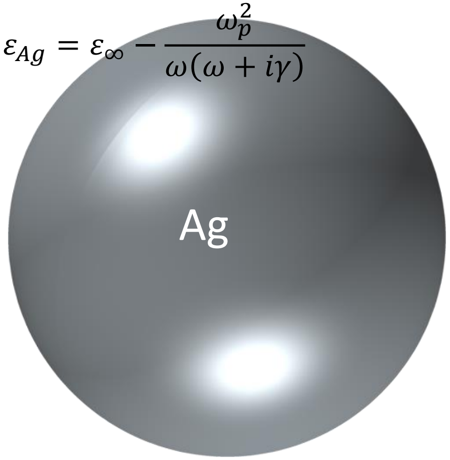
This powerpoint file contains a summary repertory of the models available with the QNM solver QNMEig.

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

plasmonic nanocavities

Silver sphere in air

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

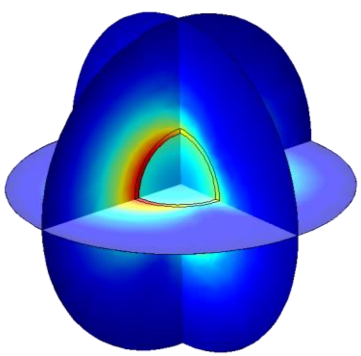


air

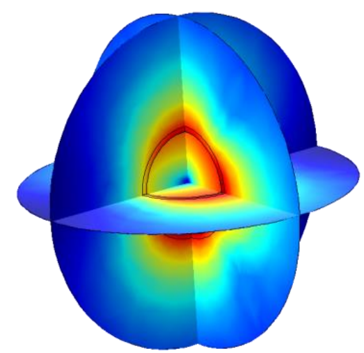
Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:
"QNMEig_Sphere.mph''

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



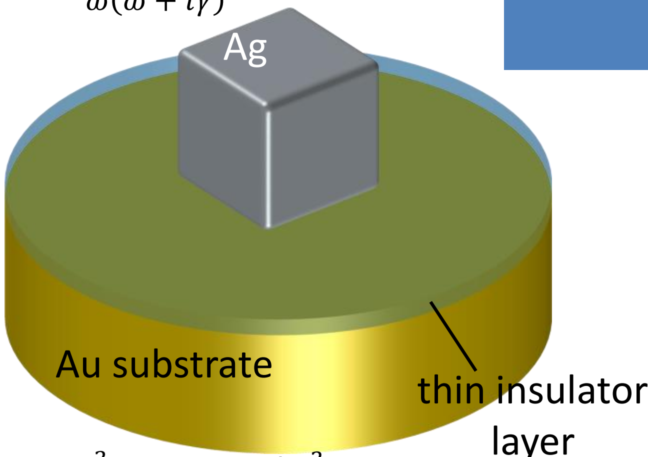
Eigenfrequency=1.2359E15+2.2070E13i Multislice: log(emw.normE)



W. Yan , R. Faggiani, P. Lalanne, Phys. Rev. B **97**, 205422 (2018).
"Rigorous modal analysis of plasmonic nanoresonators"

Silver nanocube on a coated gold substrate

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

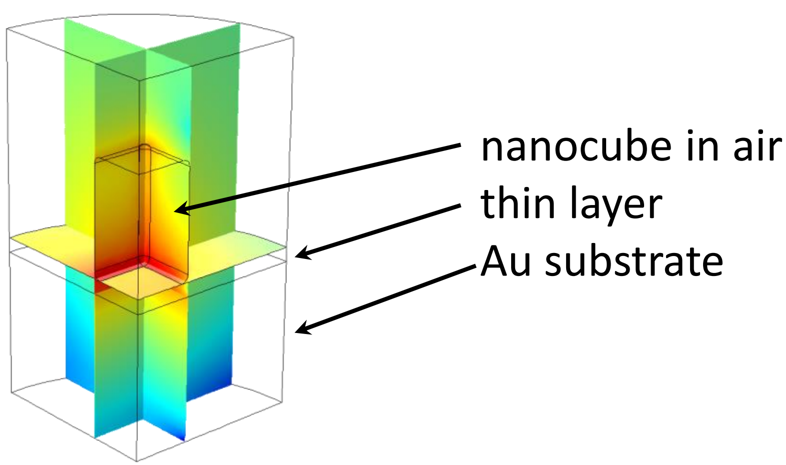


$$\varepsilon_{Au} = \varepsilon_\infty - \frac{\omega_p^2}{\omega(\omega + i\gamma)} - \frac{A\omega_1^2}{\omega^2 - \omega_1^2 + i\gamma_1}$$

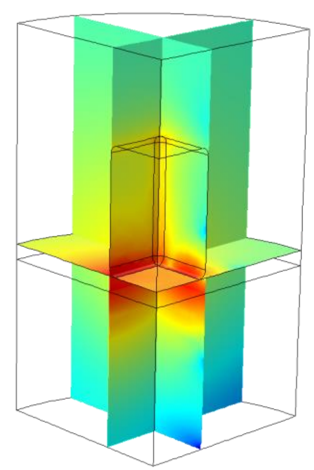
Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:
"QNMEig_Cubesubstrate.mph"

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



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

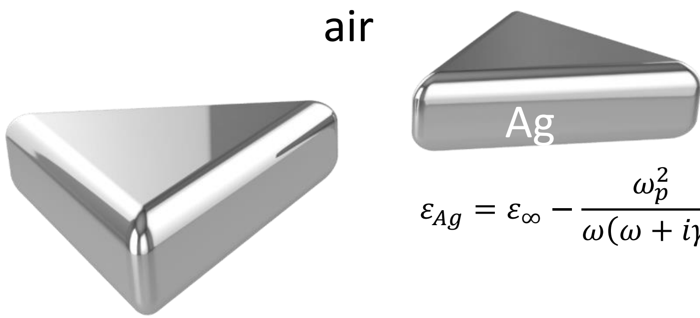


P. Lalanne, W. Yan, A. Gras, C. Sauvan, J.-P. Hugonin, M. Besbes, G. Demesy, M. D. Truong, B. Gralak, F. Zolla, A. Nicolet, F. Binkowski, L. Zschiedrich, S. Burger, J. Zimmerling, R. Remis, P. Urbach, H. T. Liu, T. Weiss, J. Opt. Soc. Am. A **36**, 686 (2019). "Quasinormal mode solvers for resonators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

Silver bowtie in air

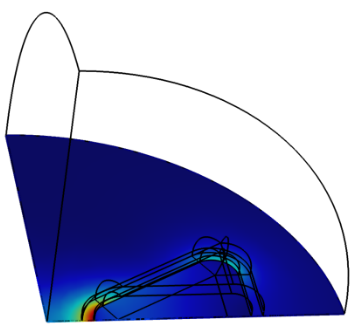
Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:
"QNMEig_bowtie.mph"

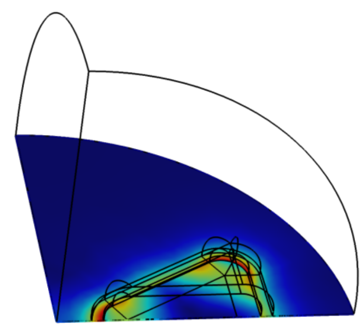


$$\varepsilon_{Ag} = \varepsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega + i\gamma)}$$

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

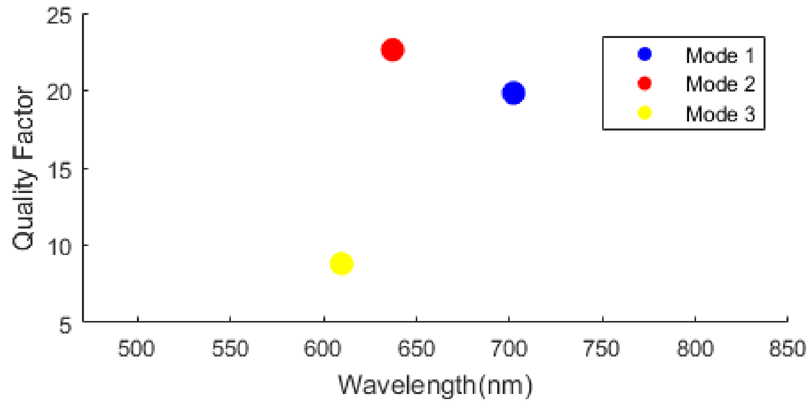


Eigenfrequency=1.0984E15+2.9362E12i Hz
Slice: Electric field norm (V/m)

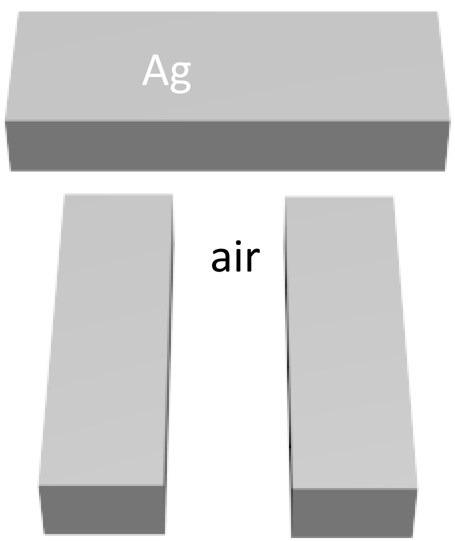


W. Yan , R. Faggiani, P. Lalanne, Phys. Rev. B **97**, 205422 (2018).
"Rigorous modal analysis of plasmonic nanoresonators"

Dolmen nanoantenna

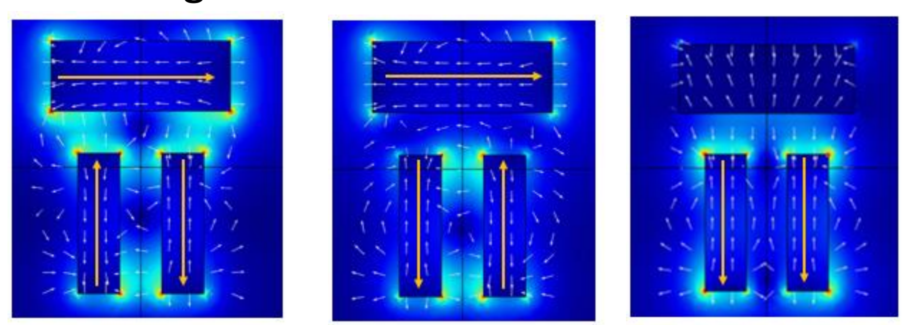


COMSOL model available on the website:
"QNM_Dolmen.mph"
"QNM_Dolmen_sym.mph"
or associated matlab files



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

Eigen electric field distributions



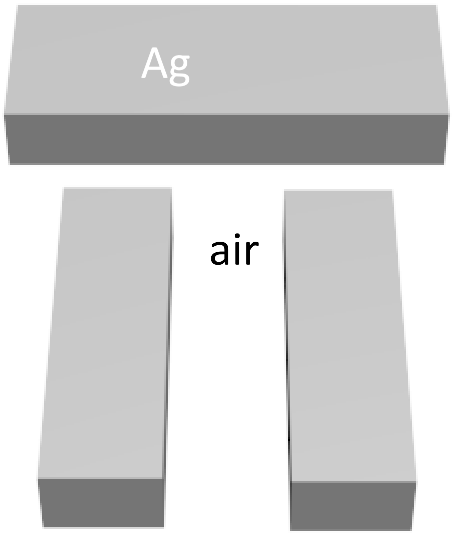
Mode1 Mode2 Mode3

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 or wutong1121@sina.com

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



COMSOL model available on the website:
“QNM_Dolmen.mph’’
“QNM_Dolmen_sym.mph’’
or associated matlab files

Main features:

- Computation the multipolar decomposition in the vectorial spherical harmonics of a QNM at the complex frequency of the QNM
- Provide multipolar decomposition that is intrinsic (excitation-independent) to the the nanoparticle
- Avoid the traditional problem that a multipolar decomposition at real frequency excitation dependent, as it depends on the frequency, polarisation, incidence angle of the illumination

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

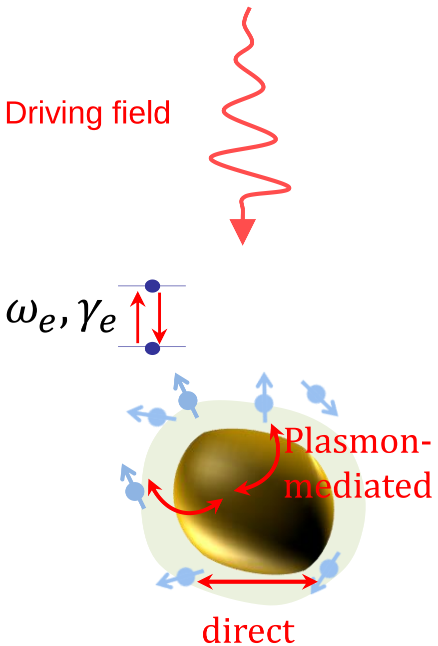
$$\left\{ \begin{aligned} \tilde{a}_{nm} &= \frac{c^2 \int \tilde{\mathbf{E}} \cdot \tilde{\mathbf{N}}_{nm}^{(3)}(R,\Omega) d\,\Omega}{n_b^2 \tilde{\omega}^2 E_{nm} \int \left| \tilde{\mathbf{N}}_{nm}^{(3)}(R,\Omega) \right|^2 d\,\Omega} \\ \tilde{b}_{nm} &= \frac{c^2 \int \tilde{\mathbf{E}} \cdot \tilde{\mathbf{M}}_{nm}^{(3)}(R,\Omega)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

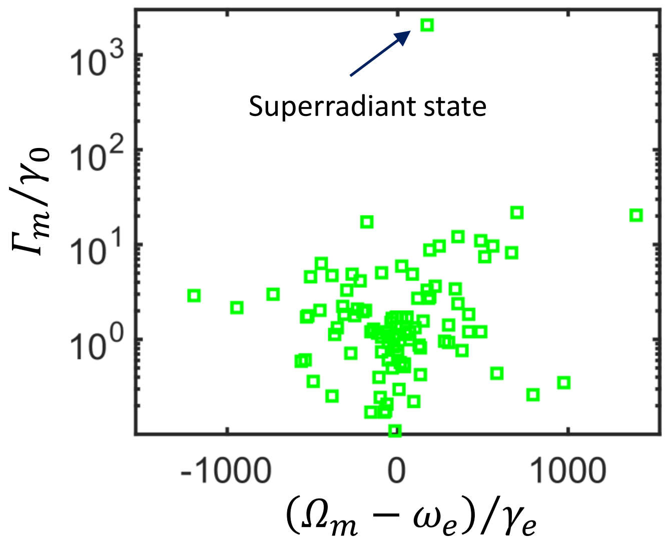
T. Wu, A. Baron, P. Lalanne, K. Vynck, Phys. Rev. A **101**, 011803(R) (2020).
"Intrinsic multipolar contents of nanoresonators for tailored scattering"

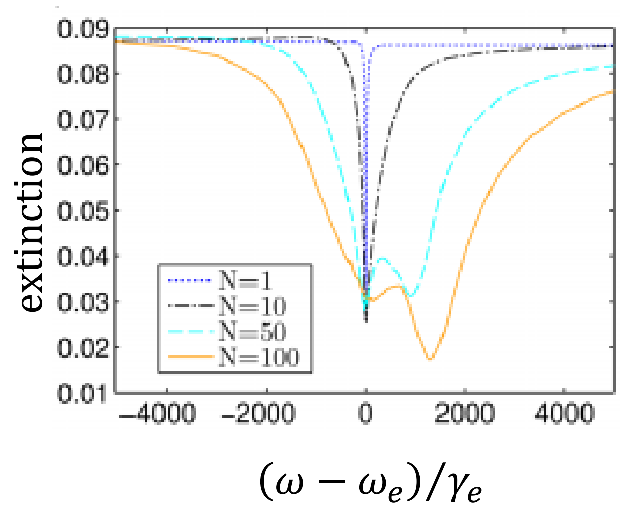
Superradiance of disordered ensembles of two-level resonators coupled by a plasmonic resonator

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).



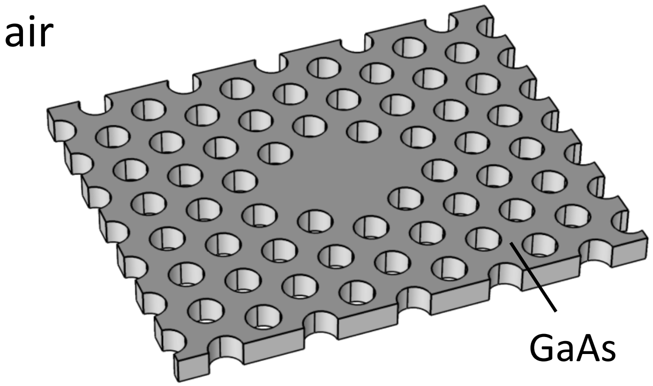




P. Fauché et al., Phys. Rev. B **95**, 195418 (2017).
"Collective scattering in hybrid nanostructures with many atomic oscillators coupled to an electromagnetic resonance"

photonic microcavities and particles

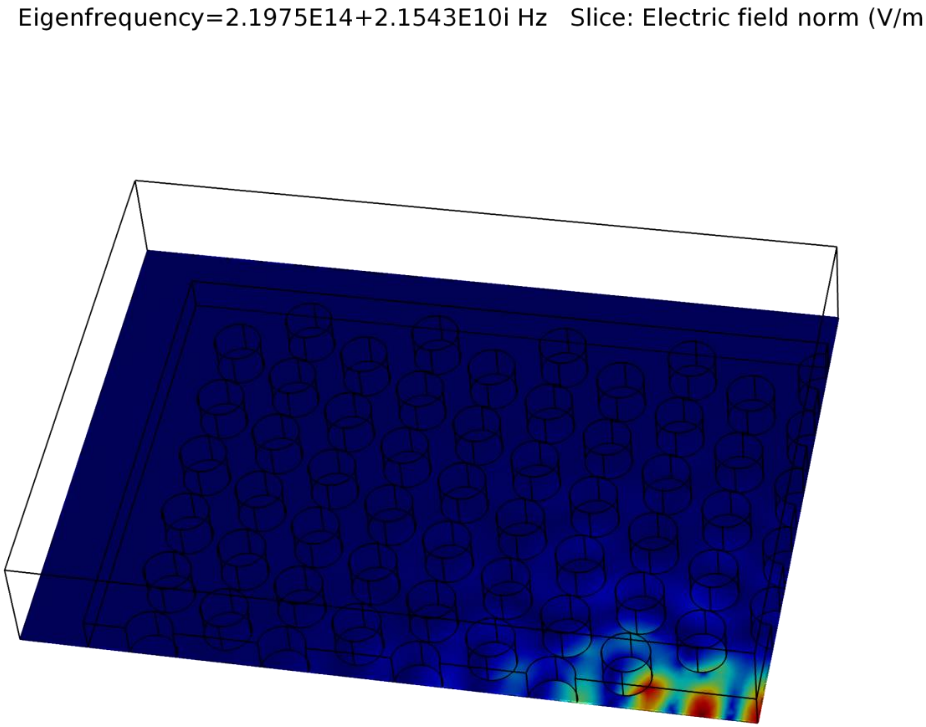
GaAs photonic crystal membrane in air



(no frequency dispersion)

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

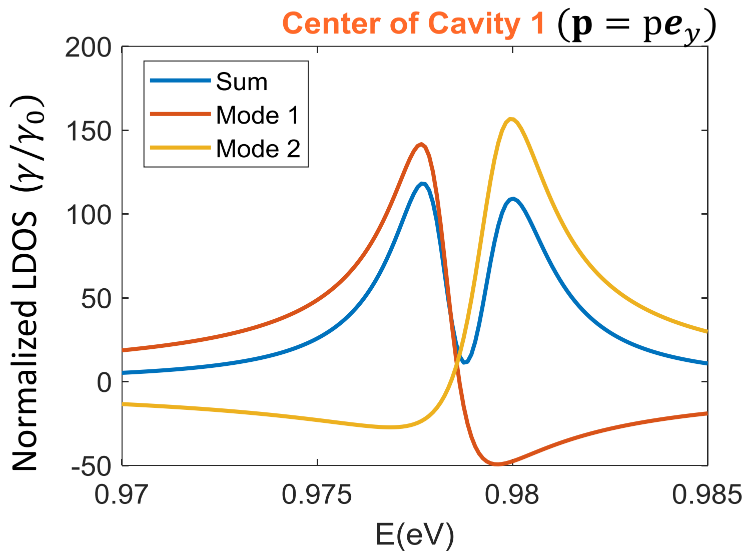
COMSOL model available on the website:
"QNMEig_GaAsPhc.mph"



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

K. G. Cognée et al., Optica **6**, 269 (2019).
"Mapping Complex Mode Volumes with Cavity Perturbation Theory"

Coupled photonic crystal cavities: non-Lorentzian LDOS



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

COMSOL model available on the website:
“QNMEig_PhCcoupled.mph’’
November 2019

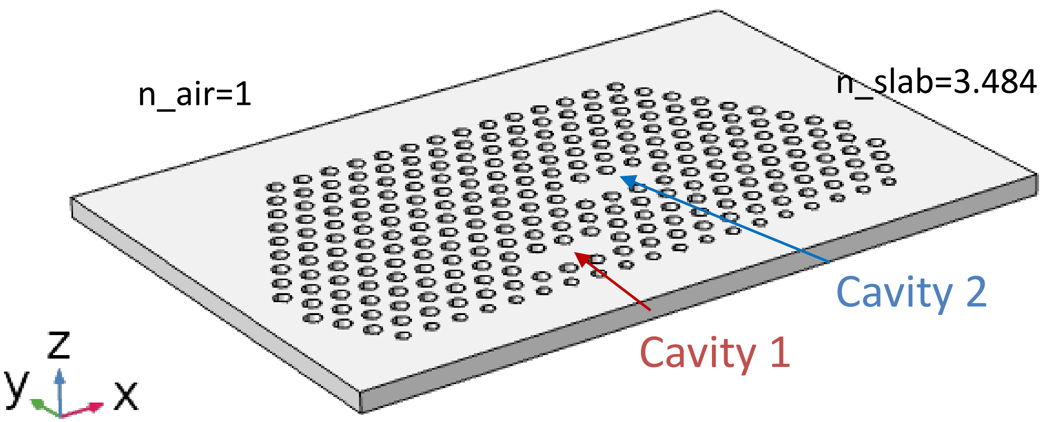
$$\frac{\gamma}{\gamma_0} = \sum_n F_n \frac{\omega}{\Omega_n} \frac{(\Gamma_n/2)^2}{(\omega-\Omega_n)^2 + (\Gamma_n/2)^2}\left(1 + \frac{\mathrm{Im}(\tilde{V}_n)}{\mathrm{Re}(\tilde{V}_n)} \frac{\omega - \Omega_n}{\Gamma_n/2}\right)$$

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

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

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

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

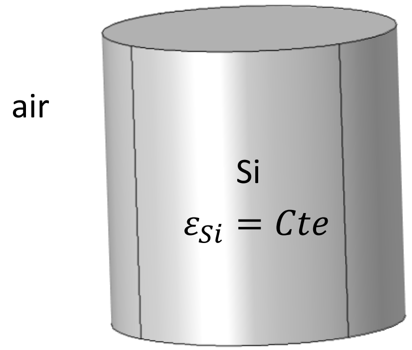


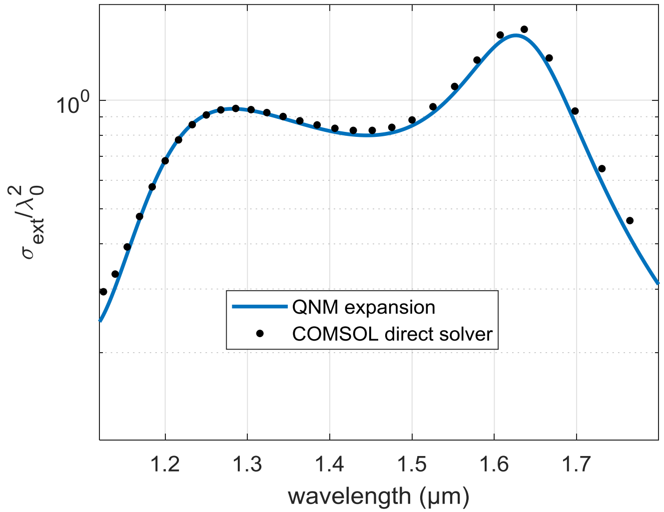
D. Pellegrino et al., Phys. Rev. Lett. **124**, 123902 (2020)
"[Non-Lorentzian Local Density of States in Coupled Photonic Crystal Cavities Probed by Near- and Far-Field Emission]"

Semiconductor nanorod in air

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

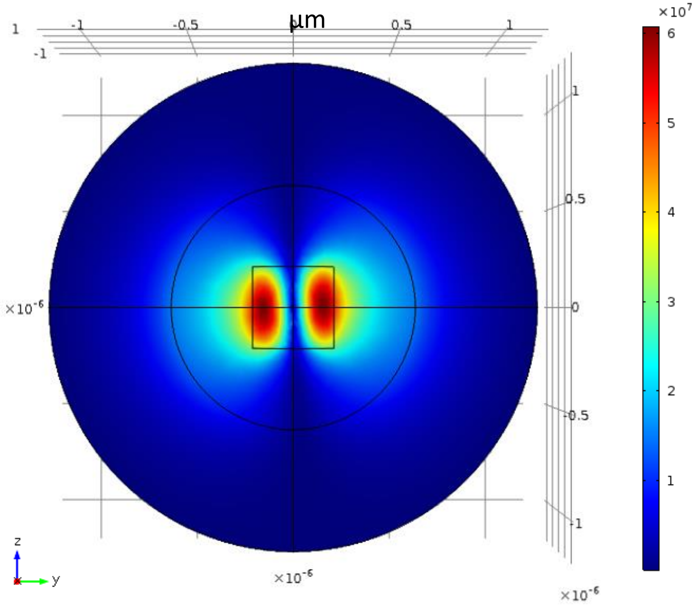
COMSOL model available on the website:
"QNMEig_Nanorod.mph"
January 2019





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.

Electric-field norm of mode with $\tilde{\lambda}$ = 1.652-0.8211i µm

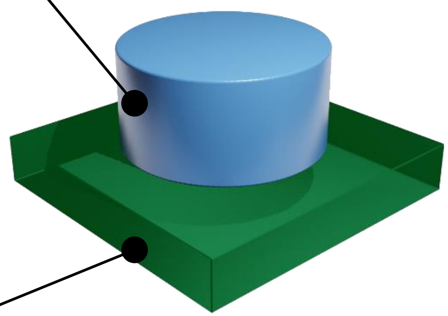


Nonlinear generation in dielectric nanoparticles on substrate

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

COMSOL model available on the website:
“QNMEig_NLnanodisk.mph’’
March 2020

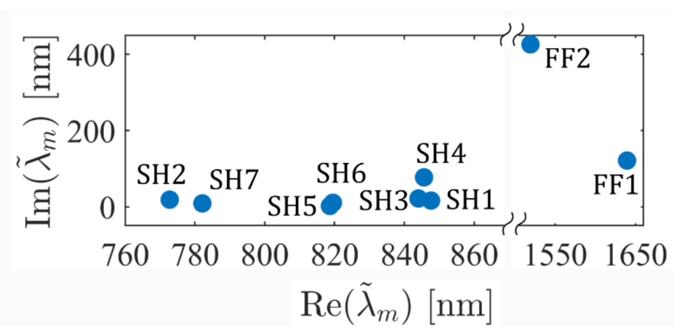
AlGaAs $\varepsilon(\omega) = \varepsilon_\infty\left(1 - \frac{\omega_p^2}{\omega^2 - \omega_0^2 + i\gamma\omega}\right)$

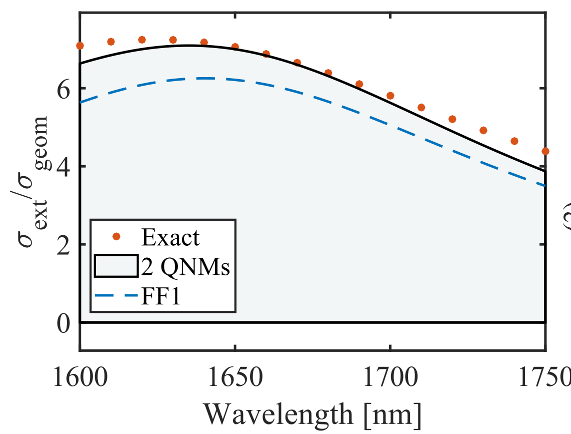


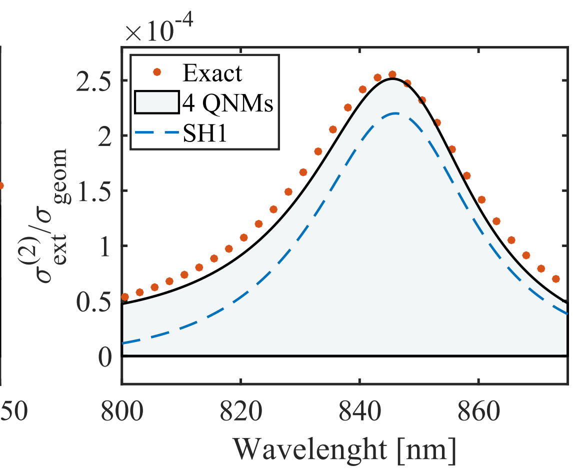
substrate AlOx $n_s = 1.6$

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



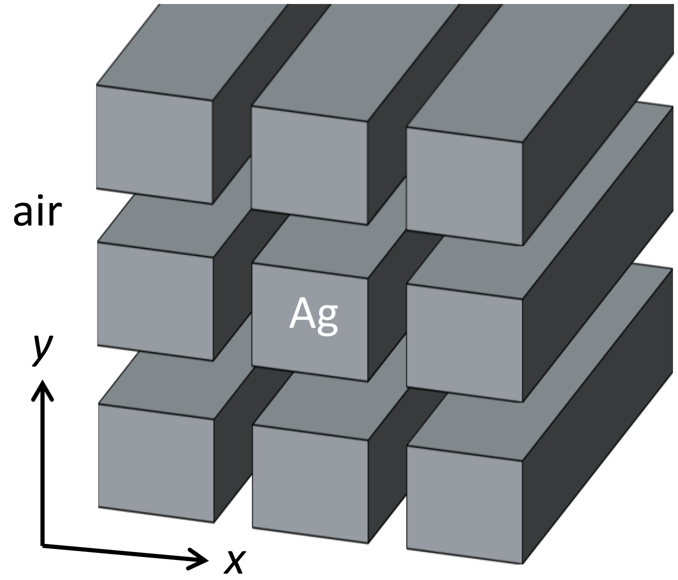




C. Gigli, T. Wu, G. Marino, A. Borne, G. Leo, and P. Lalanne, arXiv 1911.06373 (2019) & ACS Photonics (2020).
"Quasinormal-mode modeling and design in nonlinear nano-optics"

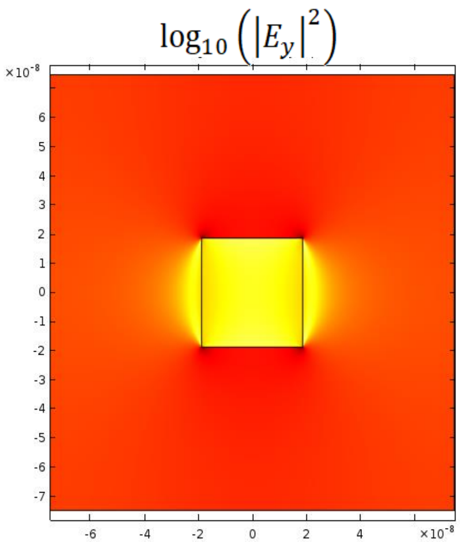
gratings and crystals

2D plasmonic crystal

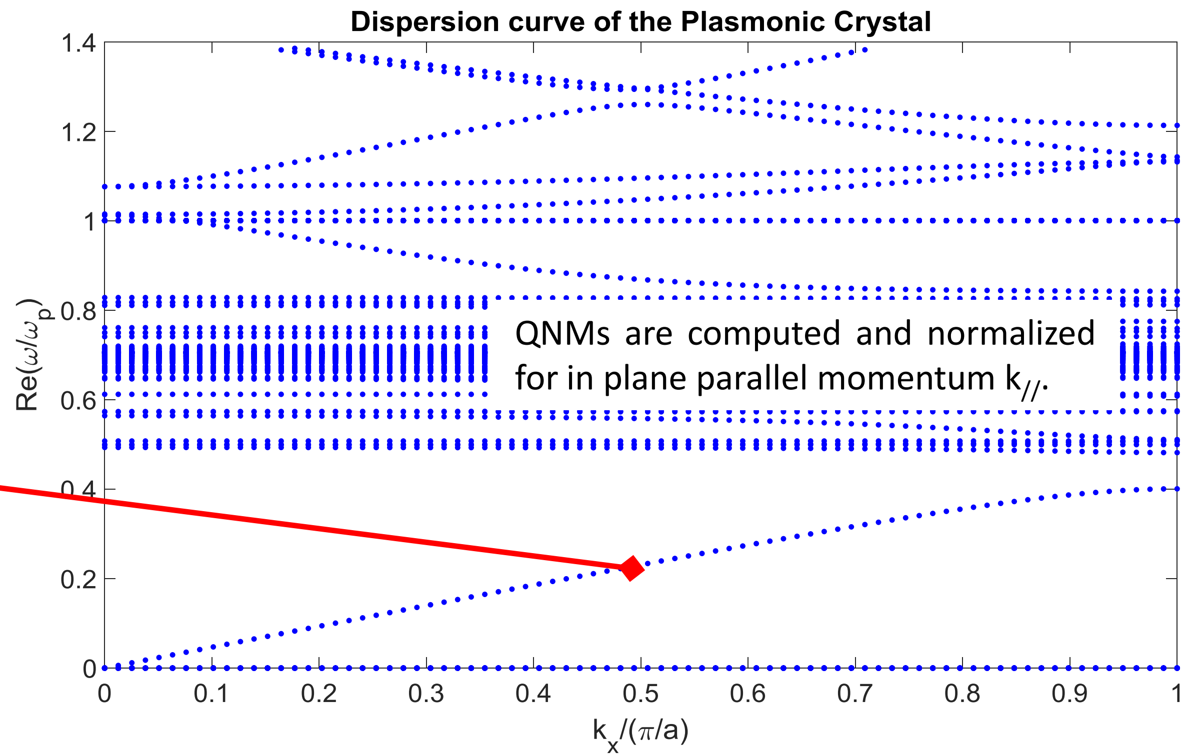


Contact: Wei Yan <yanwei@westlake.edu.cn>

COMSOL model available on the website:
“QNMEig_PlasmCrystal.mph’’

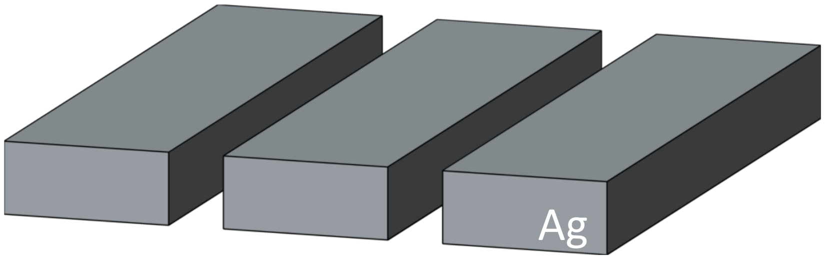


Eigenmode k_x=0.5



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"

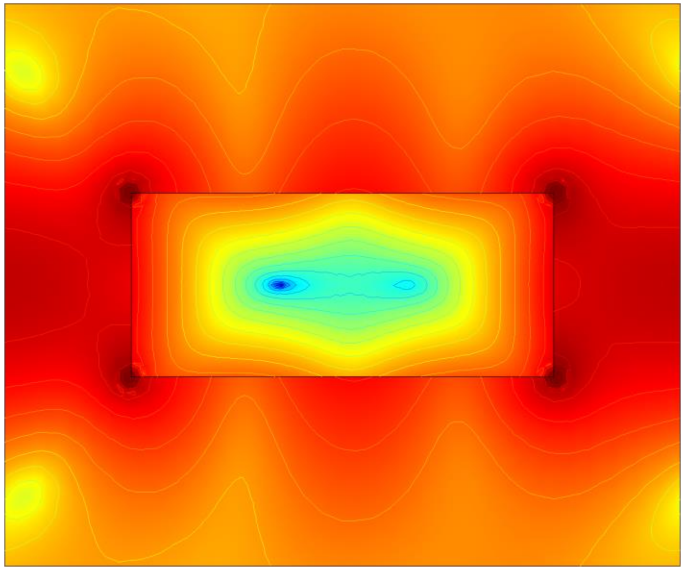
2D periodic slit array in a silver membrane in air



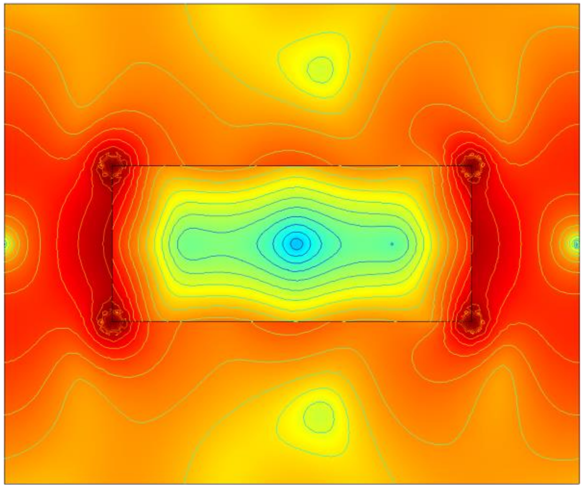
Contact: Alexandre Gras <alexandre.gras@institutoptique.fr>

COMSOL model available on the website:
"QNMEig_1DGrating.mph"

Eigenfrequency=8.7238E14+8.8110E12i Surface: log(emw.normE)
Contour: log(emw.normE)

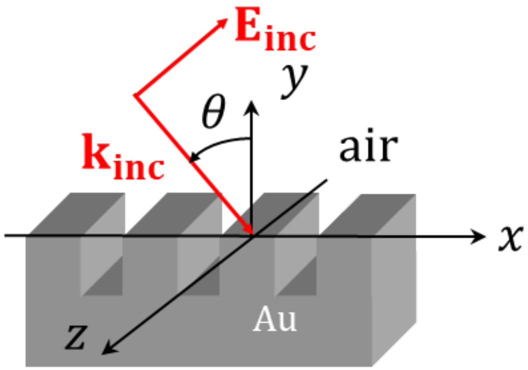


Eigenfrequency=1.1029E15+7.1210E12i Surface: log(emw.normE)
Contour: log(emw.normE)



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"

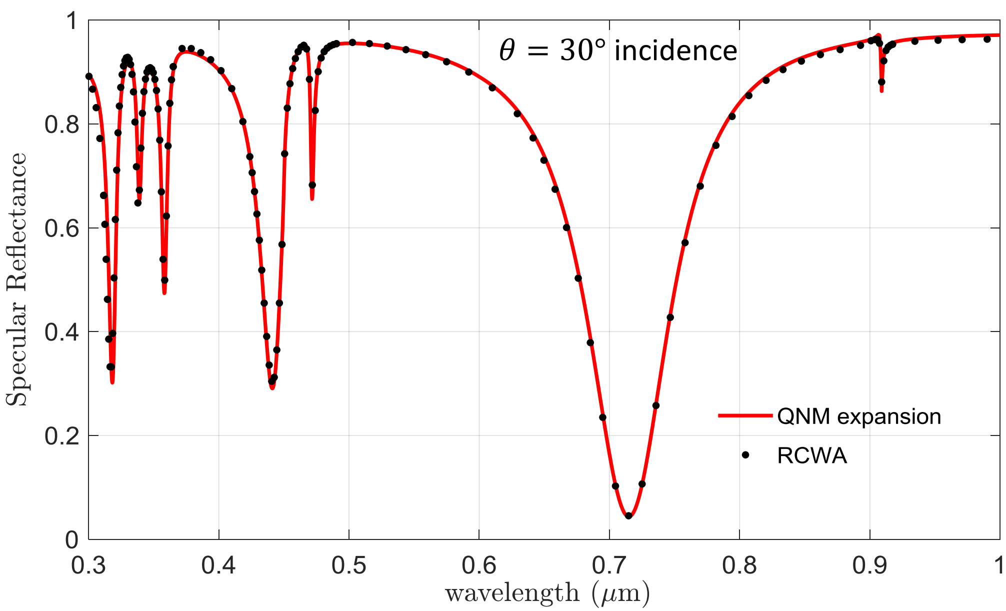
2D grating with grooves on a gold substrate with fixed incidence angle



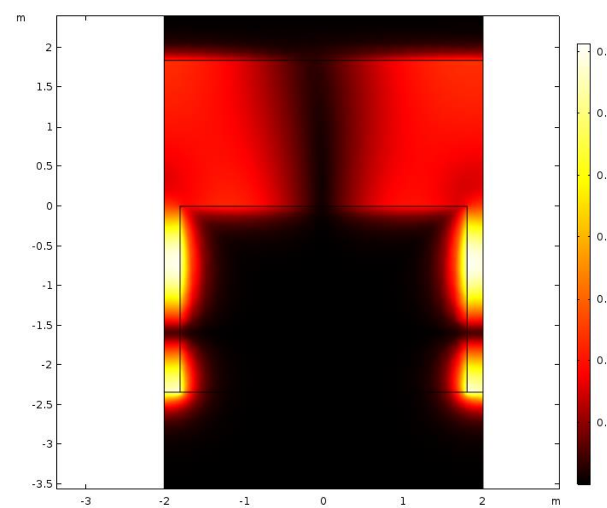
Contact: Alexandre Gras <alexandre.gras@institutoptique.fr>

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 θ, which is exactly what is happening in many experiment: the wavelength is scanned while θ is maintained constant.



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



A. Gras, W. Yan and P. Lalanne, Opt. Lett. **44**, 3494 (2019).
"Quasinormal-mode analysis of grating spectra at fixed incidence angles"

Under preparation, models for

- Bowtie nanoantenna on substate