Tutorial 2

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Photonics-2018

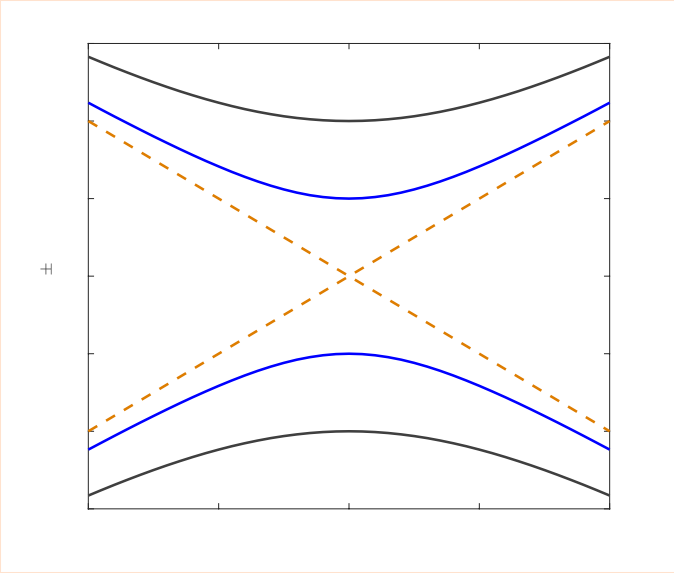
Mode coupling

Coherent perfect absorption

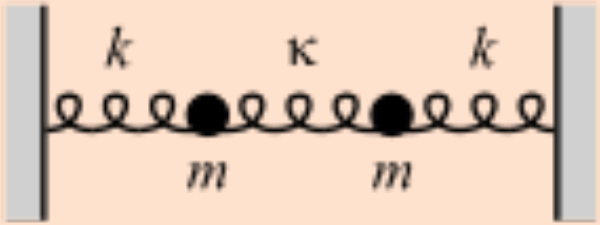
Mode coupling and strong interaction

$$H = \begin{pmatrix} E_1 & V \\ W & E_2 \end{pmatrix}$$

$$E_{\pm} = \frac{E_1 + E_2}{2} \pm \sqrt{\left(\frac{\Delta E}{2}\right)^2 + |V|^2}, \quad \Delta E = E_1 - E_2.$$



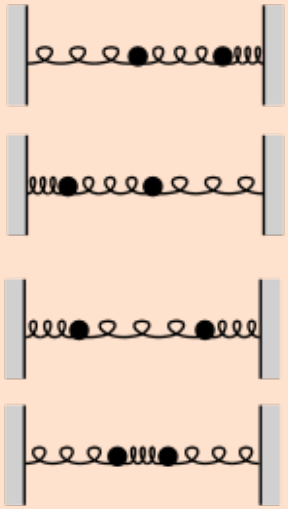
Coupled oscillators and normal modes



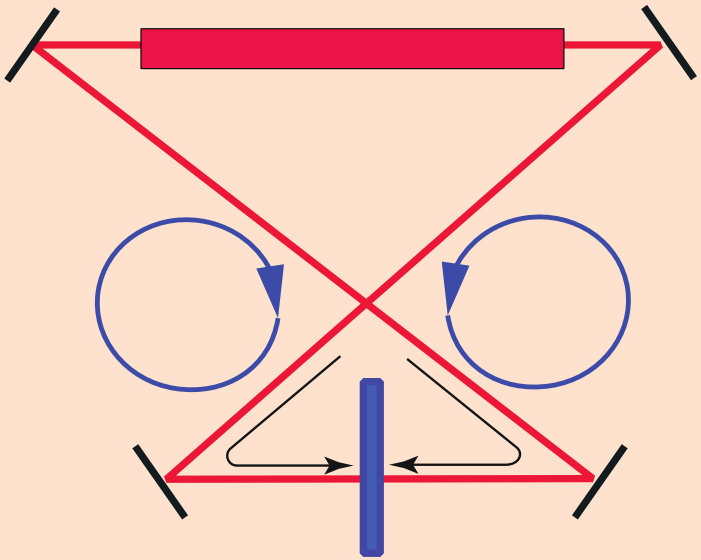
$$
\begin{aligned}
m\ddot{x}_1 &= -kx_1 - \kappa(x_1 - x_2), \\
m\ddot{x}_2 &= -kx_2 - \kappa(x_2 - x_1).
\end{aligned}
$$

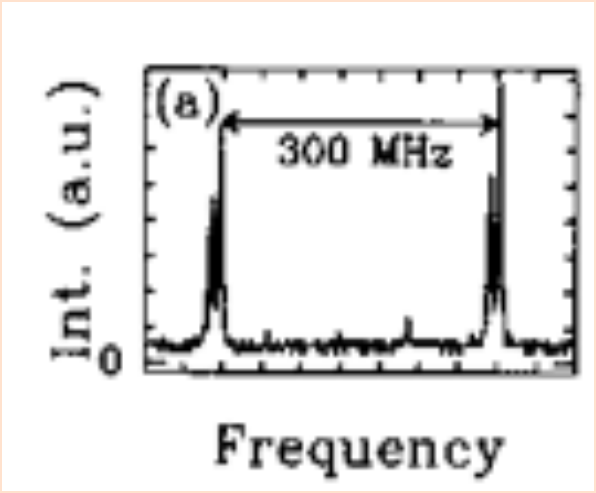
$$\omega_s \equiv \sqrt{\frac{k}{m}}$$

$$\omega_f \equiv \sqrt{\frac{k+2\kappa}{m}}$$



Example: Figure 8 Laser



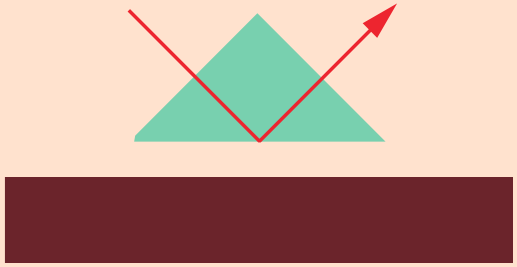


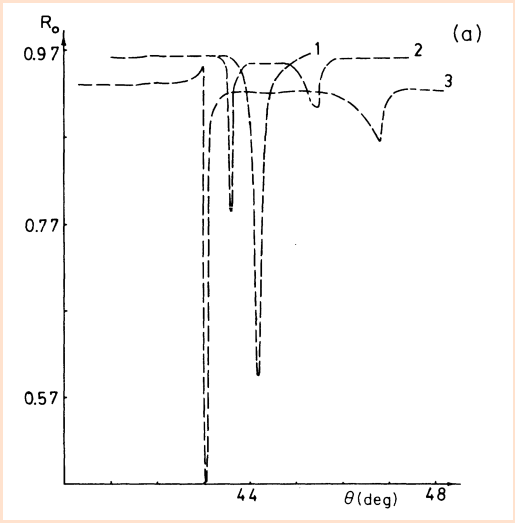
Kramers Degeneracy

Spreeuw et al, PRA 42,1415 (1990)

Example: Coupled plasmons

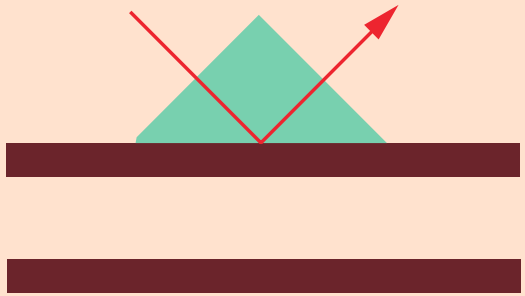
Sarid Geometry

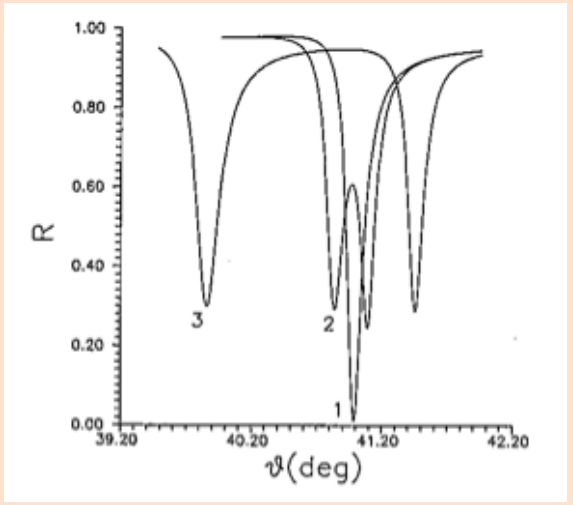




Sarid, PRL 47,1927 (1981)
SDG, GVV, GSA, PR B36, 6331(1987)
MBP, SDG, OL (1990)

Gap Plasmon Guide

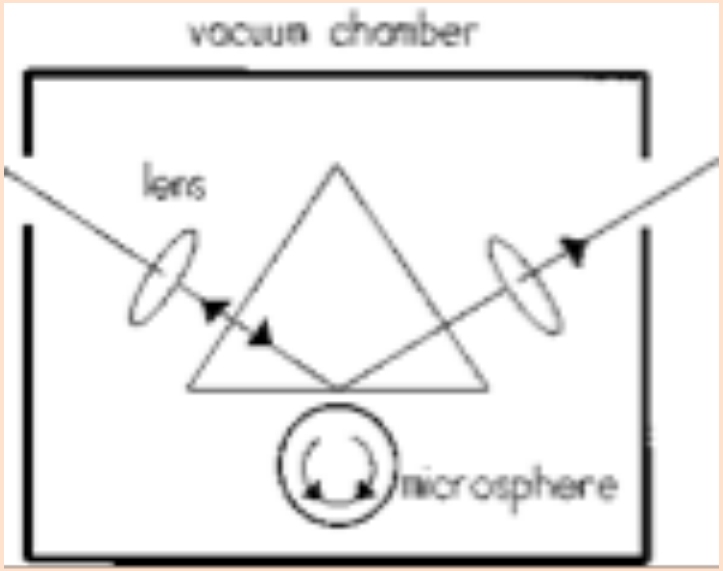


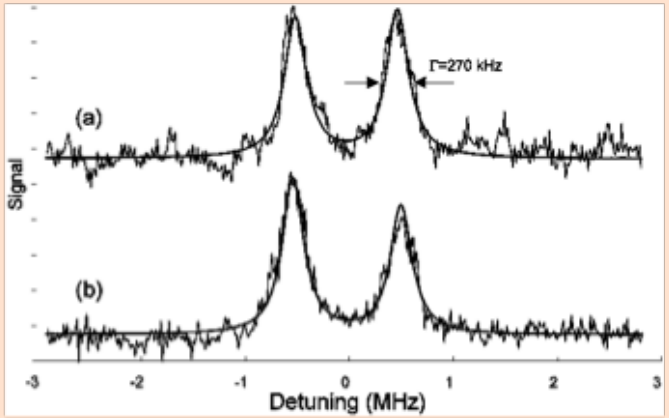


OB, PCM and CPA

Enhanced Transverse Spin

Example: Microsphere

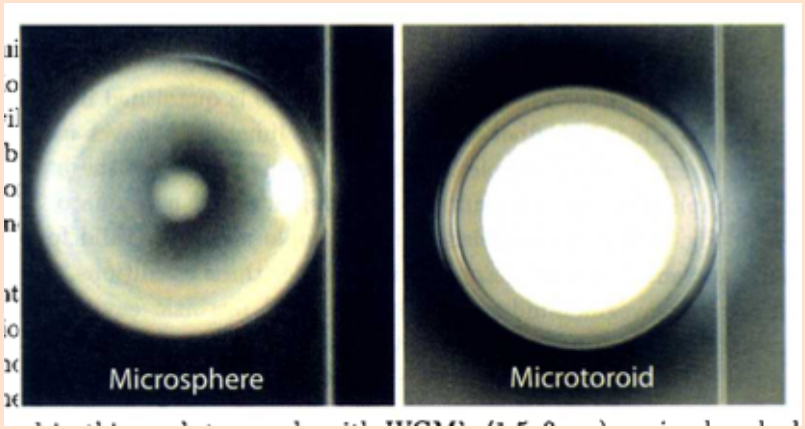


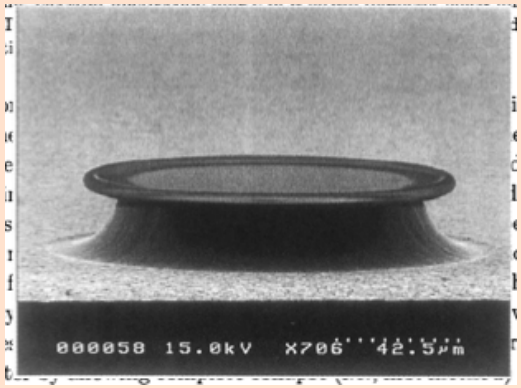


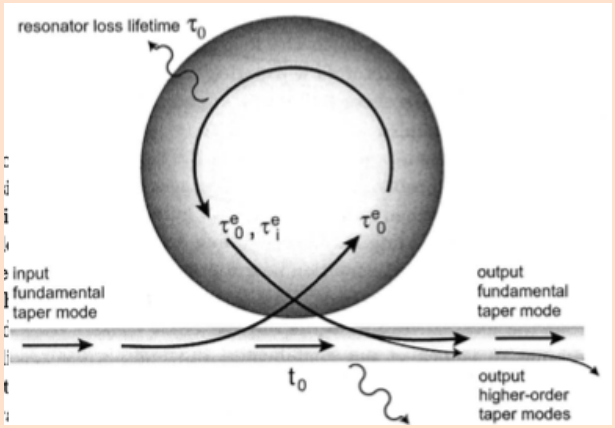
$$\text{Splitting: } \Delta\nu = 1 \text{ MHz};$$
$$\text{Width: } w = 270 \text{ KHz}$$

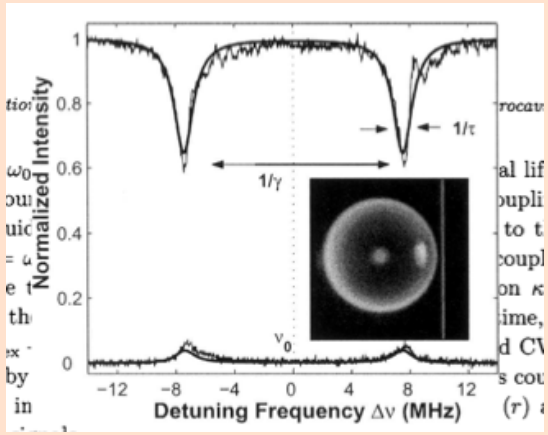
Haroche Group, OL 18,1835 (1995)

Example: Fiber-Microsphere





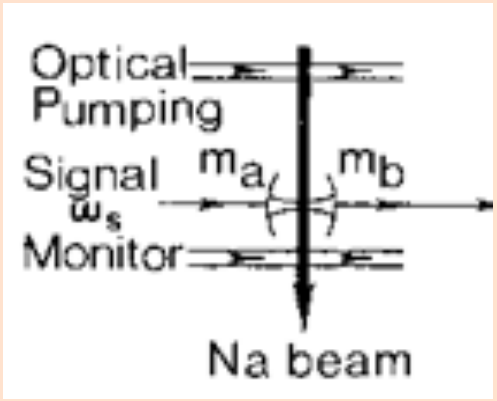


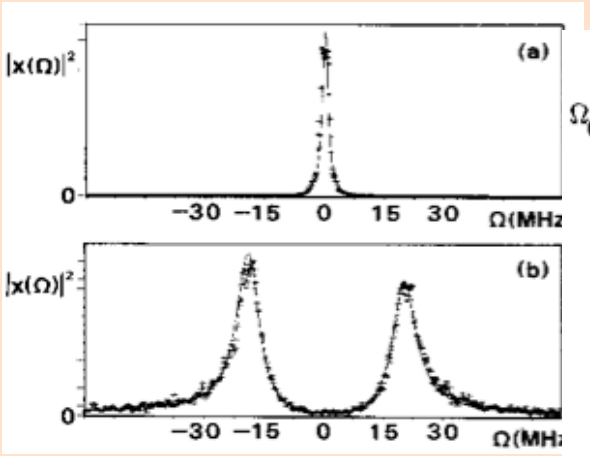


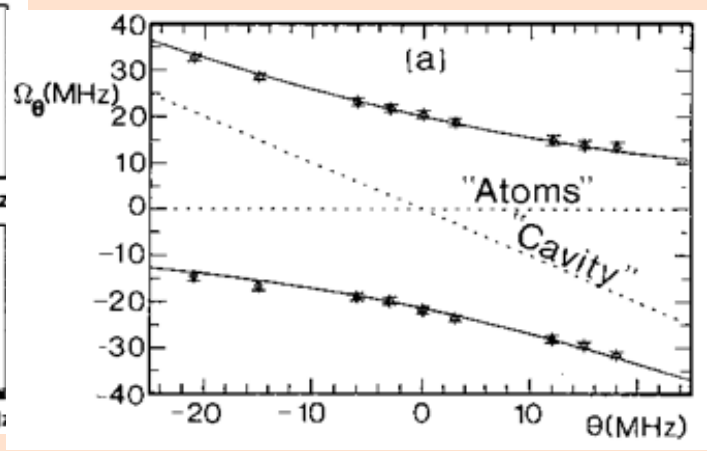
Vahala ed., Optical Microcavities, World Scientific, (2004)

Example: Atom-Cavity Interaction

Vacuum Field Rabi Splittings
Eberly, PRL 1983; Agarwal, PRL 1984





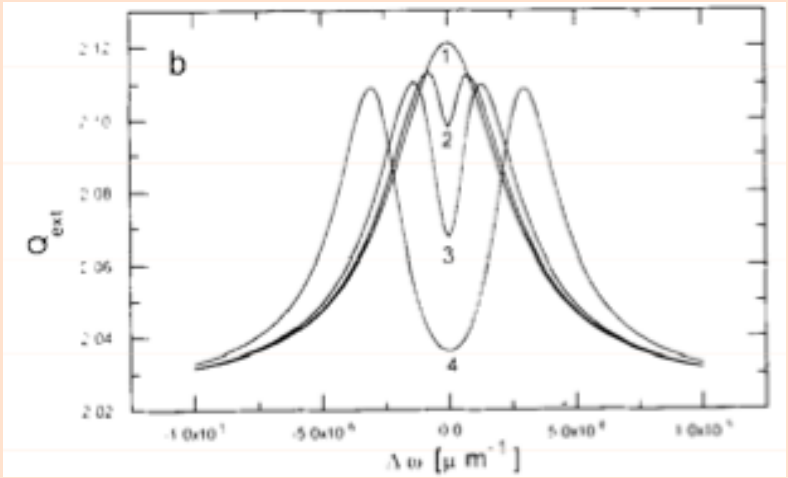


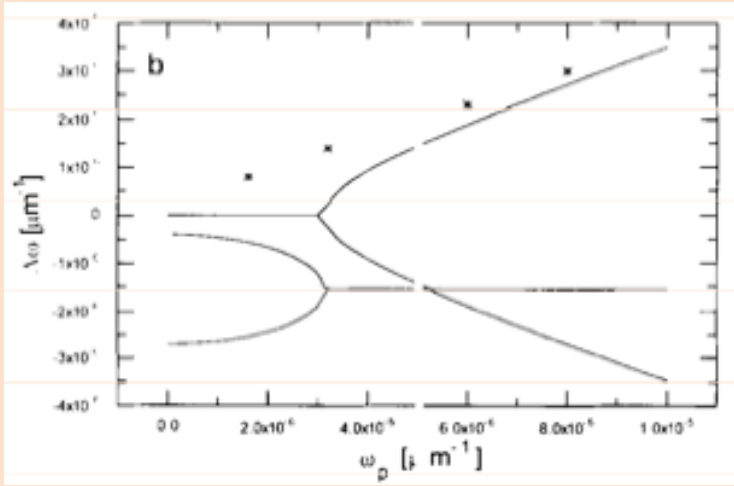
With just 40 Atoms

CALTECH Group: Raizen et al, PRL 63, 240 (1989)

Example: Atom-WGM Interaction

Whispering Gallery Modes of a doped microsphere
Q~10^10





SDG GSA, Opt. Commun 1993, 1995

Strong coupling in overdamped system

nature COMMUNICATIONS

ARTICLE

Received 27 May 2016 | Accepted 15 Nov 2016 | Published 21 Dec 2016

DOI: 10.1038/ncomms13933 OPEN

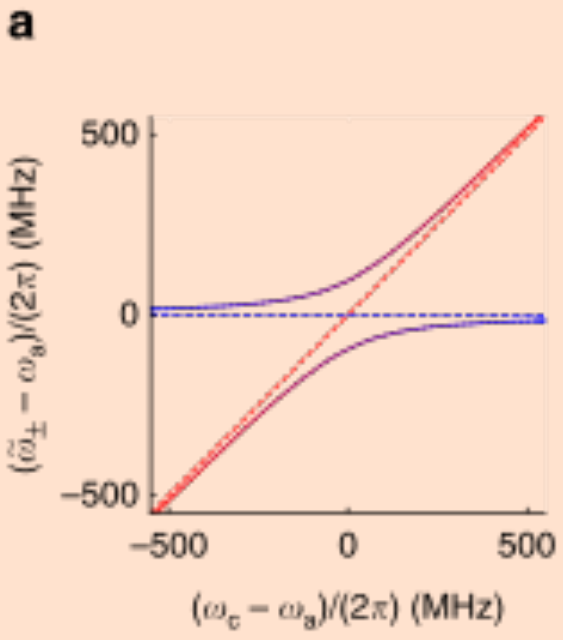
Observing coherence effects in an overdamped quantum system

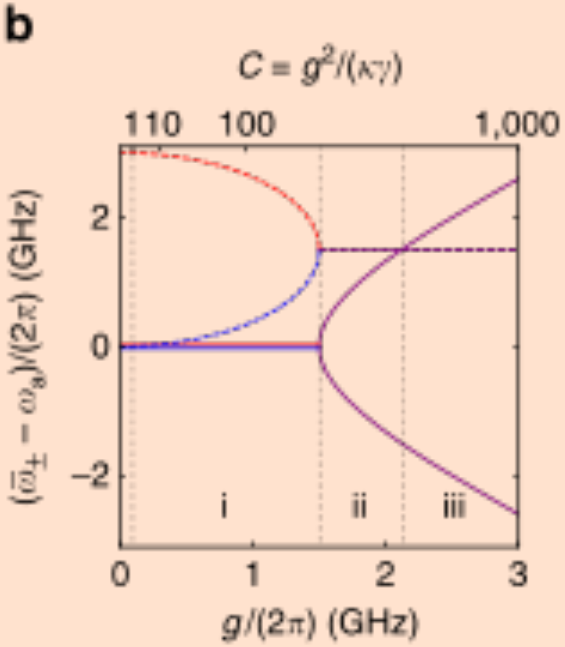
Y.-H. Lien[1,2], G. Barontini[1,2], M. Scheucher[1,3], M. Mergenthaler[1,4], J. Goldwin[2] & E.A. Hinds[1]

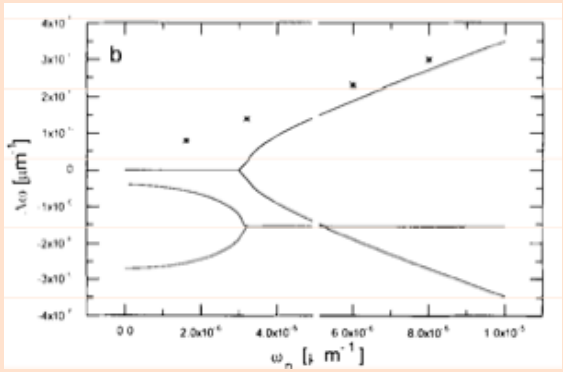
Model and eigenfrequencies

$$\hat{H} = \omega_c \hat{a}^\dagger \hat{a} + \omega_a \hat{\sigma}^\dagger \hat{\sigma} - g(\hat{\sigma}^\dagger \hat{a} + \hat{\sigma} \hat{a}^\dagger).$$

$$\omega_\pm - \omega_a = \frac{\omega_c - \omega_a}{2} \pm \sqrt{g^2 + \left(\frac{\omega_c - \omega_a}{2}\right)^2}.$$







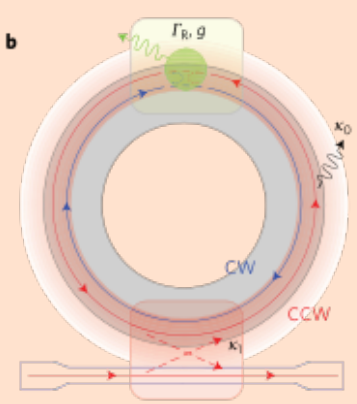
1995,
Microsphere

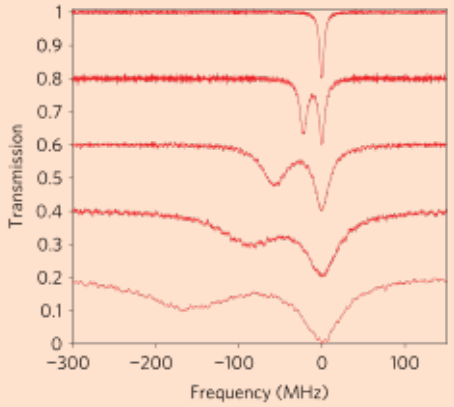
Counting Nano Particles

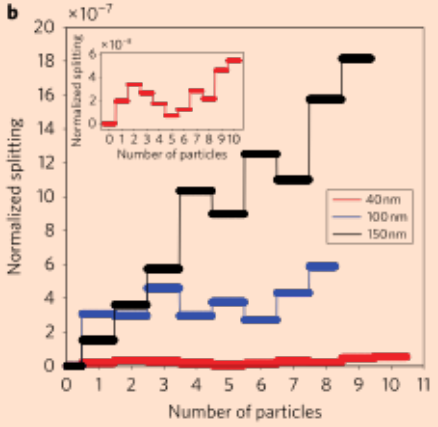
LETTERS
PUBLISHED ONLINE: 13 DECEMBER 2009 | DOI: 10.1038/NPHOTON.2009.237
nature photonics

On-chip single nanoparticle detection and sizing by mode splitting in an ultrahigh-*Q* microresonator

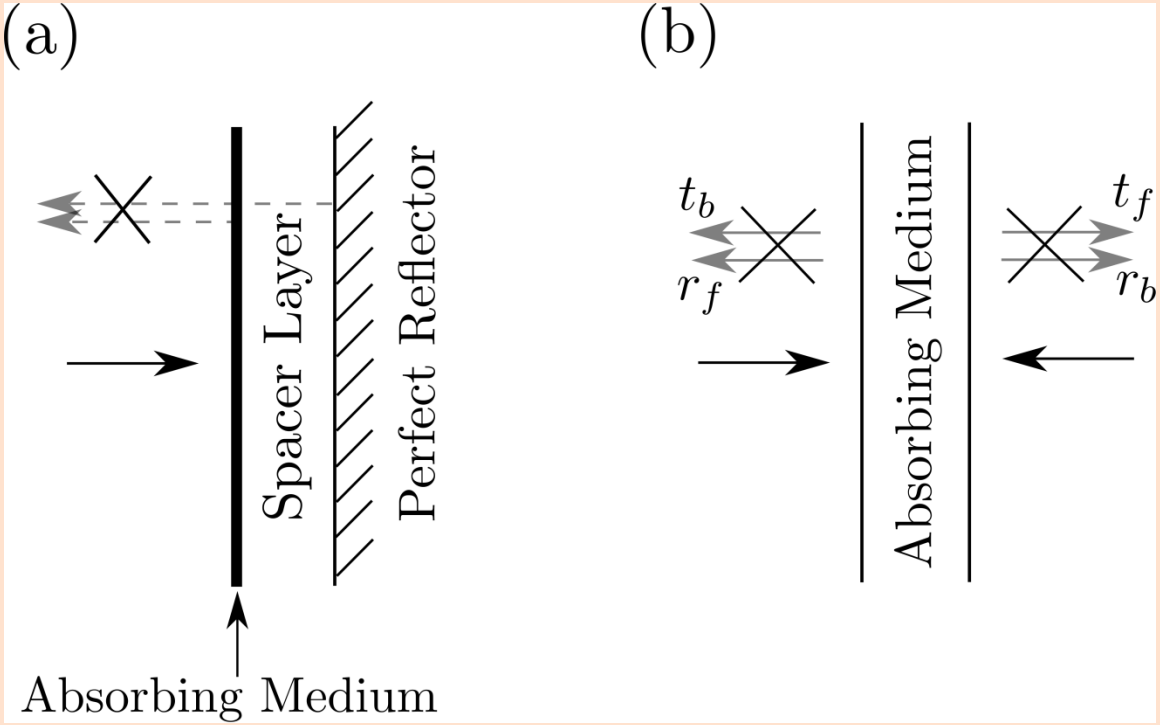
Jiangang Zhu[1], Sahin Kaya Ozdemir[1], Yun-Feng Xiao[1†], Lin Li[2], Lina He[1], Da-Ren Chen[2] and Lan Yang[1*]







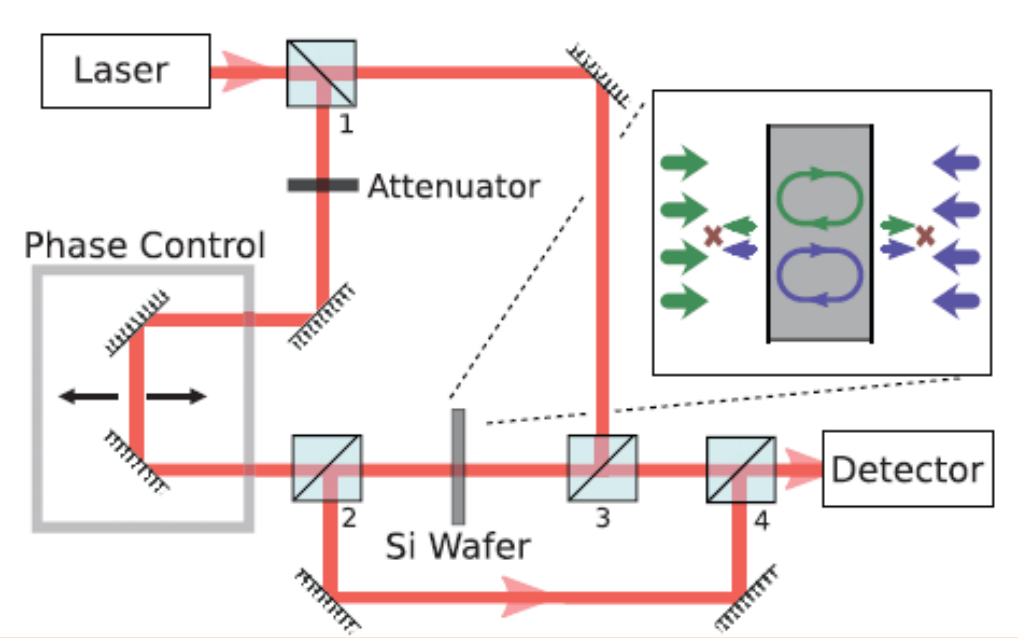
Critical coupling and Coherent perfect absorption

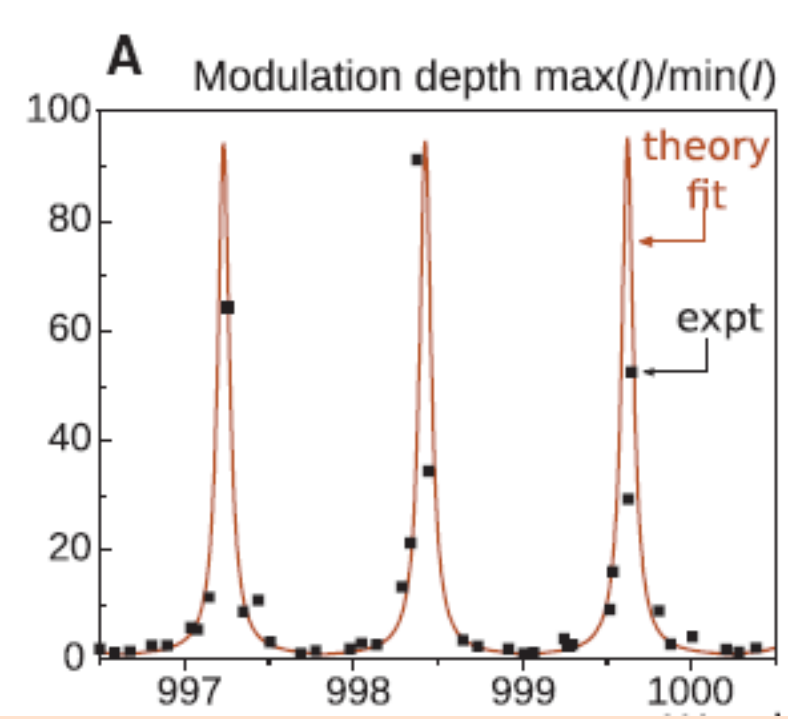


Critical coupling **Coherent perfect absorption**

SDG, NG, AB, Wave Optics, CRC 2015

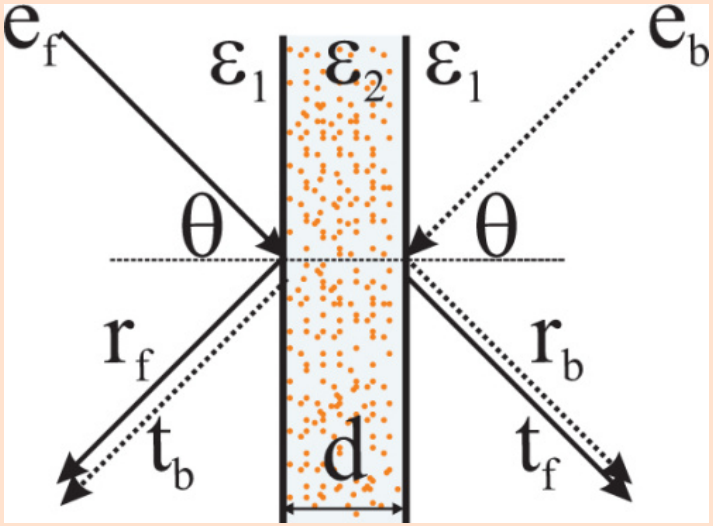
Time-Reversed Lasing and Interferometric Control of Absorption

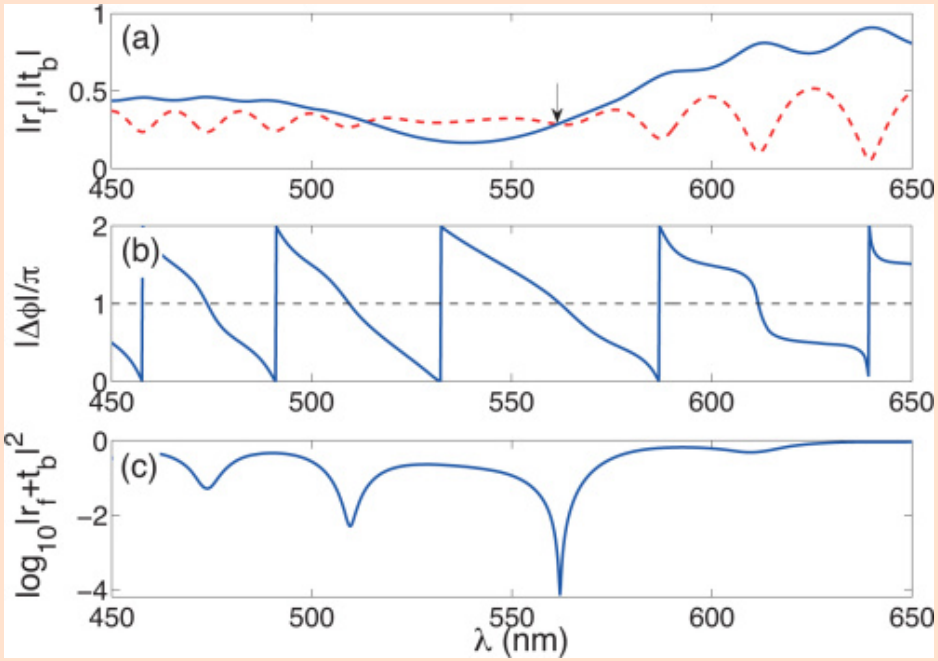




W Wan, Y D Chong , L Ge, H Noh, A D Stone and H Cao, Science 331, 889892 (2011).

Coherent perfect absorption in a composite film

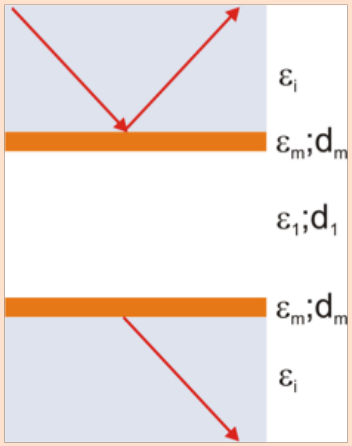




Condition for CPA: $|r| = |t|$ and $\Delta\phi = \arg(r) - \arg(t) = \pi$

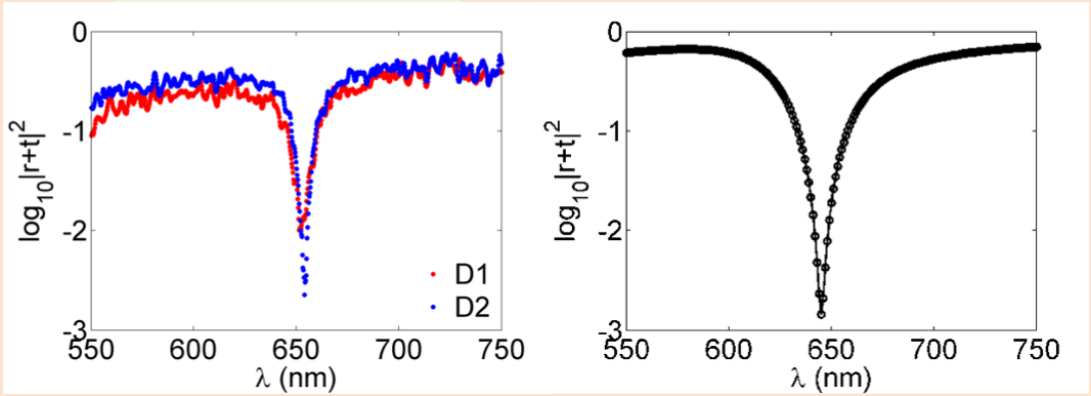
S. Dutta-Gupta, O J F Martin, S. Dutta Gupta and G S Agarwal, Opt. Express **20**, 1330 (2012).

Gap plasmon structure: Experiment & Theory

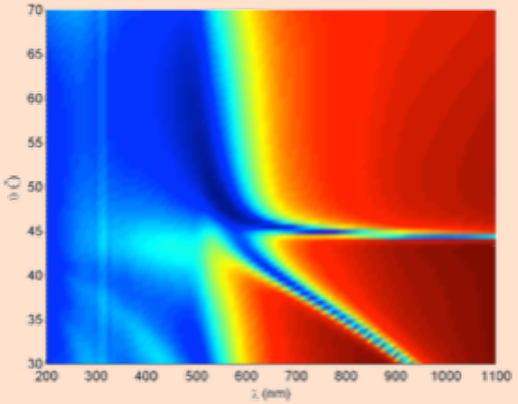


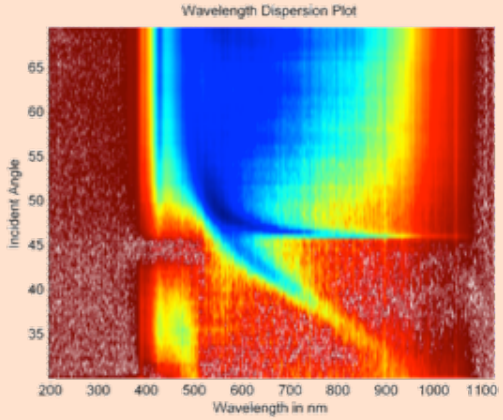
Experiment

Theory



Theory

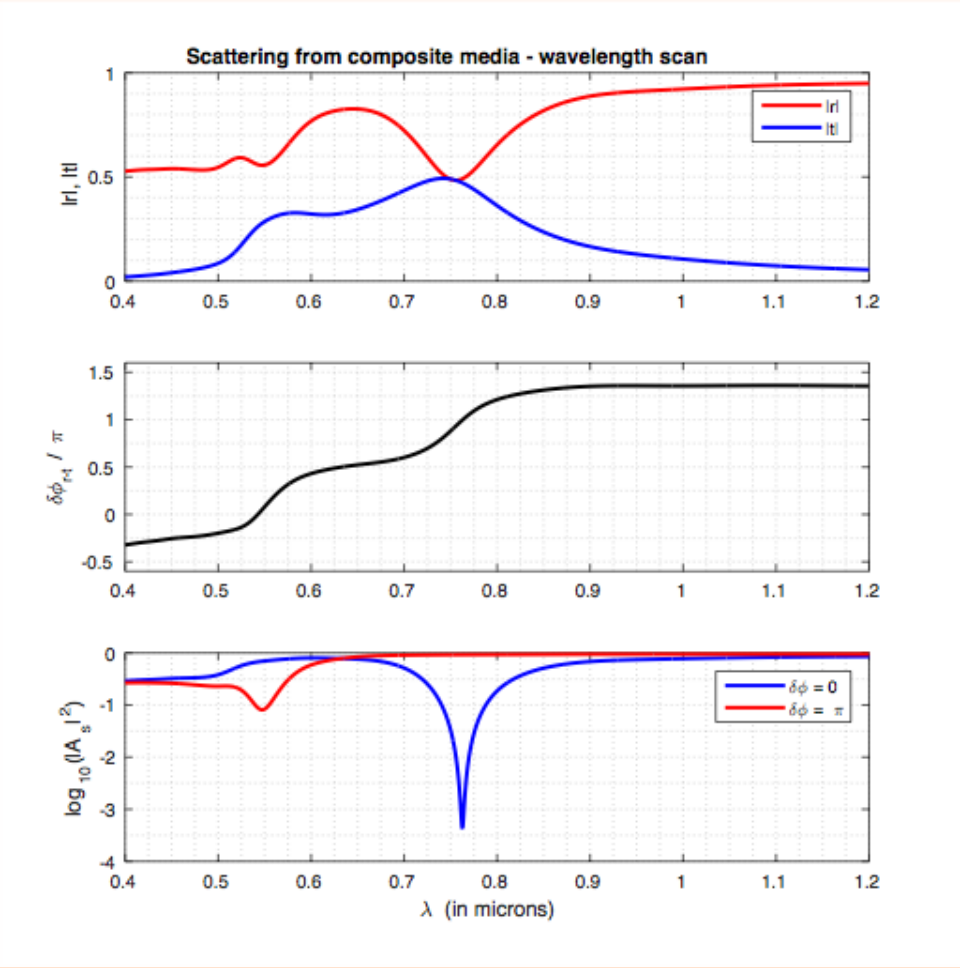




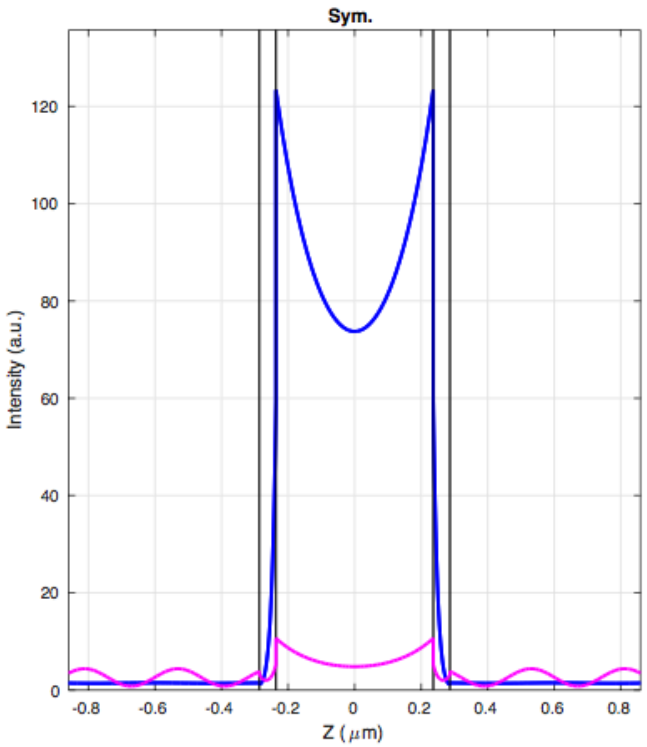
Experiment

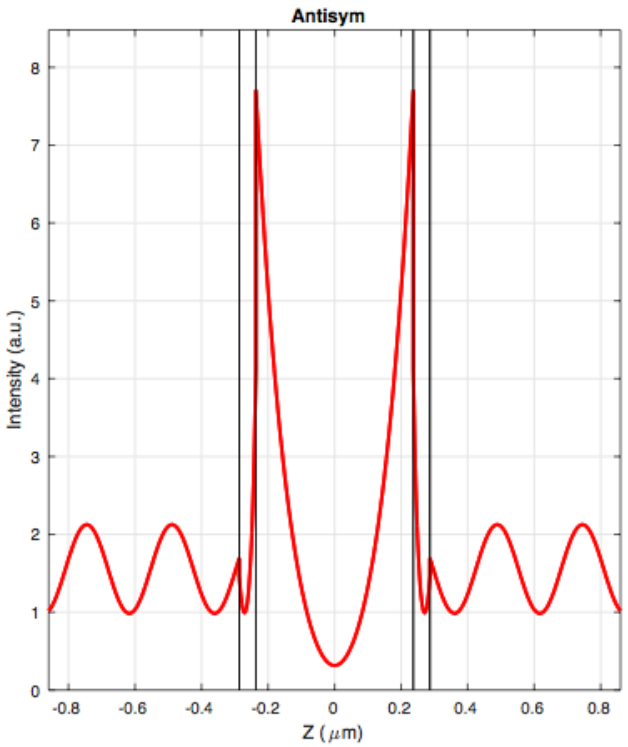
$$SiO_2 - Au(40nm) - Air(580nm) - Au(40nm) - SiO_2$$

Selective Excitation with CPA



CPA mediated field enhancement

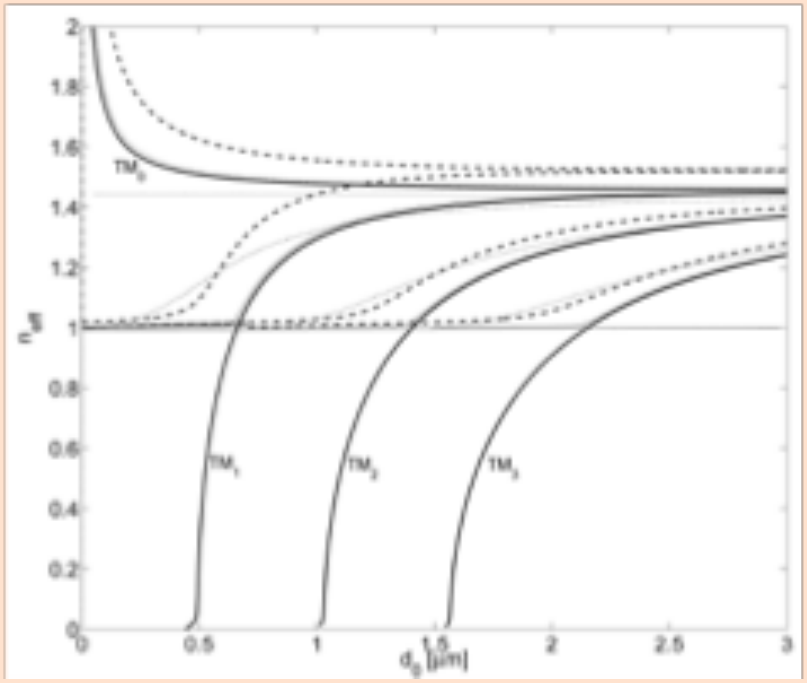


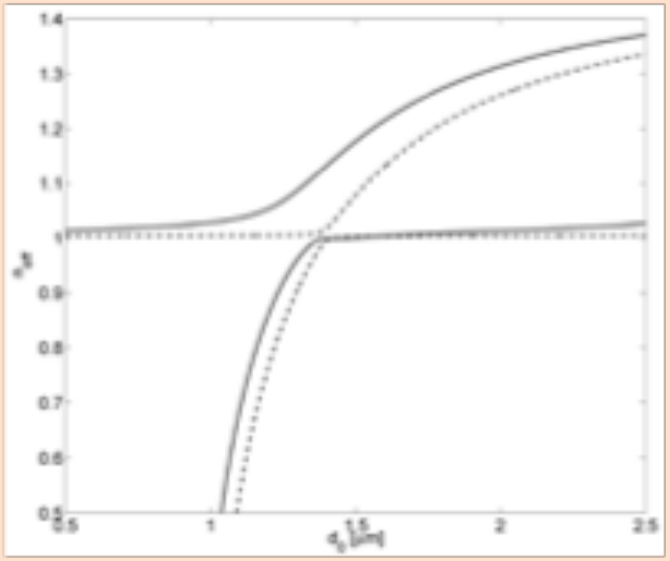


blue: CPA

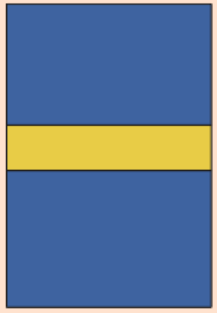
purple: away from CPA

Avoided crossing in a gap plasmon guide

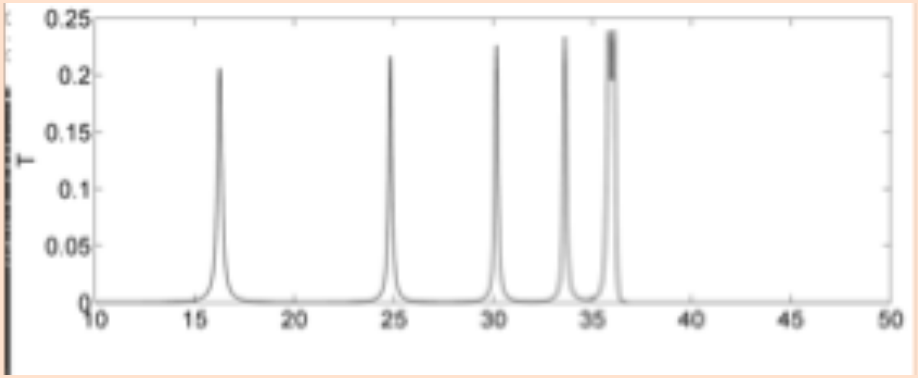




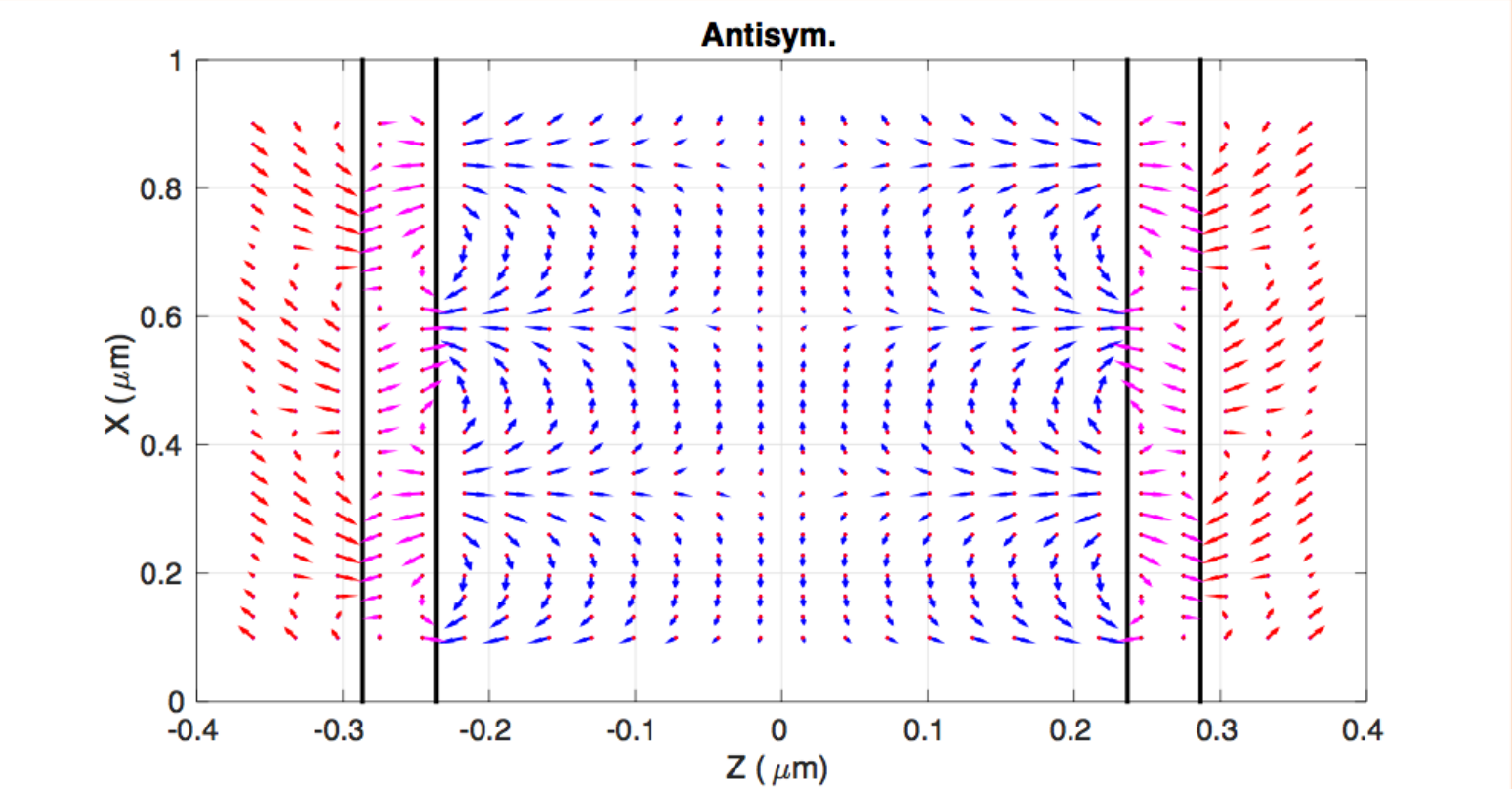

air-diel-air


m-d-m

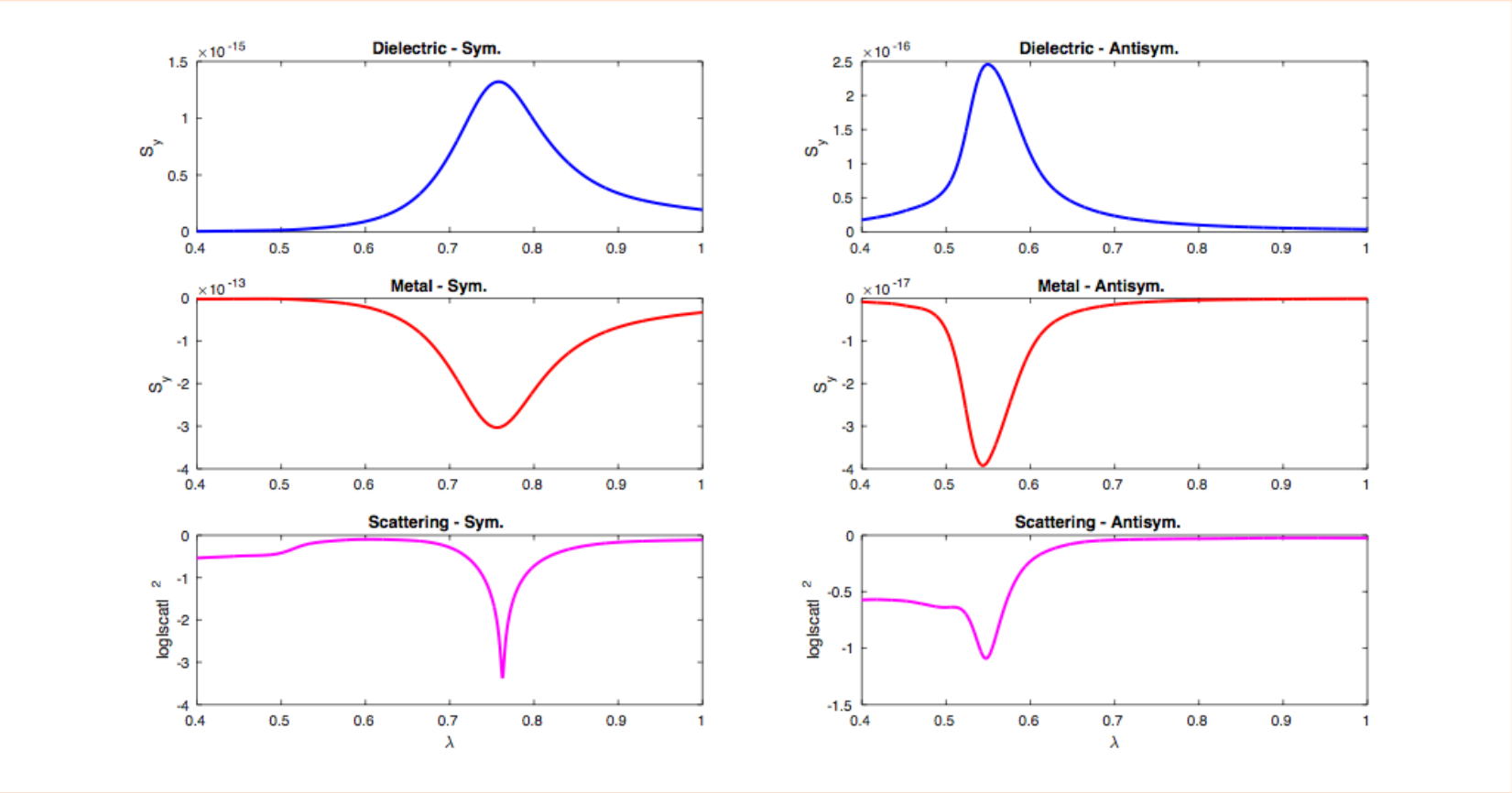

air-m-d-m-air



Antisymmetric mode: quiver plot of E



Spin angular momentum density

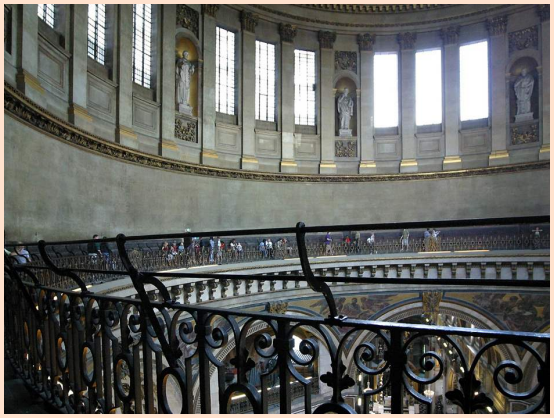


Samyo, SDG, EPJAP 2016 - EPN Highlights http://dx.doi.org/10.1051/epjap/2016160330

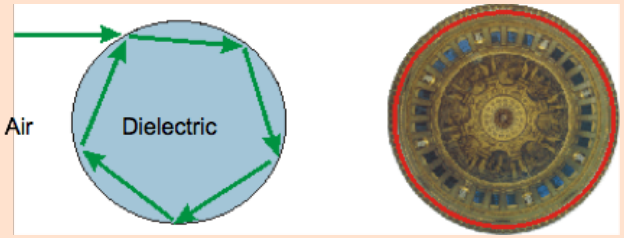
Whispering Gallery modes (WGM)

- Whispering Gallery phenomenon - by Lord Rayleigh based on observations in St. Paul's Cathedral in London
- A whisper spoken close to the wall can be heard all the way along the gallery: Hence "whispering gallery"

Lord Rayleigh
(1842 – 1919)



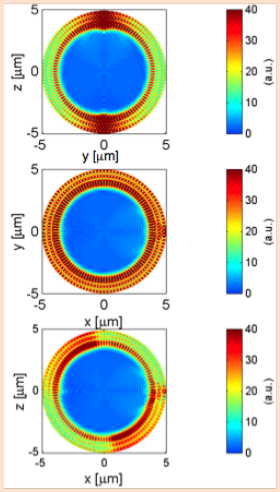
Whispering Gallery under the cupola of the St. Paul's Cathedral in London



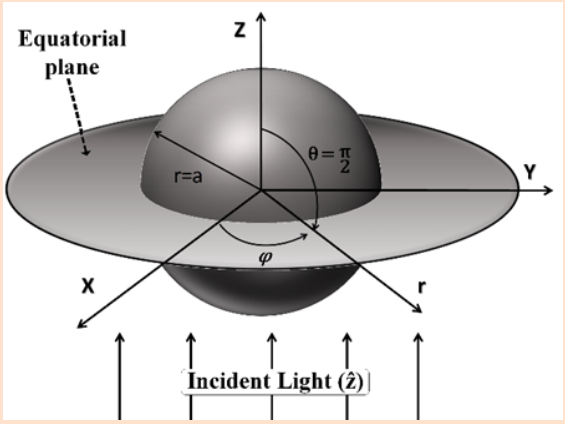
Dome of the St. Paul's Cathedral

- Extra high (10^10) Quality factor in visible
- Spatial localization – low mode volume
- Large local field enhancements

APPLICATIONS in Nonlinear Optics and Cavity QED



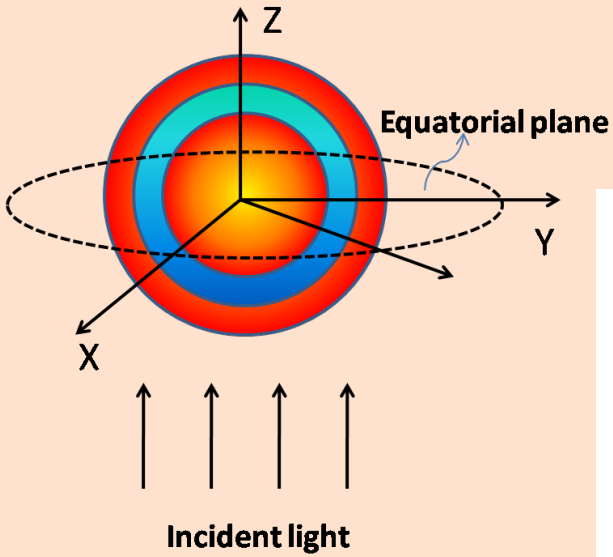
A single metallic / dielectric sphere

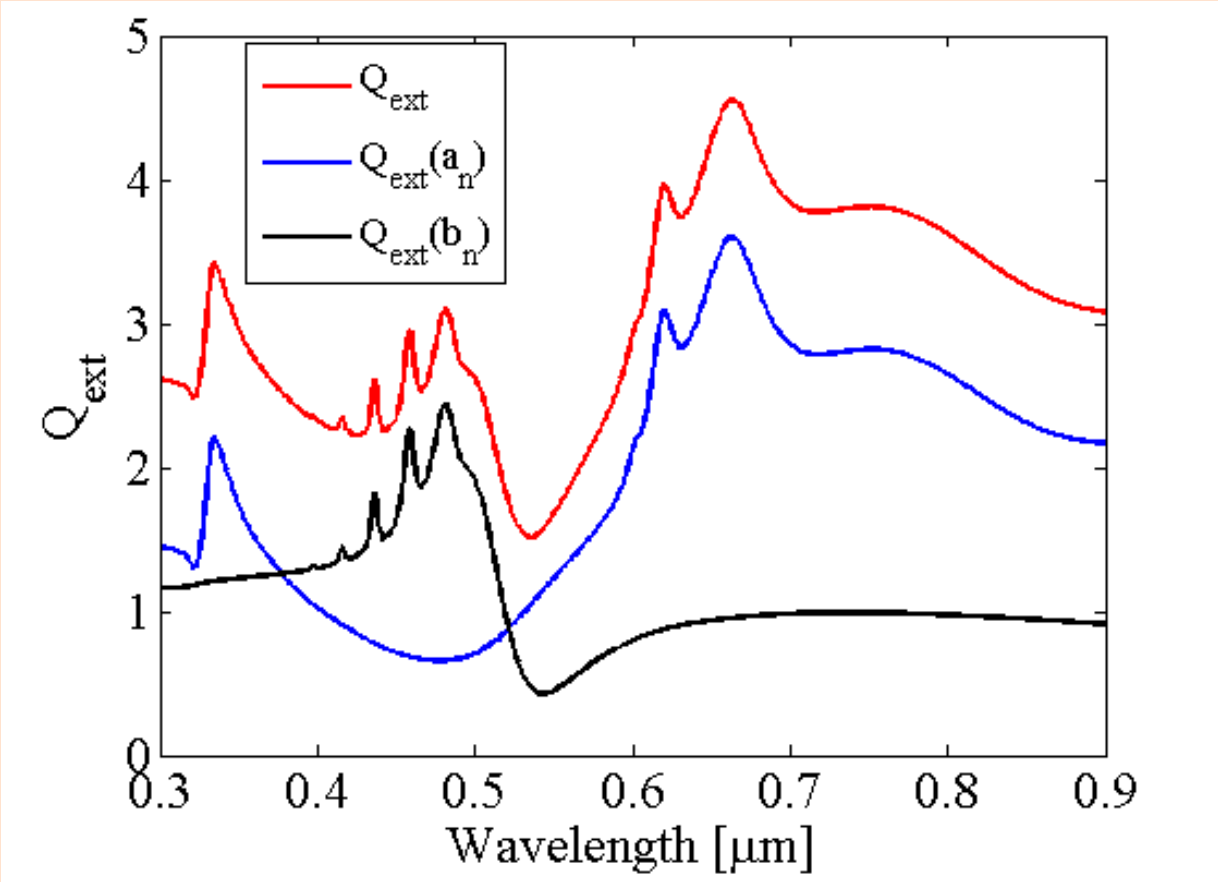


$$\mathbf{E}_s = \sum_{n=1}^{\infty} E_n (i a_n \mathbf{N}_{e1n}^{(3)} - b_n \mathbf{M}_{o1n}^{(3)}),$$

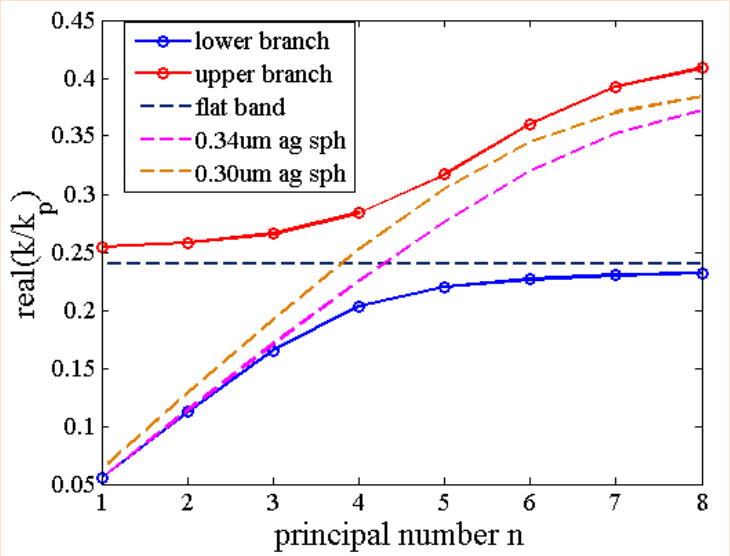
$$\mathbf{H}_s = \frac{k}{\omega\mu} \sum_{n=1}^{\infty} E_n (i b_n \mathbf{N}_{o1n}^{(3)} + a_n \mathbf{M}_{e1n}^{(3)}),$$

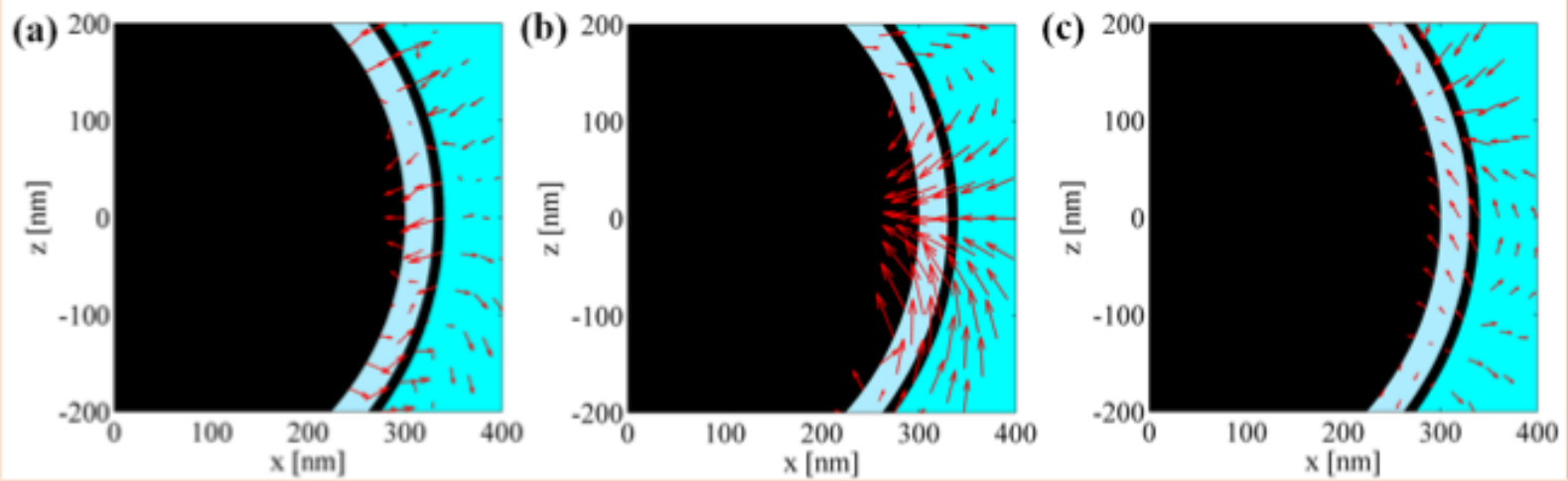
Metal-dielectric-metal nanosphere





Dispersion and Transverse Spin in MDM sphere





Field circulation

Strongly coupled systems and applications