Enhanced spontaneous emission in plasmonic nanostructures

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Introduction: Spontaneous emissions of emitters play an important role in determining the performance of luminescent dyes and optoelectronic devices. It can be modified via controlling the local electromagnetic environment[1-4]. Herein, we studied the spontaneous emission behaviors of emitters coupled with plasmonic nanostructures.

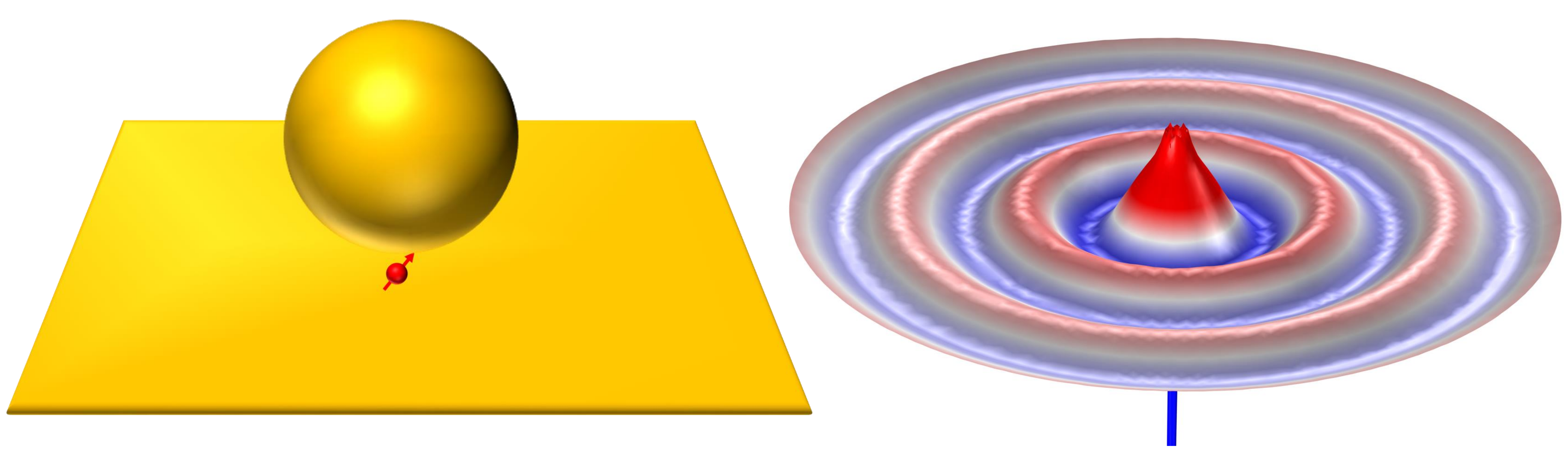

Fig 1. Schematic illustration of an emitter coupled with plasmonic nanostructures (left) and the charge density distribution induced by the radiating emitter (right).

Basic Theory:

The field induced by dipolar emitter:

$$\boldsymbol{E}(\boldsymbol{r}) = i\omega\mu\mu_0 \int_V \overleftrightarrow{\boldsymbol{G}}(\boldsymbol{r},\boldsymbol{r}`)\boldsymbol{j}(\boldsymbol{r}`)dV`$$

$$\boldsymbol{H}(\boldsymbol{r}) = \int_V [\nabla \times \overleftrightarrow{\boldsymbol{G}}(\boldsymbol{r},\boldsymbol{r}`)]\boldsymbol{j}(\boldsymbol{r}`)dV`$$

$\overleftrightarrow{\boldsymbol{G}}(\boldsymbol{r},\boldsymbol{r})$ is the dyadic Green's function of the system. Thus we can obtain G from the local field induced by oscillating dipole.

The local density of state can be written as:

$$\rho(\boldsymbol{r},\omega) = \frac{6\omega_0}{\pi c^2}\left[\boldsymbol{n_p} \cdot \mathbf{Im}\{\overleftrightarrow{\boldsymbol{G}}(\boldsymbol{r},\boldsymbol{r})\} \cdot \boldsymbol{n_p}\right]$$

And spontaneous decay rate:

$$\gamma_{sp} = \frac{\pi\omega_0}{3\hbar\varepsilon_0}|\boldsymbol{p}|^2\rho(\boldsymbol{r},\omega)$$

COMSOL Modeling:

An electric point dipole source in Wave Optics module of COMSOL Multiphysics® was applied to model the radiative behavior of emitters. The four-fold symmetry was used to reduce the necessary number of simulations. The system's Dyadic Green's function was founded by evaluating the field reacting on the point-dipole.

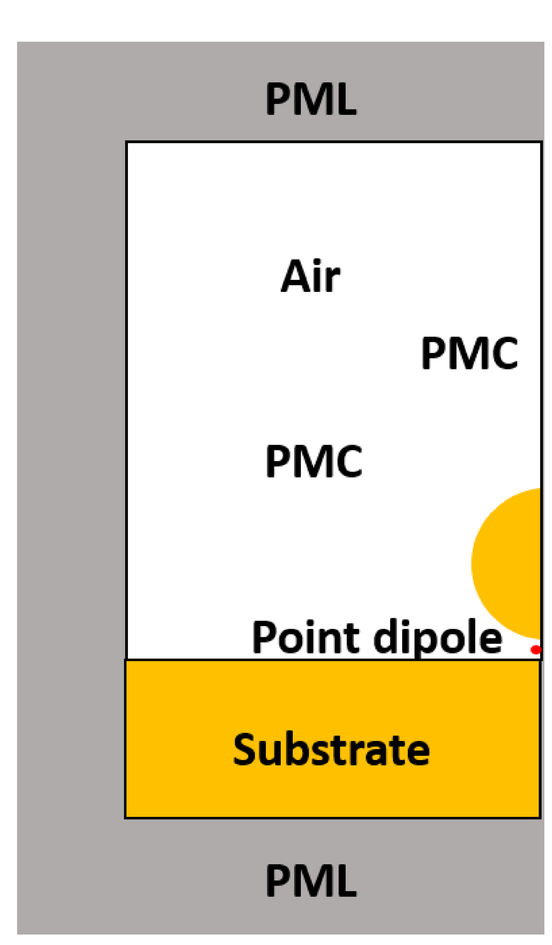

Fig 2. Schematic illustration

Result: 1) To verify our method, we first studied an emitter located above a metal sphere with varied transition energies. The simulated results from COMSOL show good agreements with rigorous analytical results from Mie theory, which confirms the validity of our simulation methods.

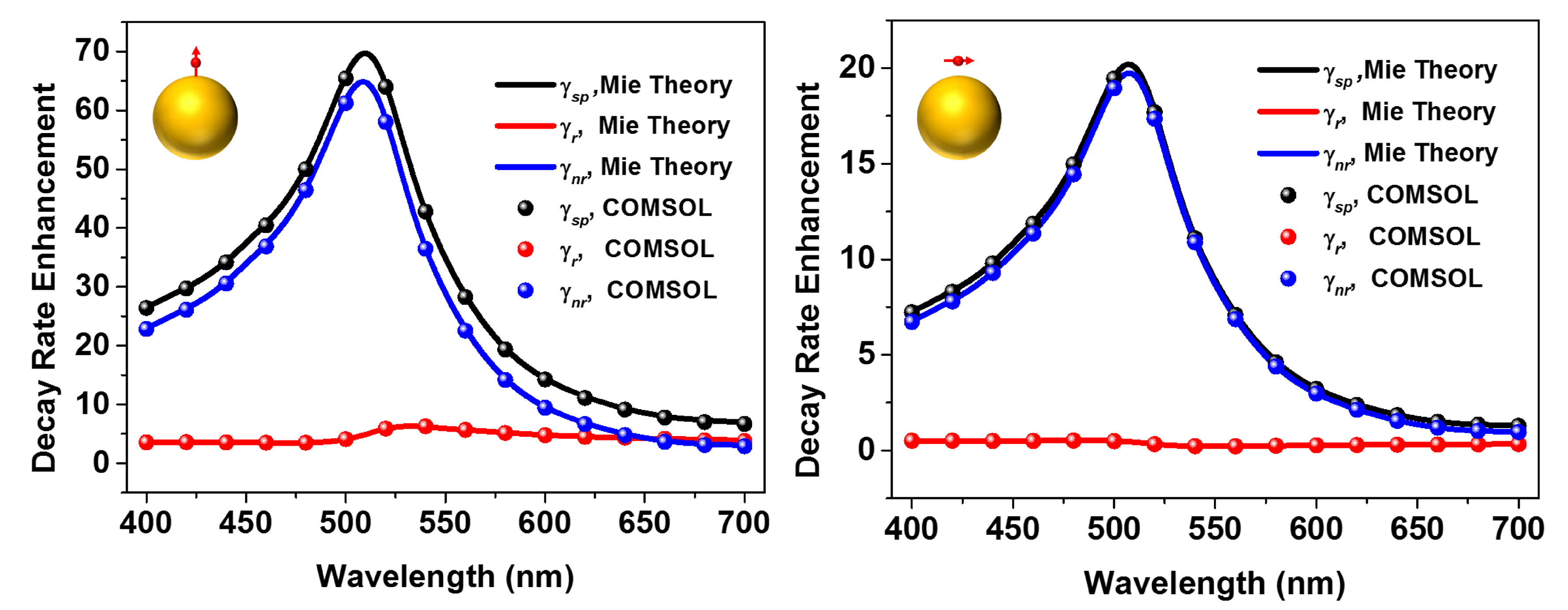

Fig 3. comparison between numerical results obtained from COMSOL and analytical results from Mie theory

2) The radiative behavior of an emitter coupled with Nps-film plasmonic structures with varied dipole orientation was studied. We found that the both γ_r and γ_{nr} decreased when the dipole orientation gradually laid on the surface. More interestingly, the quantum yield almost kept a constant in a wide range of dipole orientation.

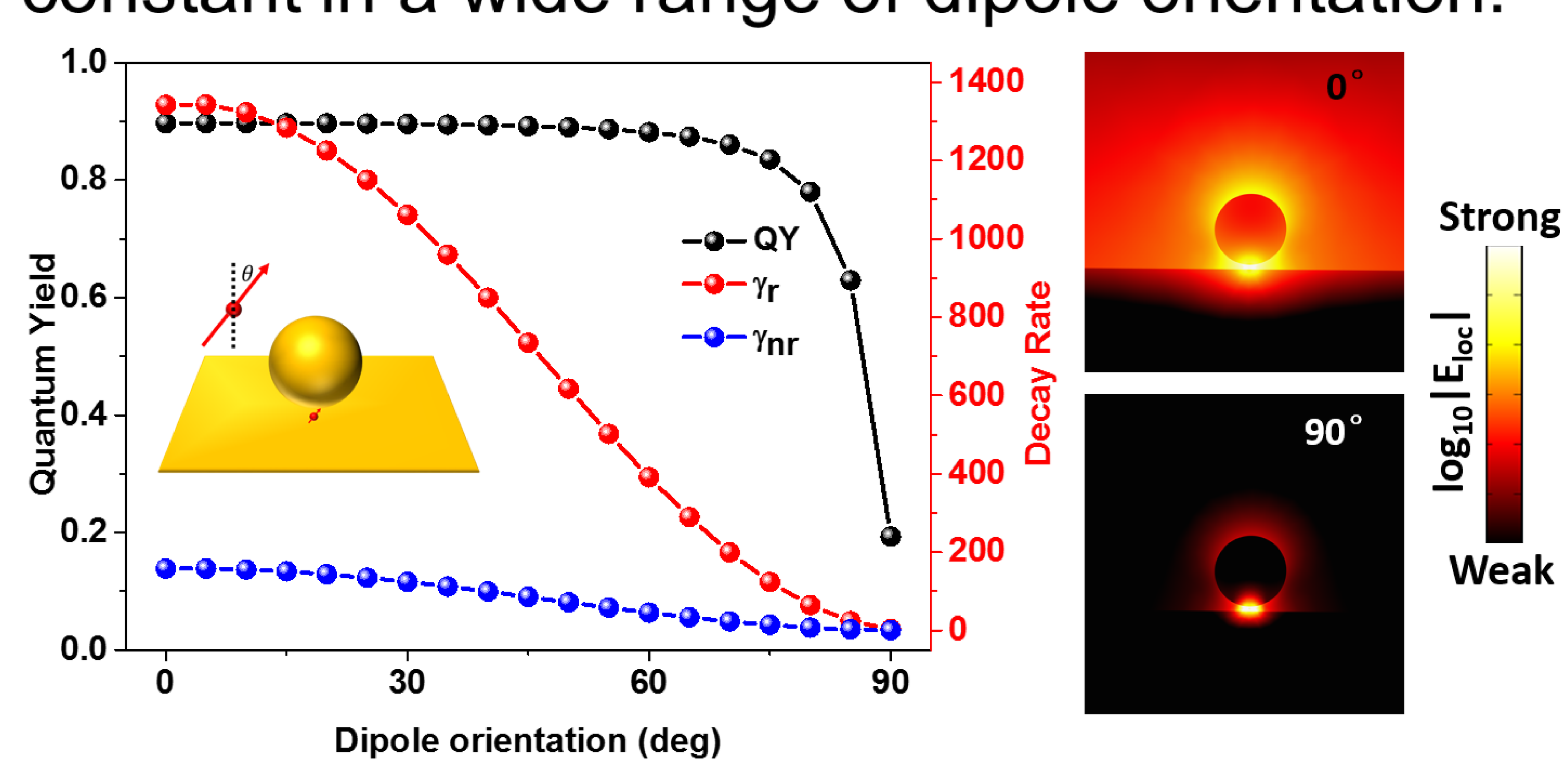

Fig 4. Decay rate and quantum yield of emitter with varied dipole orientation (left) and local electric field of dipole angle at 0 deg and 90 deg. (right)

Reference:

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