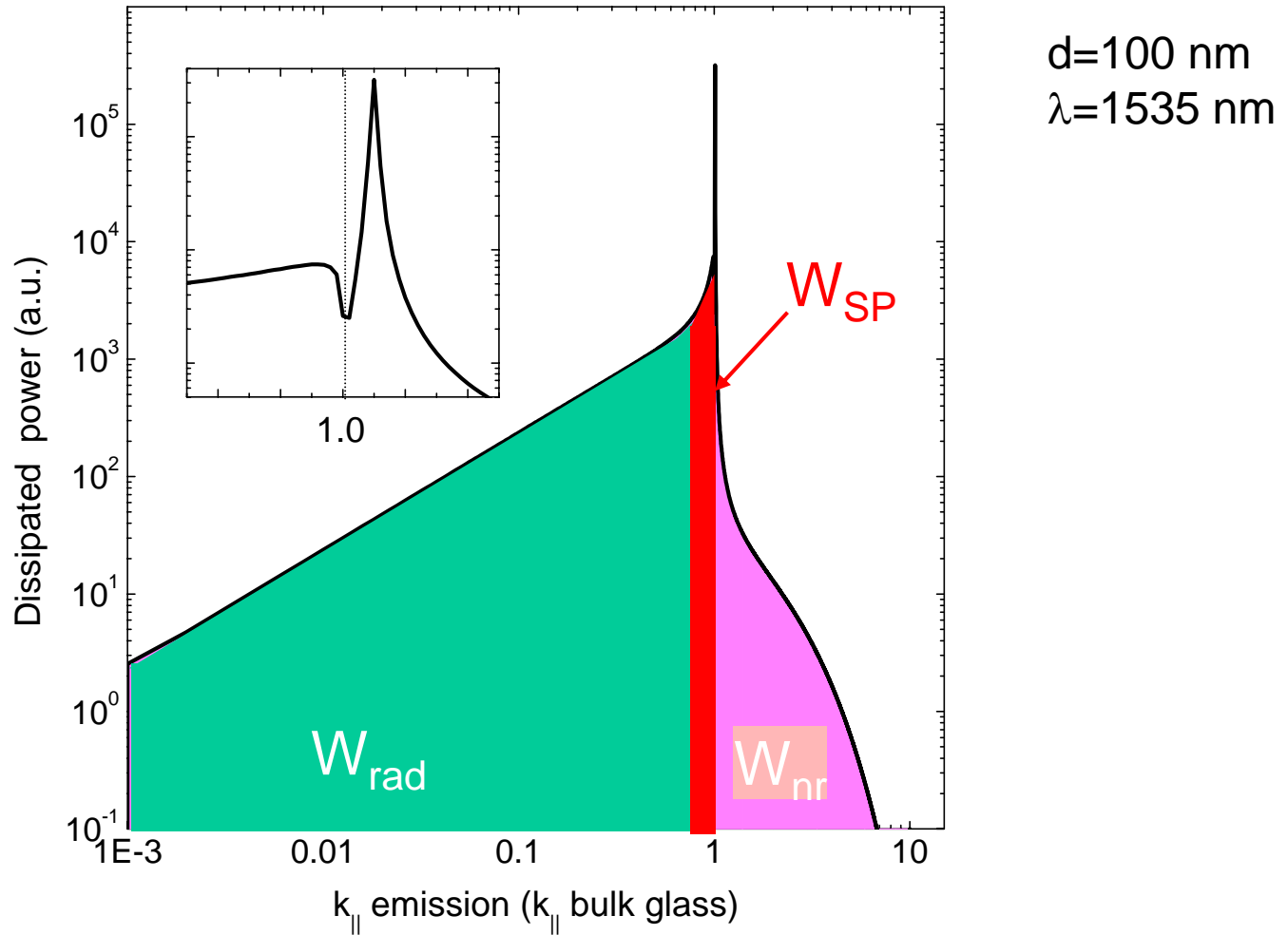


(Model for SP on planar interface, corrugation shifts model curve up)

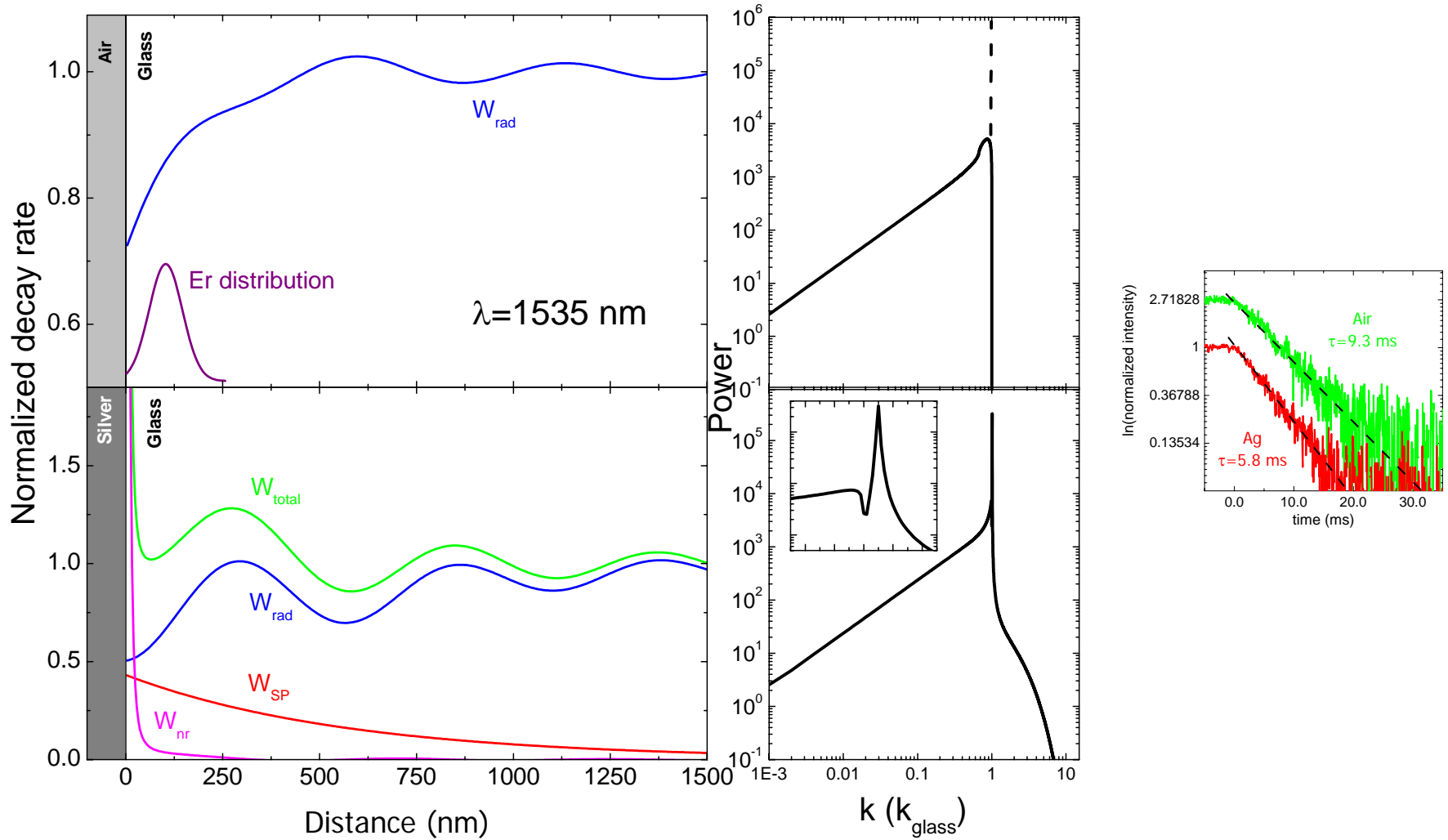
PL spectra for different angles



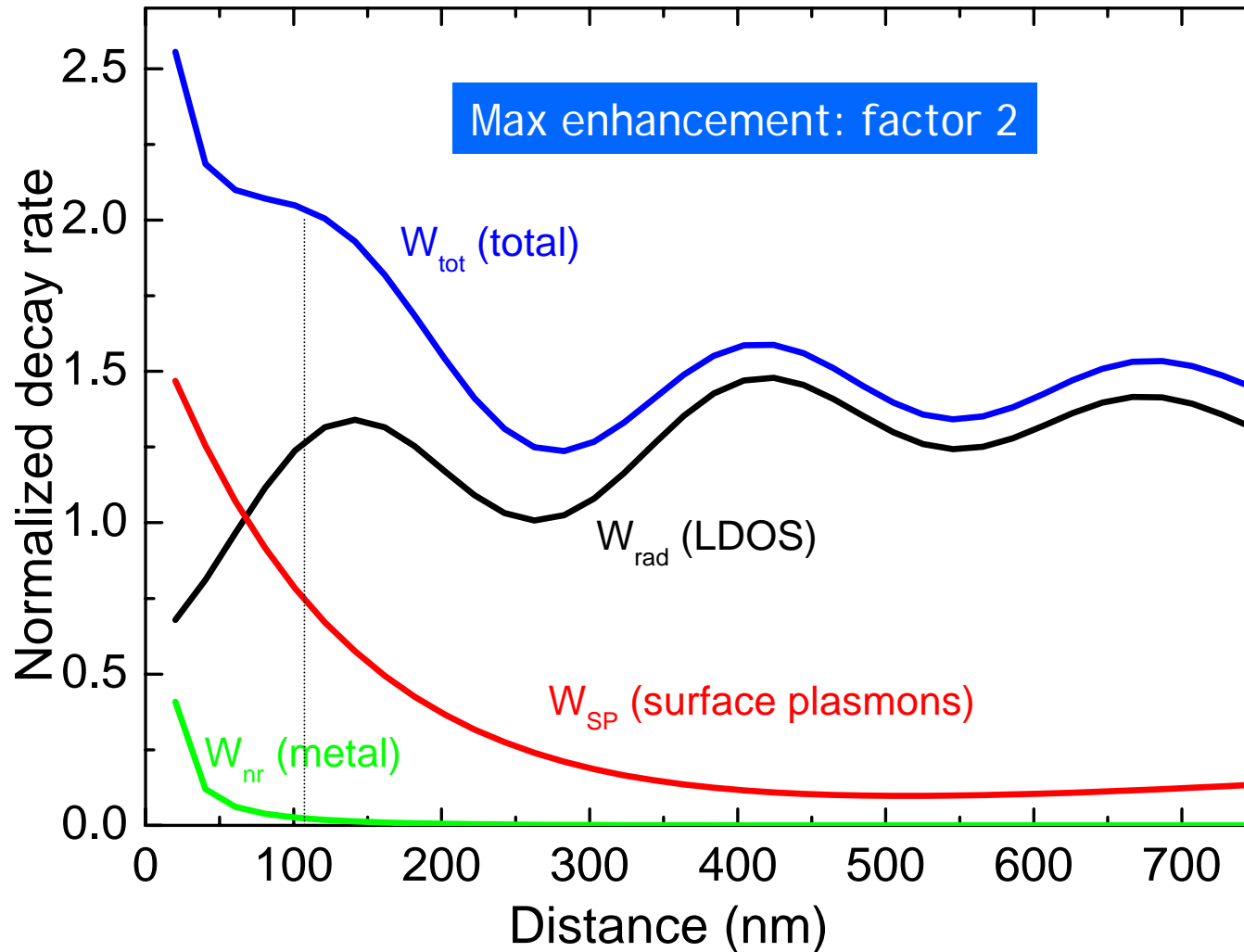
Semi-classical model: coupling dipole to metal: input $\epsilon(\omega)$



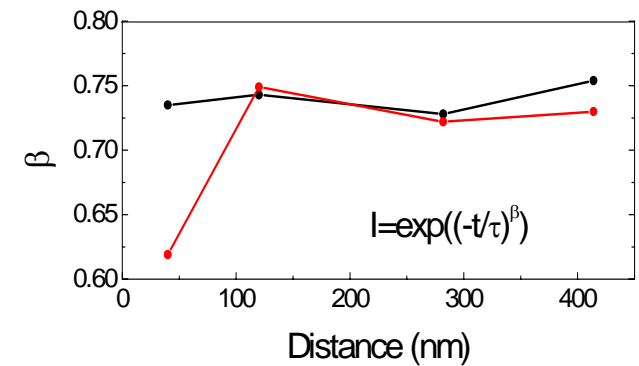
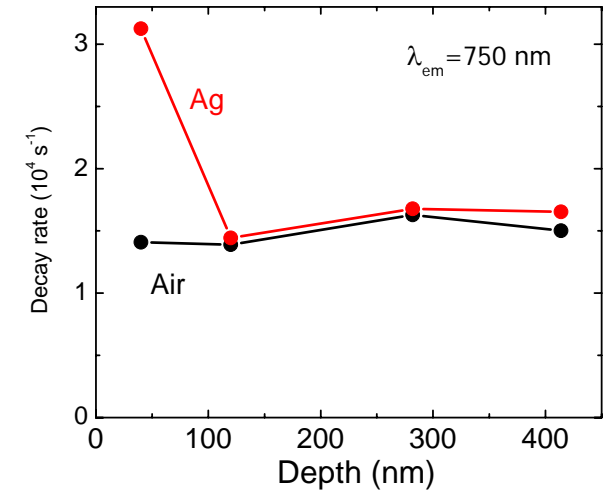
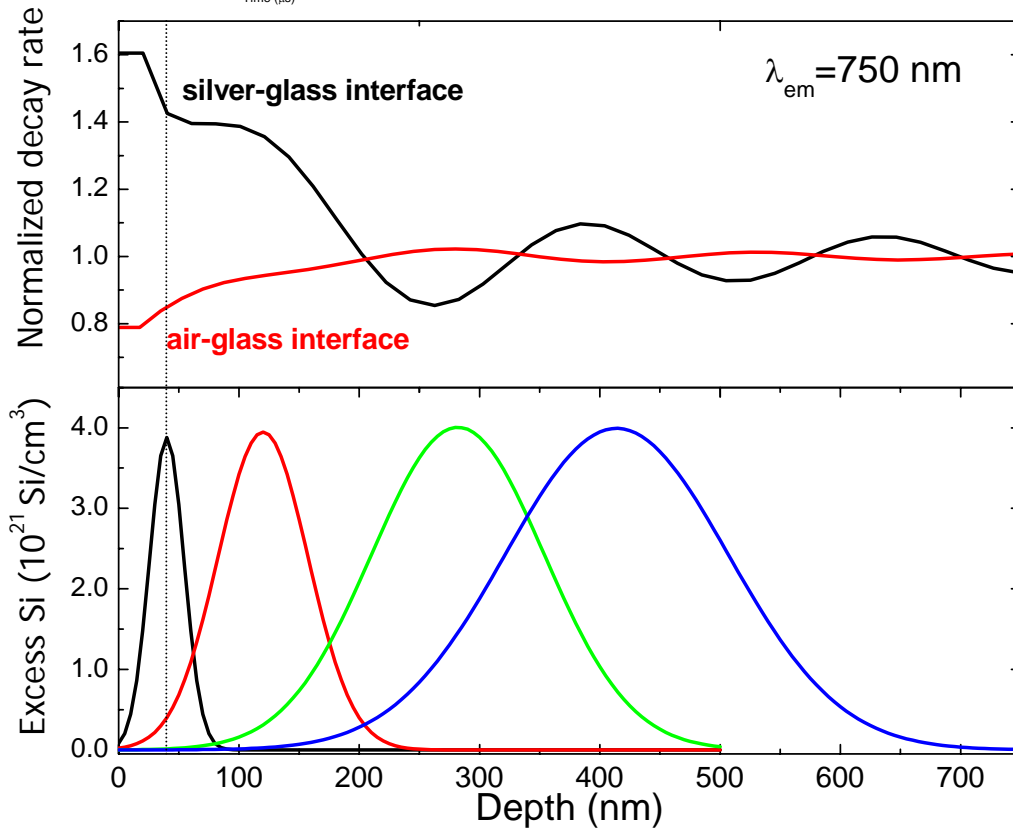
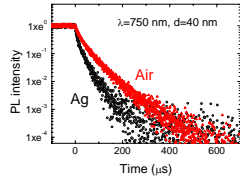
Decay rate as a function of distance to metal



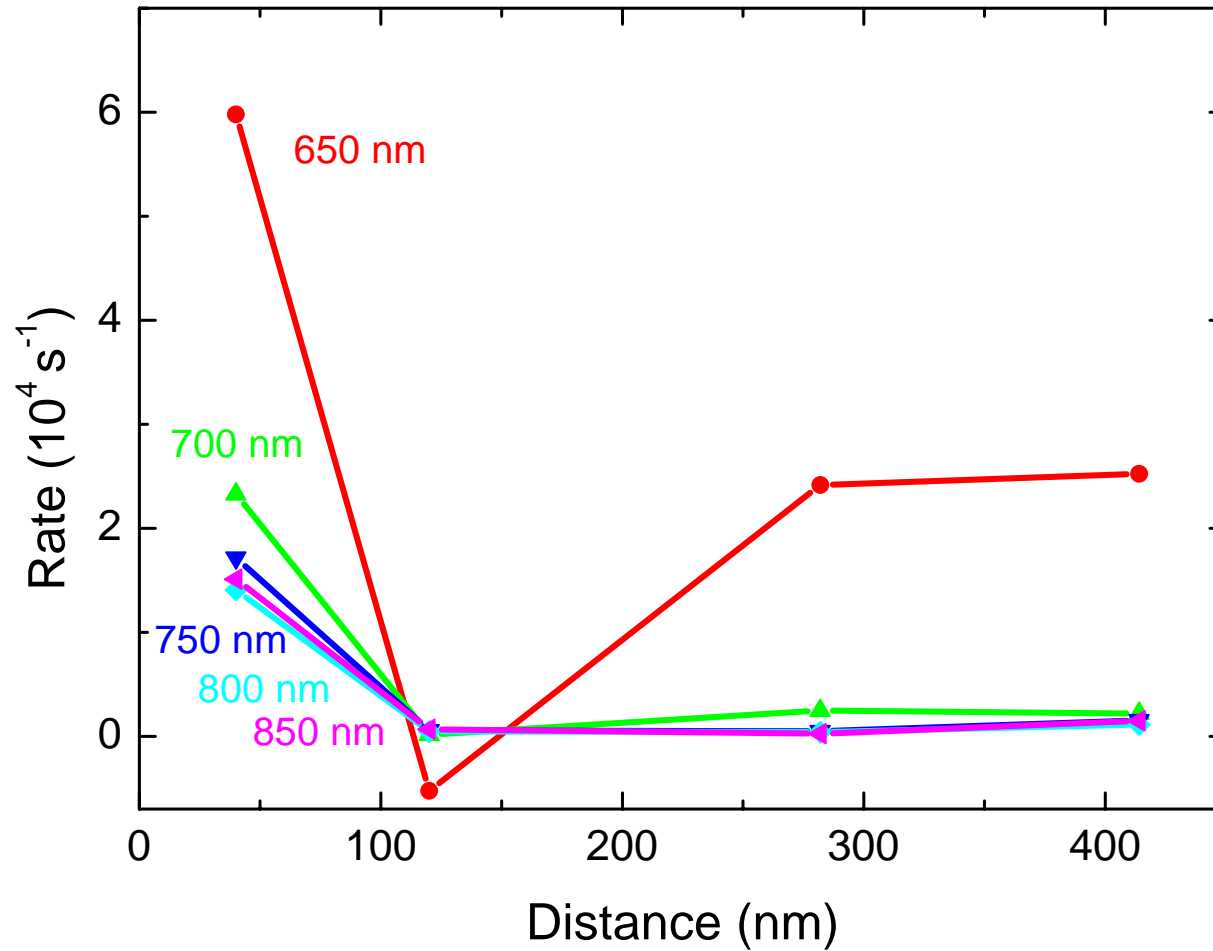
Calculated emission rate for Si nanocrystals at $\lambda=750$ nm



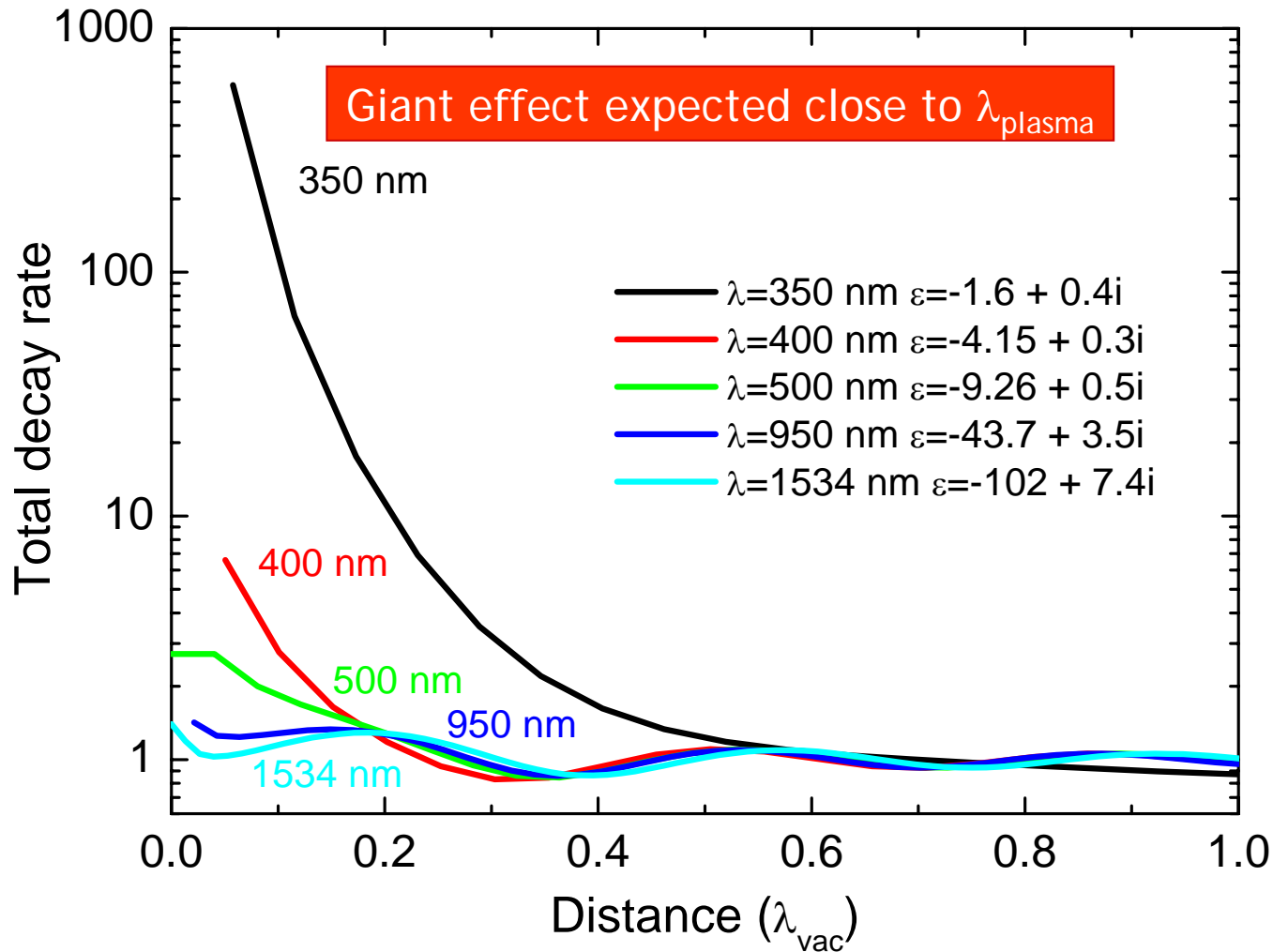
Si nanocrystals at different depths: theory & experiment



PL rate enhancement vs wavelength / depth



Plasmon coupling rate vs distance for different λ



$\lambda_{\text{plasma}}(\text{Ag})$
=320 nm

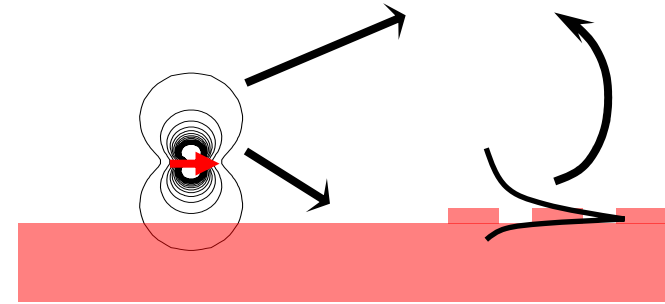
Solution:

- Shift emission λ
- or
- Change λ_{plasma}

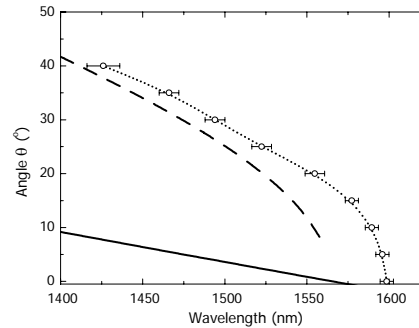
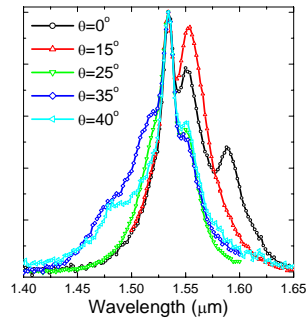
Conclusions:

Surface plasmons to:

- Turn slow emitter into fast emitter
(more power, faster modulation)
- Enhance Quantum Efficiency



Er in SiO₂



www.erbium.nl

Si nano-crystals

