

This powerpoint file contains a summary repertory of the models available with the QNM solver QNMEig.

If you develop your own models with the solver and wish to make them available, you may propose a summary with the reference to the original publication and your email address, so that potential users may contact you directly.

Please address your ppt summary sheet to  
[philippe.lalanne@institutoptique.fr](mailto:philippe.lalanne@institutoptique.fr)

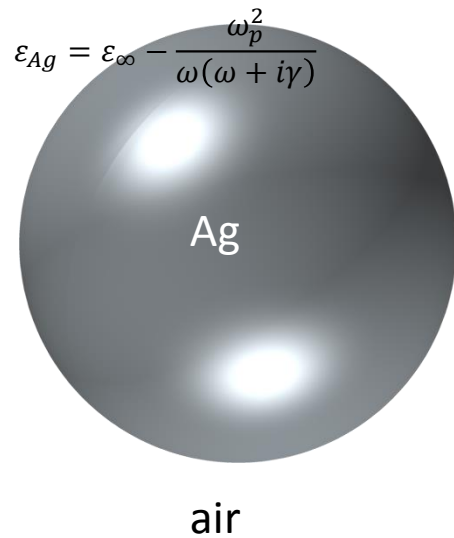
plasmonic nanocavities .....	p 2
photonic microcavities & particles .....	p 9
gratings and crystals .....	p 13

plasmonic nanocavities

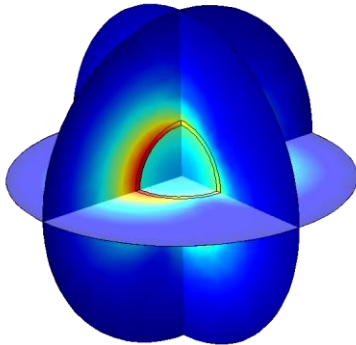
# Silver sphere in air

Contact: Wei Yan <yanwei@westlake.edu.cn>

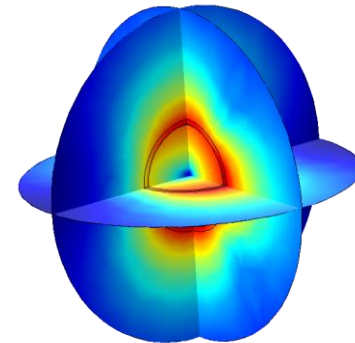
COMSOL model available on the website:  
"QNMEig\_Sphere.mph"



Eigenfrequency=9.2471E14+1.5213E14i Multislice: log(emw.normE)



Eigenfrequency=1.2359E15+2.2070E13i Multislice: log(emw.normE)

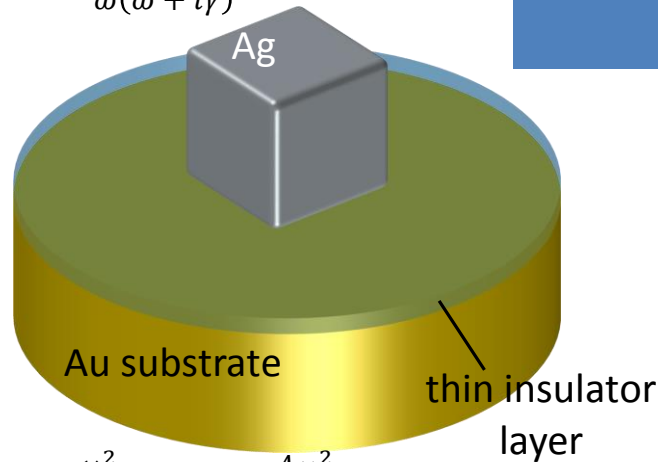


# Silver nanocube on a coated gold substrate

Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:  
"QNMEig\_Cubesubstrate.mph"

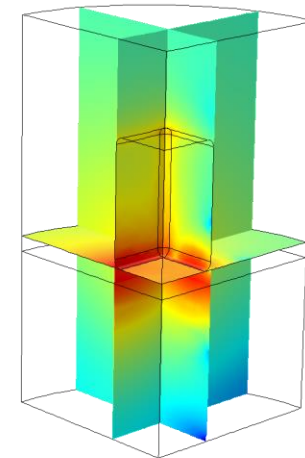
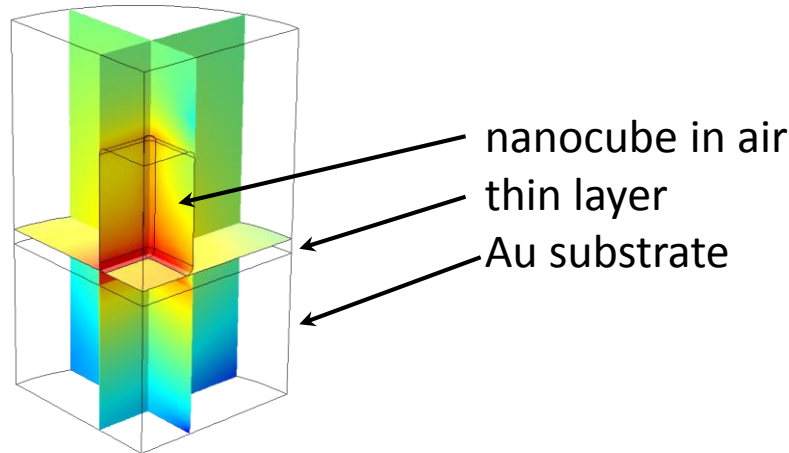
$$\varepsilon_{Ag} = \varepsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega + i\gamma)}$$



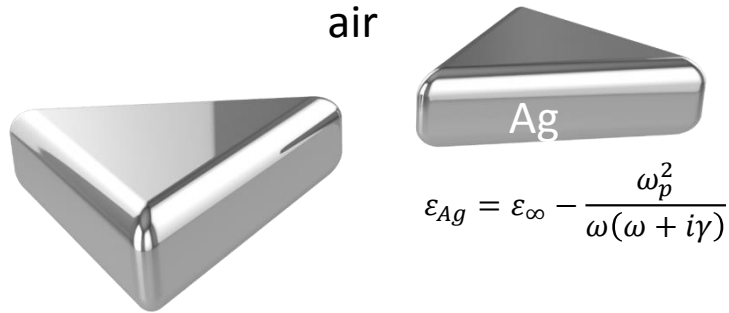
$$\varepsilon_{Au} = \varepsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega + i\gamma)} - \frac{A\omega_1^2}{\omega^2 - \omega_1^2 + i\gamma_1}$$

Eigenfrequency=4.5032E14+1.0479E13i Multislice: log(emw.normE)

Eigenfrequency=5.8505E14+3.9778E13i Multislice: log(emw.normE)



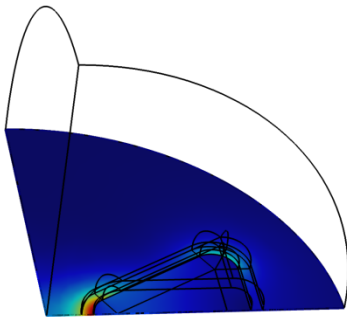
# Silver bowtie in air



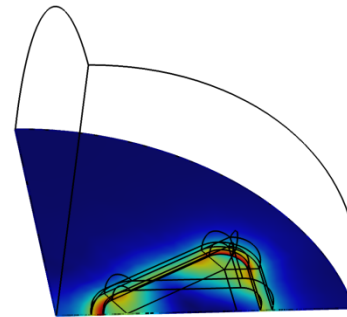
Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:  
"QNMEig\_bowtie.mph"

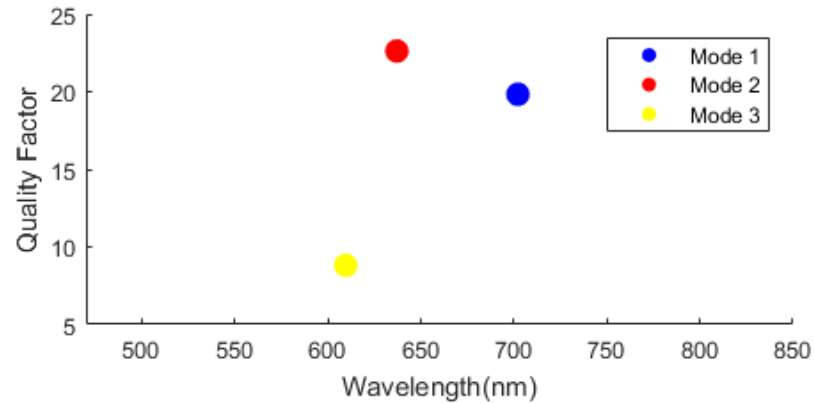
Eigenfrequency=7.5277E14+2.947E13i Hz  
Slice: Electric field norm (V/m)



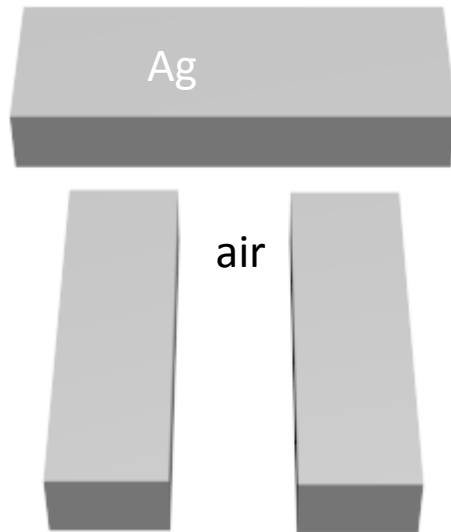
Eigenfrequency=1.0984E15+2.9362E12i Hz  
Slice: Electric field norm (V/m)



# Dolmen nanoantenna

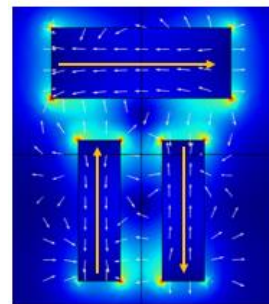


COMSOL model available on the website:  
"QNM\_Dolmen.mph"  
"QNM\_Dolmen\_sym.mph"  
or associated matlab files

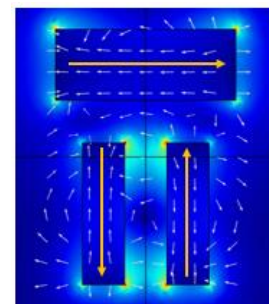


$$\epsilon_{Ag} = \epsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega + i\gamma)}$$

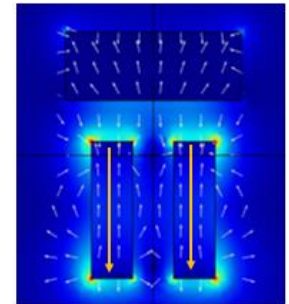
Eigen electric field distributions



Mode1



Mode2



Mode3

R. Faggiani, A. Losquin, J. Yang, E. Mårsell, A. Mikkelsen, P. Lalanne, ACS Photonics **4**, 897-904 (2017).

["Modal analysis of the ultrafast dynamics of optical nanoresonators"](#)

T. Wu, A. Baron, P. Lalanne, K. Vynck, Phys. Rev. A **101**, 011803(R) (2020).

["Intrinsic multipolar contents of nanoresonators for tailored scattering"](#)

# Multipolar decomposition of QNMs

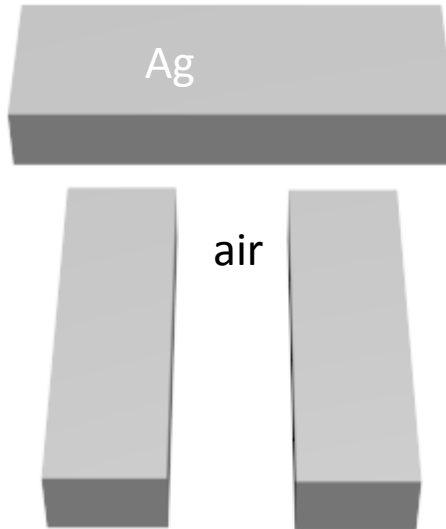
Contact: Tong WU [tong.wu@institutoptique.fr](mailto:tong.wu@institutoptique.fr) or [wutong1121@sina.com](mailto:wutong1121@sina.com)

COMSOL model available on the website:

"QNM\_Dolmen.mph"

"QNM\_Dolmen\_sym.mph"

or associated matlab files



$$\epsilon_{Ag} = \epsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega + i\gamma)}$$

$$\tilde{\mathbf{E}} = \frac{n_b^2 \tilde{\omega}^2}{c^2} \sum_{n=1}^{\infty} \sum_{m=-n}^n E_{nm} \left[ \tilde{a}_{nm} \tilde{\mathbf{N}}_{nm}^{(3)}(\mathbf{r}) + \tilde{b}_{nm} \tilde{\mathbf{M}}_{nm}^{(3)}(\mathbf{r}) \right]$$

Main features:

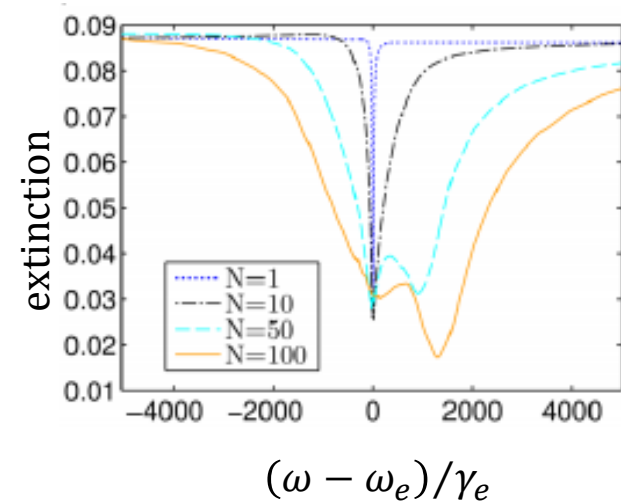
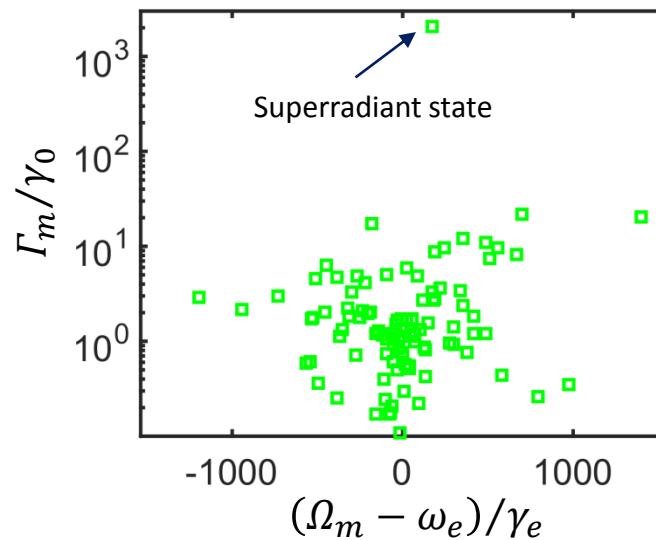
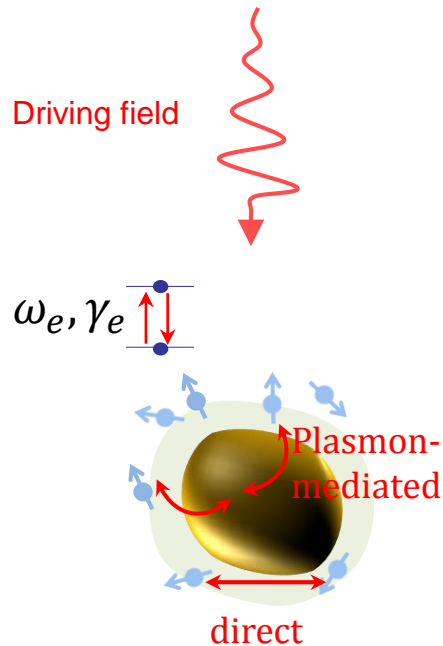
- Computation the multipolar decomposition in the vectorial spherical harmonics of a QNM at the complex frequency of the QNM
- Avoid the traditional problem that, at real frequency, a multipolar decomposition depends on the frequency, polarisation, incidence of the illumination and is not intrinsic to the nanoresonator

$$\left\{ \begin{array}{l} \tilde{a}_{nm} = \frac{c^2 \int \tilde{\mathbf{E}} \cdot \tilde{\mathbf{N}}_{nm}^{(3)}(R, \Omega) d\Omega}{n_b^2 \tilde{\omega}^2 E_{nm} \int |\tilde{\mathbf{N}}_{nm}^{(3)}(R, \Omega)|^2 d\Omega} \\ \tilde{b}_{nm} = \frac{c^2 \int \tilde{\mathbf{E}} \cdot \tilde{\mathbf{M}}_{nm}^{(3)}(R, \Omega) d\Omega}{n_b^2 \tilde{\omega}^2 E_{nm} \int |\tilde{\mathbf{M}}_{nm}^{(3)}(R, \Omega)|^2 d\Omega} \end{array} \right. \rightarrow \left\{ \begin{array}{l} \tilde{p}_x \\ \tilde{m}_z \\ \tilde{Q}_{xy}^e \end{array} \right.$$

# Superradiance of disordered ensembles of two-level resonators coupled by a plasmonic resonator

Contact: Philippe Lalanne<philippe.lalanne@institutoptique.fr>

Program to compute the superradiant and subradiant states of the coupled ensemble is available in PRB 95, 195418 (2017).



P. Fauché et al., Phys. Rev. B **95**, 195418 (2017).

["Collective scattering in hybrid nanostructures with many atomic oscillators coupled to an electromagnetic resonance"](#)

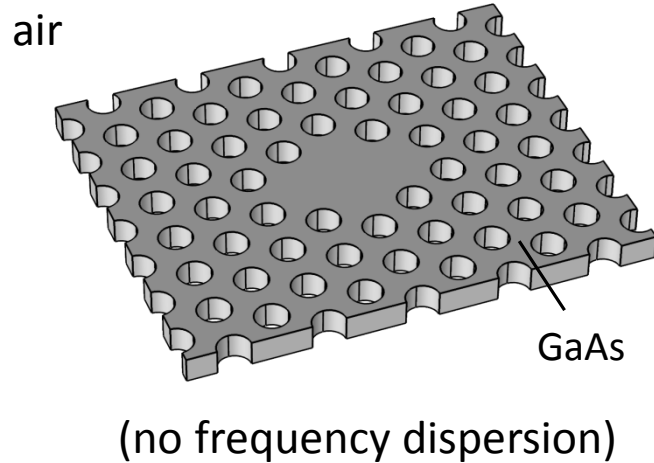


photonic microcavities and particles

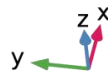
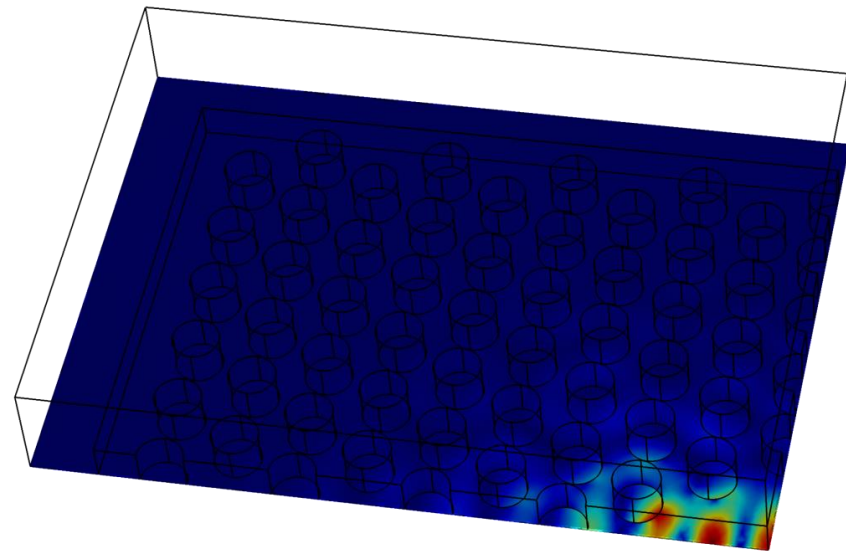
# GaAs photonic crystal membrane in air

Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:  
"QNMEig\_GaAsPhc.mph"



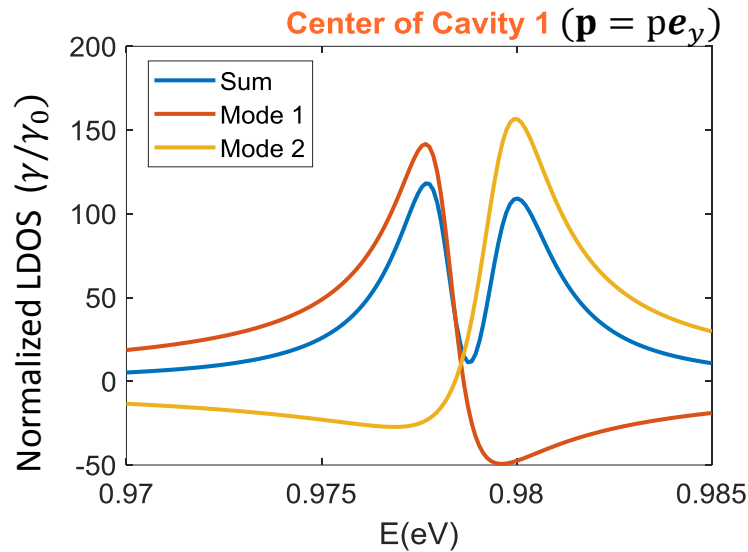
Eigenfrequency= $2.1975\text{E}14 + 2.1543\text{E}10\text{i}$  Hz Slice: Electric field norm (V/m)



# Coupled photonic crystal cavities

Contact: Tong WU<tong.wu@institutoptique.fr>

COMSOL model available on the website:  
 "QNMEig\_PhCcoupled.mph"  
 November 2019



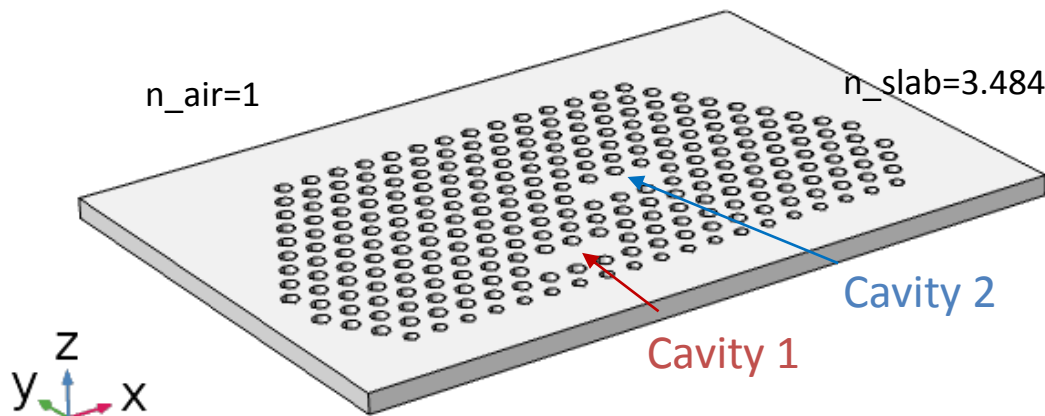
$$\frac{\gamma}{\gamma_0} = \sum_n F_n \frac{\omega}{\Omega_n} \frac{(\Gamma_n/2)^2}{(\omega - \Omega_n)^2 + (\Gamma_n/2)^2} \left( 1 + \frac{\text{Im}(\tilde{V}_n)}{\text{Re}(\tilde{V}_n)} \frac{\omega - \Omega_n}{\Gamma_n/2} \right)$$

$$F_n = \frac{3}{4\pi^2} Q_n \text{Re} \left( \frac{(\lambda/n)^3}{\tilde{V}_n} \right) \text{ (Purcell factor)}$$

$$\tilde{V}_n(\mathbf{r}) = \left[ 2\varepsilon_o \varepsilon(\mathbf{r}) (\tilde{\mathbf{E}}_n(\mathbf{r}) \cdot \mathbf{u})^2 \right]^{-1}$$

$$Q_n = -\frac{\text{Re}(\tilde{\omega}_n)}{2\text{Im}(\tilde{\omega}_n)} = \frac{\Omega_n}{\Gamma_n}$$

$$\gamma_0 = \frac{\omega^3 n}{3\pi \epsilon_0 c^3 \hbar} |\mathbf{p}|^2$$



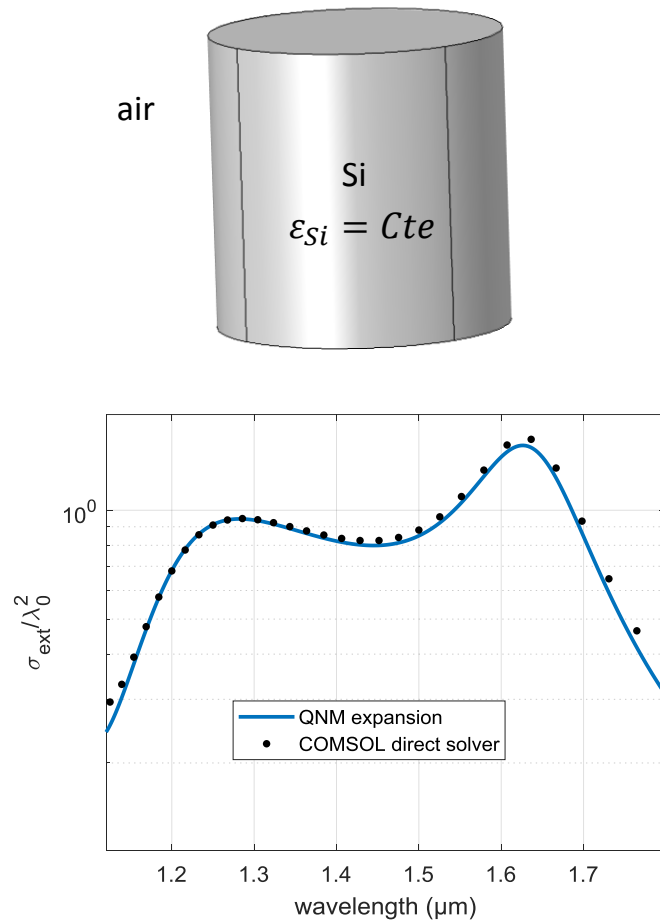
D. Pellegrino, Phys. Rev. Lett. **124**, 123902 (2020)

["Non-Lorentzian Local Density of States in Coupled Photonic Crystal Cavities Probed by Near- and Far-Field Emission"](#)

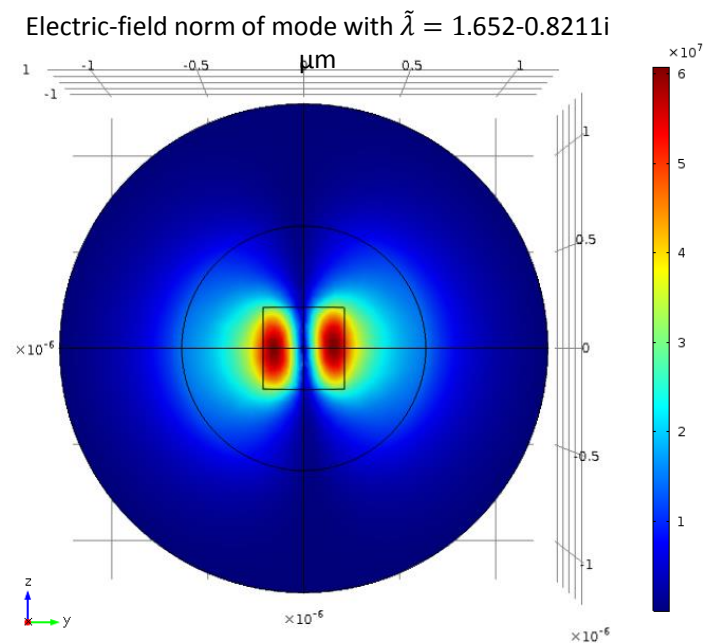
# Semiconductor nanorod in air

Contact: Alexandre Gras <alexandre.gras@institutoptique.fr>

COMSOL model available on the website:  
"QNMEig\_Nanorod.mph"  
January 2019



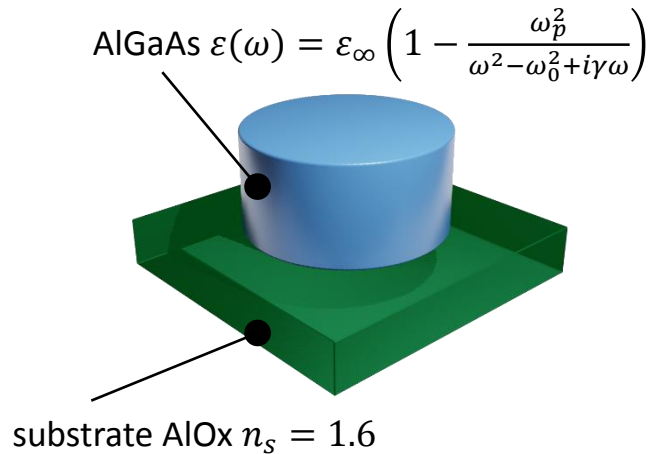
The extinction computed with the QNM-expansion is obtained with the toolbox **QNMEig\_toolbox\_1** for an incident plane wave that propagates parallel to the rod axis.



# Nonlinear generation in dielectric nanoparticles on substrate

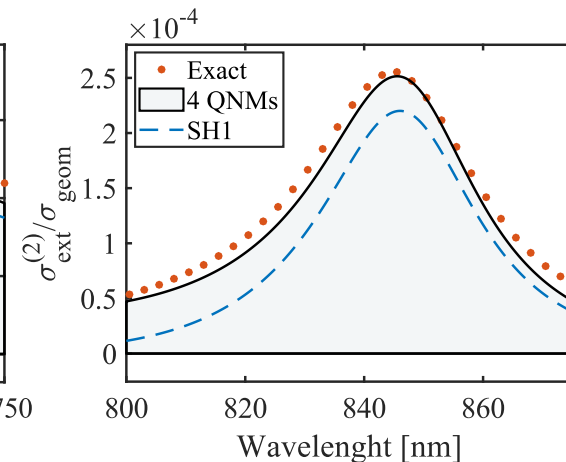
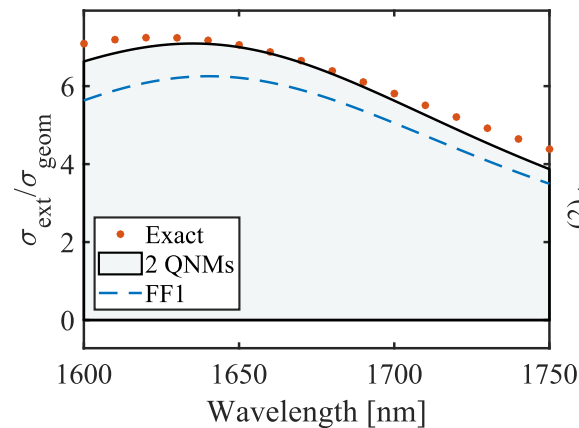
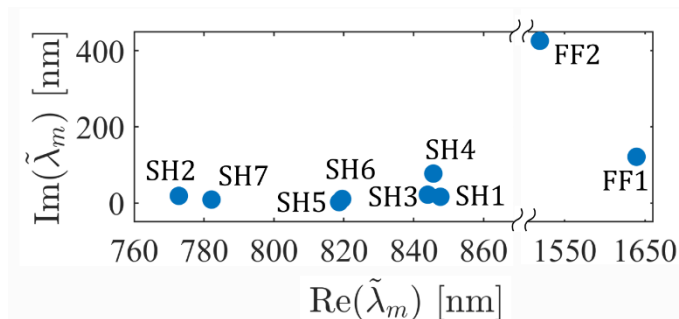
Contact: Carlo Gigli <carlo.gigli@u-paris.fr>

COMSOL model available on the website:  
"QNMEig\_NLnanodisk.mph"  
March 2020



Main features:

- Computation of linear and nonlinear scattering efficiencies by a nanoresonator on a substrate
- Analysis of mode contribution to the scattering
- Study of nonlinear overlap integral and phase matching conditions

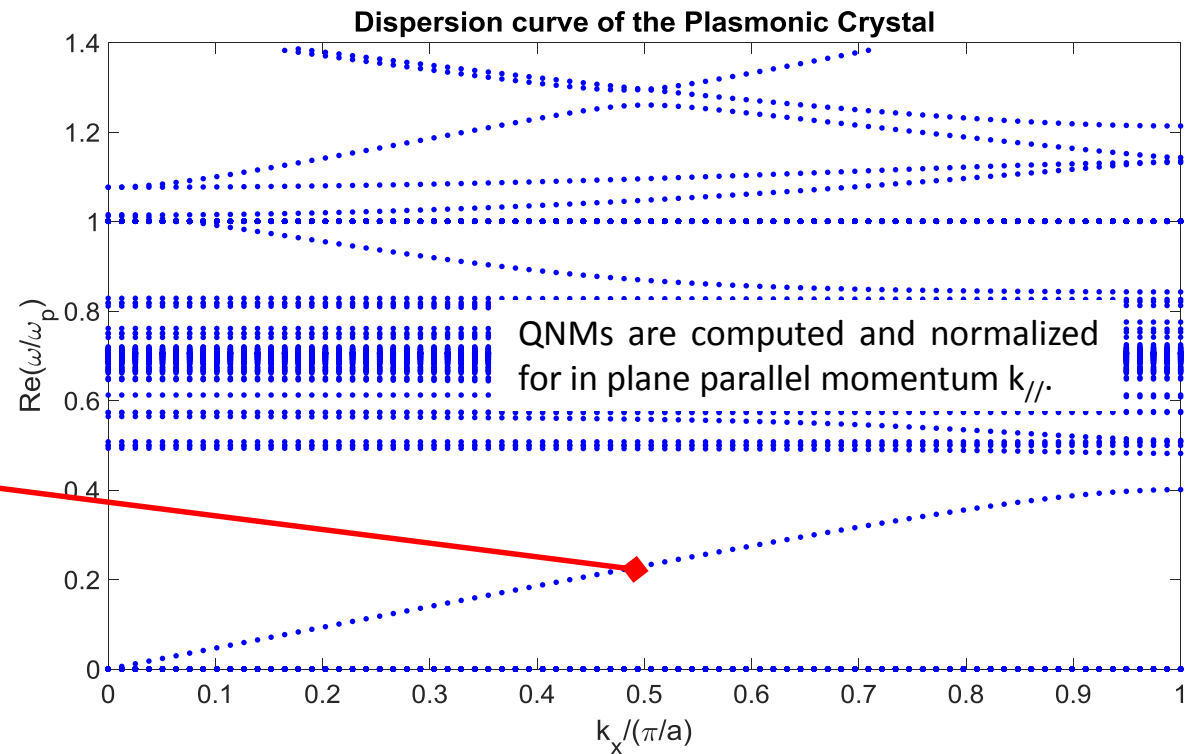
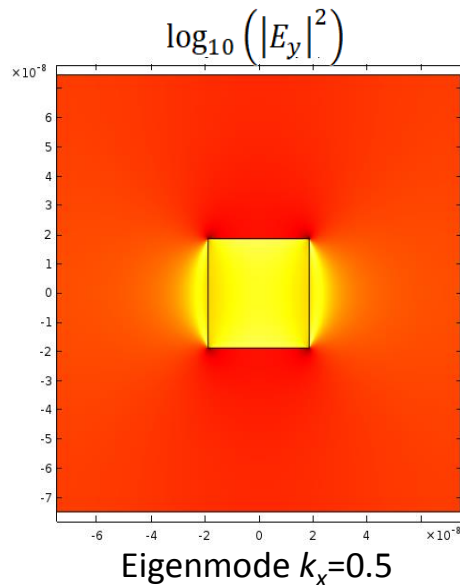
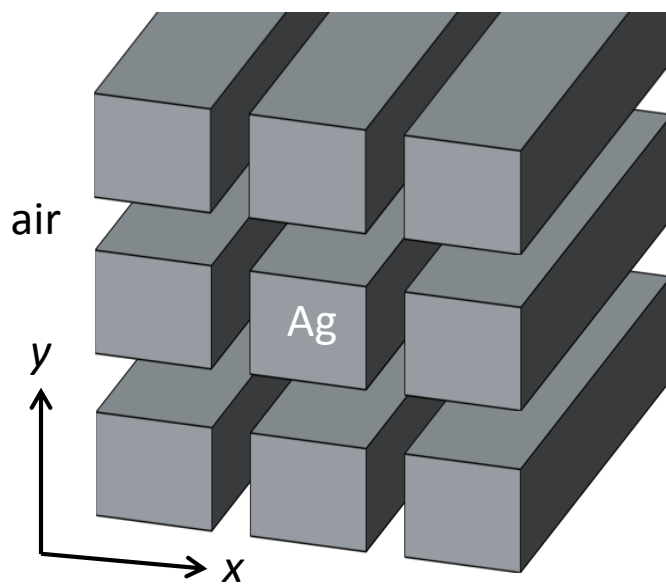


gratings and crystals

# 2D plasmonic crystal

Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:  
"QNMEig\_PlasmCrystal.mph"

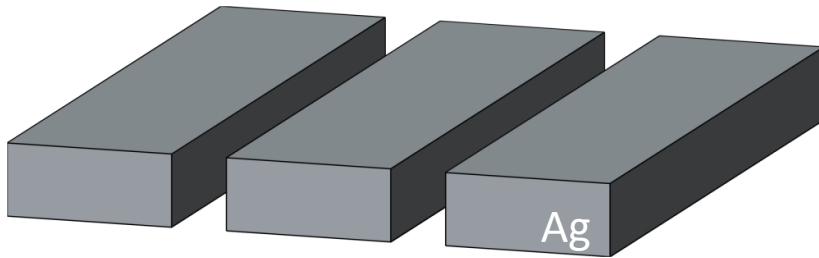


P. Lalanne, W. Yan, A. Gras, C. Sauvan, J.-P. Hugonin, M. Besbes, G. Demesy, M. D. Truong, B. Gralak, F. Zolla, A. Nicolet, F. Binkowski, L. Zschiedrich, S. Burger, J. Zimmerling, R. Remis, P. Urbach, H. T. Liu, T. Weiss, J. Opt. Soc. Am. A **36**, 686 (2019).  
"Quasinormal mode solvers for resonators with dispersive materials"

# 2D periodic slit array in a silver membrane in air

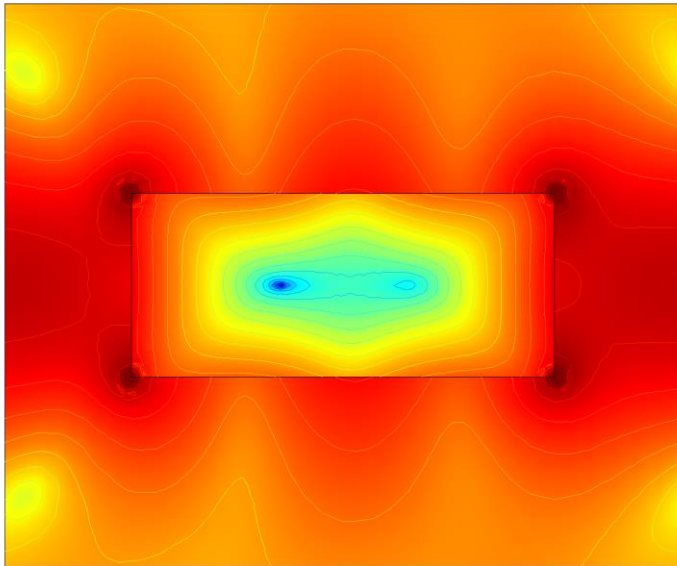
Contact: Alexandre Gras <alexandre.gras@institutoptique.fr>

COMSOL model available on the website:  
"QNMEig\_1DGrating.mph"

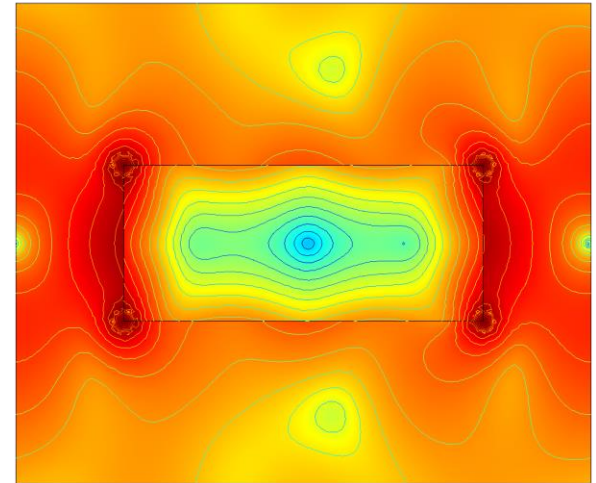


air

Eigenfrequency= $8.7238\text{E}14 + 8.8110\text{E}12i$  Surface:  $\log(\text{emw.normE})$   
Contour:  $\log(\text{emw.normE})$



Eigenfrequency= $1.1029\text{E}15 + 7.1210\text{E}12i$  Surface:  $\log(\text{emw.normE})$   
Contour:  $\log(\text{emw.normE})$



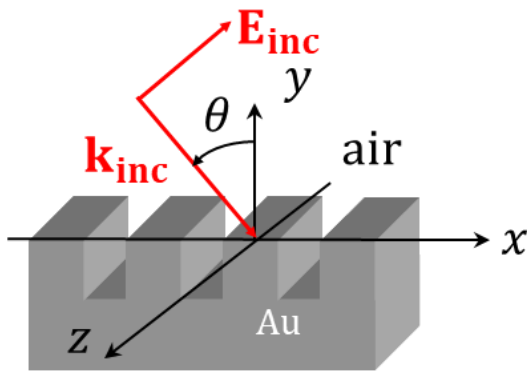
P. Lalanne, W. Yan, A. Gras, C. Sauvan, J.-P. Hugonin, M. Besbes, G. Demesy, M. D. Truong, B. Gralak, F. Zolla, A. Nicolet, F. Binkowski, L. Zschiedrich, S. Burger, J. Zimmerling, R. Remis, P. Urbach, H. T. Liu, T. Weiss, J. Opt. Soc. Am. A **36**, 686 (2019).  
"Quasinormal mode solvers for resonators with dispersive materials"



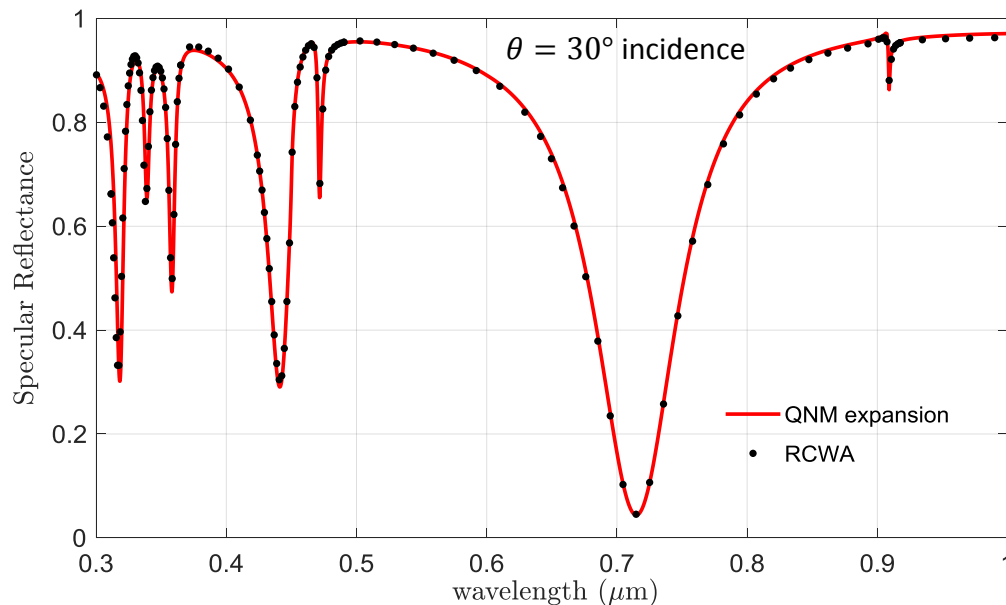
# 2D grating with grooves on a gold substrate with fixed incidence angle

Contact: Alexandre Gras <alexandre.gras@institutoptique.fr>

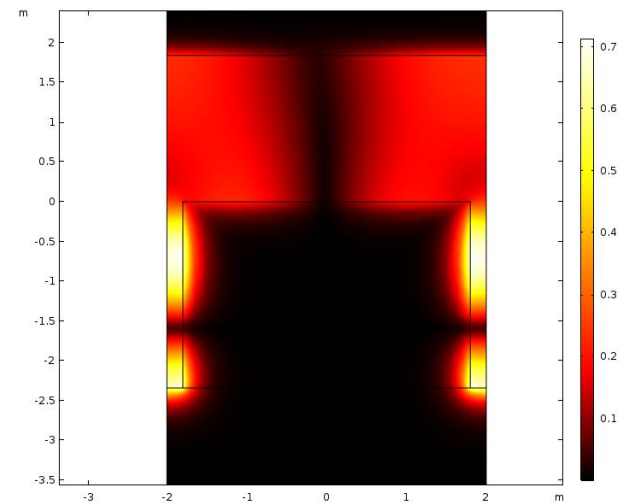
COMSOL model available on the website:  
"QNMEig\_grating\_theta.mph"



The specificity of the model is that QNMs are computed and normalized for a fixed angle of incidence  $\theta$ , which is exactly what is happening in many experiment: the wavelength is scanned while  $\theta$  is maintained constant.



Normalized  $|\tilde{H}_z|$  of mode at  
 $\tilde{\lambda}_m = 714.8 + 39.0i$  nm  
for  $\theta = 30^\circ$



Under preparation, models for

- Bowtie nanoantenna on substate