



Superabsorption of light via quantum engineering

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About this research group...



ARTICLE

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Superabsorption of light via quantum engineering

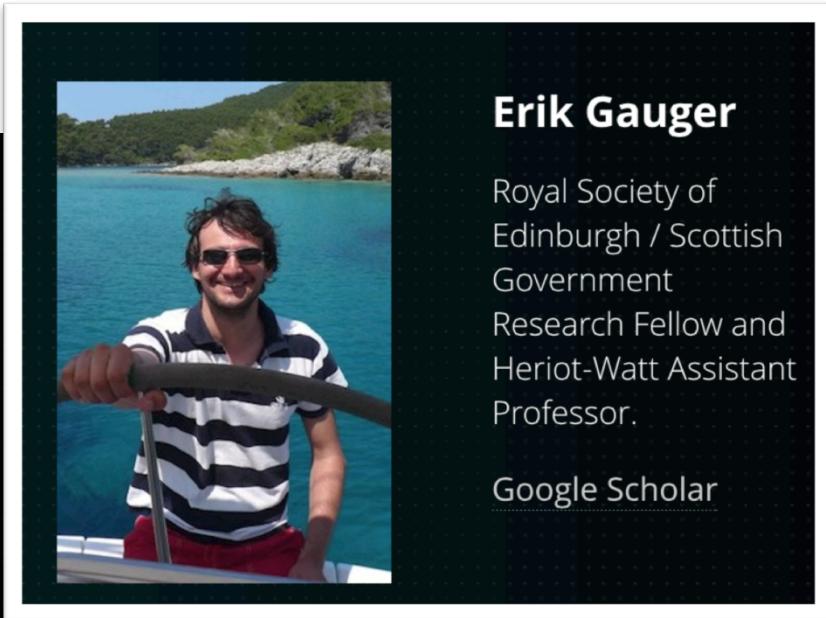
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Almost 60 years ago Dicke introduced the term superradiance to describe a signature quantum effect: N atoms can collectively emit light at a rate proportional to N^2 . Structures that superradiate must also have enhanced absorption, but the former always dominates in natural systems. Here we show that this restriction can be overcome by combining several well-established quantum control techniques. Our analytical and numerical calculations show that superabsorption can then be achieved and sustained in certain simple nanostructures, by trapping the system in a highly excited state through transition rate engineering. This opens the prospect of a new class of quantum nanotechnology with potential applications including photon detection and light-based power transmission. An array of quantum dots or a molecular ring structure could provide a suitable platform for an experimental demonstration.

About this research group...



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Erik Gauger

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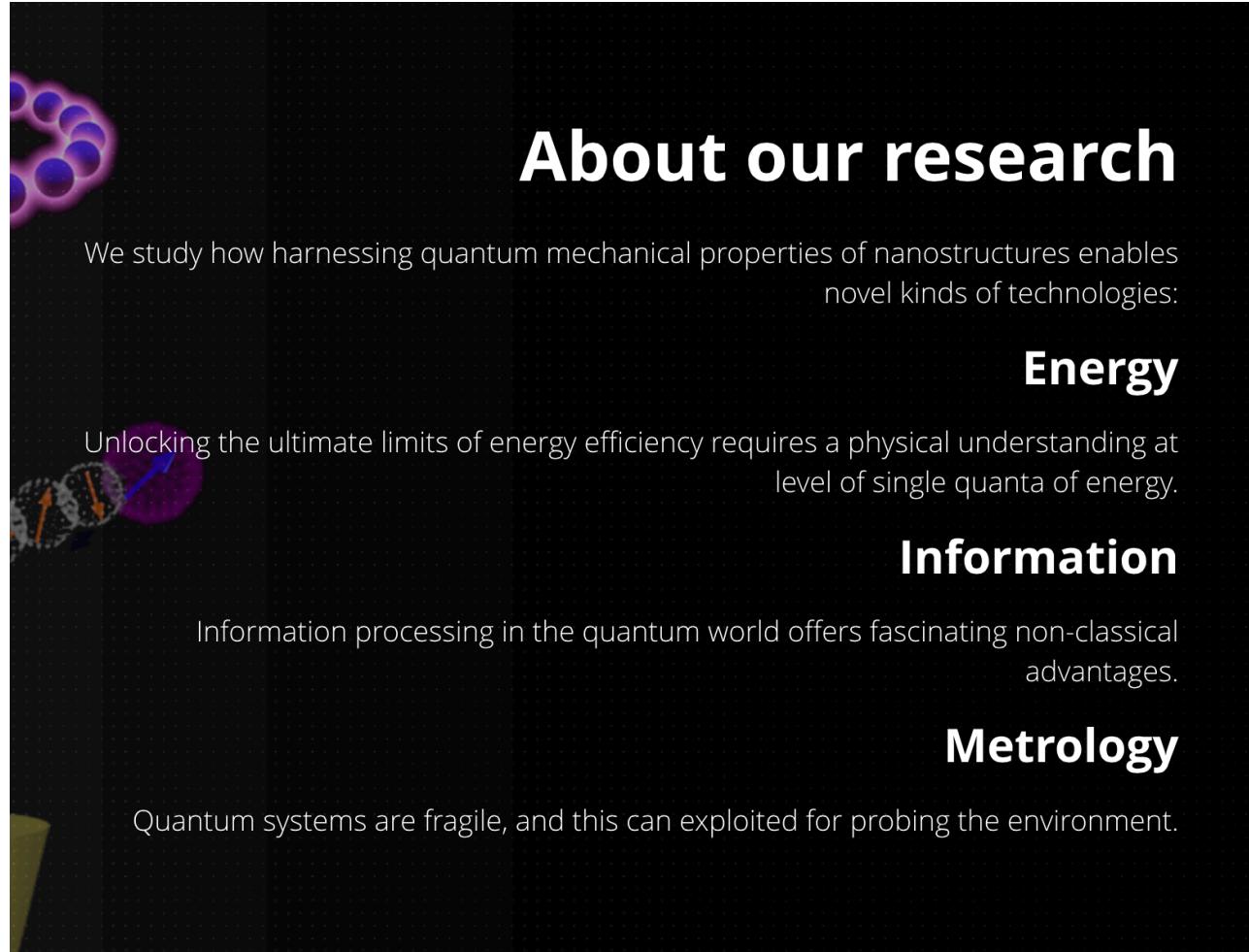
Welcome

We are the quantum technology theory group led by Dr Erik Gauger at Heriot-Watt University.

To learn more please scroll down or use the site menu.

<http://home.eps.hw.ac.uk/~eg7/>

About this research group...



About our research

We study how harnessing quantum mechanical properties of nanostructures enables novel kinds of technologies:

Energy

Unlocking the ultimate limits of energy efficiency requires a physical understanding at level of single quanta of energy.

Information

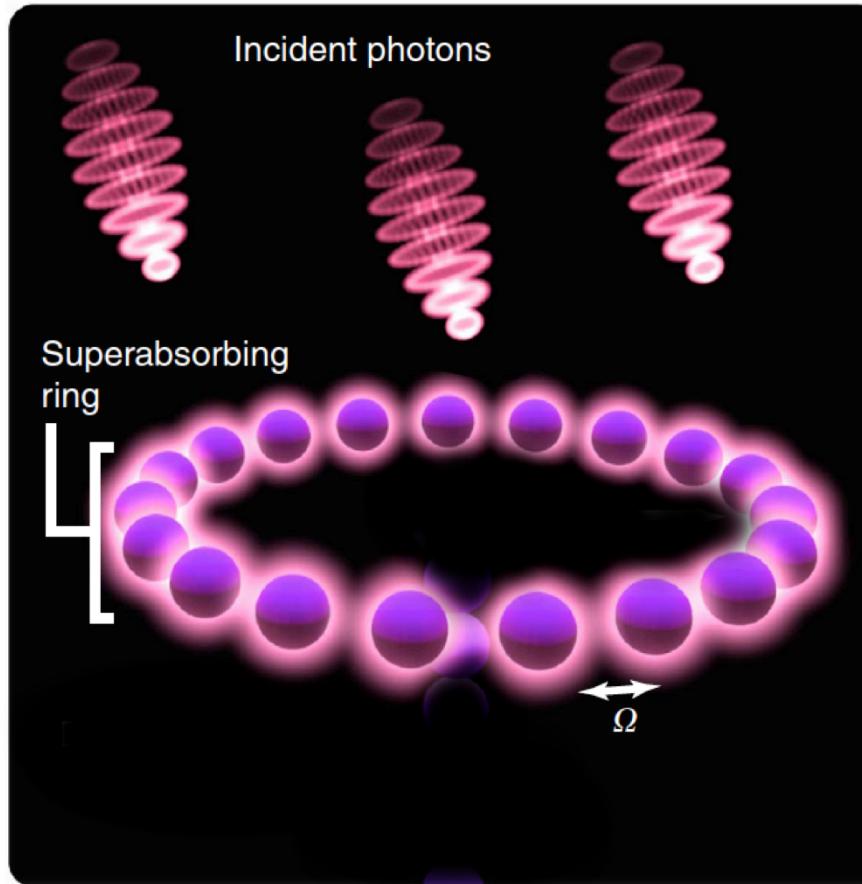
Information processing in the quantum world offers fascinating non-classical advantages.

Metrology

Quantum systems are fragile, and this can exploited for probing the environment.

<http://home.eps.hw.ac.uk/~eg7/>

Introduction



Introduction

“ Superradiance ”

Time-reversal symmetry in QM

“ Superabsorption ”

Photon sensing &
Light-based energy transmission

Need certain interactions between the atoms...

Entities with a discrete
dipole-allowed transition

Brief review of superradiance

Ensemble of N identical atoms

$$\hat{H}_s = \frac{\omega_A}{2} \sum_{i=1}^N (\mathbf{I}^i - \hat{\sigma}_z^i) = \omega_A \sum_{i=1}^N \hat{\sigma}_+^i \hat{\sigma}_-^i$$

In the regime of.. $r_{ij} \ll \lambda$

$$\hat{J}_{\pm} = \sum_{i=1}^N \hat{\sigma}_{\pm}^i, \quad \hat{J}_z = \sum_{i=1}^N \hat{\sigma}_z^i$$

Interaction Hamiltonian between light-matter

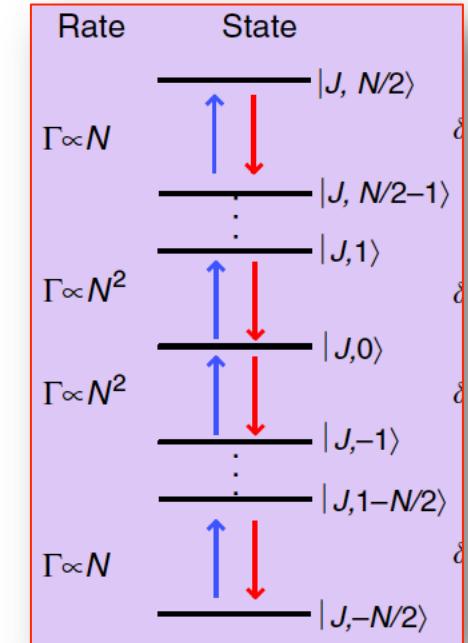
$$\hat{H}_L = -\hat{E}d(\hat{J}_+ + \hat{J}_-)$$

Transition rate between adjacent state

$$\Gamma_{M \rightarrow M-1} \approx \gamma \left(\frac{N}{2} \right)^2$$

* $\gamma = 8\pi^2 d^2 / (3\varepsilon_0 \hbar \lambda^3)$

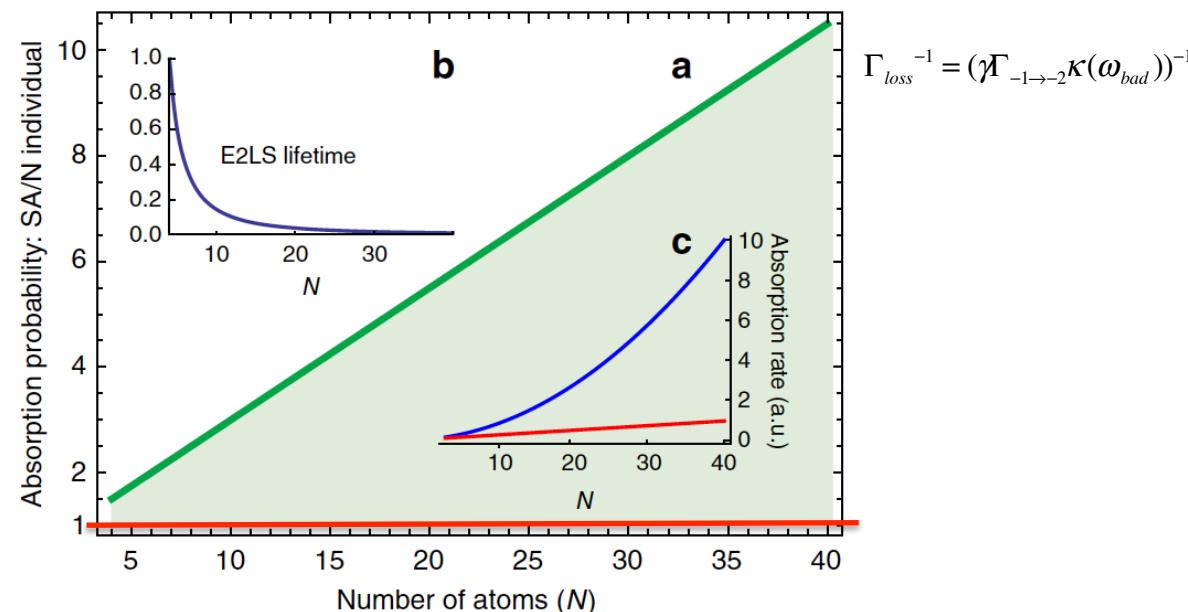
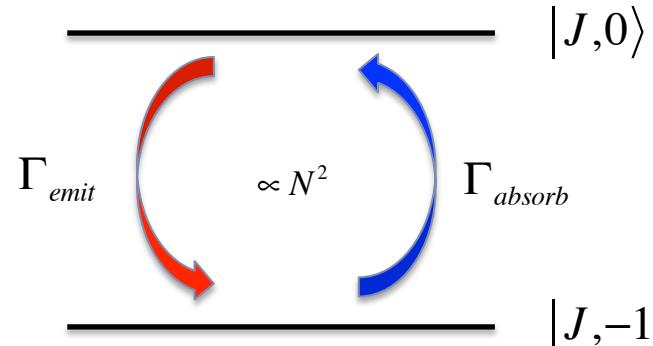
$$\begin{aligned}\hat{\sigma}_z^i &= |g\rangle_i \langle g| - |e\rangle_i \langle e| \\ \hat{\sigma}_+^i &= |e\rangle_i \langle g| \\ \hat{\sigma}_-^i &= |g\rangle_i \langle e|\end{aligned}$$



Dicke ladder state

Superabsorption

Effective two level system(E2LS) around M=0



Master Equation

Quantum optical master equation

$$\dot{\rho} = -i \left[\hat{H}_s + \hat{H}_I, \rho \right] - \gamma \sum_{\beta \in \omega} \kappa(\omega_\beta) \left((n(\omega_\beta) + 1) D[\hat{L}_\beta] \rho + n(\omega_\beta) D[\hat{L}_\beta^\dagger] \rho \right)$$

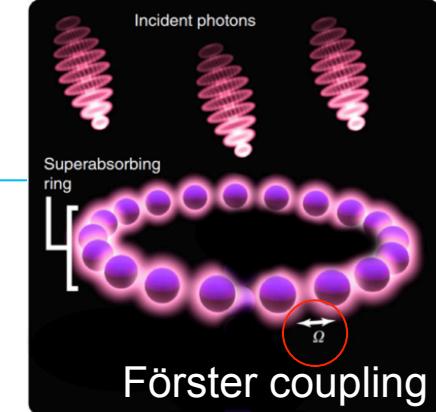
Lamb shift

with $\kappa(\omega) = \sum_k |g_k|^2 \delta(\omega - \omega_k) \equiv \chi(\omega) |g(\omega)|^2$

$$D[\hat{L}_\beta] \rho = \hat{L}_\beta \rho \hat{L}_\beta^\dagger - \frac{1}{2} \{ \hat{L}_\beta^\dagger \hat{L}_\beta, \rho \}$$

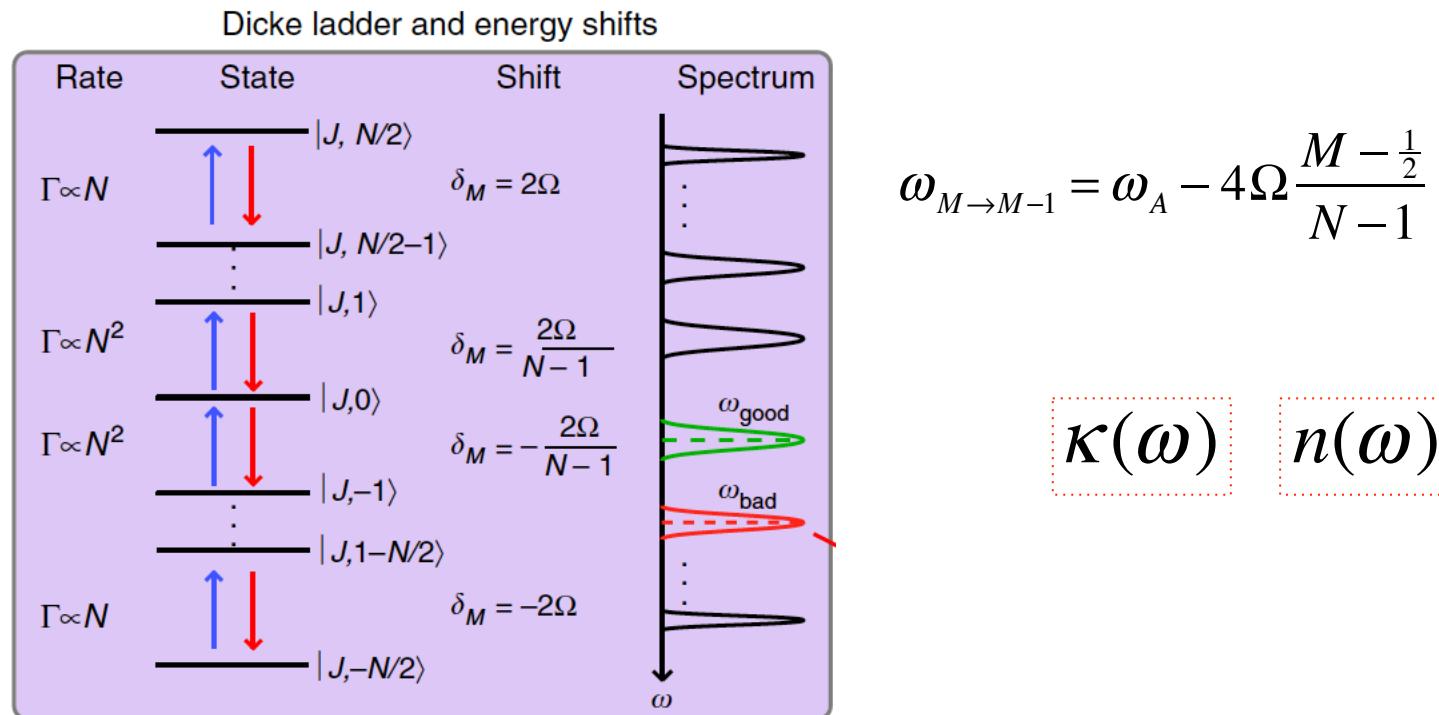
$$\boxed{\hat{H}_I = \Omega_{i,j} \sum_{i \neq j}^N (\hat{\sigma}_+^i \hat{\sigma}_-^j + \hat{\sigma}_-^i \hat{\sigma}_+^j)} : \text{Dipole-dipole interaction}$$

$$\Omega(i,j) = \frac{d^2}{4\pi\epsilon_0 r_{ij}^3} \left[1 - \frac{3(\hat{\epsilon}_a \cdot \vec{r}_{ij})^2}{r_{ij}^2} \right] \approx \frac{d^2}{4\pi\epsilon_0 r_{ij}^3}$$



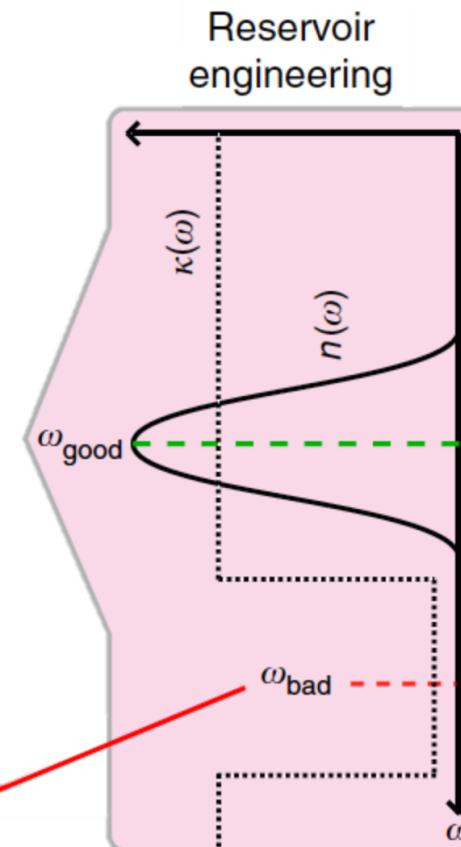
For the “ring” structure

$$\delta E_M = \langle J, M | \hat{H}_I | J, M \rangle = \Omega \frac{J^2 - M^2}{J - \frac{1}{2}}$$



Transition rate engineering

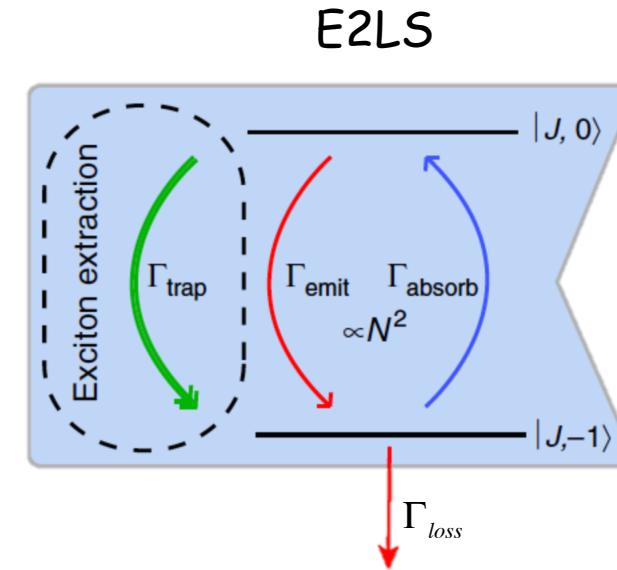
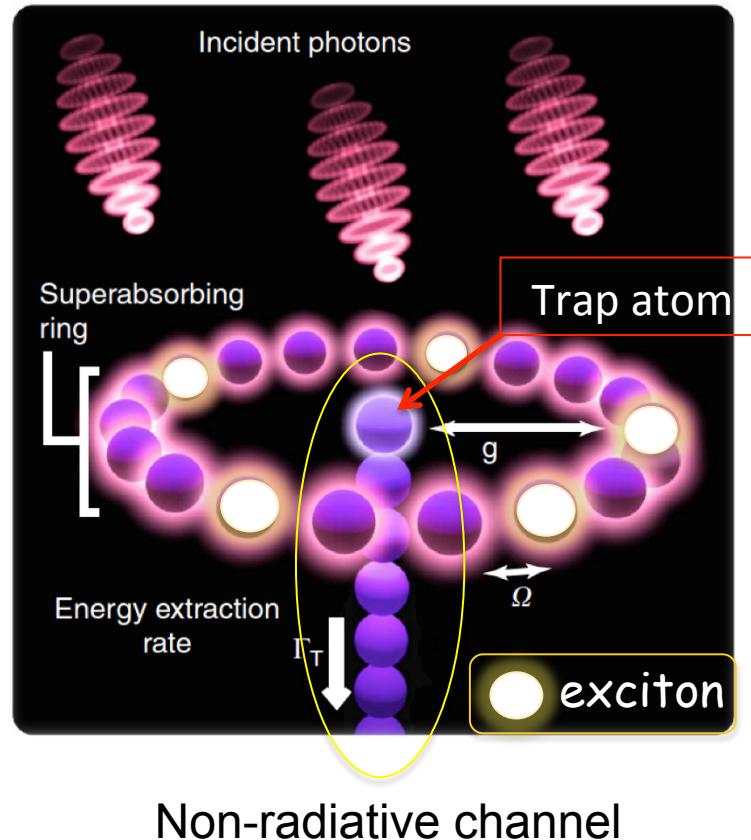
$$\kappa(\omega) \text{ & } n(\omega)$$



Rely on
Frequency selectivity

Energy harvesting

Trapping **Collective Extraction**



Trapping Hamiltonian...

$$\hat{H}_T = g \left(\hat{J}_+ \hat{\sigma}_-^T + \hat{J}_- \hat{\sigma}_+^T \right) + \omega_{trap} \hat{\sigma}_+^T \hat{\sigma}_-^T$$

From the master equation...

Add,

$$D\left[\hat{L}_{trap}\right]\rho \quad \hat{L}_{trap} = \sqrt{\Gamma_{trap}} |J,-1\rangle\langle J,0|$$

The rate of exciton extraction

$$I_{trap}(t) = \Gamma_{trap} Tr\left[|J,0\rangle\langle J,0|\rho(t)\right]$$

For, $\Gamma_{trap} \gg \Gamma_{emit}$

$$I_{trap}(t) = I_{max} \approx \Gamma_{absorb} \approx \mu \left(\frac{N}{2} + \frac{N^2}{4} \right)$$

$$\mu = \kappa(\omega_{good})n(\omega_{good})$$

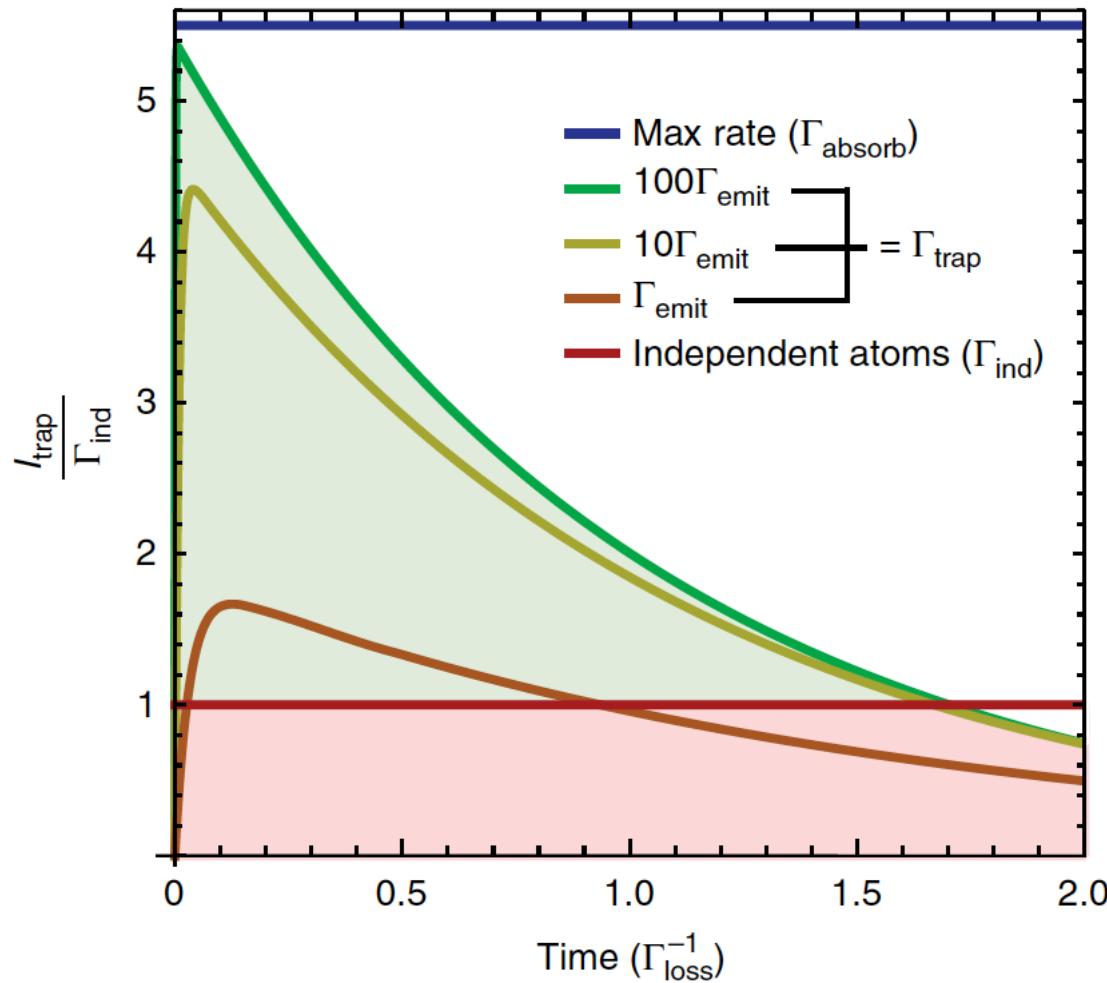
$$\Gamma_{loss} \equiv \kappa(\omega_{bad})(n(\omega_{bad})+1)\Gamma_{-1 \rightarrow -2} \quad E2LS$$

$$\Gamma_{emit} \equiv \kappa(\omega_{good})(n(\omega_{good})+1)\Gamma_{0 \rightarrow 1} \quad \Gamma_{trap} \gg \Gamma_{emit}$$

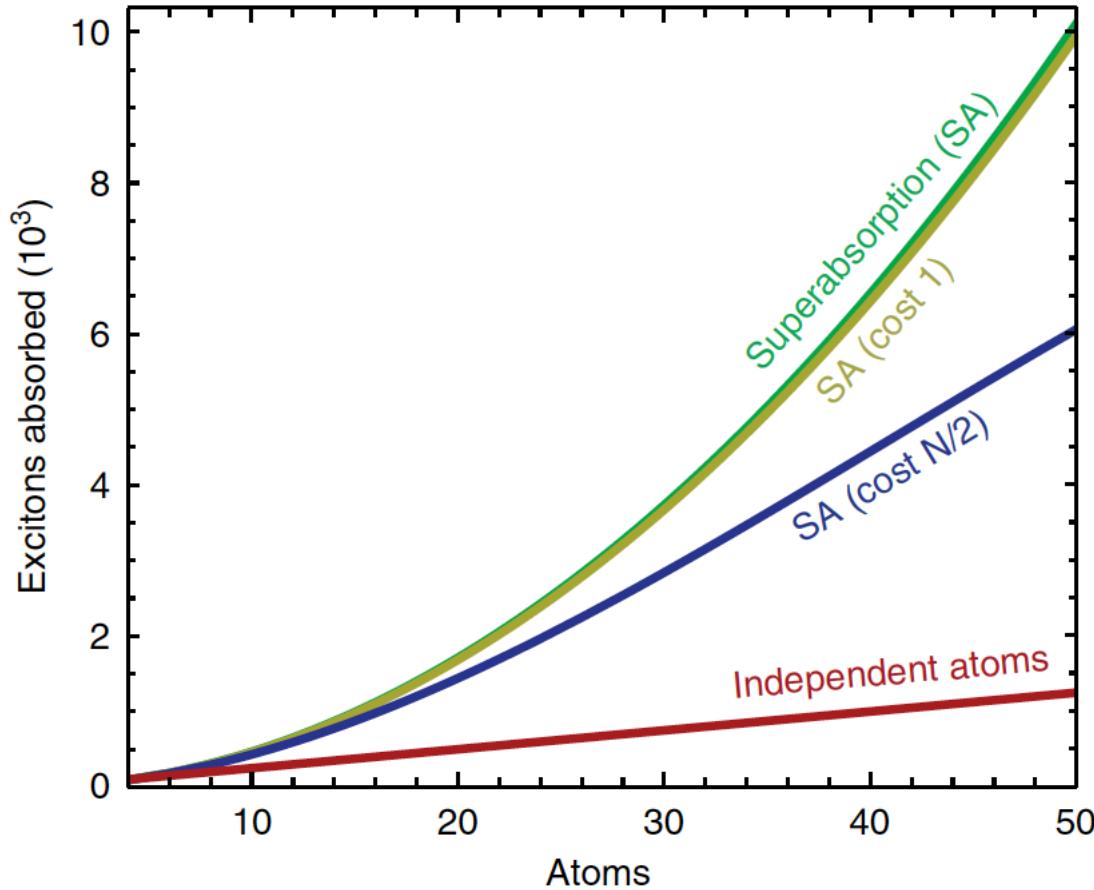
$$\Gamma_{absorb} \equiv \kappa(\omega_{good})n(\omega_{good})\Gamma_{-1 \rightarrow 0}$$

$$\Gamma_{ind} = n(\omega_{good})N_\gamma$$

$$I_{trap}(t) = I_{max} \approx \Gamma_{absorb} \approx \mu \left(\frac{N}{2} + \frac{N^2}{4} \right)$$



Reinitialization





Thank you