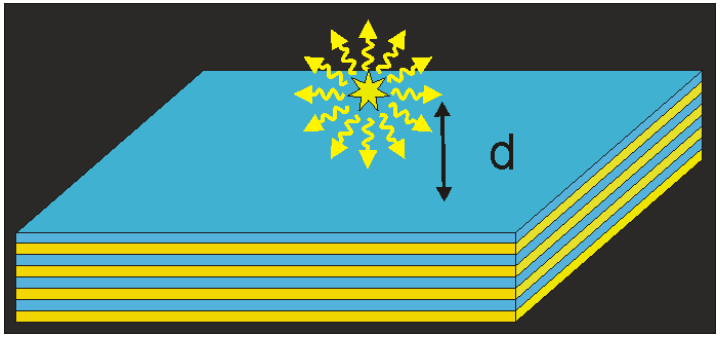
P.N.Lebedev Physical Institute of the Russian Academy of Sciences



Skolkovo Resident

COMSOL MULTIPHYSICS® INVESTIGATION OF RADIATIVE AND NONRADIATIVE CHANNELS OF QUANTUM EMITTER FLUORESCENCE NEAR HYPERBOLIC METAMATERIAL

A. PAVLOV, V. KLIMOV, I. ZABKOV, D. GUZATOV

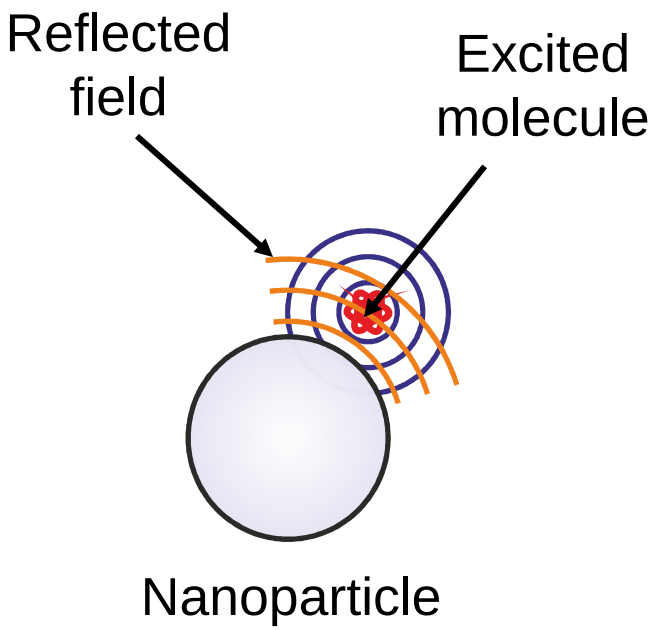
COMSOL CONFERENCE ROTTERDAM2013

QUANTUM EMISSION CONTROL APPLICATIONS

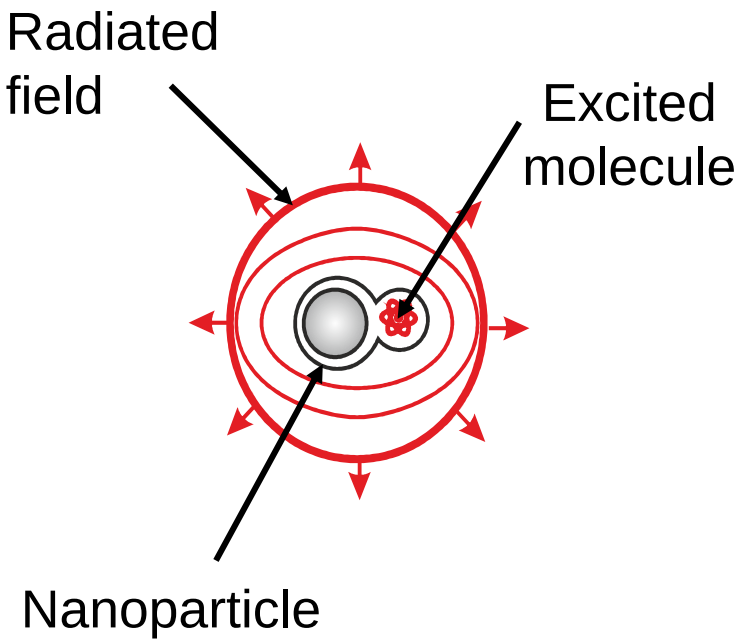
- **Nanolasers**
- **Quantum computing**
- **Single photon sources**
- **SPASER**
- **Chemical and biological nanosensors**
- **Single molecule detection (SNOM)**
- **Etc…**

FLUORESCENCE CHANNELS OF MOLECULE NEAR NANOPARTICLE

Total decay rate



Radiative & nonradiative decay rate



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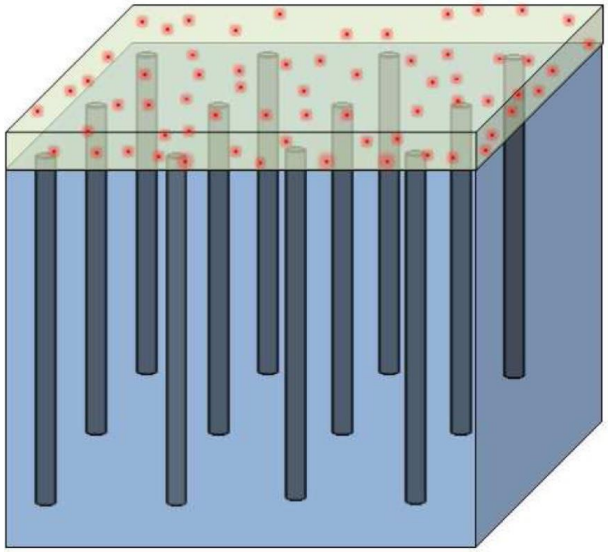
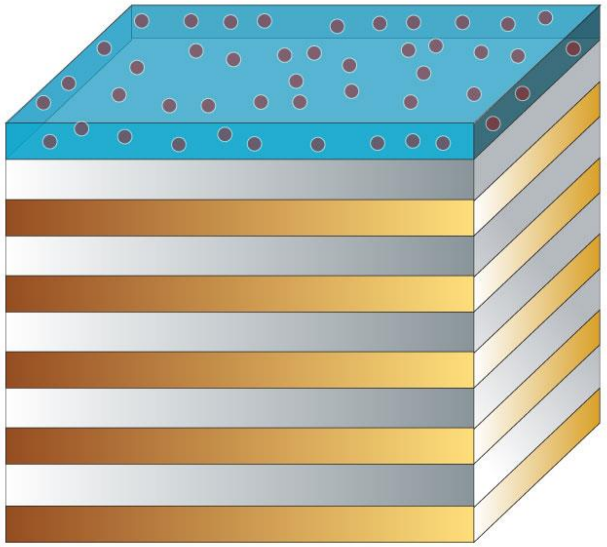
HYPERBOLIC METAMATERIALS

HMM of 1st type



Noginov et al., Opt. Lett., 2010

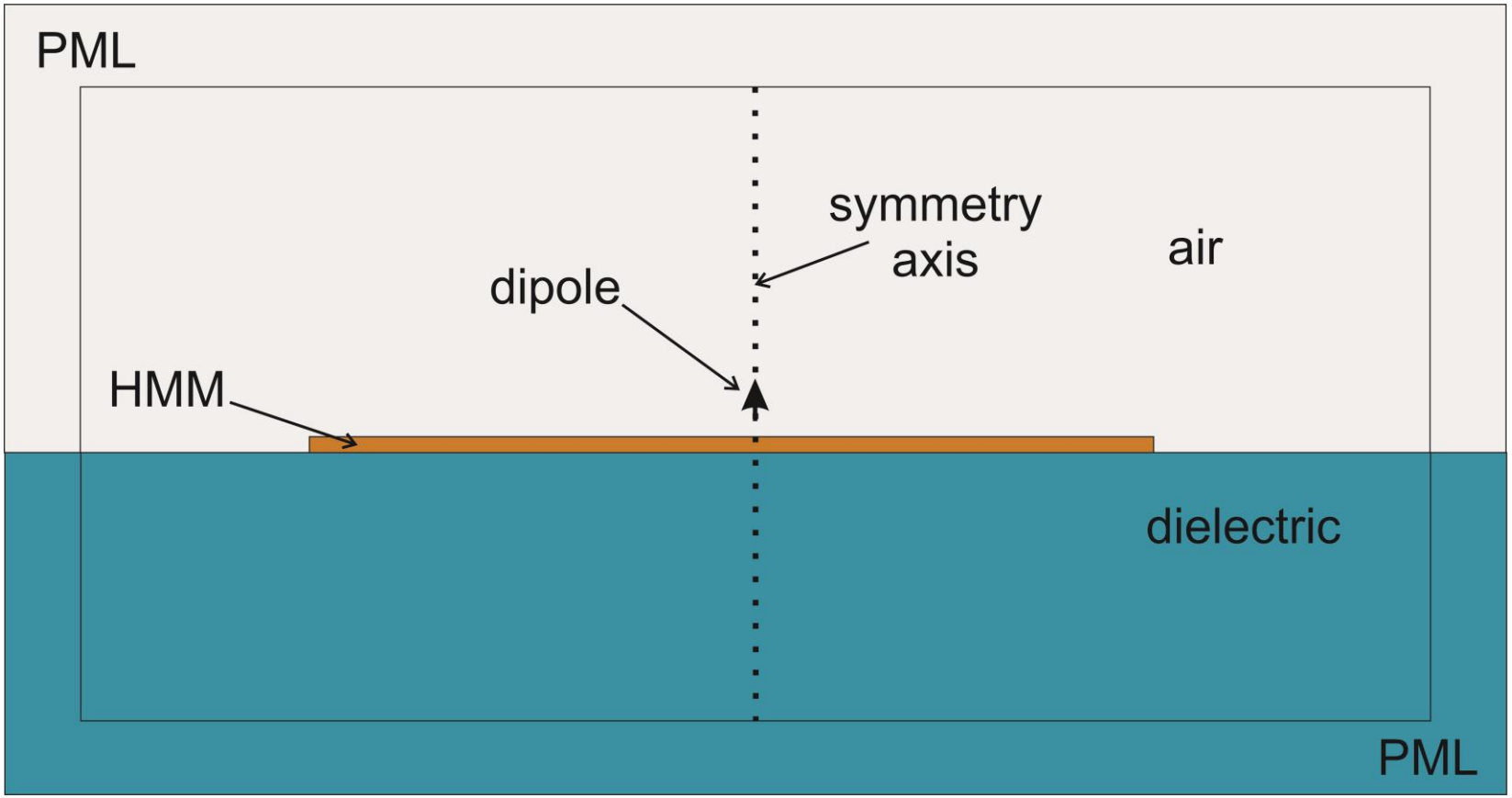
HMM of 2nd type



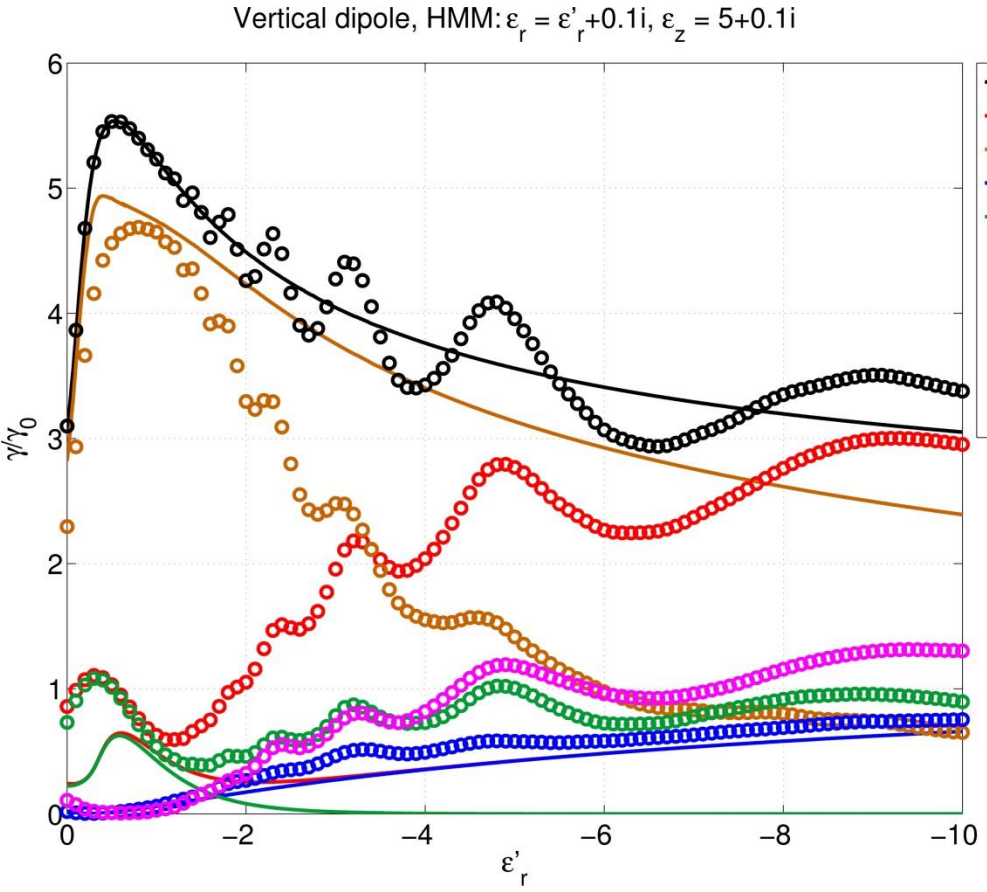
$$\varepsilon_x = \frac{\varepsilon_m + \varepsilon_d}{2}; \varepsilon_z = \frac{2\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}$$

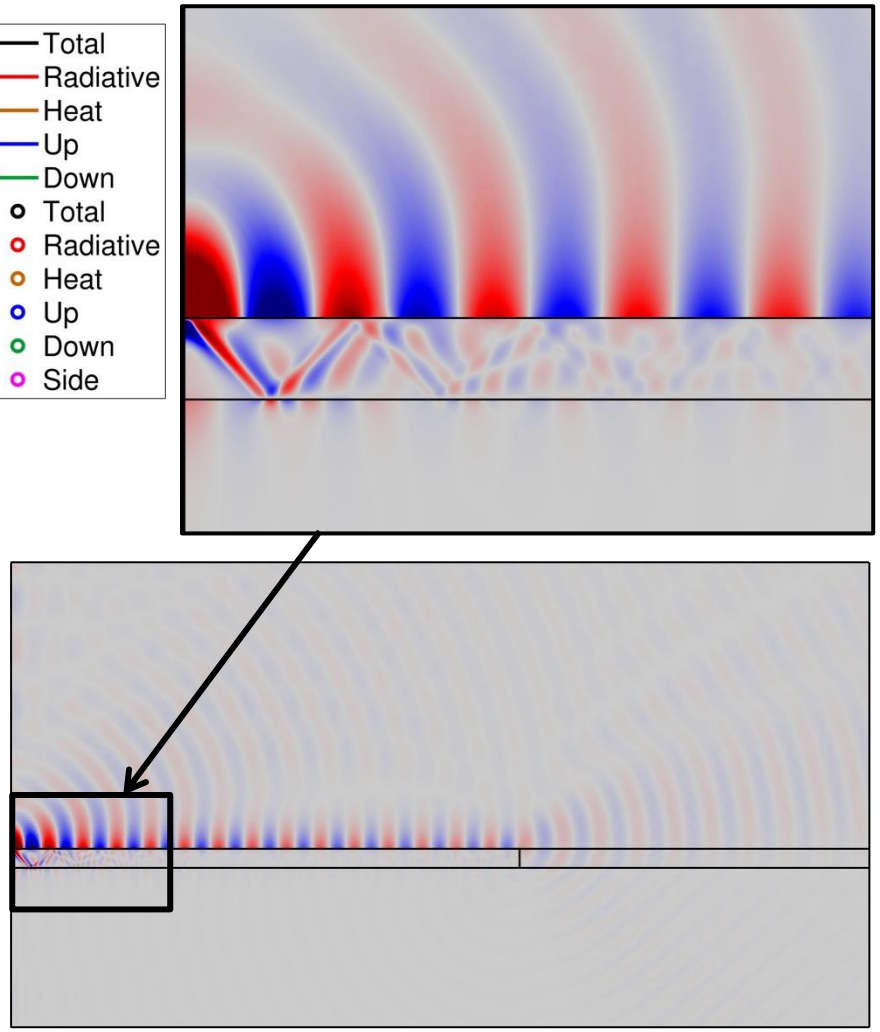
Jacob et al., Applied Physics B, 2010

AXISYMMETRIC GEOMETRY
(WITHOUT NANOANTENNAS)



FLUORESCENCE NEAR HMM
(WITHOUT NANOANTENNAS)





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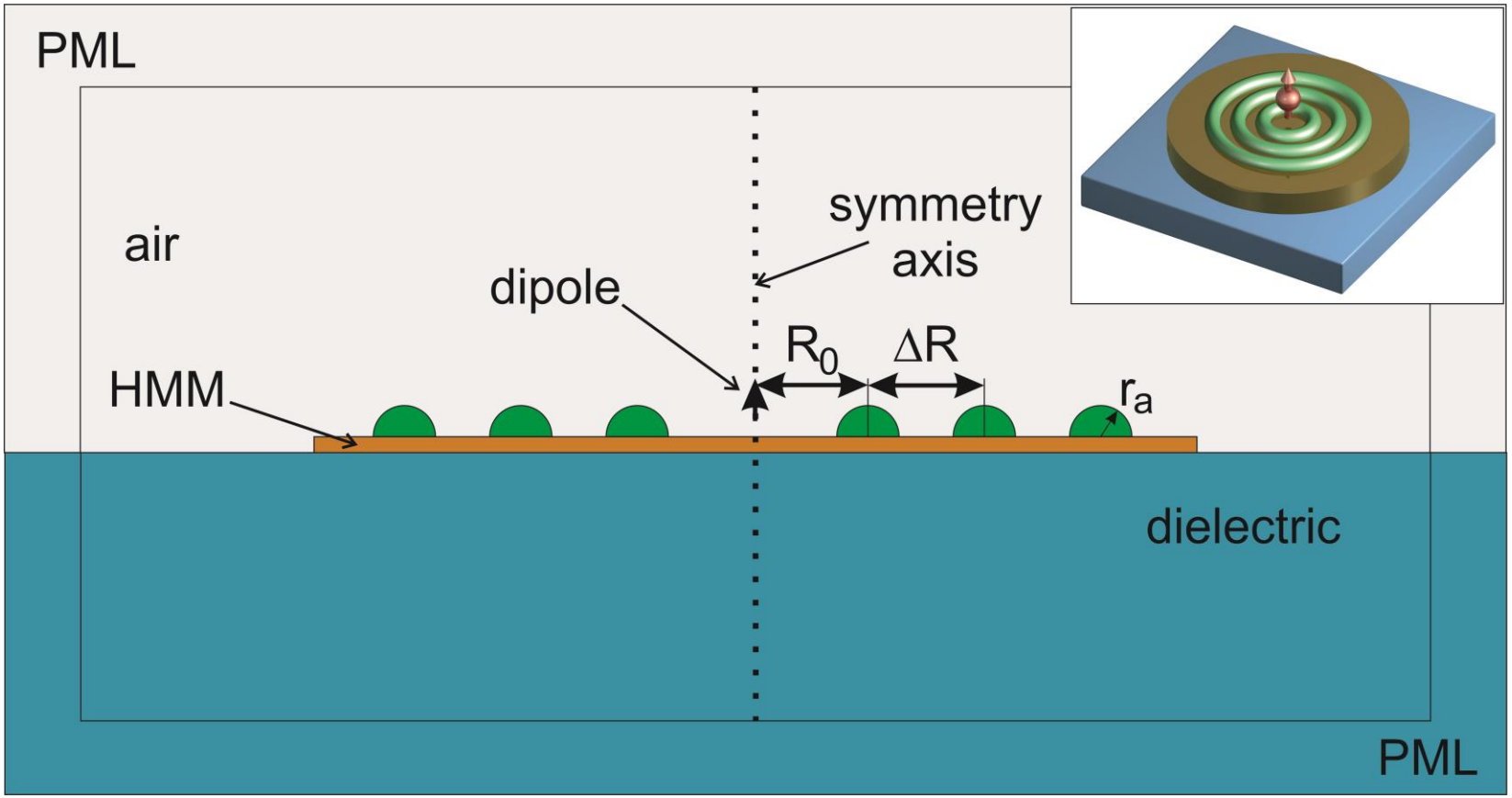
AXISYMMETRIC GEOMETRY
(WITH NANOANTENNAS)



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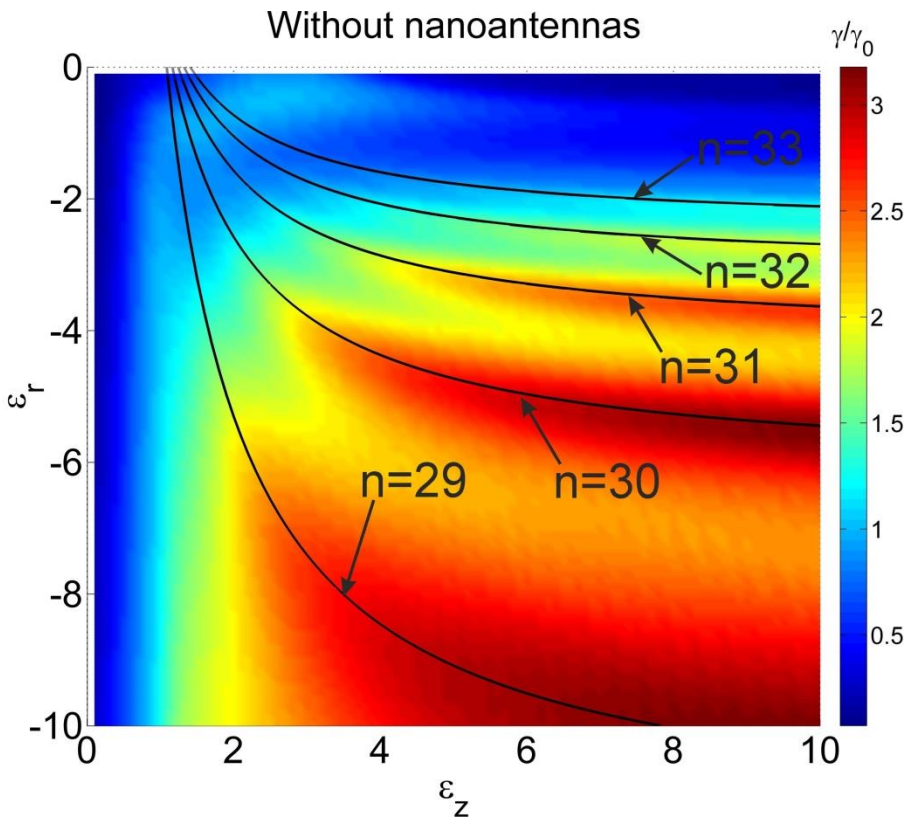
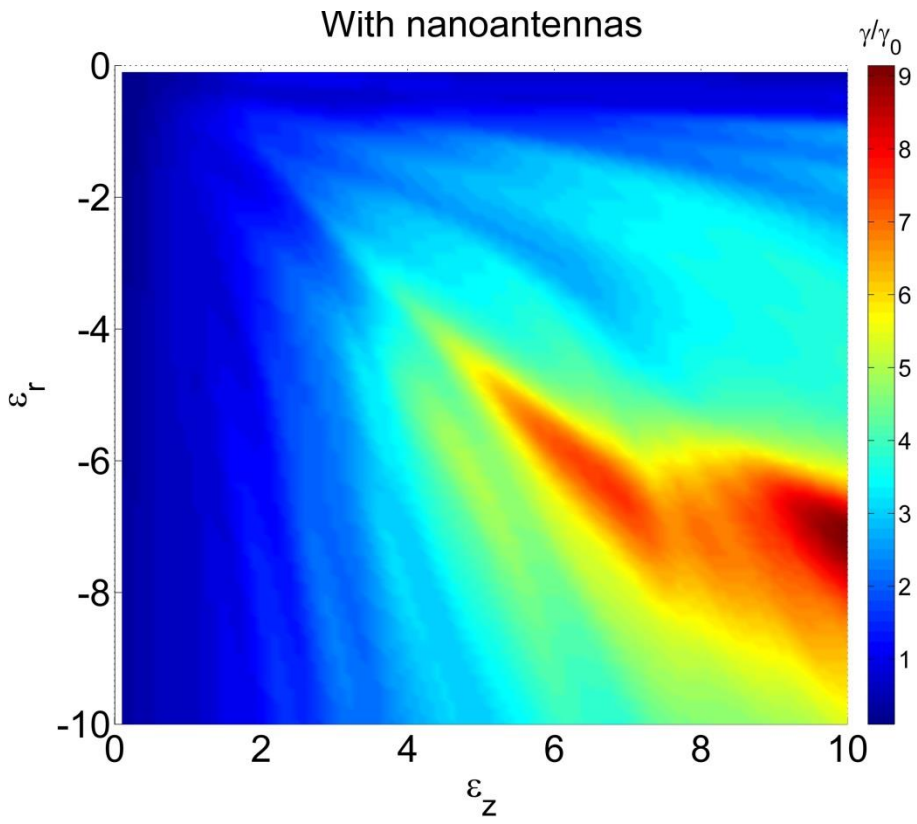
FLUORESCENCE NEAR HMM

Radiation decay rate:





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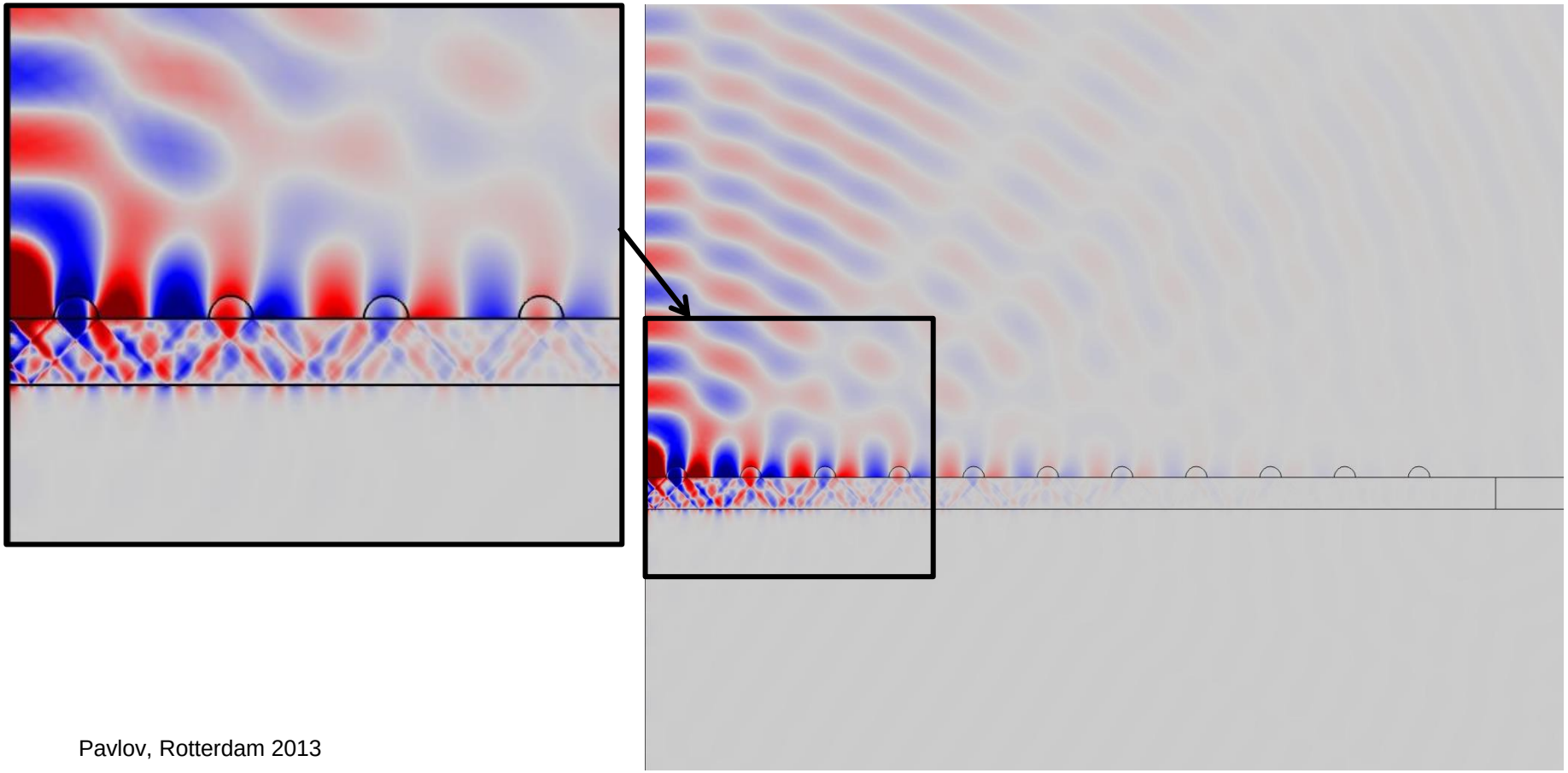
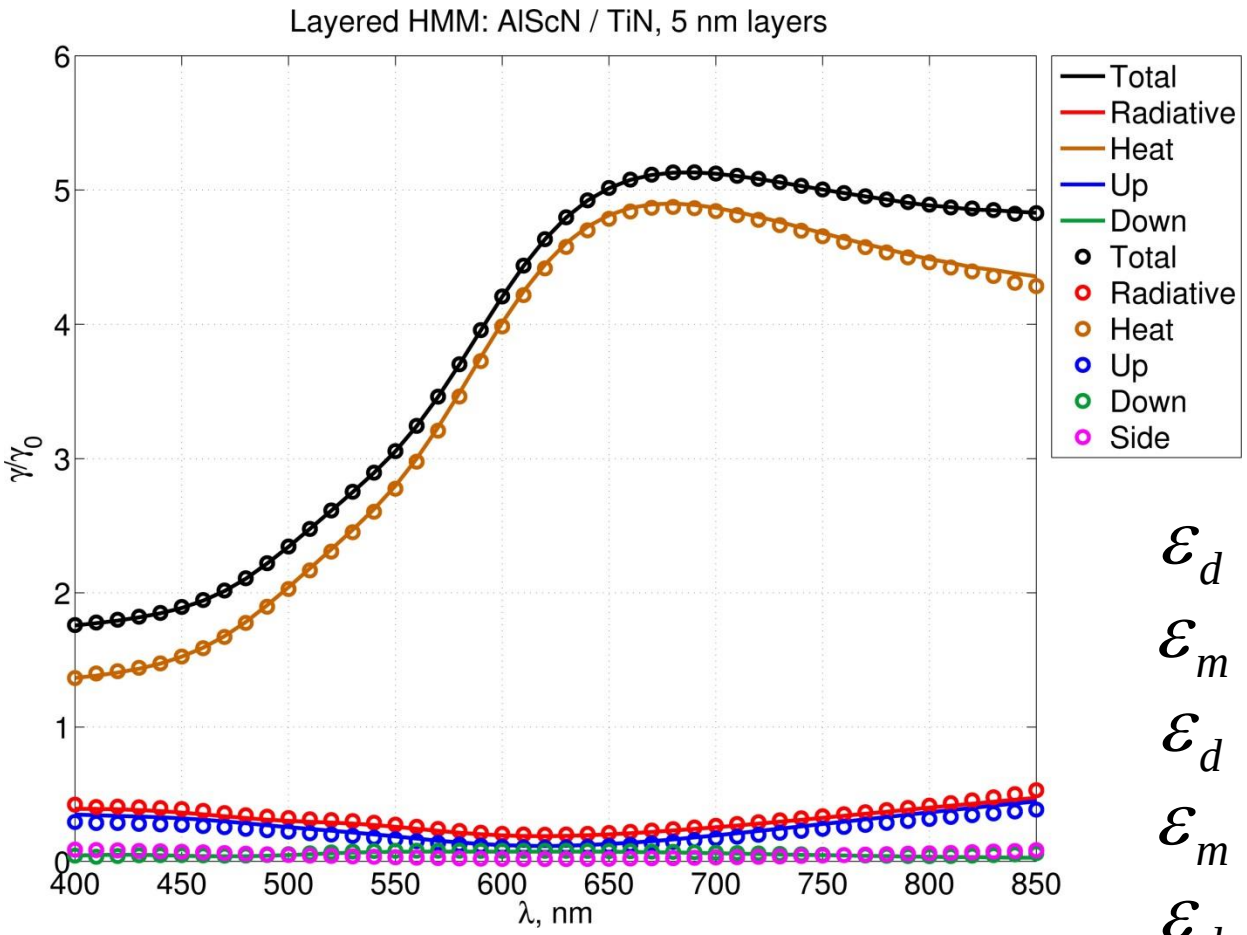
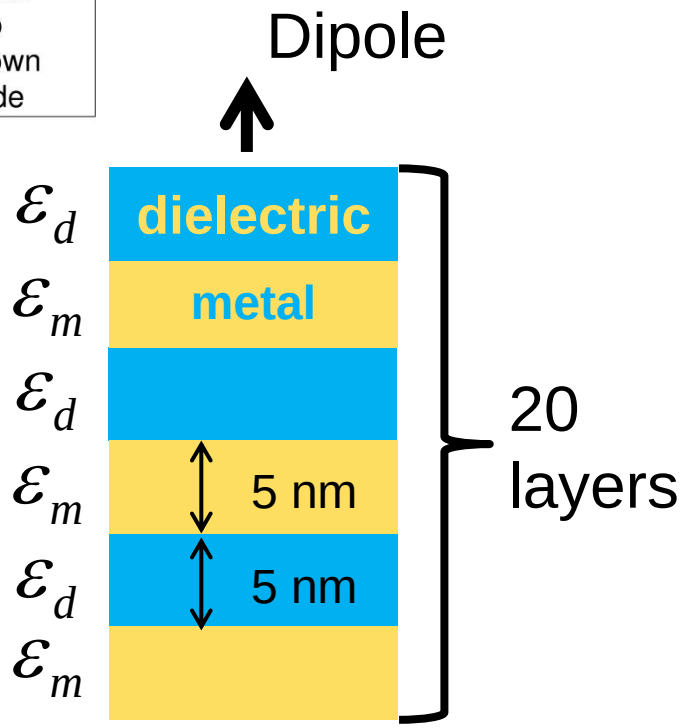
FLUORESCENCE NEAR HMM
(WITH NANOANTENNAS)

HMM with nanoantennas:
high radiation rate and high directivity!



ACTUAL HMM REALIZATION





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CONCLUSIONS

- **Radiative and nonradiative channels of fluorescence near hyperbolic metamaterial were studied**
- **Regime was found when radiative rate can be higher than nonradiative due to finite sample size**
- **Was shown that radiative rate be substantially increased when placing nanoantennas on the metamaterial surface**
- **Nice agreement of COMSOL simulation with analytical results was found**

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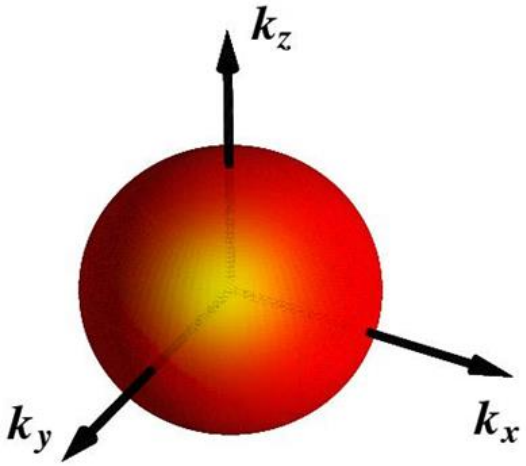
DISPERSION RELATION FOR HMM
(HYPERBOLIC METAMATERIAL)

Finite density of states

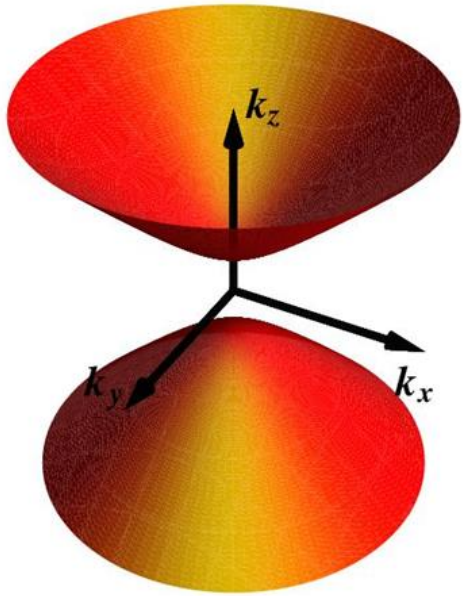
Finite decay rate



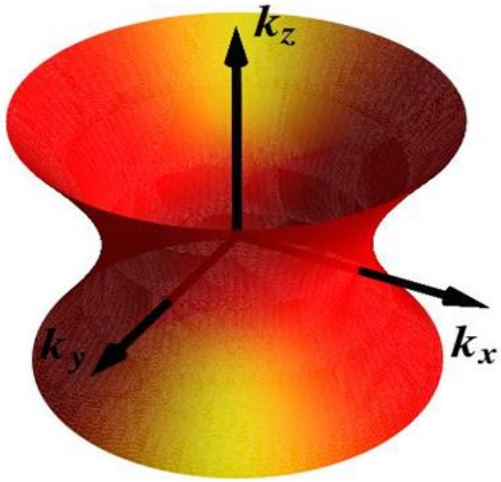
$$k_0^2 = \frac{k_x^2 + k_y^2}{\varepsilon_z} + \frac{k_z^2}{\varepsilon_p}$$

Infinite density of states

Infinite decay rate

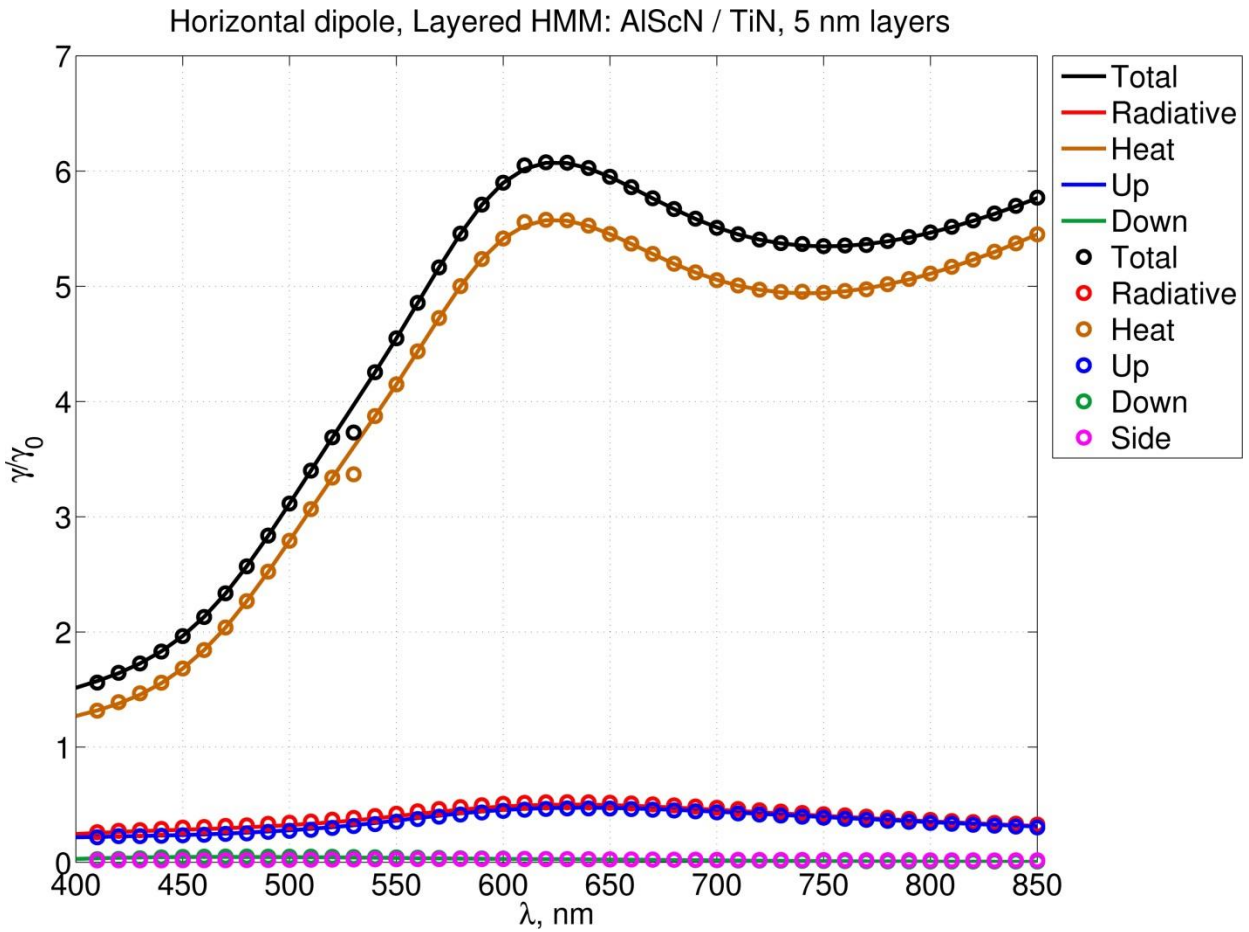


$$k_0^2 = -\frac{k_x^2 + k_y^2}{|\varepsilon_z|} + \frac{k_z^2}{\varepsilon_p}$$



$$k_0^2 = \frac{k_x^2 + k_y^2}{\varepsilon_z} - \frac{k_z^2}{|\varepsilon_p|}$$

ACTUAL HMM REALIZATION
(HORIZONTAL DIPOLE)



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