Top

Left side

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the lectures pdfs are available at:

https://www.physics.umd.edu/rgroups/amo/orozco/results/2022/Results22.htm

Correlations in Optics and Quantum Optics; A series of lectures about correlations and coherence. November 2022

Luis A. Orozco
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BOS.QT

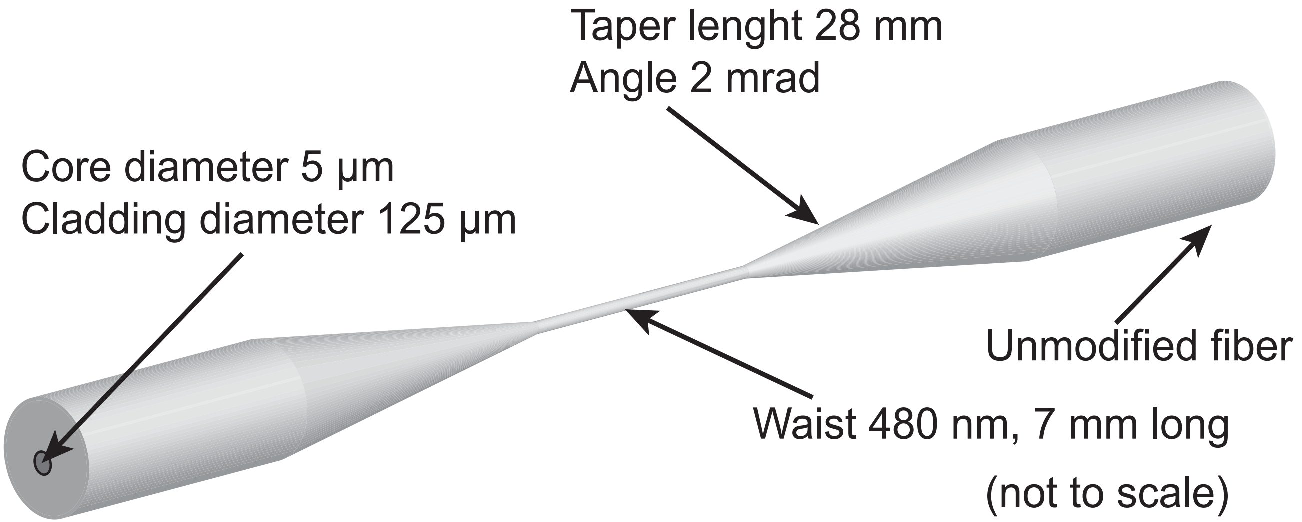
Lesson 10

Tentative list of topics to cover:

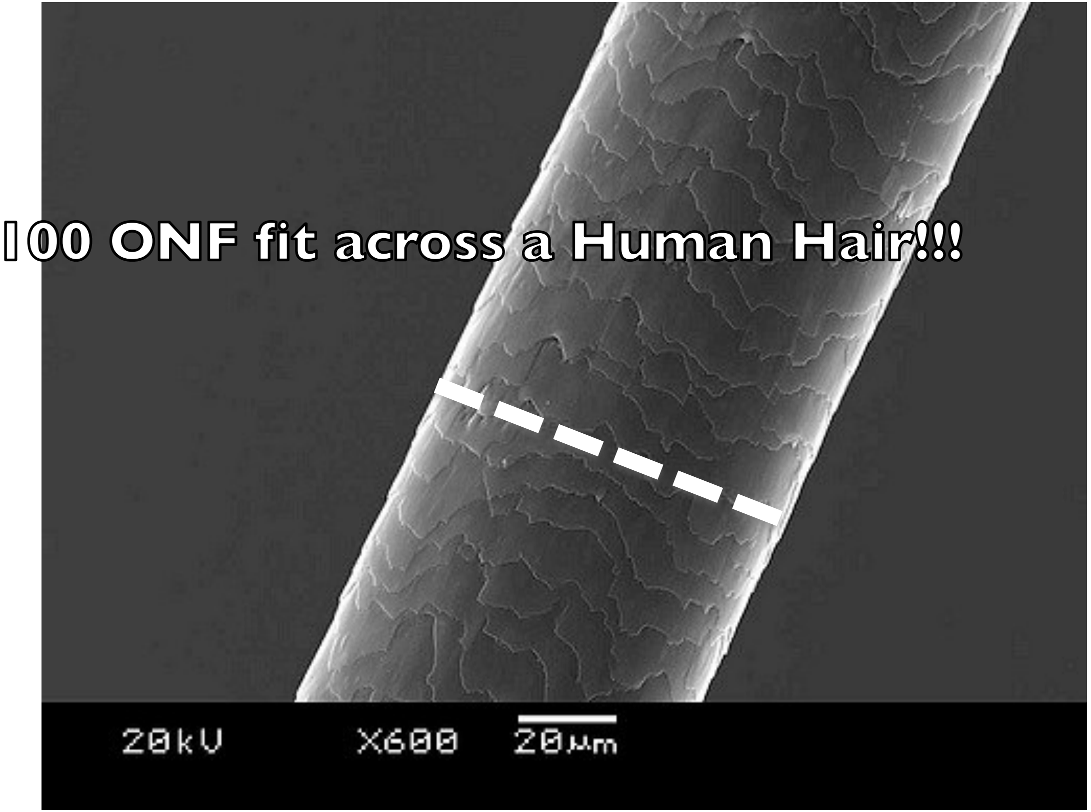
- From statistics and linear algebra to power spectral densities
- Historical perspectives and examples in many areas of physics
- Correlation functions in classical optics (field-field; intensity-intensity; field-intensity) part iii
- Optical Cavity QED
- Correlation functions, quantum examples
- Correlations and conditional dynamics for control
- Correlations of the field and intensity
- From Cavity QED to waveguide QED.

From Cavity QED to Waveguide QED

Optical Nanofibers

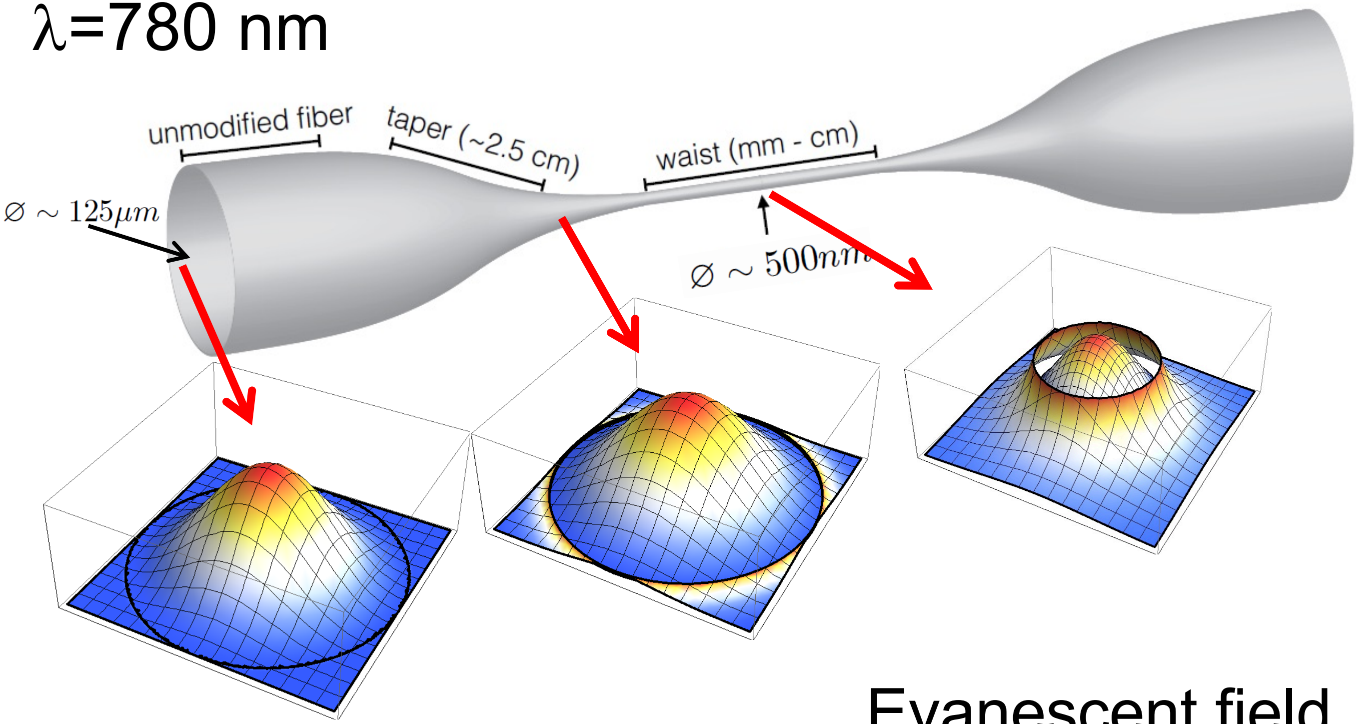


The scale



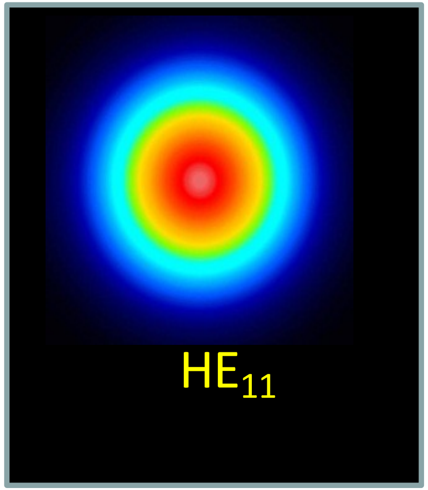
Optical Nanofibers

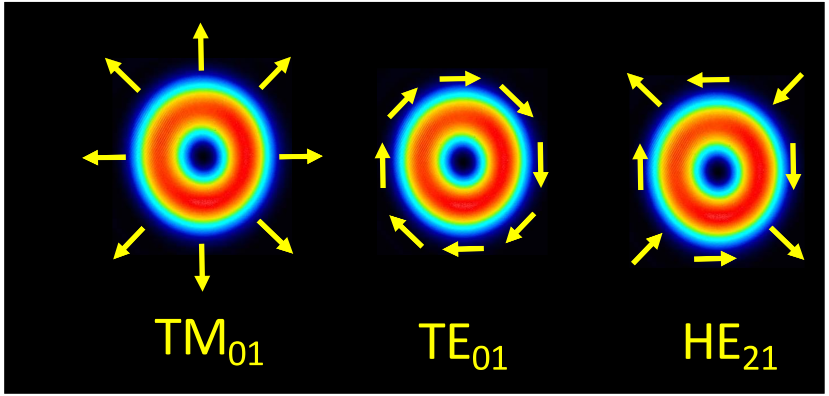
λ=780 nm



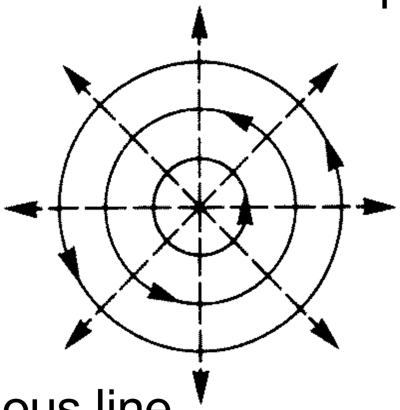
Evanescent field

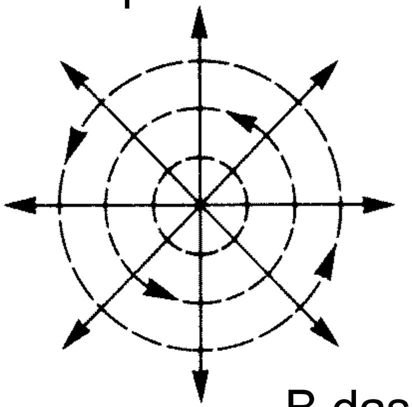
Lowest order fiber modes
Intensities and polarizations





Transversal component of the polarization



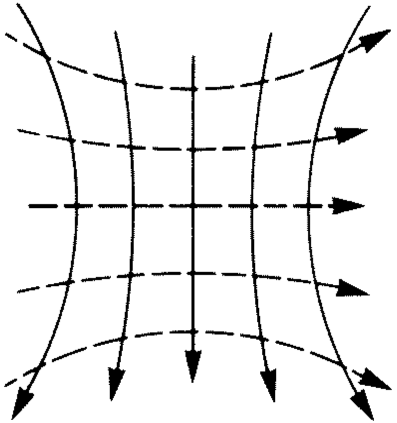


E continuous line

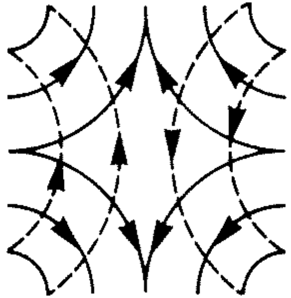
B dashed line

TE_{01}

TM_{01}

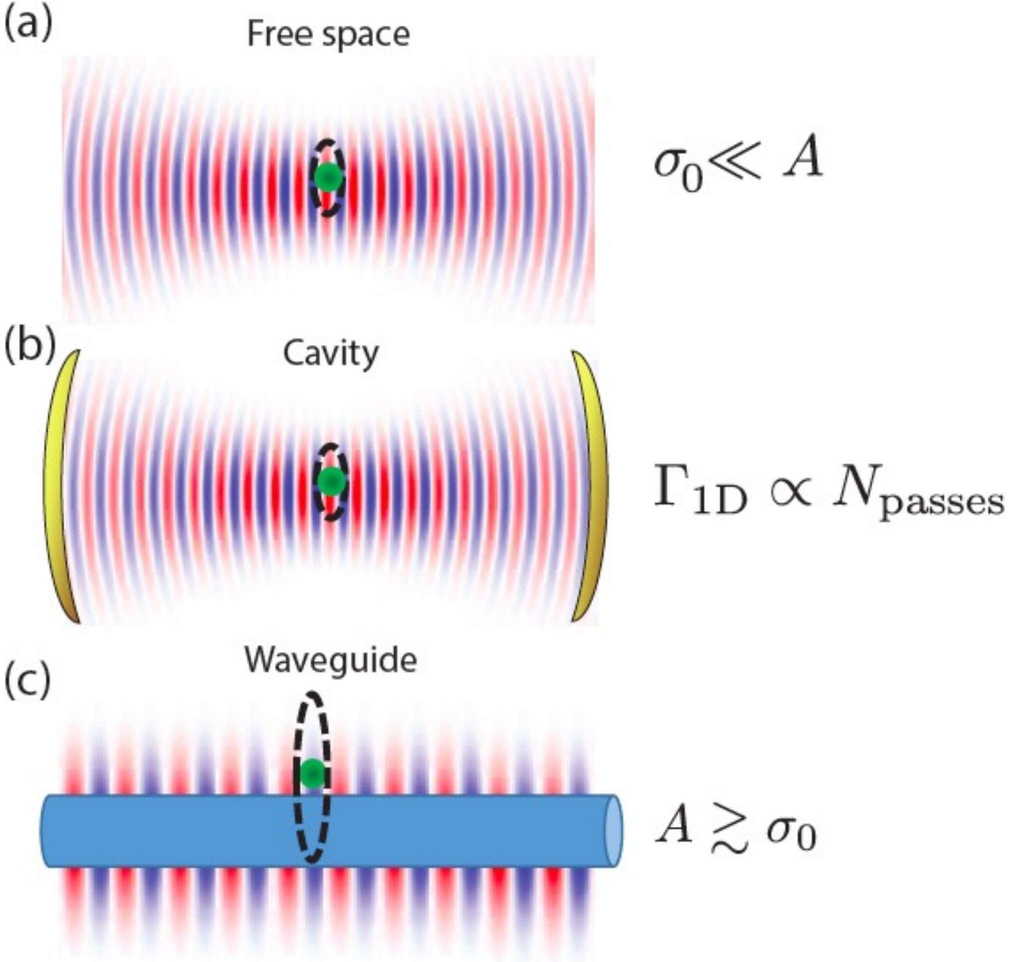


HE_{11}



HE_{21}

Introduction to optical nanofibers, as waveguide



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Decay into the nanofiber mode

Density of modes in 1D

$$\gamma_{1D} \approx \frac{2\pi}{\hbar} \rho(k) \langle H_{int} \rangle^2$$

Decay into the nanofiber mode

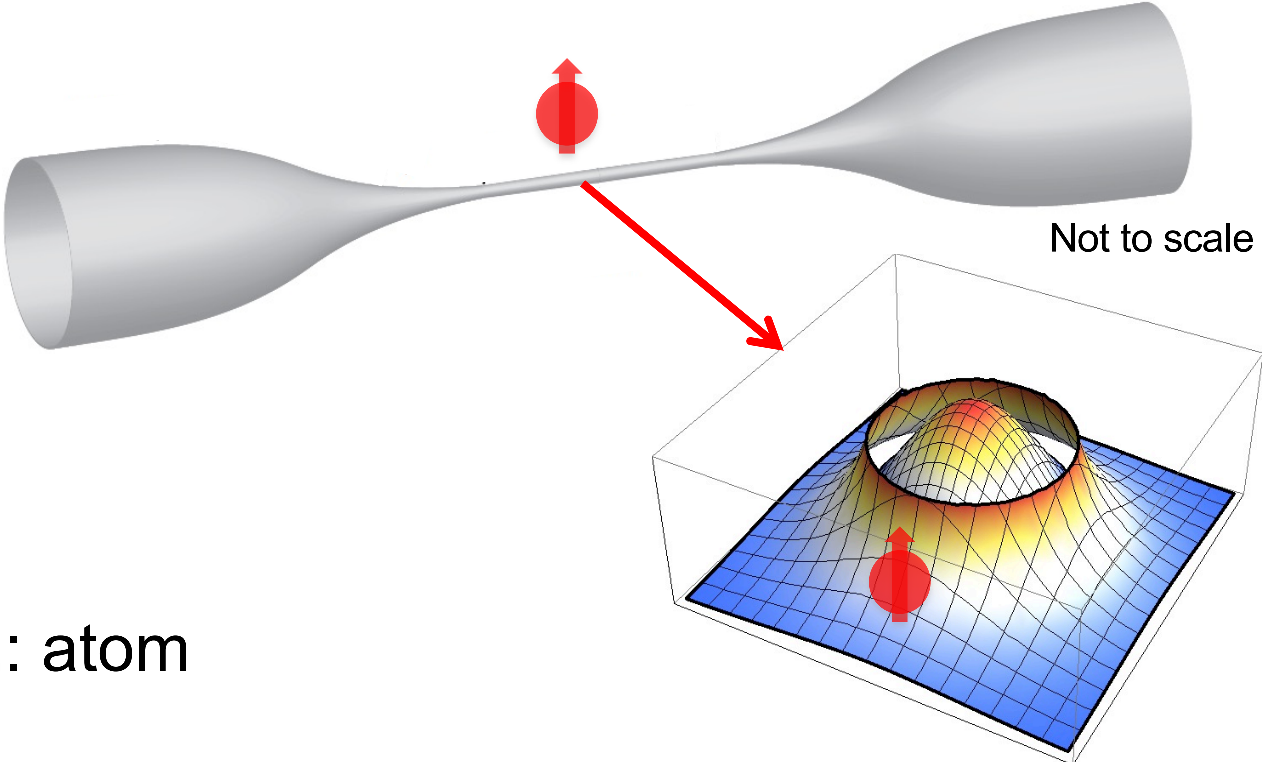
Density of modes

$$\gamma_{1D} \approx \frac{2\pi}{\hbar} \rho\left(k\right) \left\langle H_{int} \right\rangle^2$$

Proportional to the electric field of the guided mode.

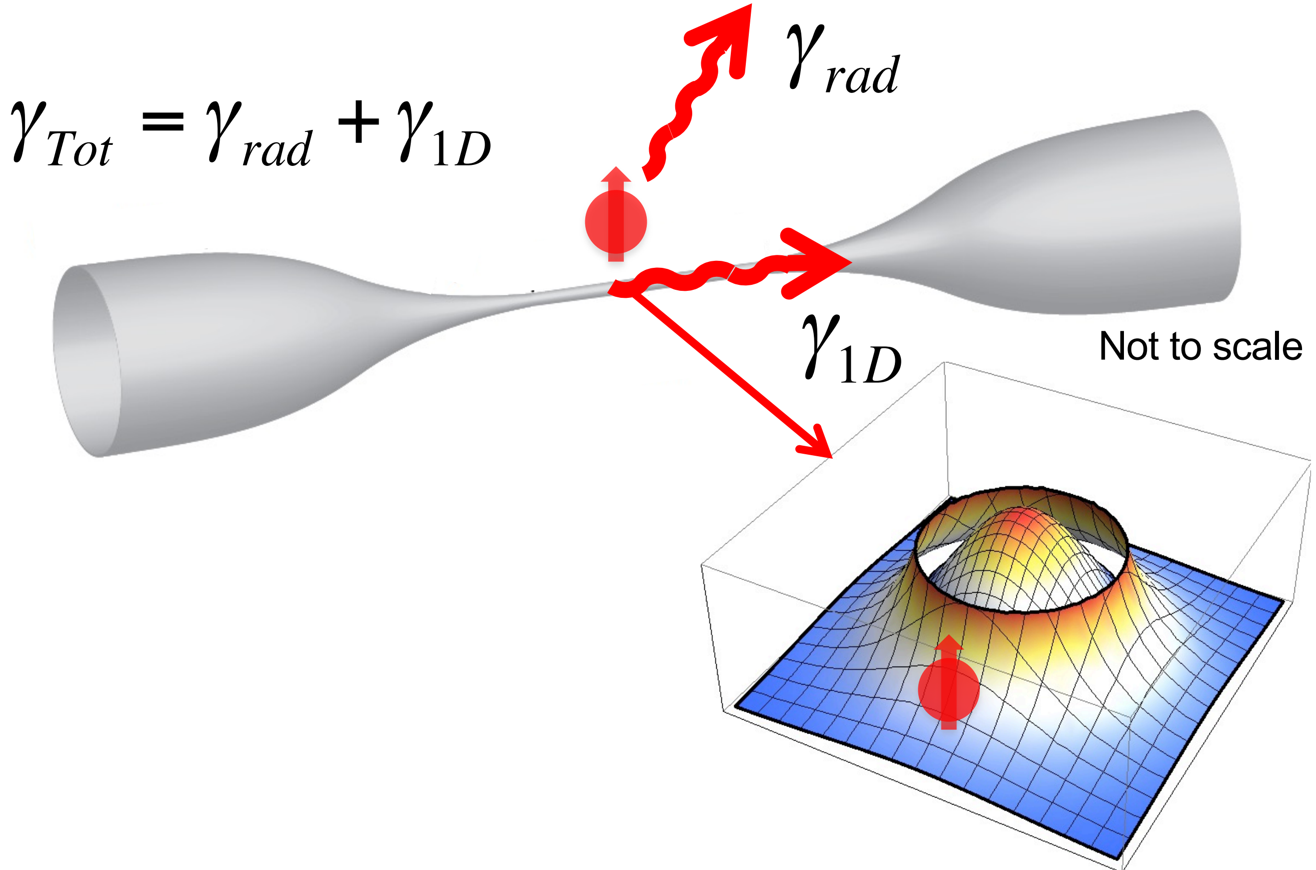
$$|E|^2 = \mathcal{E}^2 \left[K_0^2(qr) + wK_1^2(qr) + fK_2^2(qr)\right]$$

Evanescent Coupling

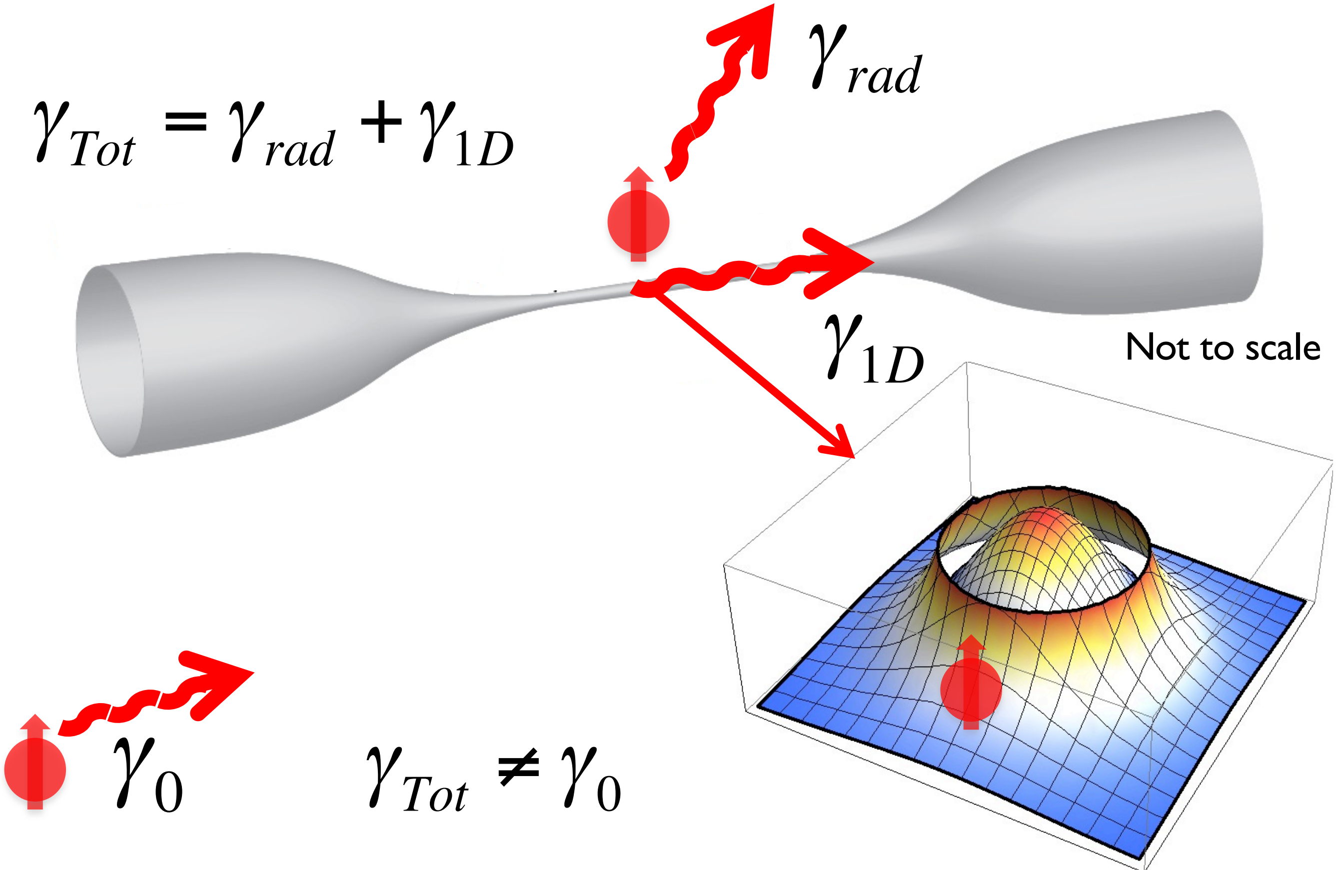


 : atom

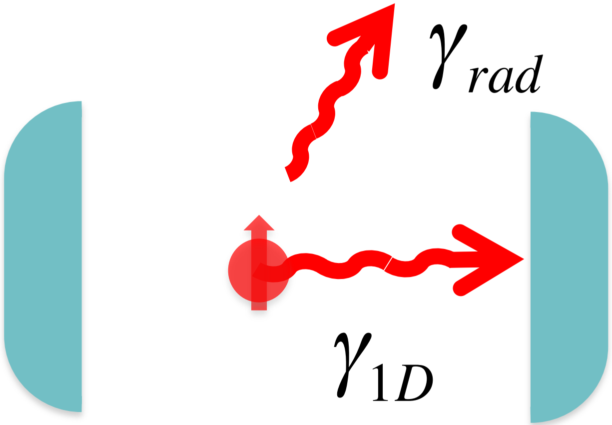
Evanescent Coupling

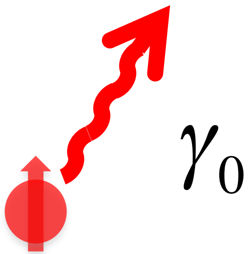


Evanescent Coupling



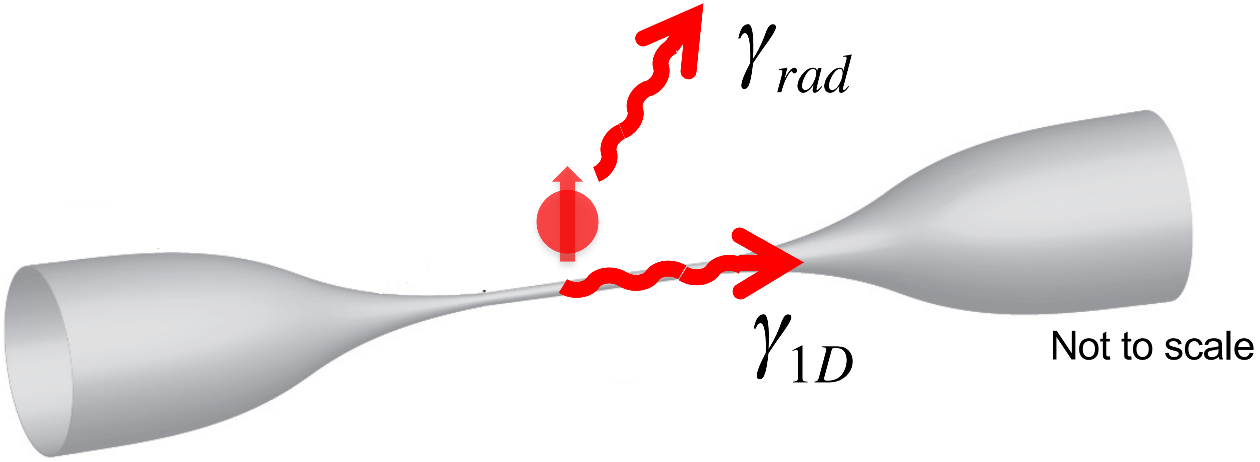
Coupling Enhancement



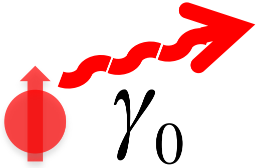


$$\alpha = \frac{\gamma_{1D}}{\gamma_0}$$

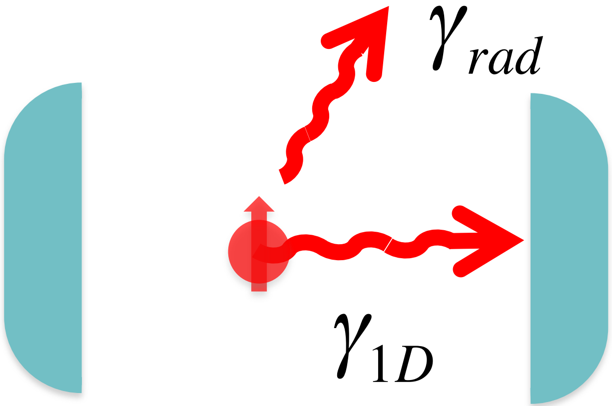
Coupling Enhancement

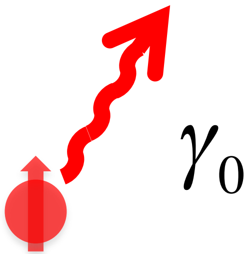


$$\alpha = \frac{\gamma_{1D}}{\gamma_0}$$



Coupling Efficiency

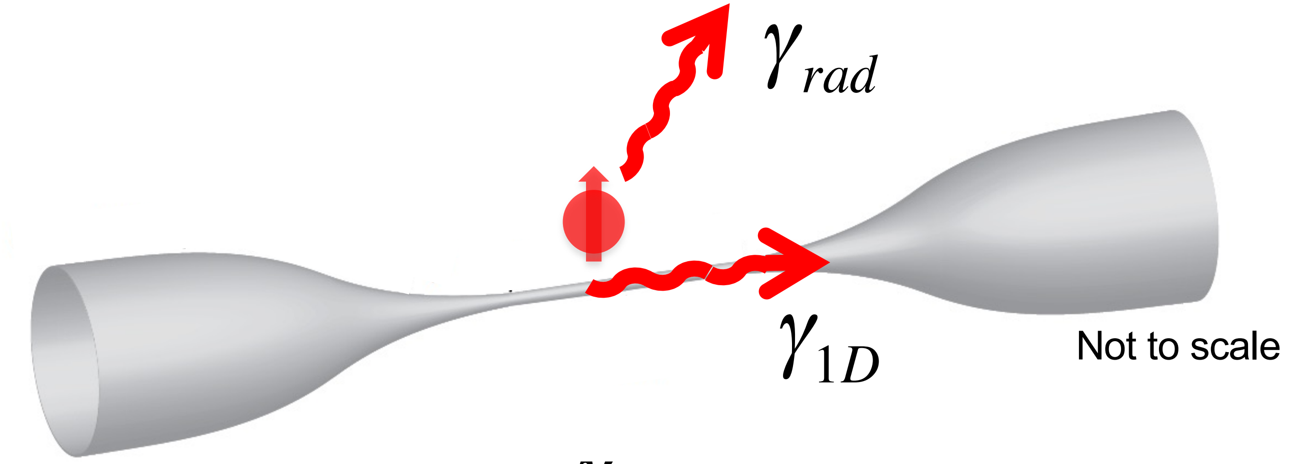




$$\beta = \frac{\gamma_{1D}}{\gamma_{Tot}} \quad ; \quad \gamma_{Tot} = \gamma_{1D} + \gamma_{rad}$$

γ_{rad} may not be γ_0

Coupling Efficiency

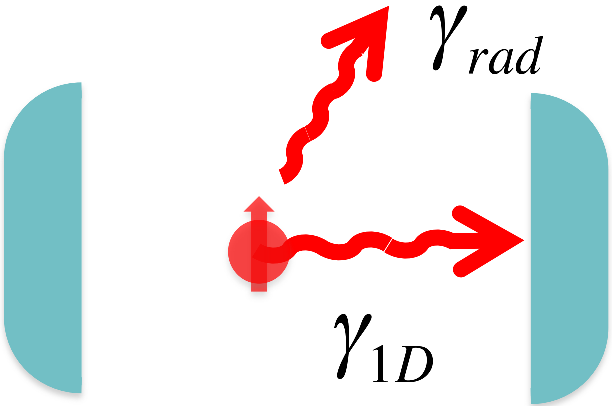


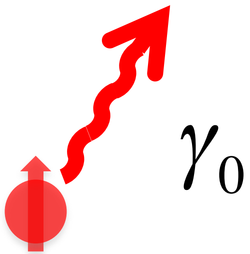
$$\beta = \frac{\gamma_{1D}}{\gamma_{Tot}}$$

γ_{rad} may not be γ_0

$$\gamma_{Tot} = \gamma_{rad} + \gamma_{1D}$$

Purcell Factor

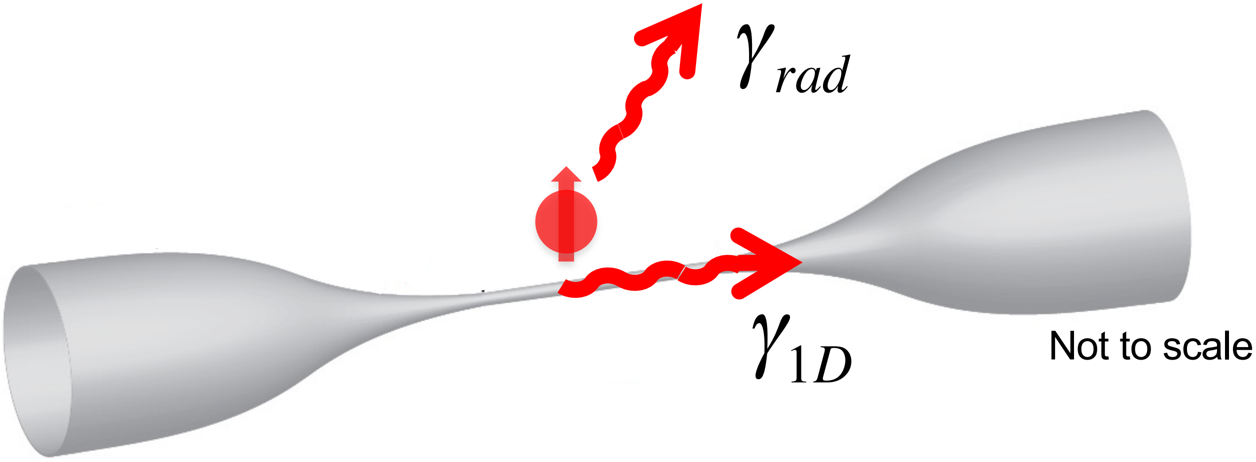




$$F_P = \frac{\gamma_{tot}}{\gamma_0} = \frac{\alpha}{\beta}$$

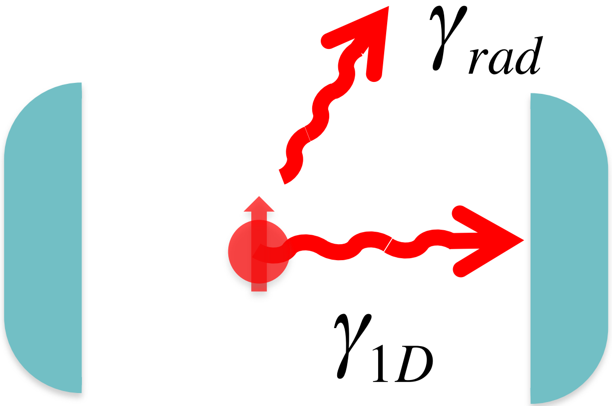
$$\gamma_{Tot} = \gamma_{1D} + \gamma_{rad}$$

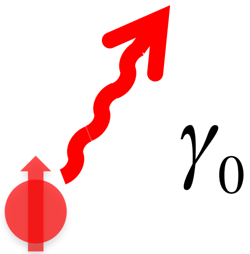
Purcell Factor



$$F_P = \frac{\gamma_{tot}}{\gamma_0} = \frac{\alpha}{\beta}$$

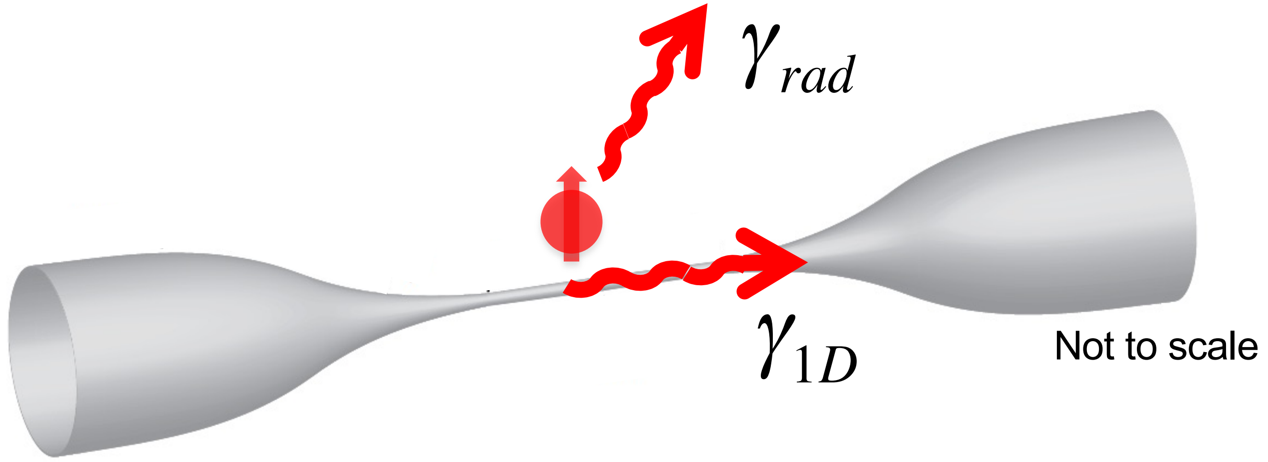
Cooperativity





$$C_1 = \frac{\beta}{(1-\beta)} = \frac{\gamma_{1D}}{\gamma_{rad}}$$

Cooperativity



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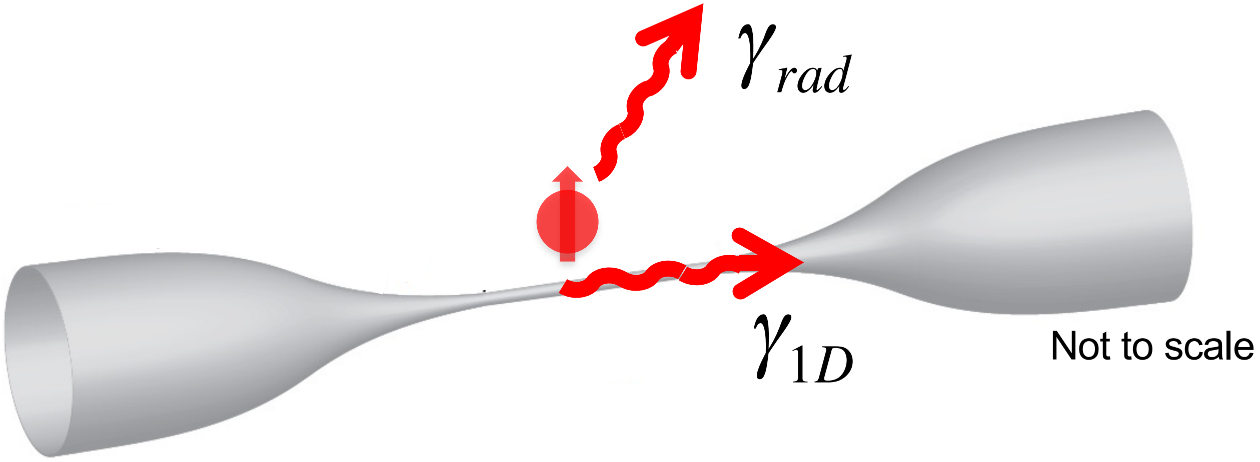
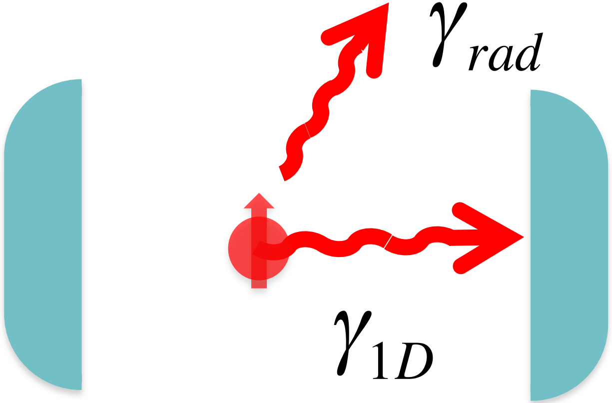
Cooperativity

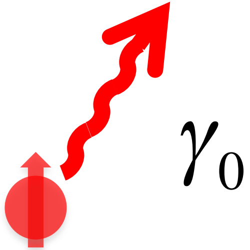


$$C_1 = \frac{\beta}{(1-\beta)} = \frac{\gamma_{1D}}{\gamma_{rad}}$$

C_1 is the ratio of what goes into the selected mode to what goes into all the rest

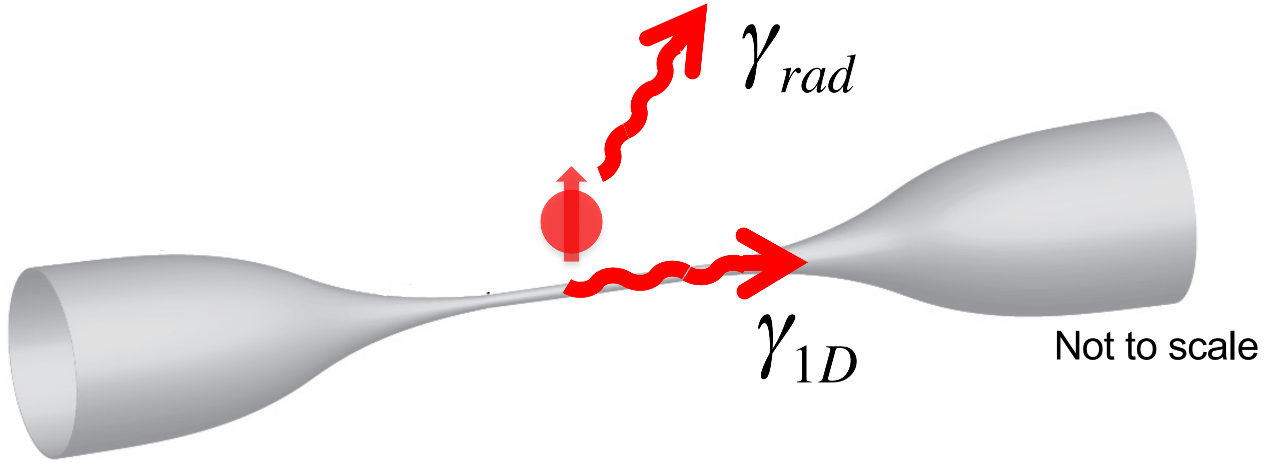
Cooperativity





$$C_1 = \frac{\sigma_0}{Area_{\text{mode}}} \frac{1}{T}$$

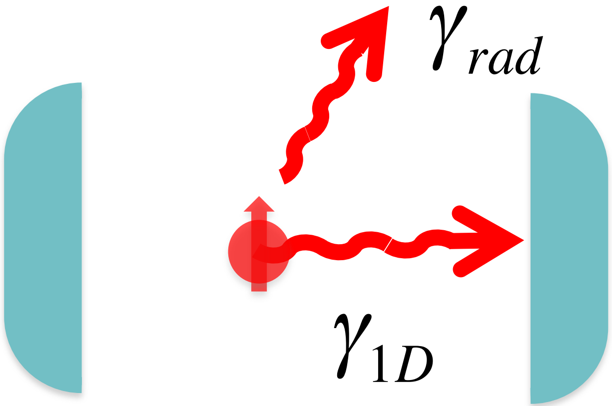
Cooperativity



no mirrors
T=1

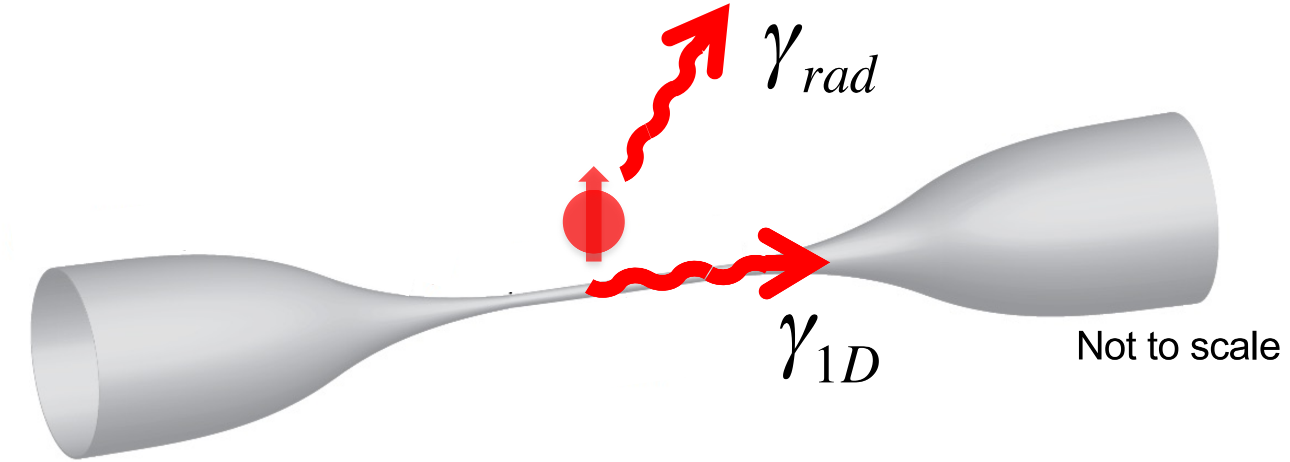
$$C_1 = \frac{\sigma_0}{Area_{\mathrm{mode}}}$$

Cooperativity



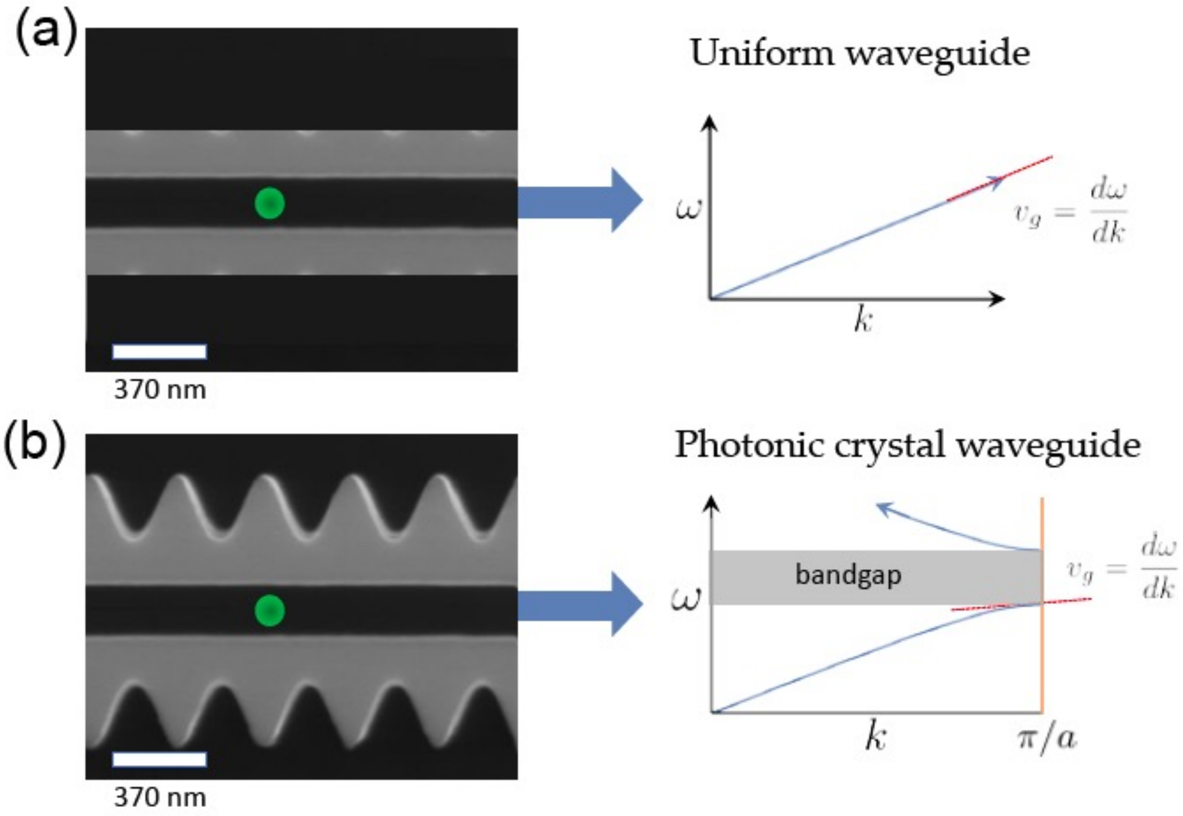
$$C_1 = \frac{g^2}{\kappa\gamma_{rad}} = \left(\frac{\sigma_0}{A_{\text{mode}}}\right)\left(\frac{c}{v_g}\right) = \frac{\gamma_{1D}}{\gamma_{rad}}$$

Cooperativity



$$C_1 = \frac{\sigma_0}{Area_{\mathrm{mode}}} n_{eff} = \frac{\gamma_{1D}}{\gamma_{rad}}$$

What happens on a photonic structure?



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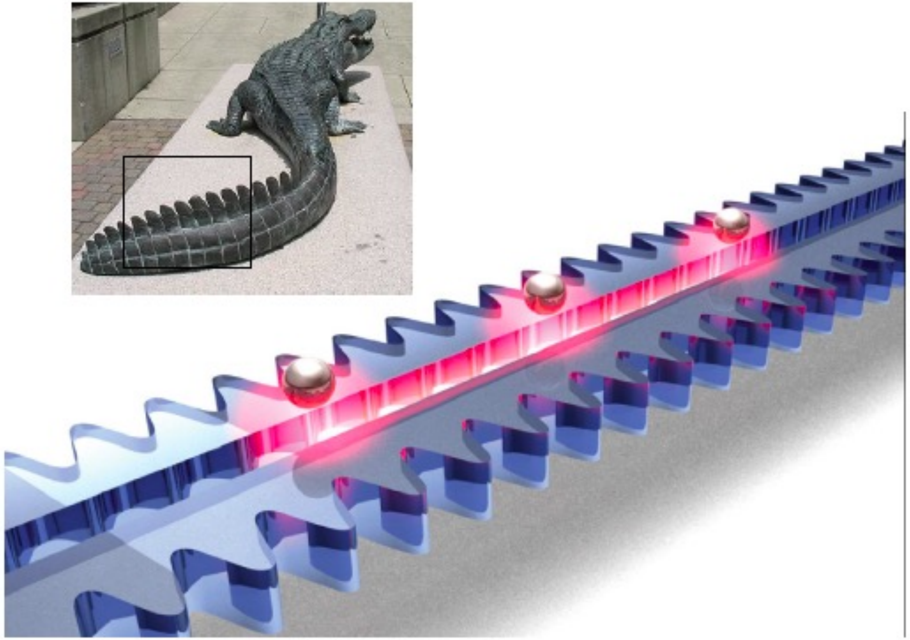
The alligator photonic crystal waveguide (Cal Tech)



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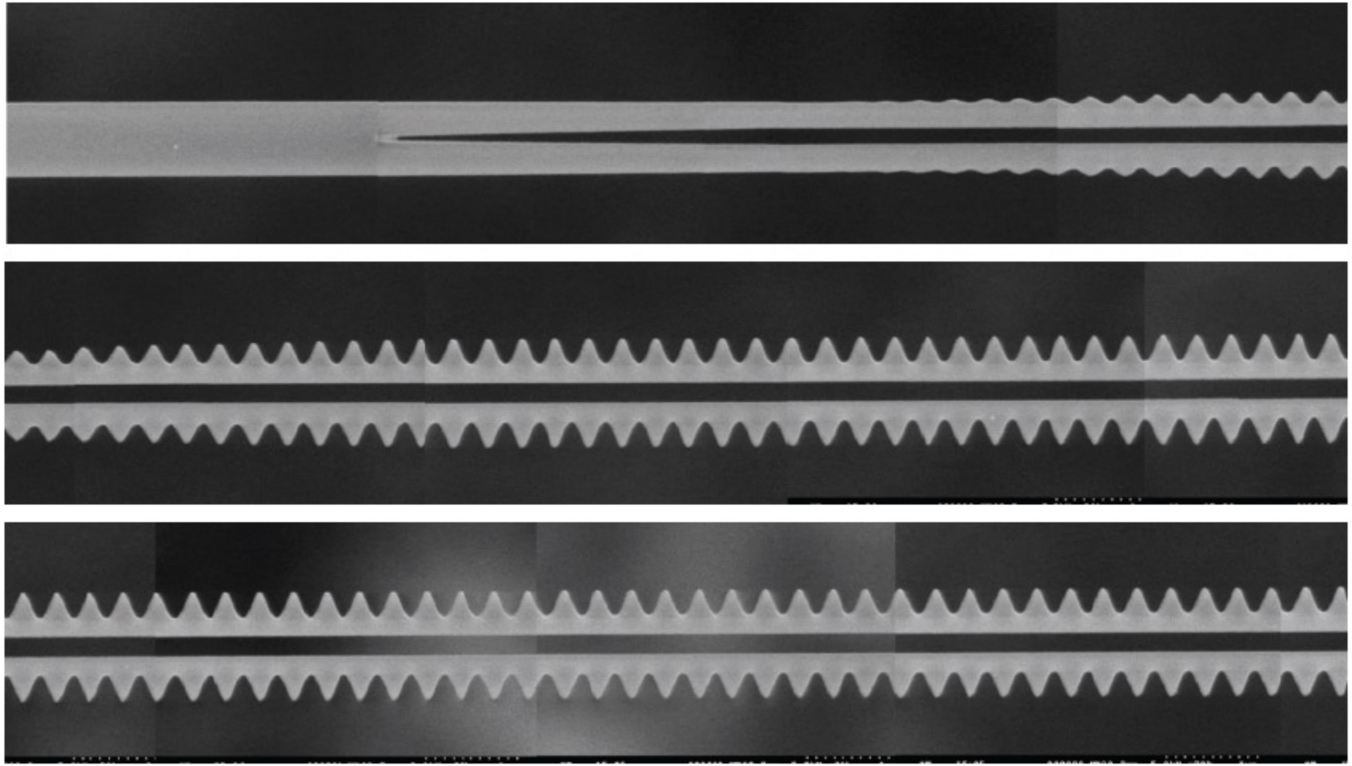
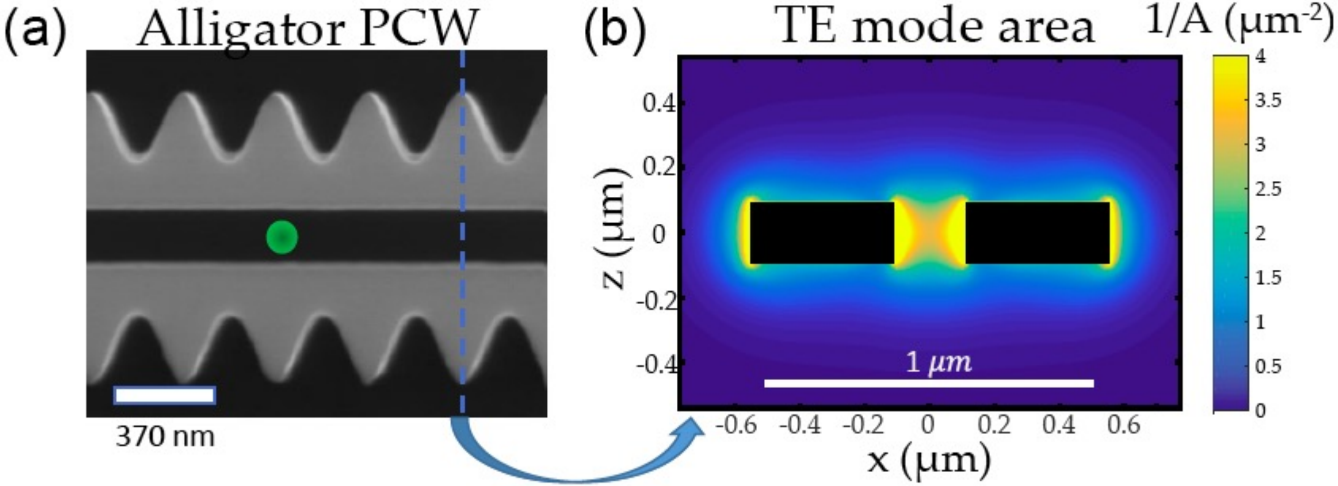


Mode area: $$A_k = \frac{\int_{\text{area}} \mathrm{d}^2\mathbf{r}\ \epsilon(\mathbf{r})|\mathbf{E}_k(\mathbf{r})|^2}{\max\left[\ \epsilon(\mathbf{r})|\mathbf{E}_k(\mathbf{r})|^2\ \right]}.$$



Scanning electron microscope

Cross section of the intensity

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Because there is a bandgap, the cooperativity grows with it. It can also create a “cavity mode” that does not move attached to the atom

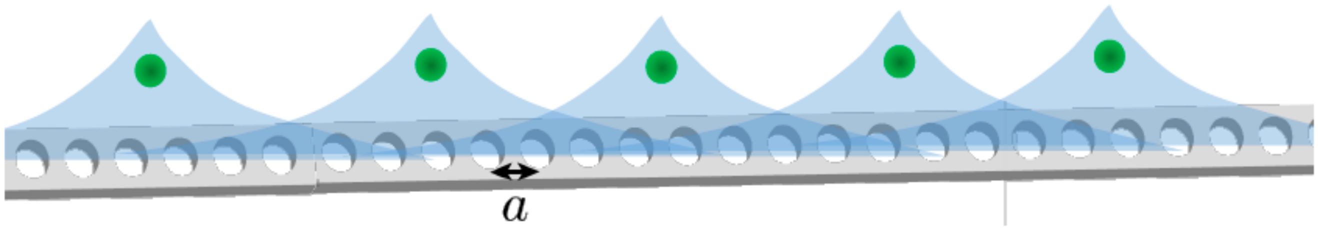

Figure 1.12: Atoms coupled to the bandgap of a photonic crystal waveguide. The atoms and photon cloud form atom-photon bound states.

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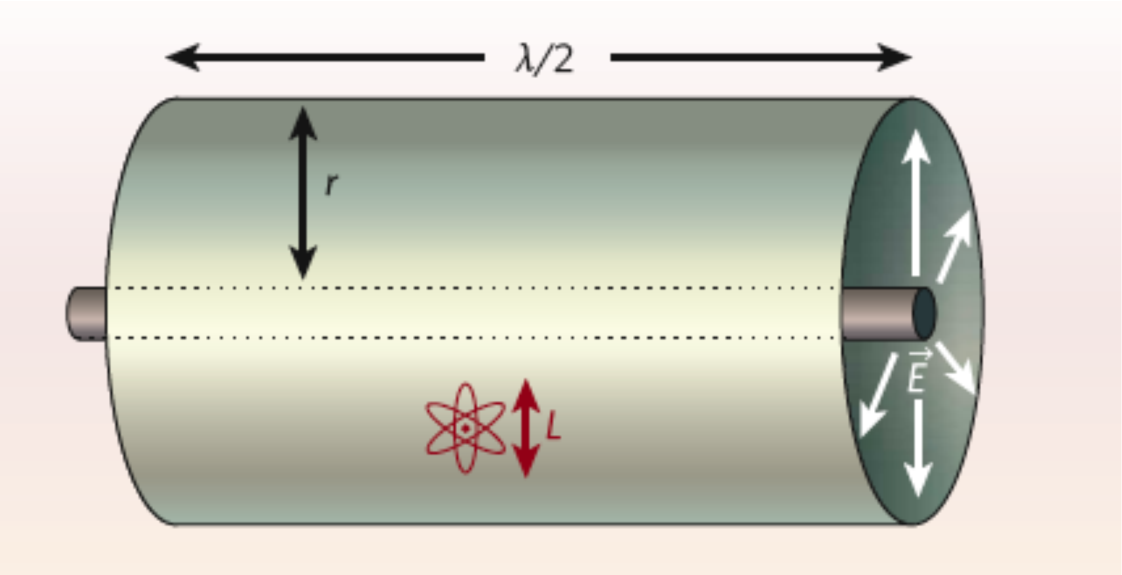
Limit of coupling atom and electromagnetic field, the case of circuit QED

nature Vol 451|7 February 2008

Wiring up quantum systems

R. J. Schoelkopf and S. M. Girvin

The emerging field of circuit quantum electrodynamics could pave the way for the design of practical quantum computers.



The dipole *d* with characteristic length *L* is in a coaxial cavity of lengh λ/2 and radius *r*

The coaxial mode volume is much more confined than λ^3

$$g = \frac{dE_v}{\hbar}; \quad d = eL$$

$$V_{eff} = \pi r^2 \lambda / 2;$$

$$\frac{\varepsilon_0}{2} E_v^2 = \frac{\hbar\omega}{V_{ef}}$$

$$E_v = \frac{1}{r}\sqrt{\frac{\hbar\omega^2}{2\pi^2\varepsilon_0 c}}$$

$$\frac{g}{\omega} = \left(\frac{L}{r}\right)\sqrt{\frac{e^2}{2\pi^2\varepsilon_0\hbar c}} = \left(\frac{L}{r}\right)\sqrt{\frac{2\alpha}{\pi}}$$

Now the coupling constant can be a percentage of the frequency

$$\frac{g}{\omega} = \left(\frac{L}{r}\right)\sqrt{\frac{2\alpha}{\pi}} = 0.068\left(\frac{L}{r}\right)$$

This is not Jaynes Cummings model

You can continue the calculation, assume for wQED that T=1 and L~r, to find γ_{1d}

$$\gamma_{1d} \sim 0.03\,\omega$$

quite different than free space, $L \ll \lambda$

$$\gamma_0 = \frac{\omega^3 d^2}{\pi \varepsilon_0 \hbar c^3} \sim 2\omega\alpha \left(\frac{L}{\lambda/_{2\pi}} \right)^2$$

Thanks