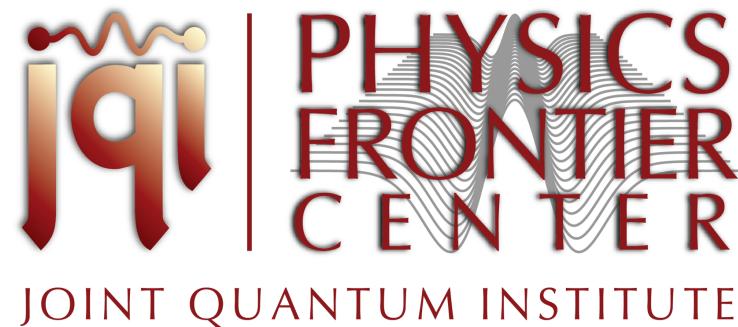


Electrodinámica cuántica de cavidades y de guías de onda 6 lección

Postgrado, Física, UNAM, México, Marzo 2019

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www.jqi.umd.edu



Introducción a Nanofibras, un ejemplo de guías de onda

Artículo de revisión:

P. Solano, J. A. Grover, J. E. Hoffman, S. Ravets, F. K. Fatemi, L. A. Orozco, and S. L. Rolston “Optical Nanofibers: A New Platform for Quantum Optics”. *Advances in Atomic Molecular and Optical Physics*, Vol. 46, 355-403, Edited by E. Arimondo, C. C. Lin, and S. F. Yelin, Academic Press, Burlington (2017).

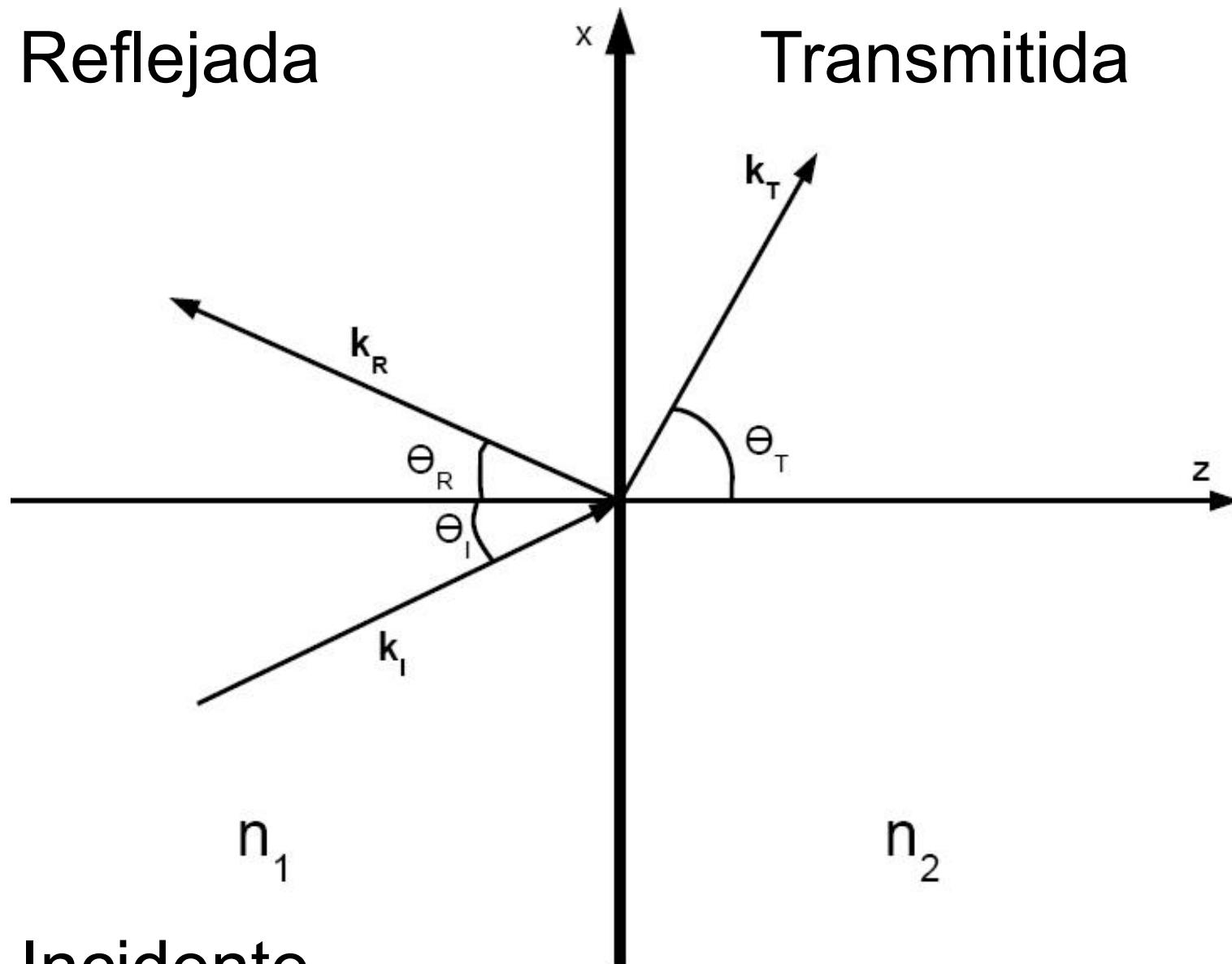
ArXiv:1703.10533

1. Introducción

Ley de Snell-Descartes

Reflejada

Transmitida

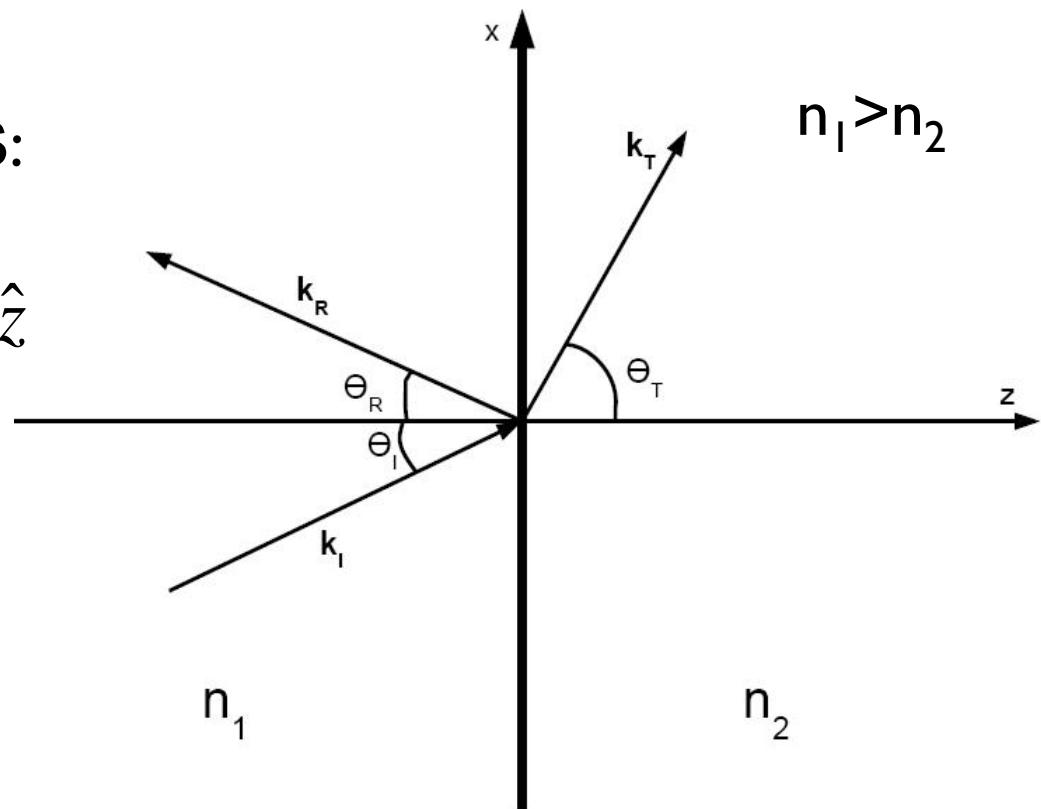


$$n_1 > n_2$$

Ondas Evanescentes:

$$\mathbf{k}_T = k_T \sin(\theta_T) \hat{x} + k_T \cos(\theta_T) \hat{z}$$

$$\sin(\theta_T) = \frac{n_1}{n_2} \sin(\theta_I) > 1$$



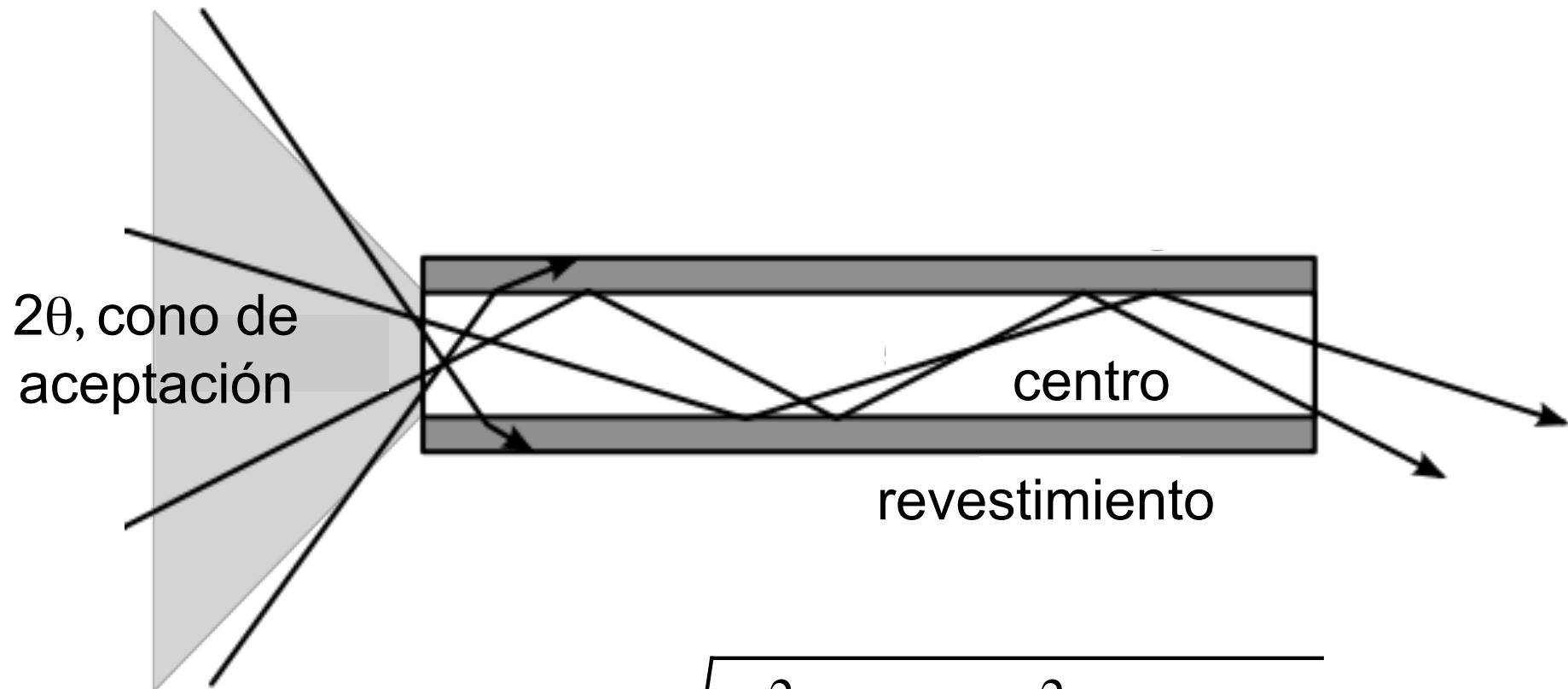
$$\cos(\theta_T) = \sqrt{1 - \sin^2(\theta_T)} = i\sqrt{\sin^2(\theta_T) - 1}$$

$$\mathbf{E}_T = \mathbf{E}_0 e^{i(\mathbf{k}_T \cdot \mathbf{r} - \omega t)}$$

$$\mathbf{E}_T = \mathbf{E}_0 e^{-\kappa z} e^{i(kx - \omega t)}$$

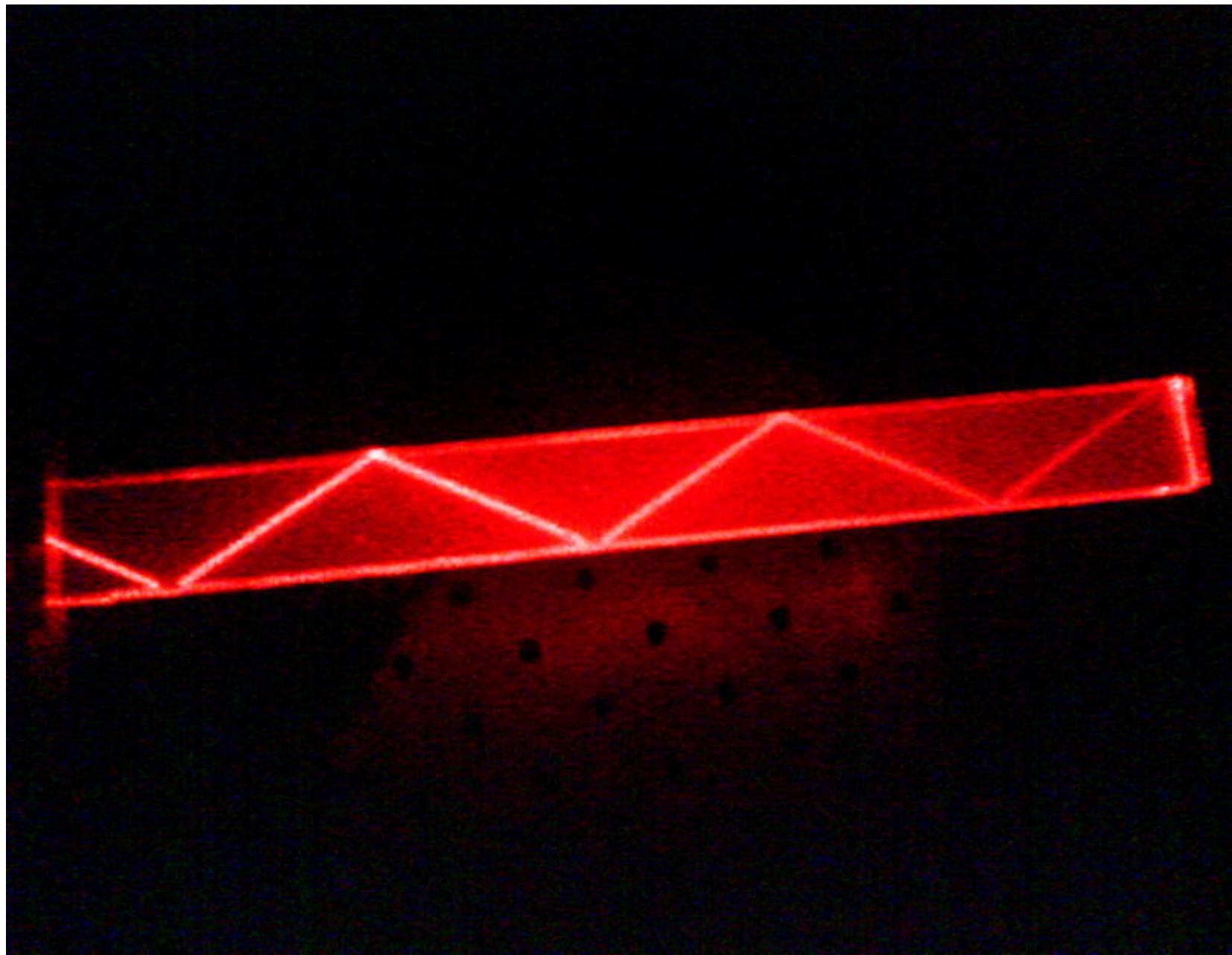
$$\kappa = \frac{1}{\lambda/2\pi} \sqrt{\left(n_1 \sin(\theta_I)\right)^2 - n_2^2}, \quad k = \frac{n_1}{\lambda/2\pi} \sin(\theta_I)$$

Fibra multimodal con centro y revestimiento



$$\sin \theta = \sqrt{n_{\text{centro}}^2 - n_{\text{revestimiento}}^2} \propto V$$

Fibras uni-modales la diferencia del índice de refracción del centro y del revestimiento es muy pequeña (0.01 a 0.001)

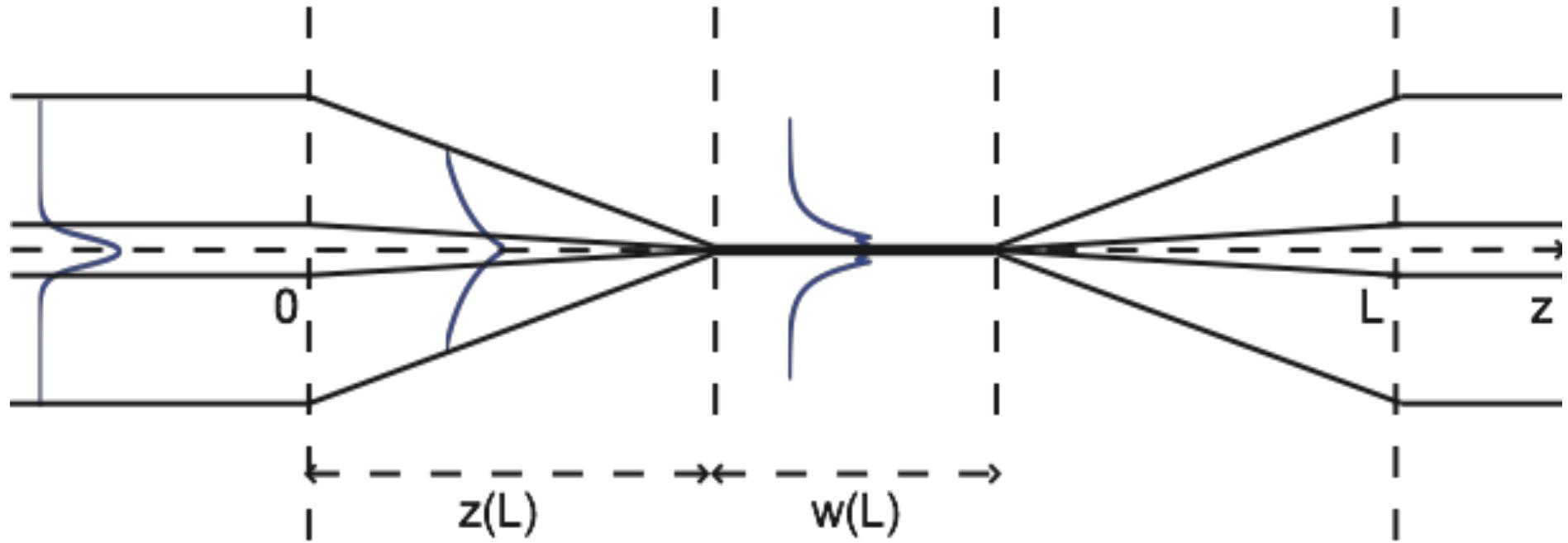


Para mantener la luz es necesario satisfacer la reflección total interna en todos los puntos.

Criterio de adiabaticidad

guía centro-recubrimiento disminución gradual

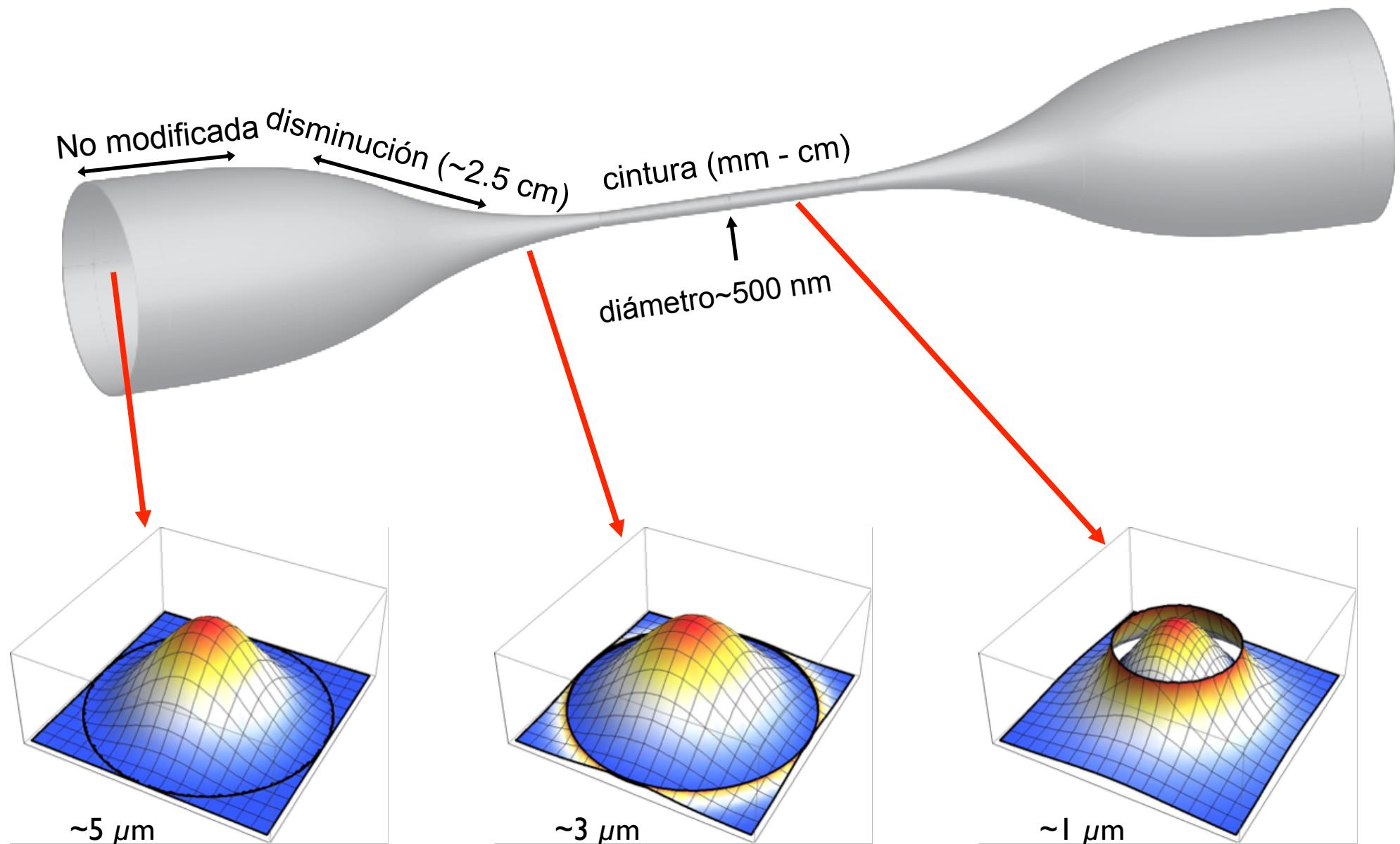
guía aire-recubrimiento



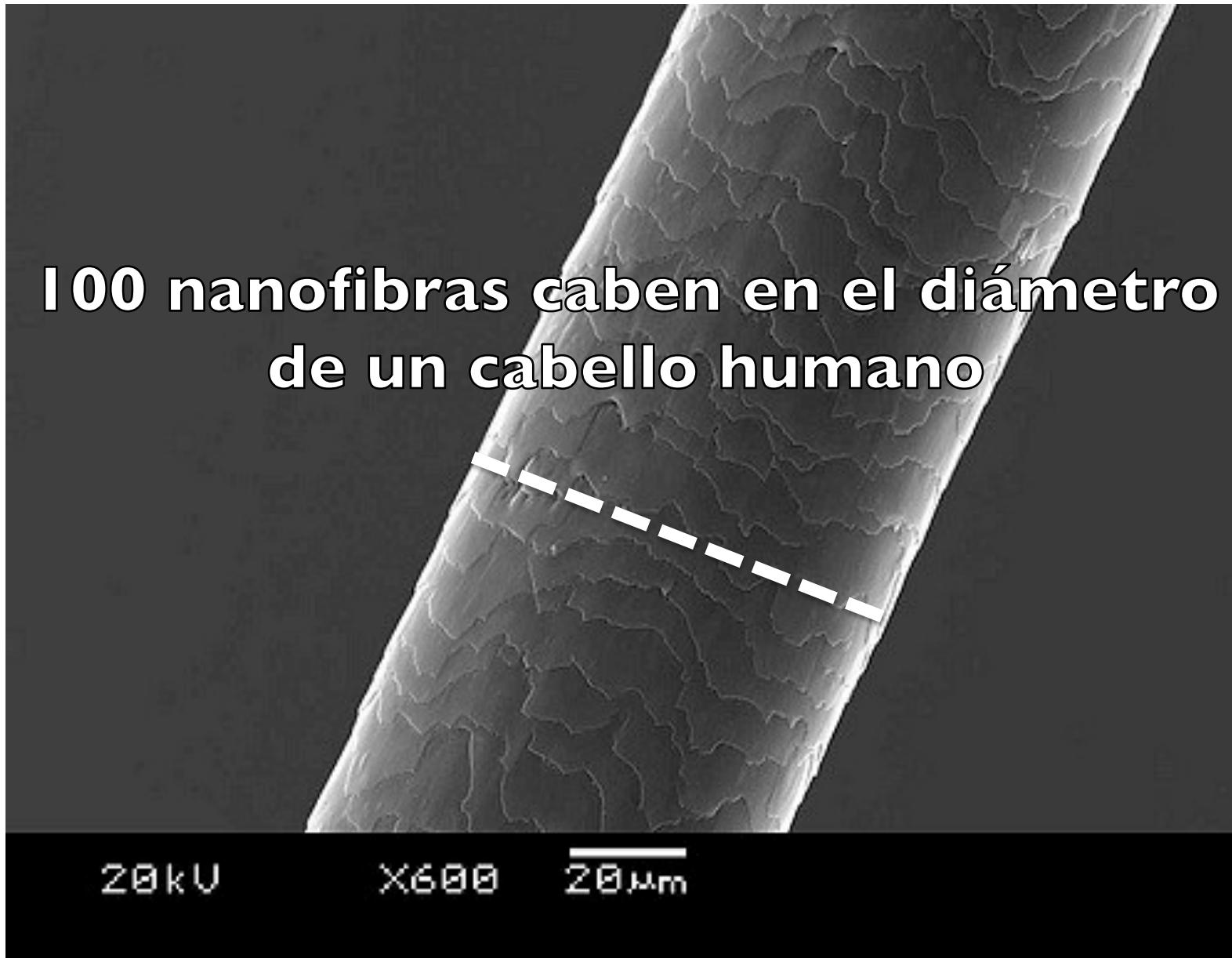
Campo evanescente en la nanofibra.

- La onda decae en una distancia de $\lambda/2\pi$.
- La nanofibra guía el modo y no hay radiación ni difracción.
- Muy diferente a un haz enfocado.

Nanofibra óptica



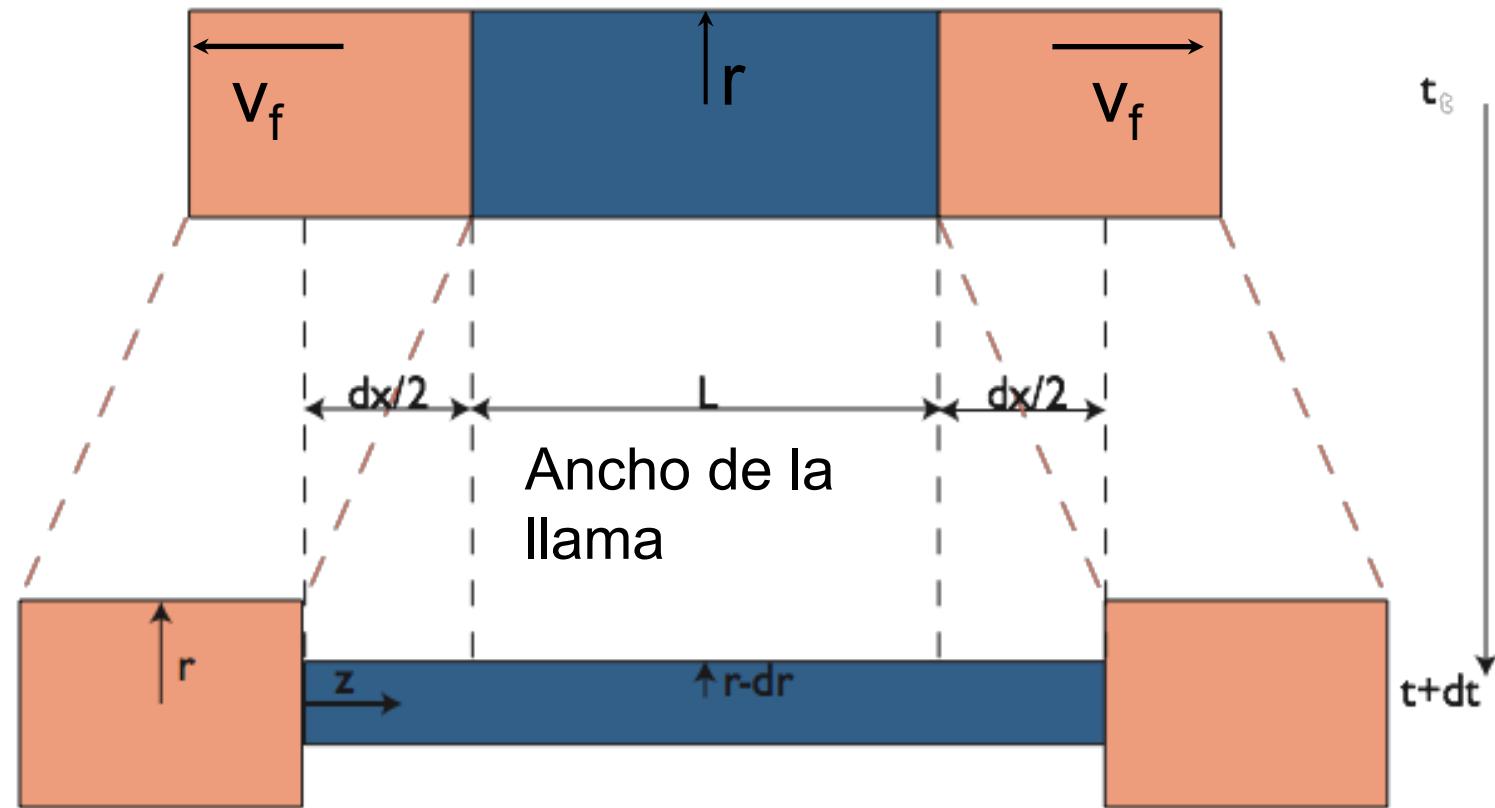
Escala de las nanofibras



2. Fabricación

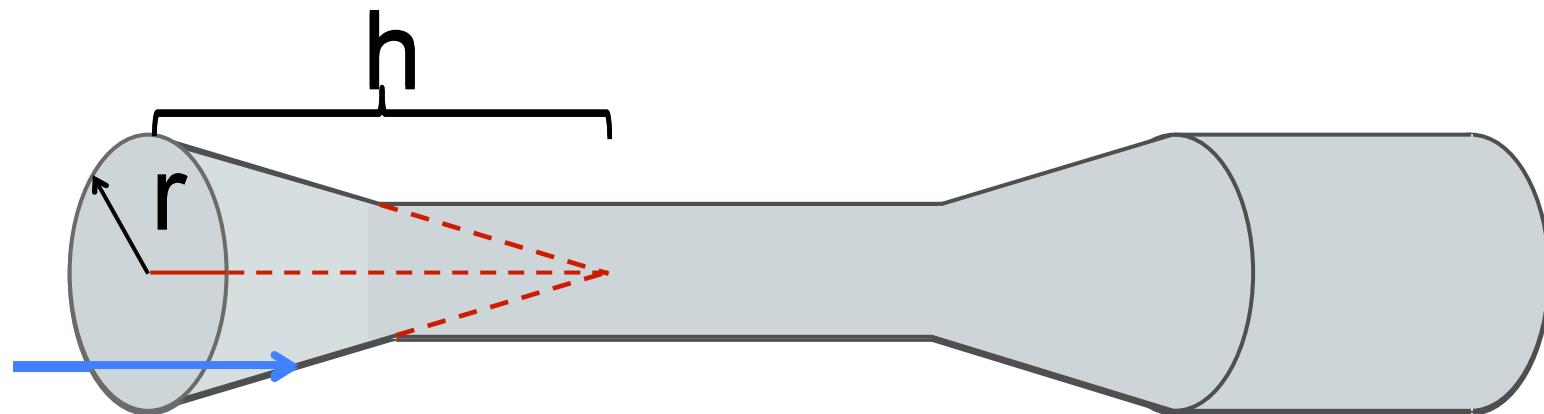
- Conservación de volumen
- Ambiente ultralimpio
- Control nanométrico
- Diagnóstico (transmisión) *in situ*

Conservación de volumen



$$\frac{dr}{dx} = -\frac{r}{2L} \quad \rightarrow \quad r(t) = r_0 \exp\left(-\frac{v_f t}{2L_0}\right)$$

Criterio de adiabaticidad: Mantener la reflección total interna.



Sistéma de imagen

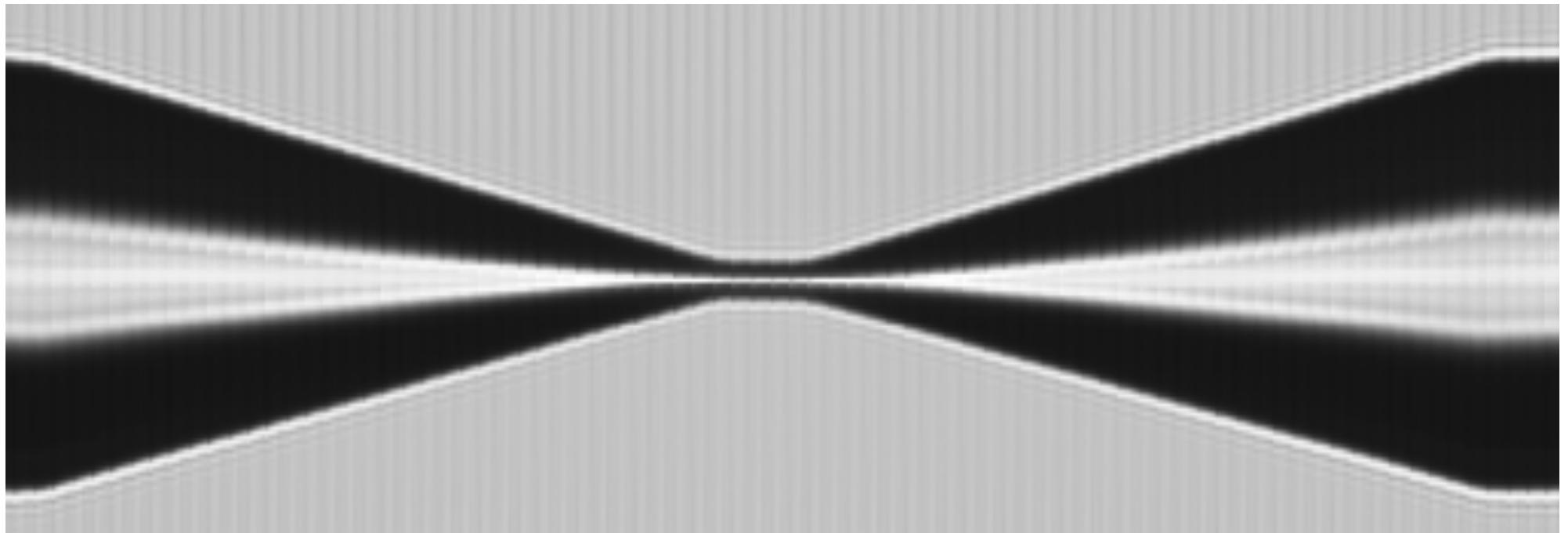
Abrazaderas

Motores

Micrómetros de
alineamiento

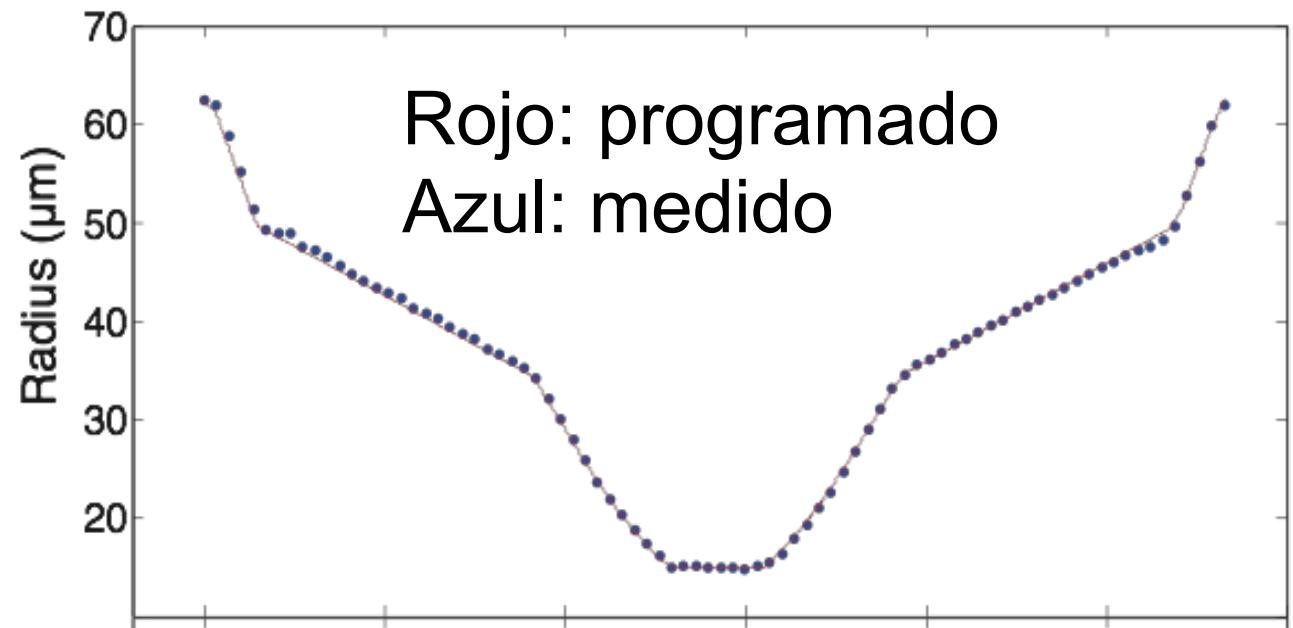
Fla

Microscopio óptico



Cintura de 10 μm de diámetro

a)



b)

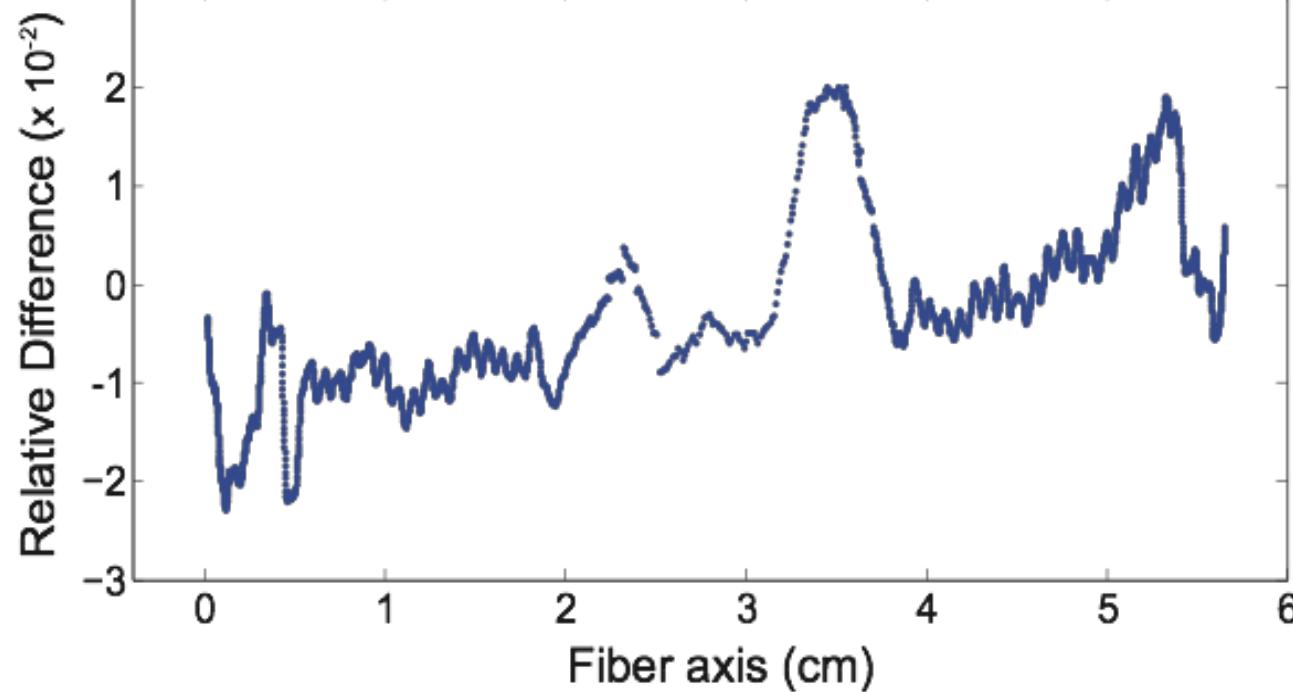
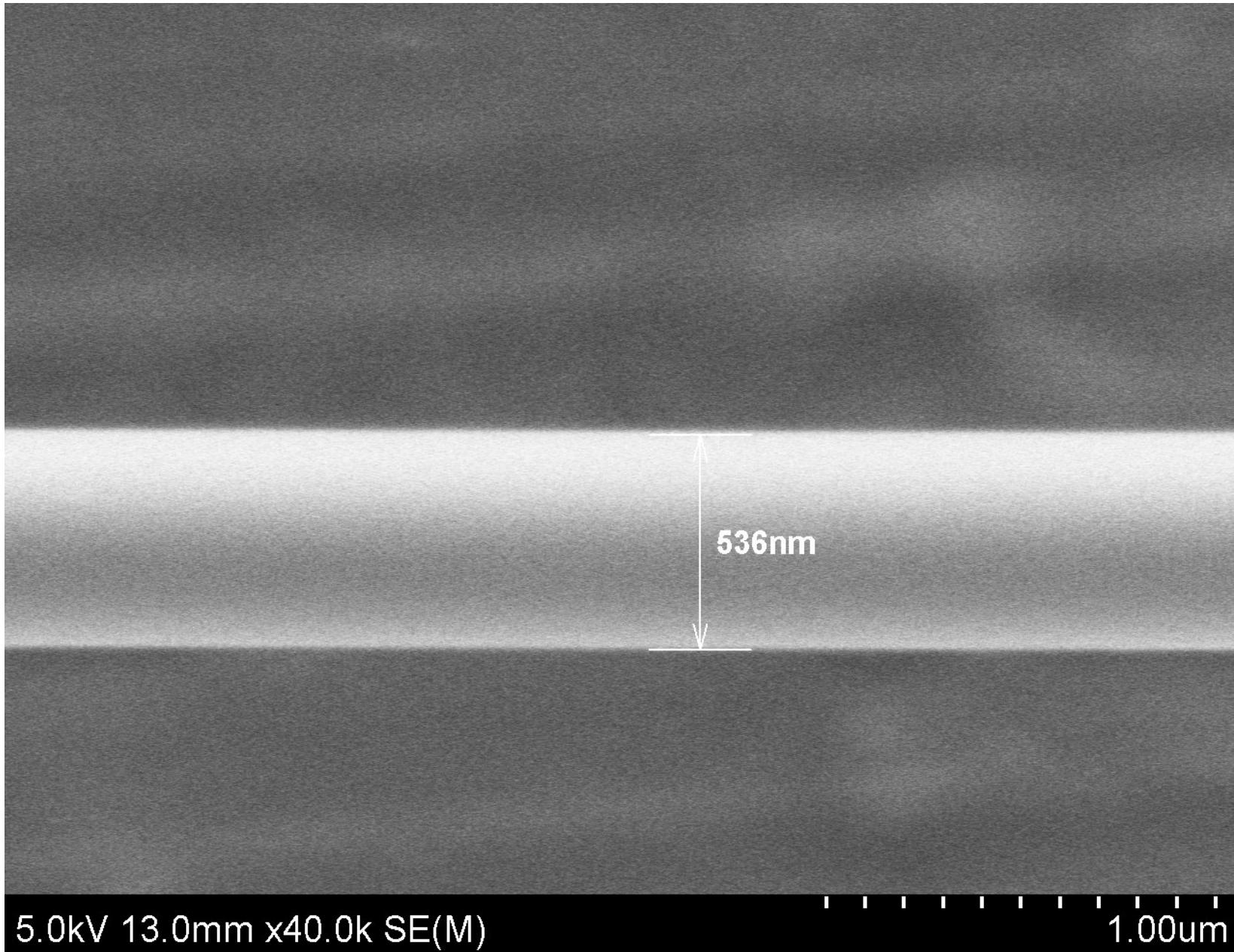
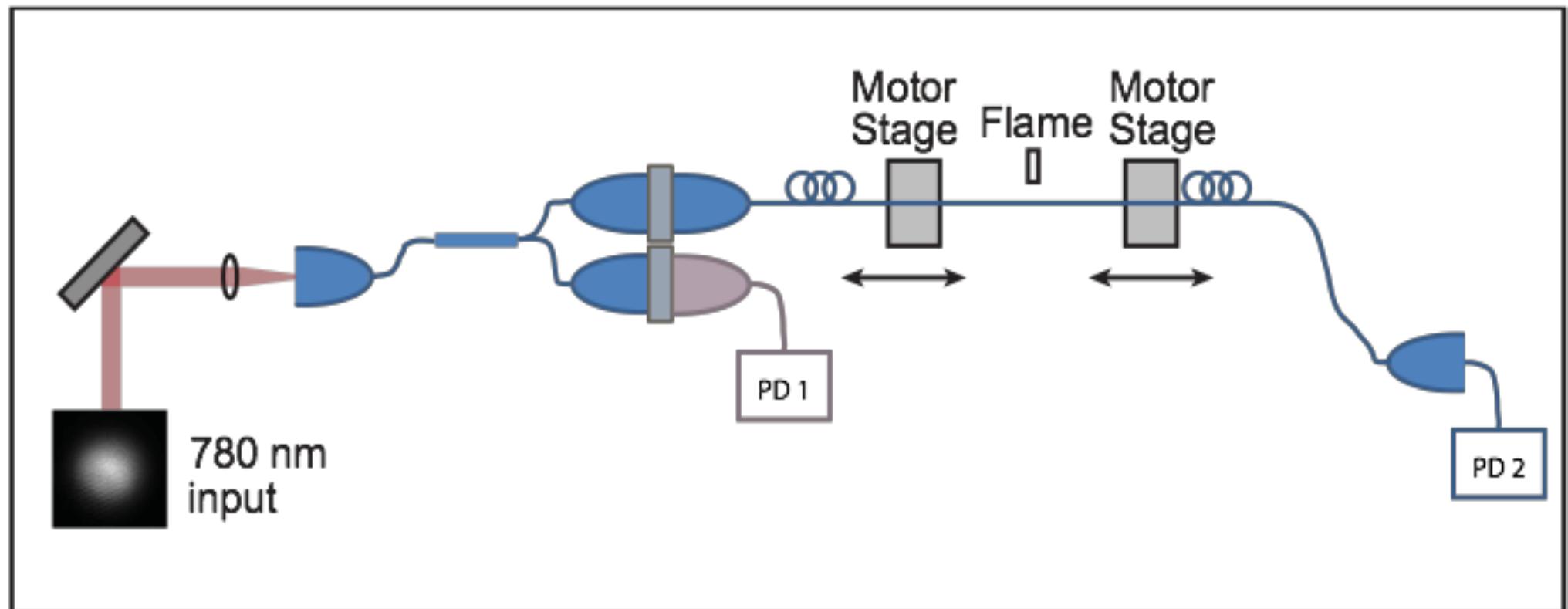


Imagen de la nanofibra por microscopía electrónica de barrido

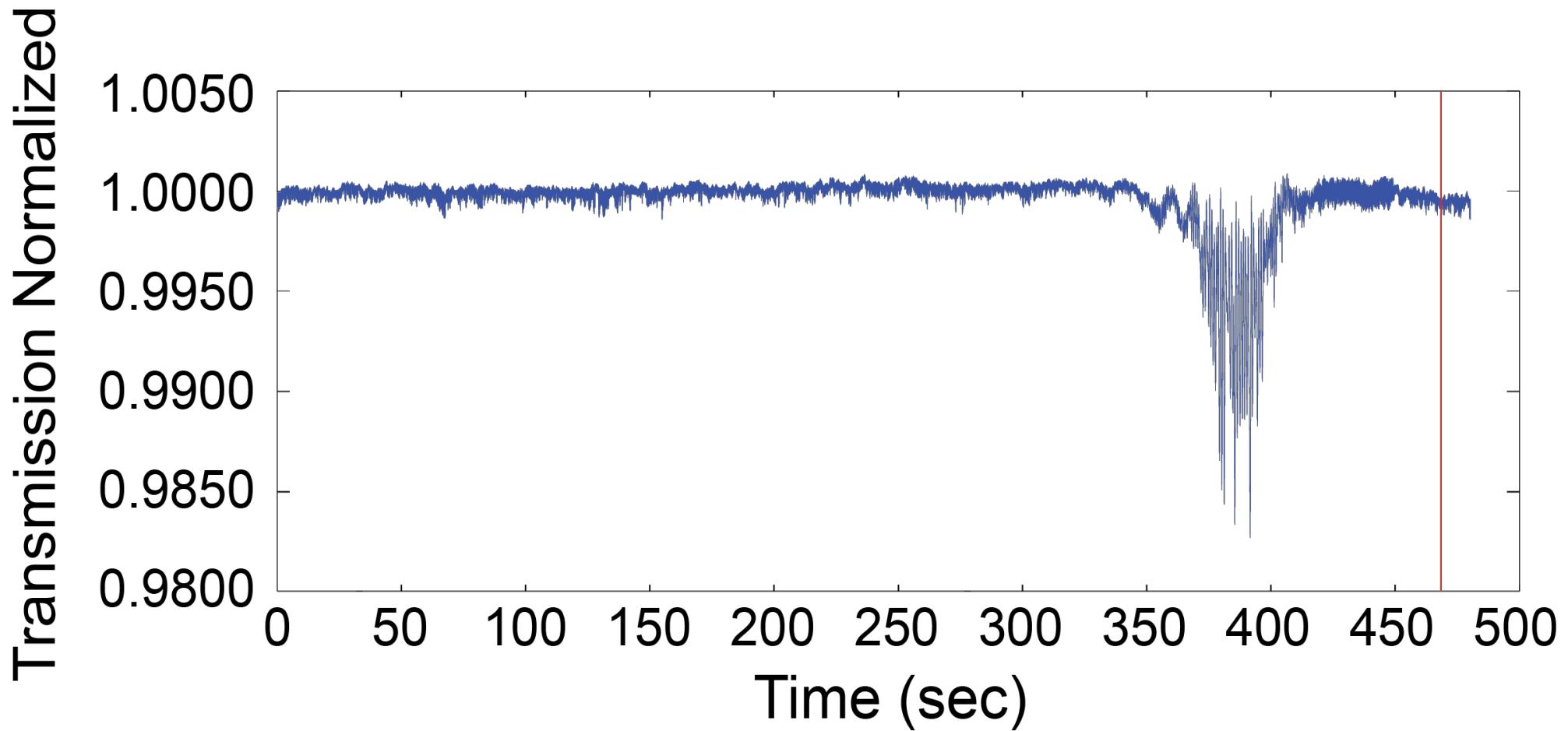


Esquema de la medición *in situ*



$$\text{Transmisión (t)} = (\text{PD2(t)} / \text{PD1(t)}) / \text{Normalización}$$

Transmisión ultra-alta



Transmisión = 99.95 ± 0.02 %

pérdida = 2.6×10^{-5} dB/mm

3. Modos electromagnéticos

Modo fundamental de la fibra HE₁₁

$$E_x(r, \phi, z, t) = A_{\text{lin}} \frac{\beta_{11} J_1(h_{11}a)}{2q_{11}K_1(q_{11}a)} e^{i(\omega t - \beta_{11}z)}, \quad (4a)$$

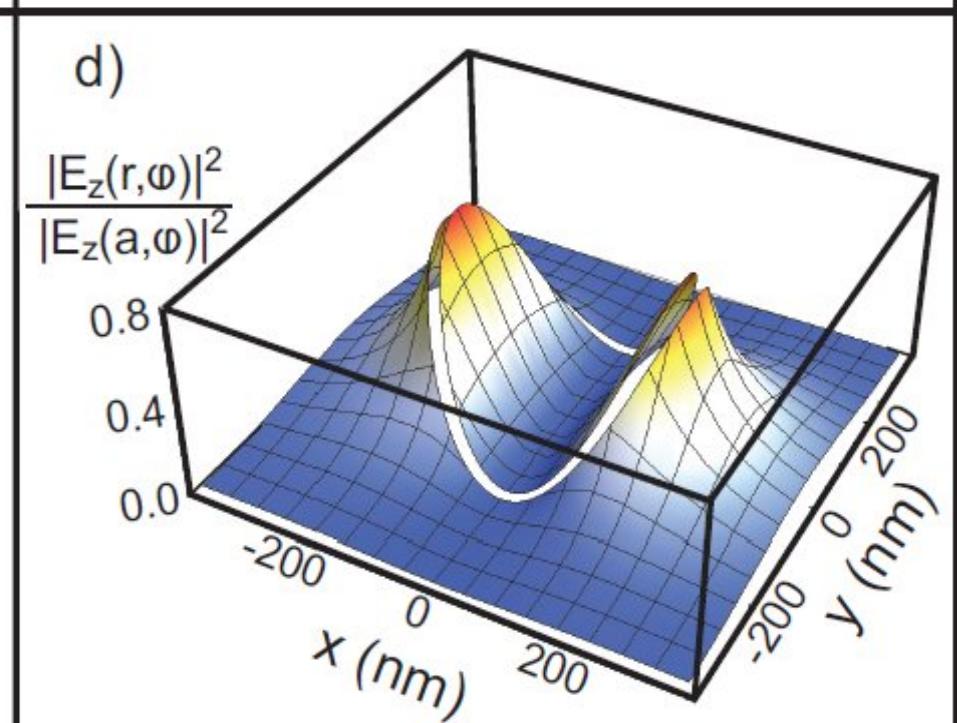
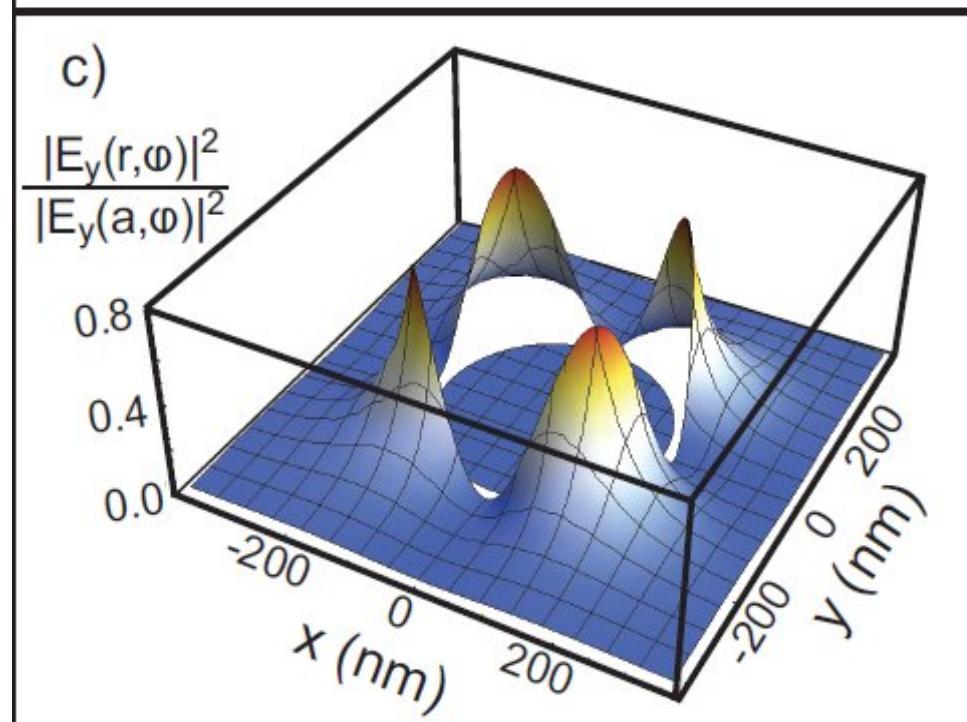
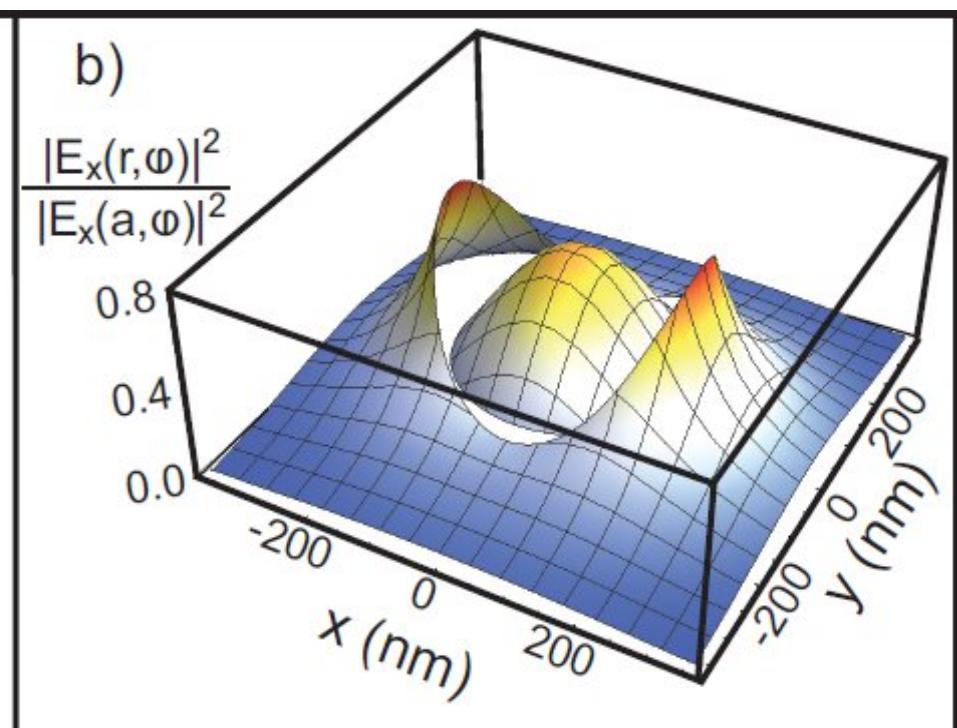
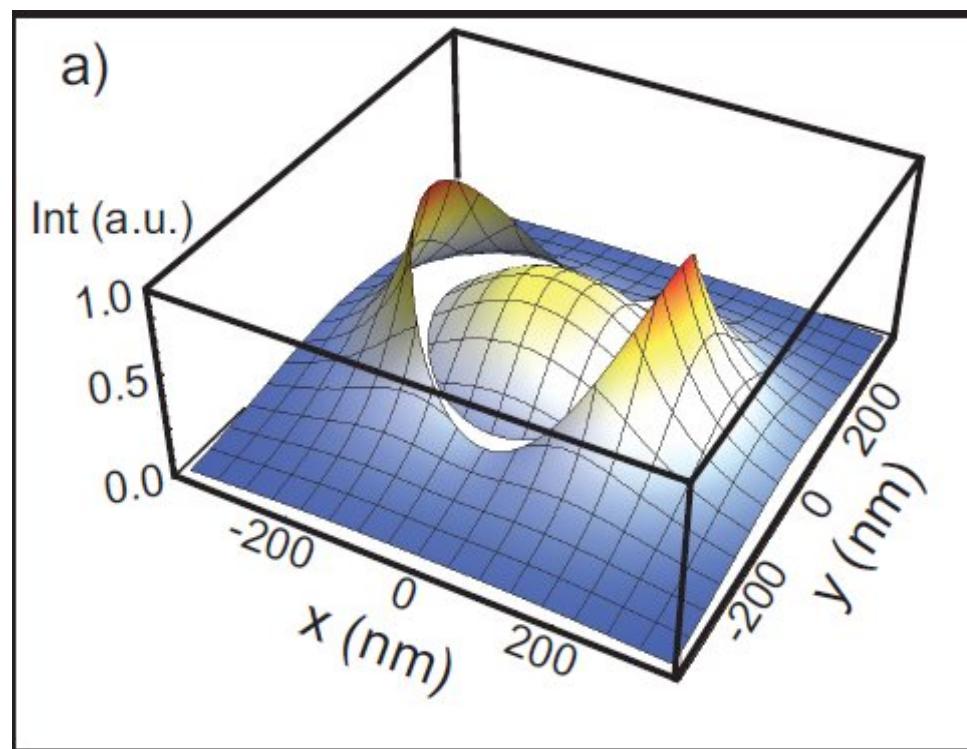
$$\times [(1 - s_{11})K_0(q_{11}r) \cos(\varphi_0) + (1 + s_{11})K_2(q_{11}r) \cos(2\phi - \varphi_0)] e^{i(\omega t - \beta_{11}z)},$$

$$E_y(r, \phi, z, t) = A_{\text{lin}} \frac{\beta_{11} J_1(h_{11}a)}{2q_{11}K_1(q_{11}a)} e^{i(\omega t - \beta_{11}z)}, \quad (4b)$$

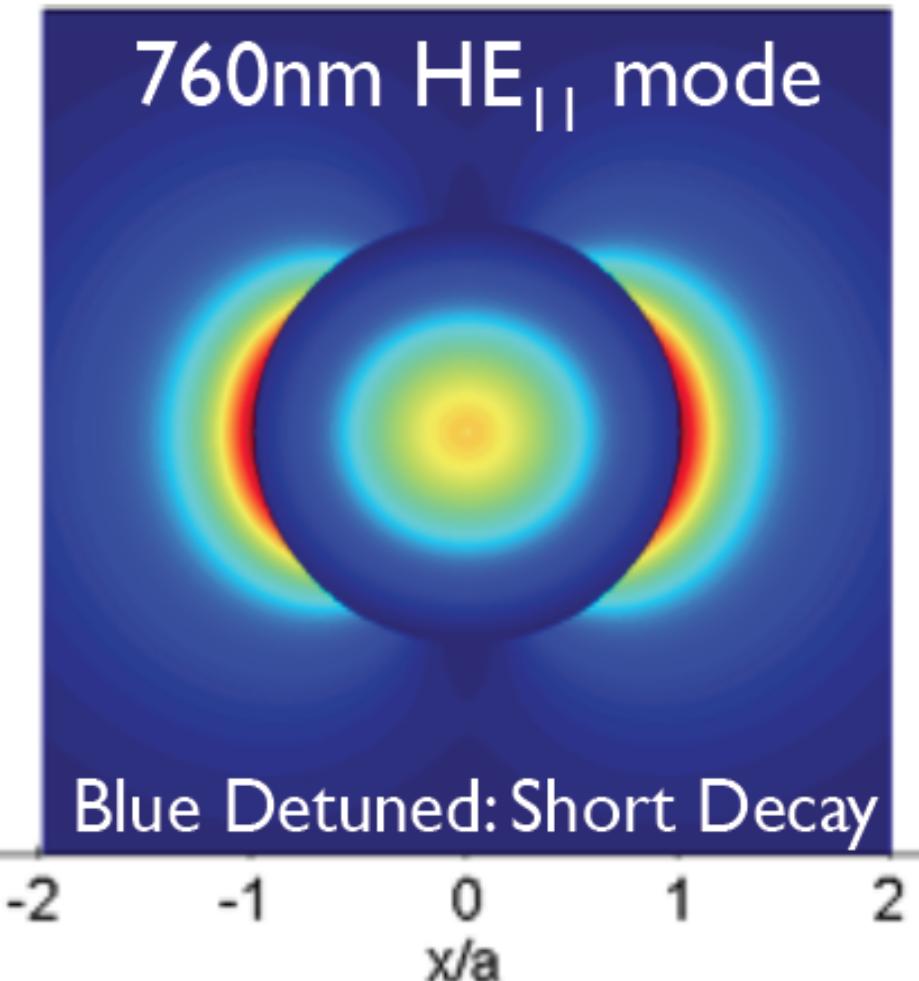
$$\times [(1 - s_{11})K_0(q_{11}r) \sin(\varphi_0) + (1 + s_{11})K_2(q_{11}r) \sin(2\phi - \varphi_0)] e^{i(\omega t - \beta_{11}z)},$$

$$E_z(r, \phi, z, t) = iA_{\text{lin}} \frac{J_1(h_{11}a)}{K_1(q_{11}a)} K_1(q_{11}r) \cos(\phi - \varphi_0) e^{i(\omega t - \beta_{11}z)}, \quad (4c)$$

Tres componentes y parte dentro de la fibra y parte fuera de la fibra. part inside and one outside



Modo fundamental en una nanofbra óptica con polarización lineal.

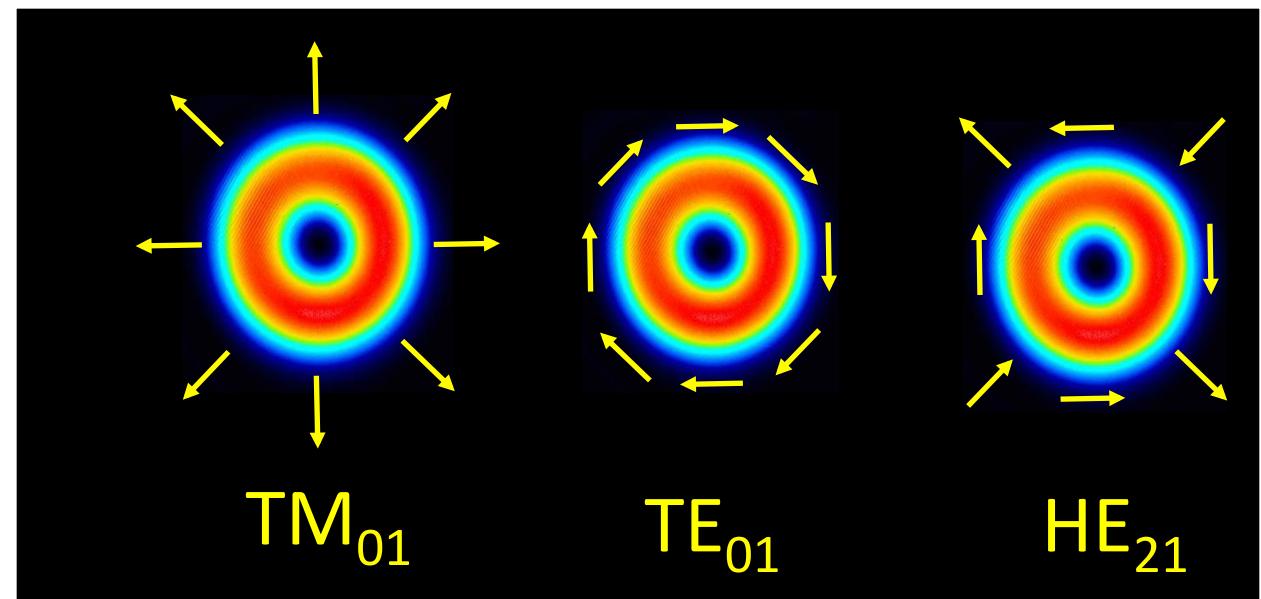
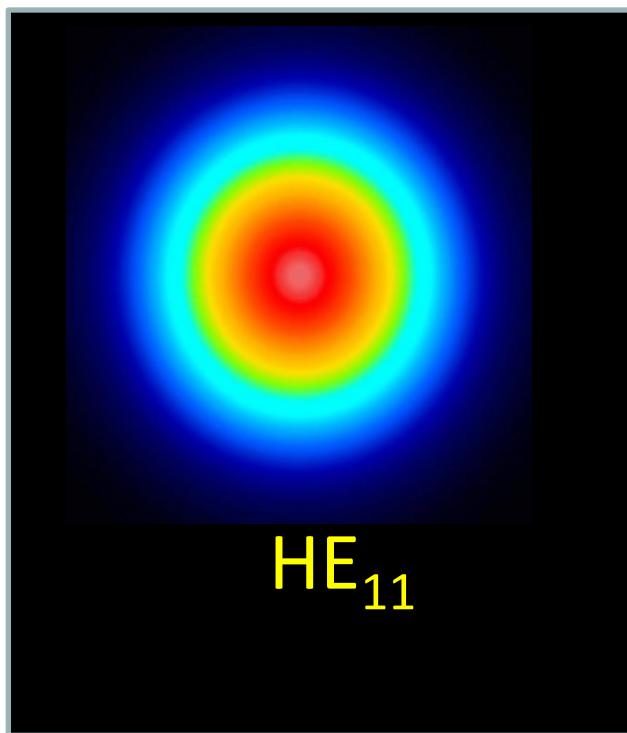


radio ~ 250 nm

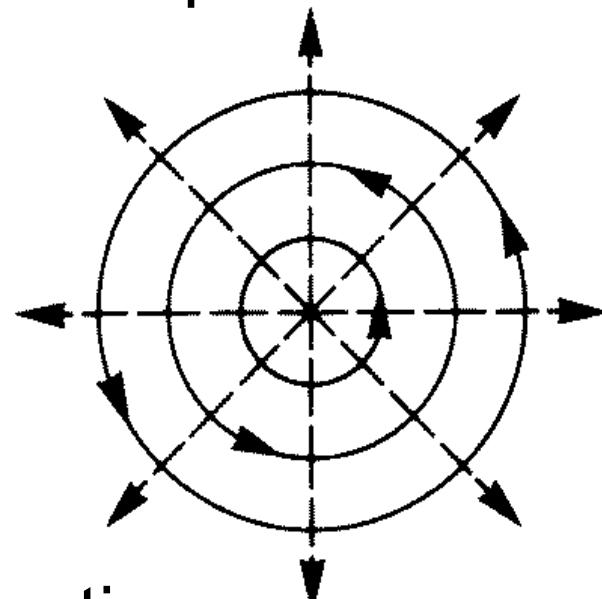
Longitud de decaimiento:
 ~ 100 nm

Intensidad 1 mW en el
campo evanescente
 $5 \times 10^8 \text{ mW/cm}^2$ equivale a
10⁸ veces la intensidad
de saturación de la línea
 D_2 en Rb.

Intensidad de modos superiores en comparación con el fundamental

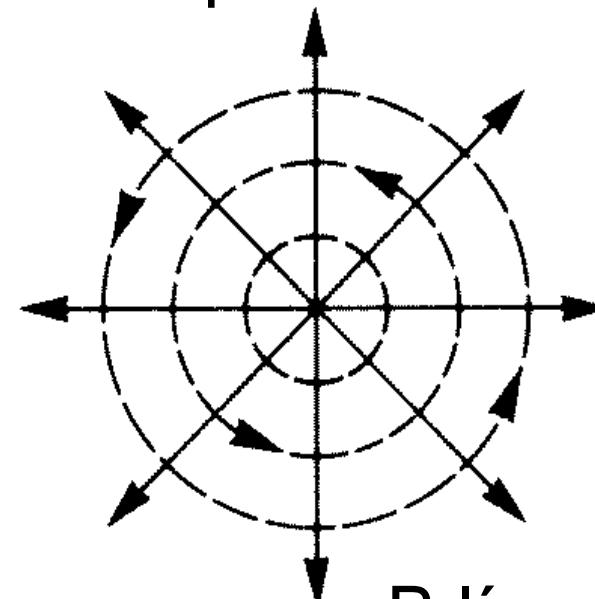


Componente transversal de la polarización



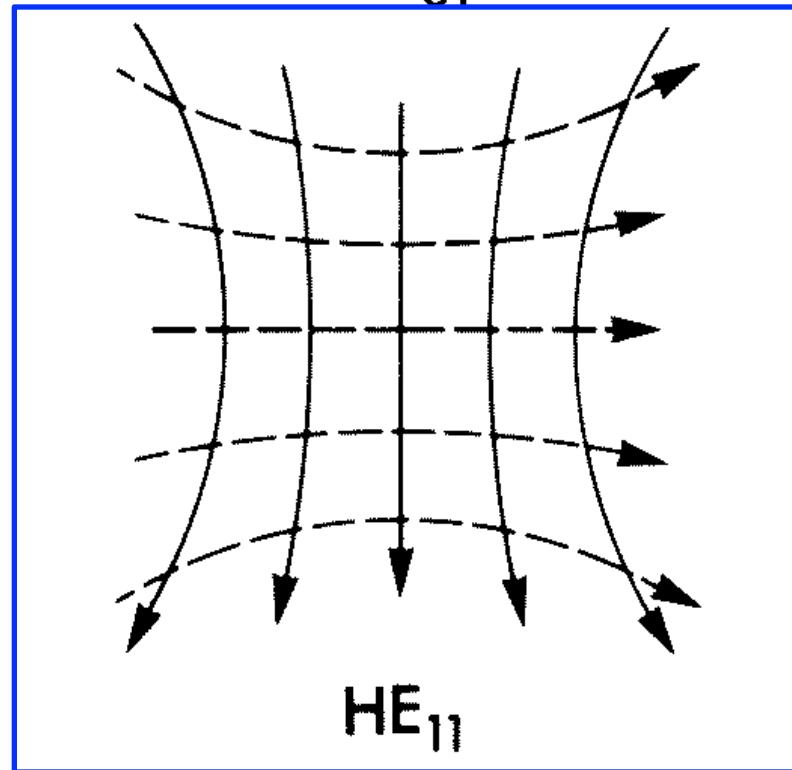
E línea continua

TE_{01}

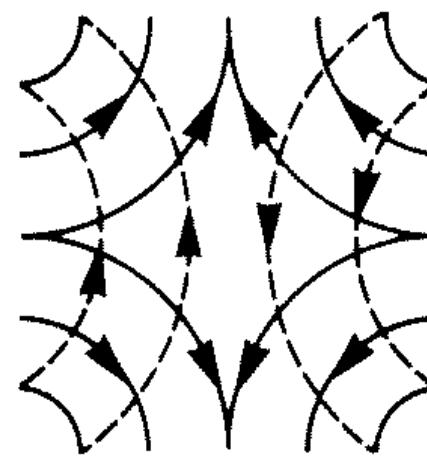


B línea punteada

TM_{01}

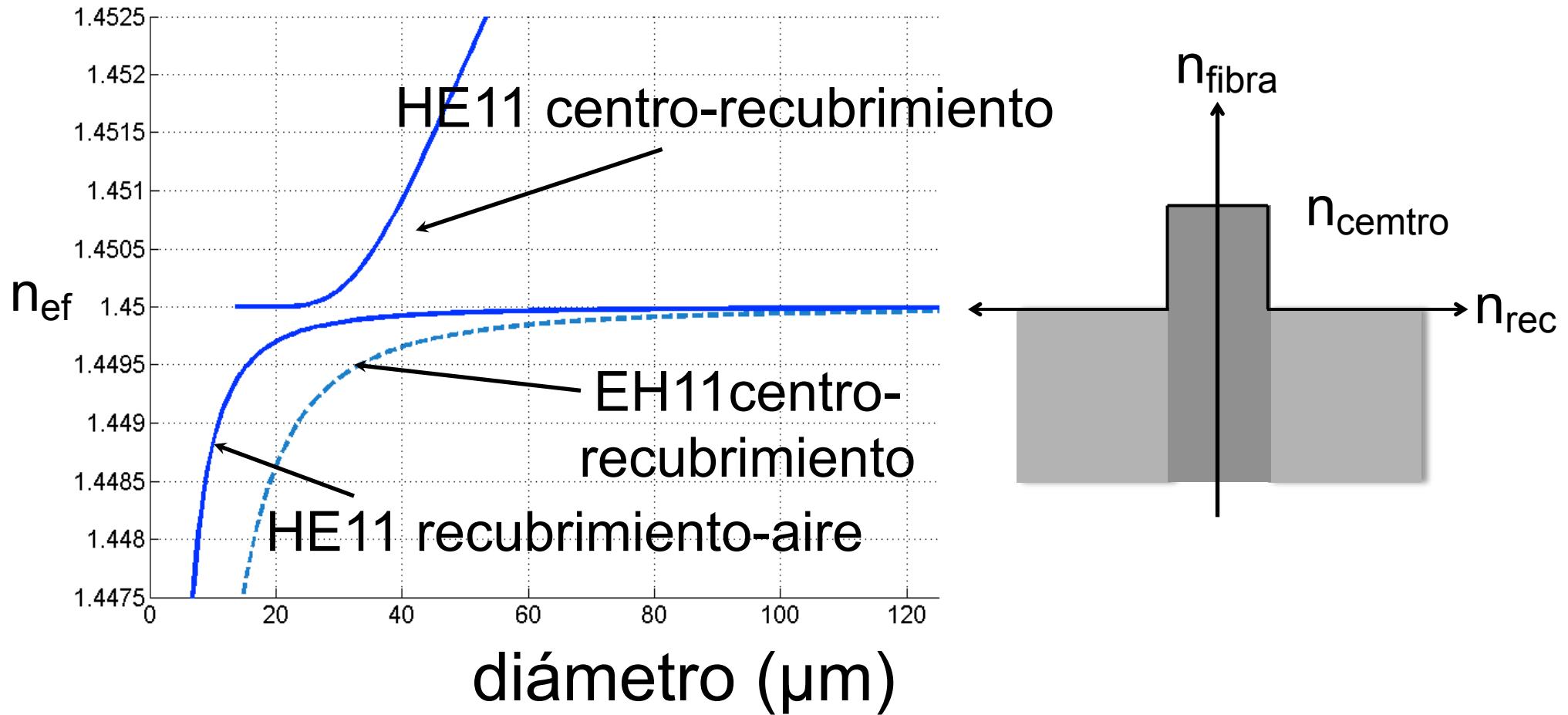


HE_{11}

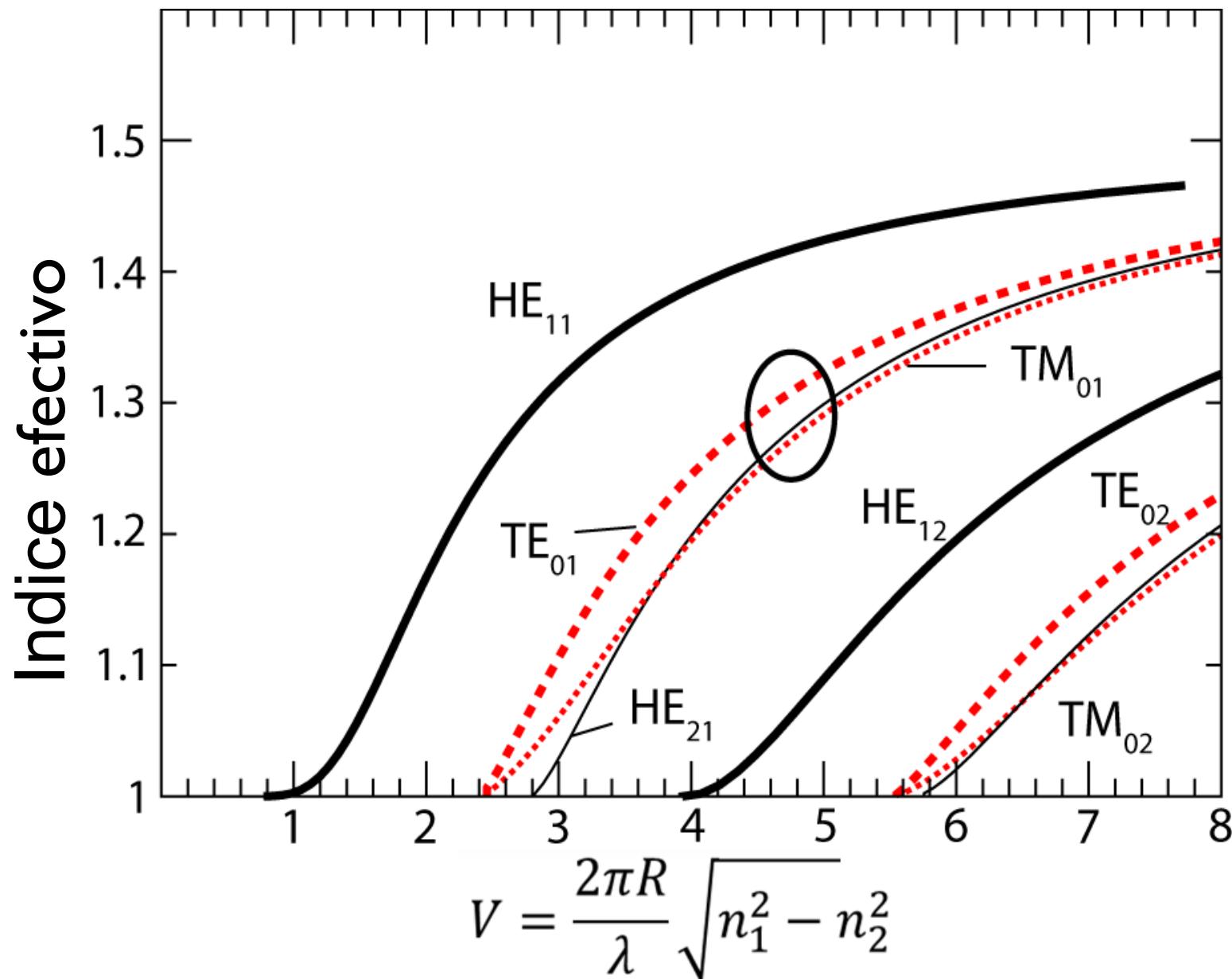


HE_{21}

Evolución de los modos en una fibra con dos capas



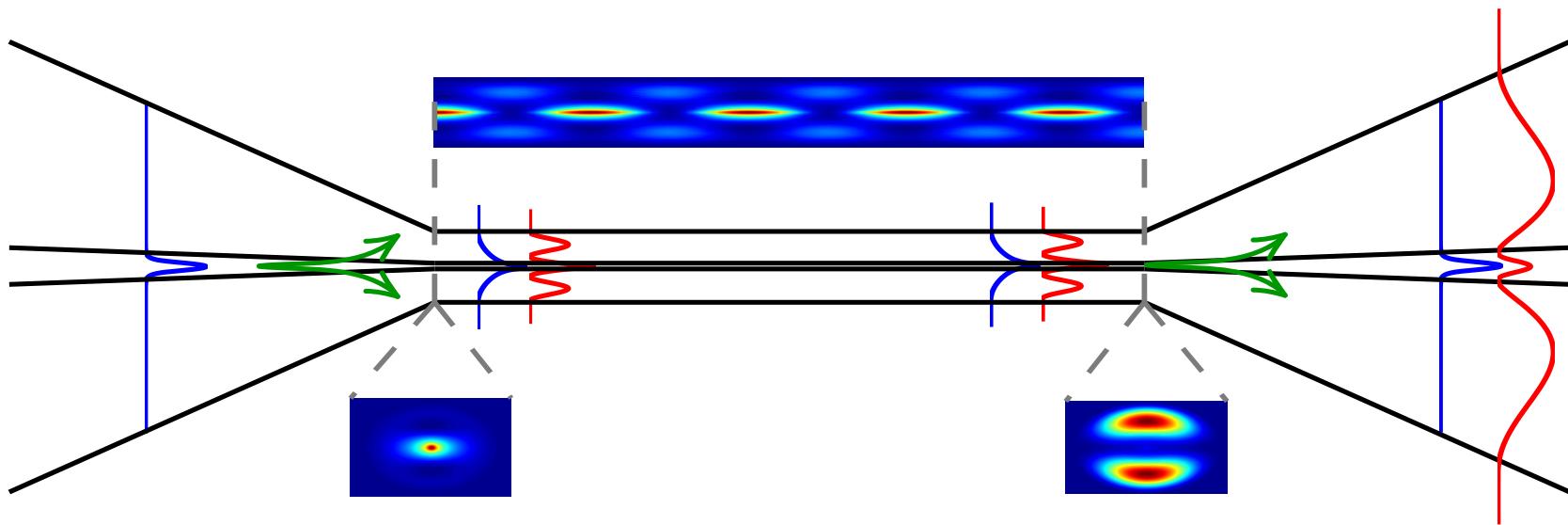
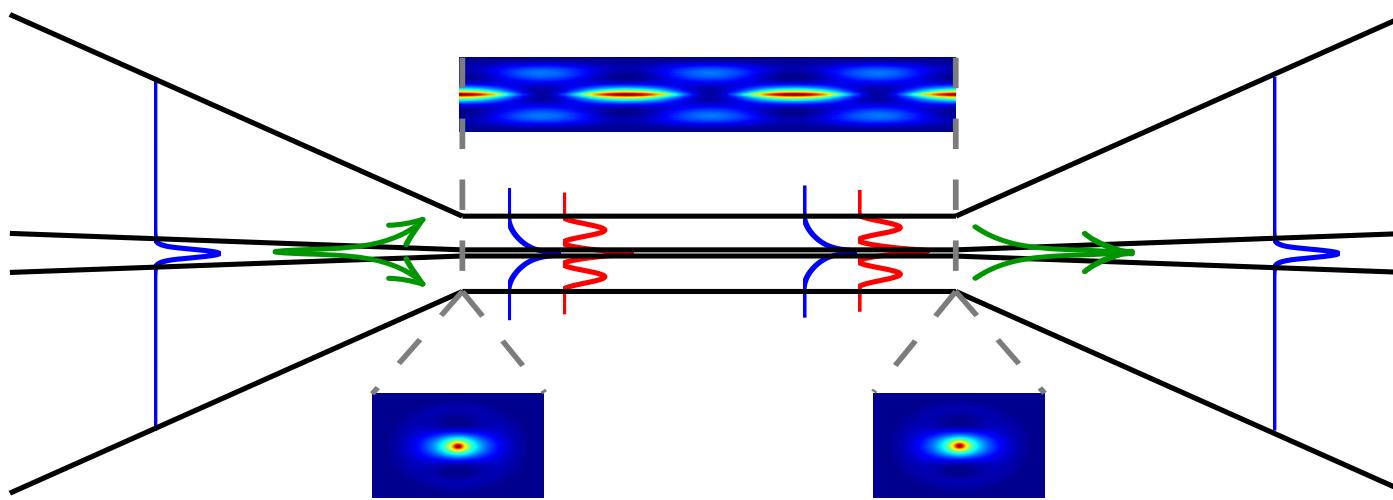
$\beta = k^* n_{\text{ef}}$, constante de propagación de un modo de la fibra.
 $k = 2\pi/\lambda$



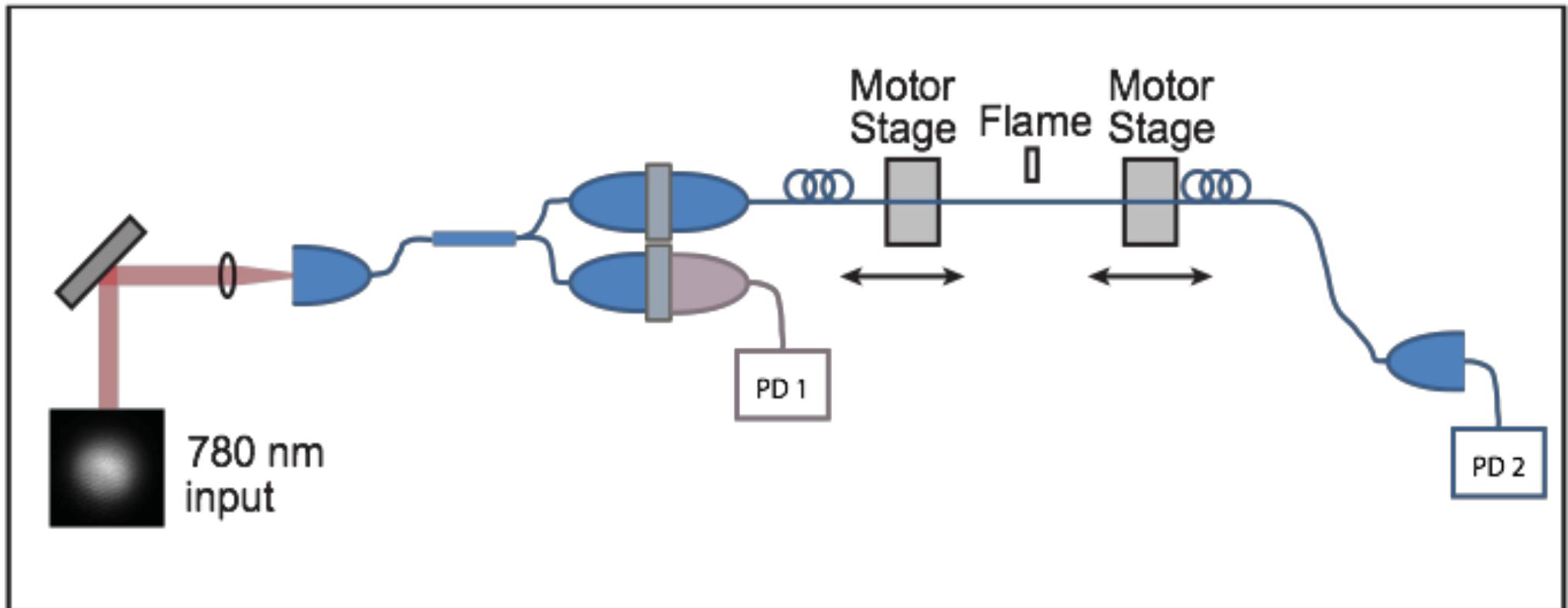
V está relacionada al ángulo de
aceptación y al radio R de la fibra.

$$\sin \theta = \sqrt{n_{\text{centro}}^2 - n_{\text{revestimiento}}^2}$$

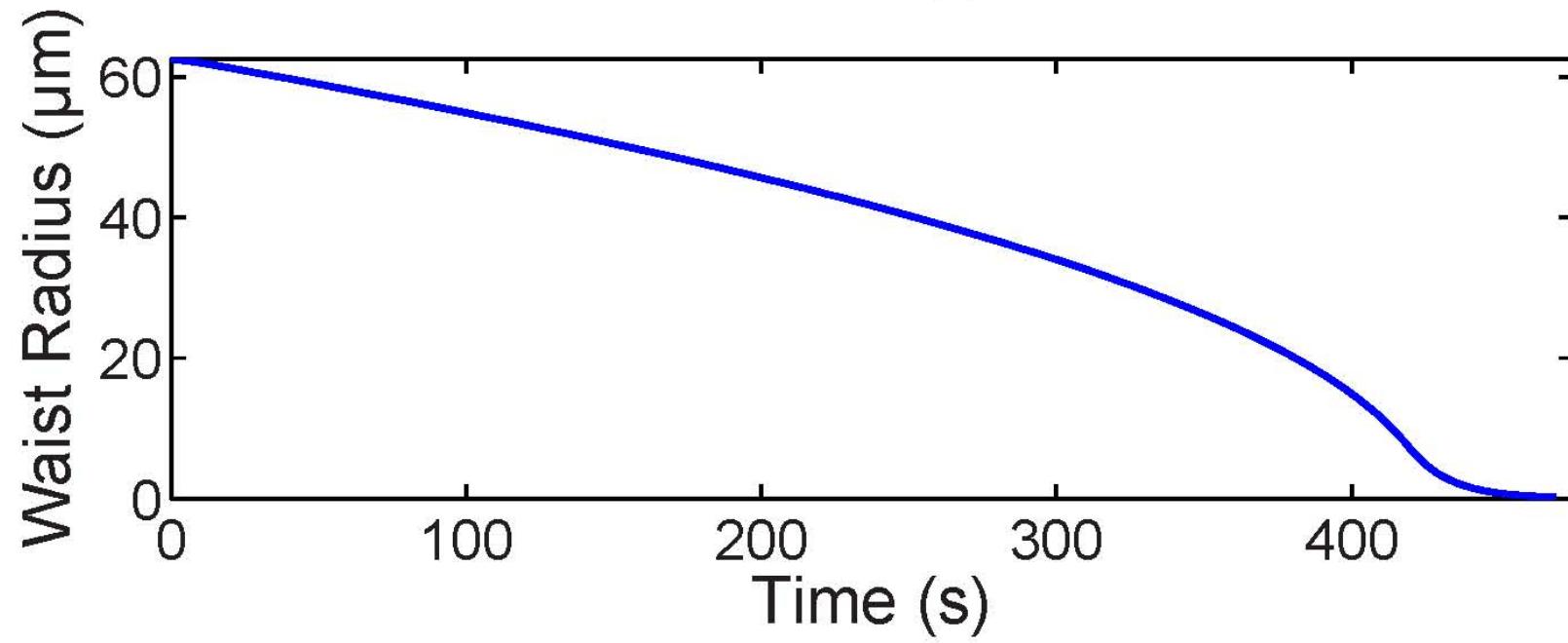
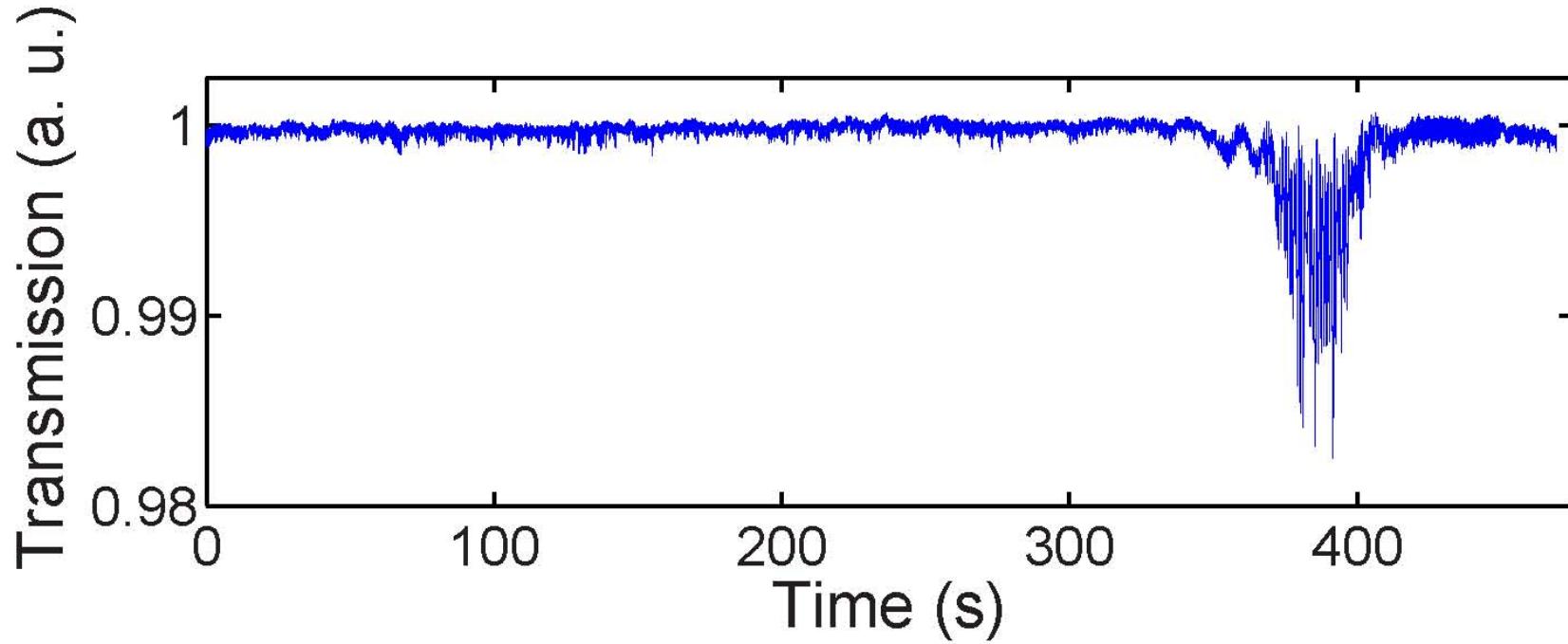
Batido de modos



Esquema de la medición

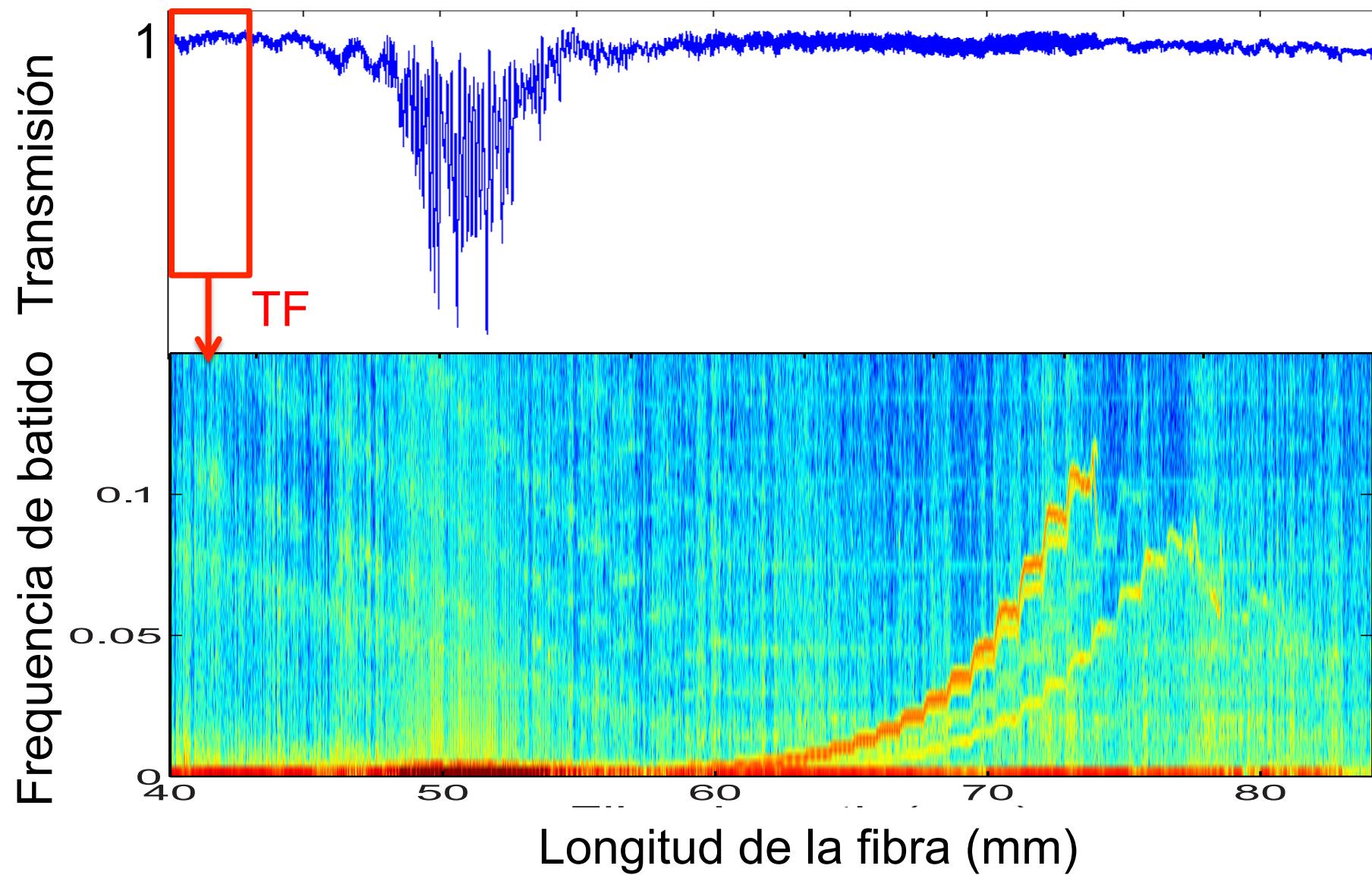


$$\text{Transmisión (t)} = (\text{PD2(t)} / \text{PD1(t)}) / \text{Normalización}$$

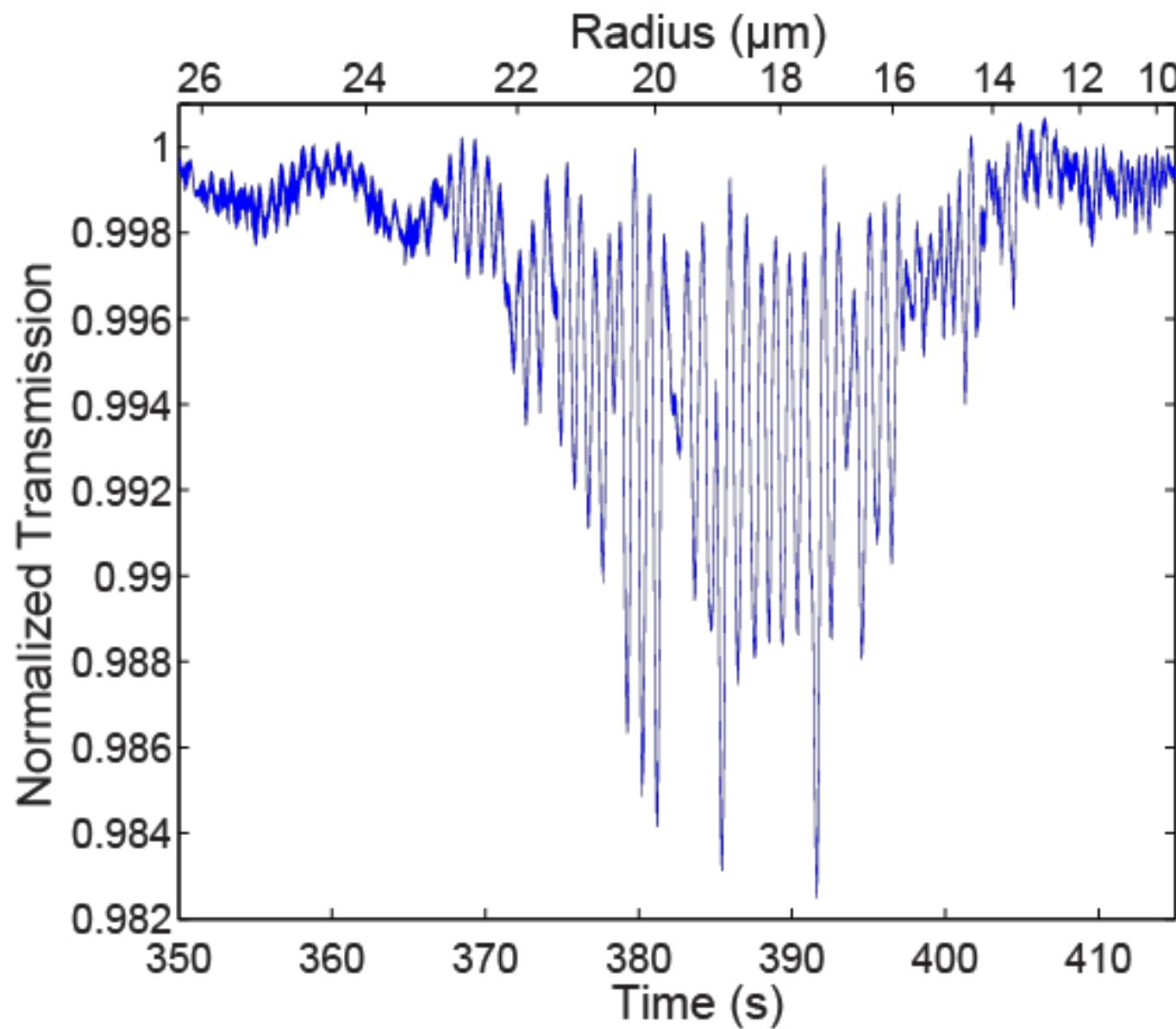


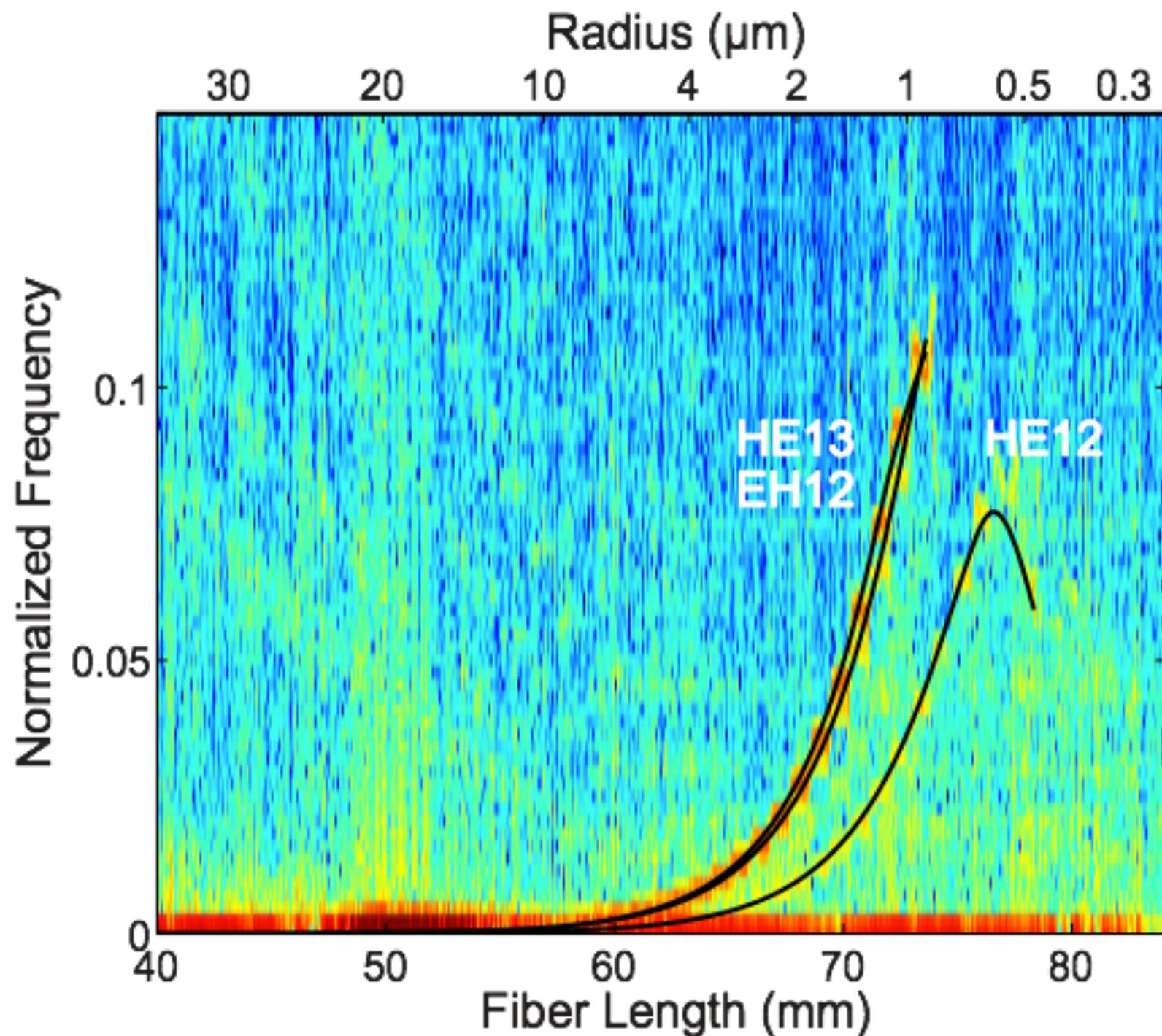
Espectrograma de la transmisión

Transformada de Fourier de una sección de tiempo
(Transformada de Gabor) de la señal de una fibra lineal con 2
mrad.

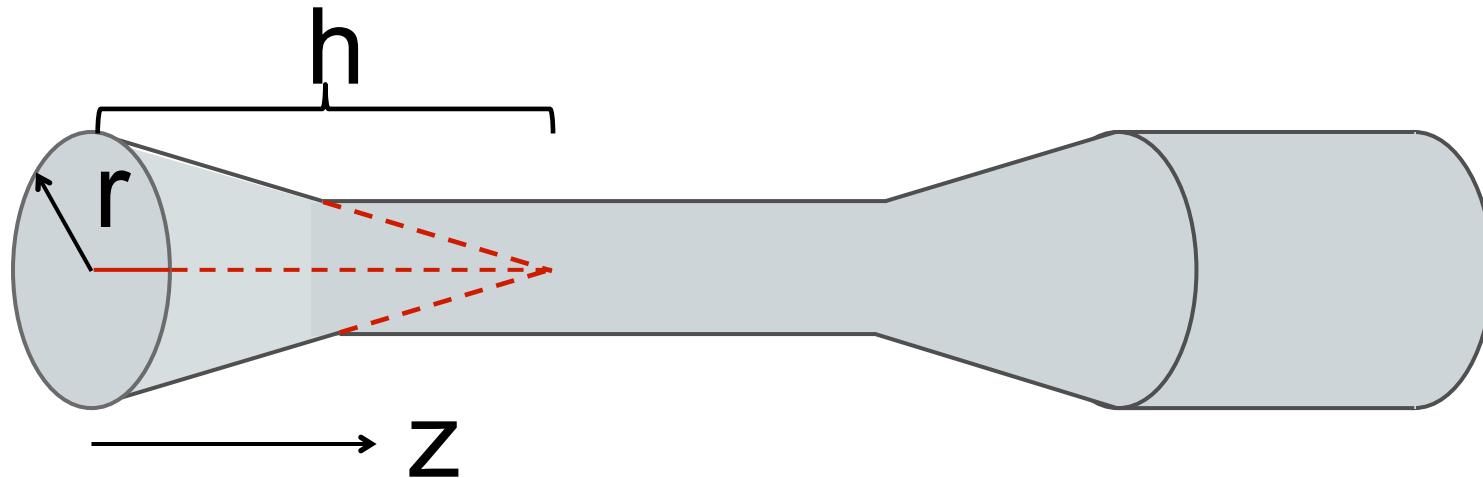


Oscilaciones durante el estirado





Criterio de adiabaticidad: Mantener la reflección total interna.



Dos escalas de longitud:

$$h = \frac{r(z)}{\frac{dr(z)}{dz}} = \frac{r(z)}{\Omega}$$

$b \ll h$

$$b = \frac{2\pi}{\beta_1(z) - \beta_2(z)}$$

4. Propiedades de polarización

Los gradientes de E en la dirección radial son muy grandes.

- $\text{Div } \mathbf{E}=0$ (Ley de Gauss) implica componentes longitudinales grandes.

$$\frac{\partial E_r}{\partial r} + \frac{\partial E_z}{\partial z} = 0$$

- El campo evanescente debe tener una componente longitudinal para compensar el gradiente radial

Polarización en la cintura de la nanofibra

$$\nabla \cdot \vec{E} = 0$$

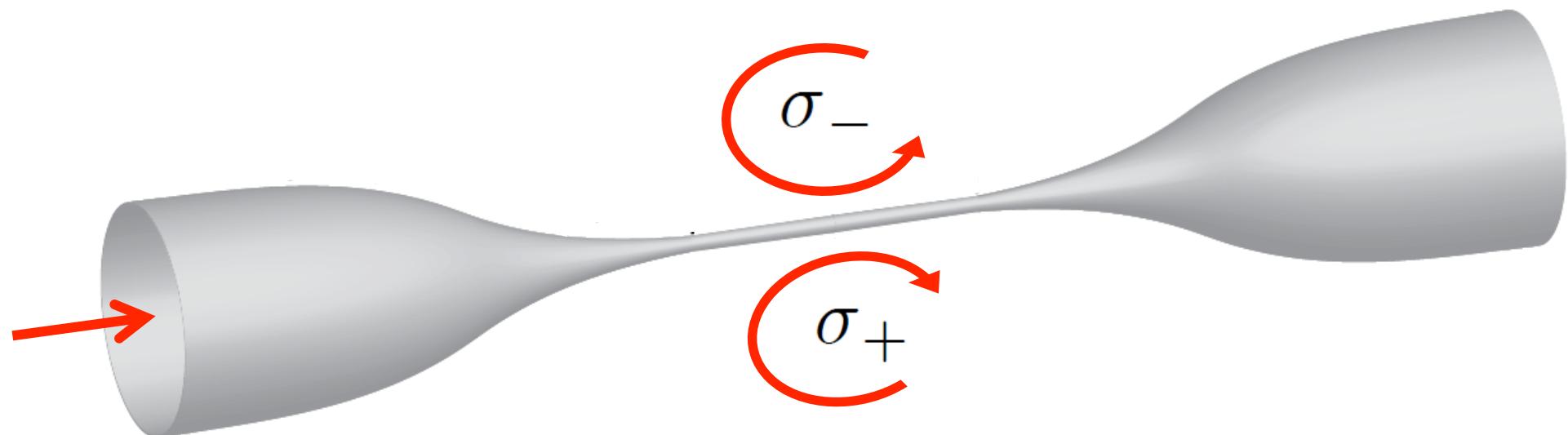
$$\nabla_T \cdot \vec{E} + \frac{2\pi}{\lambda} i E_Z = 0$$



Polarización en la cintura de la nanofibra

$$\nabla \cdot \vec{E} = 0$$

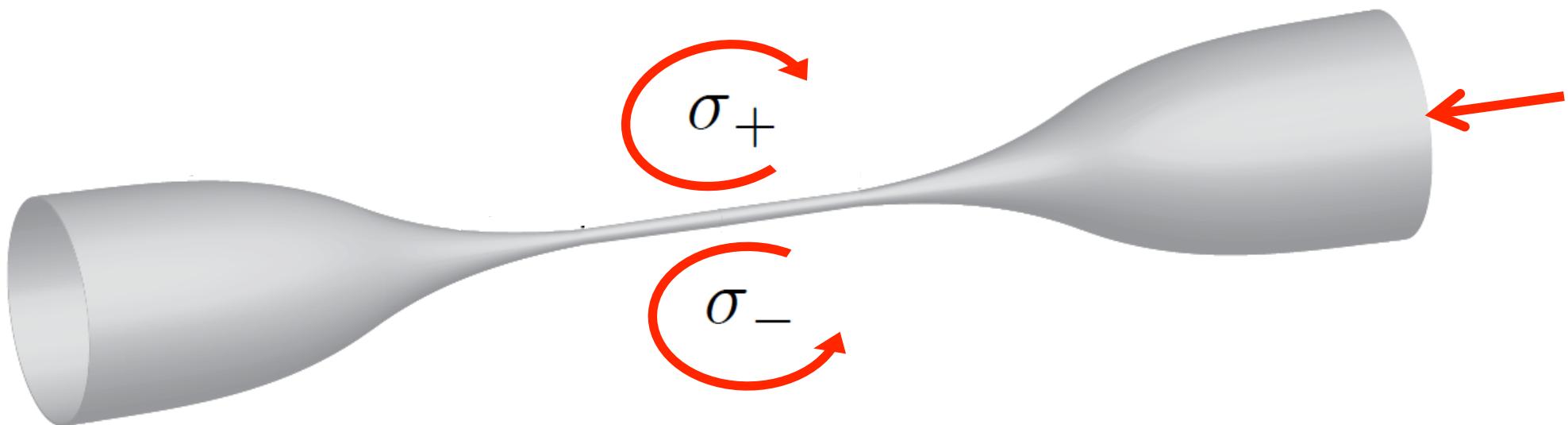
$$\nabla_T \cdot \vec{E} + \frac{2\pi}{\lambda} i E_Z = 0$$



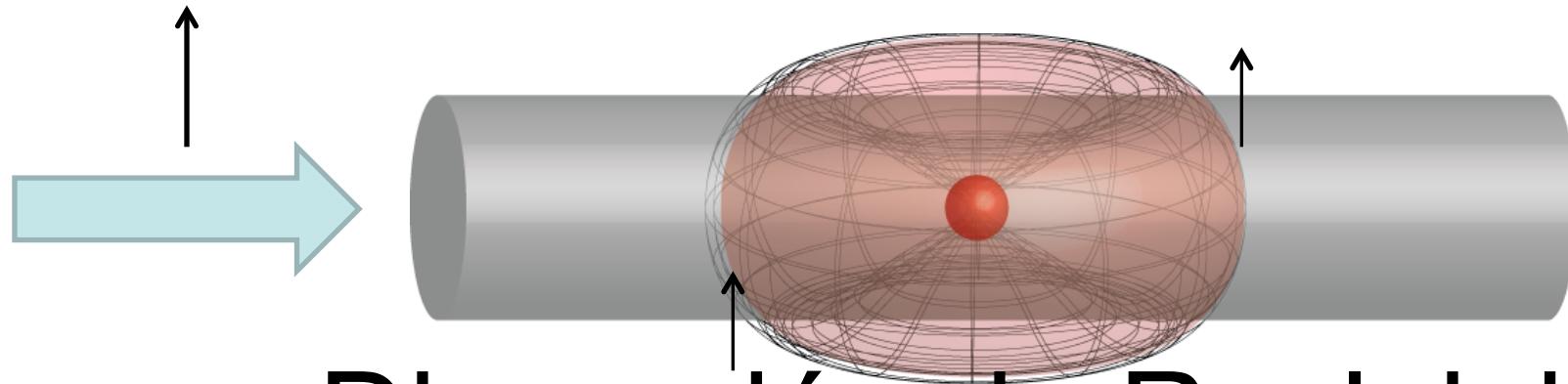
Polarización en la cintura de la nanofibra

$$\nabla \cdot \vec{E} = 0$$

$$\nabla_T \cdot \vec{E} + \frac{2\pi}{\lambda} i E_Z = 0$$



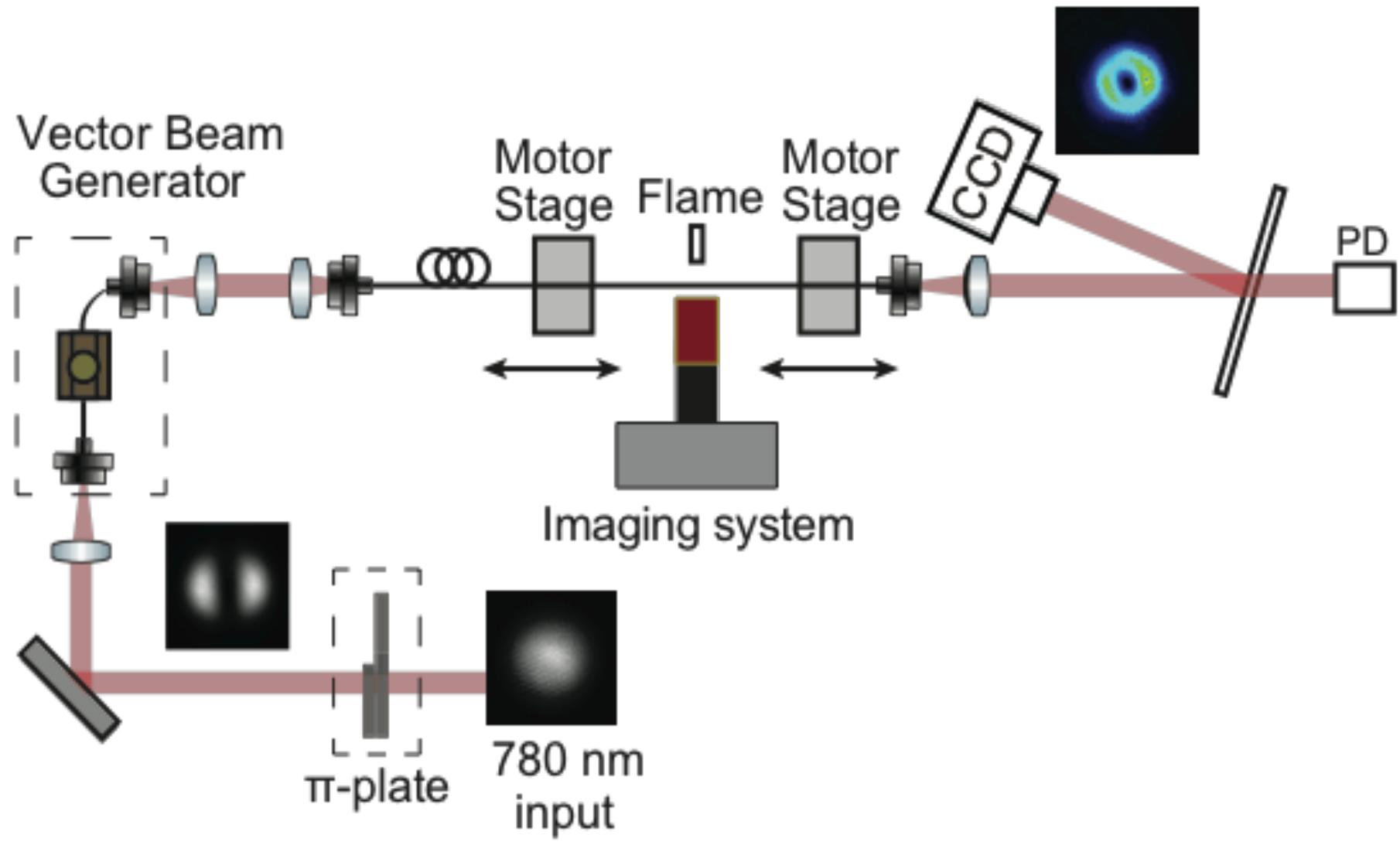
5. Mediciones del radio

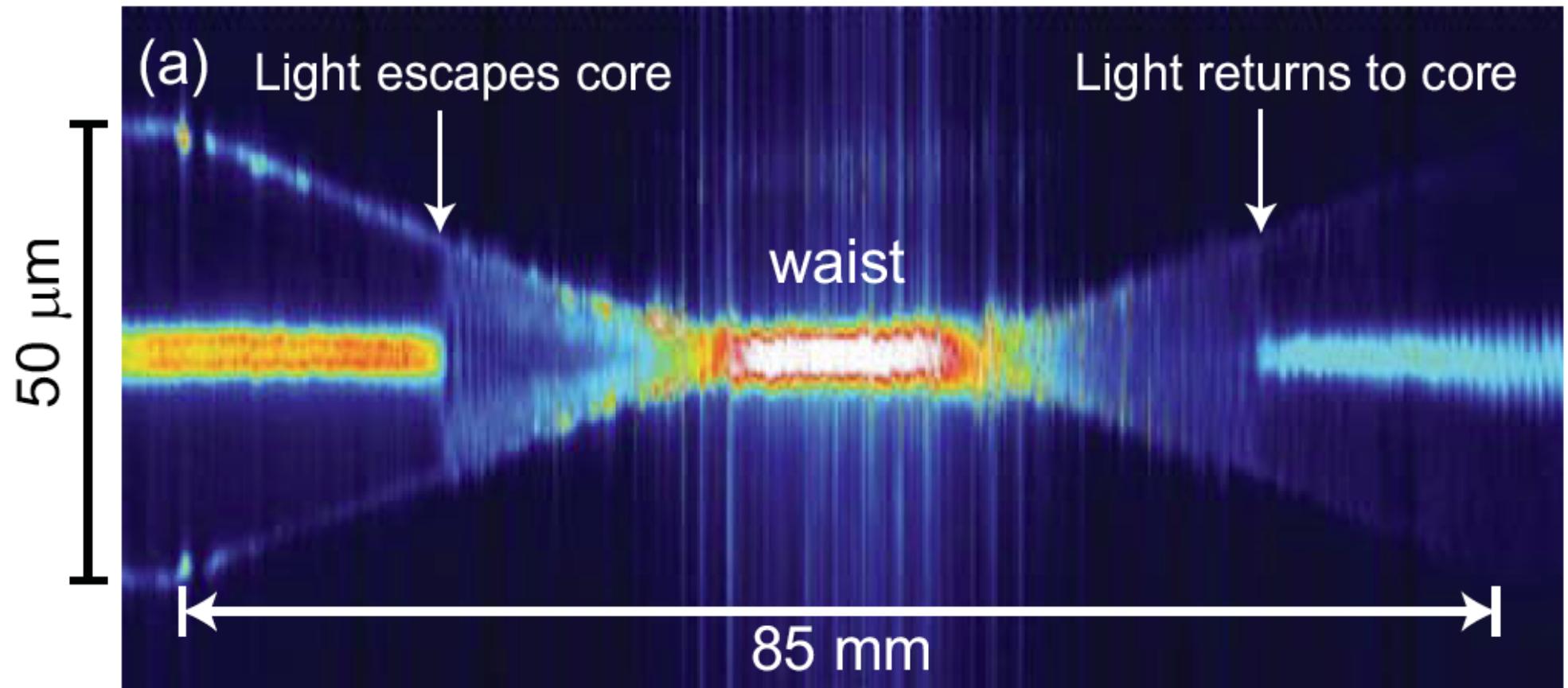


Dispersión de Rayleigh

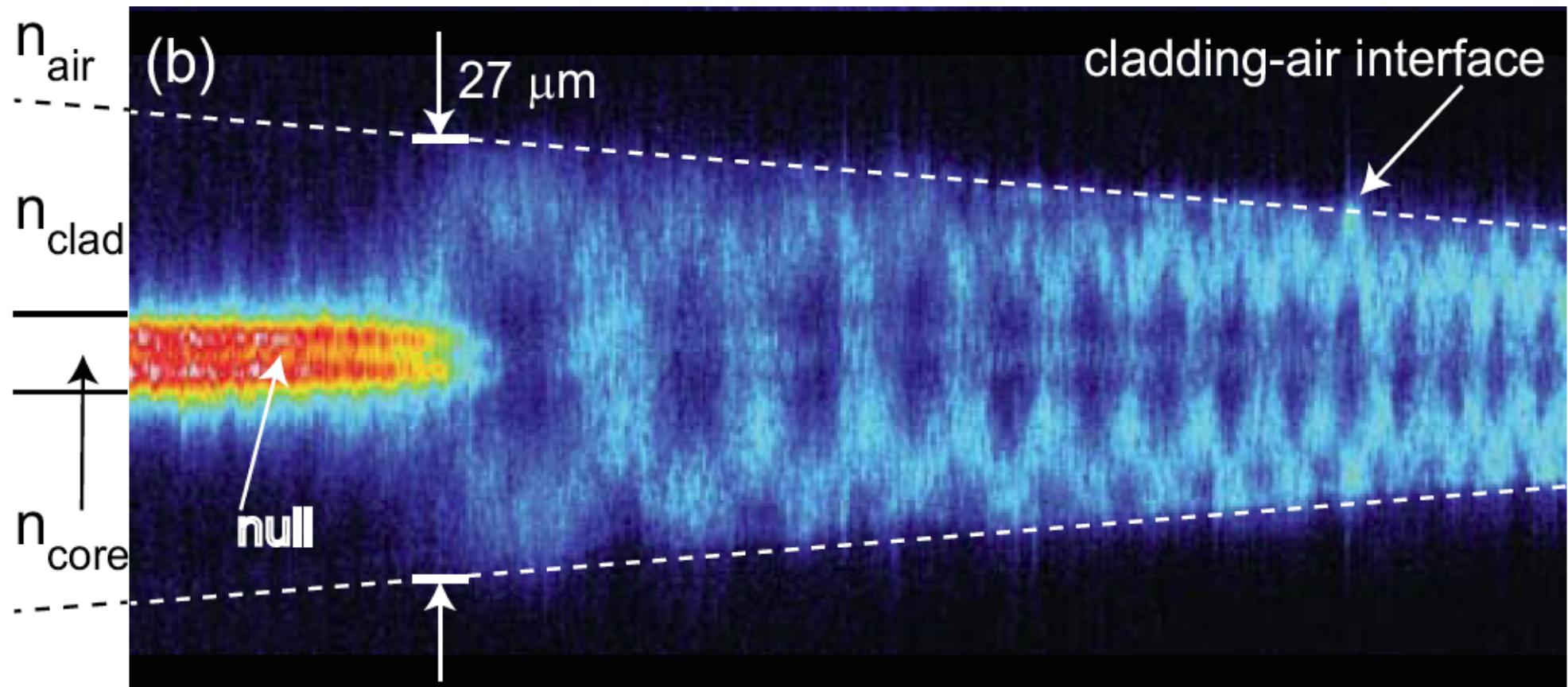
Puede deberse a muchos factores:

- Fluctuaciones de la densidad
- Impurezas de iones y o átomos
- Fluctuaciones en la interface
- Burbujas entre el centro y el recubrimiento



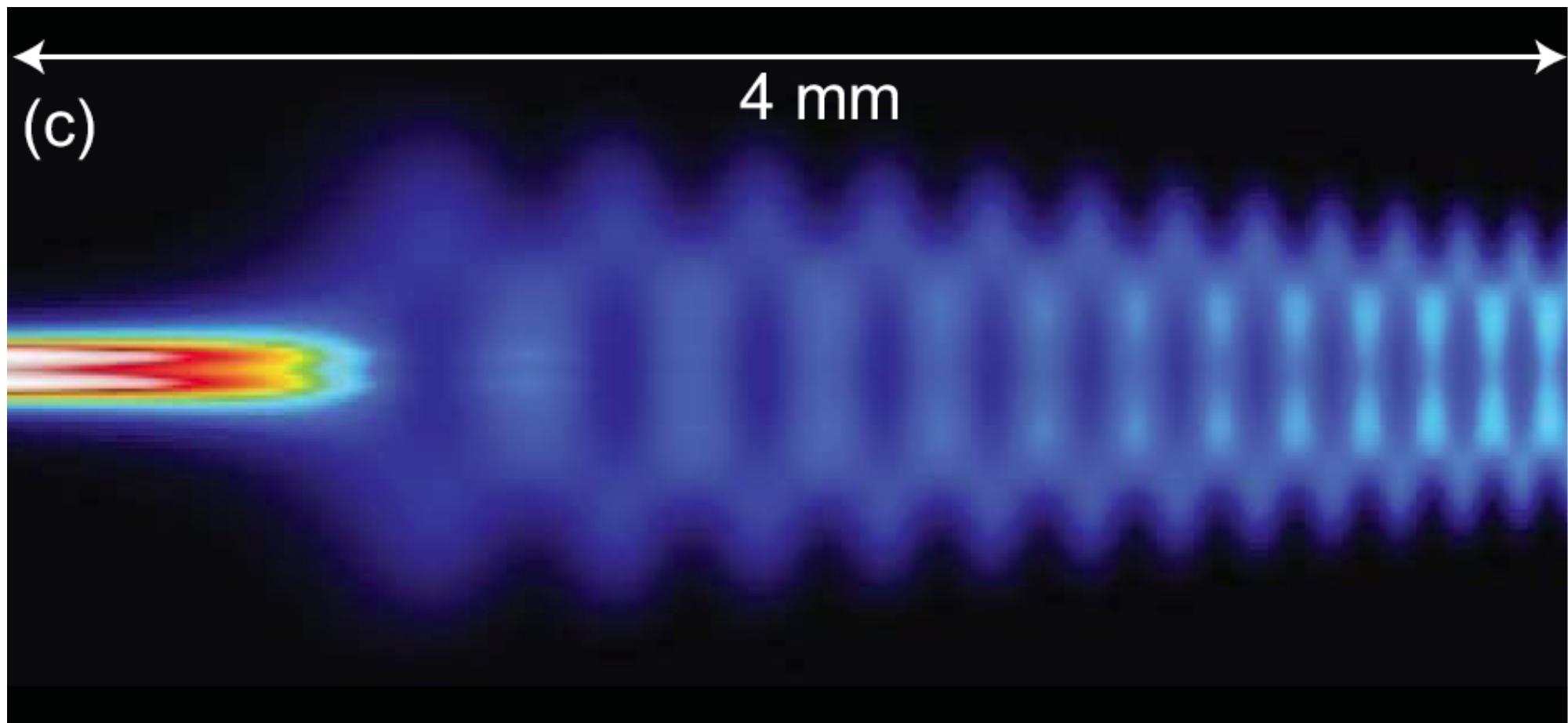


Transición del centro al recubrimiento

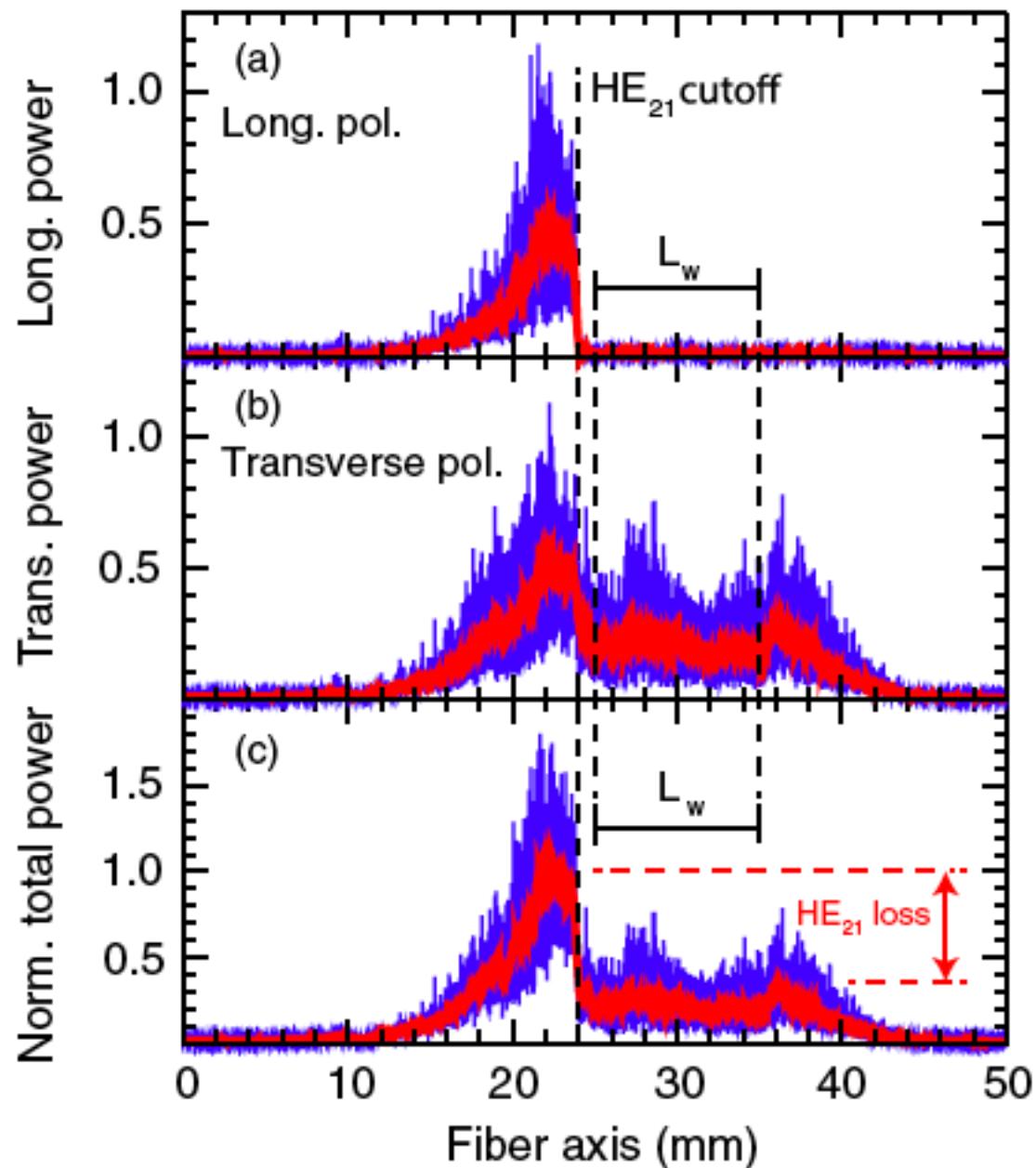


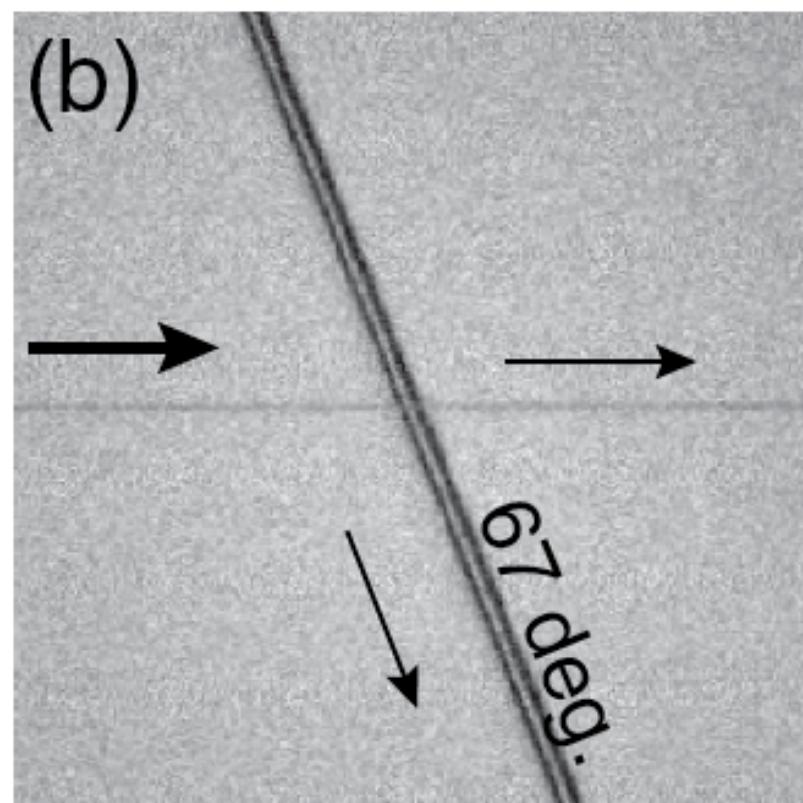
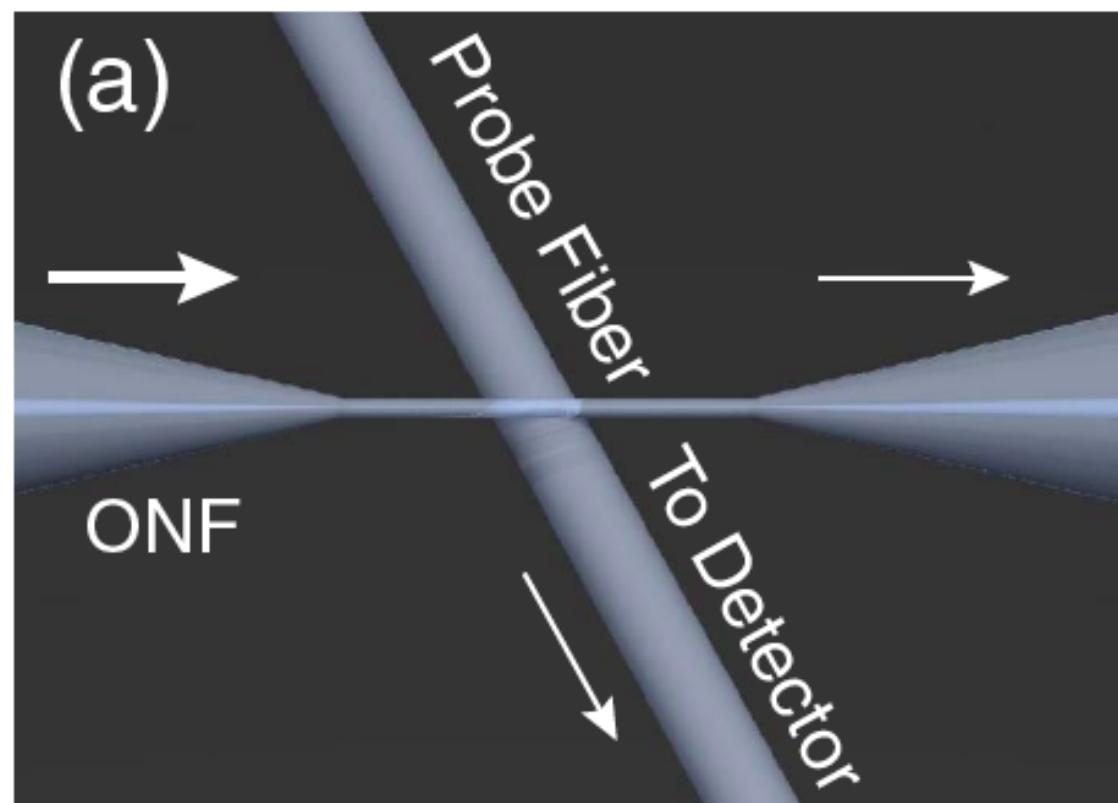
Excitación de muchos modos; óptica de rayos

Cálculo de la propagación

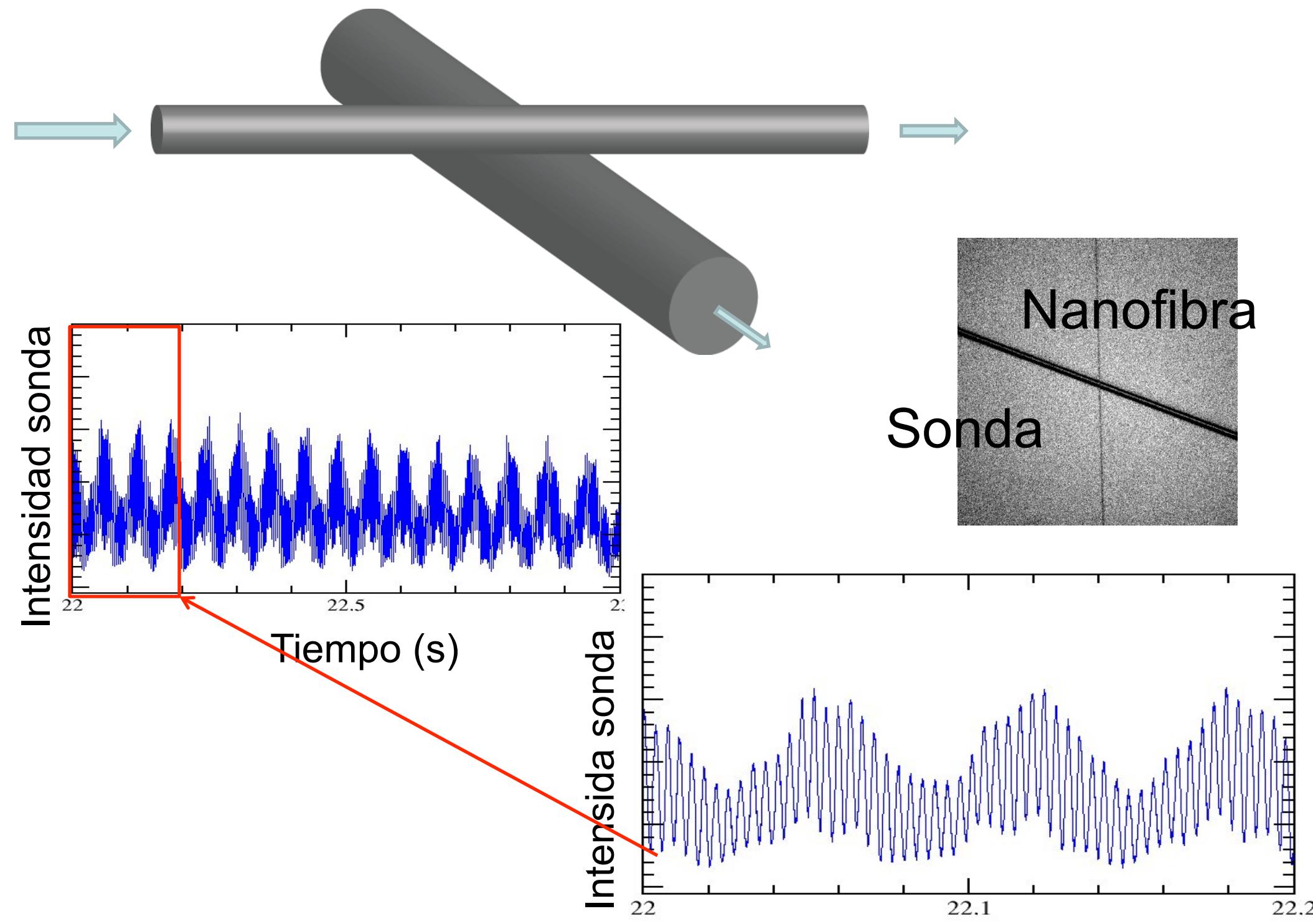


Polarización observada en la dispersión de Rayleigh

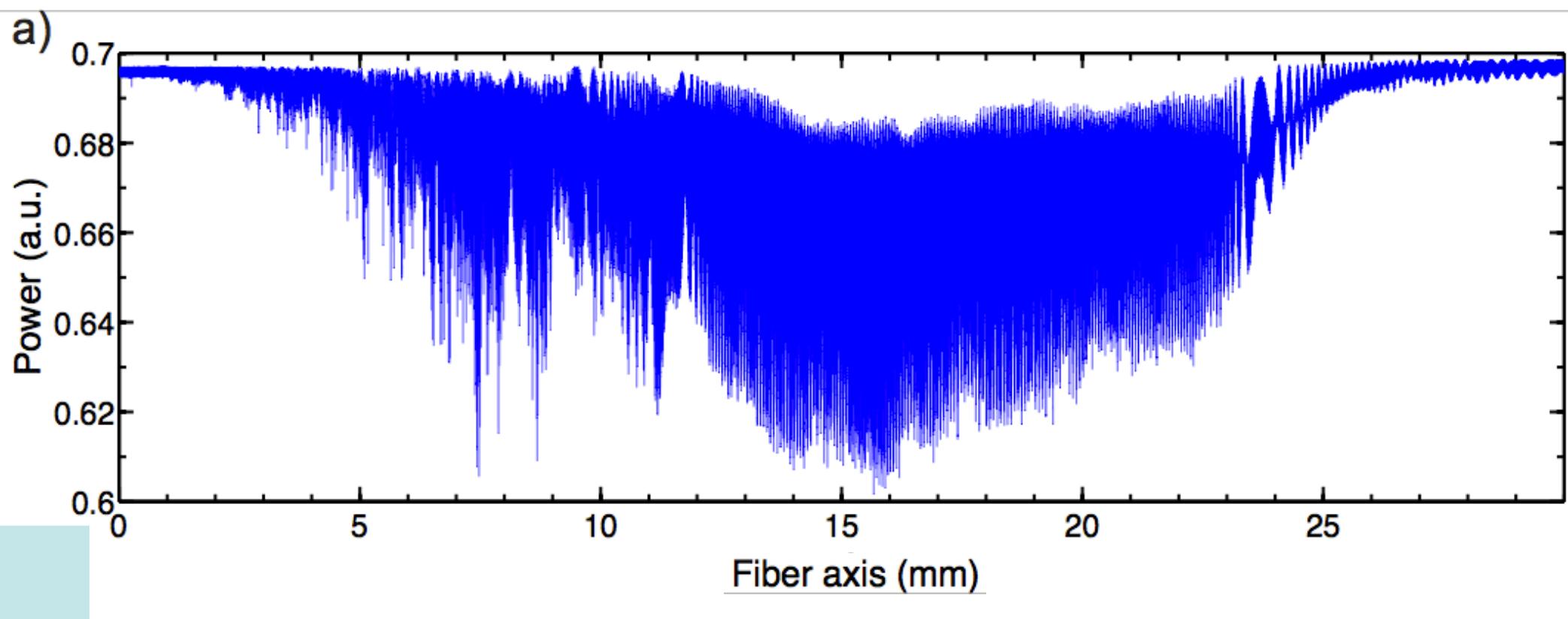




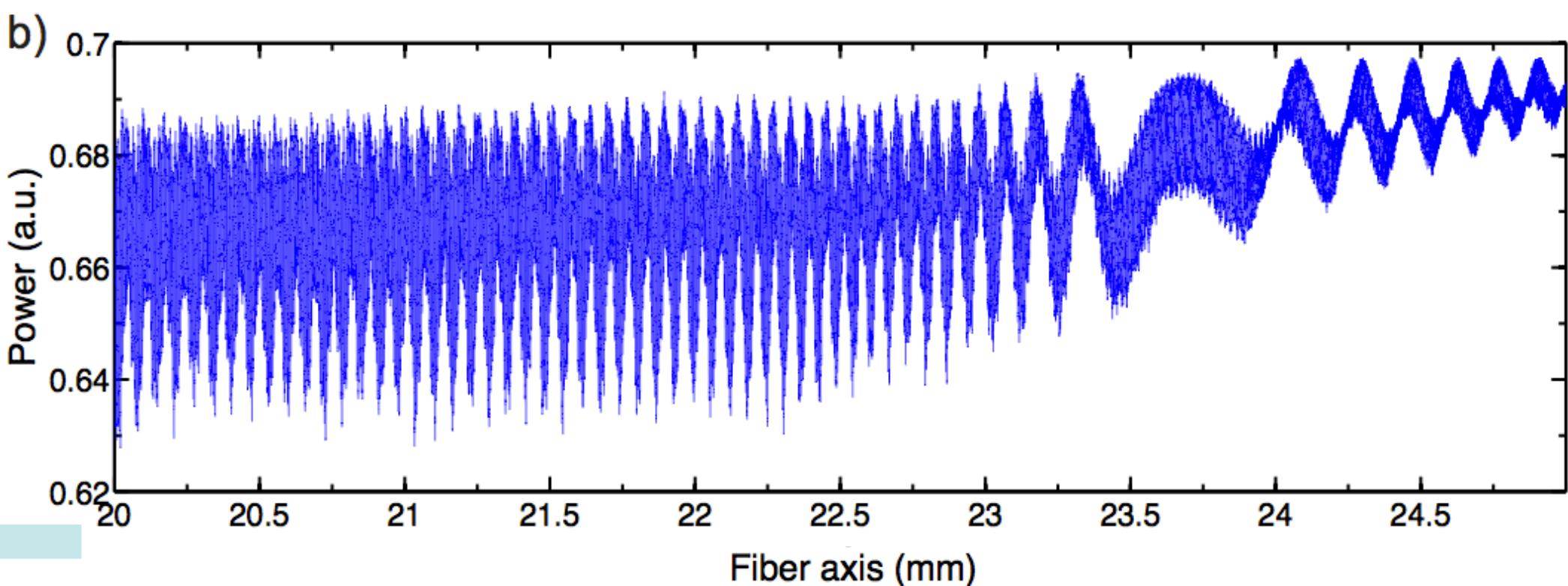
Mapeo directo del batido



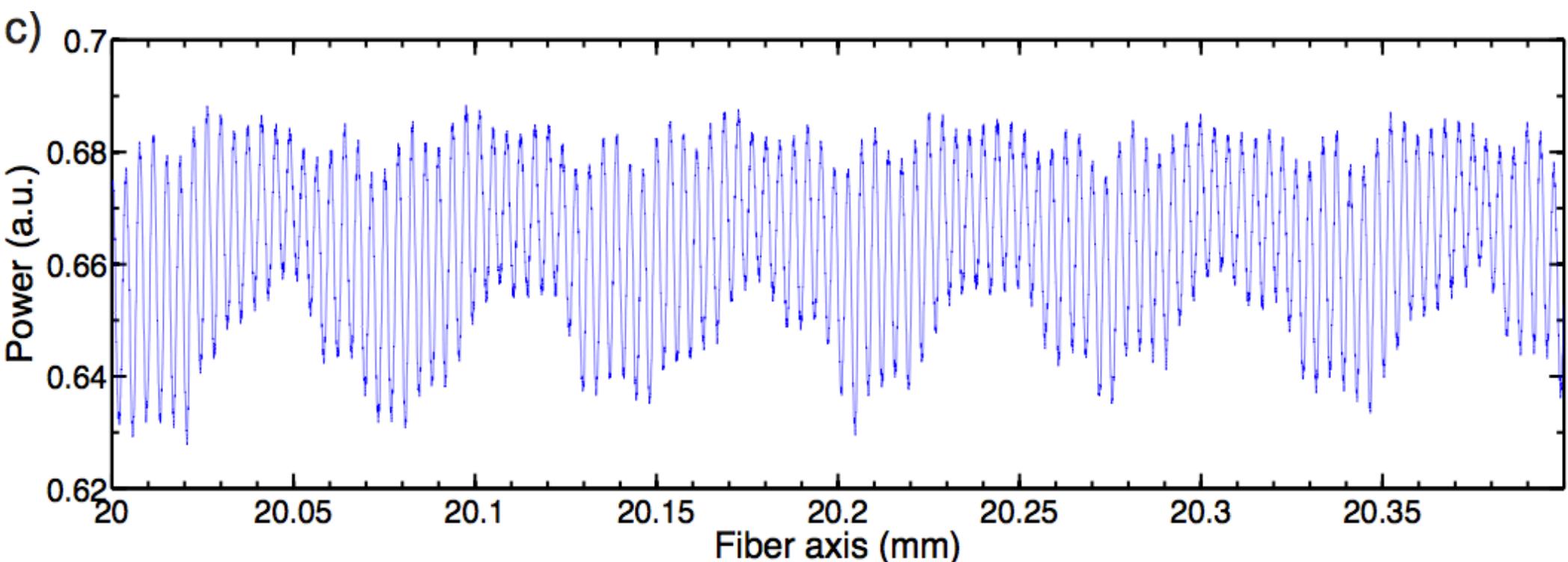
Luz trasmisita por la sonda

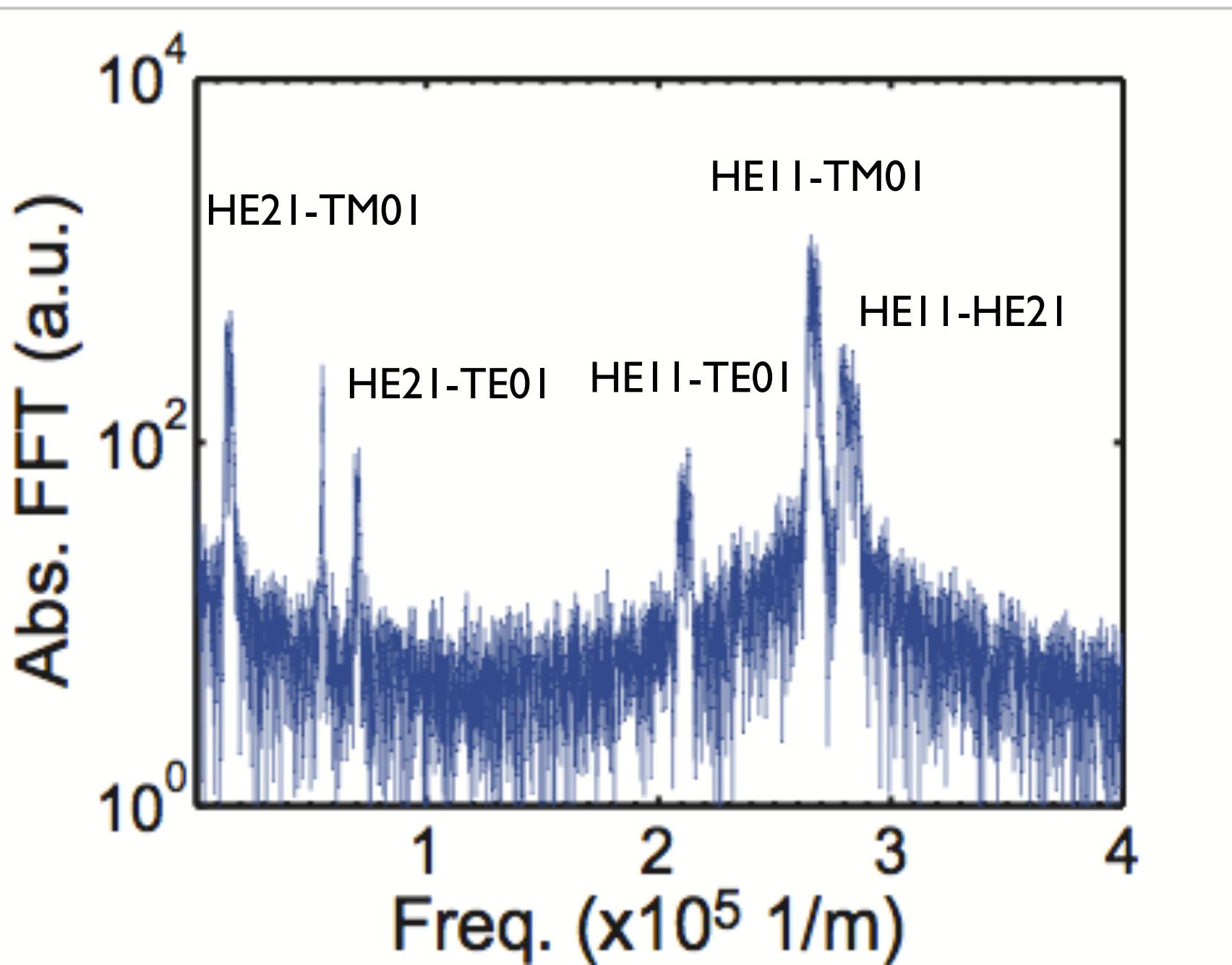


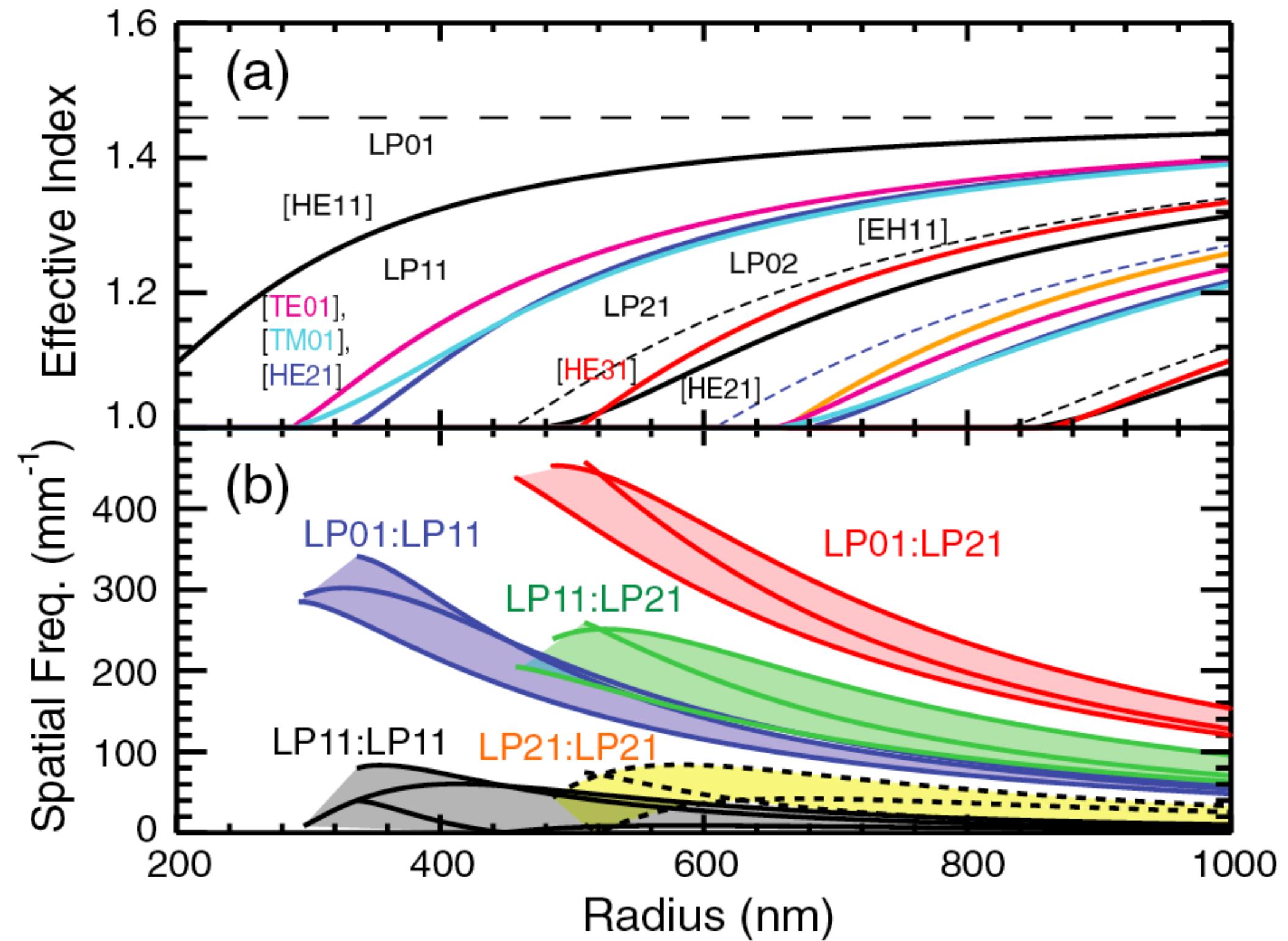
Luz transmitida por la fibra sonda



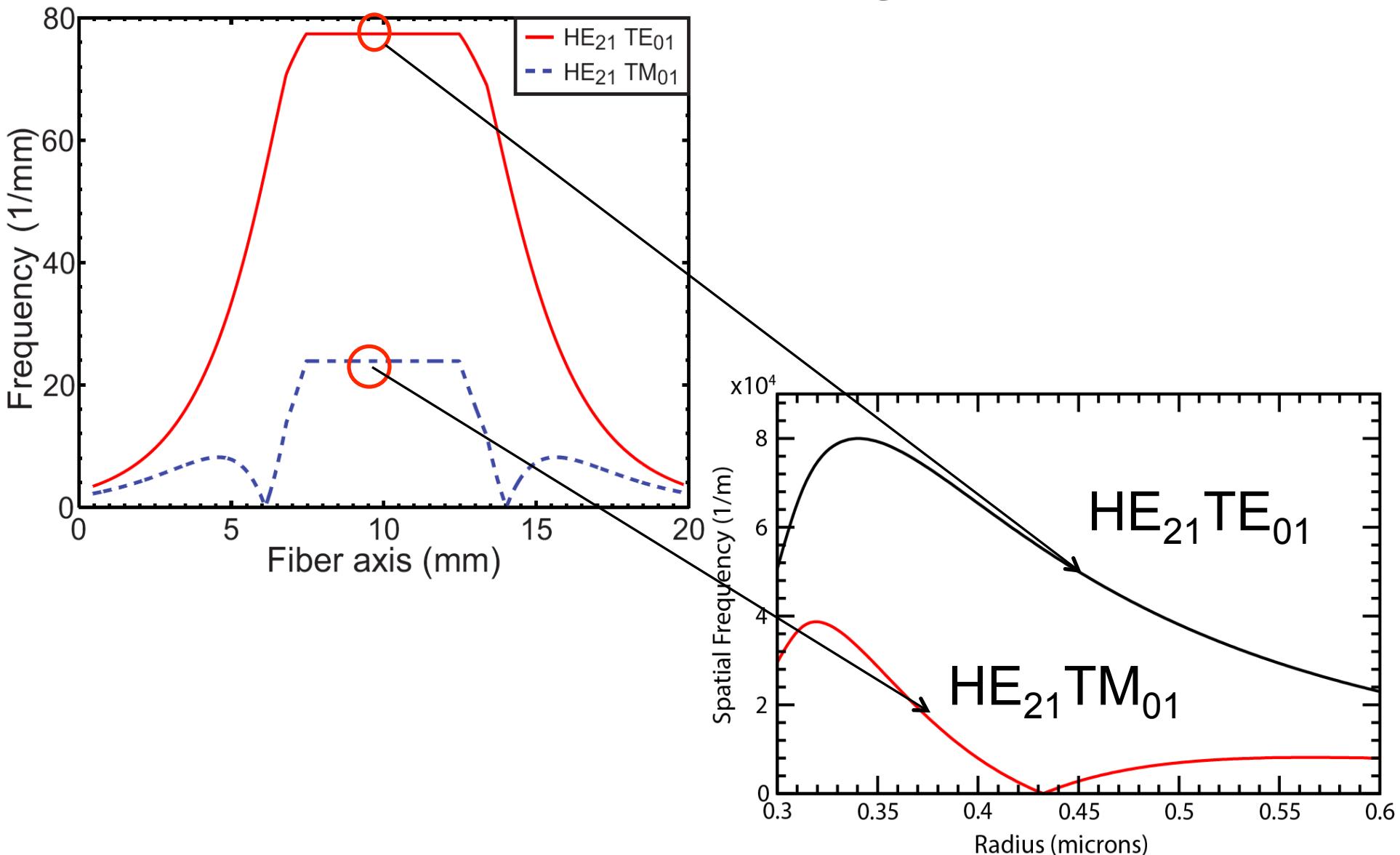
Luz trasmisita por la sonda



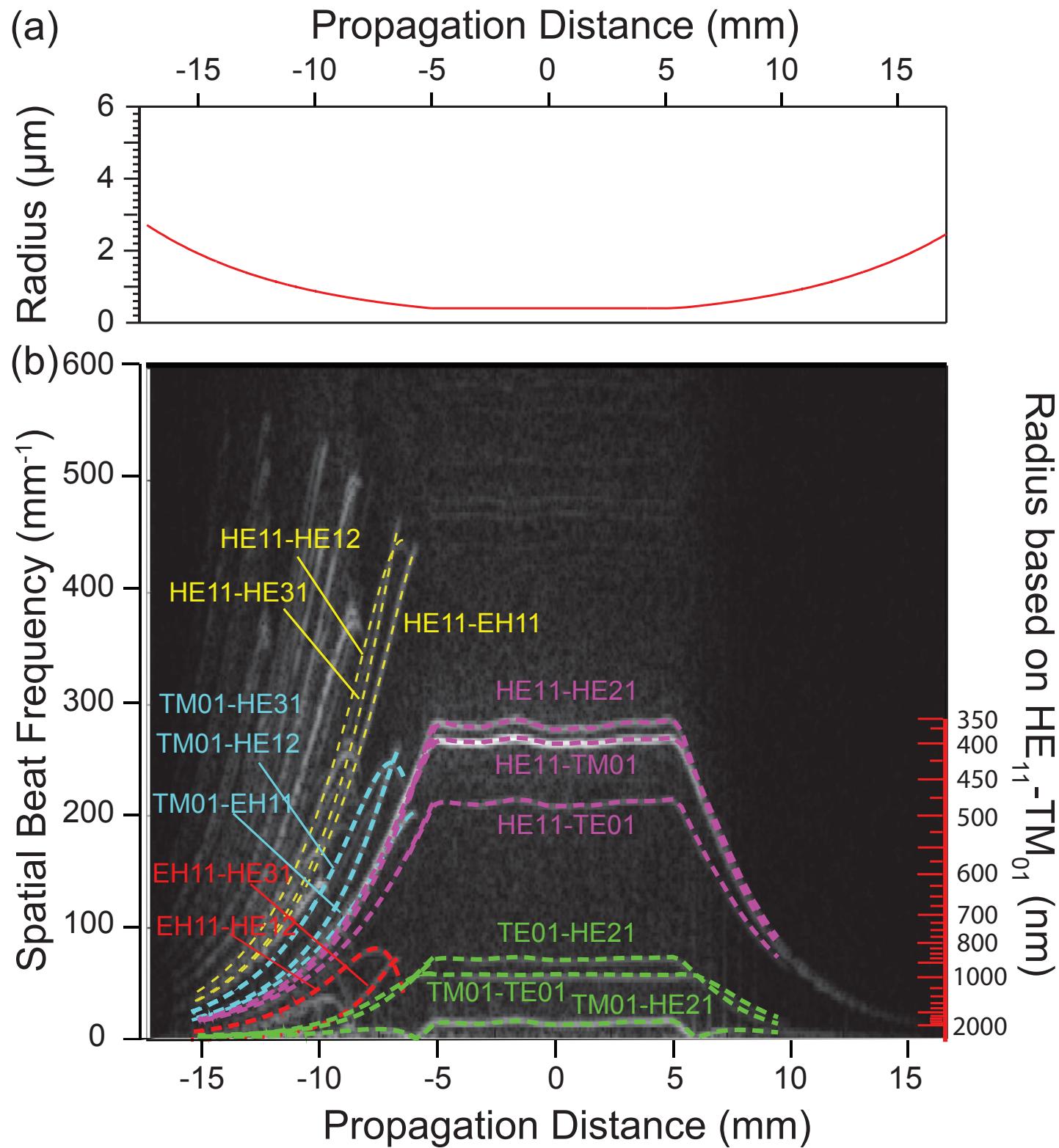


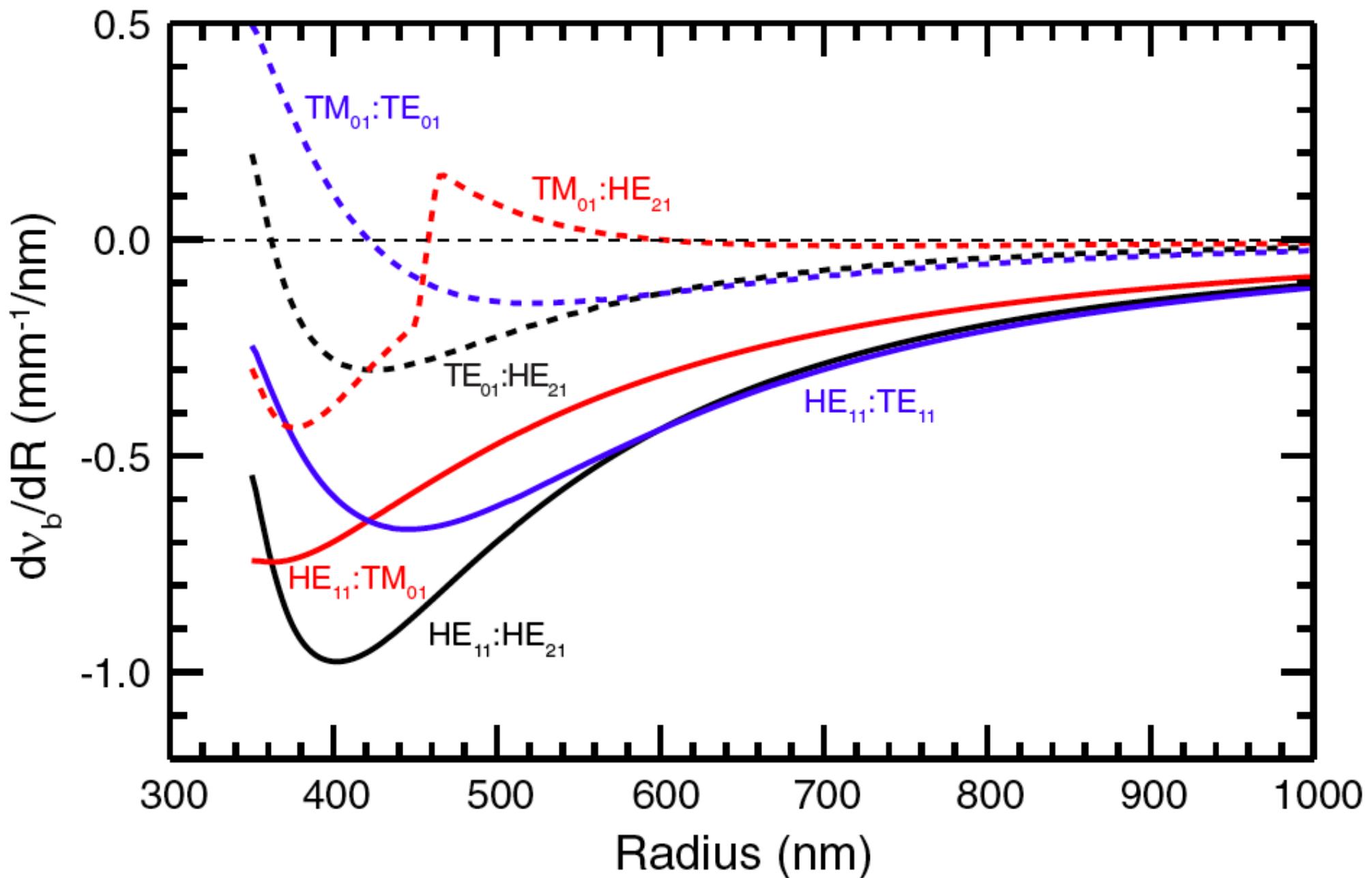


Espectrograma

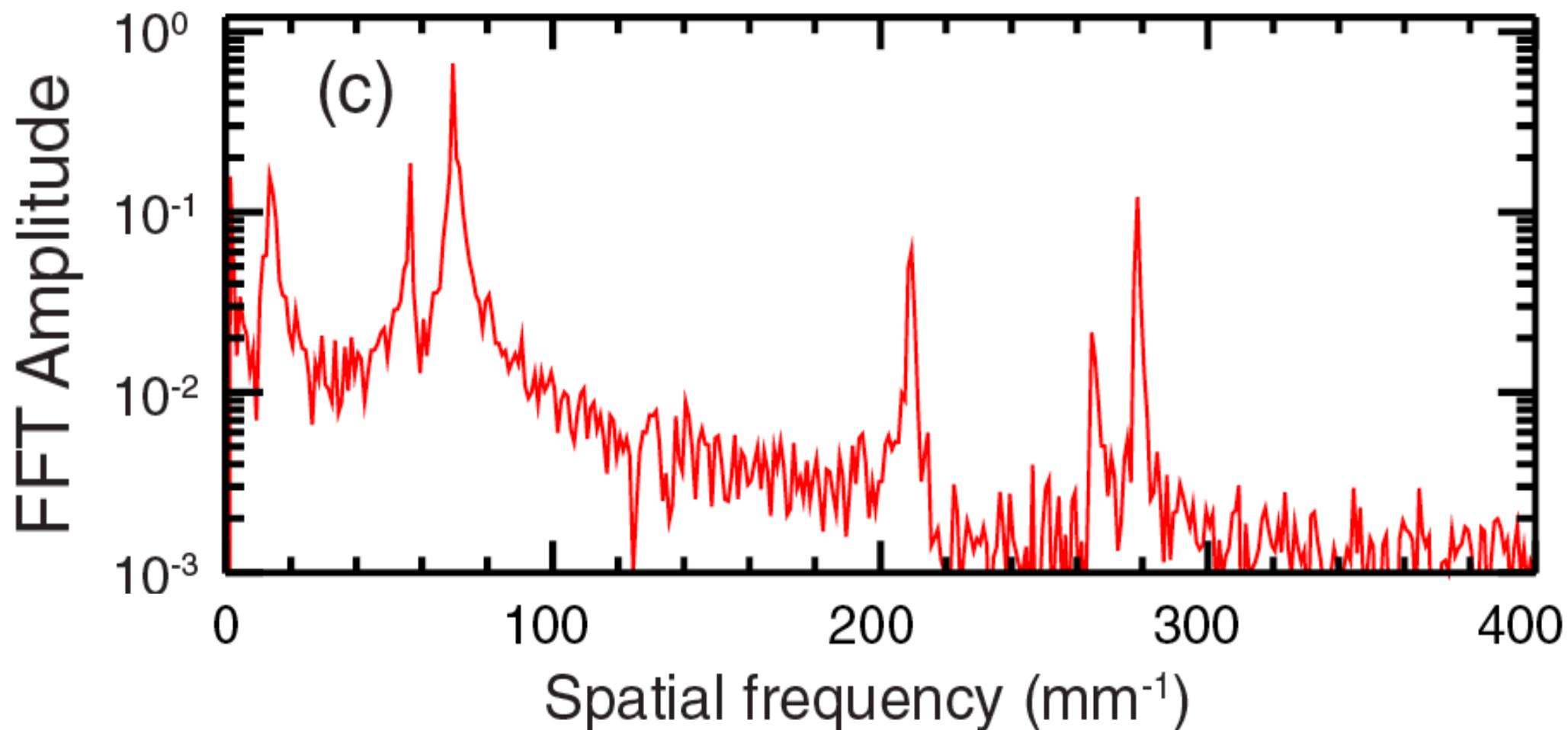


El batido de los modos espaciales depende del radio, (structured illumination microscopy)

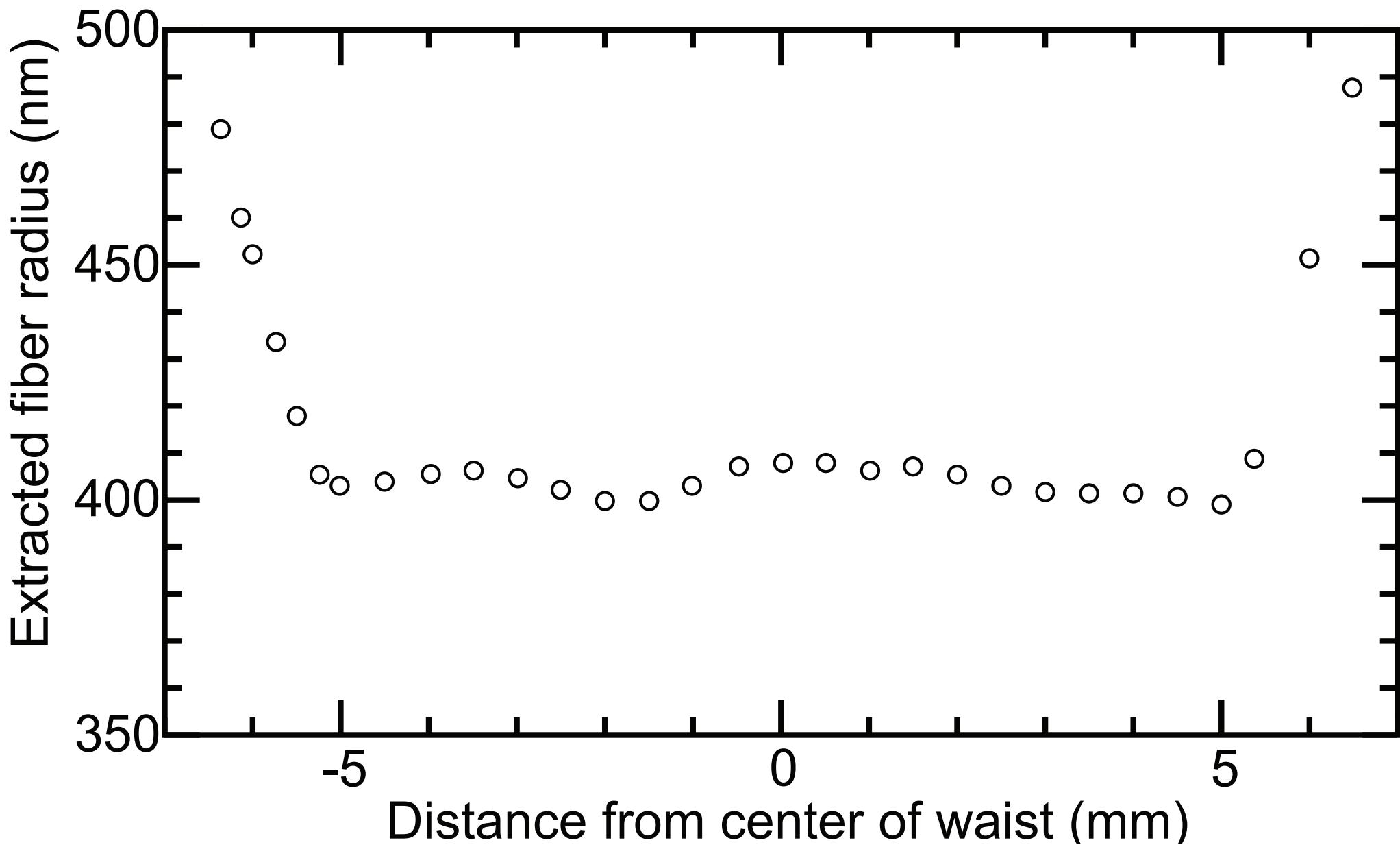




FFT en una zona de 300 μm

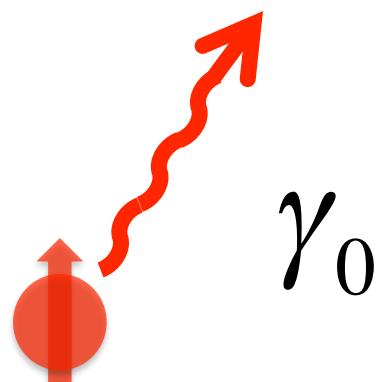
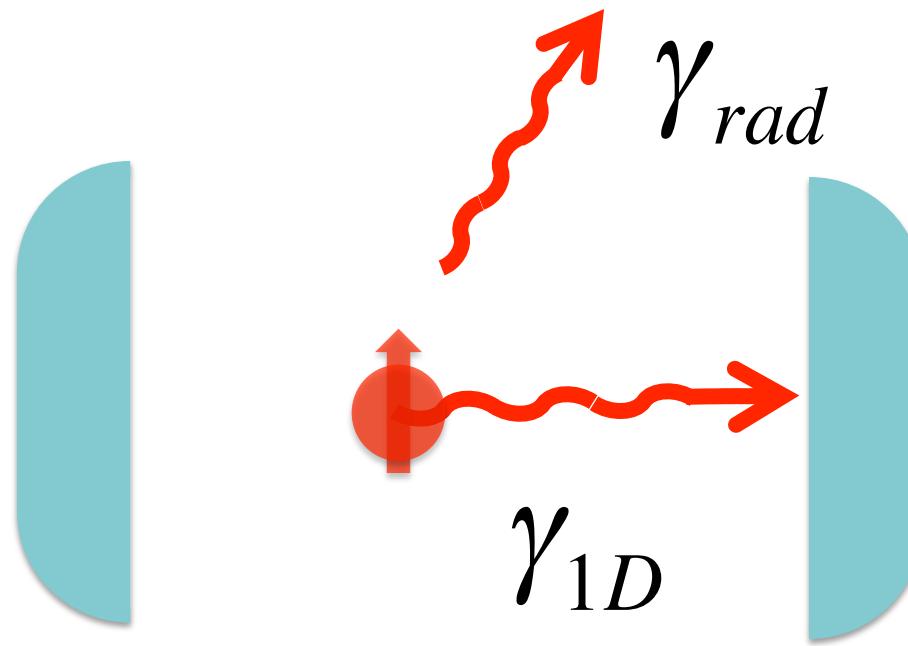


Extracción del radio en base a la frecuencia de batido con una resolución de menos de 1 angstrom

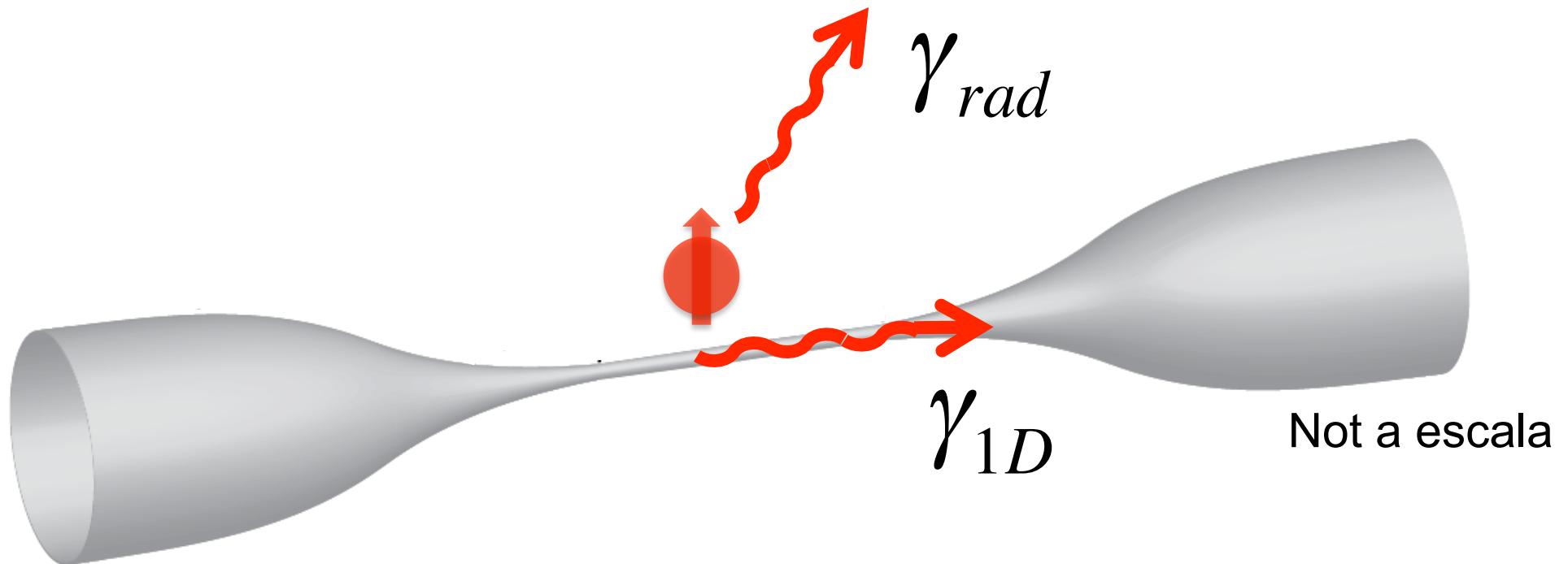


De la electrodinámica de cavidades a la
electrodinámica de guías de onda

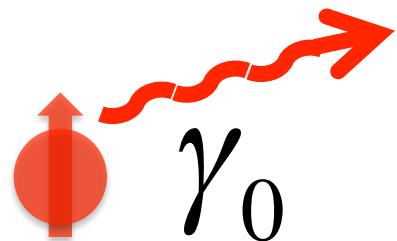
Cavity QED



Waveguide QED



Queremos los átomos afuera.



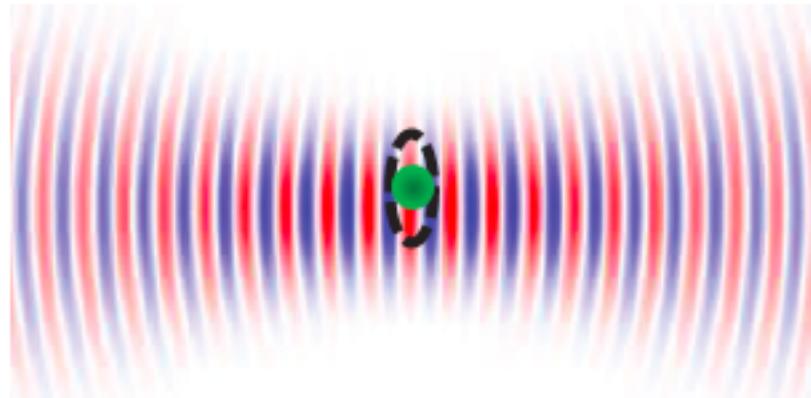
¿Qué cambios le pasan a cavity
QED si no tenemos cavidad?

- Usemos una guía de onda para confinar transversalmente el campo electromagnético; el área del modo puede ser menor a λ^2
- Enfoquémonos a cómo utilizarla con átomos, no vamos a hablar a cerca de otros qubits (estado sólido, superconductores, etc.)
- Estructuras fotónicas, por ejemplo nanofibras ópticas.

Coupling atoms to cavities
and waveguides

(a)

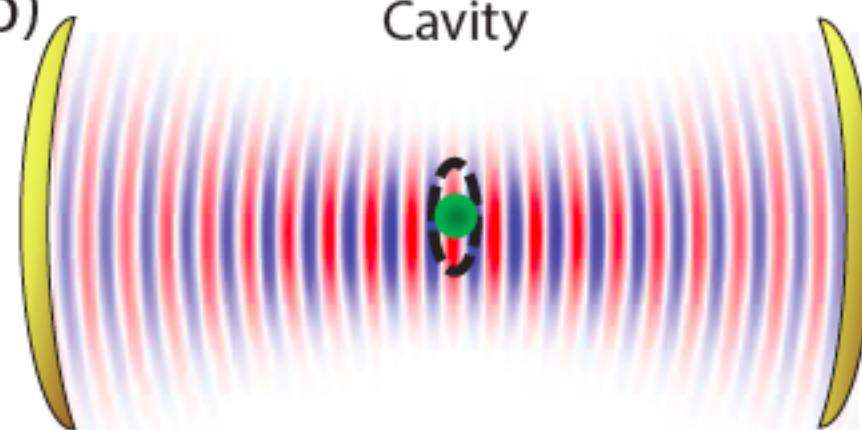
Free space



$$\sigma_0 \ll A$$

(b)

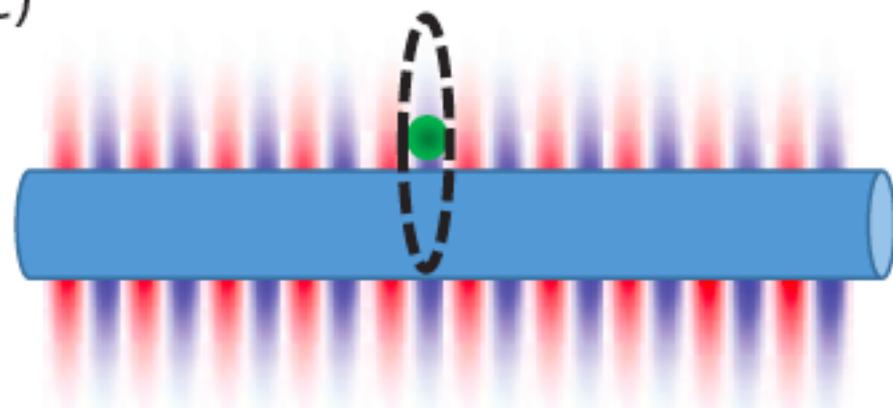
Cavity



$$\Gamma_{1D} \propto N_{\text{passes}}$$

(c)

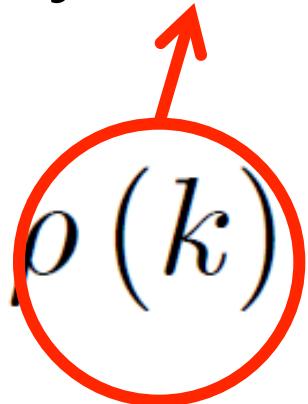
Waveguide



$$A \gtrsim \sigma_0$$

Decaimiento en el modo de la nanofibra

Density of modes in 1D

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


Decaimiento en el modo de la nanofibra

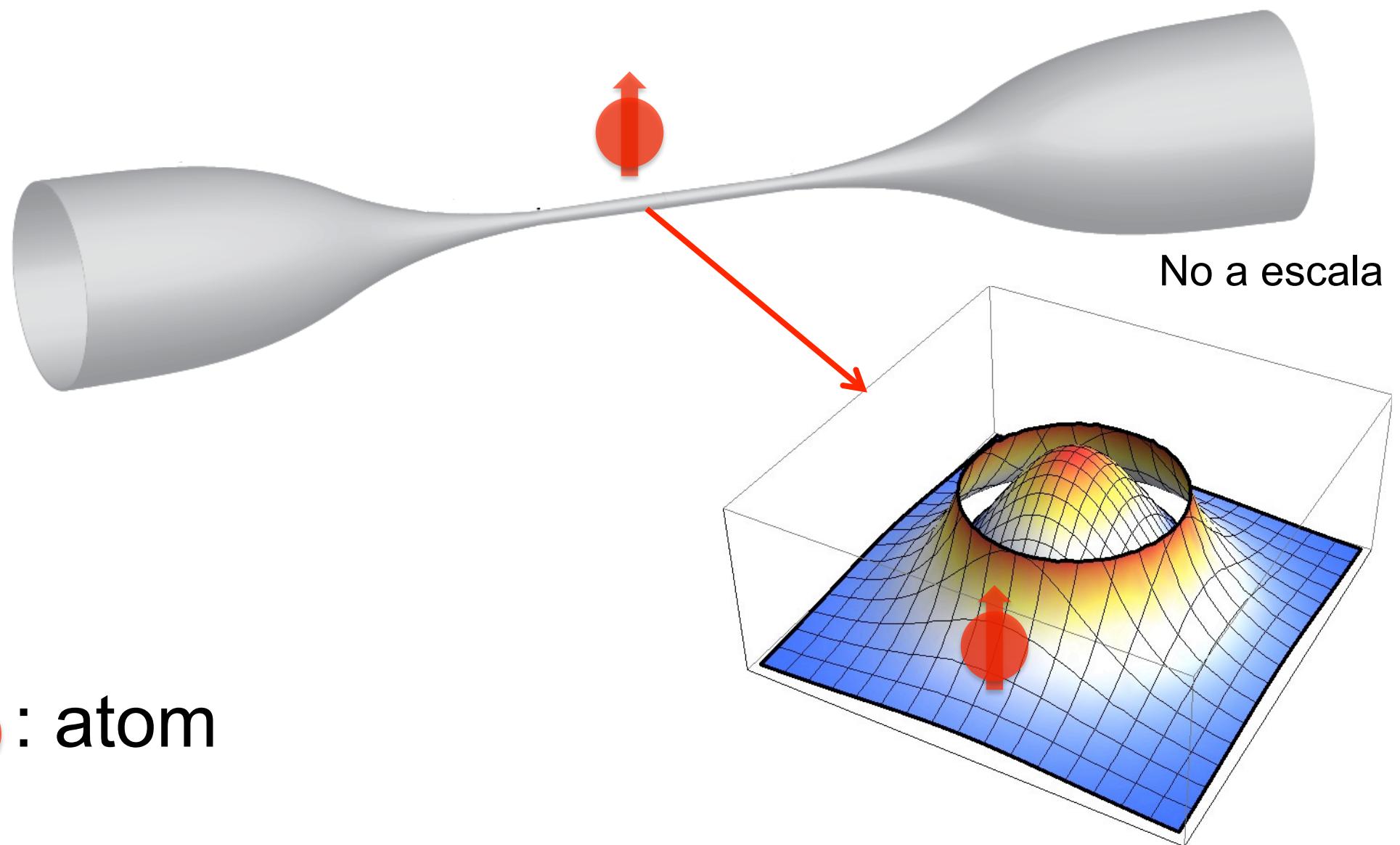
Densidad de modos

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

Proporcional al campo eléctrico del modo guiado.

$$|E|^2 = \epsilon^2 [K_0^2(qr) + wK_1^2(qr) + fK_2^2(qr)]$$

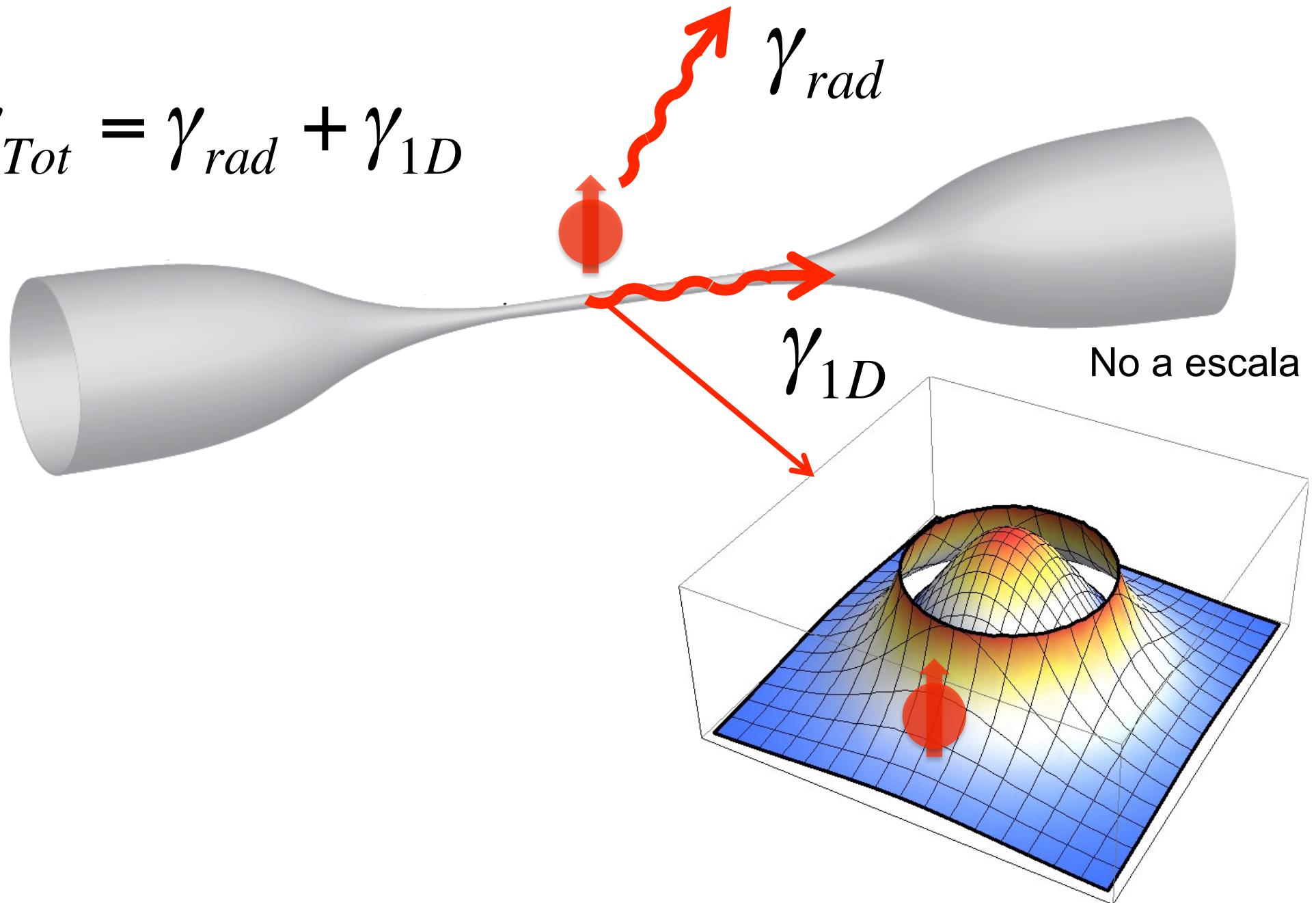
Acoplamiento evanescente



 : atom

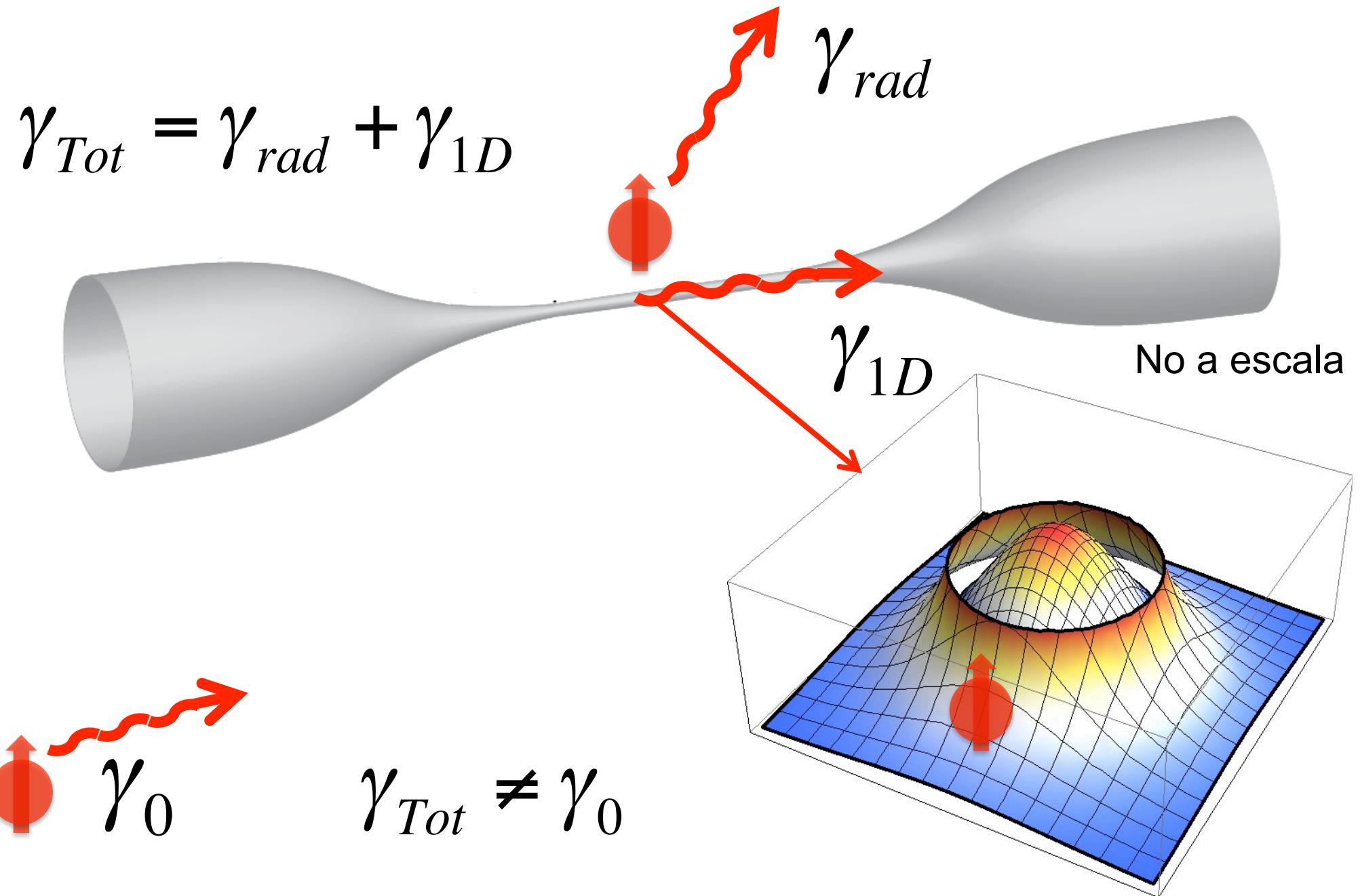
Acoplamiento evanescente

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

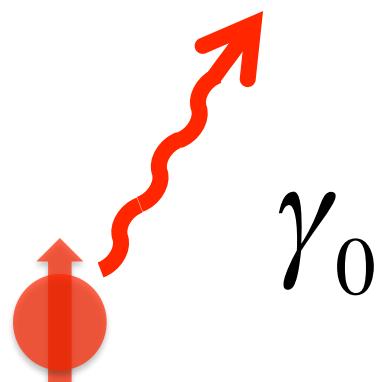
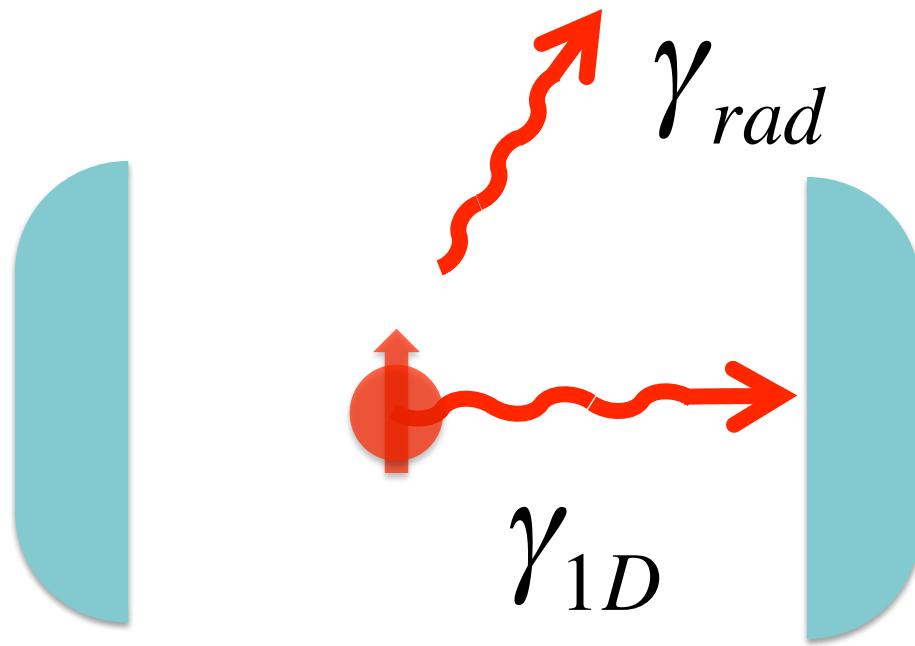


Acoplamiento evanescente

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

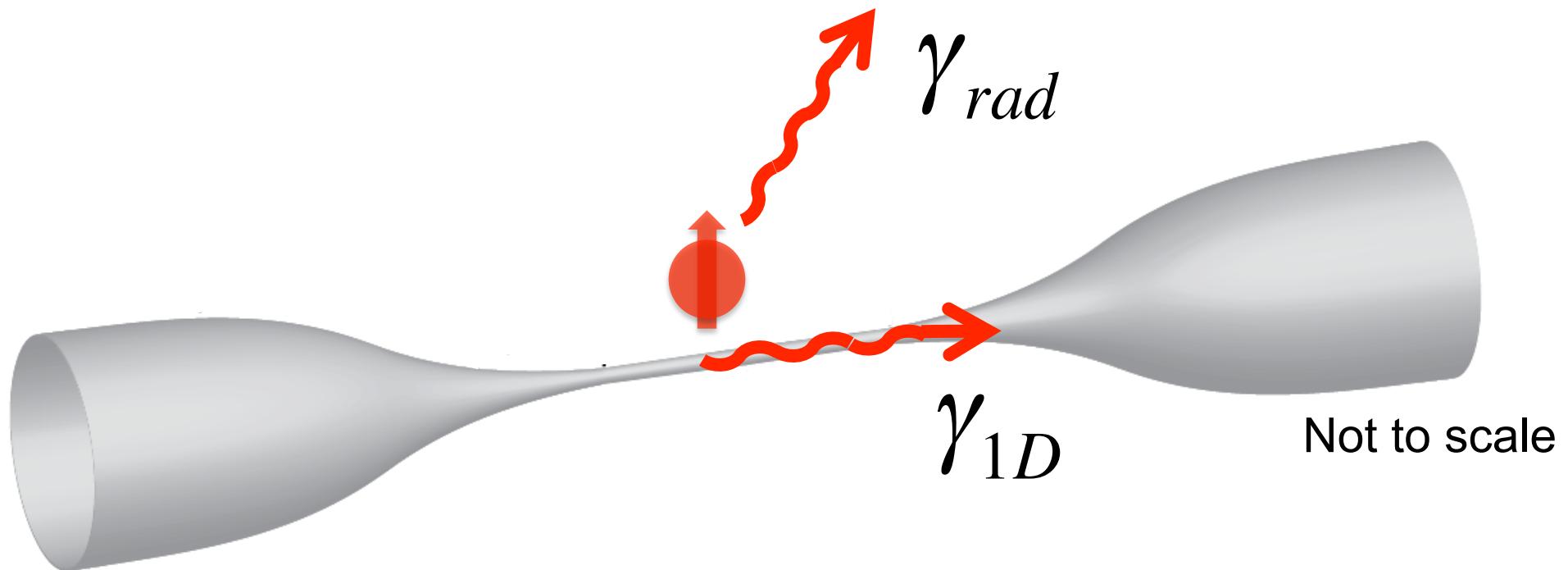


Mejora del Acoplamiento

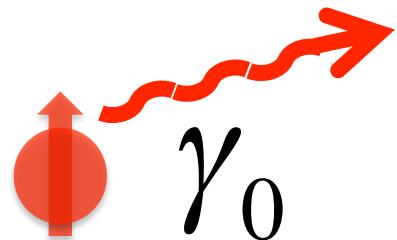


$$\alpha = \frac{\gamma_{1D}}{\gamma_0}$$

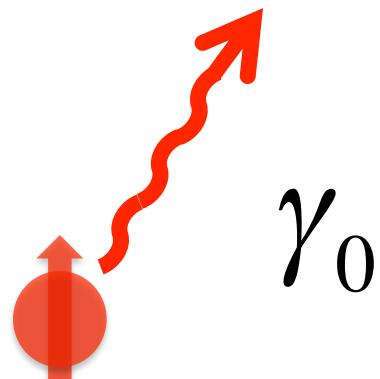
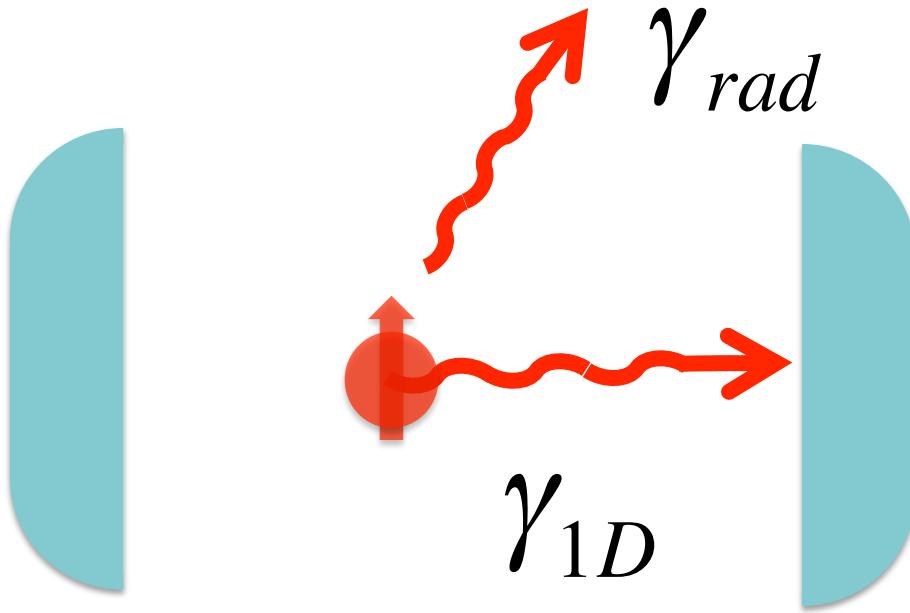
Mejora del Acoplamiento



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

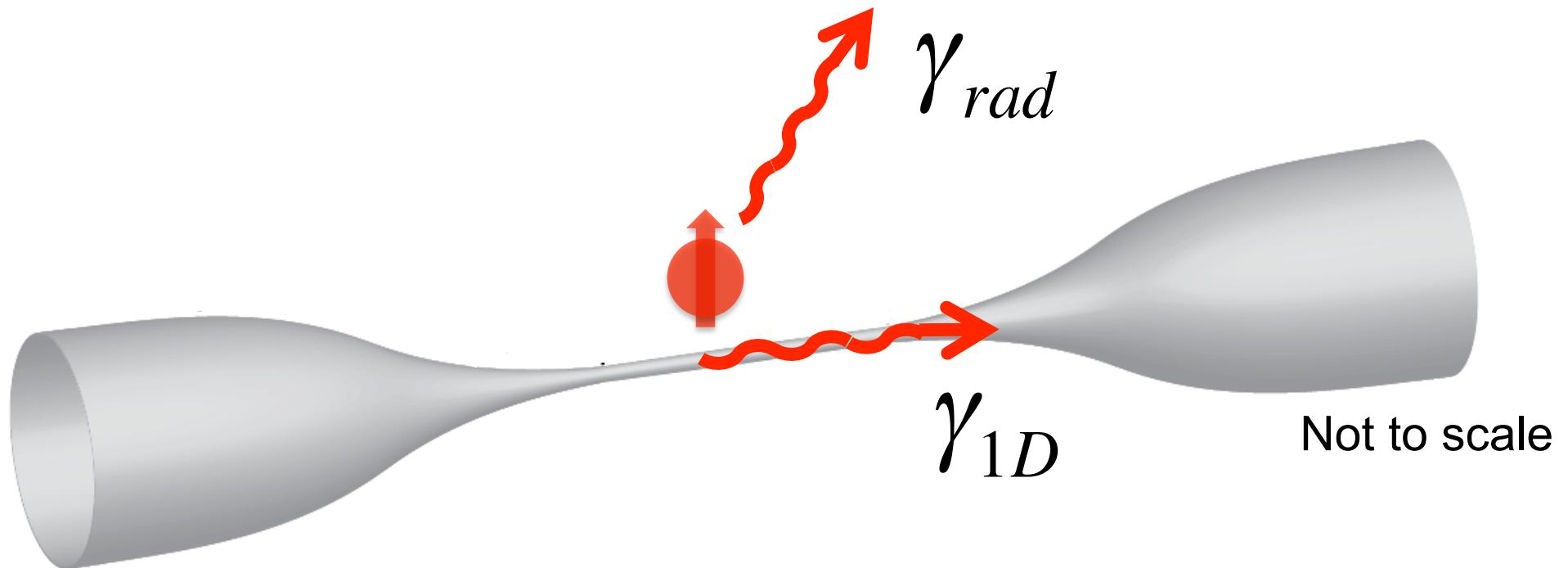


Eficiencia del Acoplamiento



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

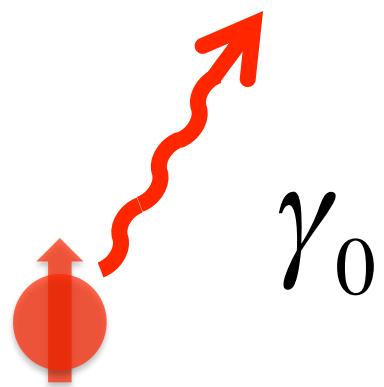
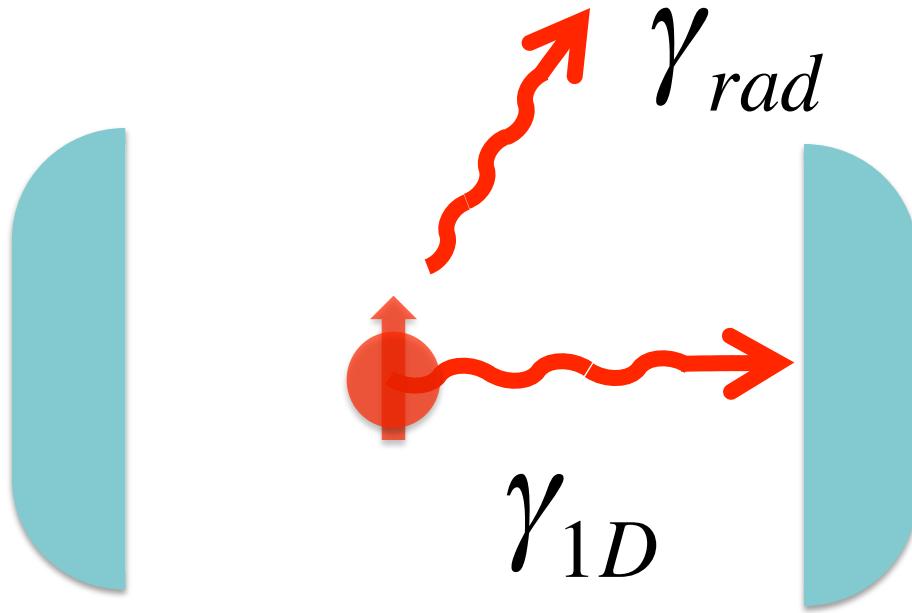
Eficiencia del Acoplamiento



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

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

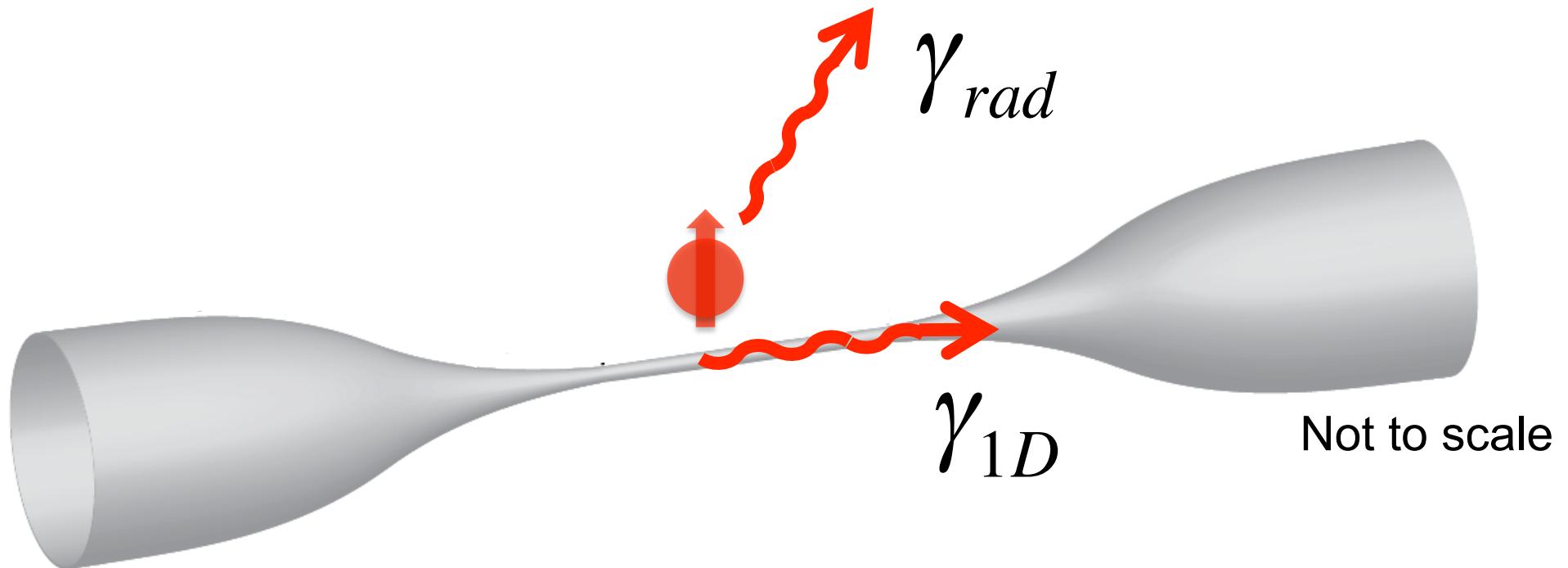
Purcell Factor



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

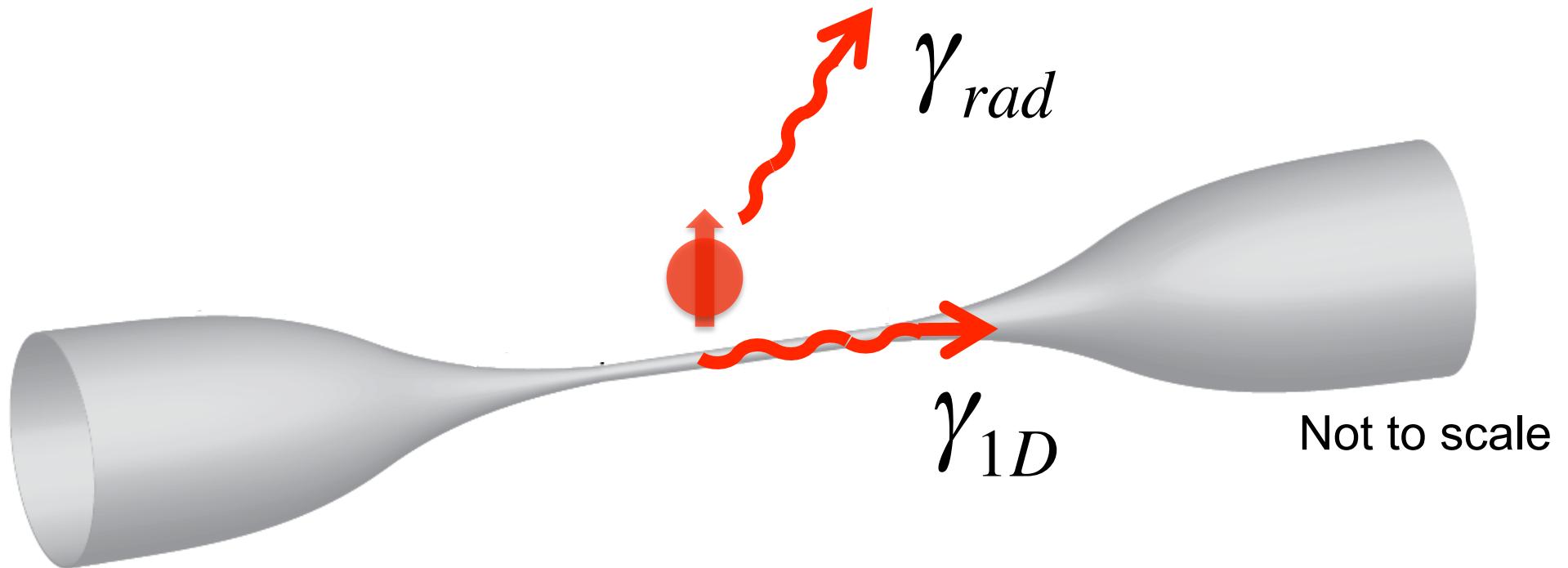
$$\gamma_{Tot} = \gamma_{1D} + \gamma_{rad}$$

Purcell Factor



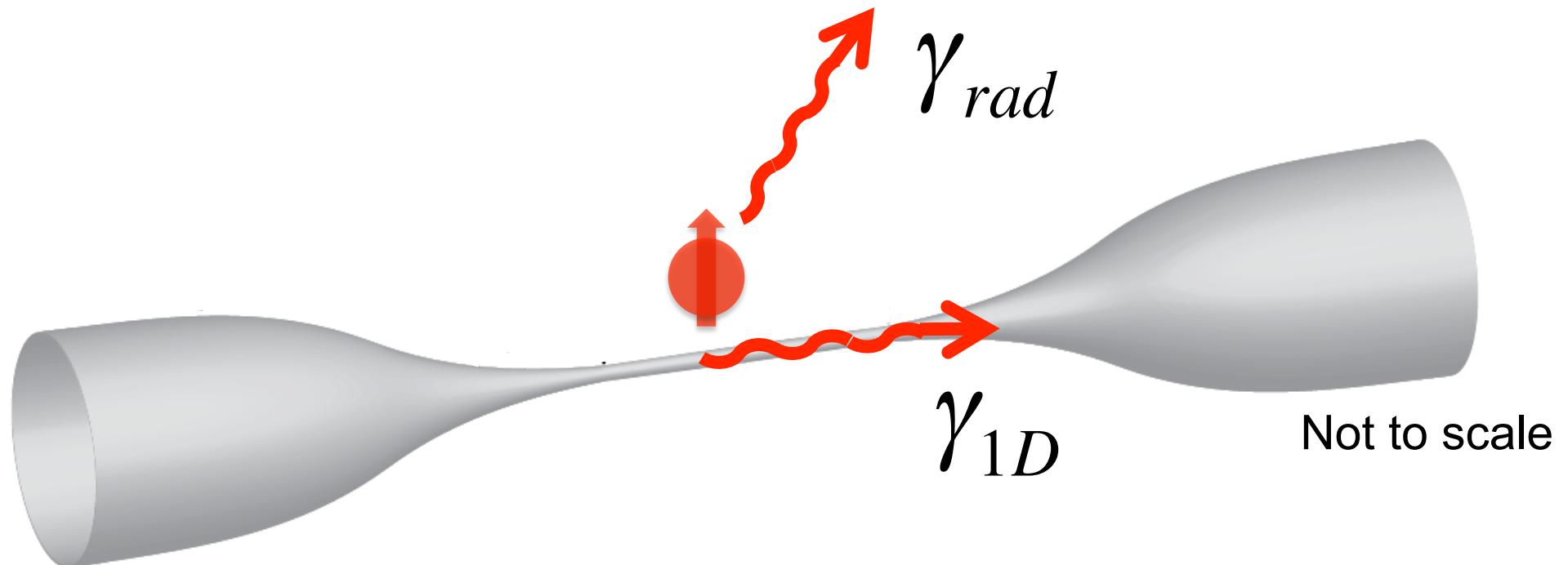
$$F_P = \frac{\gamma_{tot}}{\gamma_0} = \frac{\alpha}{\beta}$$

Cooperativity



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

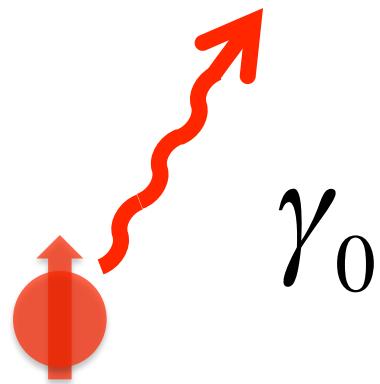
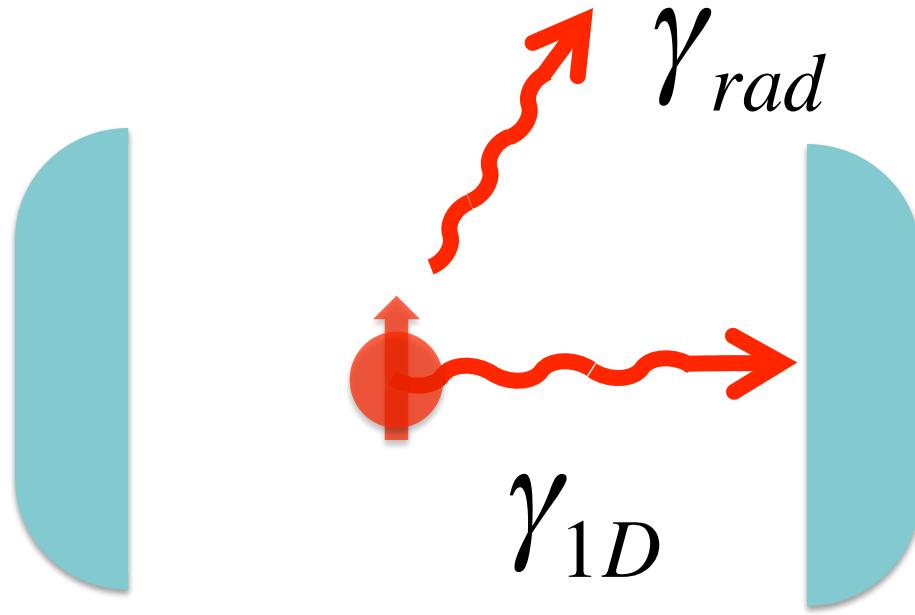
Cooperativity



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

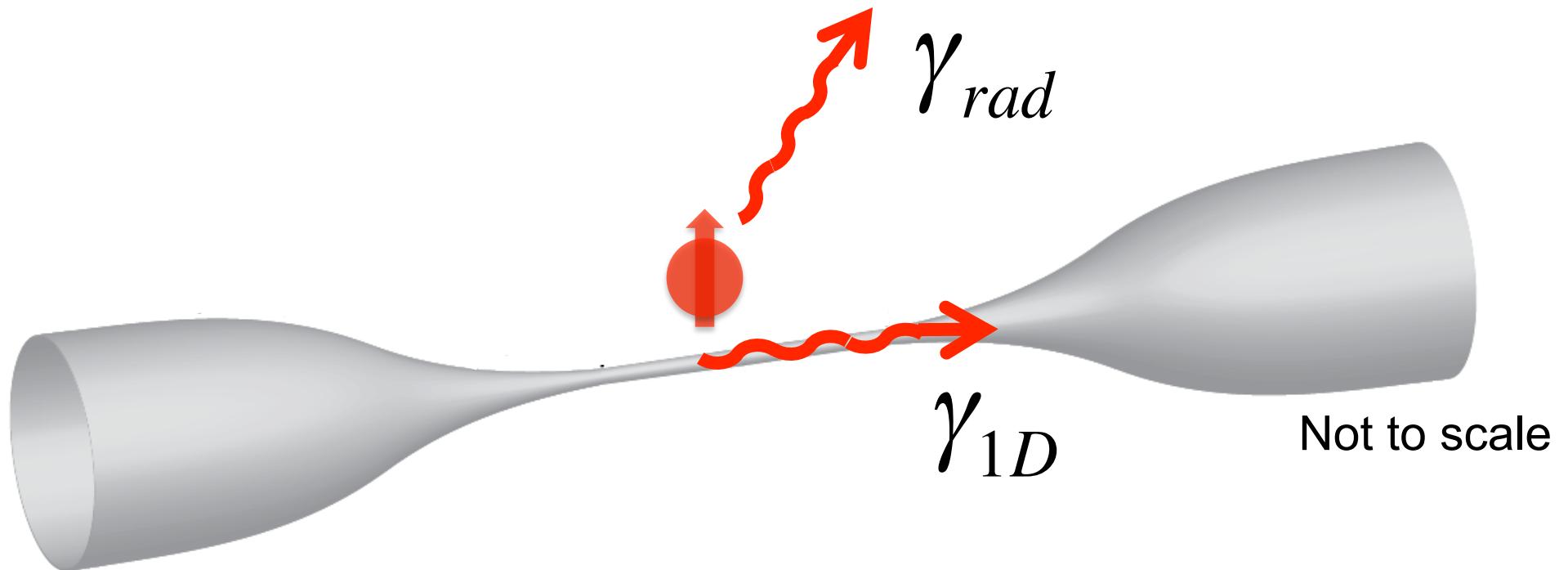
C_1 is the ratio of what goes into the selected mode to what goes into all the rest

Cooperatividad



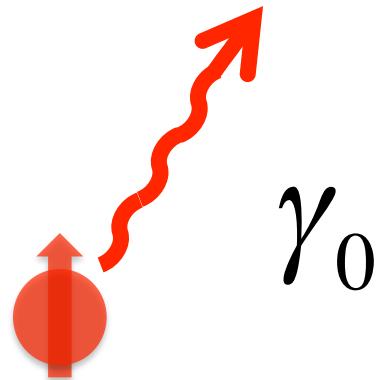
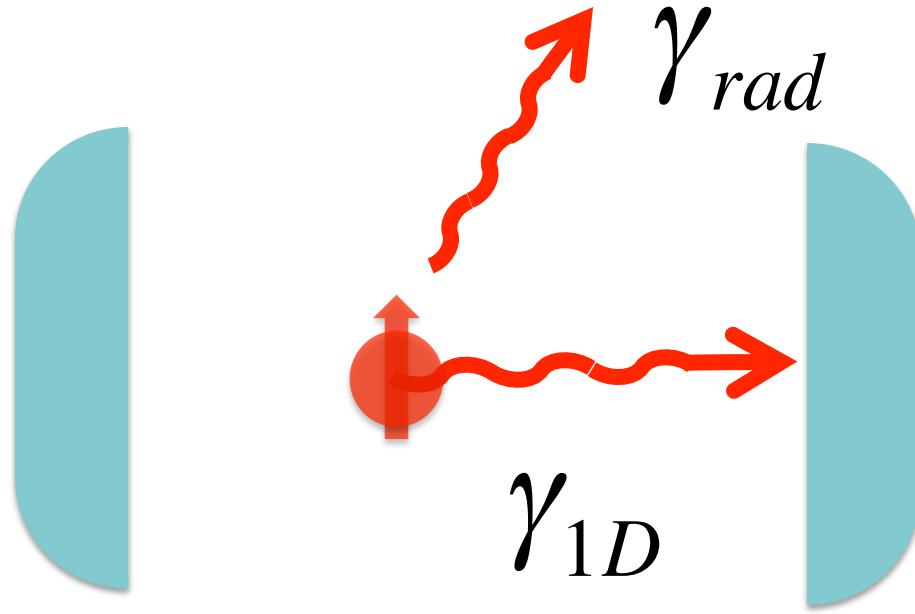
$$C_1 = \frac{\beta}{(1 - \beta)} = \frac{\gamma_{1D}}{\gamma_{rad}}$$

Cooperatividad



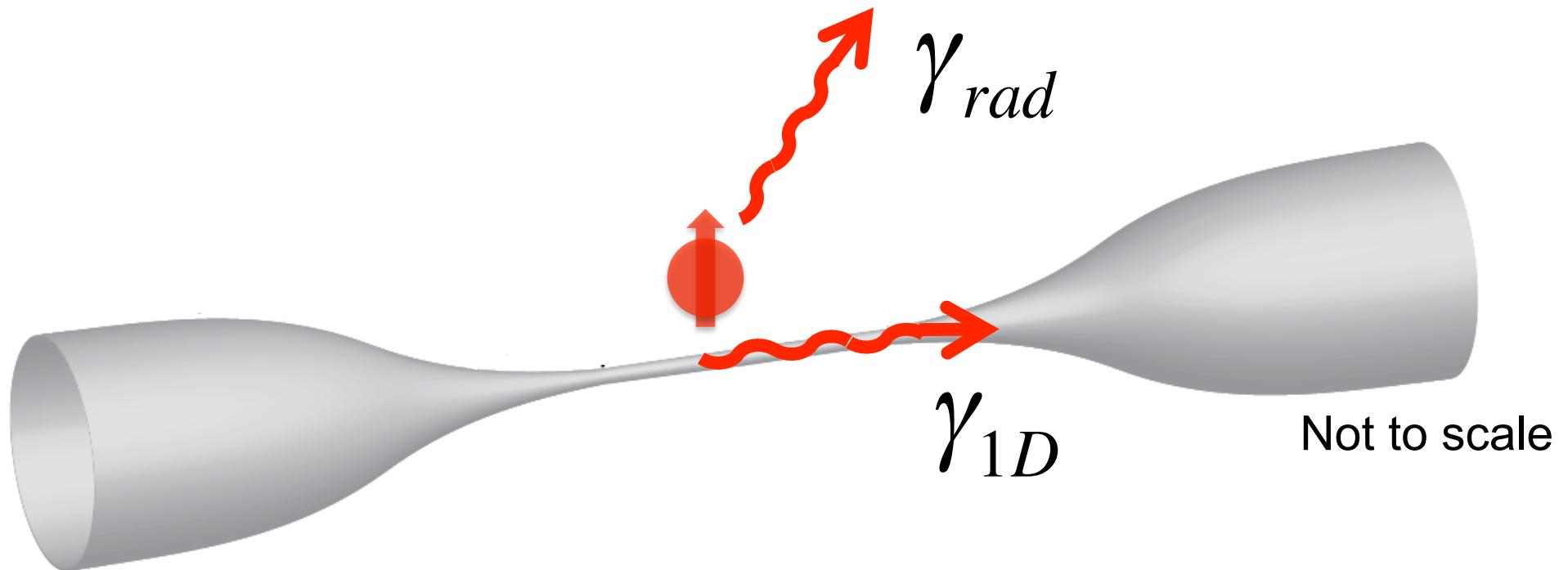
$$C_1 = \frac{\beta}{(1 - \beta)} = \frac{\gamma_{1D}}{\gamma_{rad}}$$

Cooperativity



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

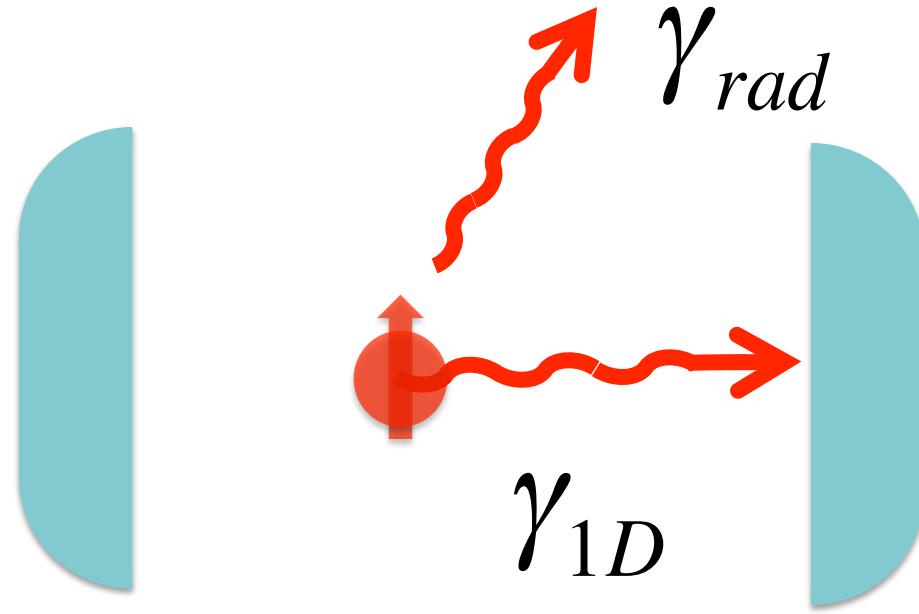
Cooperativity



no mirrors
 $T=1$

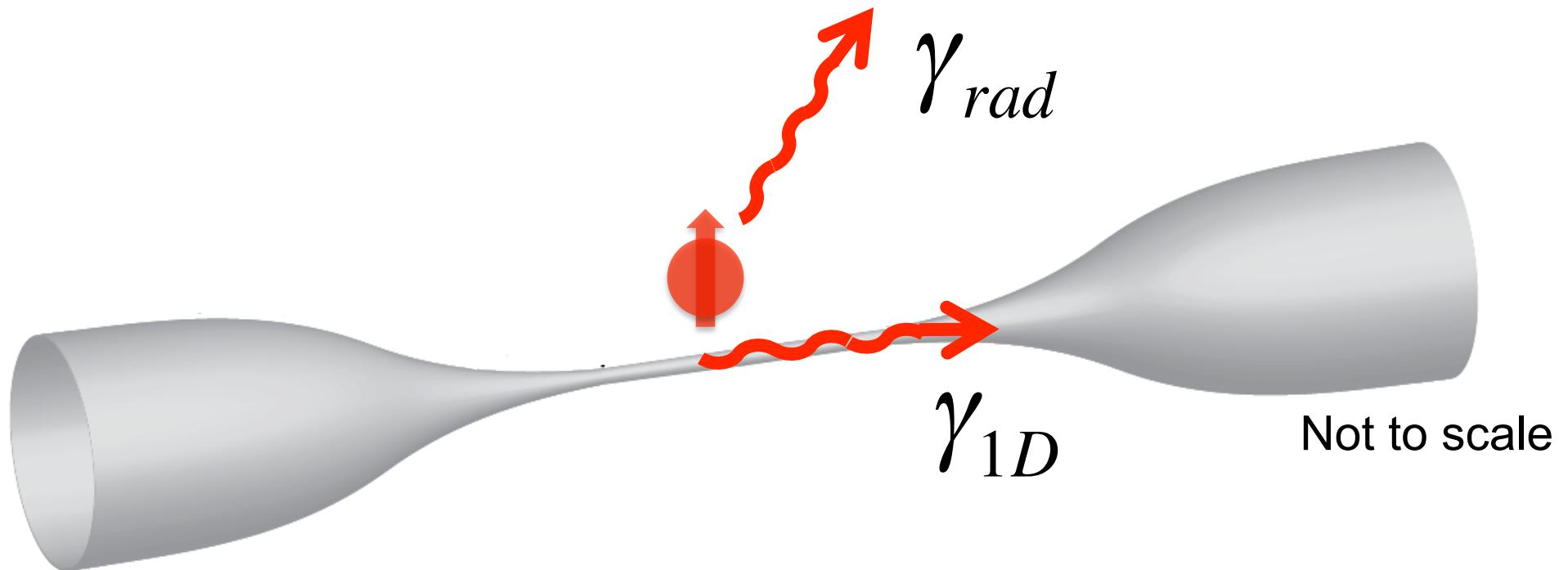
$$C_1 = \frac{\sigma_0}{Area_{\text{mode}}}$$

Cooperativity



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

Cooperatividad



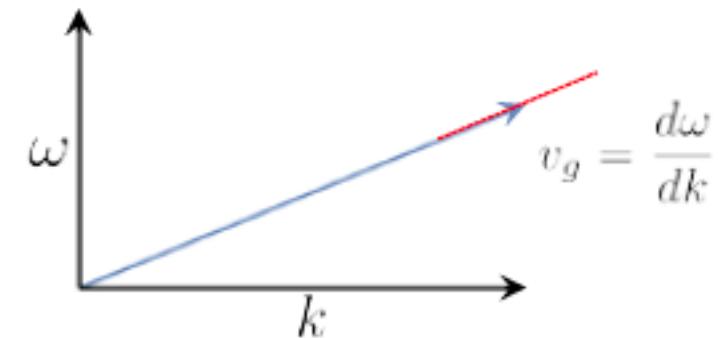
$$C_1 = \frac{\sigma_0}{Area_{\text{mode}}} n_{\text{eff}} = \frac{\gamma_{1D}}{\gamma_{\text{rad}}}$$

¿Qué pasa si ahora tenemos una
estructura fotónica?

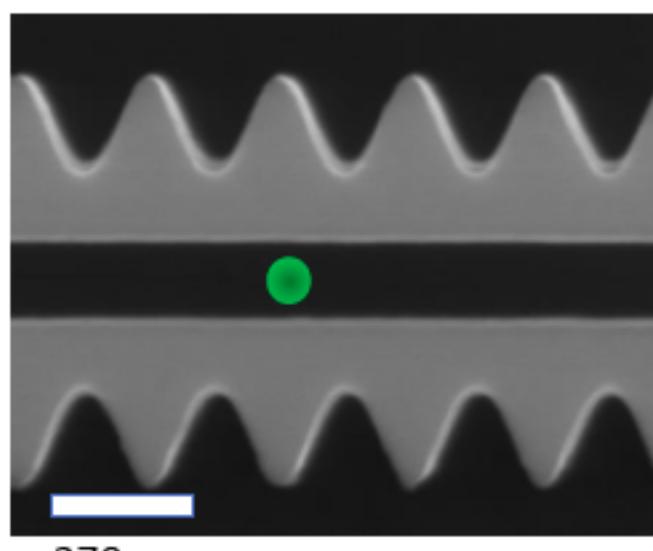
(a)



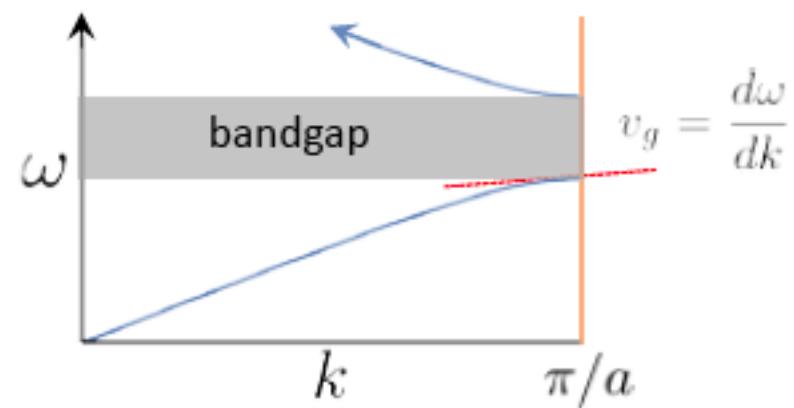
Uniform waveguide



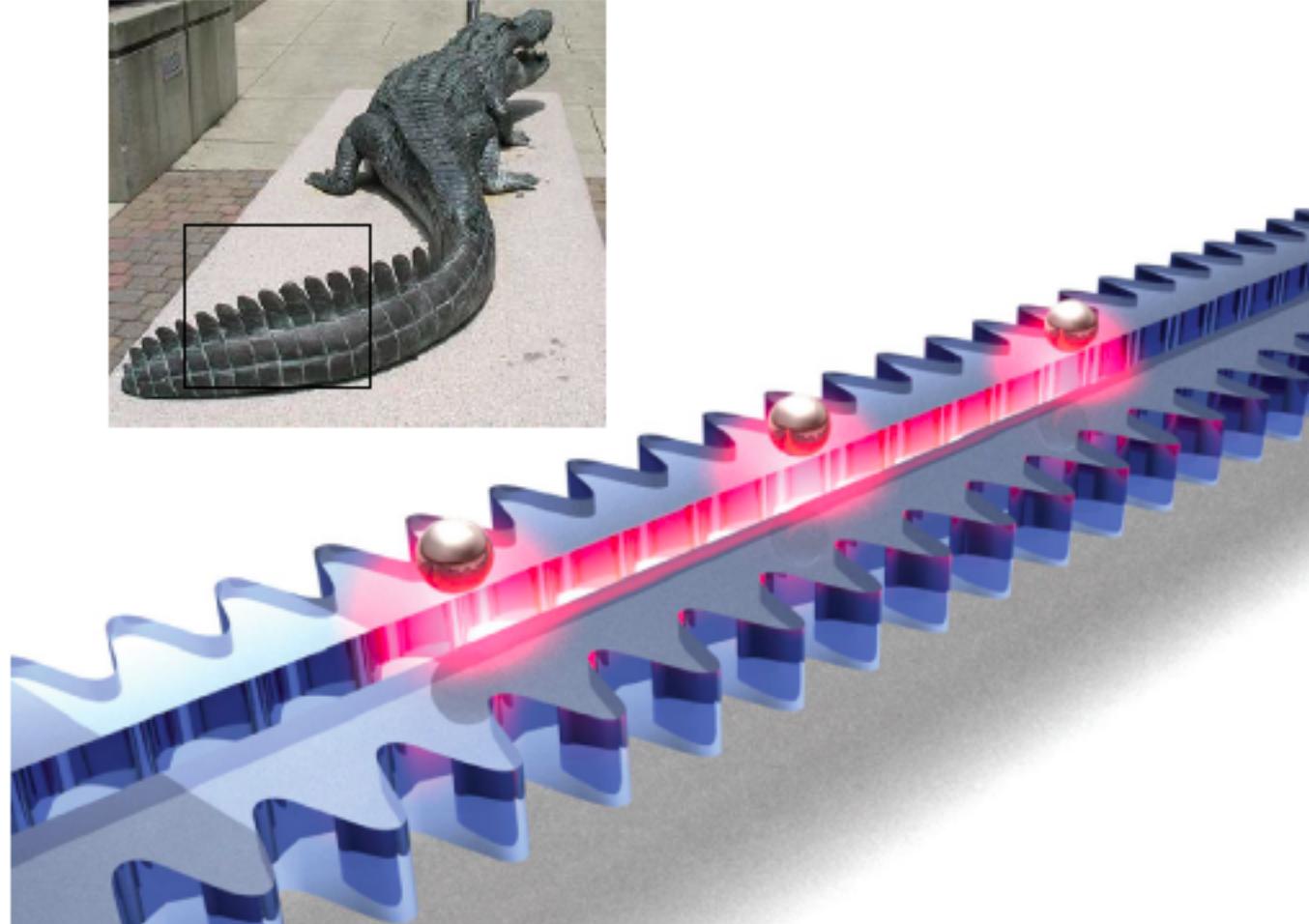
(b)

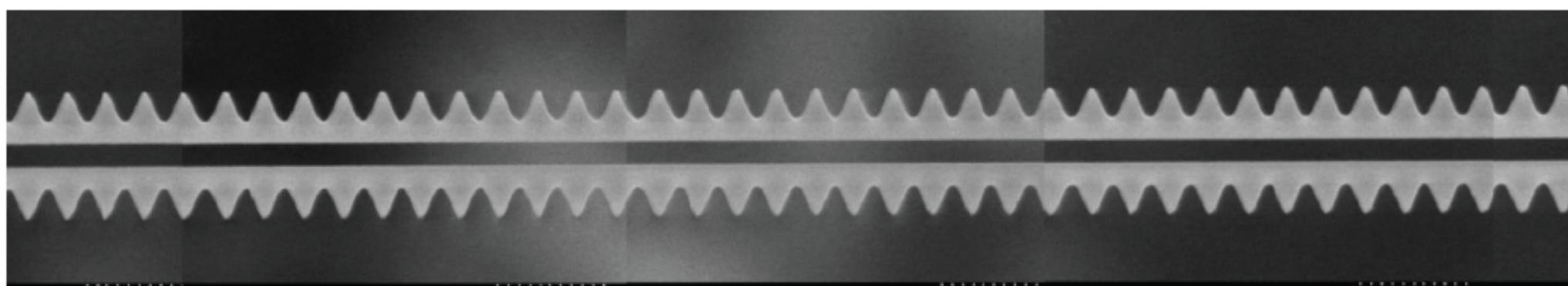
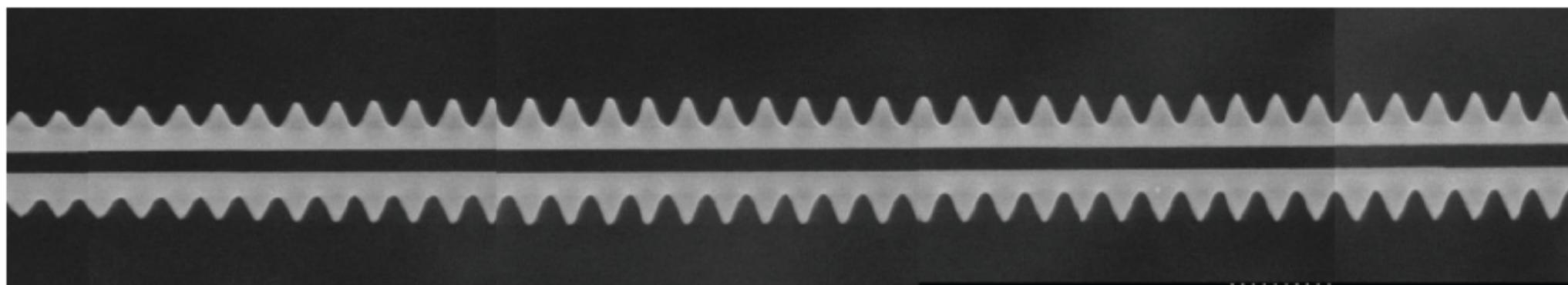
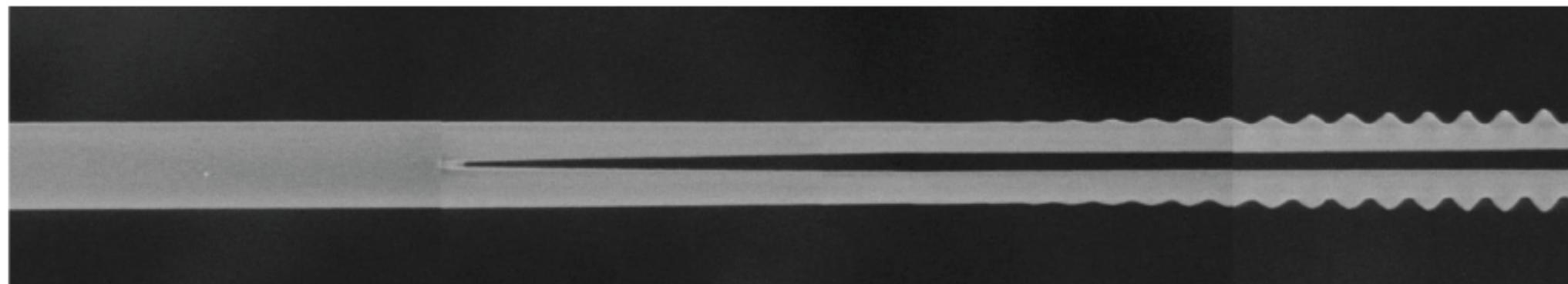


Photonic crystal waveguide



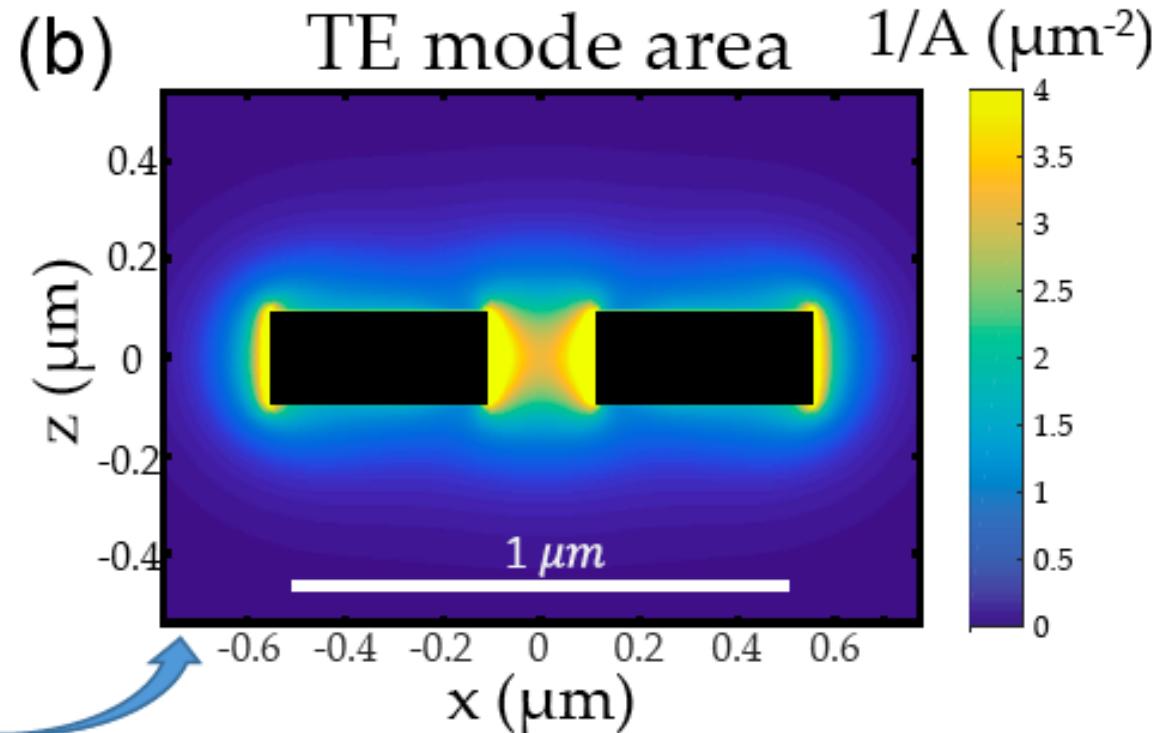
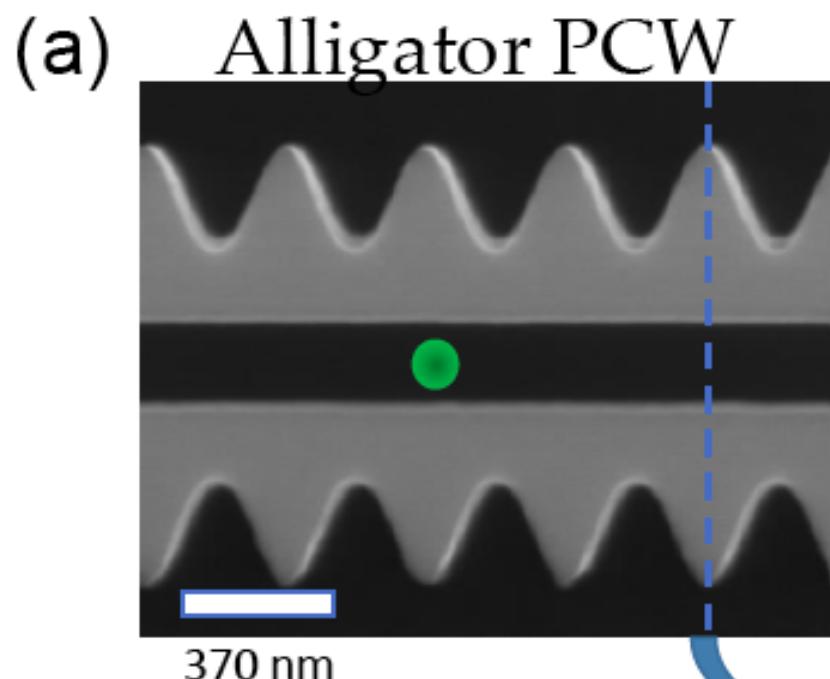
La guía de onda caimán de cristal fotónico. (CalTech)





Area del modo

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



Scanning electron
microscope

Sección de la
intensidad

Debido a que hay un intervalo de banda (band gap), la cooperatividad crece con él. También puede crear un "modo de cavidad" unido al átomo que no se mueve

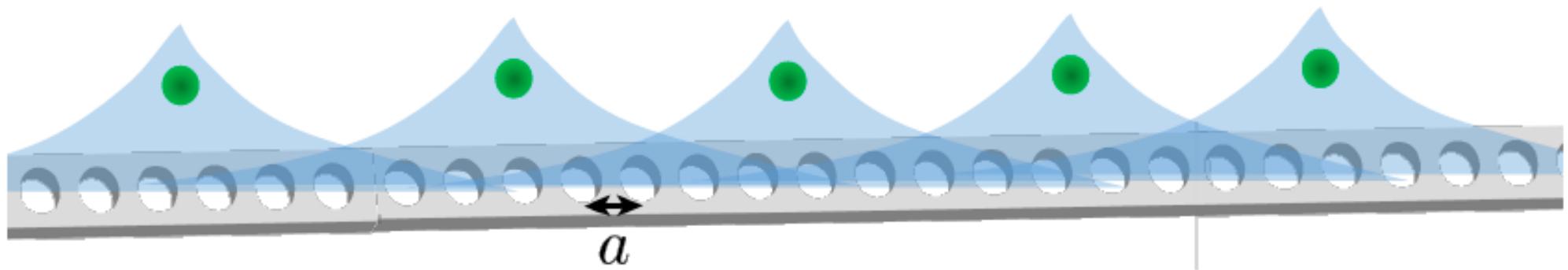
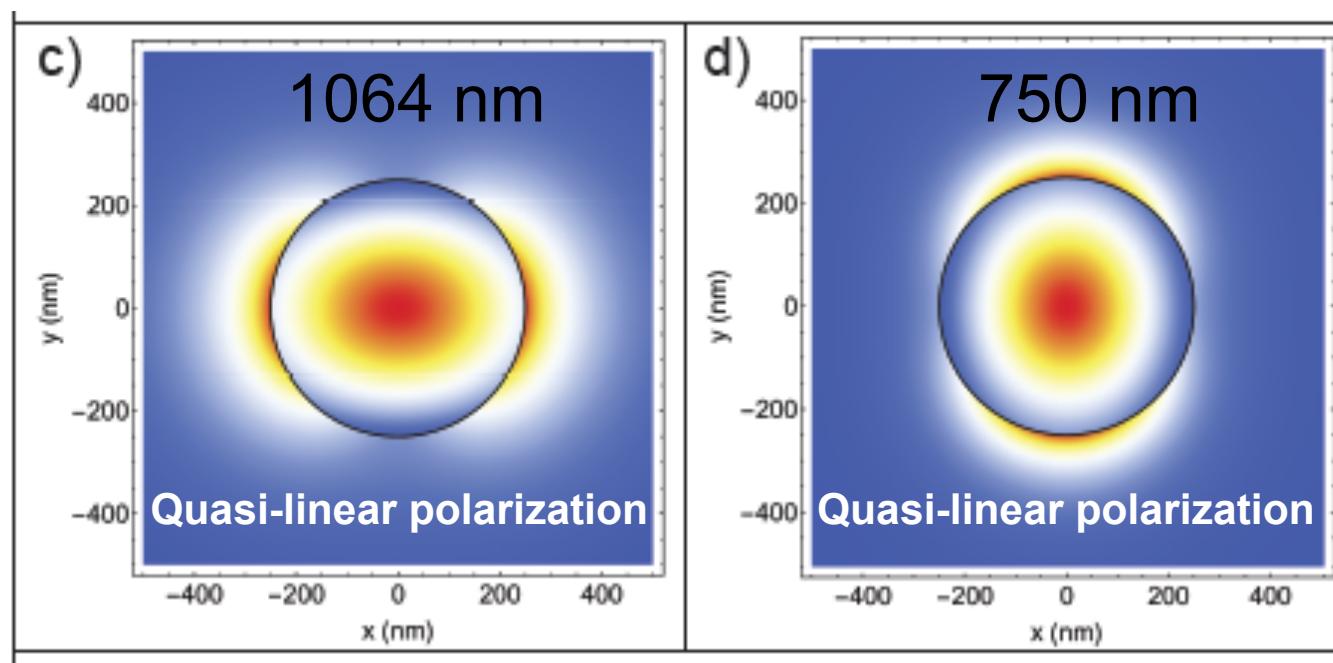
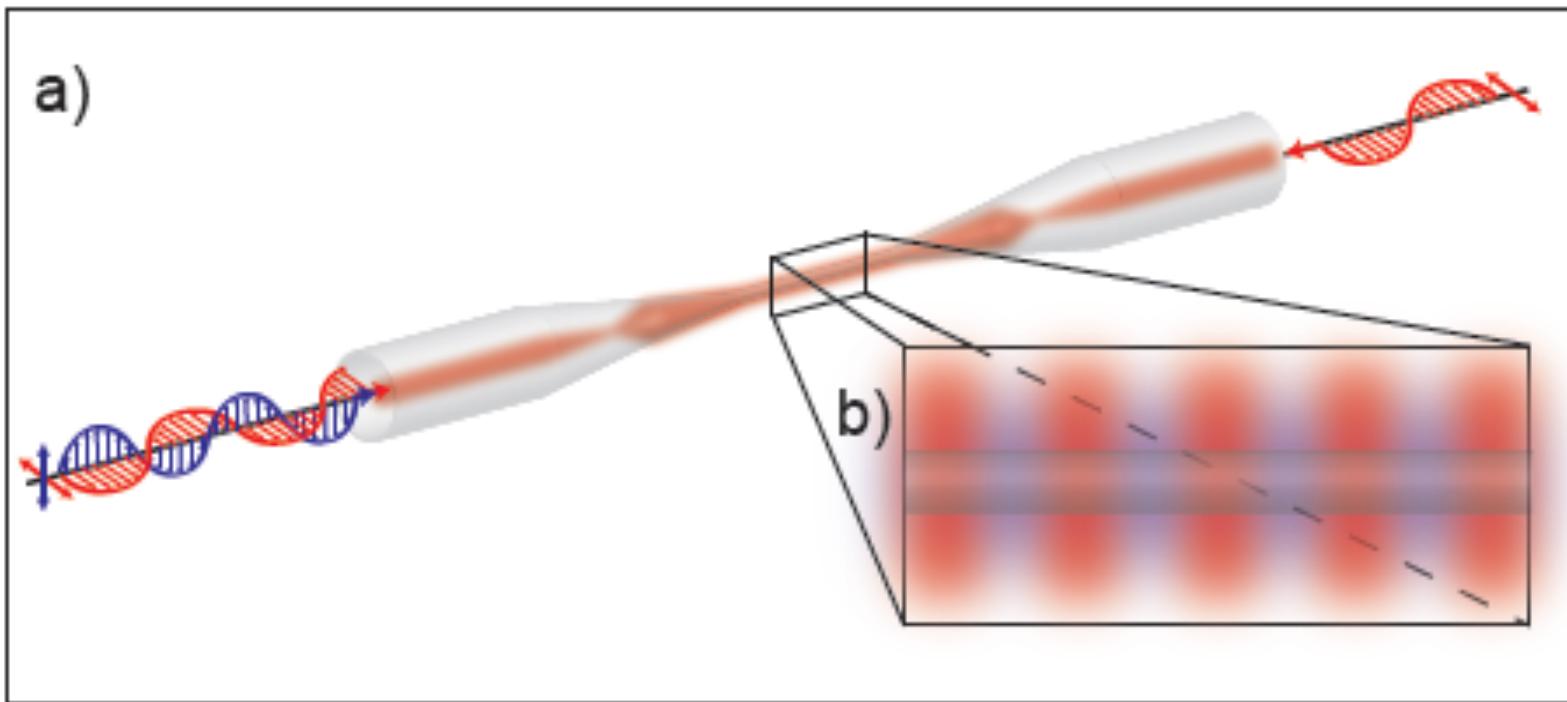


Figure 1.12: Atoms coupled to the bandgap of a photonic crystal waveguide. The atoms and photon cloud form atom-photon bound states.

- Interacciones dipole-dipole entre átomos a través de la guía de onda. Fuerzas entre ellos.
- Estructura periódica de átomos en una nanoestructura periódica o en una trampa de luz con periodicidad.
- Plataforma nueva para información cuántica ya acoplada directamente a guías de onda (fibras).

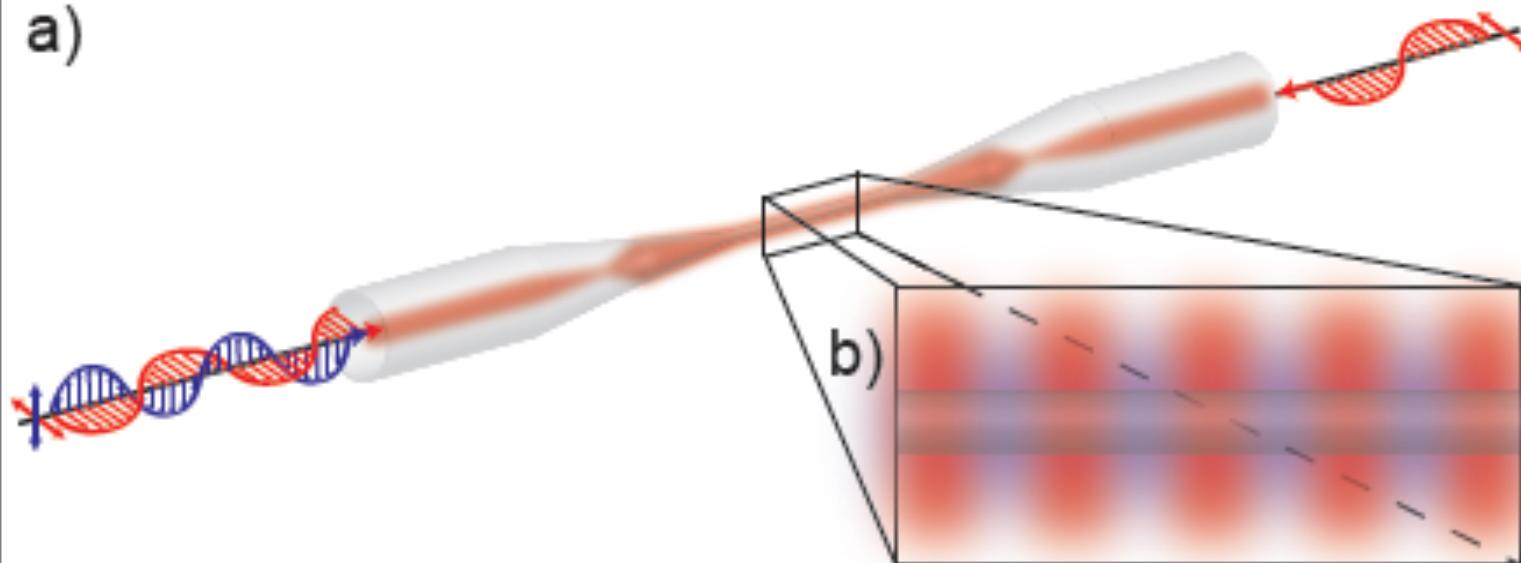
Atrapamiento de Átomos

Esquema de atrapamiento

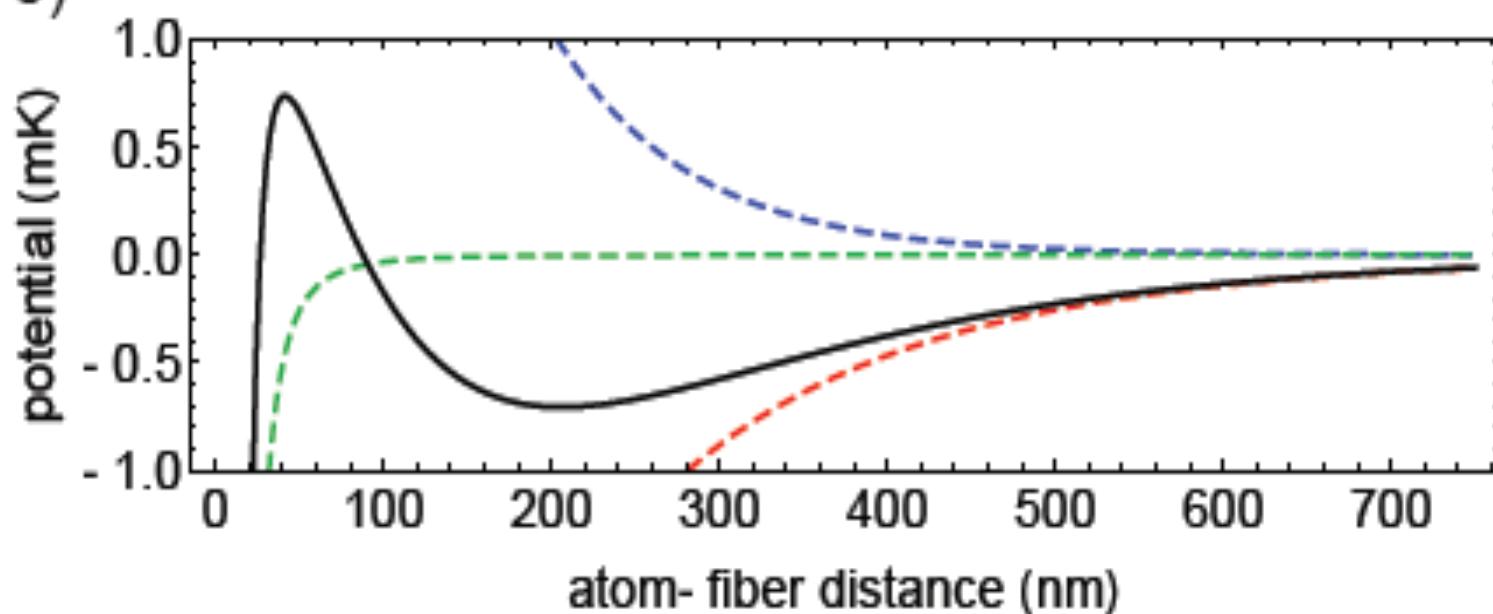


Esquema de atrapamiento

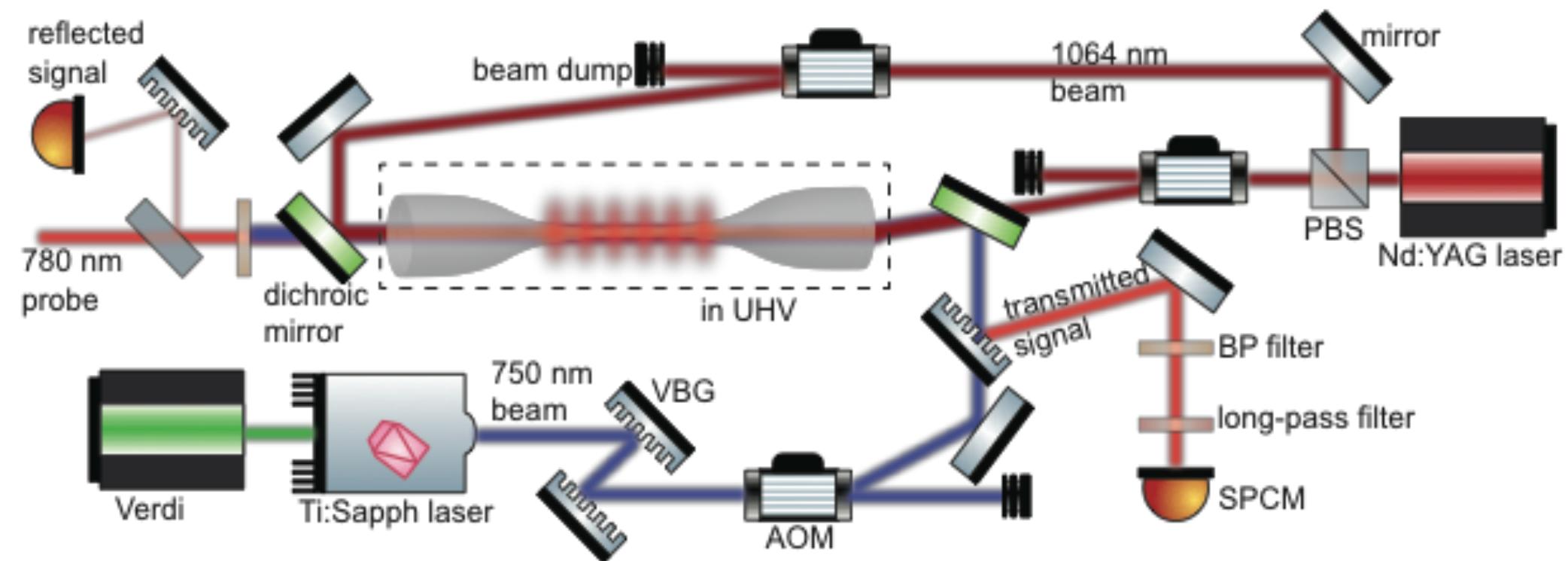
a)



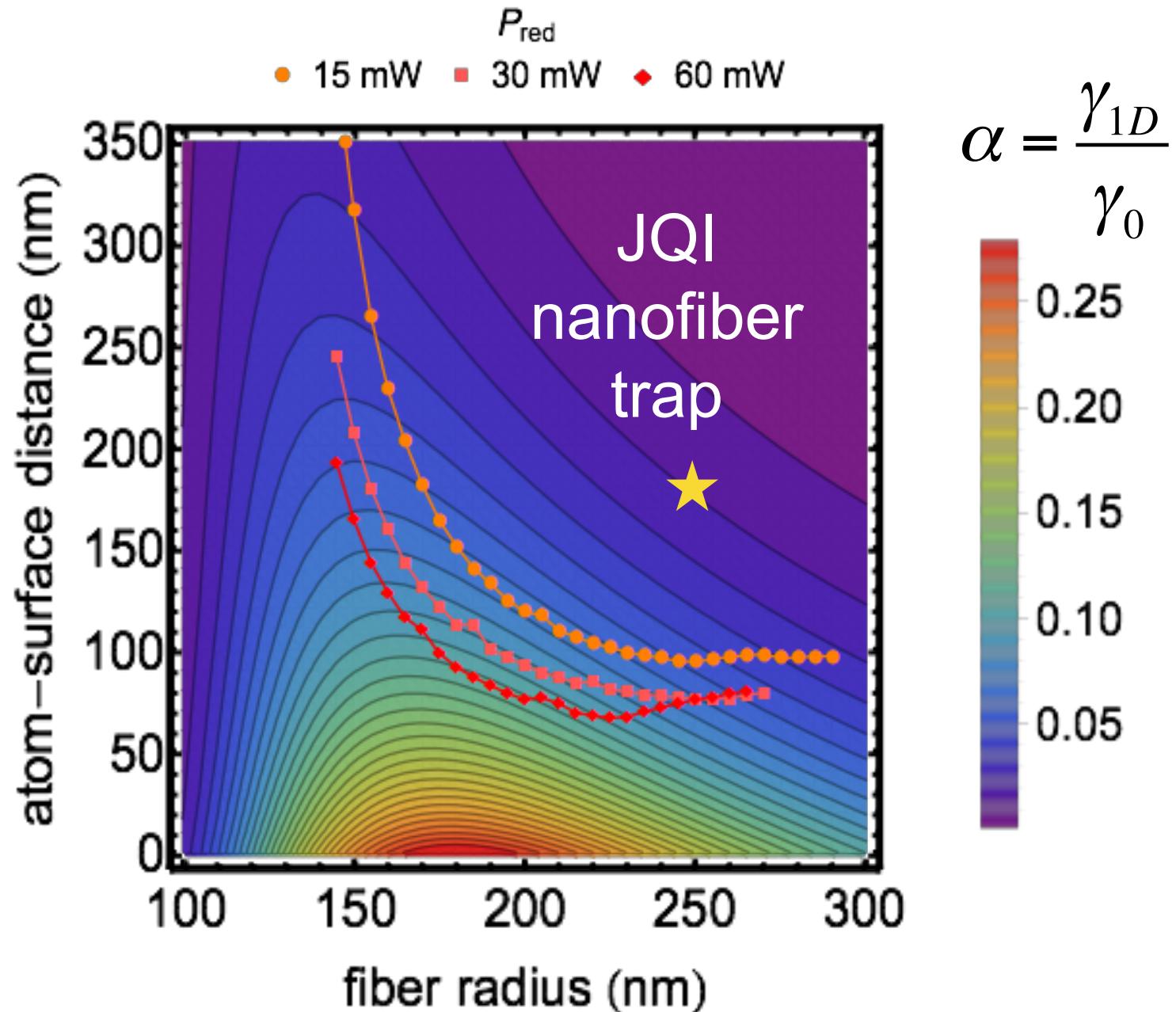
e)



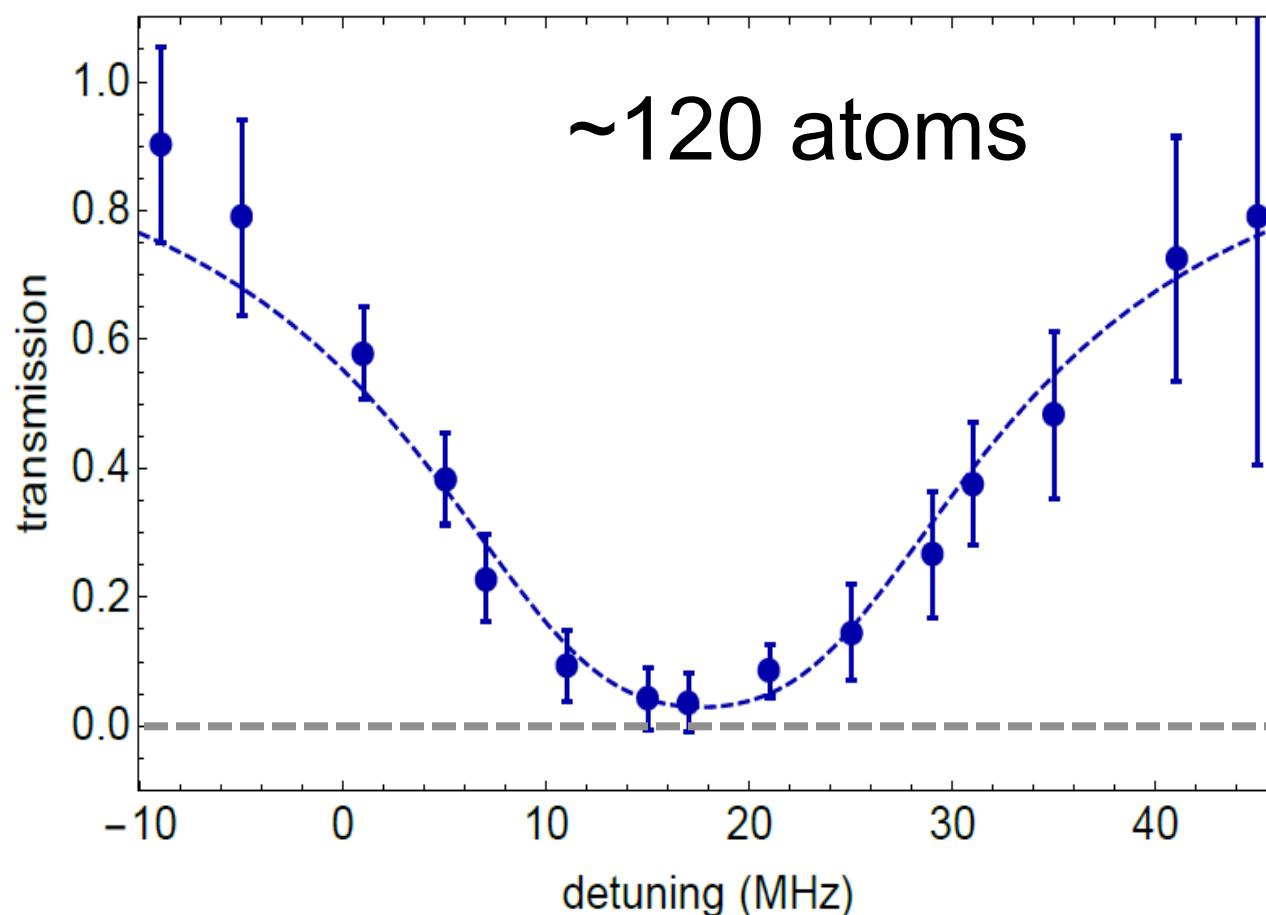
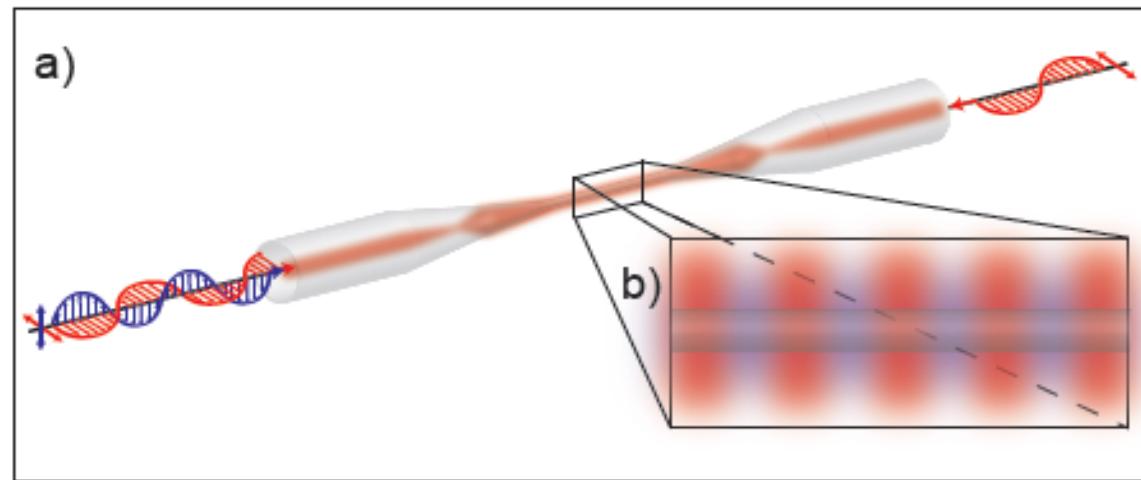
Trampa con una nanofibra óptica



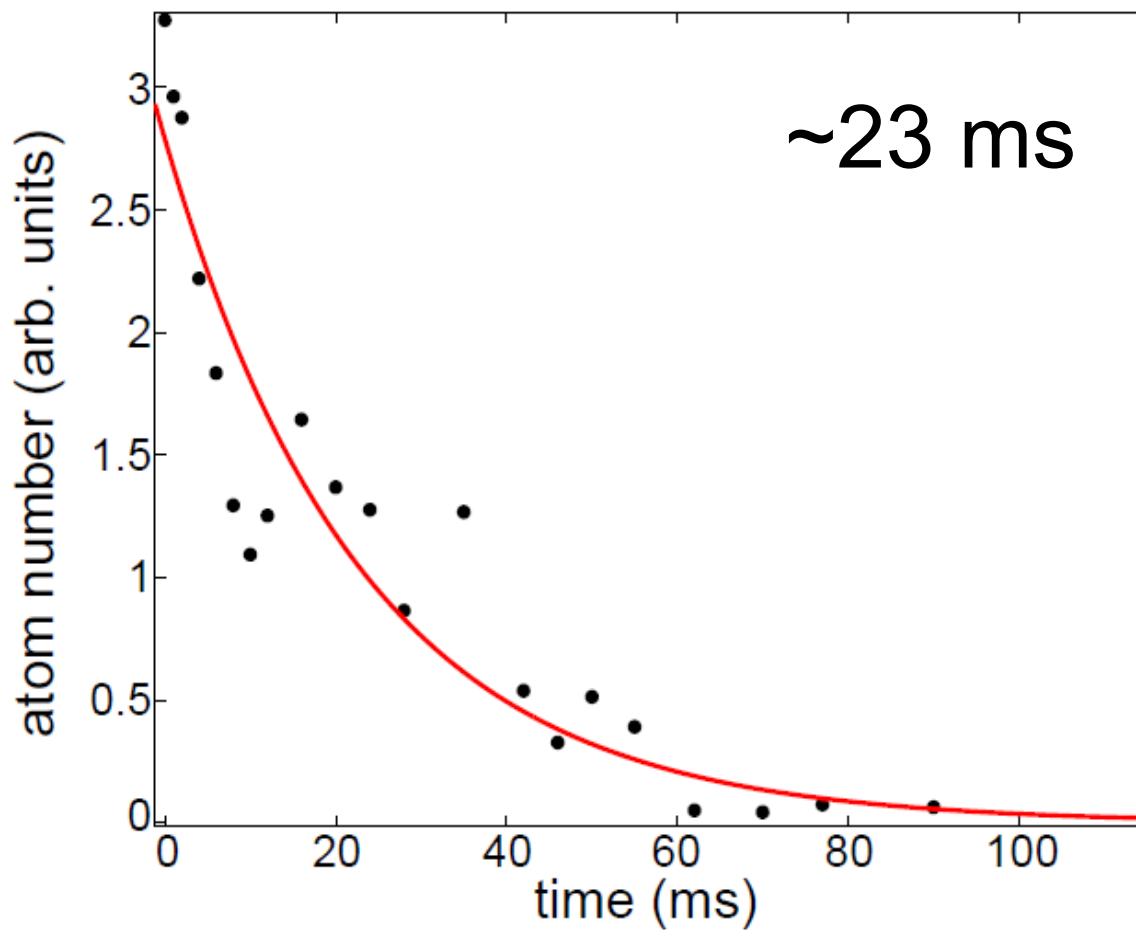
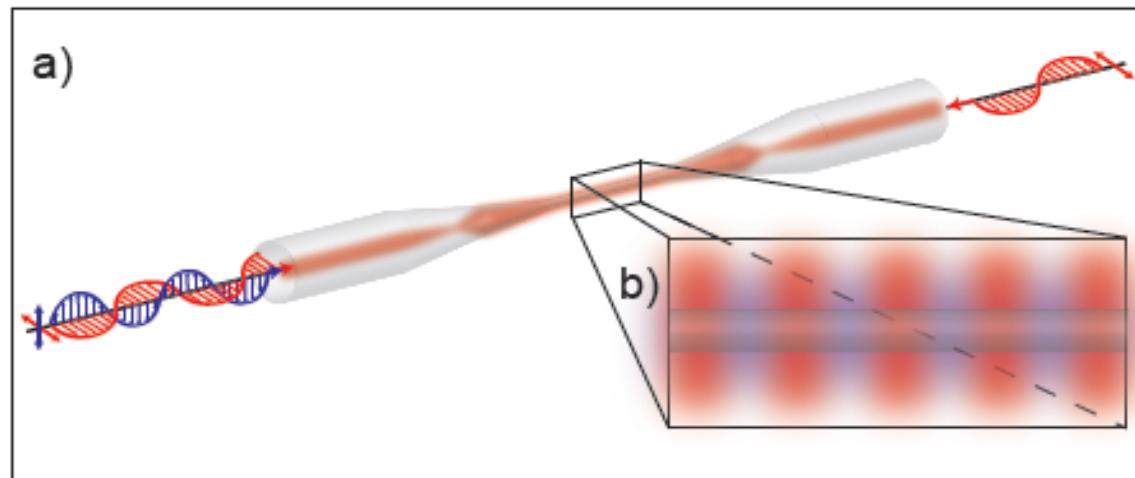
Mejora de atrapamiento



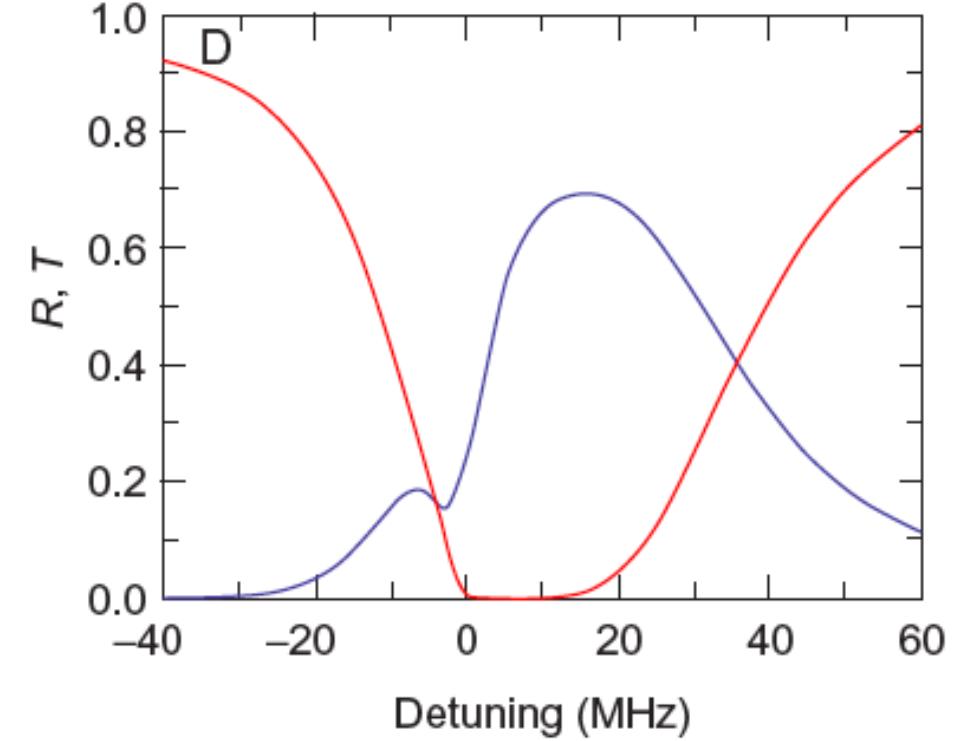
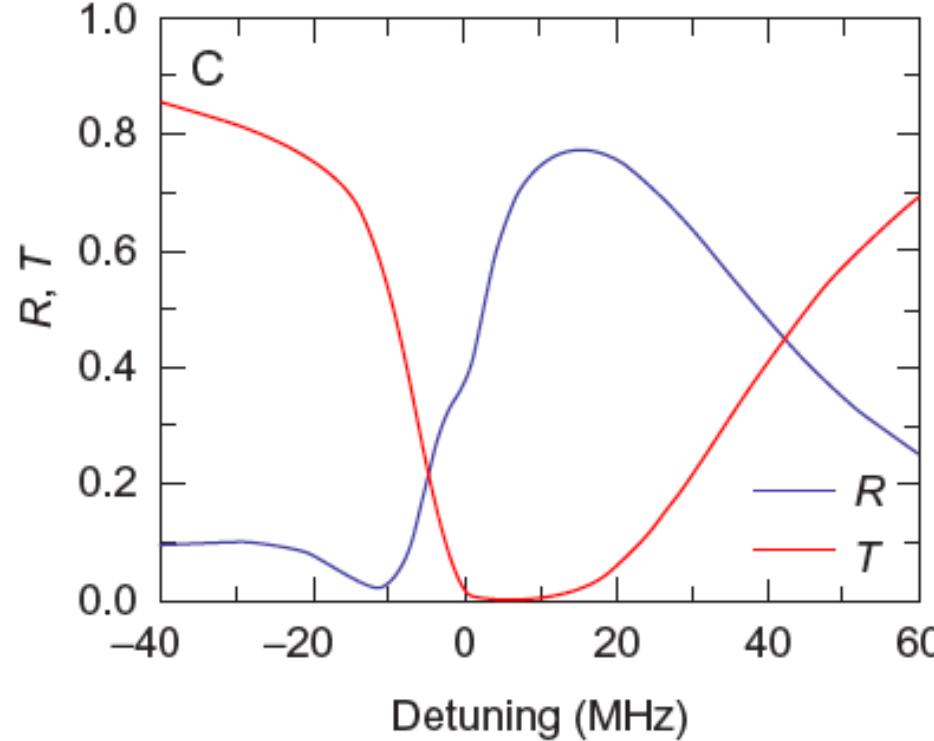
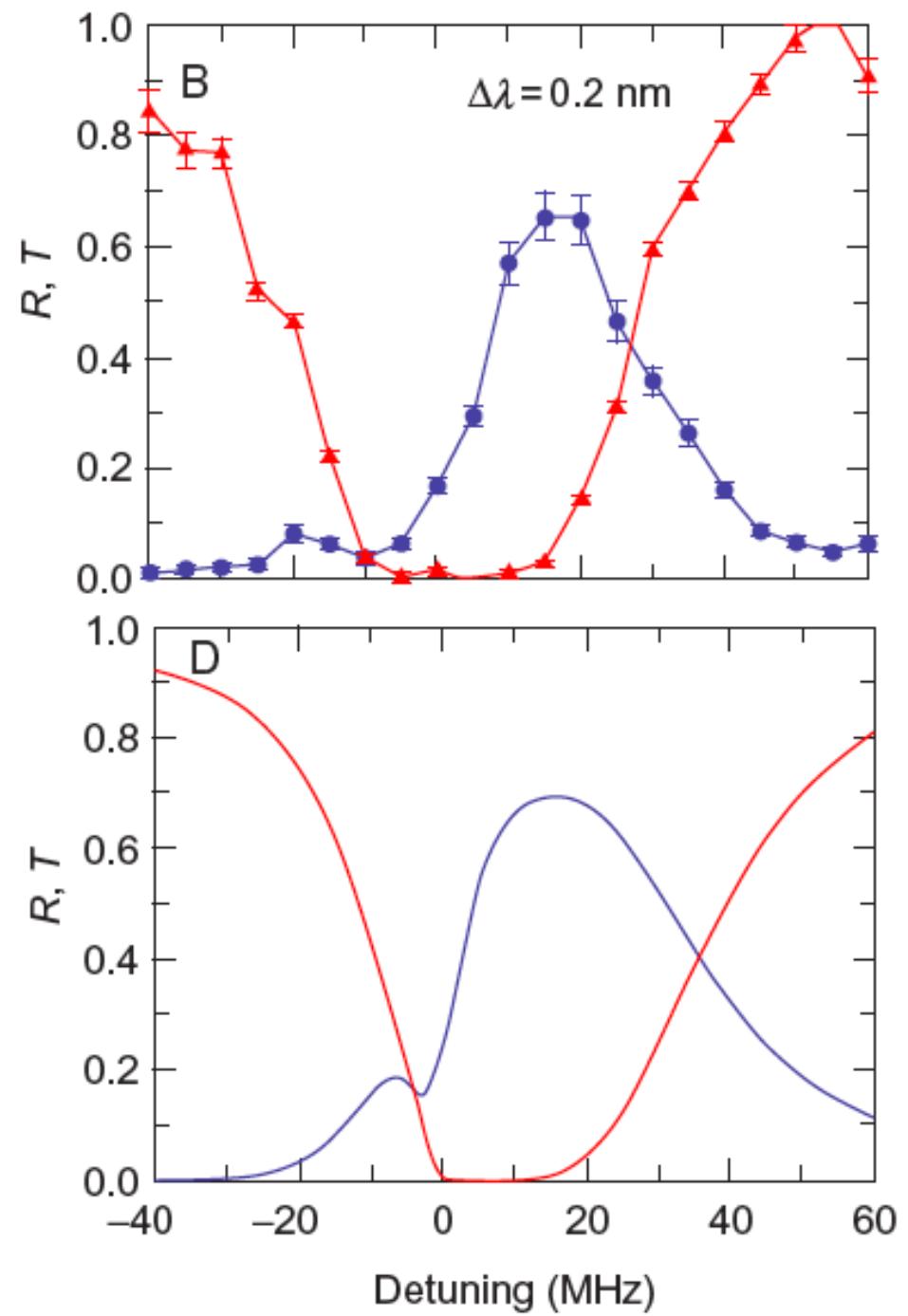
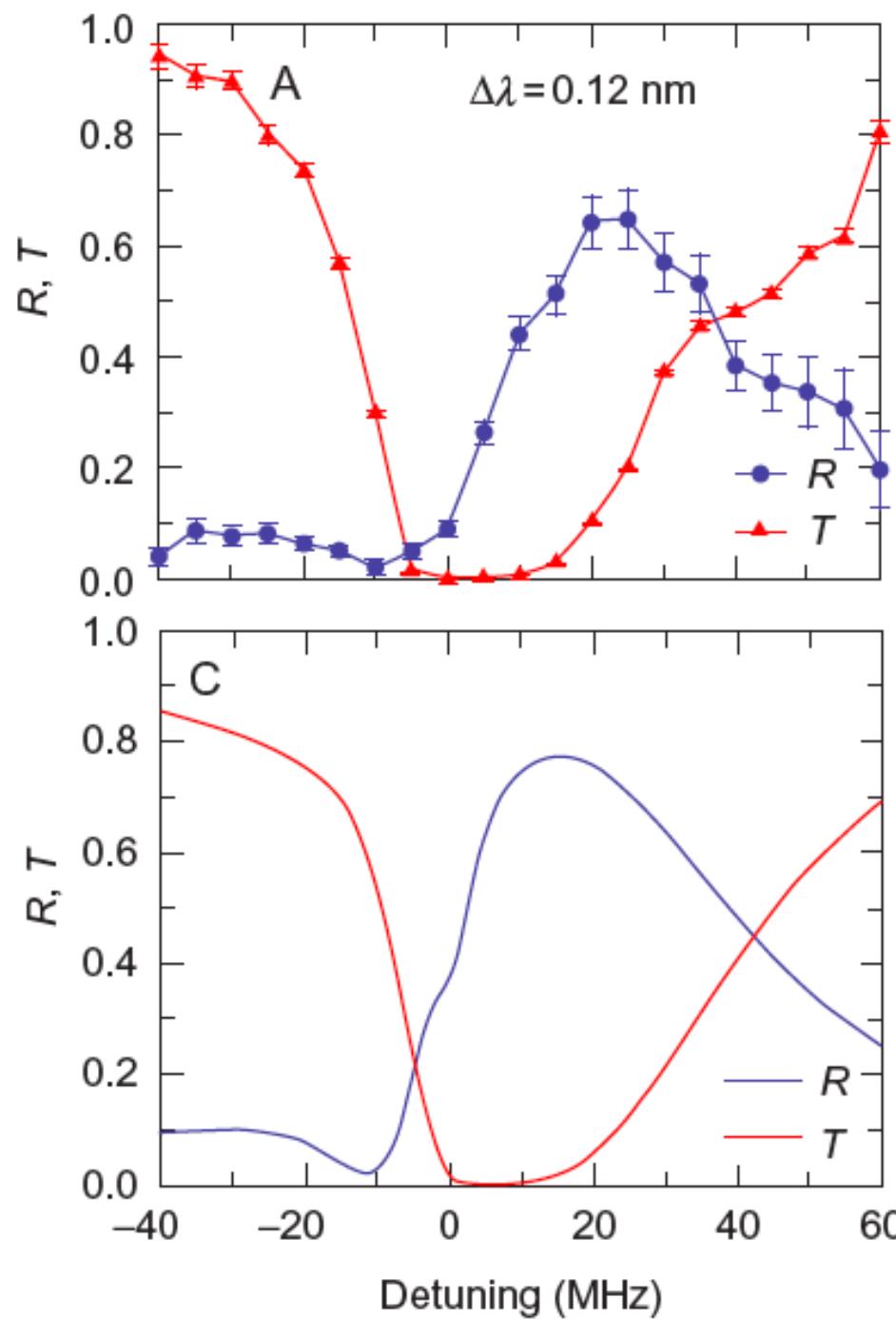
Esquema de atrapamiento



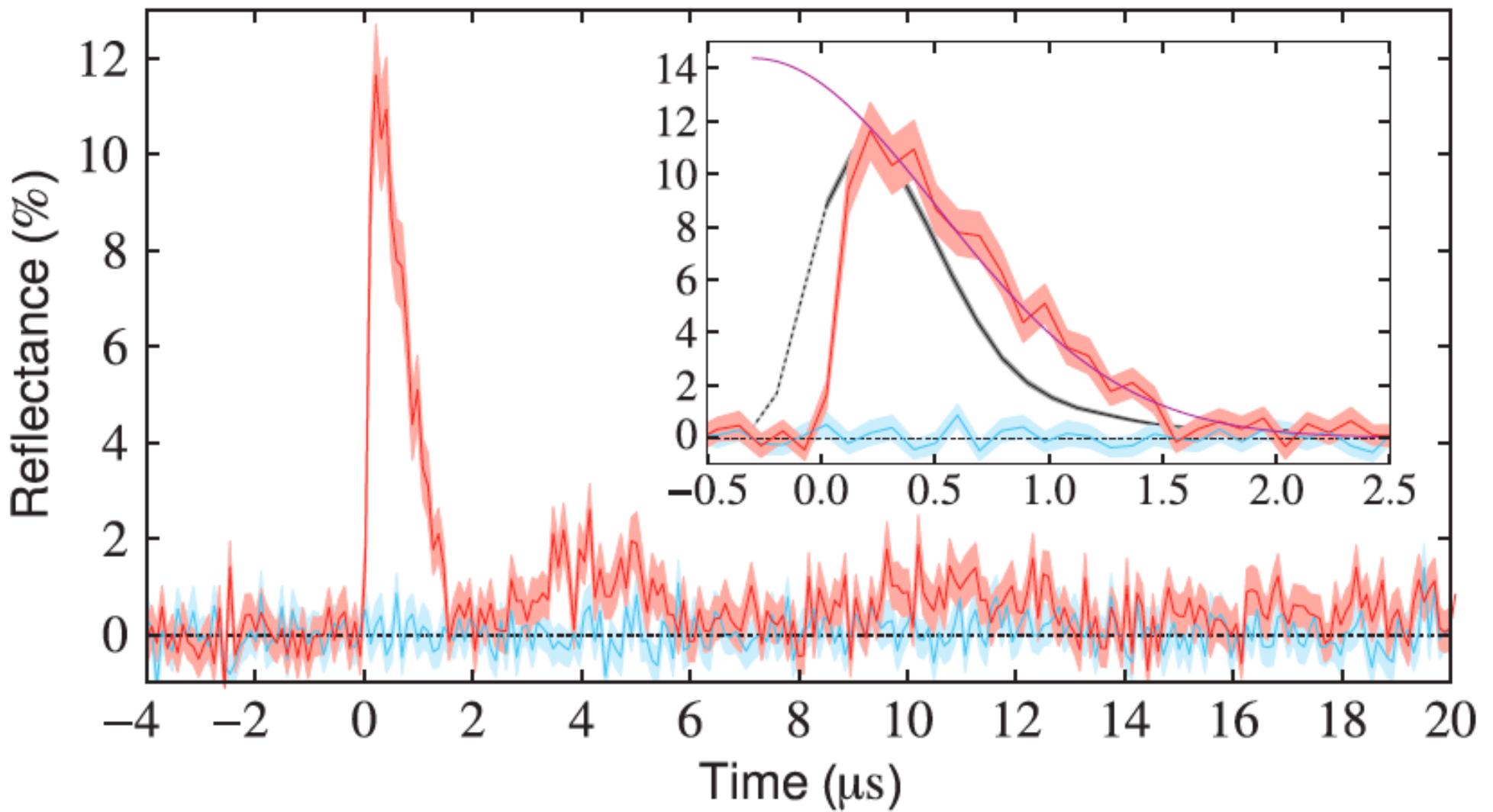
Esquema de atrapamiento



Reflección and Transmisión por
átomos atrapados en la
nanofibra. Arreglo periódico.

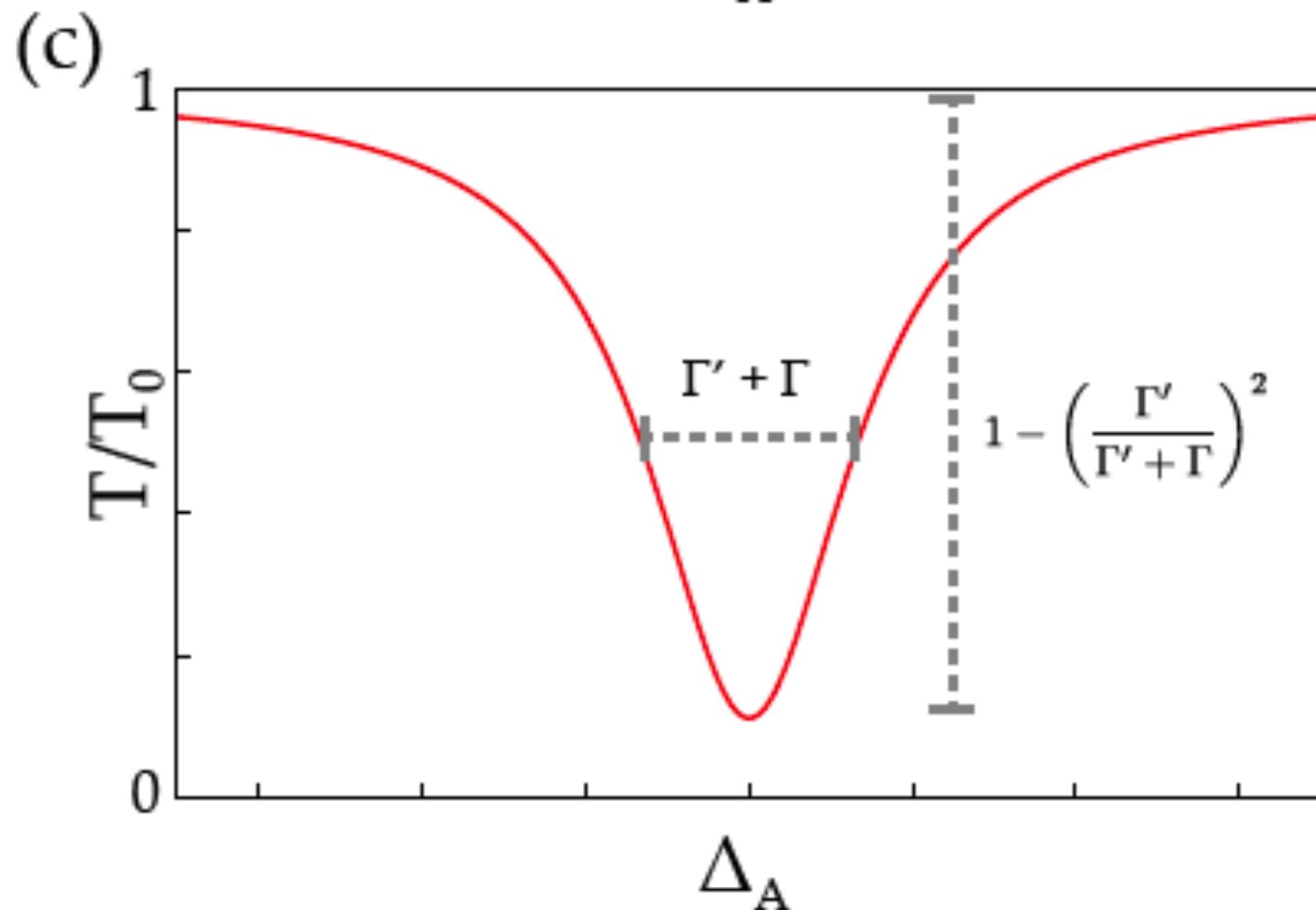


N. V. Corzo, B. Gouraud, A. Chandra, A. Goban, A. S. Sheremet, D. Kupriyanov, J. Laurat. "Large Bragg reflection from one-dimensional chains of trapped atoms near a nanoscale waveguide." Phys. Rev. Lett. 117, 133603 (2016).

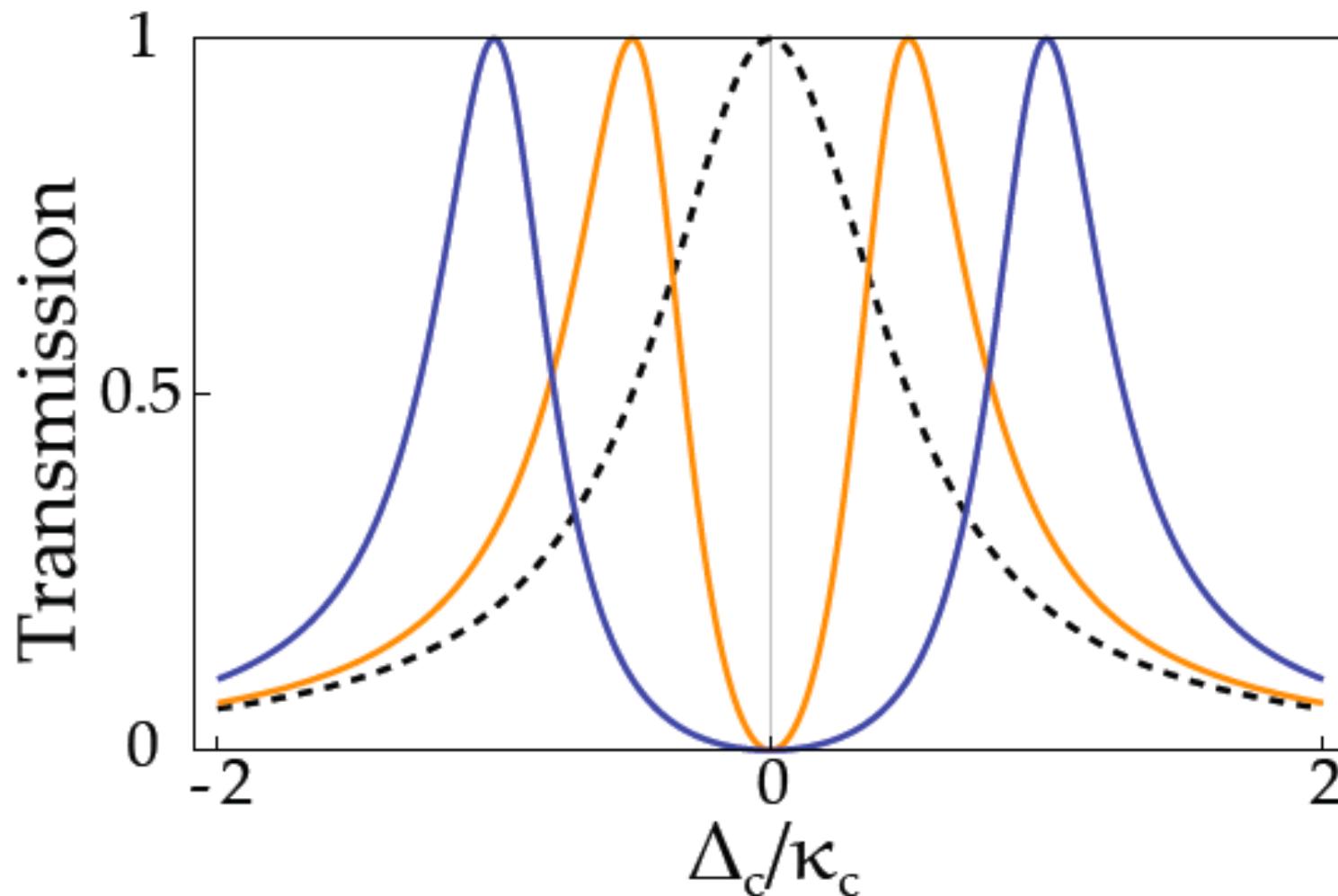


H. L. Sørensen, J. B. Beguin, K. W. Kluge, I. Iakourov, A. S. Sørensen, J. H. Müller, E. S. Polzik, J. Appel, 2016. "Coherent backscattering of light on one-dimensional atomic strings." Phys. Rev. Lett. **117**, 133604 (2016).

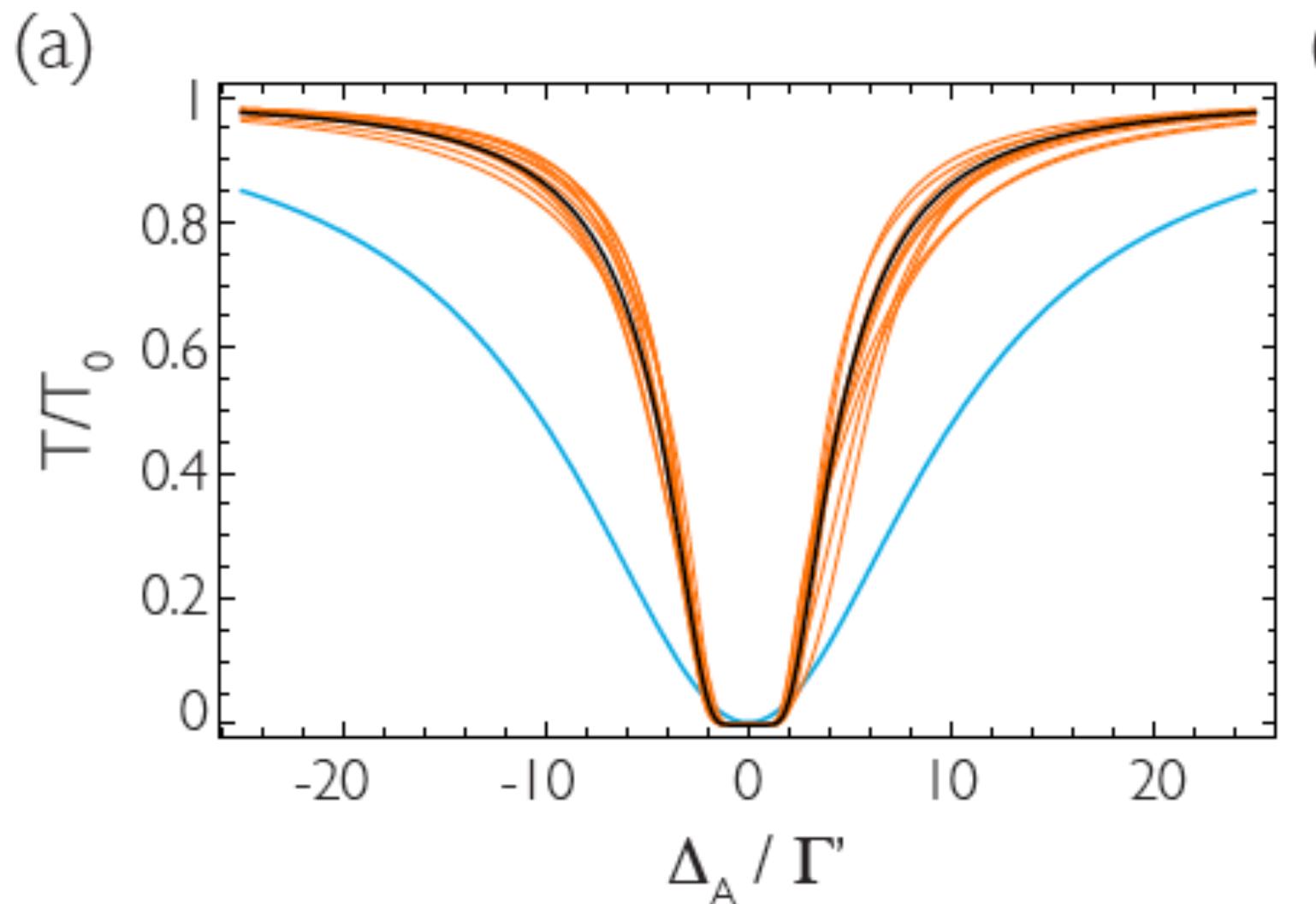
Espectro de Transmisión calculado a través de unaa guía de onda cuasi-1D con un dipolo

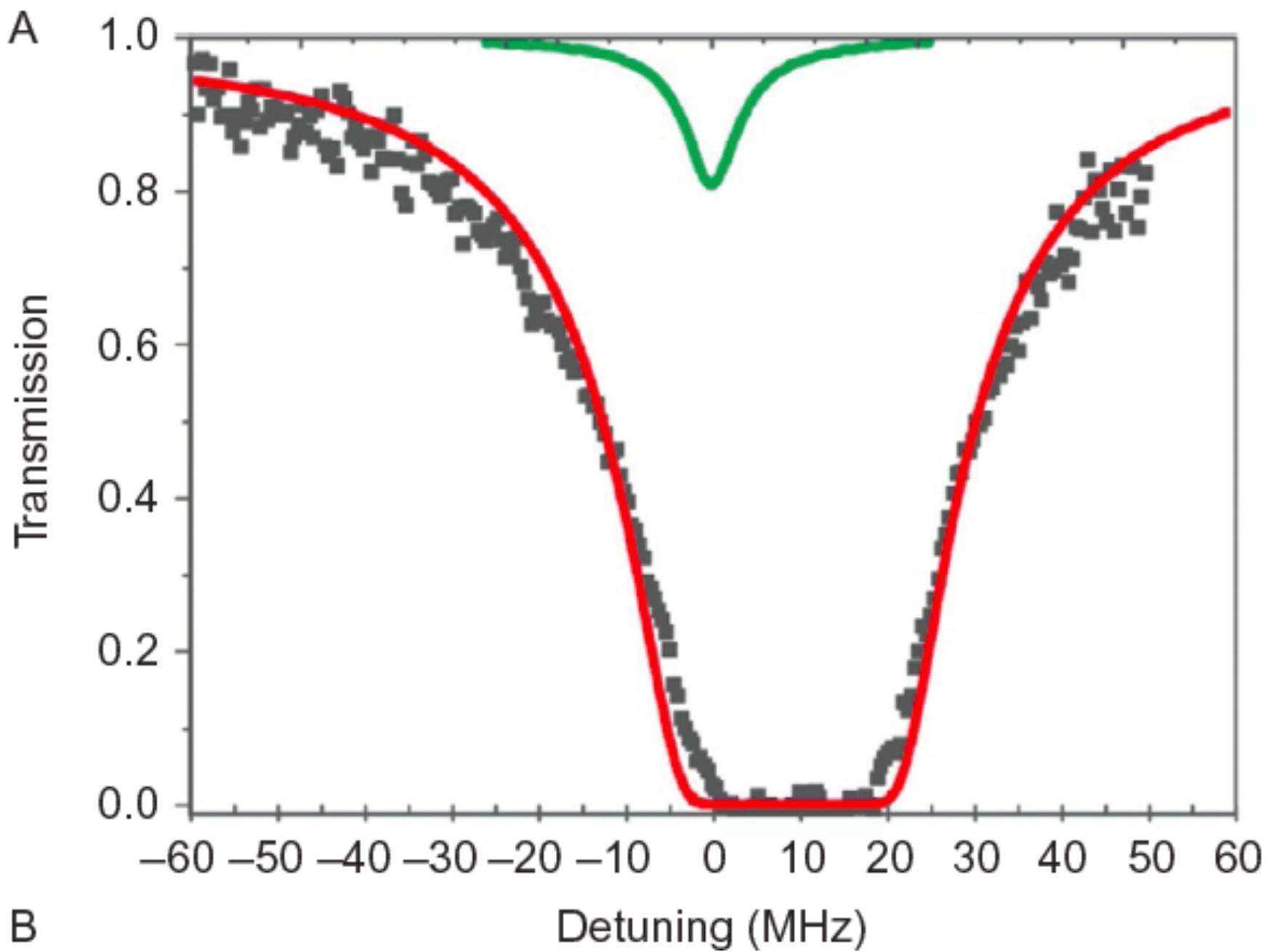


Espectro de transmisión calculado en una cavidad con un dipolo mostrando vacuum Rabi splitting



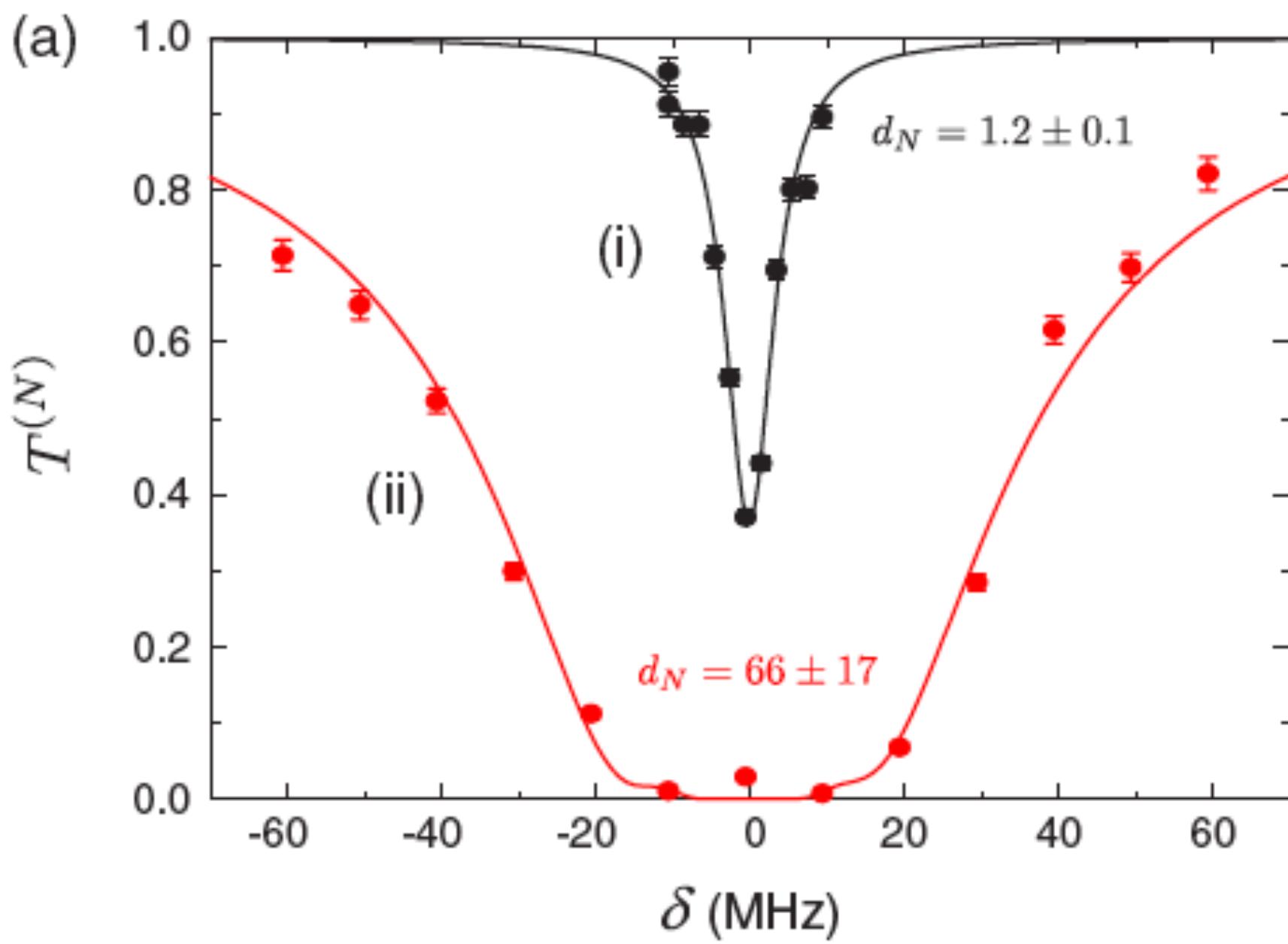
Espectro de transmisión a través de una guía de onda sin estructura (nanofibra)





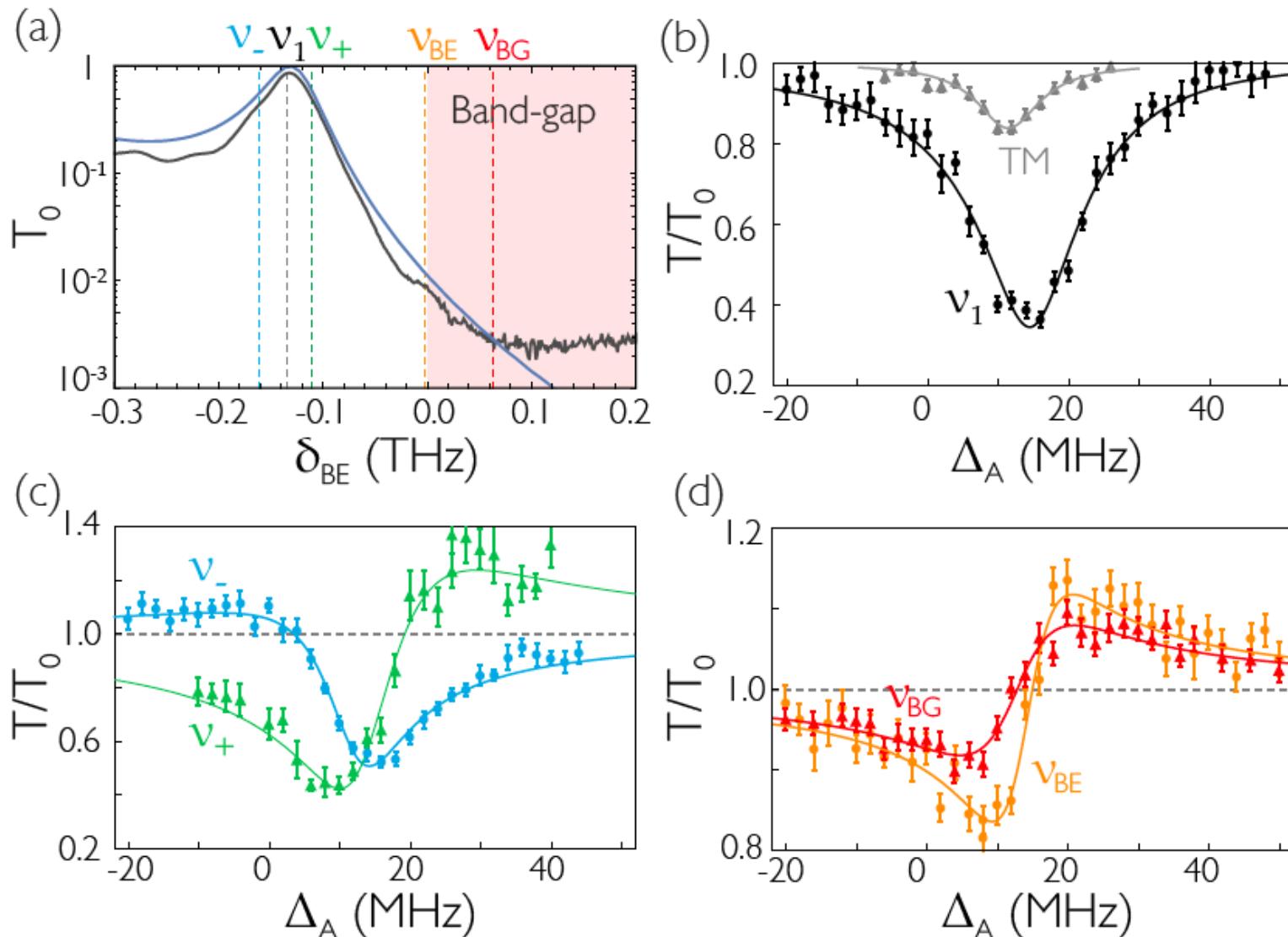
B

E. Vetsch, D. Reitz, G. Sagué, R. Schmidt, S. T. Dawkins, A. Rauschenbeutel, A. "Optical interface created by laser-cooled atoms trapped in the evanescent field surrounding an optical nanofiber." Phys. Rev. Lett. 104, 203603 (2010).



A. Goban, K. S. Choi, D. J. Alton, D. Ding, C. Lacroûte, M. Pototschnig, T. Thiele, N. P. Stern, and H. J. Kimble "Demonstration of a State-Insensitive, Compensated Nanofiber Trap," Phys. Rev. Lett. 109, 033603 (2012).

Espectro de transmisión medido a travez de la banda fotónica de la guía de onda (caimán).



Experimentos de óptica cuántica



Superradiance for Atoms Trapped along a Photonic Crystal Waveguide

A. Goban,^{1,2} C.-L. Hung,^{1,2,†} J. D. Hood,^{1,2} S.-P. Yu,^{1,2} J. A. Muniz,^{1,2} O. Painter,^{2,3} and H. J. Kimble^{1,2,*}

¹*Norman Bridge Laboratory of Physics 12-33, California Institute of Technology, Pasadena, California 91125, USA*

²*Institute for Quantum Information and Matter, California Institute of Technology, Pasadena, California 91125, USA*

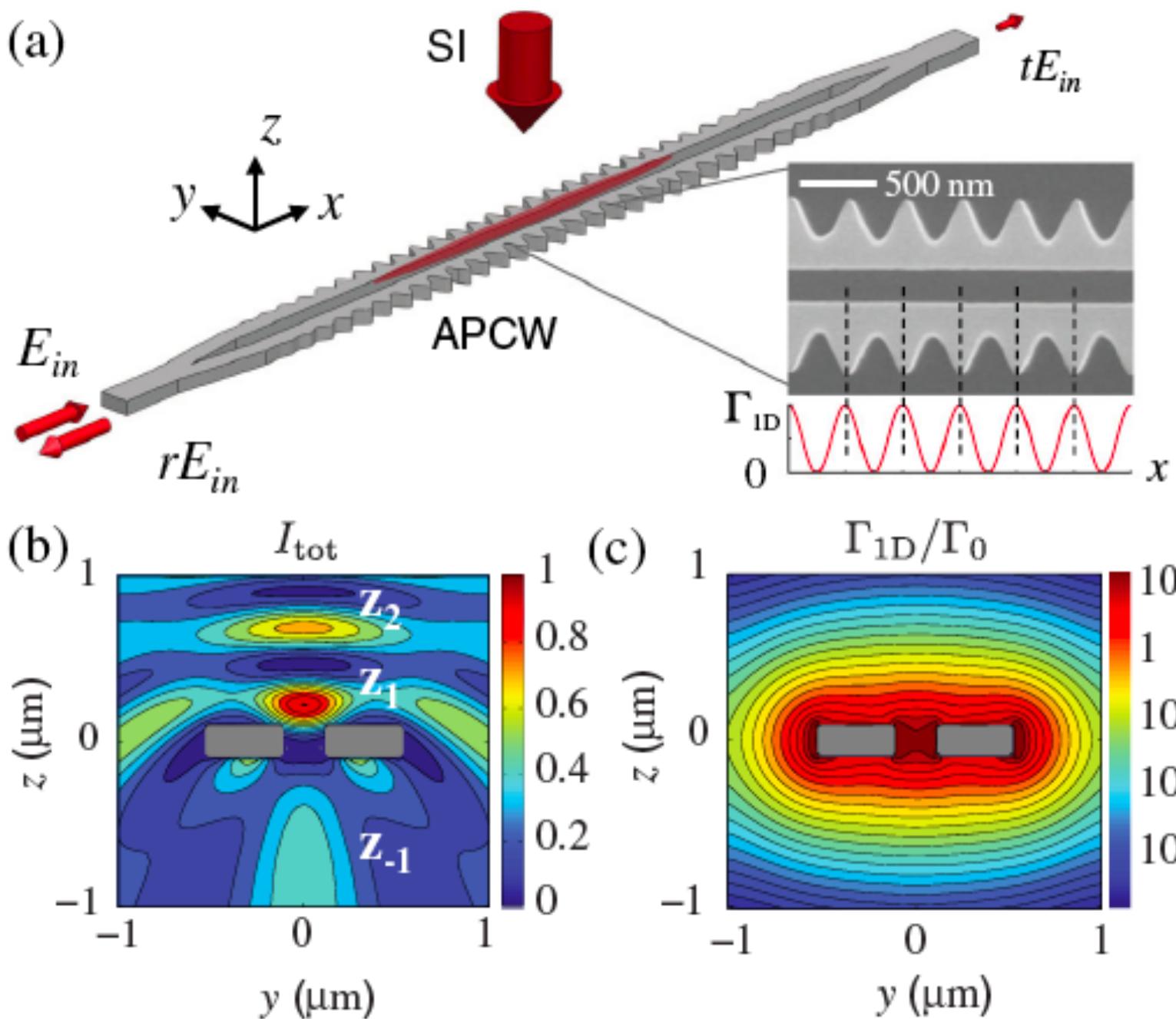
³*Thomas J. Watson, Sr., Laboratory of Applied Physics 128-95, California Institute of Technology, Pasadena, California 91125, USA*

(Received 14 March 2015; published 5 August 2015)

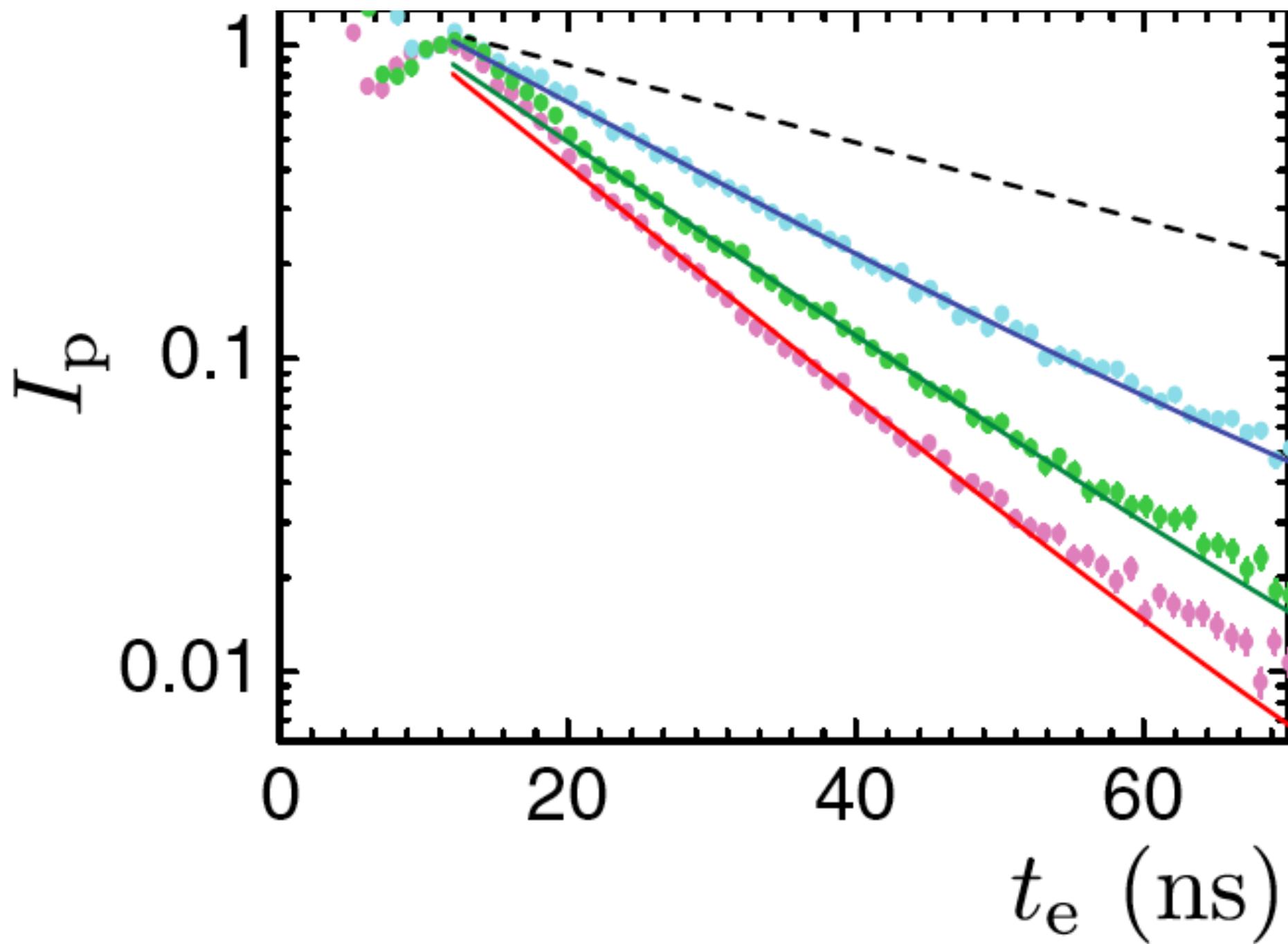
We report observations of superradiance for atoms trapped in the near field of a photonic crystal waveguide (PCW). By fabricating the PCW with a band edge near the D_1 transition of atomic cesium, strong interaction is achieved between trapped atoms and guided-mode photons. Following short-pulse excitation, we record the decay of guided-mode emission and find a superradiant emission rate scaling as $\bar{\Gamma}_{\text{SR}} \propto \bar{N}\Gamma_{1D}$ for average atom number $0.19 \lesssim \bar{N} \lesssim 2.6$ atoms, where $\Gamma_{1D}/\Gamma' = 1.0 \pm 0.1$ is the peak single-atom radiative decay rate into the PCW guided mode, and Γ' is the radiative decay rate into all the other channels. These advances provide new tools for investigations of photon-mediated atom-atom interactions in the many-body regime.

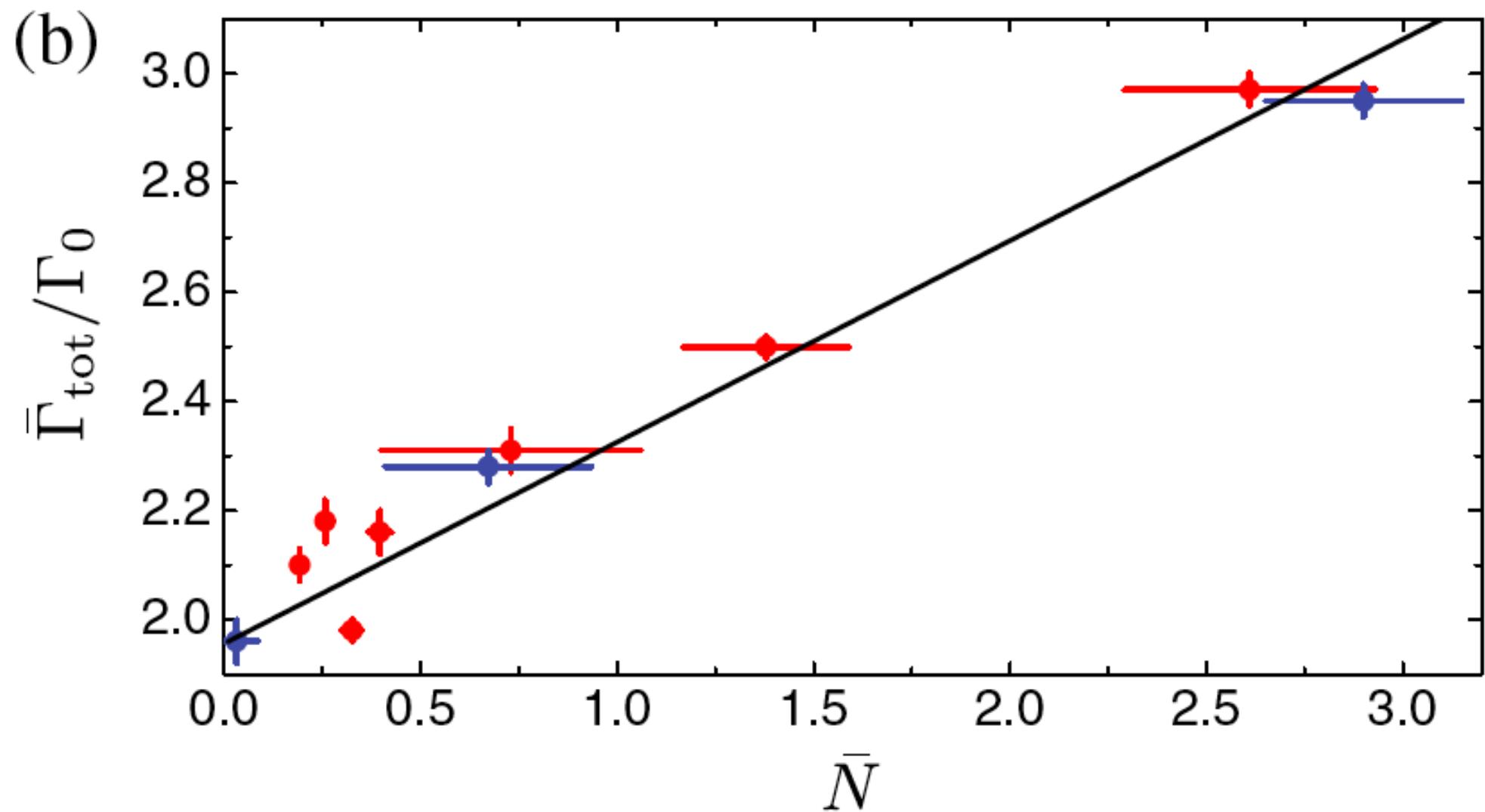
DOI: [10.1103/PhysRevLett.115.063601](https://doi.org/10.1103/PhysRevLett.115.063601)

PACS numbers: 42.50.Ct, 37.10.Gh, 42.70.Qs



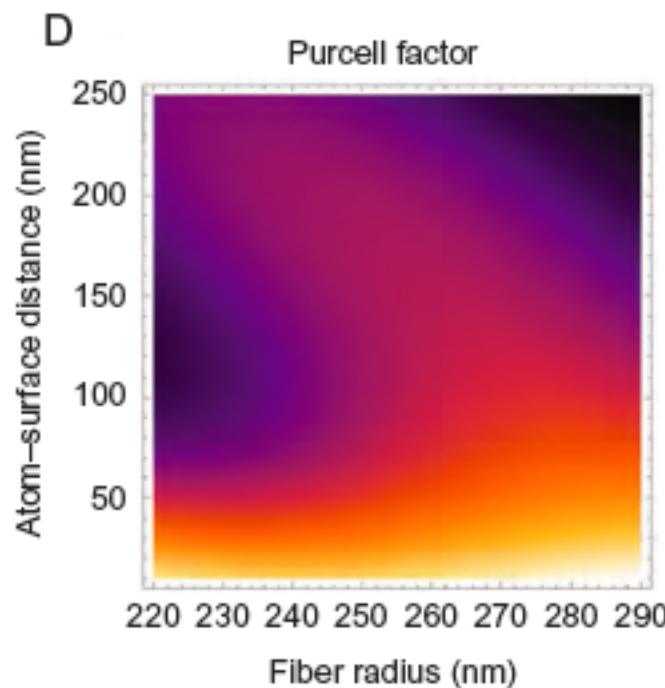
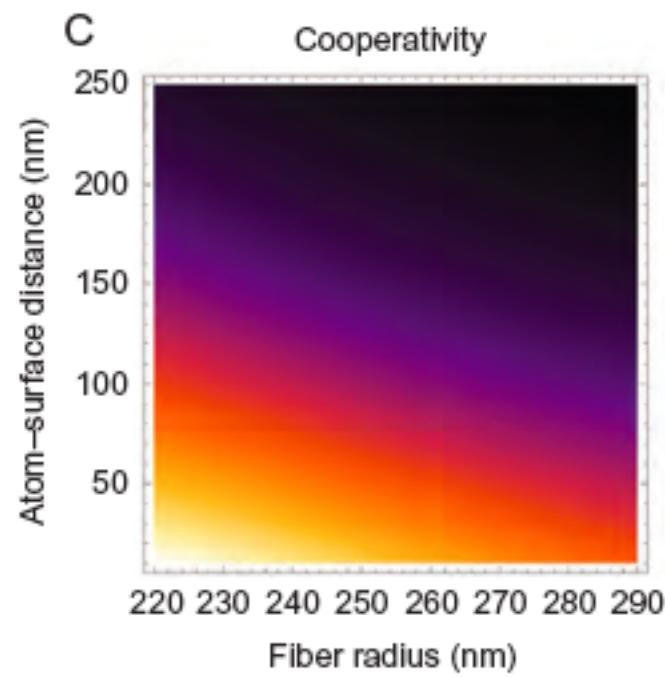
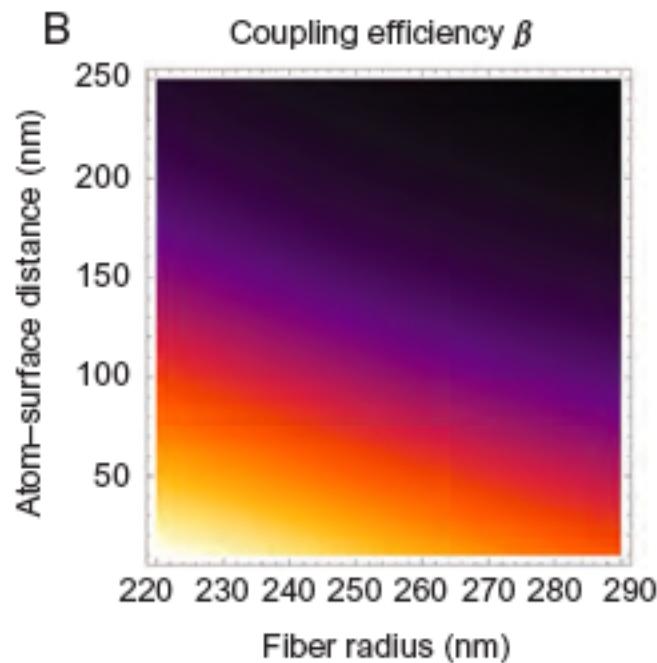
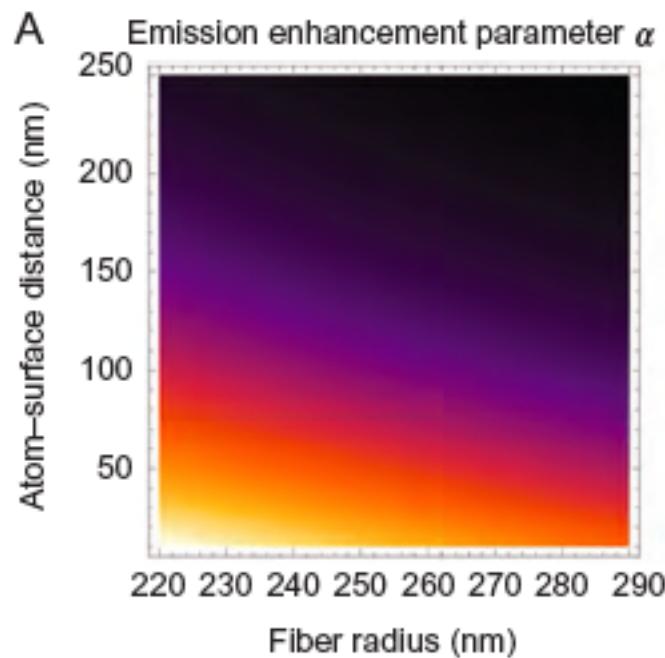
A. Goban, C.-L. Hung, J. D. Hood, S.-P. Yu, J. A. Muniz, O. Painter, and H. J. Kimble, "Superradiance for Atoms Trapped along a Photonic Crystal Waveguide," Phys. Rev. Lett. **115**, 063601 (2015)



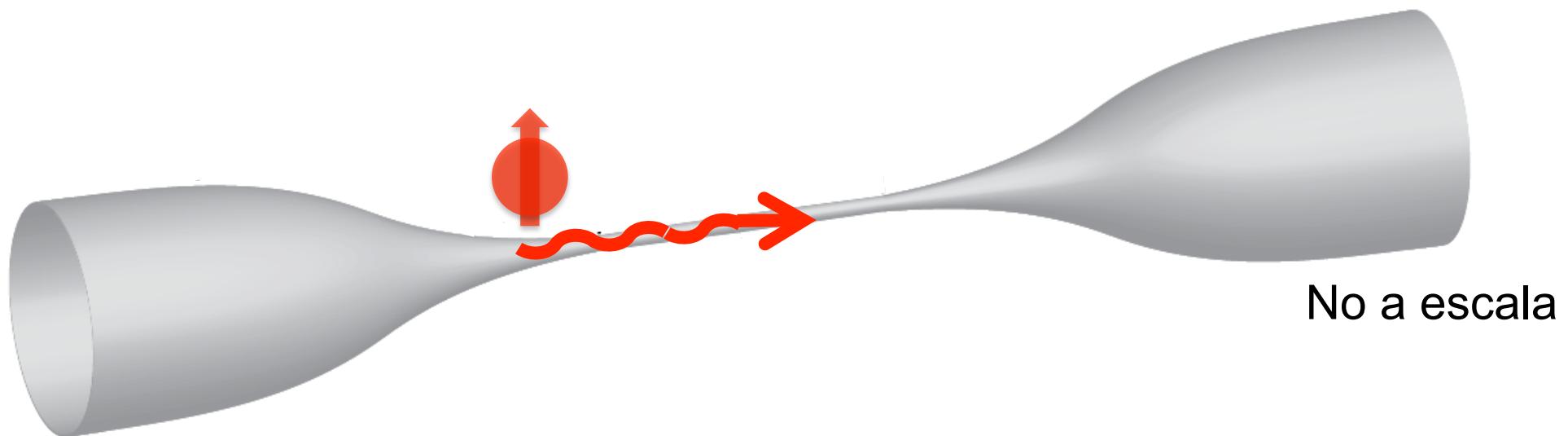


¿Se puede ver un efecto atómico colectivo con átomos en una guía de onda?

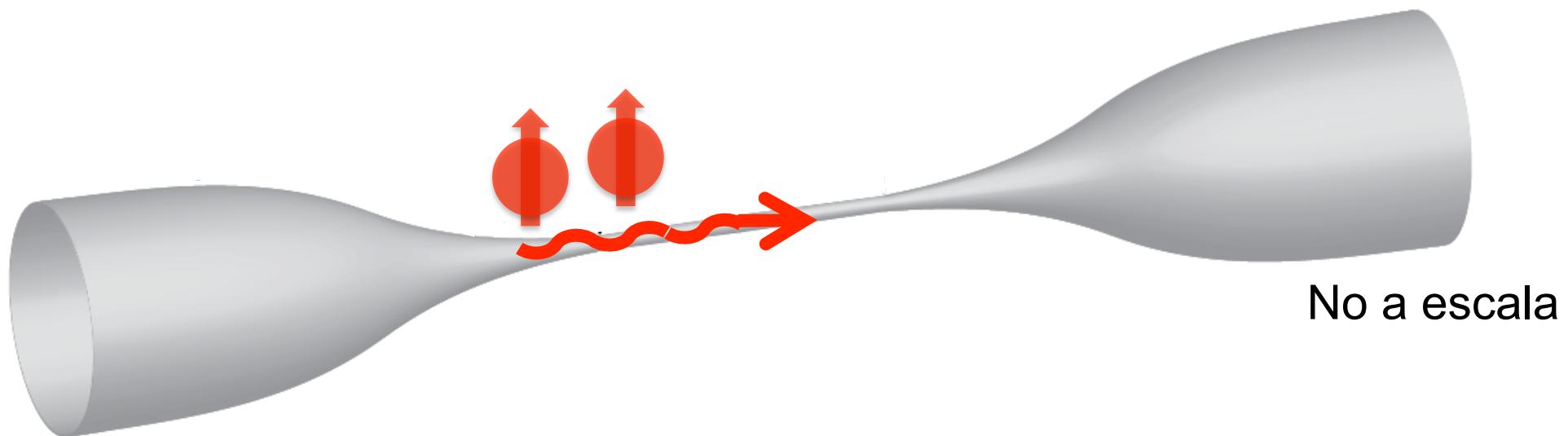
Parámetros de acoplamiento para nanofibras



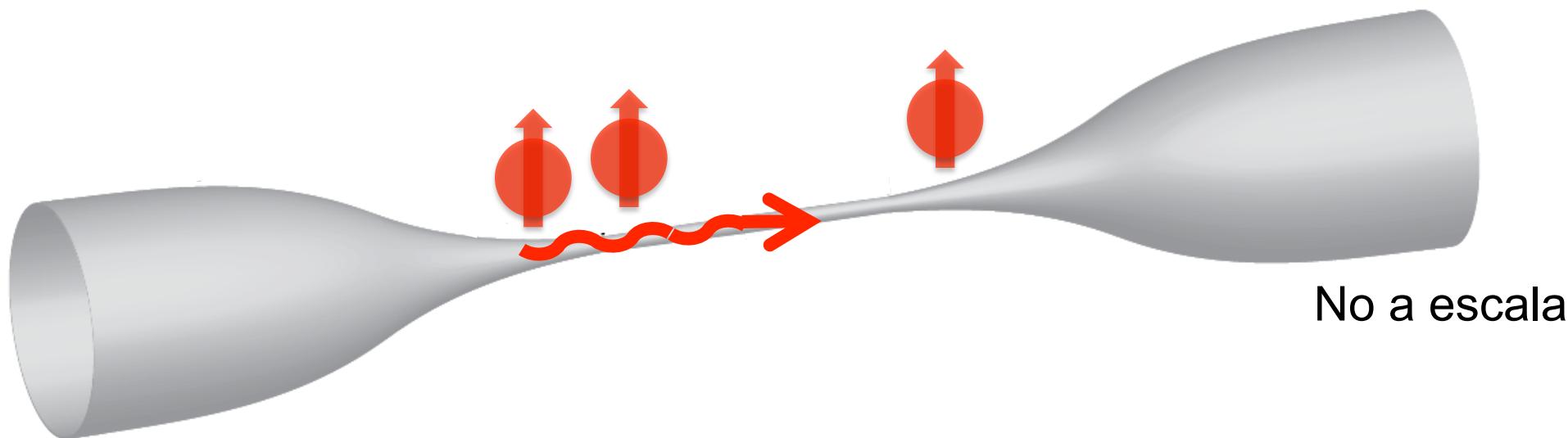
Interacciones de rango infinito

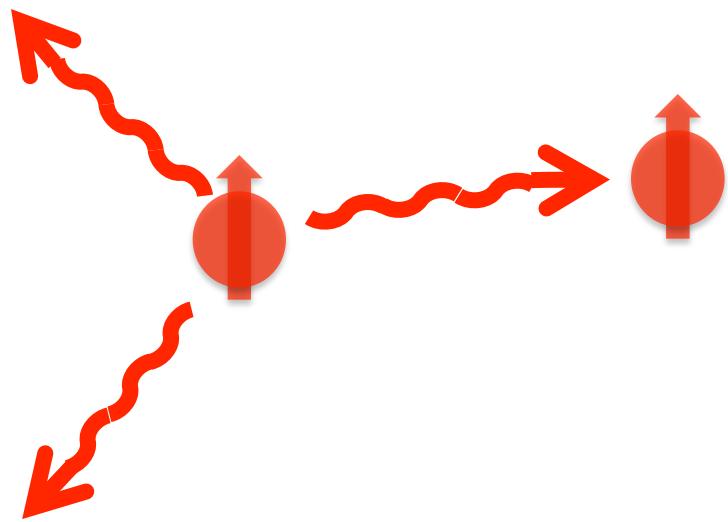


Interacciones de rango infinito

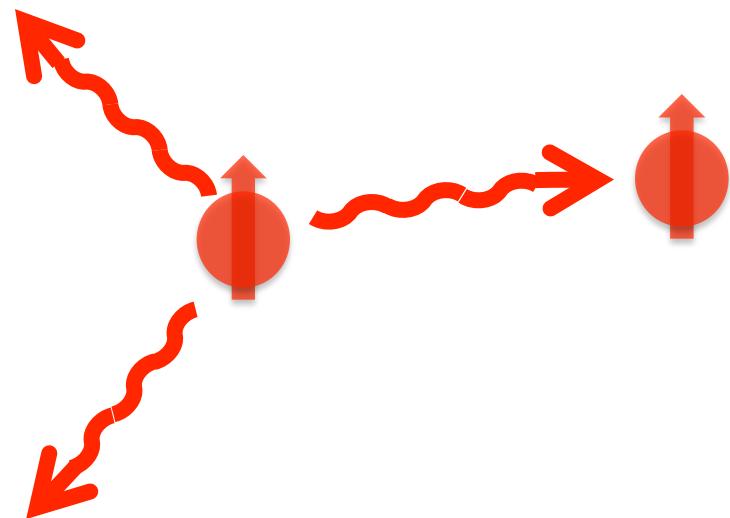


Interacciones de rango infinito

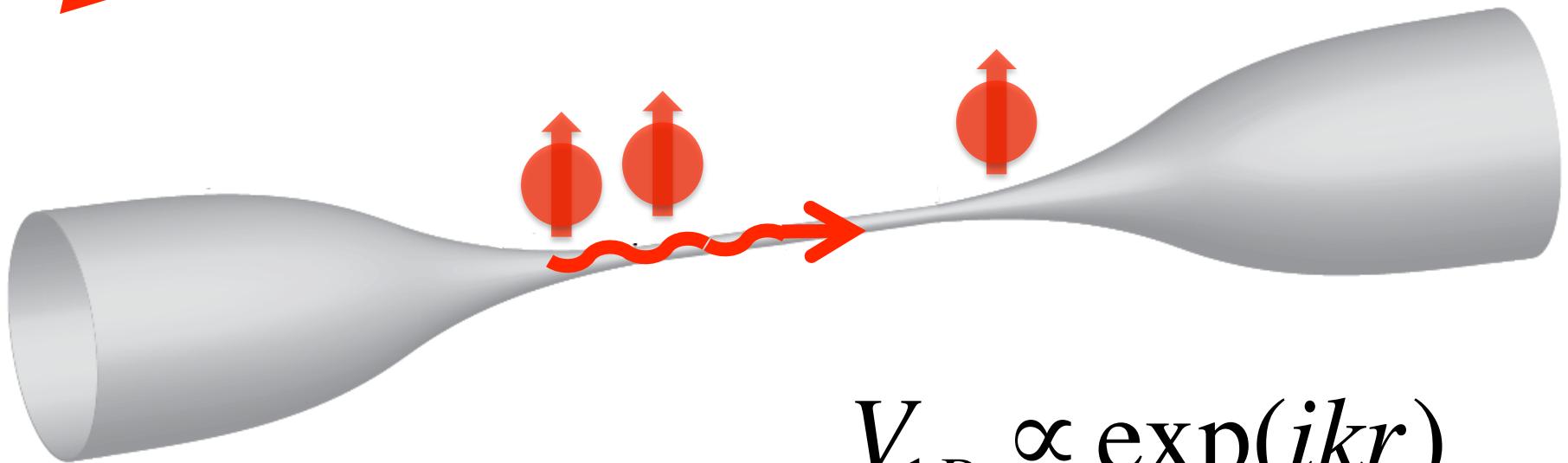




$$V_{free} \propto \frac{\exp(ikr)}{kr}$$

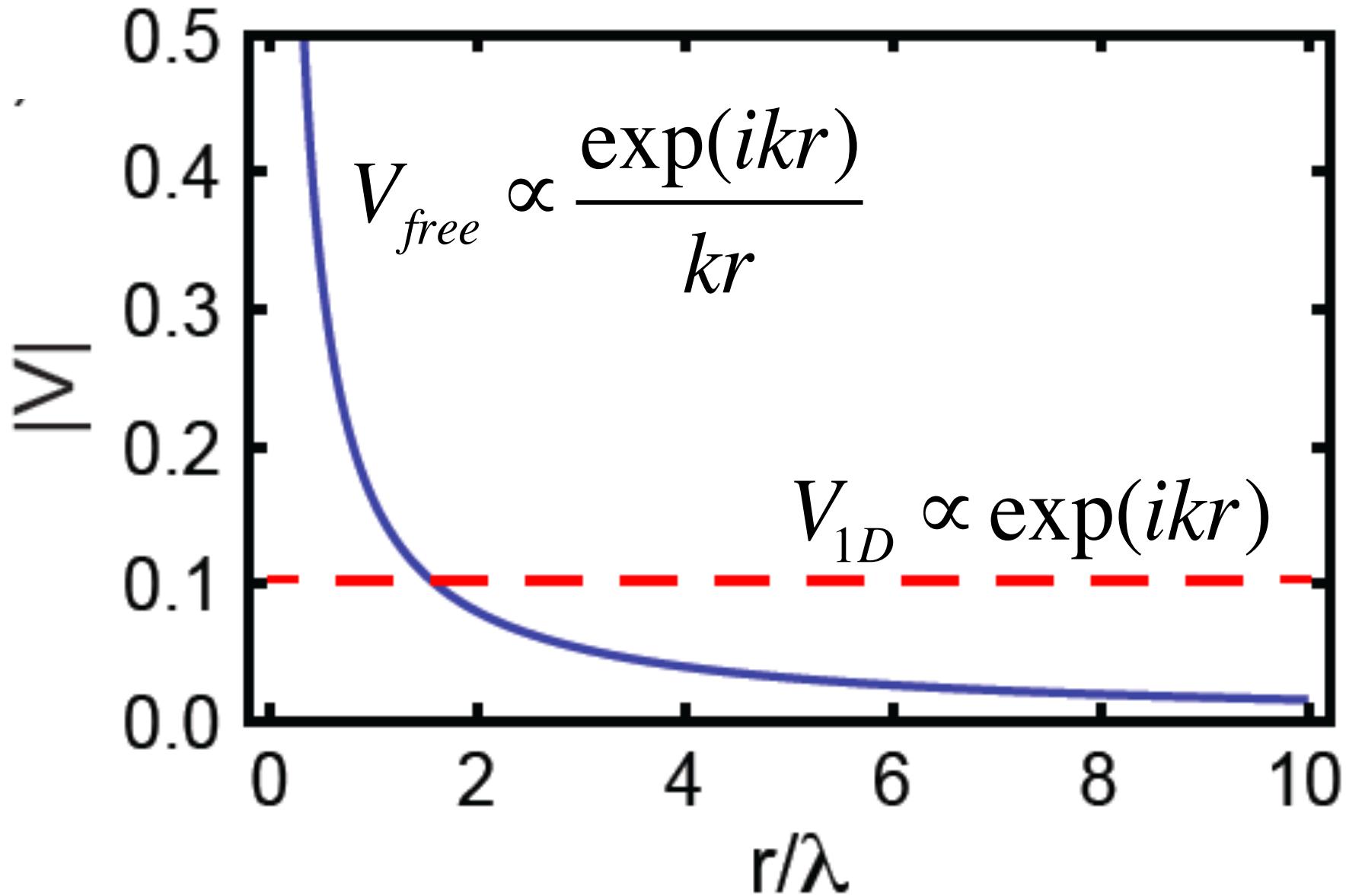


$$V_{free} \propto \frac{\exp(ikr)}{kr}$$



$$V_{1D} \propto \exp(ikr)$$

Infinite Range Interactions



Super- y Sub-radianza

(una explicación clásica)

“Cuando dos tubos de órgano del mismo tono se colocan uno al lado del otro, se producen complicaciones que no pocas veces causan problemas en la práctica. En casos extremos, las tuberías pueden casi reducirse entre sí al silencio. Incluso cuando la influencia mutua es más moderada, puede llegar a provocar que las canalizaciones suenen al unísono, a pesar de las pequeñas diferencias inevitables.

Lord Rayleigh (1877) en "The Theory of Sound"

Super- y Sub-radianza

(una explicación clásica)

Necesitamos la respuesta de un oscilador
debido a otro oscilador cercano:

$$\ddot{a}_1 + \gamma_0 \dot{a}_1 + \omega_0^2 a_1 = \frac{3}{2} \omega_0 \gamma_0 \hat{d}_1 \cdot \vec{\mathcal{E}}_2(\vec{r}) a_1,$$

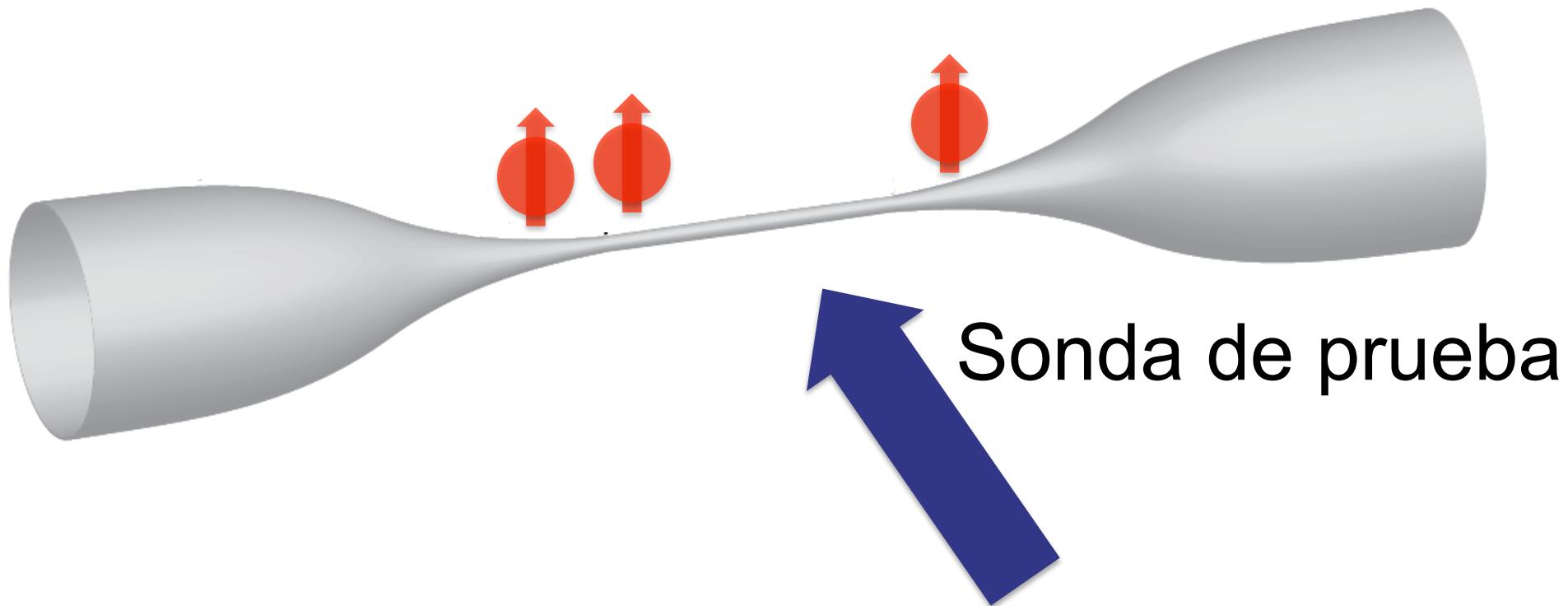
assuming $a_1 = a_{10} \exp i(\omega - i/2)t$

$$\gamma = \gamma_0 + \frac{3}{2} \gamma_0 \text{Im} \left\{ \hat{d}_1 \cdot \vec{\mathcal{E}}_2(\vec{r}) \right\}, \quad \text{with} \left| \hat{d}_1 \cdot \vec{\mathcal{E}}_2(0) \right| = \frac{2}{3}$$

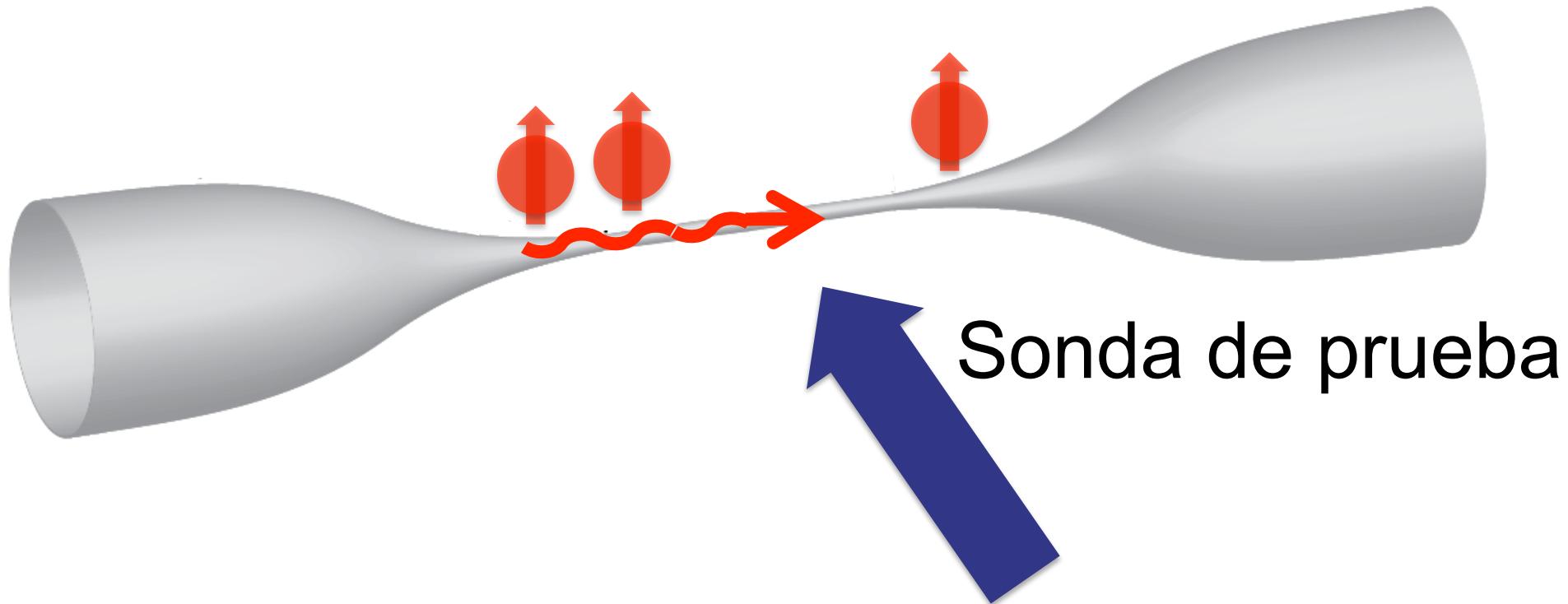
$$\omega = \omega_0 - \frac{3}{4} \gamma_0 \text{Re} \left\{ \hat{d}_1 \cdot \vec{\mathcal{E}}_2(\vec{r}) \right\}$$

Observación de
interacciones de rango
infinito

La idea detrás del experimento

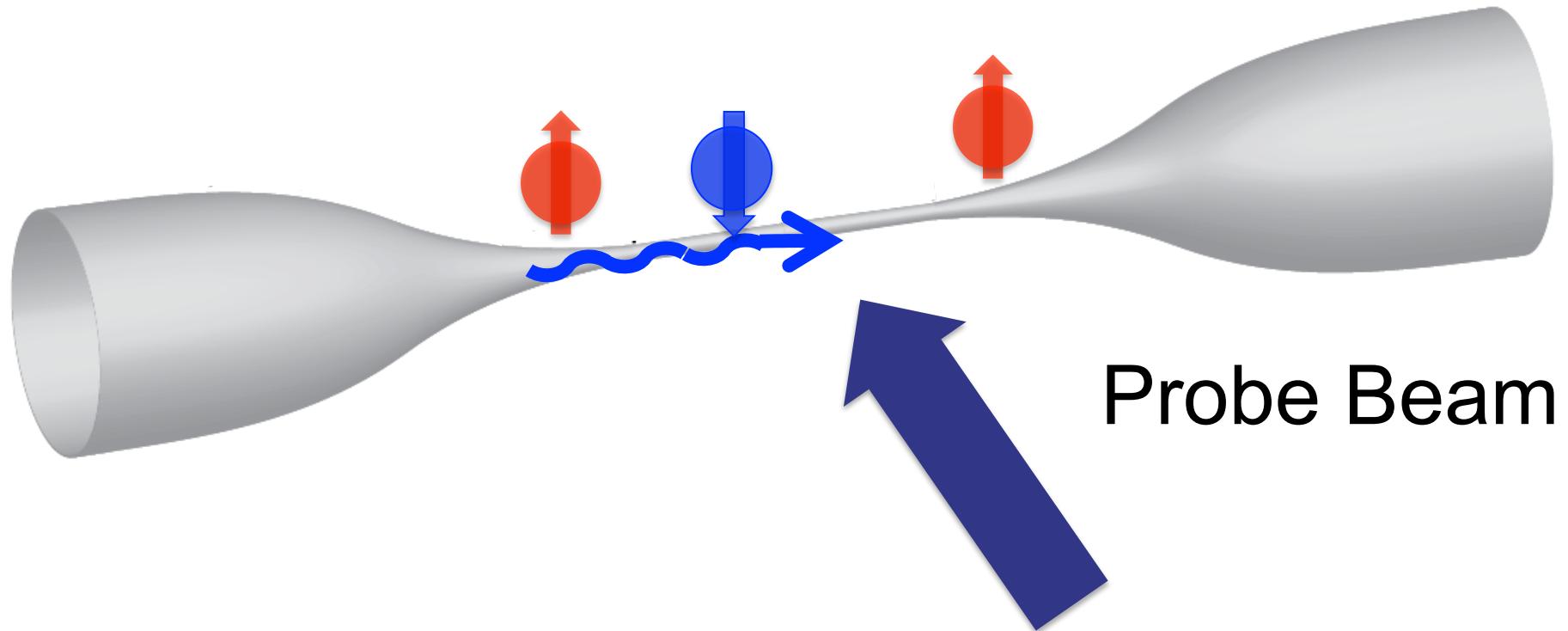


La idea detrás del experimento



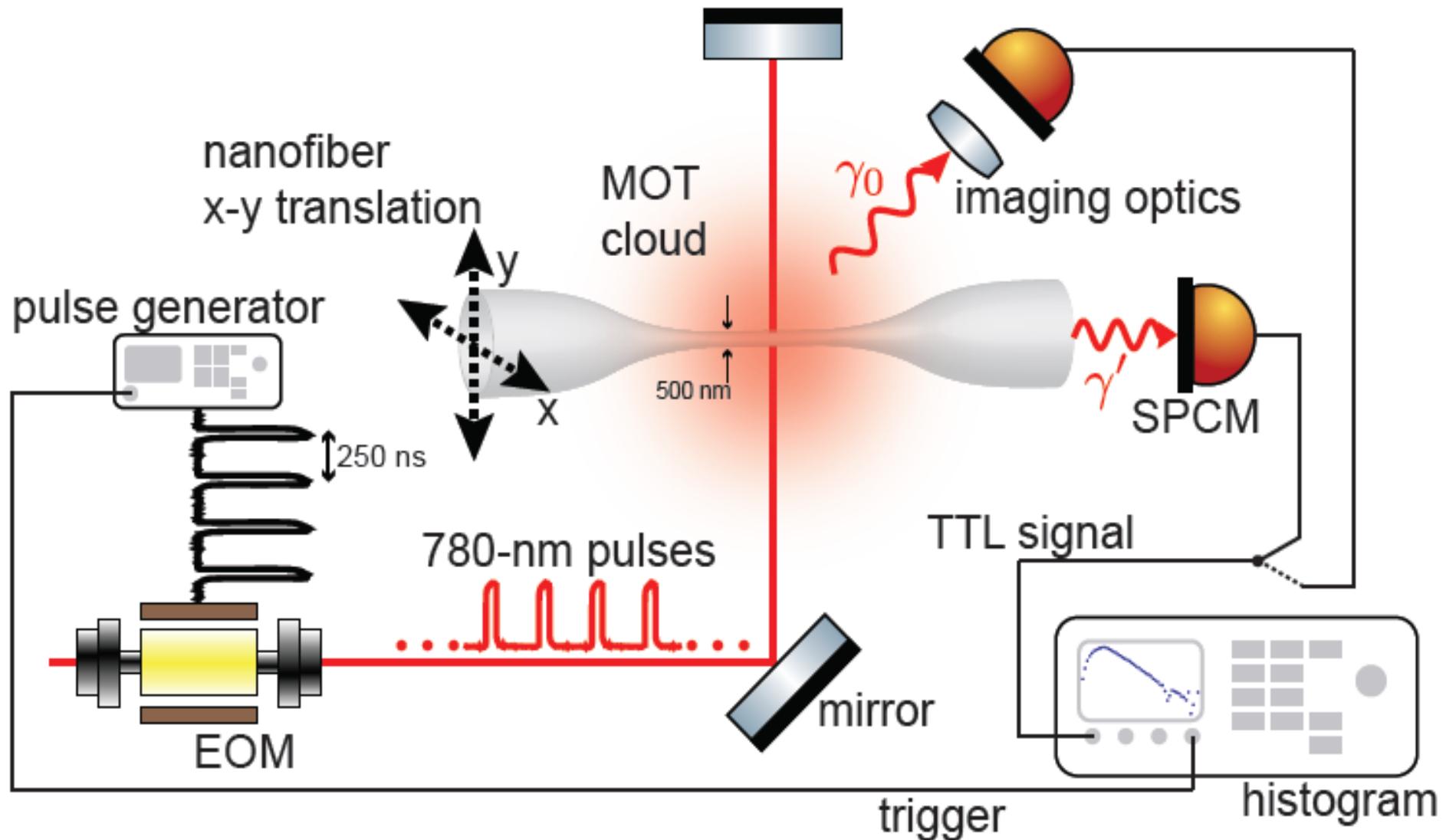
Busquemos modificaciones a la vida media radiaativa de un grupo de átomos alrededor de la nanofibra.

The idea behind the experiment

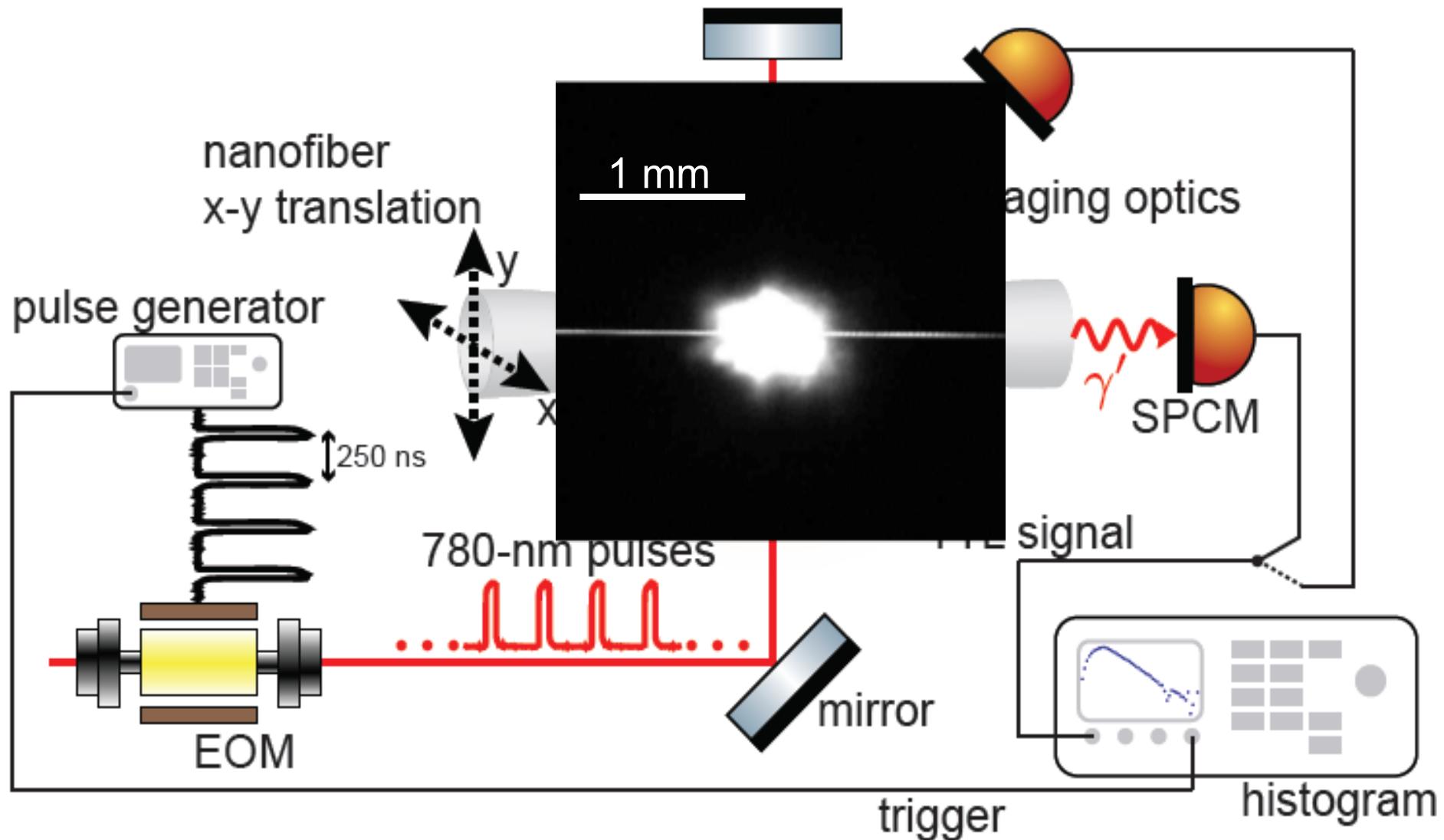


The sub- and super-radiant behavior depend on the phase relation of the atomic dipoles along the common mode

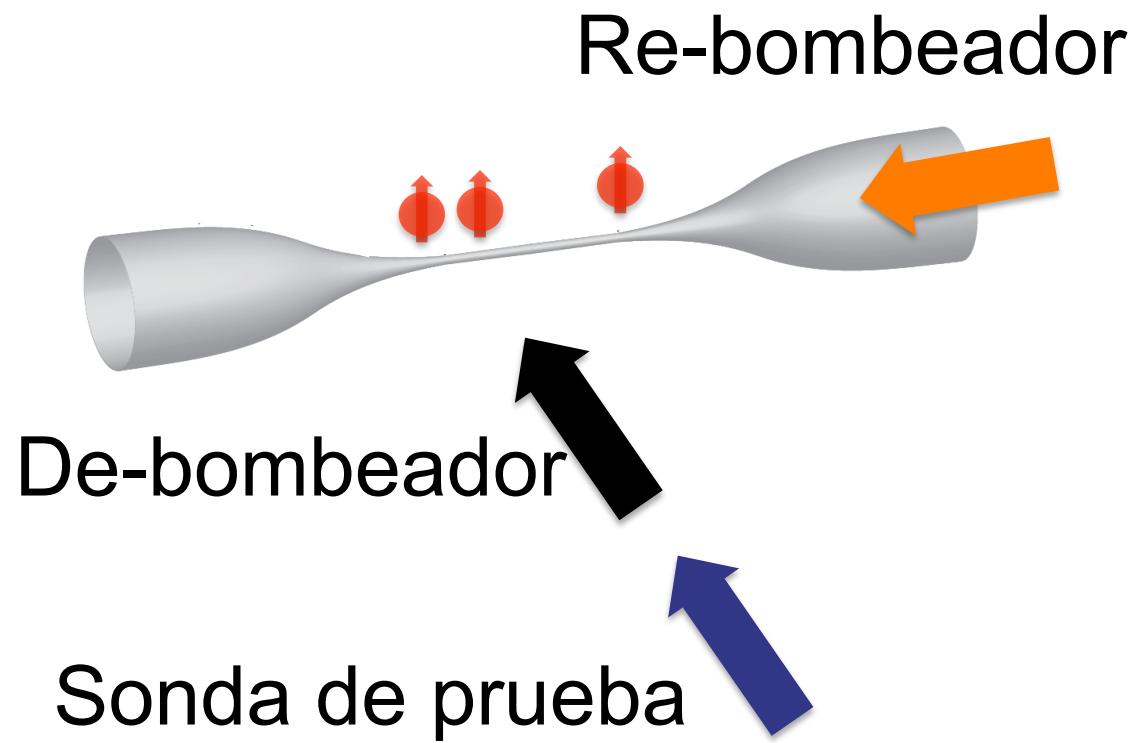
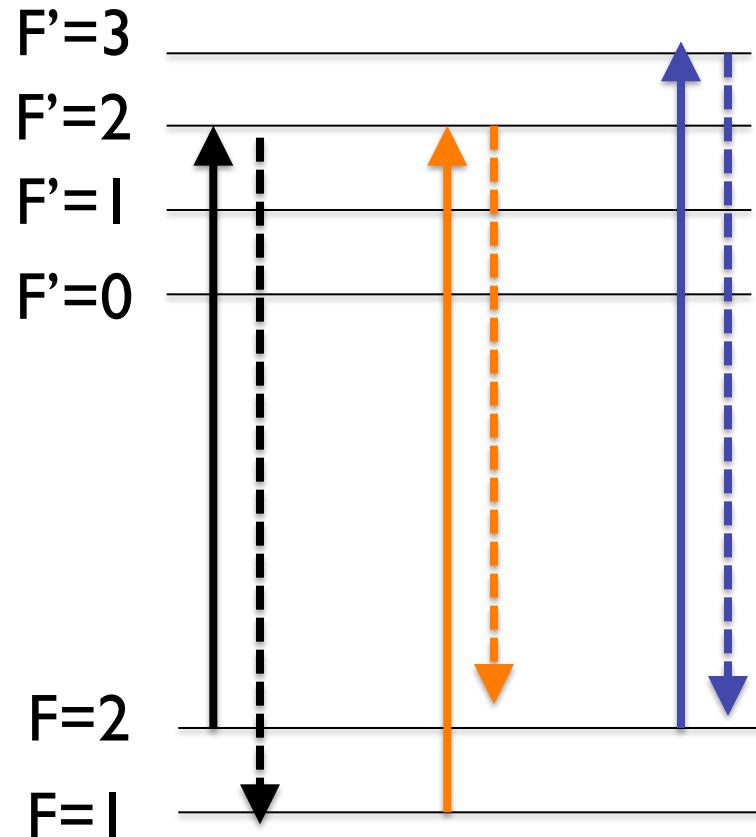
Medición de la vida media radiativa



Medición de la vida media radiativa

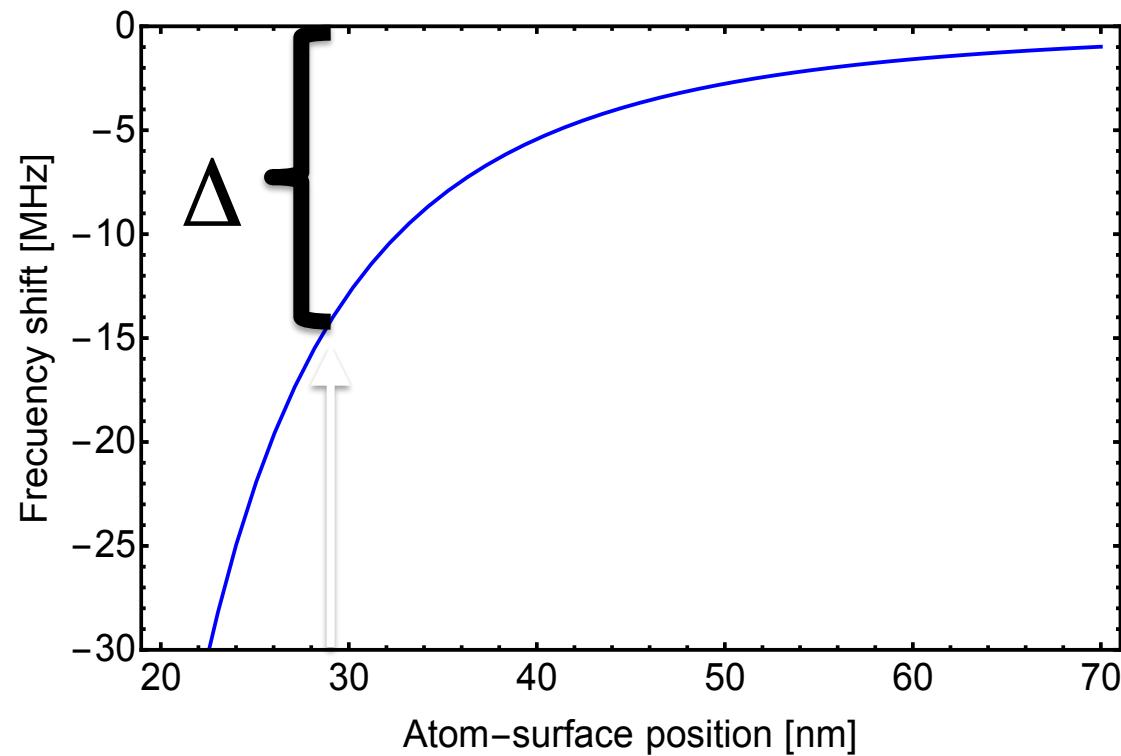
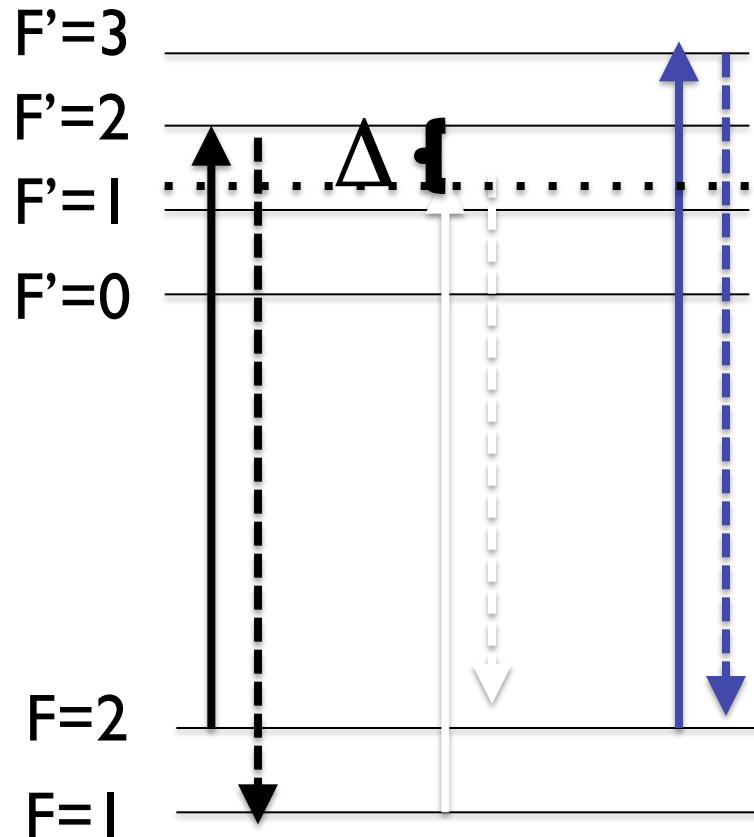


Preparación de los Átomos



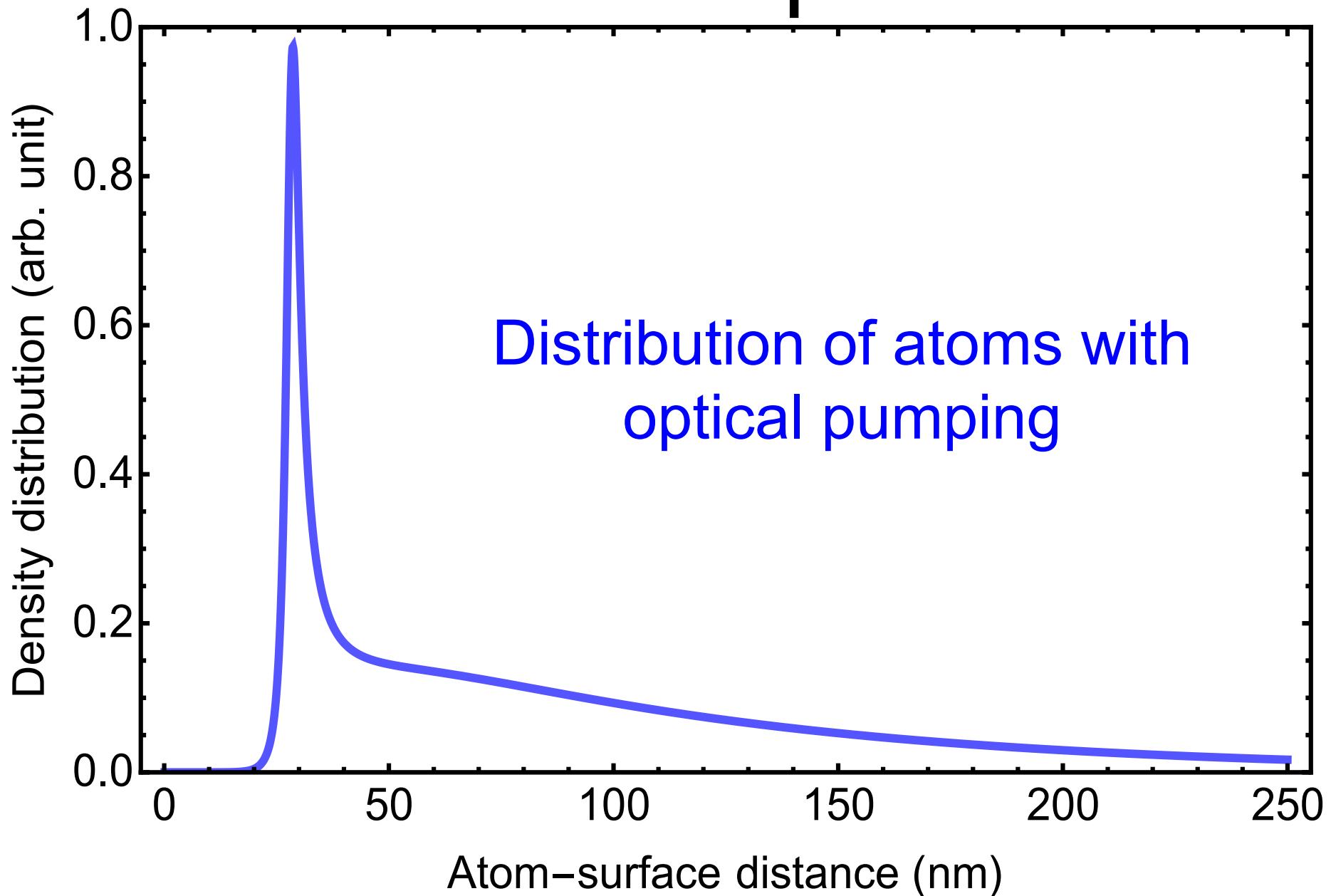
De-pump Re-pump Probe

Preparación de los Átomos

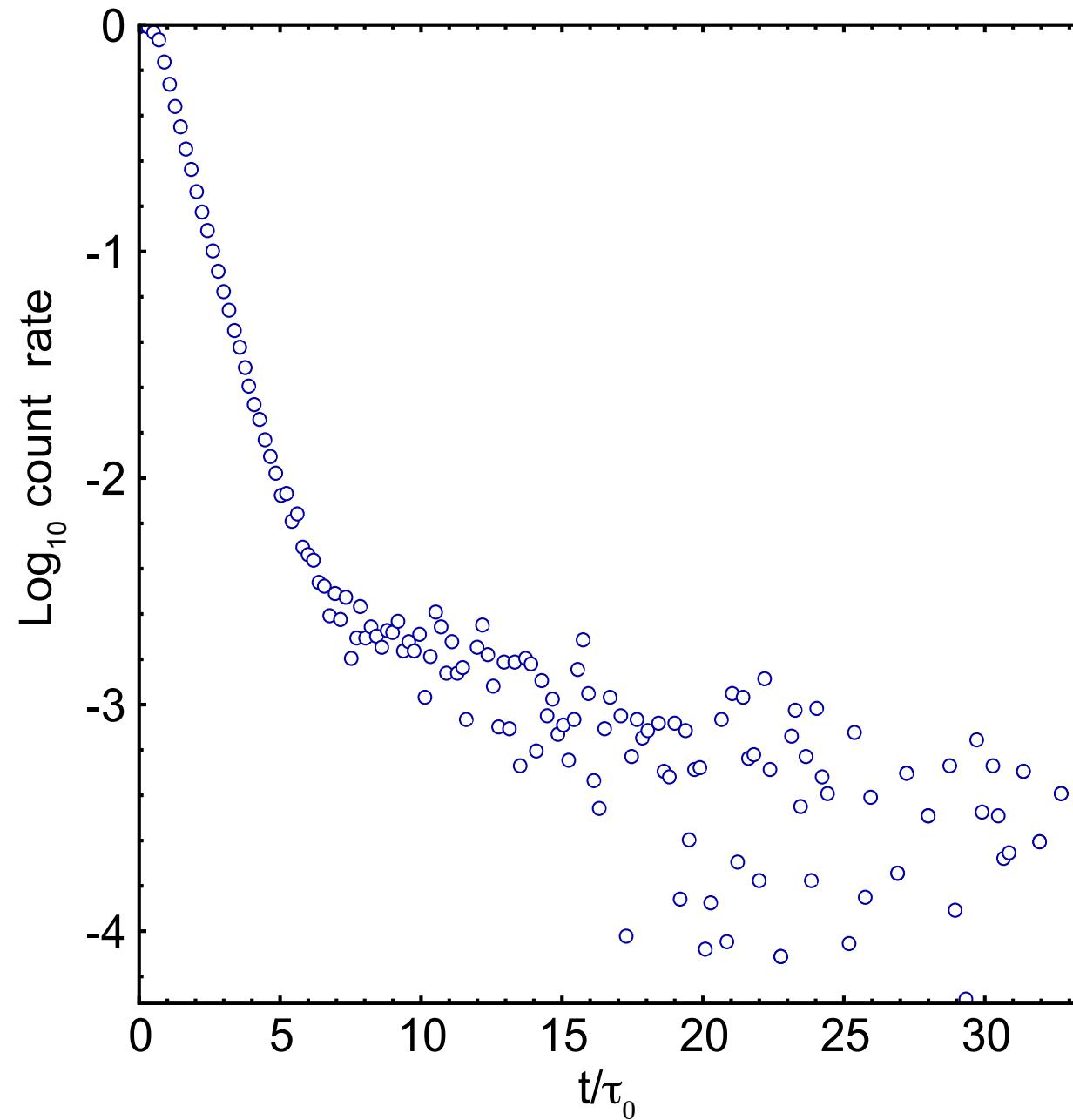


De-pump Re-pump Probe

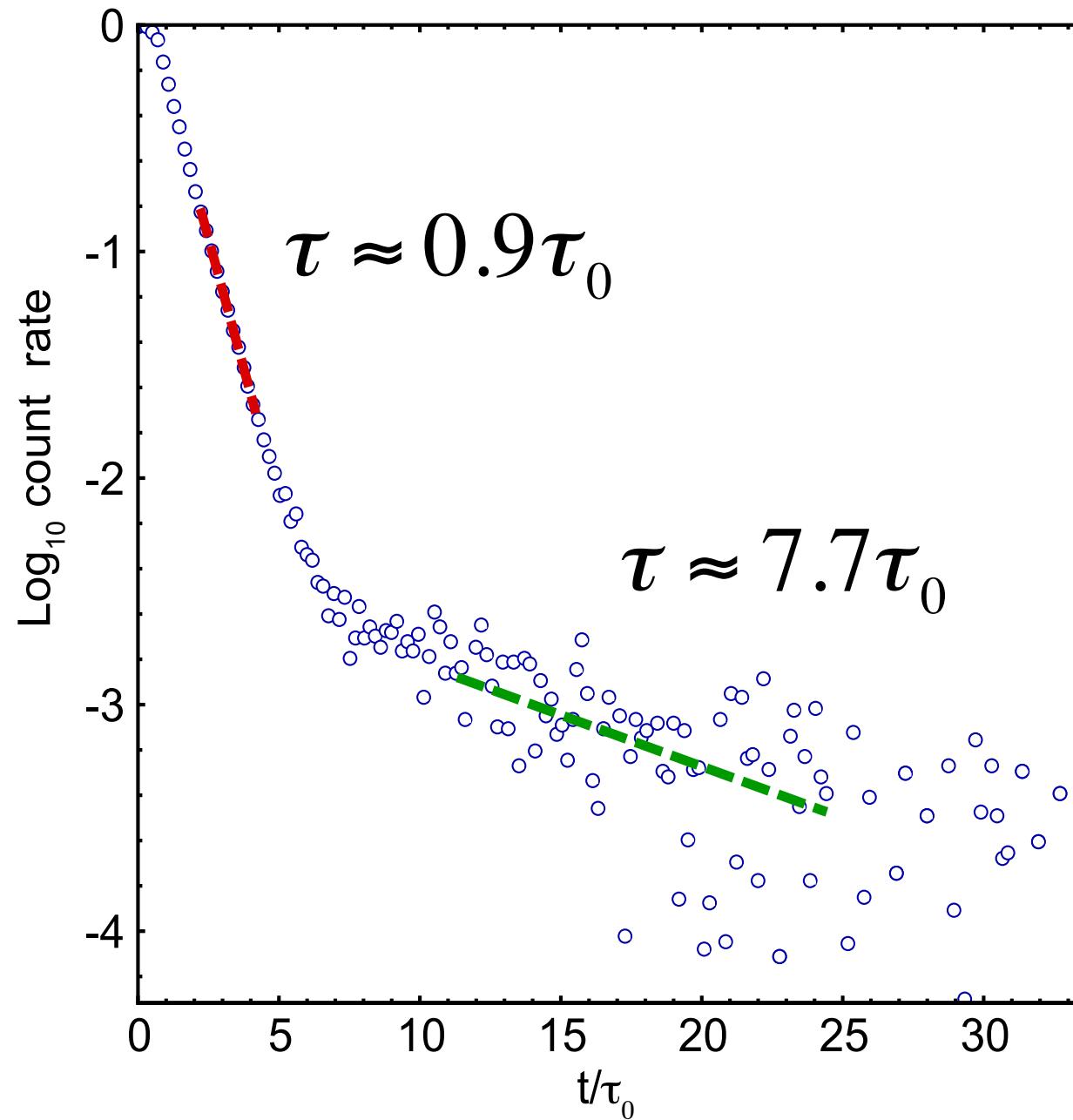
Distribución átomica con bombeo óptico



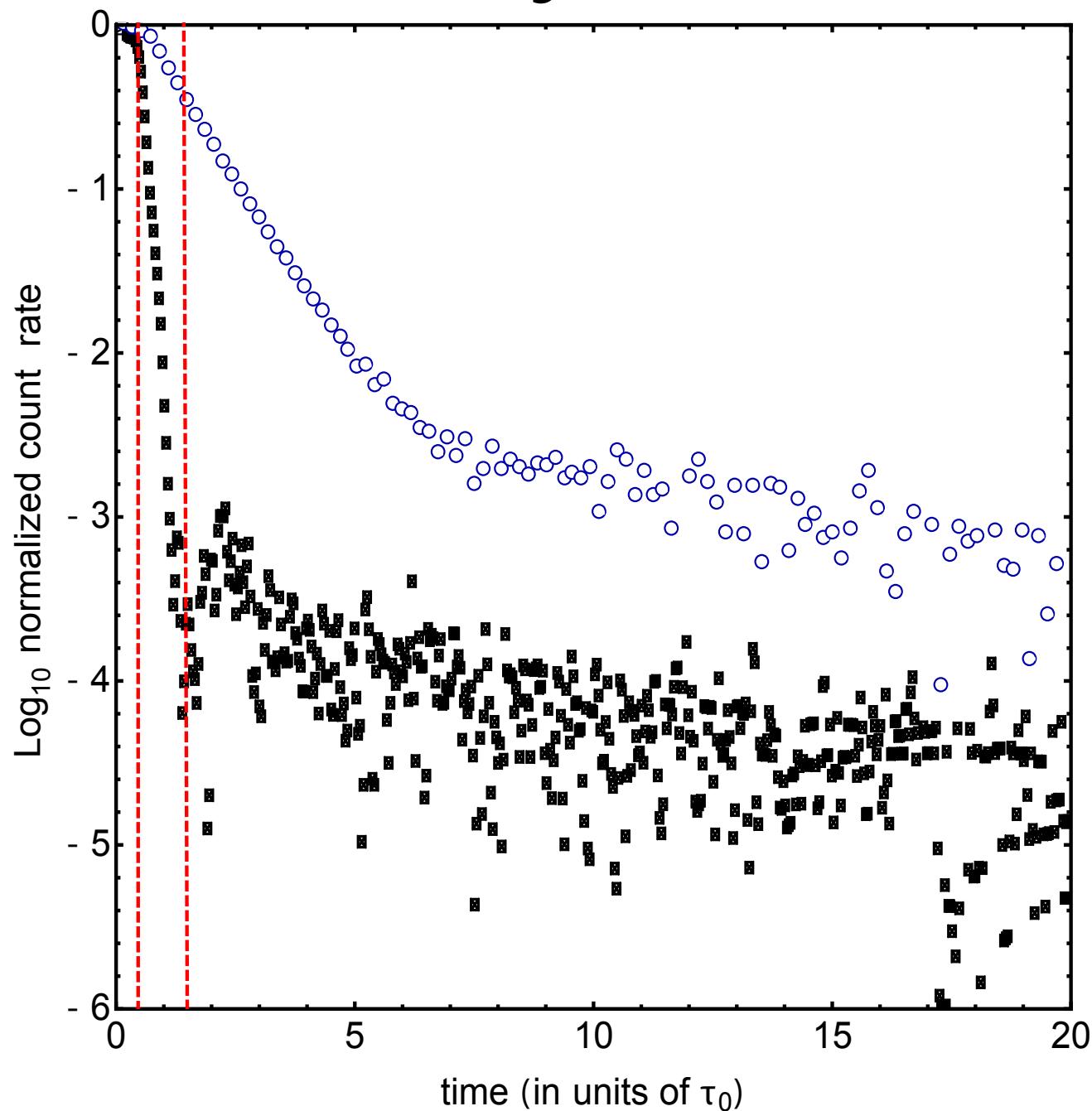
Dos vidas medias distintas



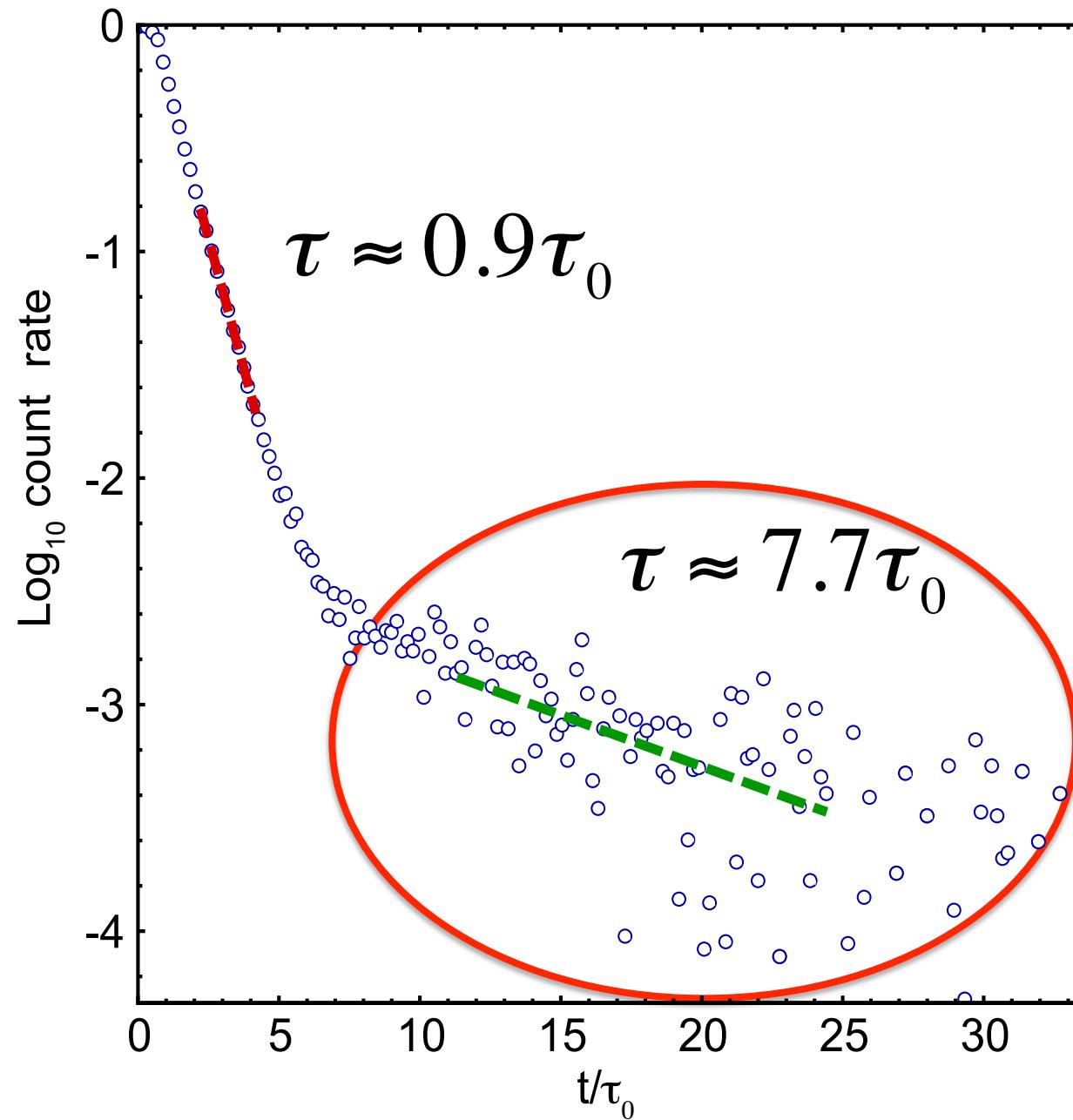
Dos vidas medias distintas



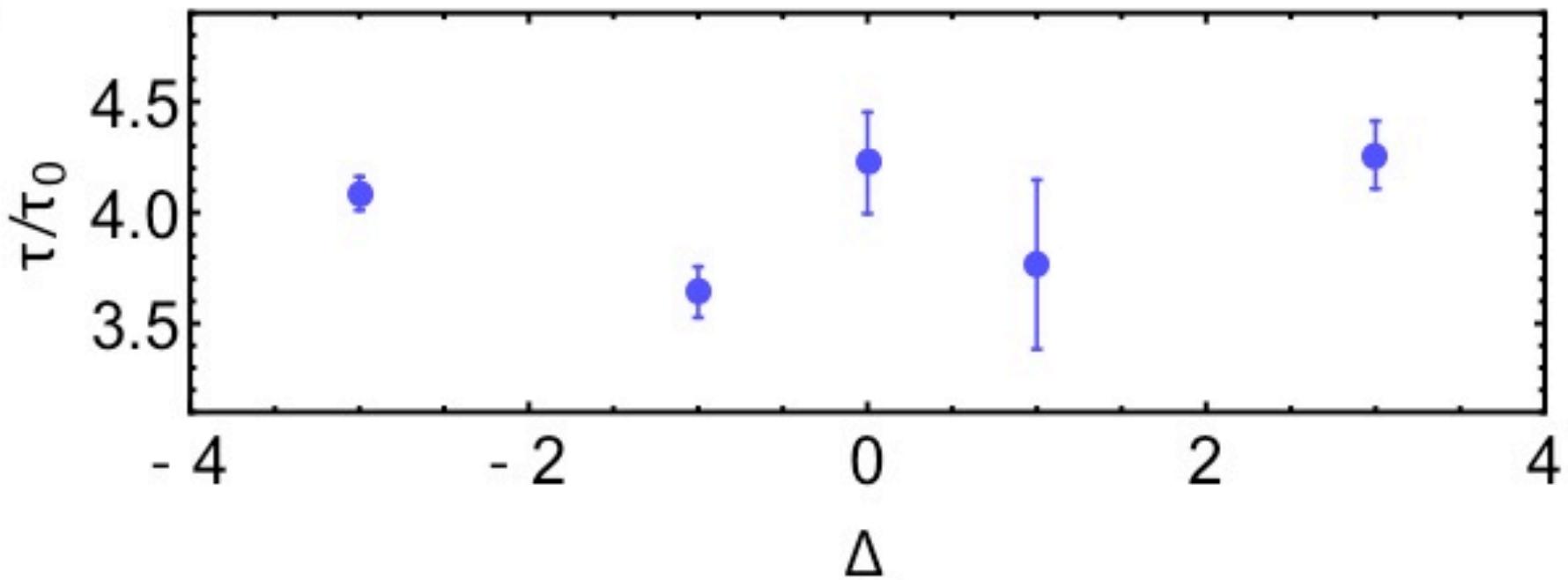
Pulso y señal



Dos vidas medias distintas

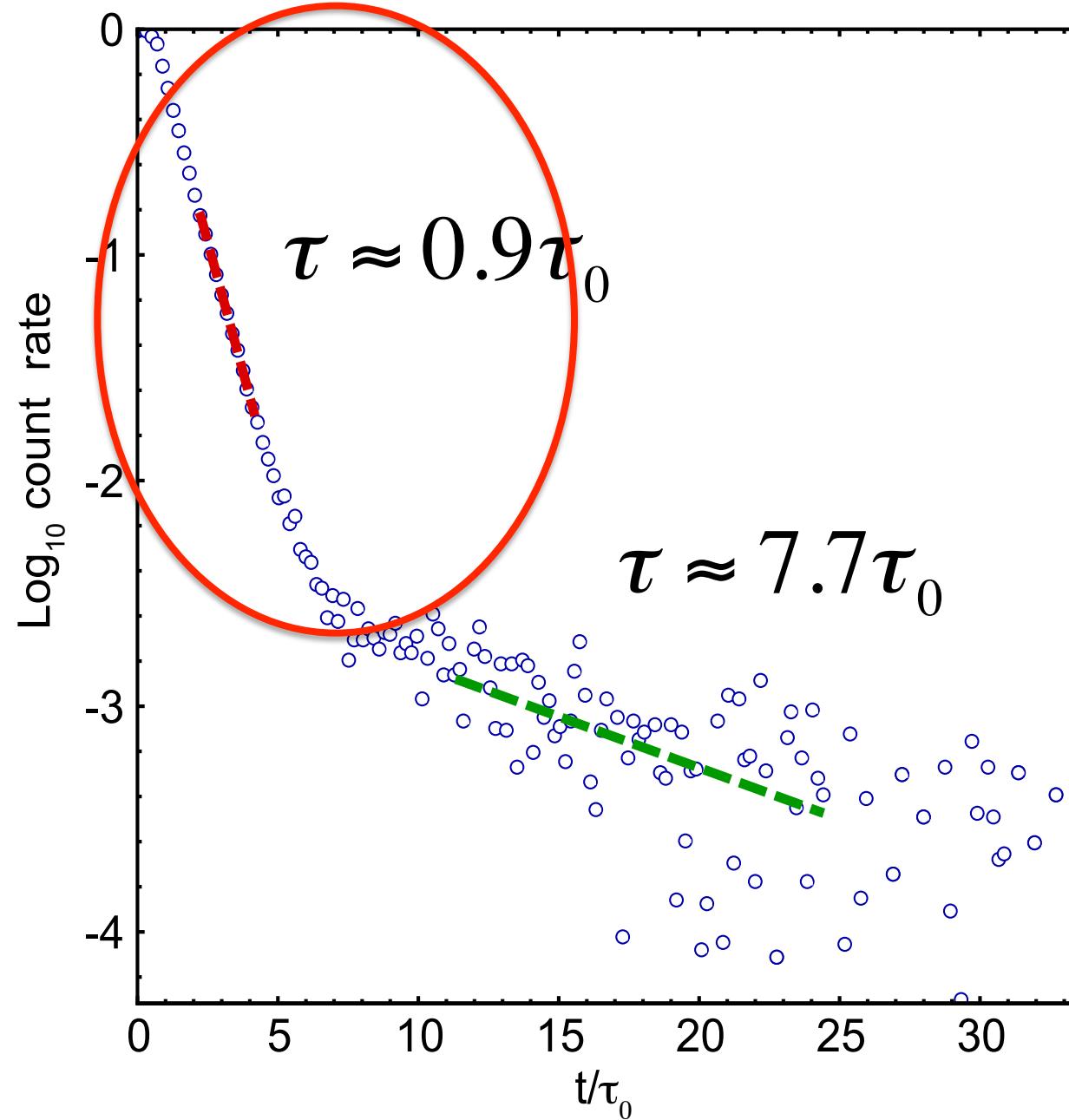


Tiempo de decaimiento vs desencaje atómico

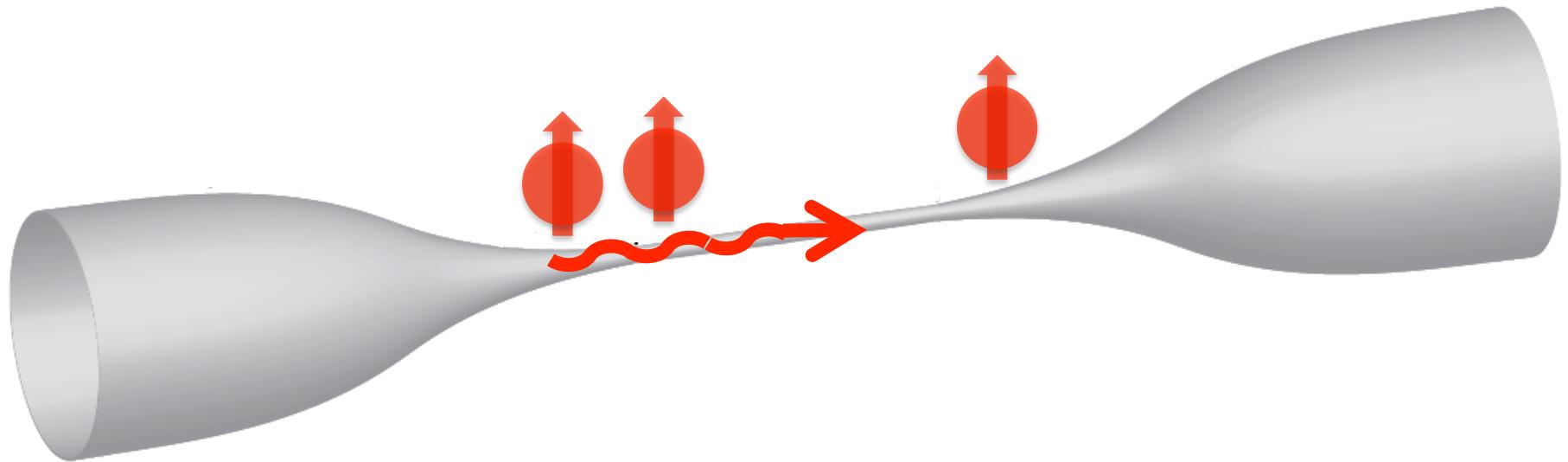


No hay atrapamiento de radiación para tiempos largos

Dos vidas medias distintas

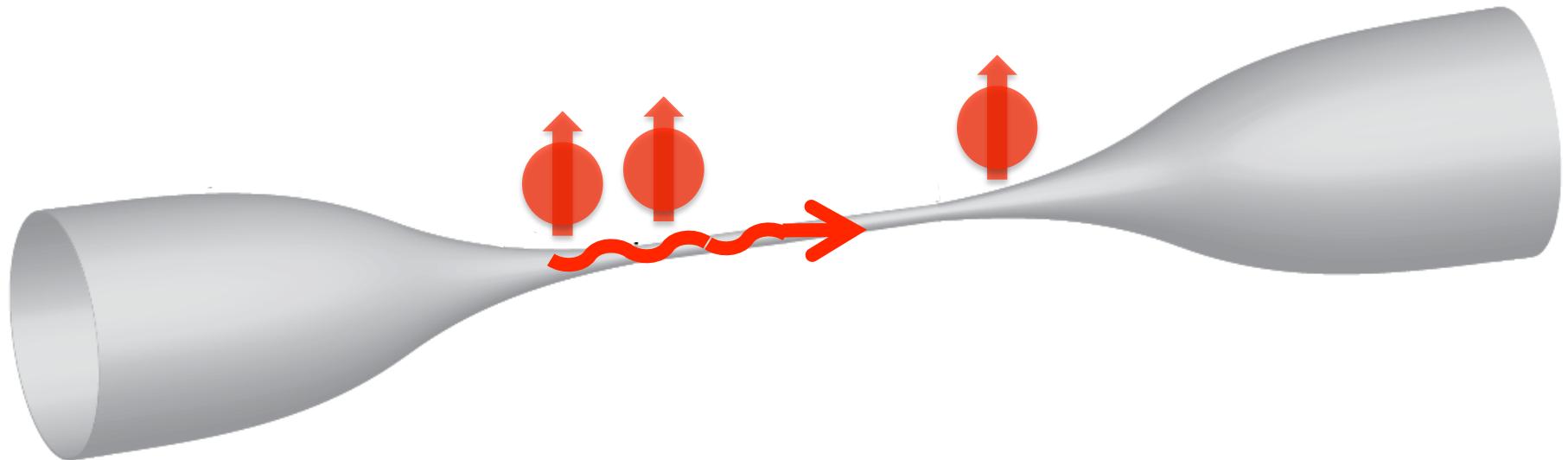


Dependencia de N



$$\gamma_{\text{sup}} = \gamma_{\text{rad}} + N\gamma_{1D}$$

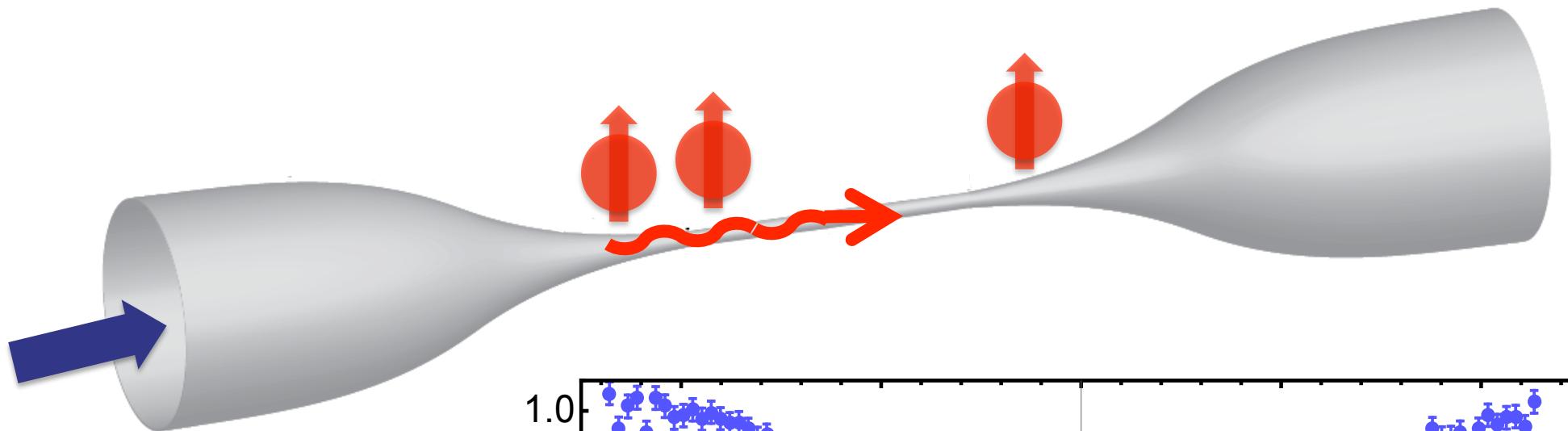
Dependencia de N



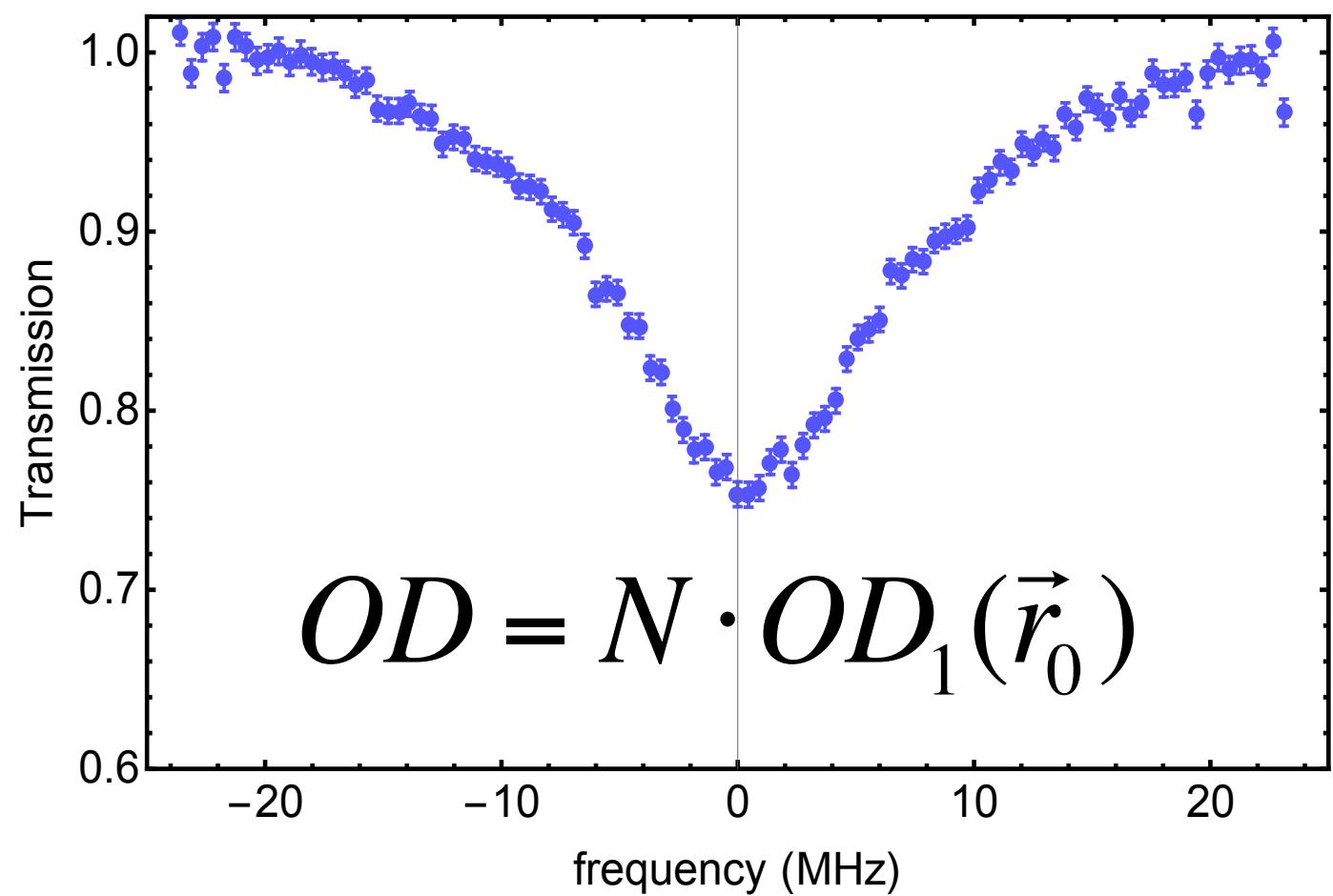
$$\gamma_{\text{sup}} = \gamma_{\text{rad}} + N\gamma_{1D}$$

La superradianza depende del número de átomos.

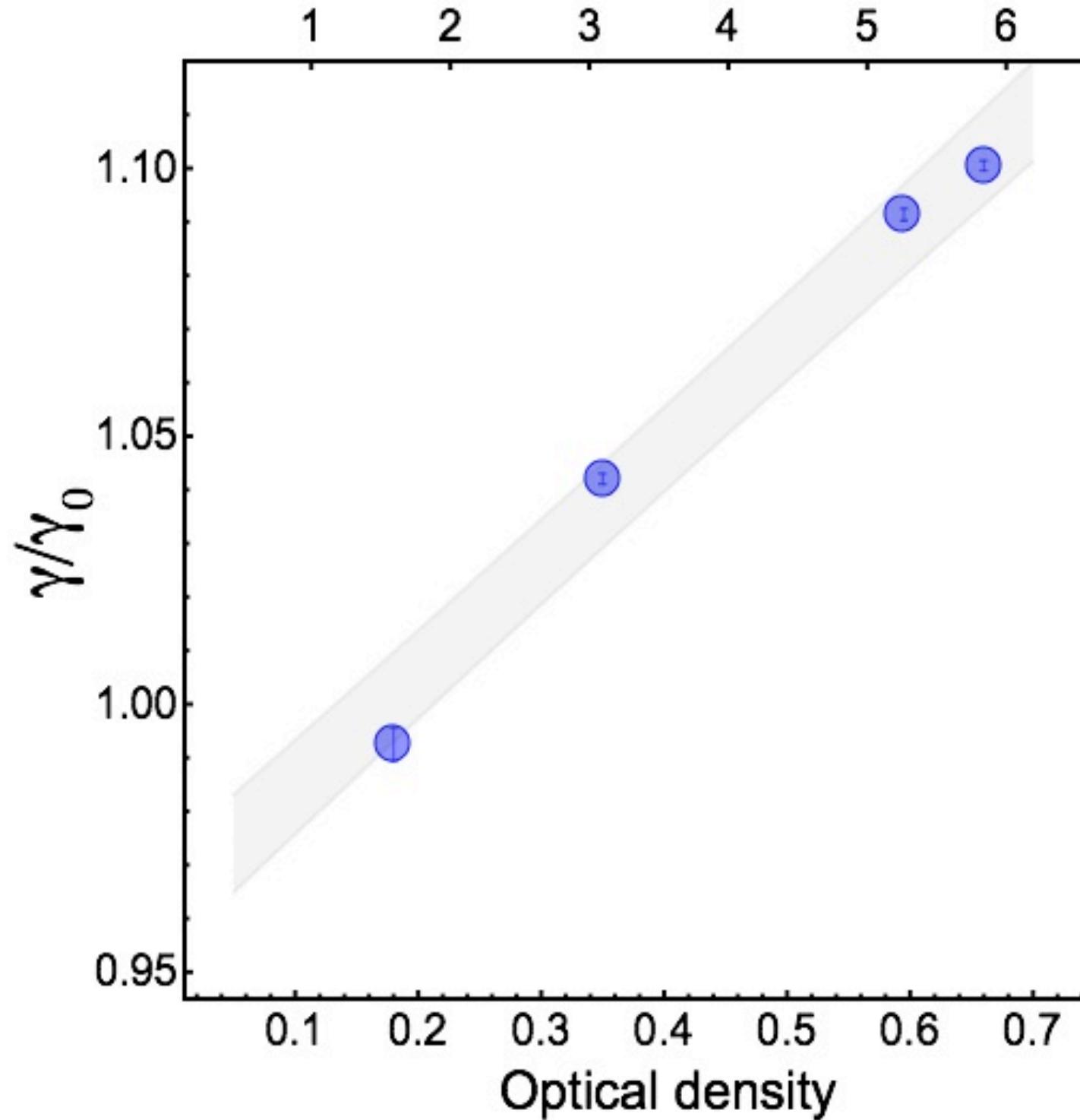
Medición de N



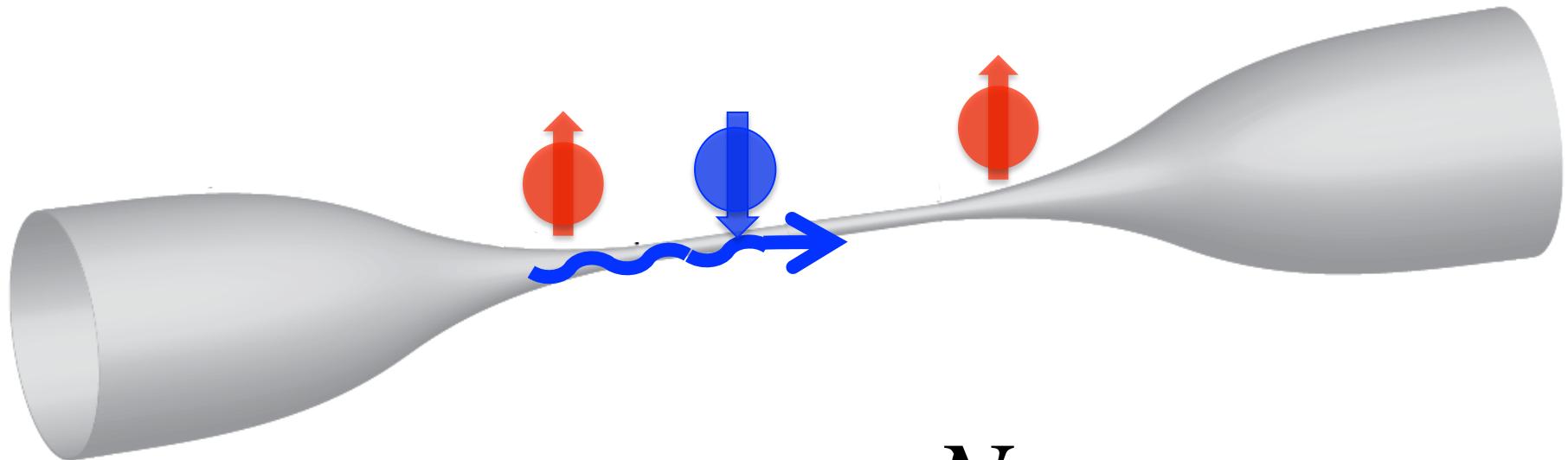
Probe



Average number of atoms

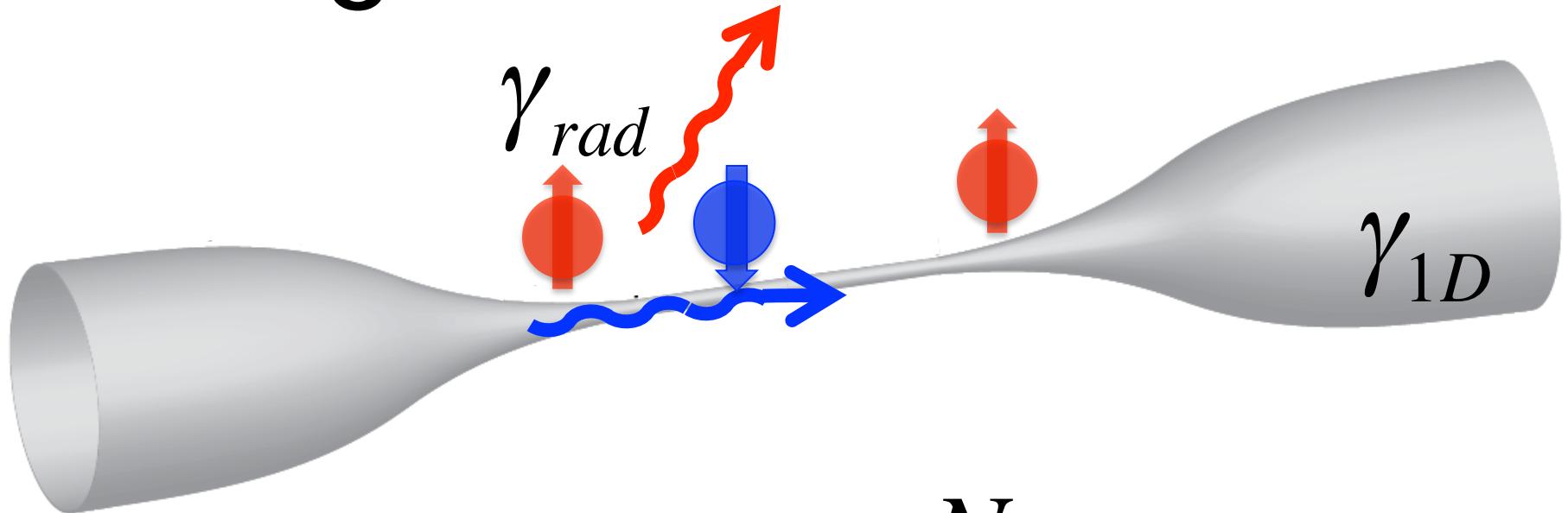


¿Sub-radianza?



$$\gamma_{\text{sup}} = \gamma_{\text{rad}} + N\gamma_{1D}$$

¿Sub-radianza?

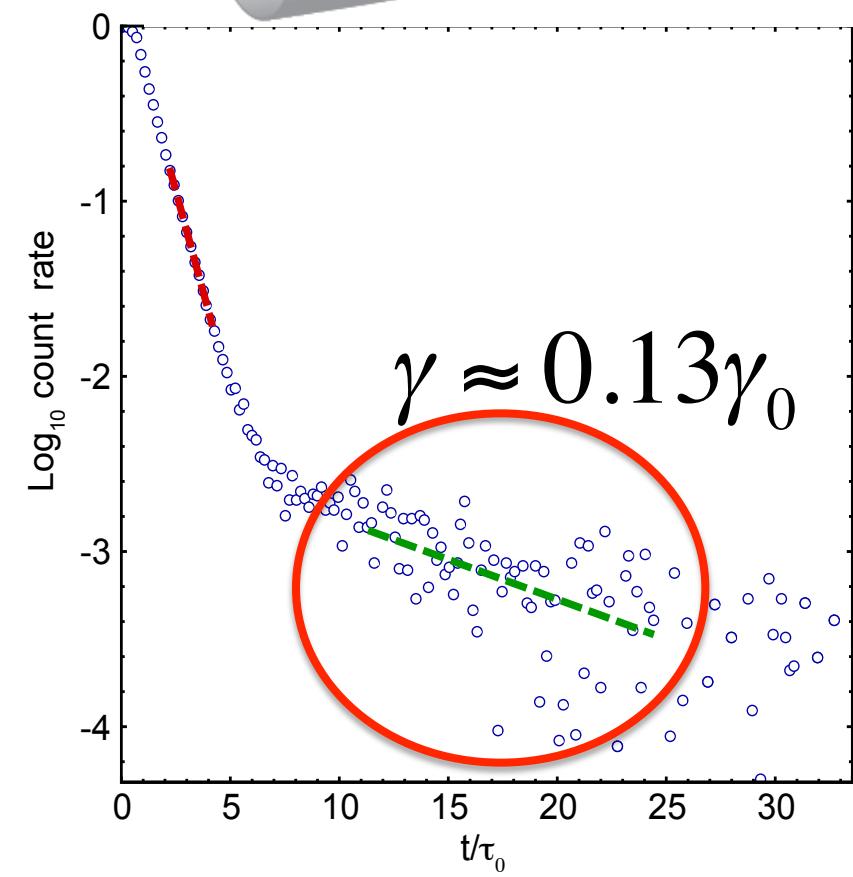
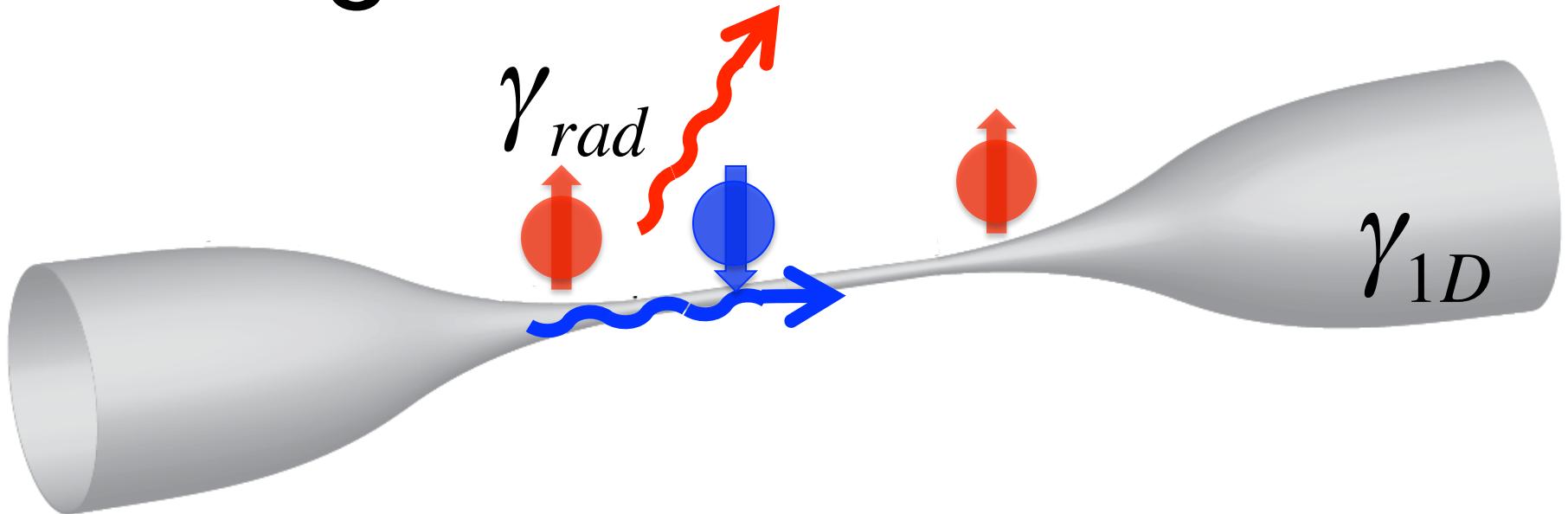


$$\gamma_{\text{sup}} = \gamma_{\text{rad}} + N\gamma_{1D}$$

$$\gamma_{\text{sub}} = \gamma_{\text{rad}} - \gamma_{1D}$$

La subradianza de rango infinito está limitada.

¿Sub-radianza?



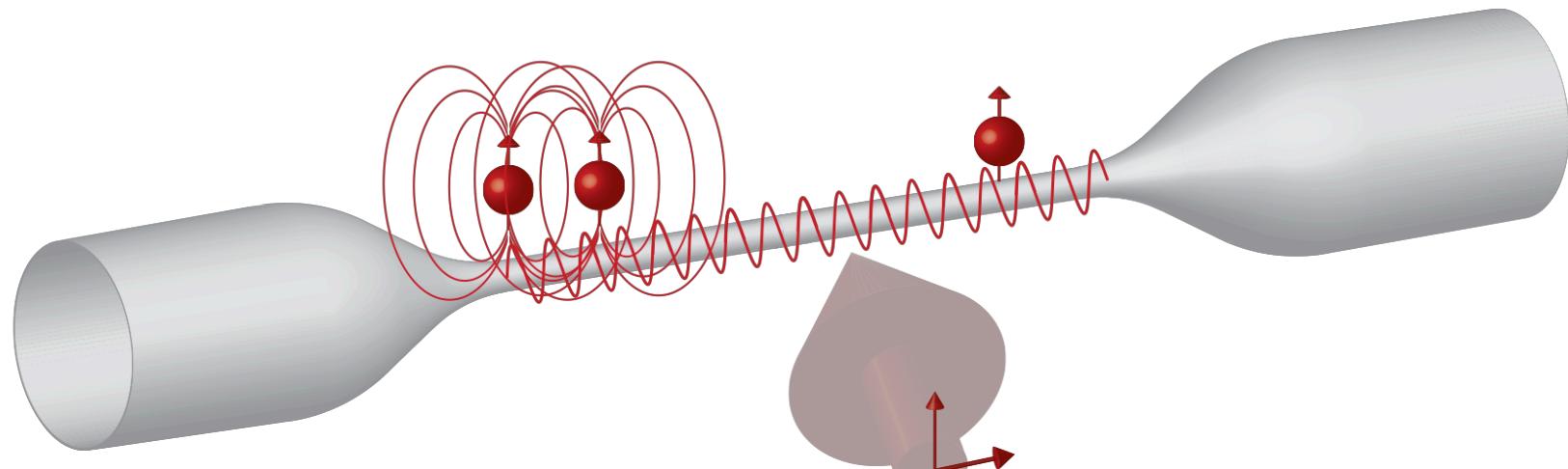
$$\gamma_{sub} = \gamma_{rad} - \gamma_{1D} \approx 0.9\gamma_0$$

La tasa de decaimiento medida es demasiado lenta.

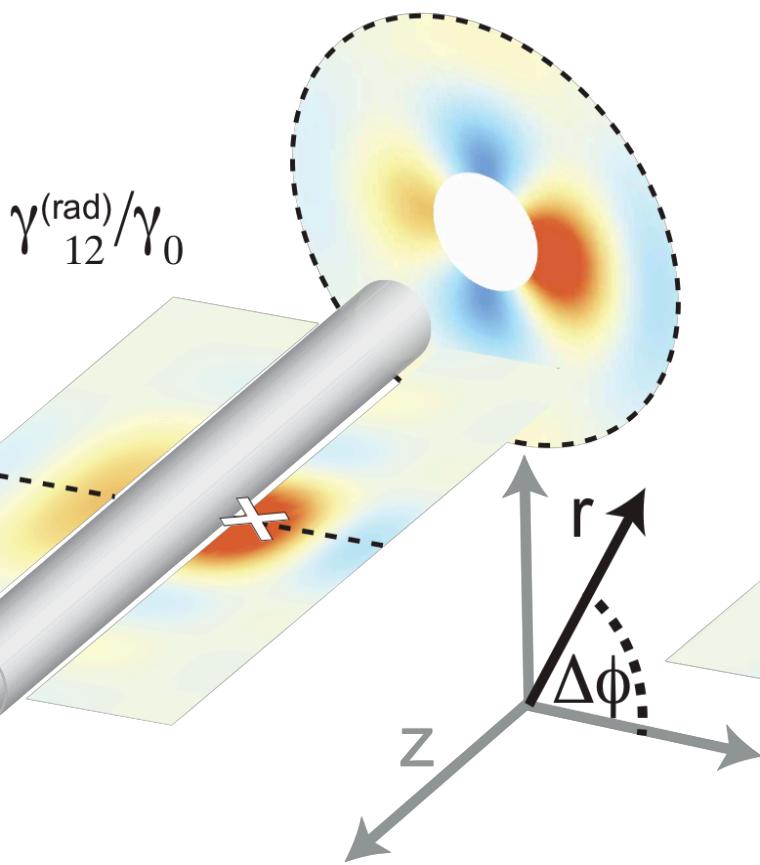
Entendiendo la señal

Entendiendo la Señal

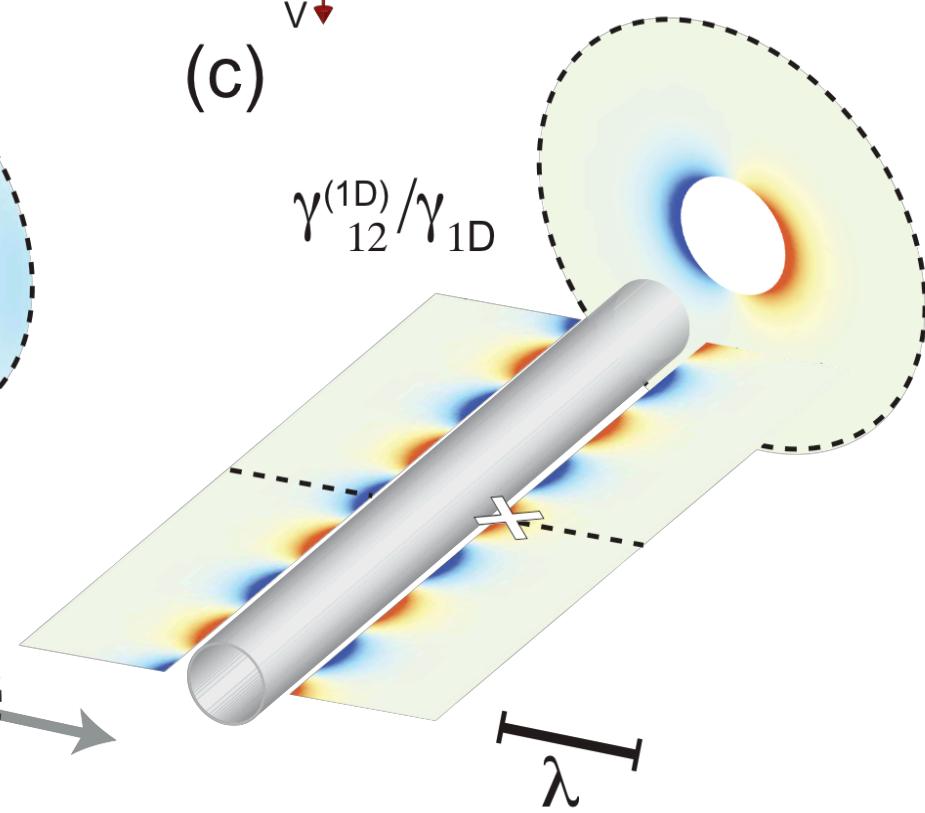
(a)



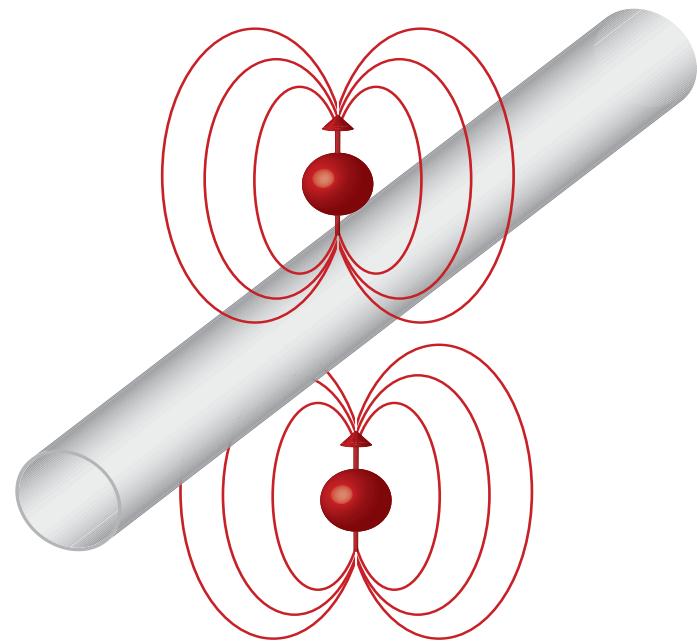
(b)



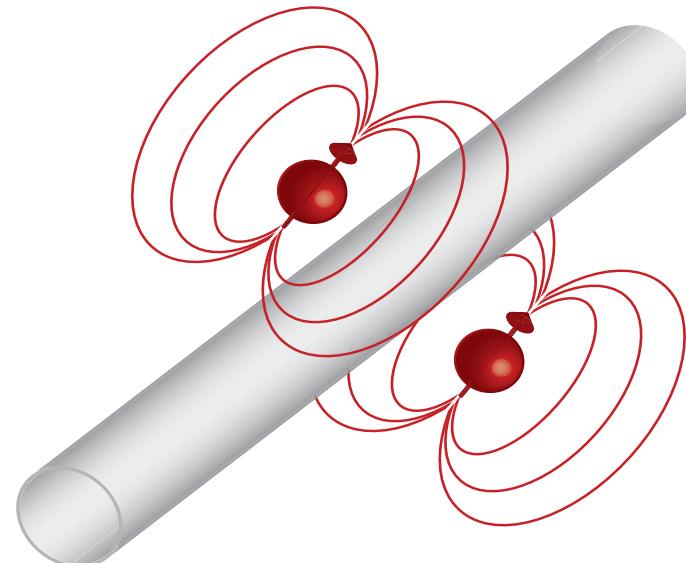
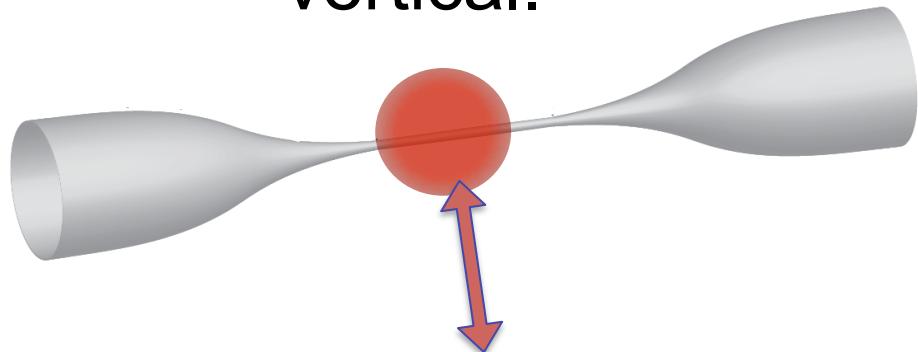
(c)



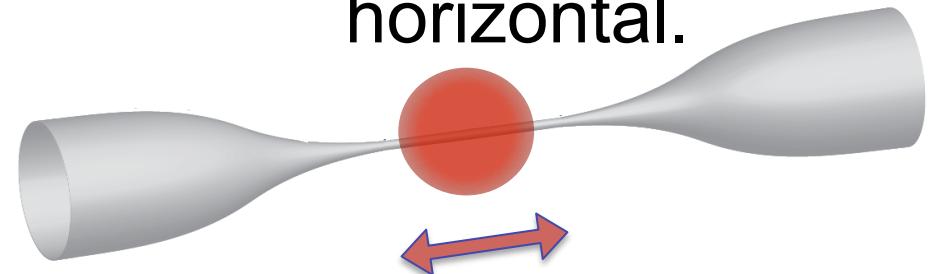
Dependencia de la señal en la polarización



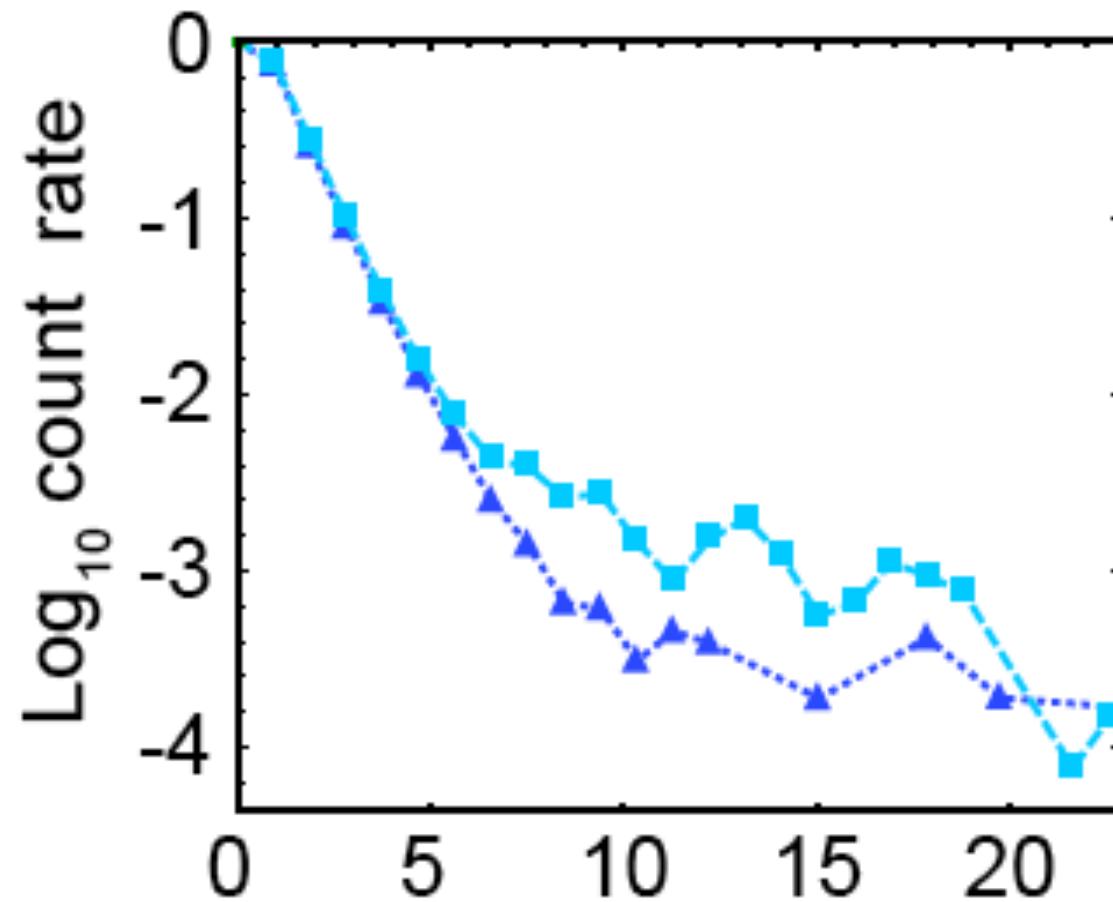
Sonda con polarización vertical.



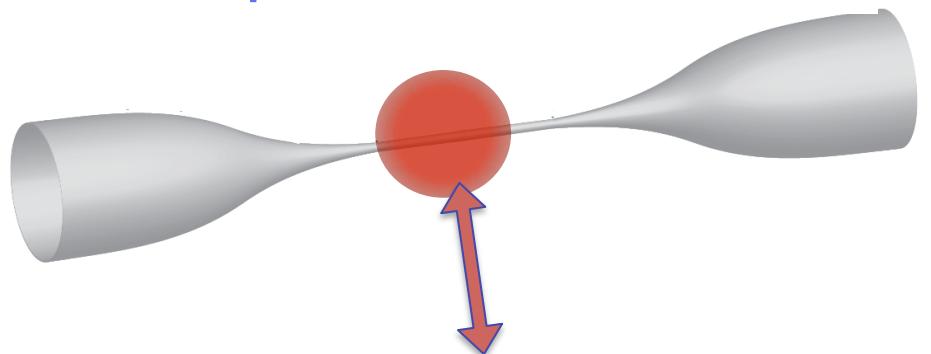
Sonda con polarización horizontal.



Señal dependiente de la polarización

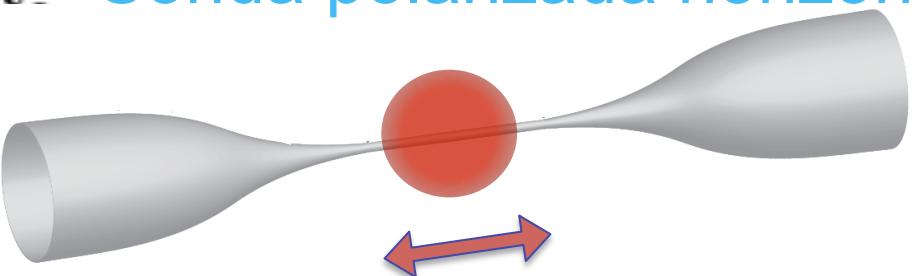


Sonda polarizada vertical

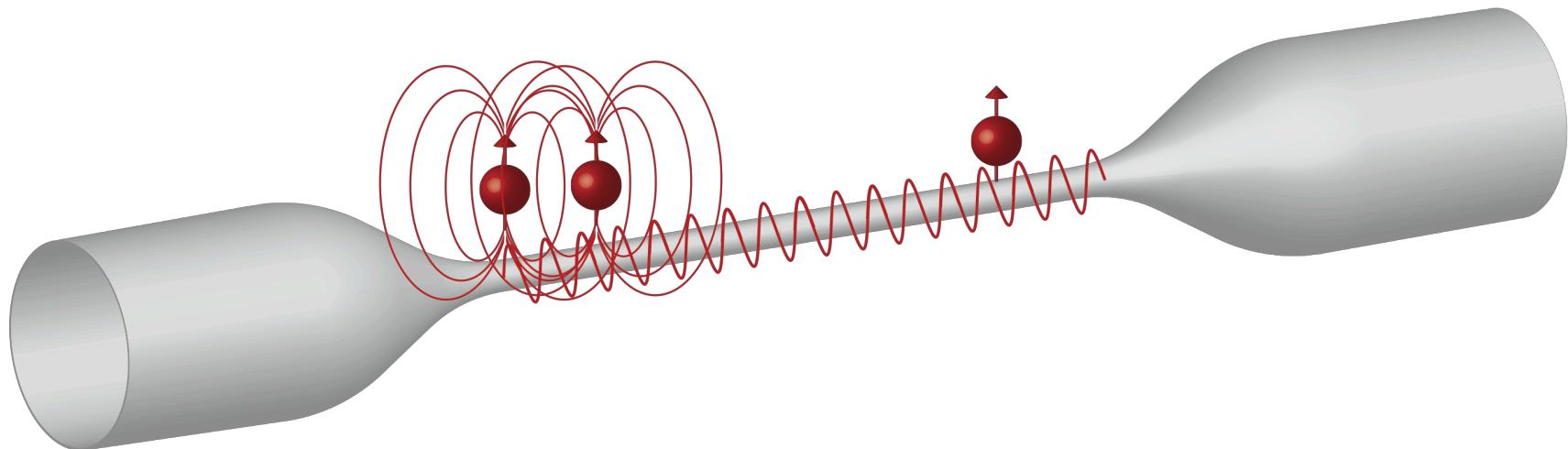


t/τ

Sonda polarizada horizontal



Señal Sub-radiante



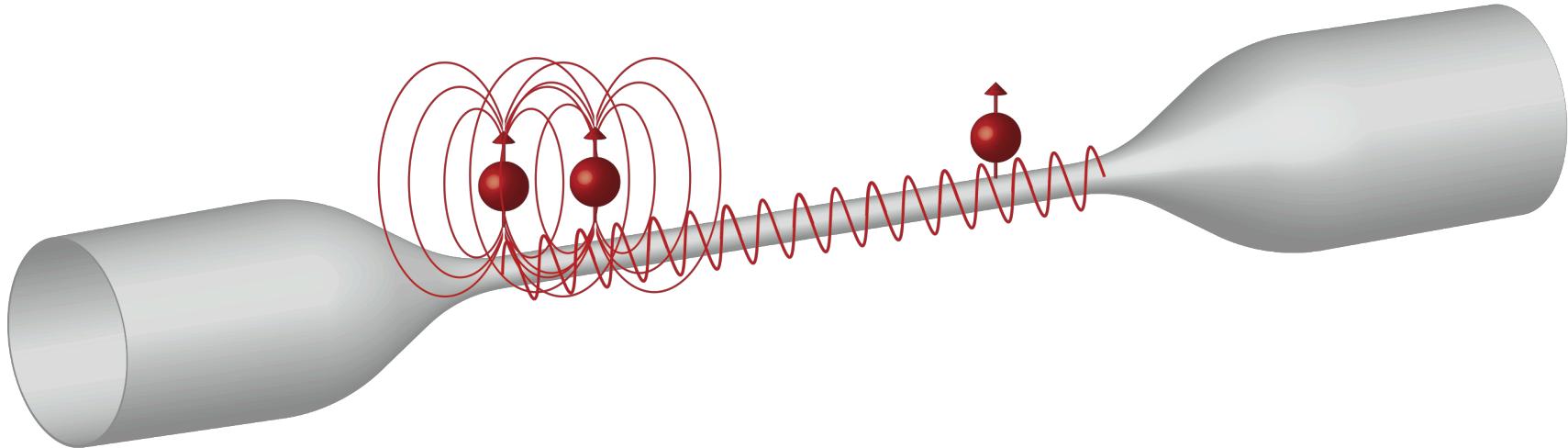
- Distancia de interacción menor a λ : todos los modos se cancelan.
- Distancia de interacción mayor a λ : solo un modo se cancela

$$\gamma_{sub} = \gamma_{rad} - \gamma_{1D} \approx 0.9\gamma_0$$

Medimos

$$\gamma_{sub} = 0.13\gamma_0$$

Señal Super-radiante



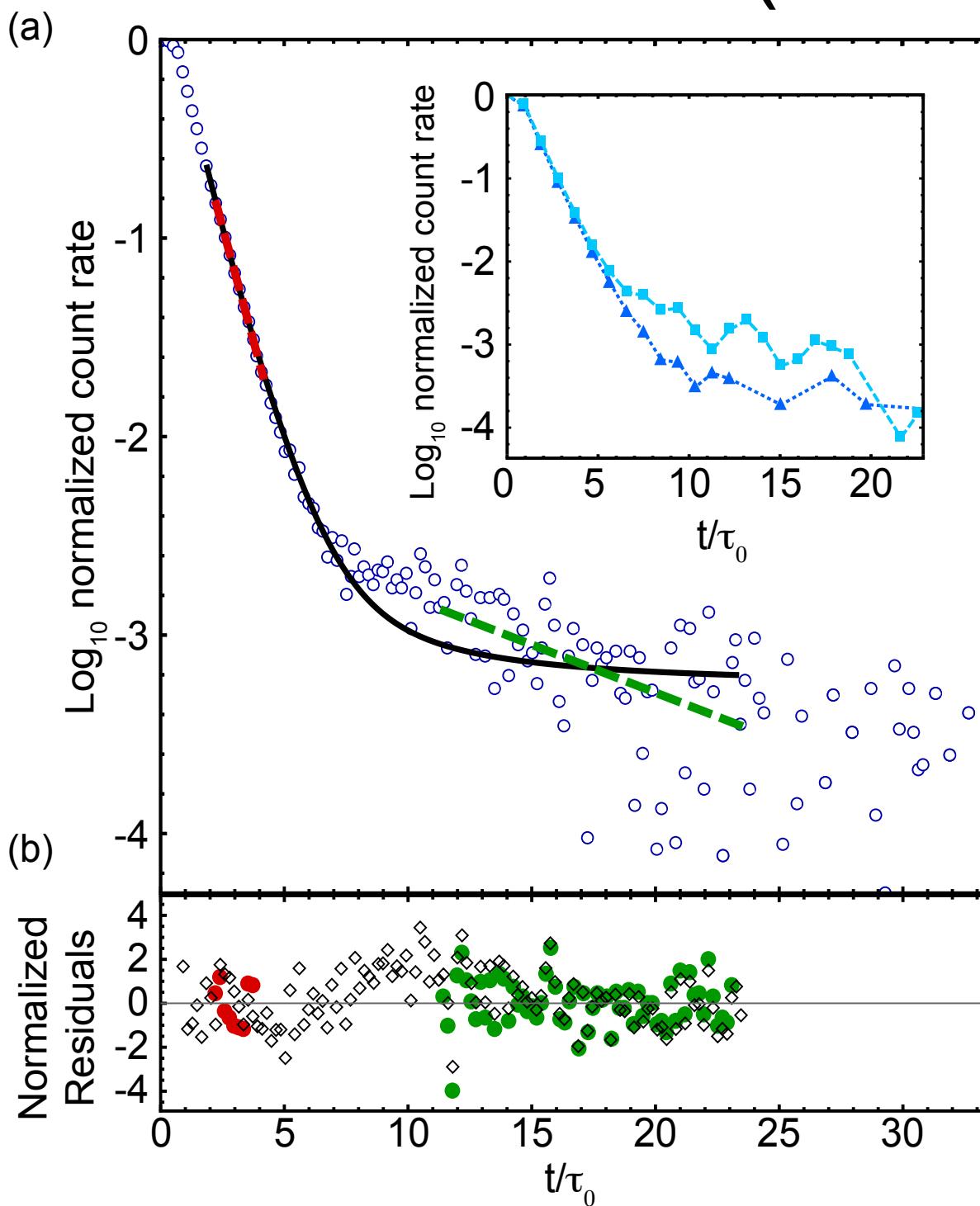
- Distancia de interacción menor a λ : todos los modos mejoran.
- Distancia de interacción mayor a λ : solo un modo se mejora

$$\gamma_{\text{sup}} = \gamma_{\text{rad}} + N\gamma_{1D}$$

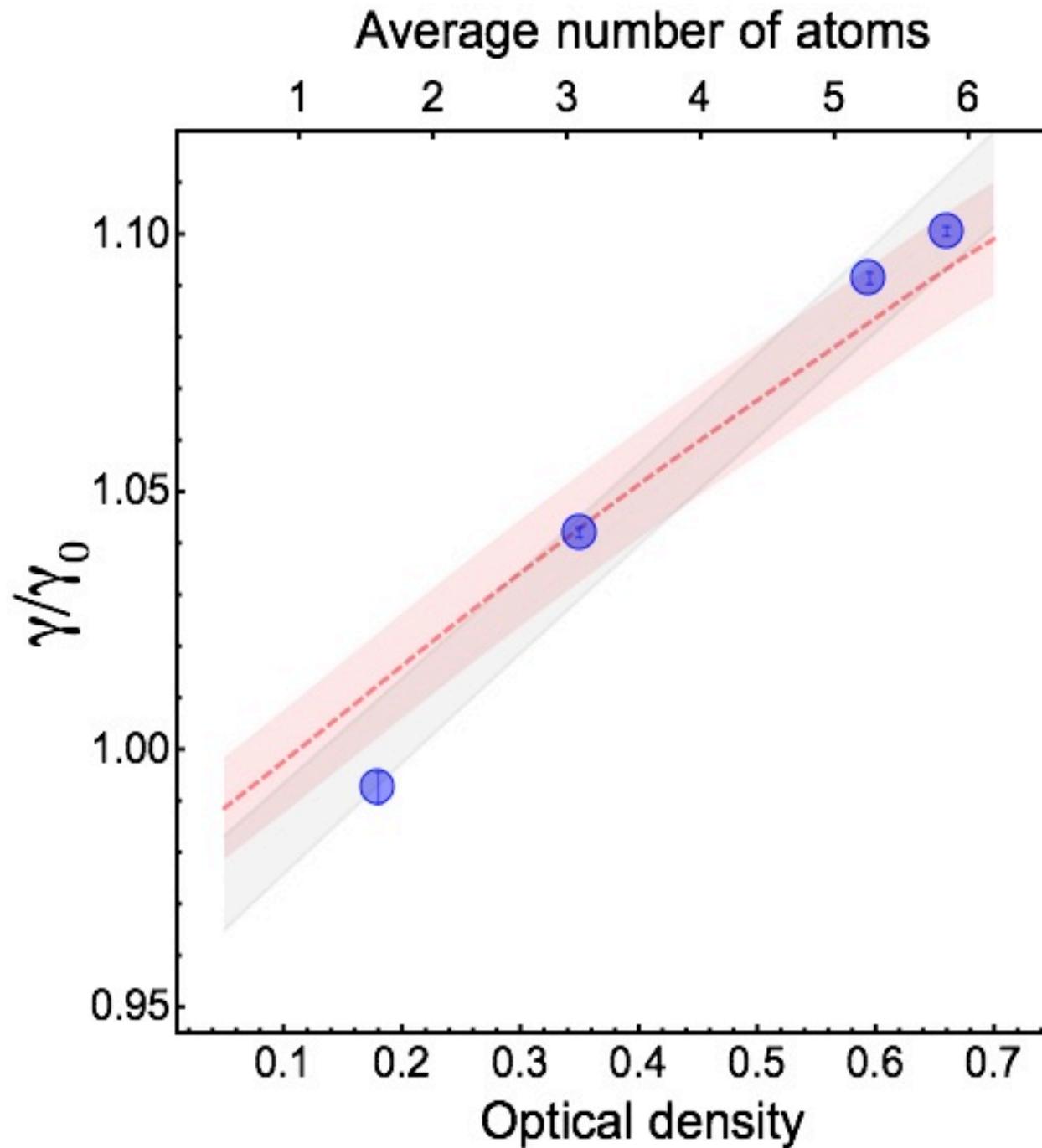
Medimos

$$\gamma_{\text{sup}} = 1.1\gamma_0$$

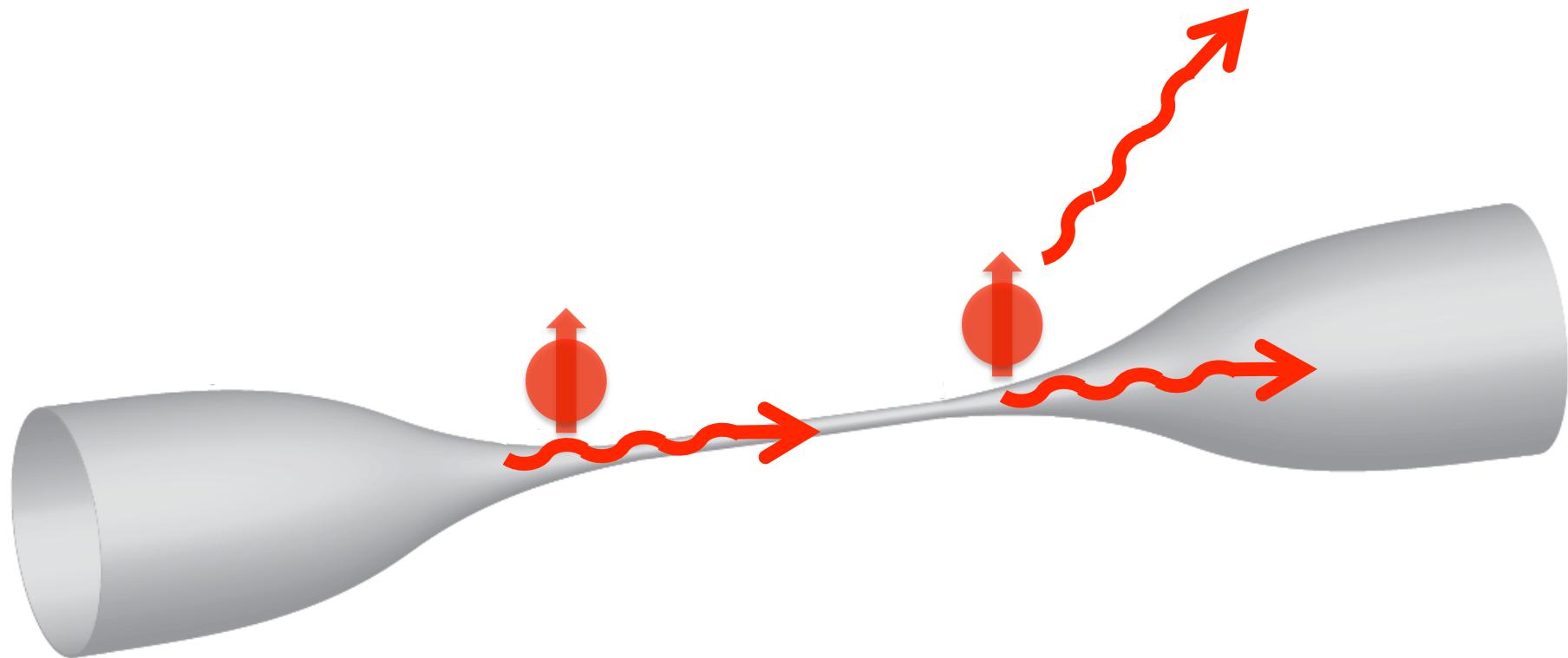
Ajuste de la simulación (Monte Carlo)



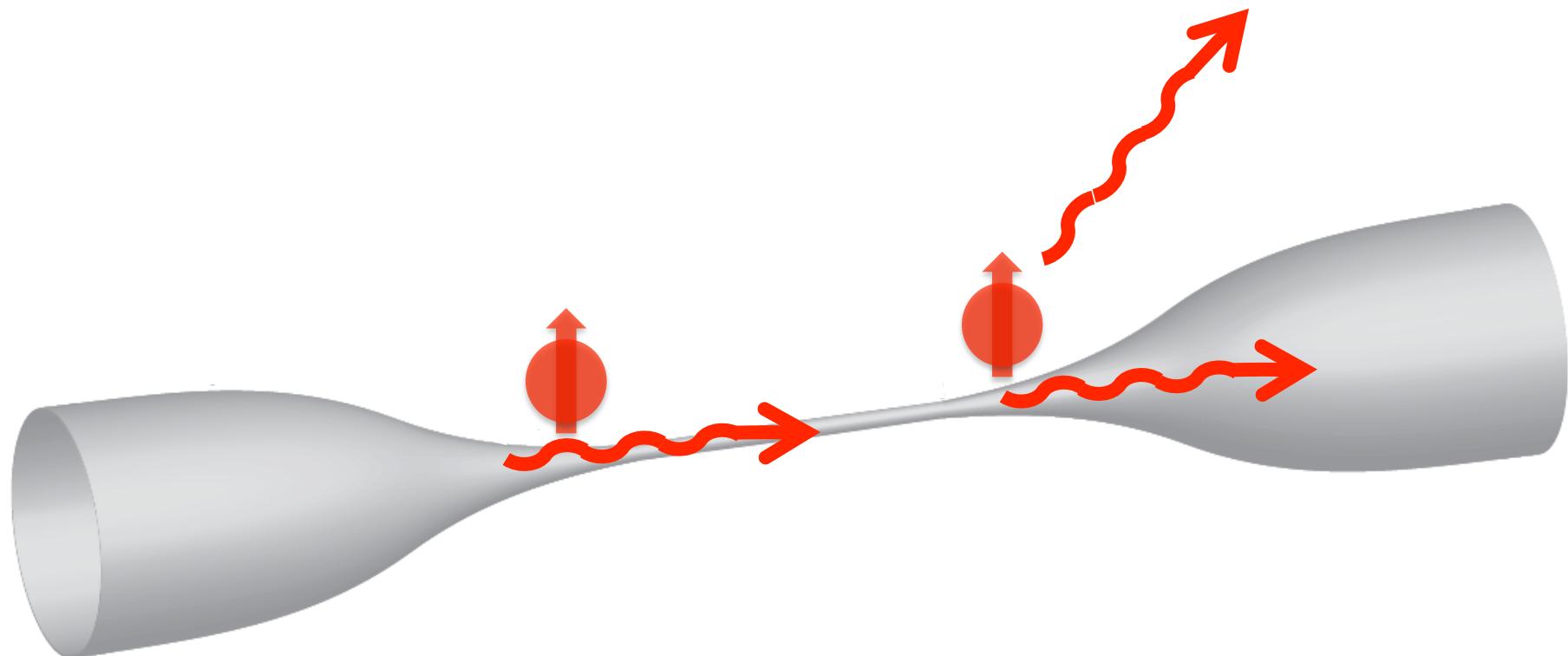
Ajuste de la simulación



Modificación a larga distancia del decaimiento atómico

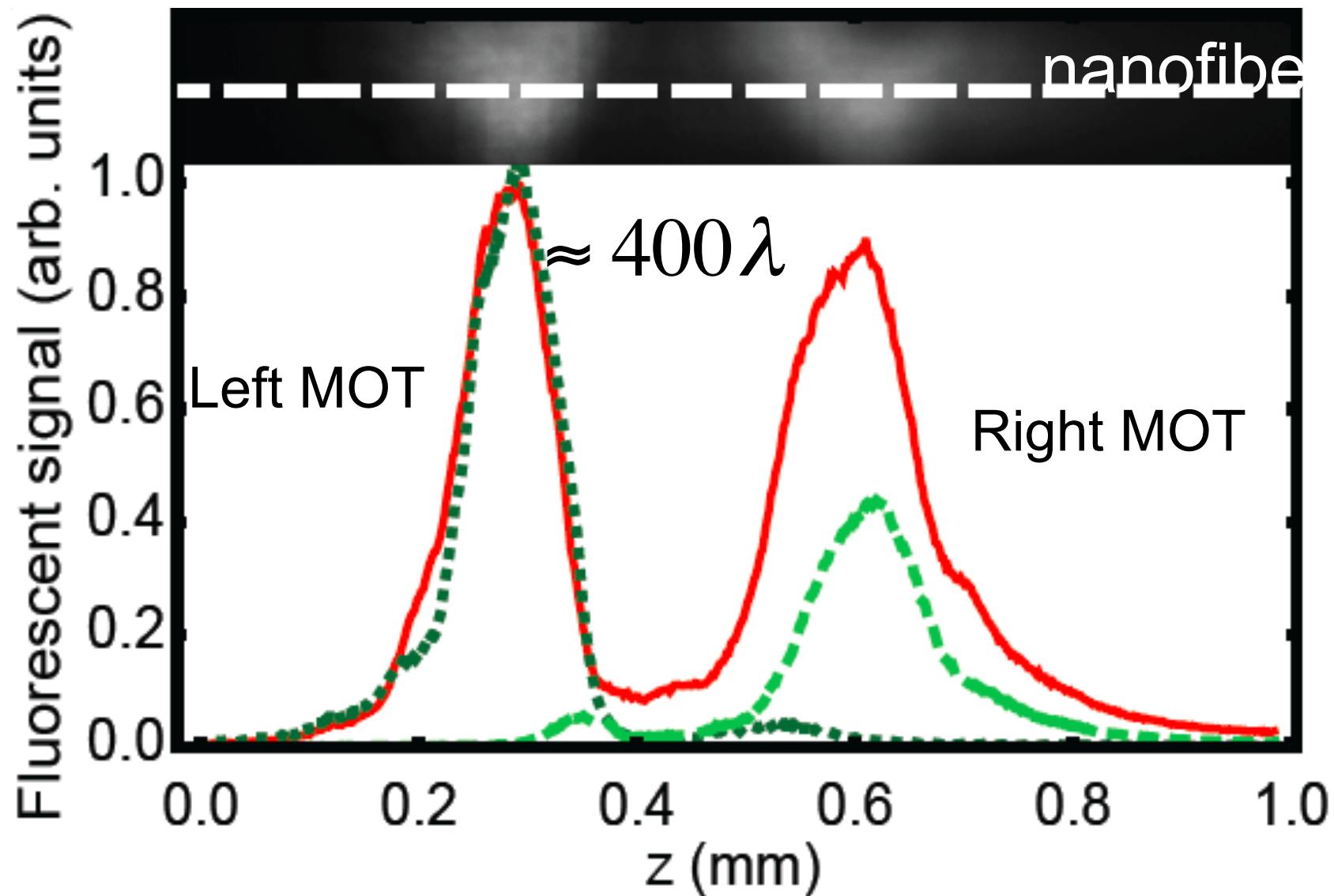


Modificación a larga distancia del decaimiento atómico

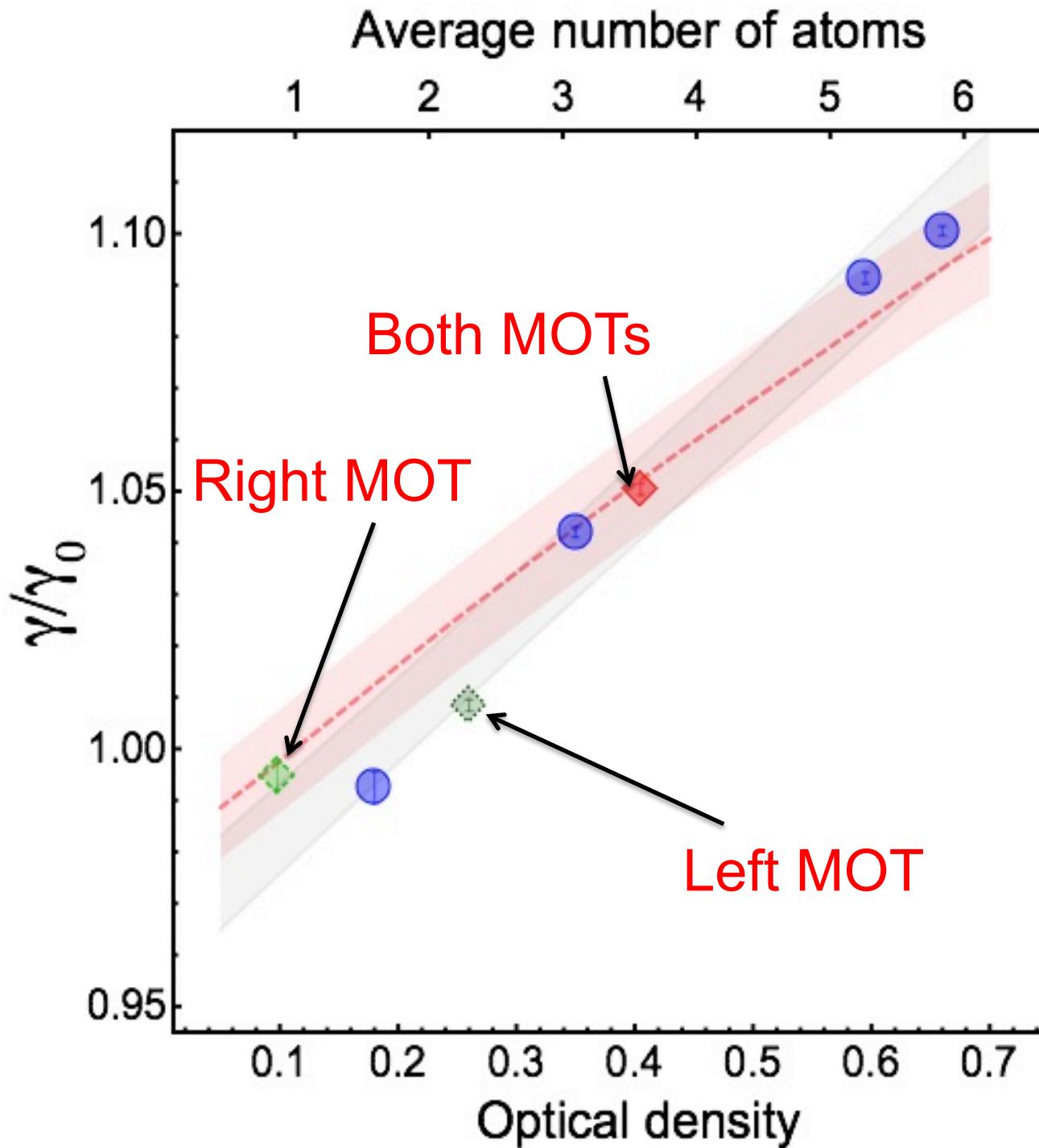


Tenemos densidades atómicas suficientemente bajas para observar interacciones de rango infinito.

Separando la trampa MOT en dos



Evidencia de interacciones de rango infinito



Bibliografía:

Peter Lodahl, Sahand Mahmoodian, and Søren Stobbe,
“Interfacing single photons and single quantum dots with
photonic nanostructures,” Rev. Mod. Phys. 87, 347 (2015).

P. Solano, J. A. Grover, J. E. Hoffman, S. Ravets, F. K. Fatemi,
L. A. Orozco, and S. L. Rolston “Optical Nanofibers: A New
Platform for Quantum Optics.” Advances in Atomic Molecular
and Optical Physics, Vol. 46, 355-403, Edited by E. Arimondo,
C. C. Lin, and S. F. Yelin, Academic Press, Burlington 2017.

Slides at:

<http://www.physics.umd.edu/rgroups/amo/orozco/results/2019/Results19.htm>

Merci