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Interaction of two Rydberg rubidium atoms in the vicinity of an optical nanofiber

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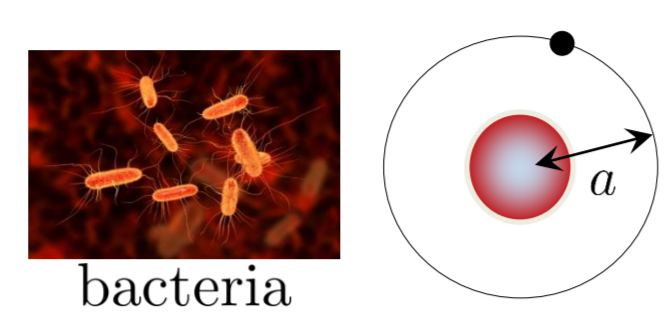
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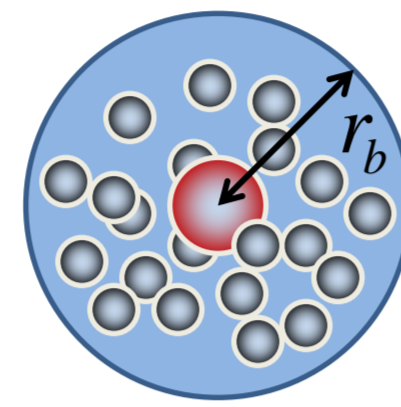
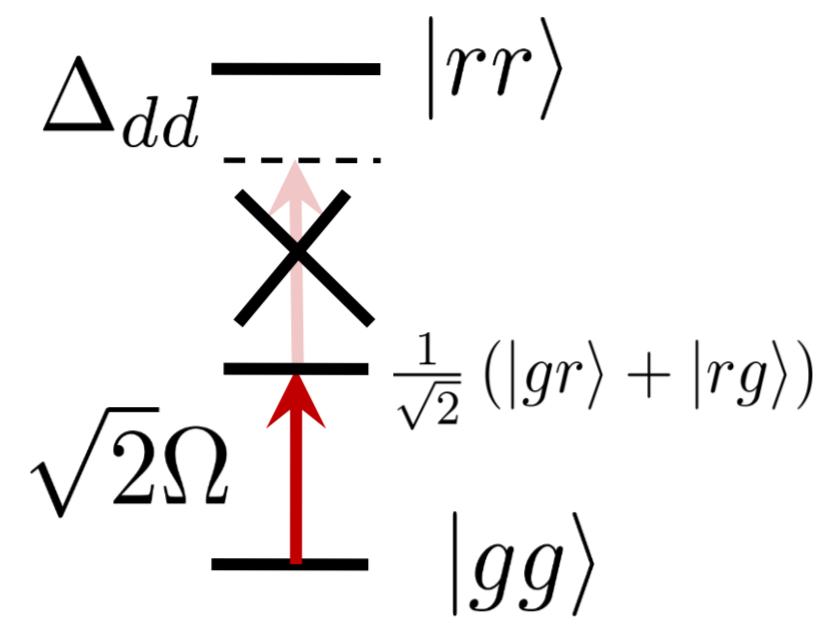
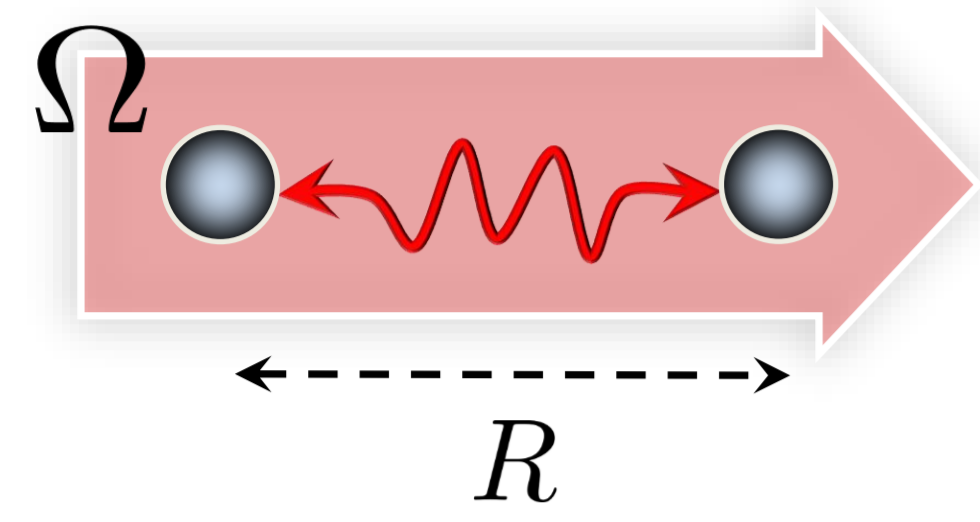
RYDBERG atoms and RYDBERG blockade

RYDBERG state – $n \geq 30$
radiative lifetime – n^5
dipole matrix elements – n^2
 $\Delta_{dd} \approx \frac{C_6}{r^6}$, $C_6 \sim n^{11}$



rubidium
 $n \approx 50$
 $\tau_r \approx 50 \mu\text{s}$
 $a \approx 1 \mu\text{m}$

rubidium
for $n \approx 60$
and $R \approx 4 \mu\text{m}$,
 $\Delta_{dd} \approx 10 \text{MHz}$

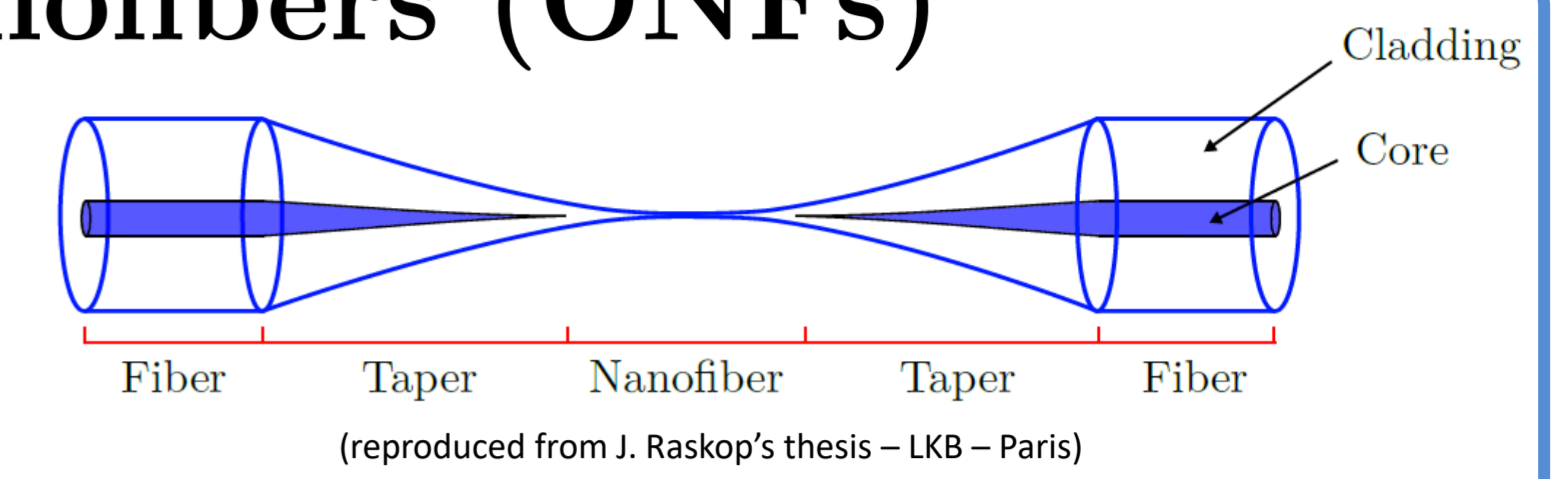


Within the blockade sphere dipole-dipole interactions allow for the existence of only one excitation

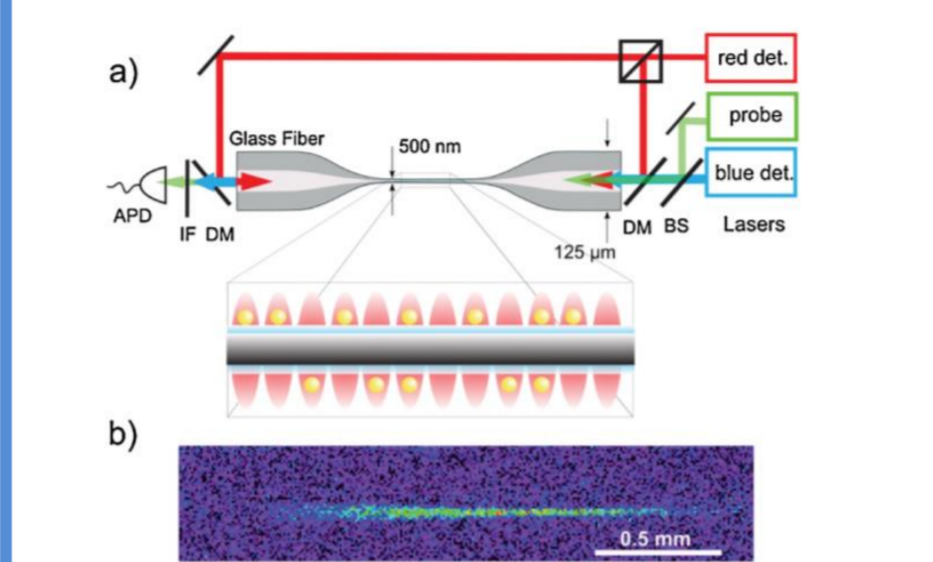
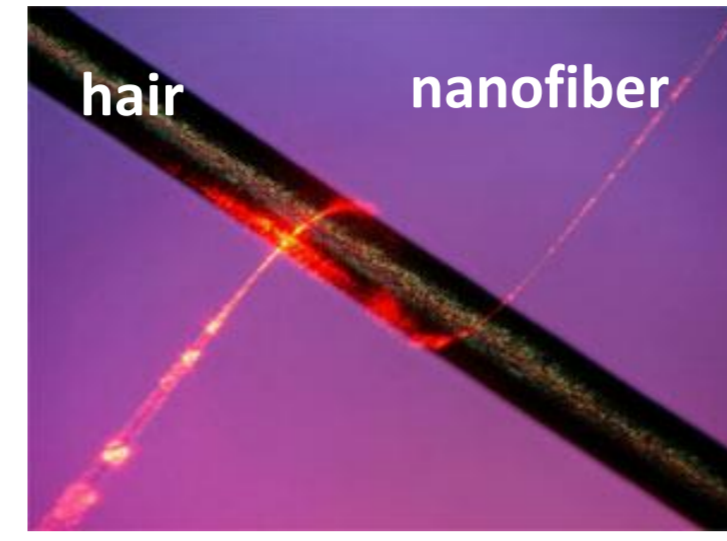
➔ Many applications in quantum technologies (computing, communication, nonlinear quantum optics)

Optical Nanofibers (ONFs)

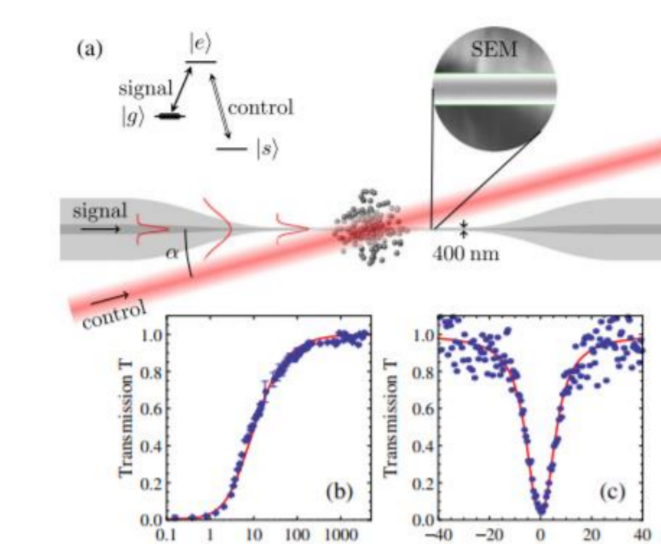
Tapered silica optical fibers
 $r < \lambda$



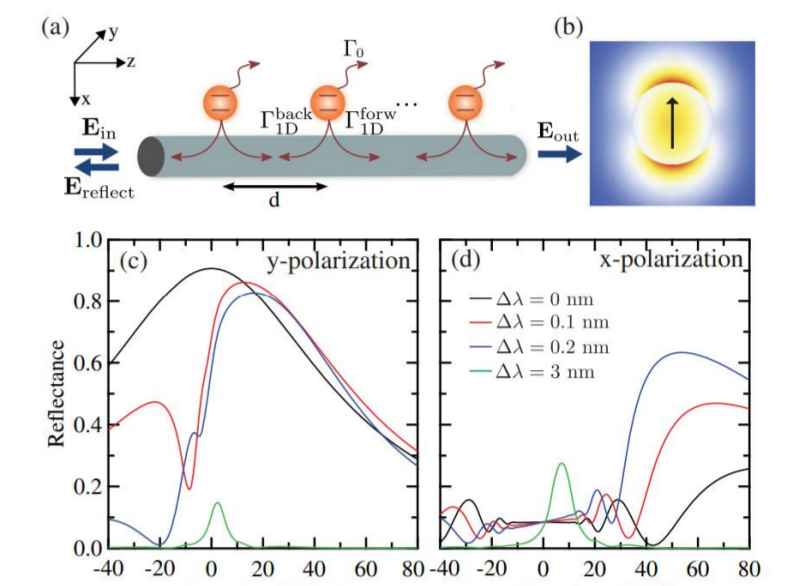
in the waist region, strong coupling of nearby atoms to guided mode **evanescent** component



Atom trapping
Le Kien et al, Phys. Rev. A 70 063403 (2004),
Vetsch et al, Phys. Rev. Lett. 104 203603 (2010)

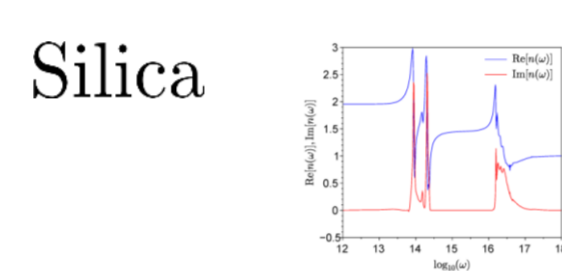
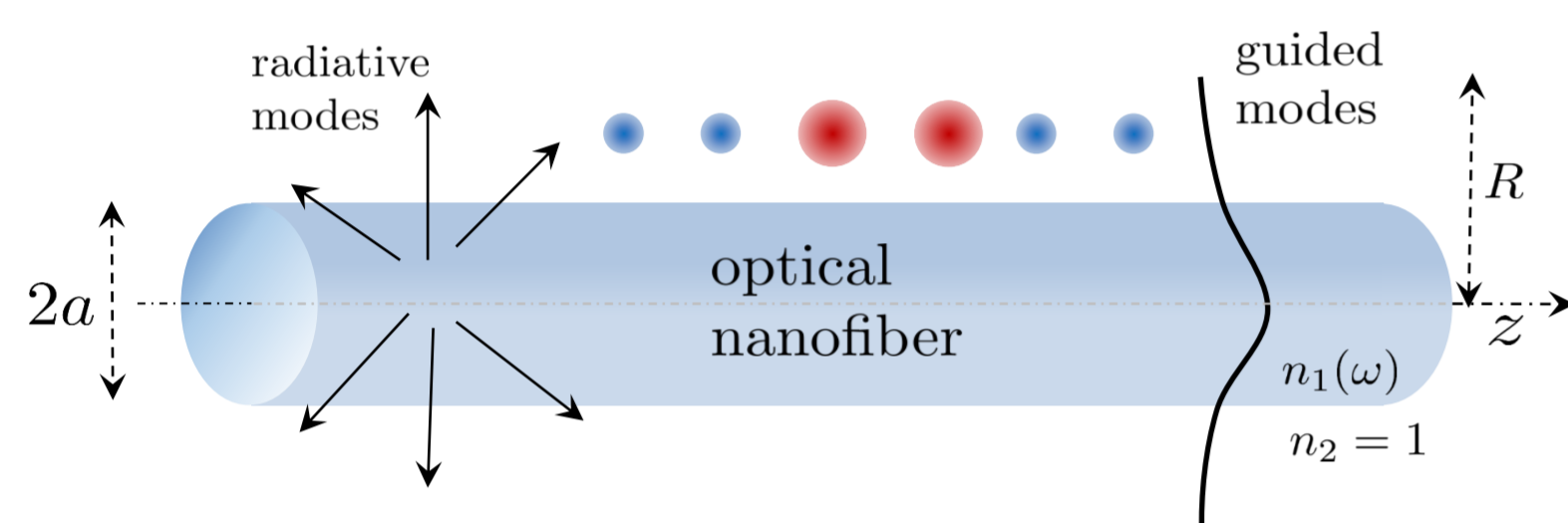


EIT-based quantum memory
Gouraud et al, Phys. Rev. Lett. 114 180503 (2015)



Atomic Bragg reflector
Corzo et al, Phys. Rev. Lett. 117 133603 (2016)

RYDBERG atom-nanofiber interface for quantum technologies



Previous works

THEORY

EXPERIMENT

Here
VAN DER WAALS interaction of two RYDBERG ⁸⁷Rb atoms → RYDBERG blockade?

Atom-atom interaction in the presence of an ONF

$$H_{\text{eff}} = \frac{1}{\epsilon_0} \hat{\mathbf{d}}_A \cdot \bar{\mathbf{T}}(\mathbf{r}_A, \mathbf{r}_B) \cdot \hat{\mathbf{d}}_B + \text{quadrupolar terms}$$

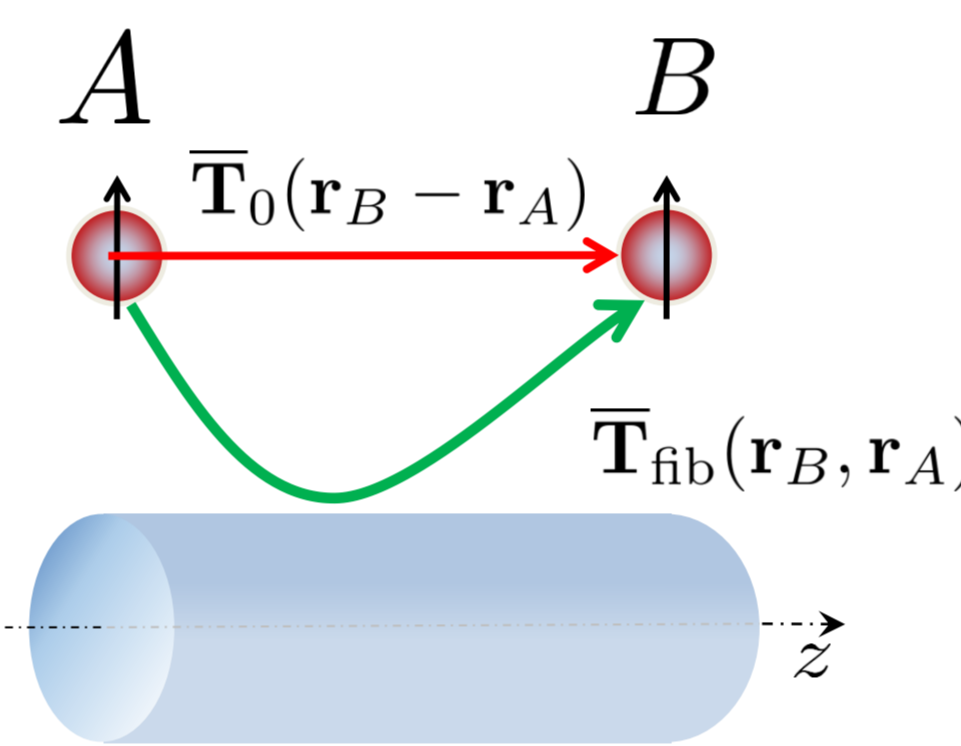
J. Block and S. Scheel, Phys. Rev. A 96, 062509 (2017).

Non-retarded GREEN's function

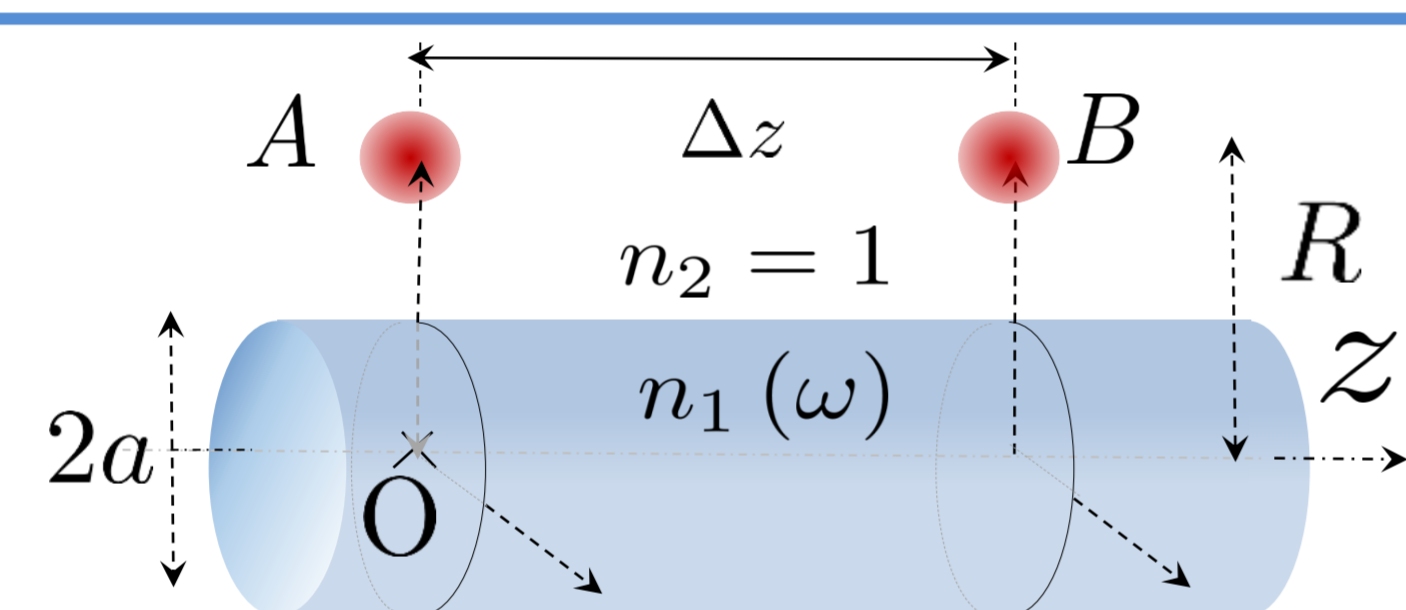
$$\bar{\mathbf{T}}(\mathbf{r}_A, \mathbf{r}_B) \equiv - \lim_{\omega \rightarrow 0^+} \left(\frac{\omega}{c}\right)^2 \bar{\mathbf{G}}(\mathbf{r}_A, \mathbf{r}_B, \omega) = \bar{\mathbf{T}}_0 + \bar{\mathbf{T}}_{\text{fib}}$$

vacuum GREEN's function $\bar{\mathbf{T}}_0 = -\frac{1}{4\pi r_{AB}^3} (\bar{\mathbf{I}} - 3\mathbf{u}_{AB} \otimes \mathbf{u}_{AB})$

fiber GREEN's function $\bar{\mathbf{T}}_{\text{fib}}$



S states



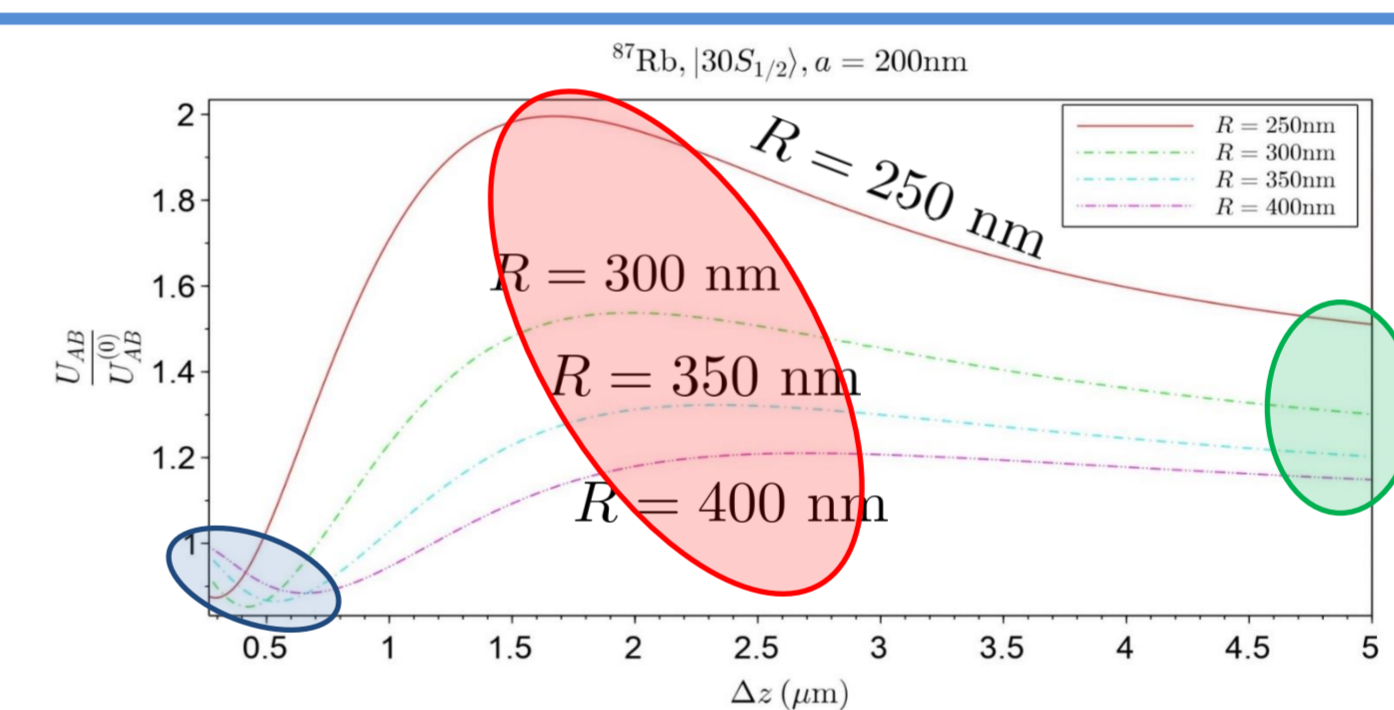
A, B prepared in $|30S_{1/2}\rangle$, $R_A = R_B = R$, $a = 200 \text{ nm}$

$\frac{U_{AB}}{U_{AB}^{(0)}} < 1$ at short distance

$\frac{U_{AB}}{U_{AB}^{(0)}} \rightarrow 1$ for $\Delta z \rightarrow 0$

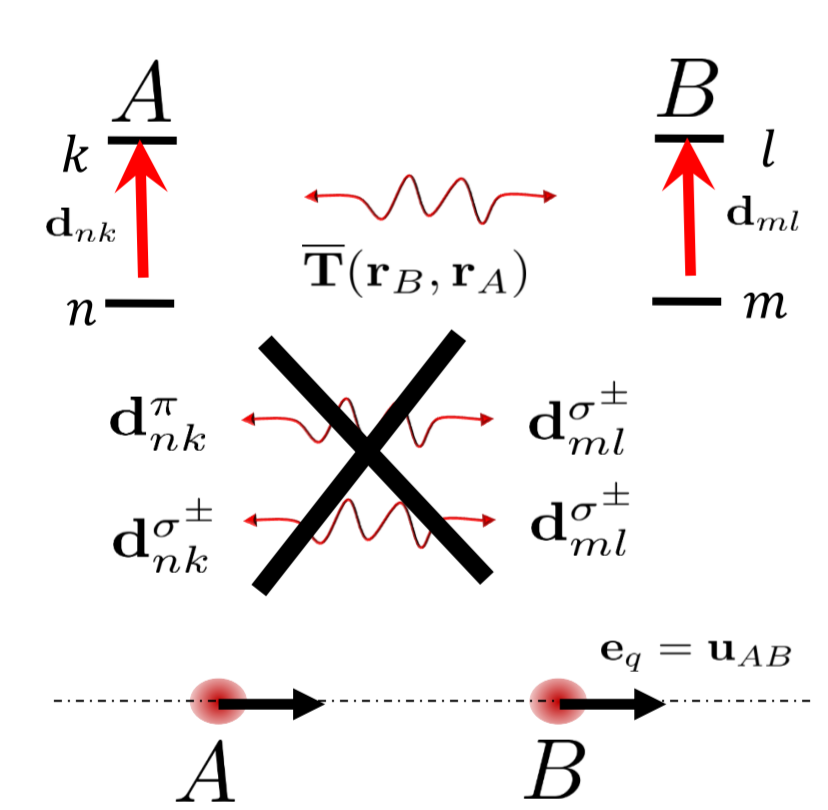
$\frac{U_{AB}}{U_{AB}^{(0)}} > 1$ for $\Delta z \approx R$

asymptote for $\Delta z \gg R$?



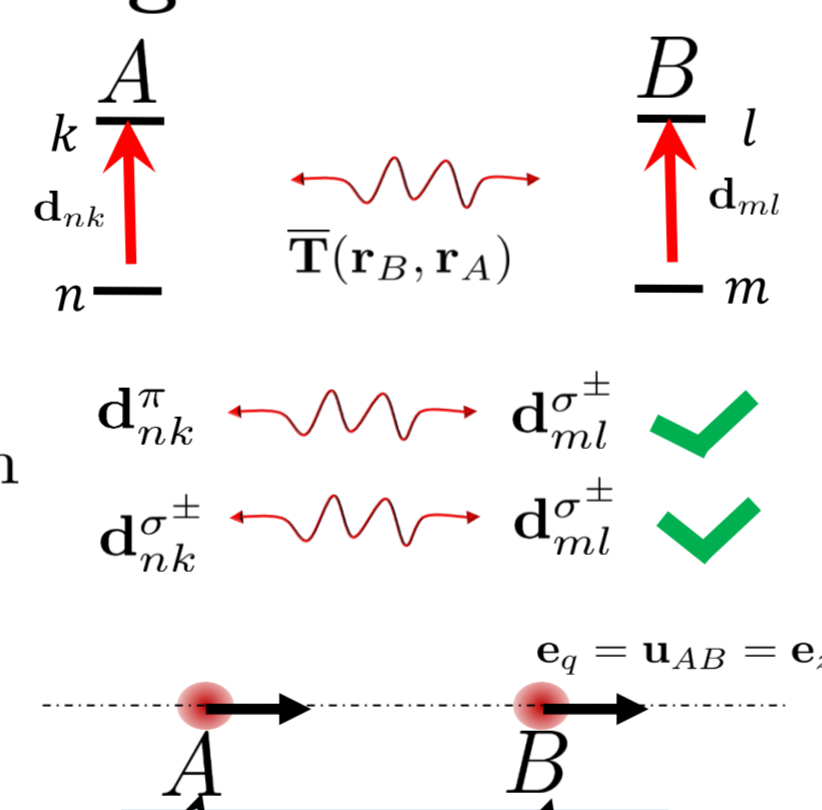
- Same qualitative behaviour for all n's
- RYDBERG blockade seemingly favoured by the ONF for RYDBERG S states

P states : nanofiber-induced symmetry breaking



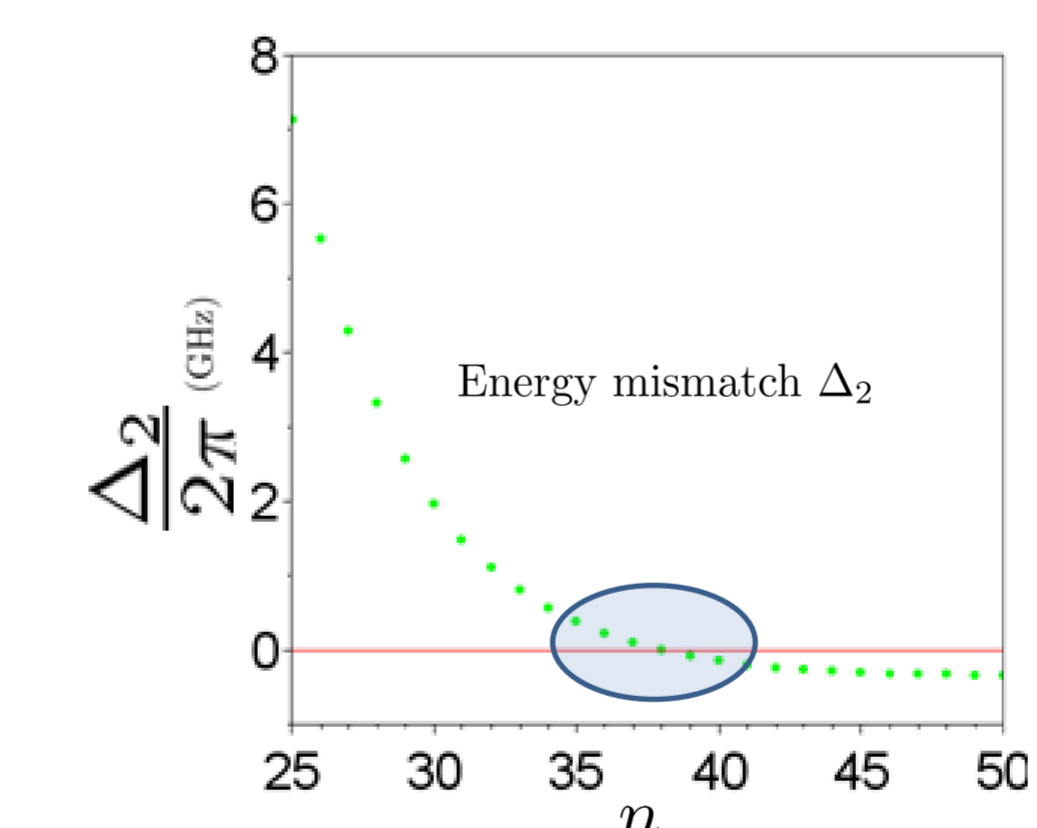
VAN DER WAALS Hamiltonian couples transitions in A and B

In free-space, certain transitions cannot be coupled when quantization and interatomic axes coincide, because of a rotation symmetry. The presence of the nanofiber breaks the symmetry and makes these couplings allowed.



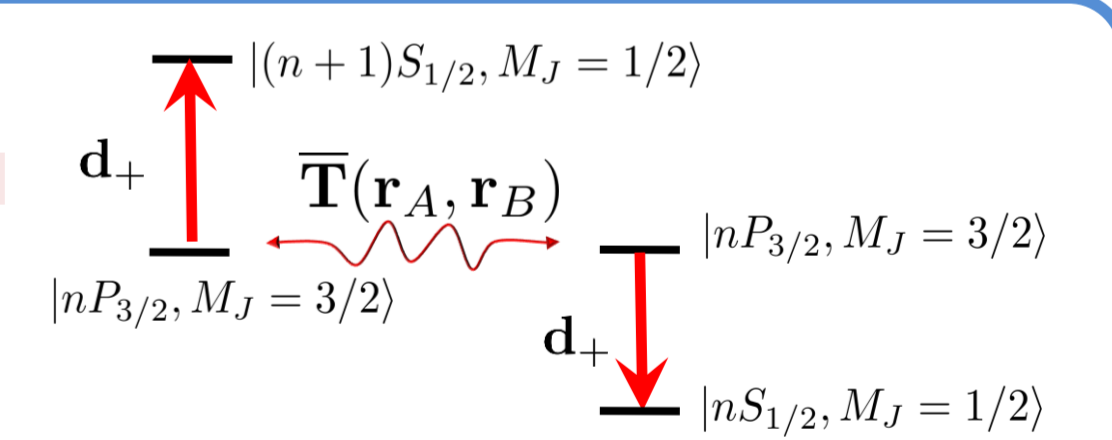
P states : FÖRSTER quasiresonance

A pair of $\sigma^+ - \sigma^+$ transitions activated by the fiber becomes dominant



Near resonant process for $n \approx 37$

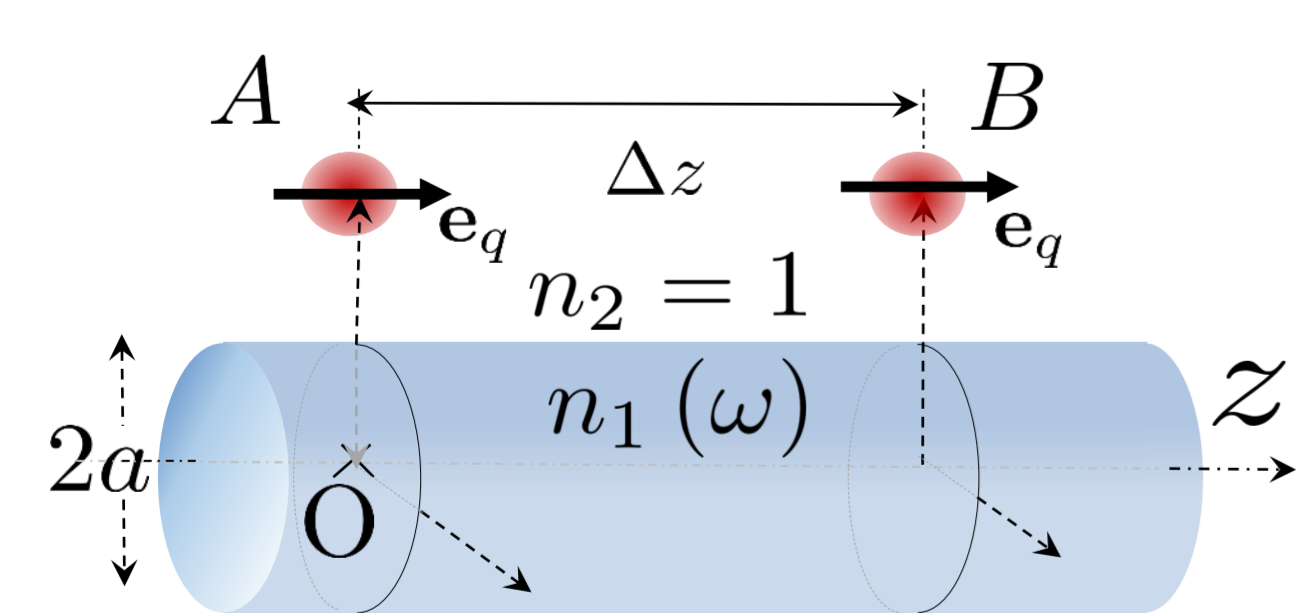
Energy mismatch becomes negative for $n > 37$



Strong enhancement of the potential

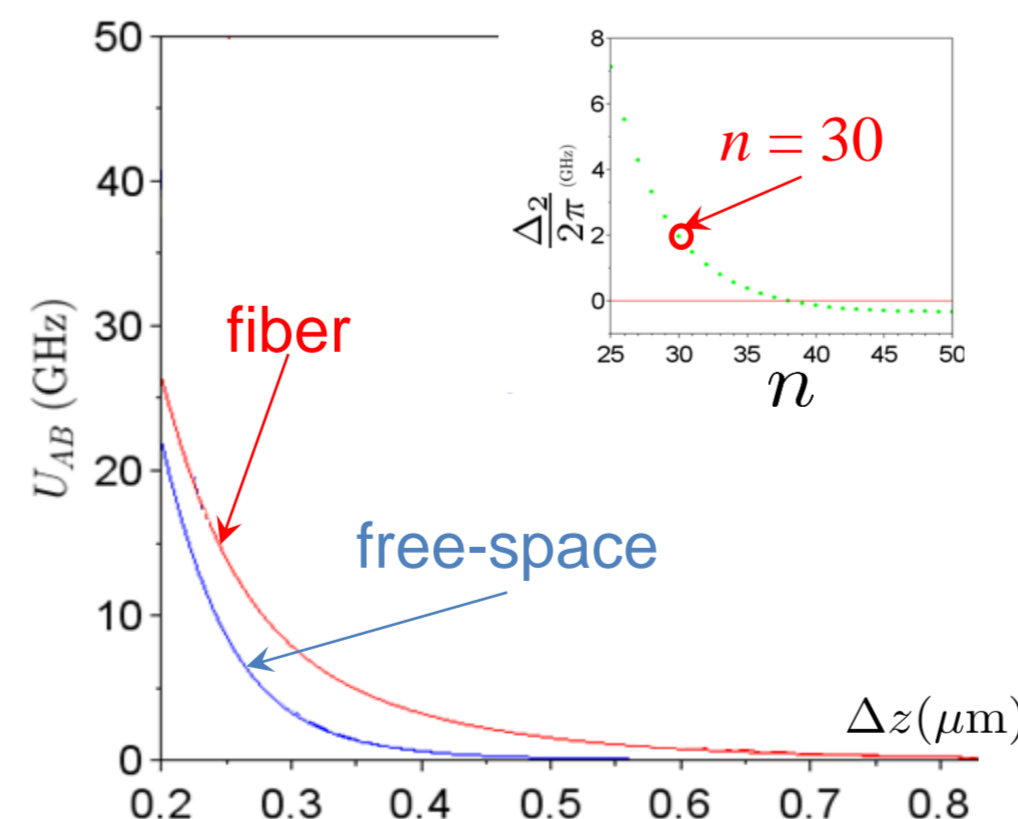
Change of the nature of the potential

P states : nature of atom-atom interaction

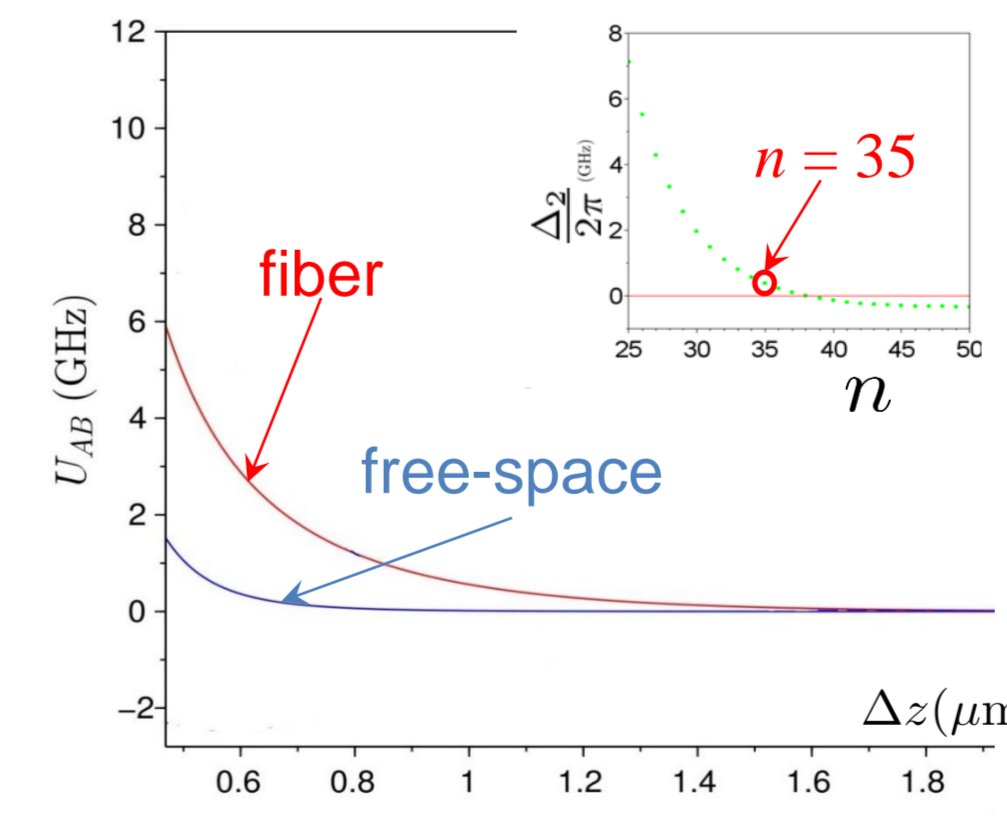


A, B prepared in $|nP_{3/2}, M = 3/2\rangle$
 $R = 250 \text{ nm}$, $a = 200 \text{ nm}$
quantization axis along (Oz)

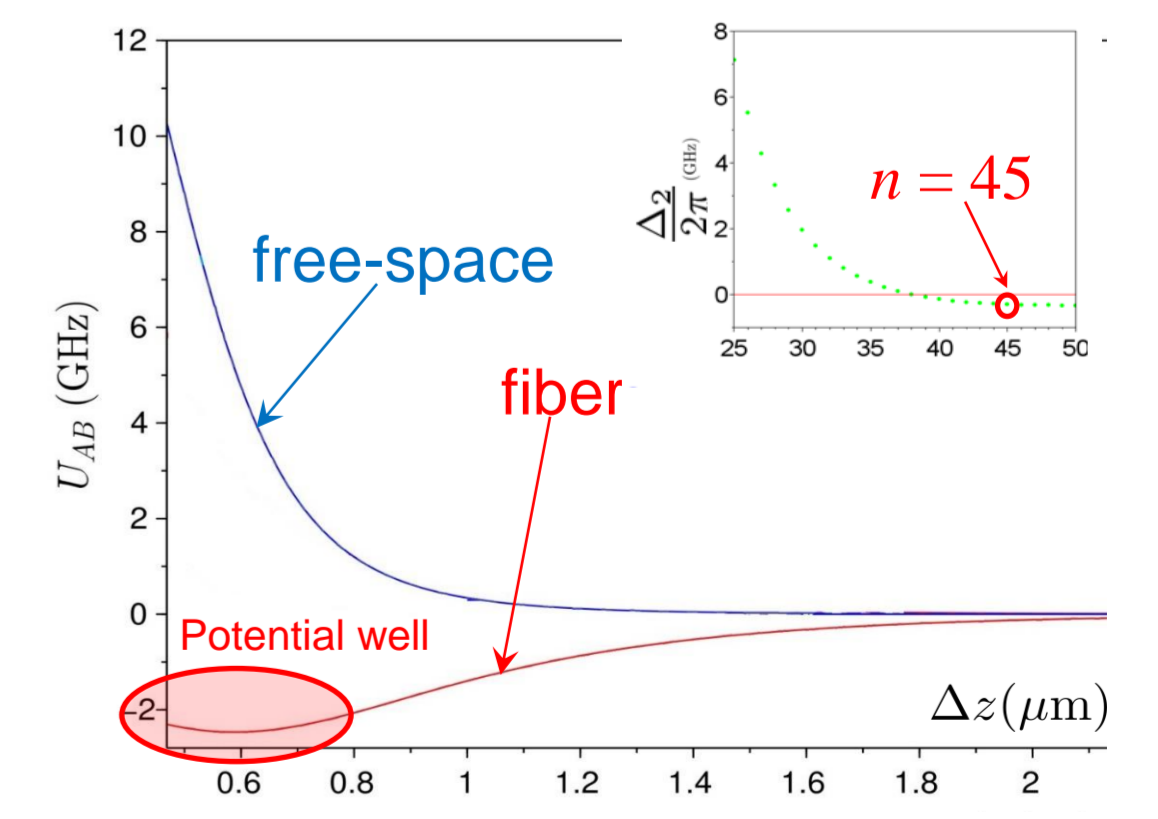
Enhancement for $n = 30$



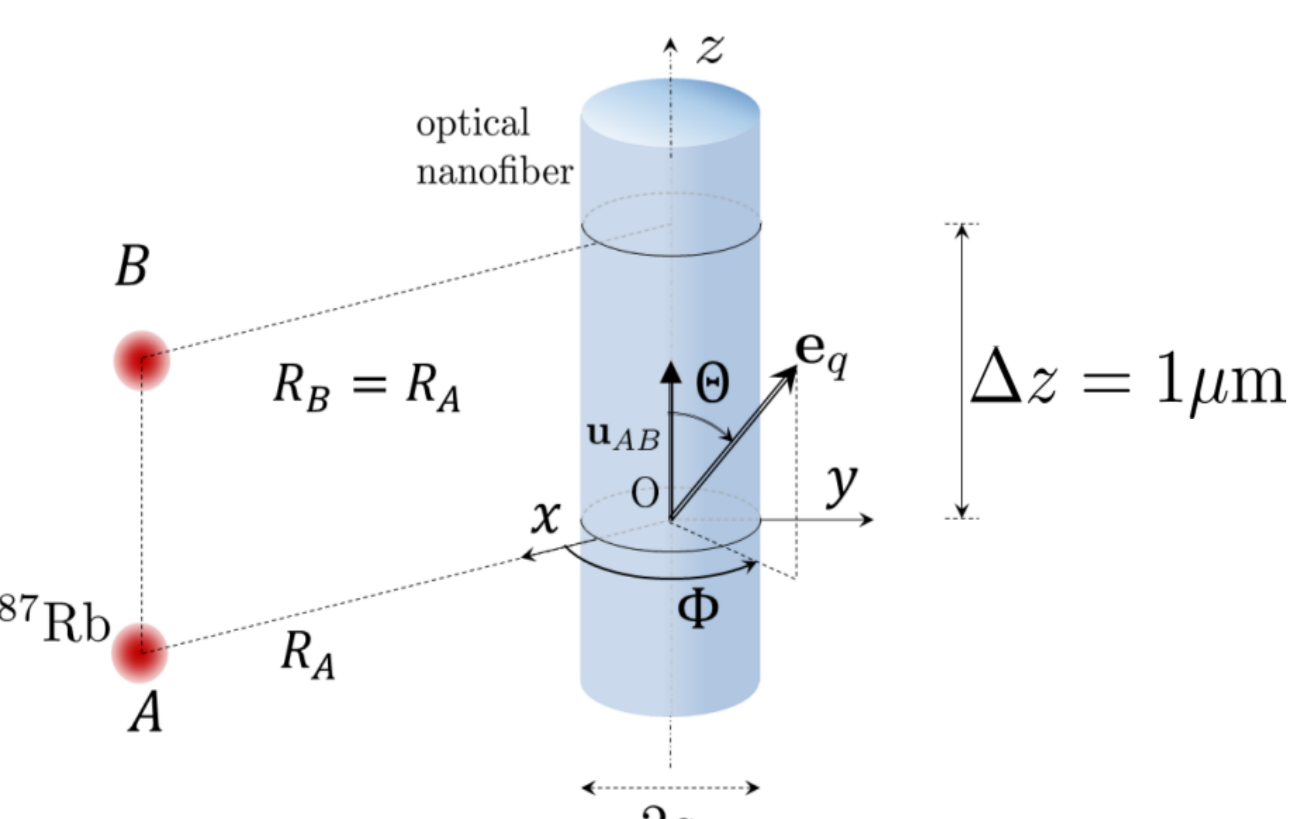
Stronger enhancement for $n = 35$



New behaviour for $n = 45$



P states : modification of interaction anisotropy



A, B in $|30P_{3/2}, M_J = 3/2\rangle$
 $R_A = R_B = R = 250 \text{ nm}$

