Superabsorption of light via quantum engineering

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[3] *Centre for Engineered Quantum Systems, School of Mathematics and Physics, The University of Queensland, St Lucia, Queensland 4072, Australia*

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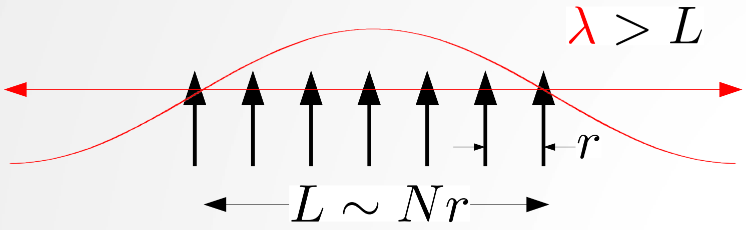
presented by

Simon E. Nigg

January 14th, 2014

Basel, CMT Journal Club

Superradiance in a nutshell



$$\boldsymbol{H} = \boldsymbol{H}_0 + q(\vec{\boldsymbol{E}} \cdot \vec{d}) \sum_{j=1}^{N} (\boldsymbol{\sigma}_j^+ + \boldsymbol{\sigma}_j^-)$$

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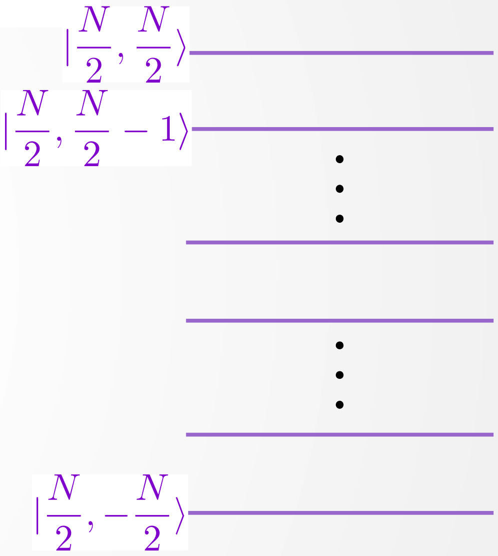

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$$\boldsymbol{J}^x = (\boldsymbol{J}^+ + \boldsymbol{J}^-)/2 \qquad [\boldsymbol{J}^2, \boldsymbol{J}^\pm]_- = 0$$

$$\boldsymbol{J}^y = -i(\boldsymbol{J}^+ - \boldsymbol{J}^-)/2 \qquad [\boldsymbol{J}^z, \boldsymbol{J}^\pm]_- \neq 0$$

Dicke states: $|J, M\rangle$ $\quad (M = -J, -J+1, \ldots, J-1, J)$

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Decay rates:

free atom decay rate

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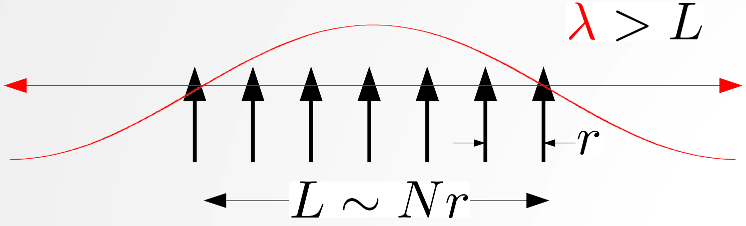

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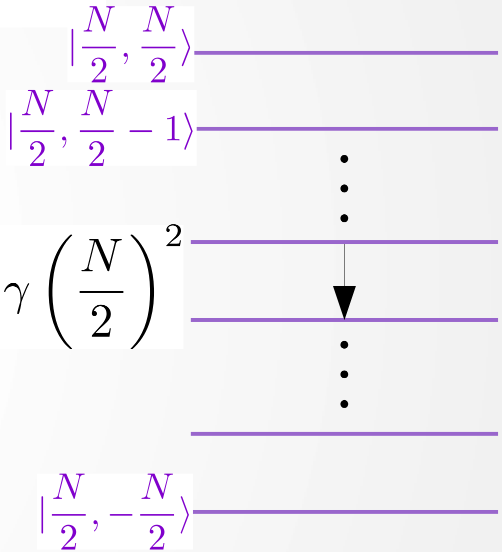

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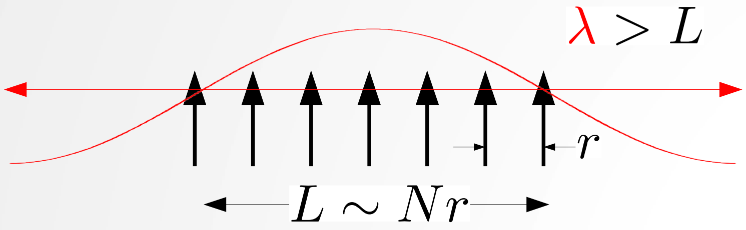

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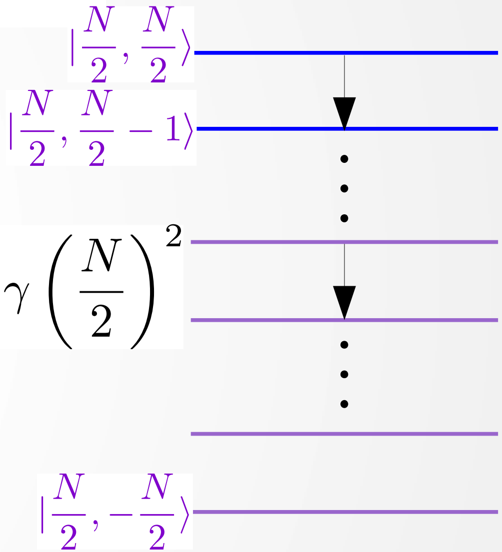

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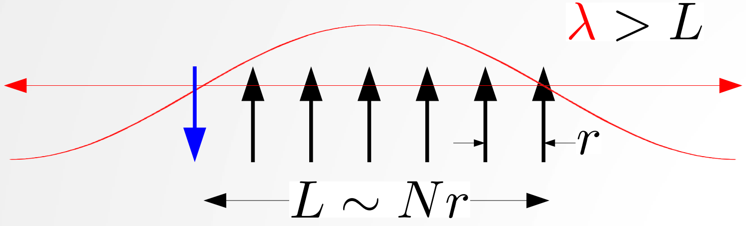

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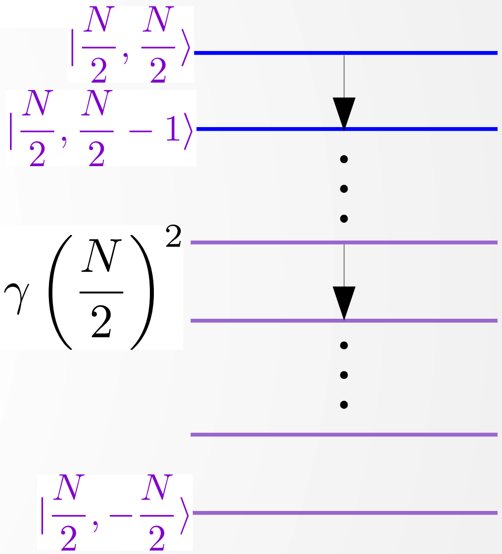

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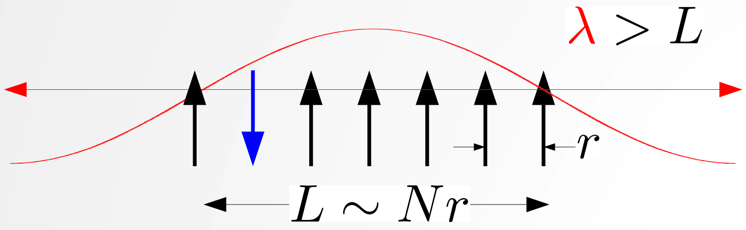

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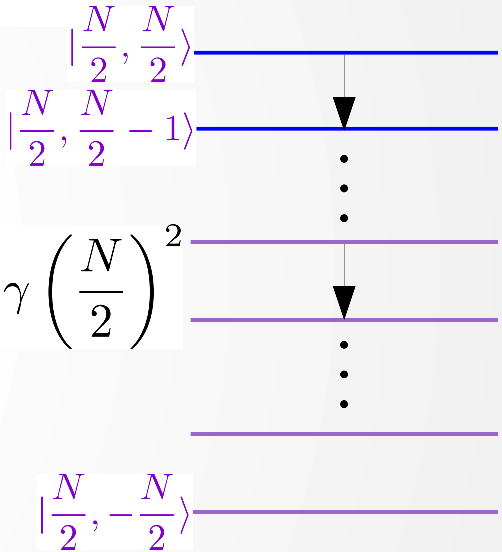

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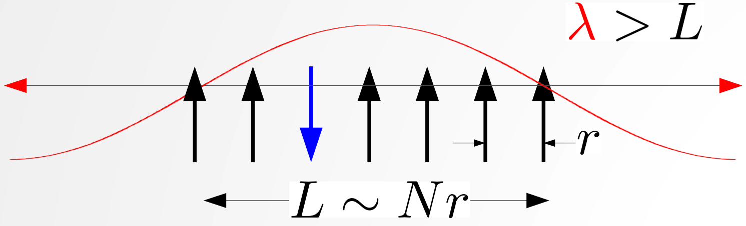

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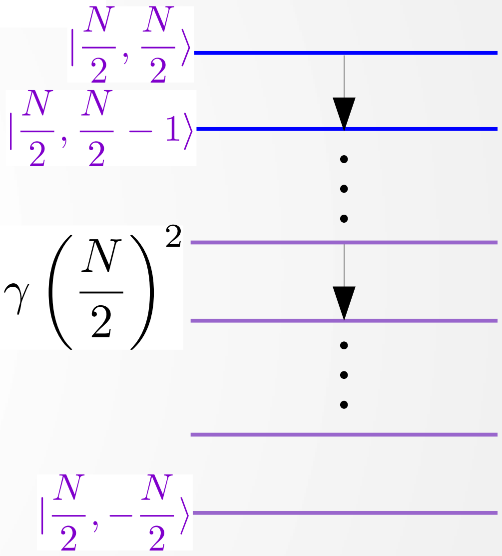

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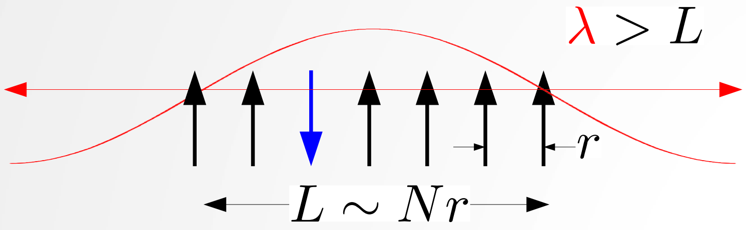

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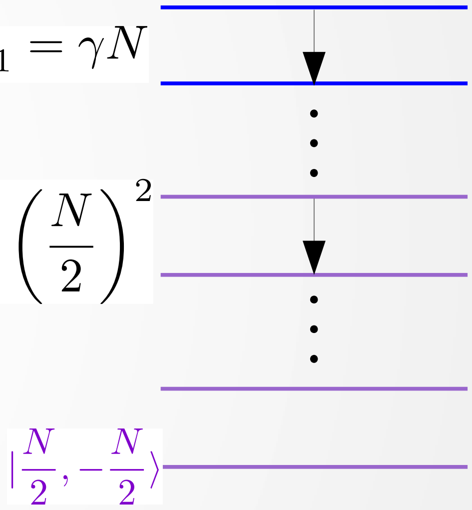

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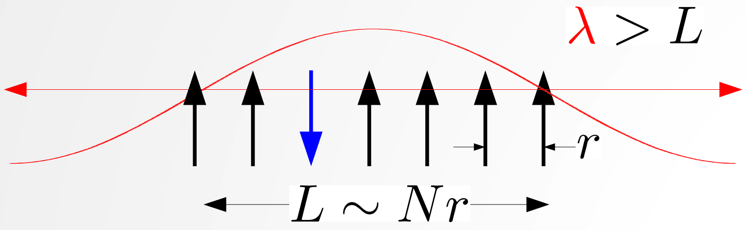

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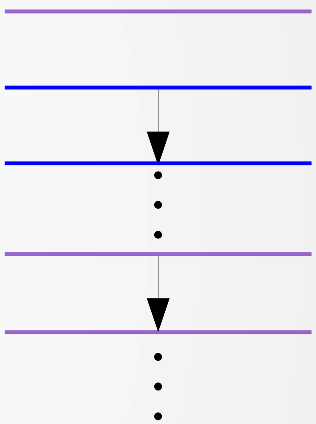

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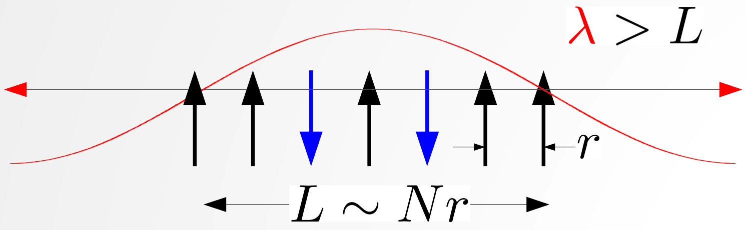

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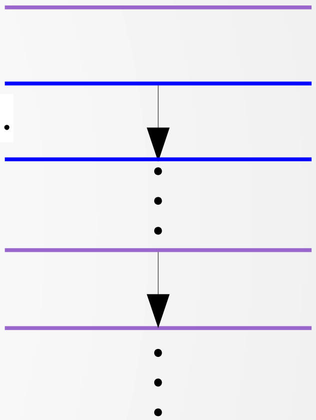

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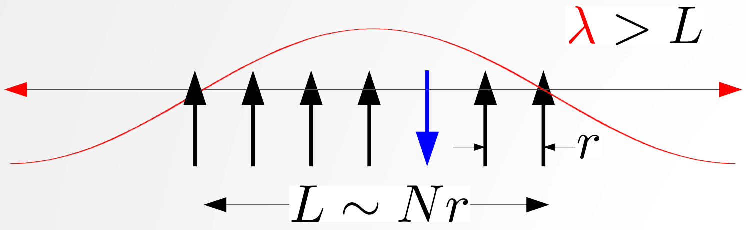

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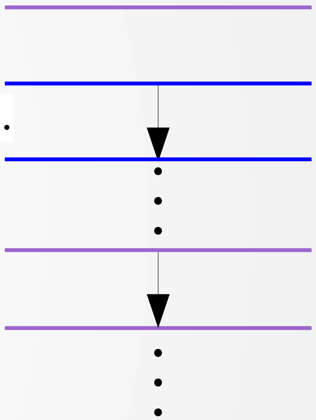

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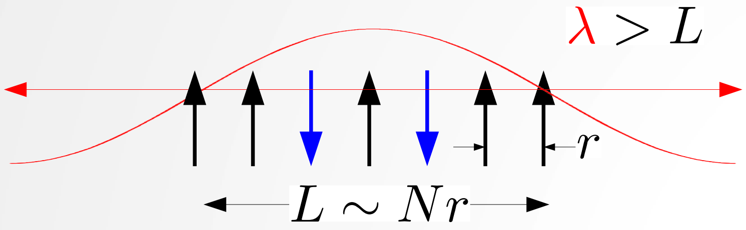

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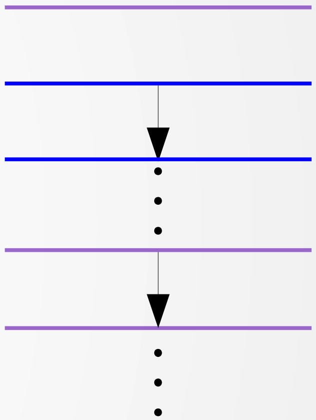

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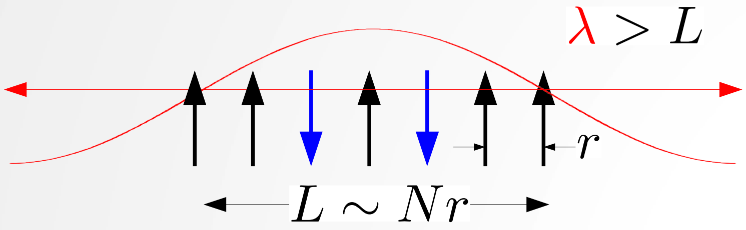

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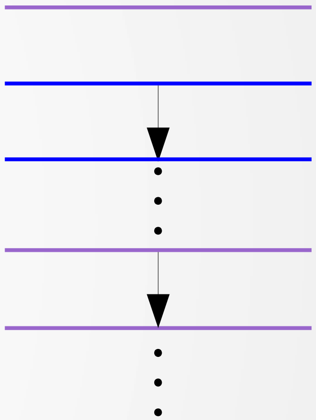

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Enhanced emission rate
compared to classical case for N > 4

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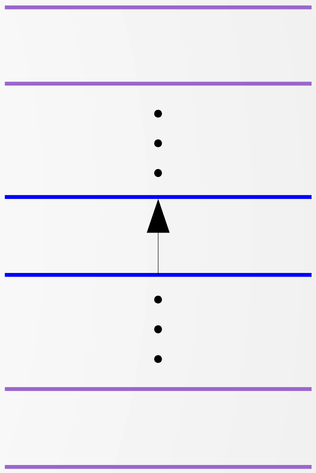
From Superradiance to Superabsorption

Time reversal symmetry: Superradiance $\Leftrightarrow$ Superabsorption

$$\Gamma_{-1\to 0} \sim N^2$$



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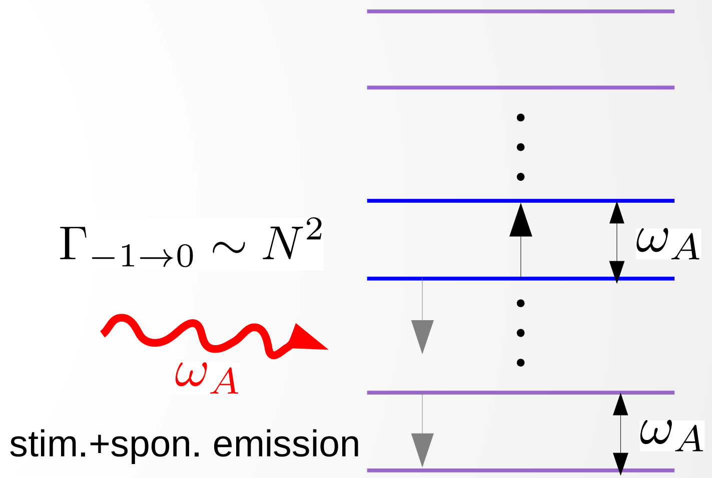

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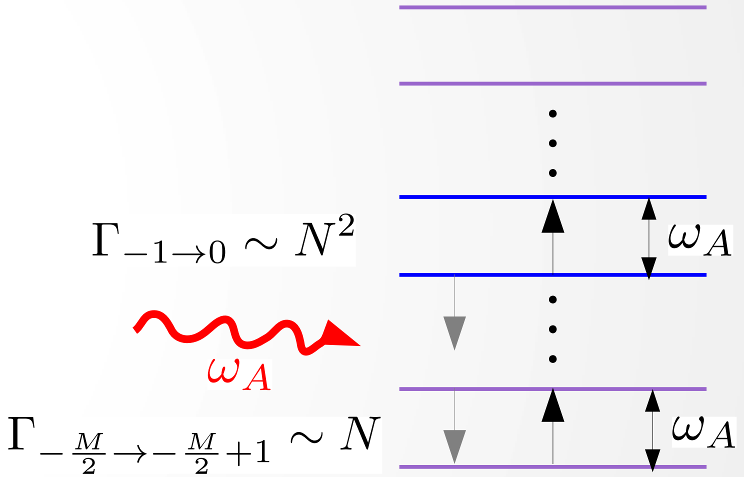

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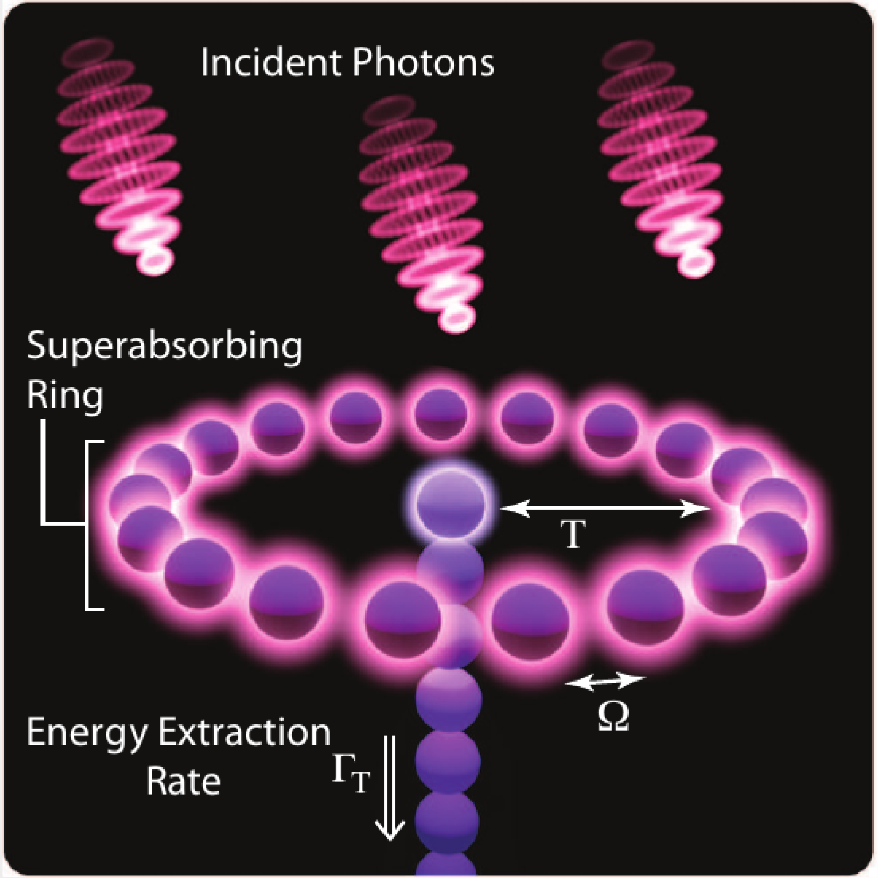


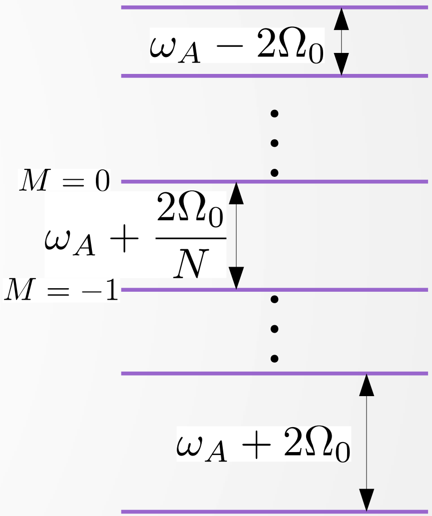
$$\boldsymbol{H}_I = \Omega_0 \sum_{j=1}^{N} (\boldsymbol{\sigma}_j^+ \boldsymbol{\sigma}_{j+1}^- + h.c.)$$

P.B.C. $\boldsymbol{\sigma}_{N+1}^{\pm} = \boldsymbol{\sigma}_1^{\pm}$

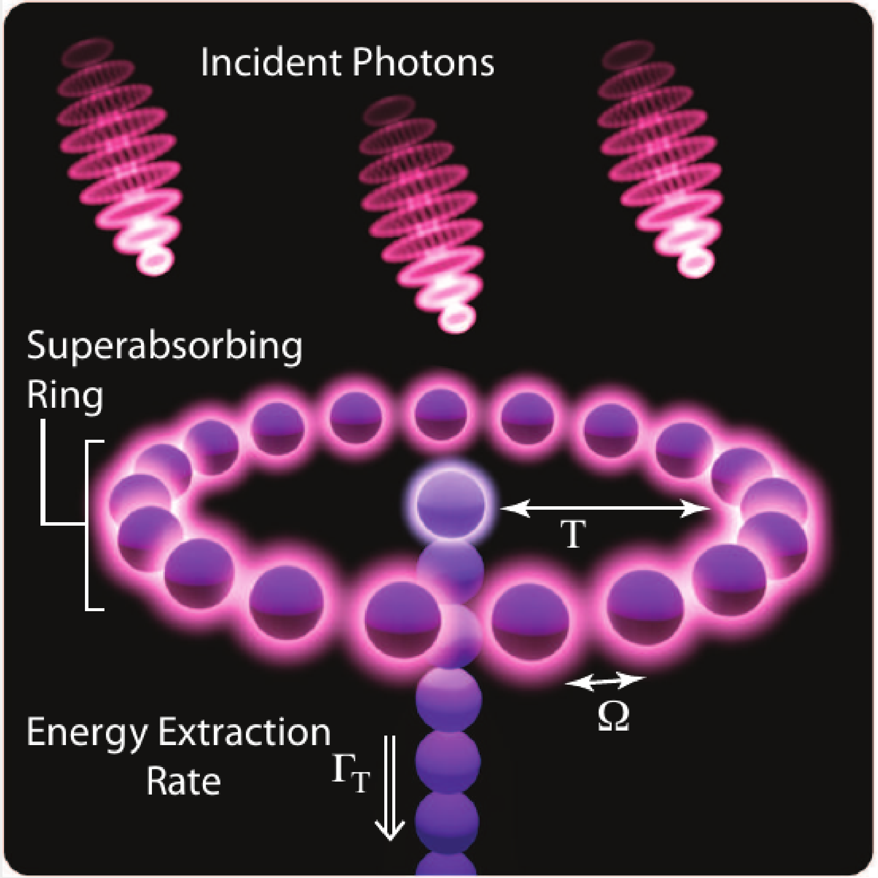
$$[\boldsymbol{H}_I, \boldsymbol{J}^z]_- = 0 \quad [\boldsymbol{H}_I, \boldsymbol{J}^2]_- = 0$$

$$\delta E_M = \Omega_0 \frac{J^2 - M^2}{J - \frac{1}{2}}$$

$$\omega_{M \to M-1} = \omega_A - 4\Omega_0 \frac{M - \frac{1}{2}}{N - 1}$$



From Superradiance to Superabsorption



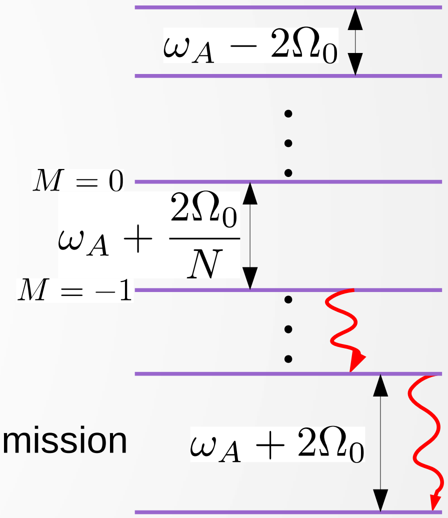
$$\boldsymbol{H}_I = \Omega_0 \sum_{j=1}^{N} \left(\boldsymbol{\sigma}_j^+ \boldsymbol{\sigma}_{j+1}^- + h.c. \right)$$

P.B.C. $\boldsymbol{\sigma}_{N+1}^{\pm} = \boldsymbol{\sigma}_1^{\pm}$

$$[\boldsymbol{H}_I, \boldsymbol{J}^z]_- = 0 \quad [\boldsymbol{H}_I, \boldsymbol{J}^2]_- = 0$$

$$\delta E_M = \Omega_0 \frac{J^2 - M^2}{J - \frac{1}{2}}$$

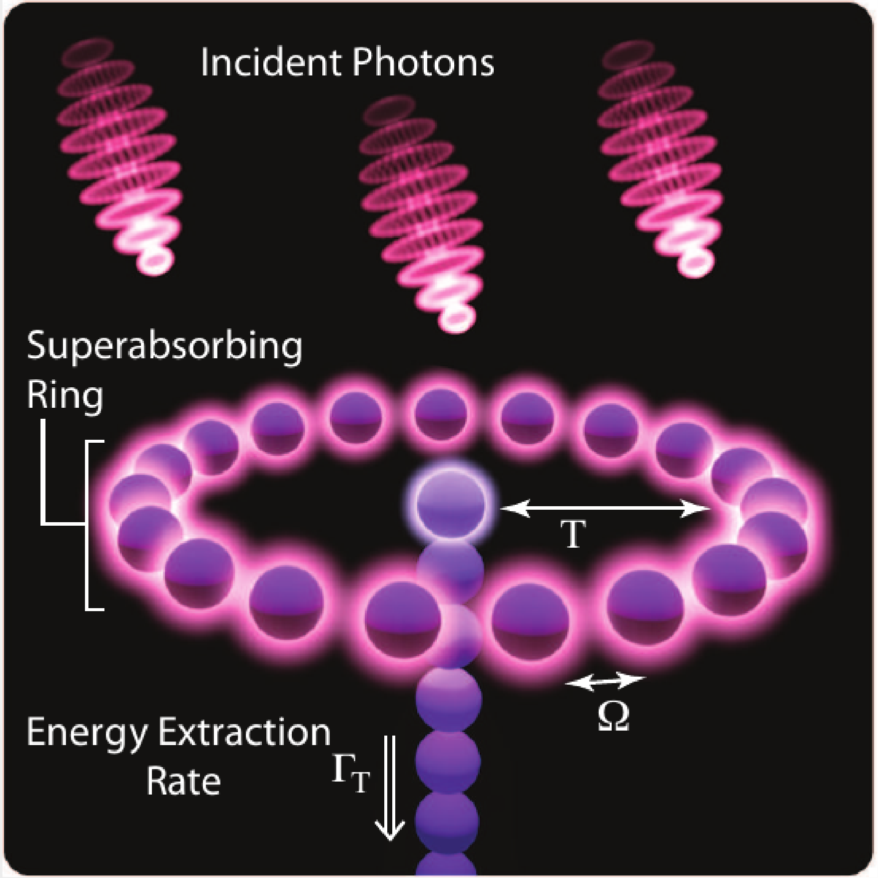
$$\omega_{M \to M-1} = \omega_A - 4\Omega_0 \frac{M - \frac{1}{2}}{N - 1}$$



~~stim.~~+spon. emission

bath engineering!

From Superradiance to Superabsorption



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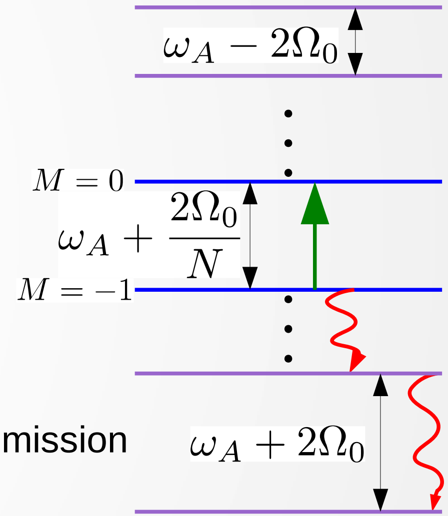
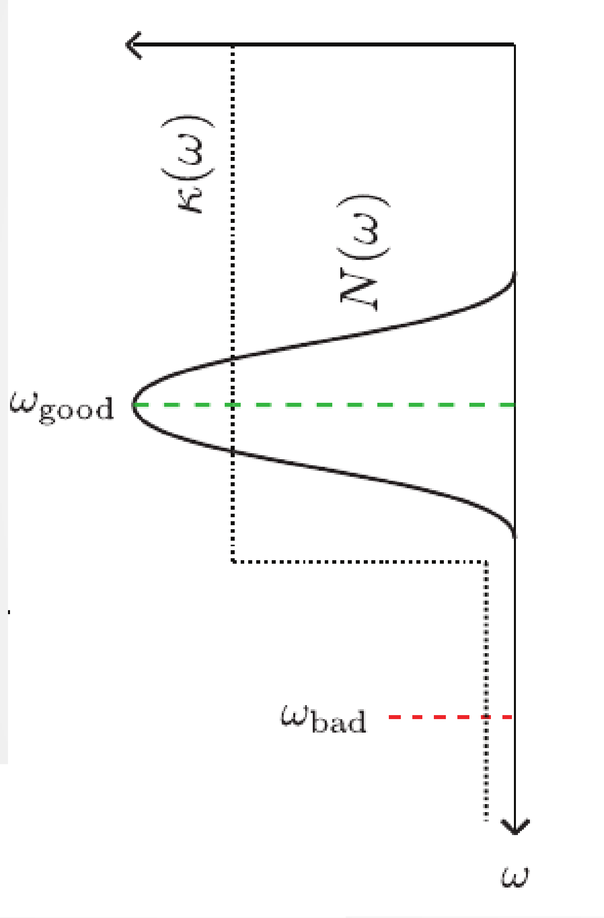


~~stim.~~+spon. emission

bath engineering!

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

From Superradiance to Superabsorption



$$\boldsymbol{H}_I = \Omega_0 \sum_{j=1}^{N} \left(\boldsymbol{\sigma}_j^+ \boldsymbol{\sigma}_{j+1}^- + h.c. \right)$$

P.B.C. $\boldsymbol{\sigma}_{N+1}^{\pm} = \boldsymbol{\sigma}_1^{\pm}$

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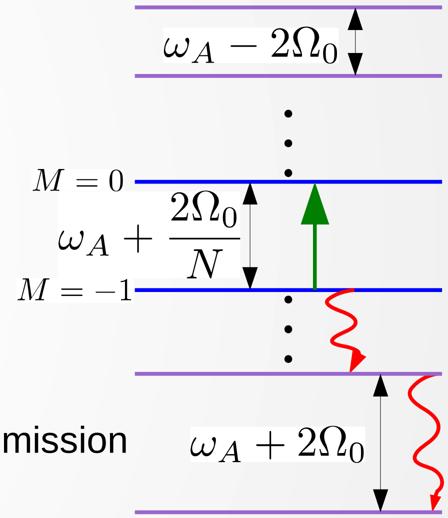

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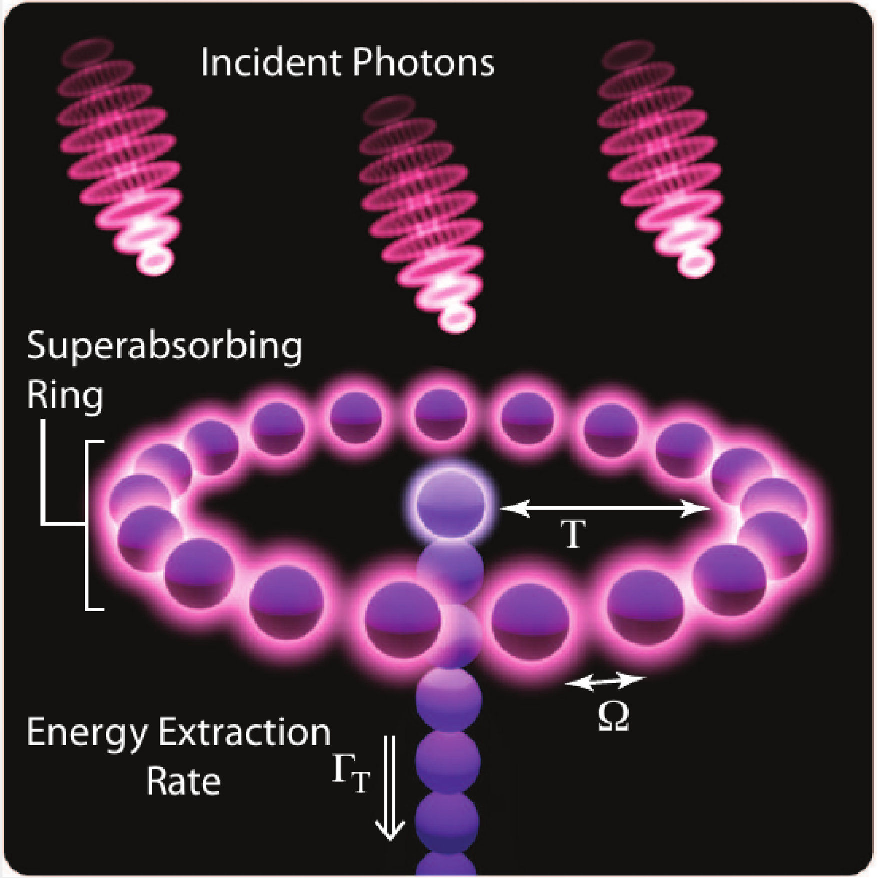
bath engineering!

$$\dot{\rho} = -i[\boldsymbol{H} + \boldsymbol{H}_I, \rho]$$
$$-\gamma \sum_{\beta} \kappa(\omega_\beta) \Big([n(\omega_\beta) + 1] D[\boldsymbol{L}_\beta]\rho + n(\omega_\beta) D[\boldsymbol{L}_\beta^\dagger]\rho \Big)$$

Towards applying superabsorption

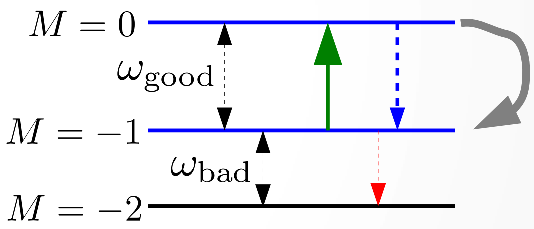


$$\boldsymbol{H}_T = g(\boldsymbol{J}^+\boldsymbol{\sigma}_T^- + h.c.) + \omega_{\text{trap}}\boldsymbol{\sigma}_T^+\boldsymbol{\sigma}_T^-$$

Phenomenological dissipator

$$D[\boldsymbol{L}_{\text{trap}}] \quad \text{with} \quad \boldsymbol{L}_{\text{trap}} = \sqrt{\Gamma_{\text{trap}}}\,|\tfrac{N}{2},-1\rangle\langle\tfrac{N}{2},0|$$

$$\Rightarrow\; I_{\text{trap}}(t) = \Gamma_{\text{trap}}\text{tr}\left[|\tfrac{N}{2},0\rangle\langle\tfrac{N}{2},0|\,\rho(t)\right]$$



$$\omega_{\text{trap}} = \omega_{\text{good}}$$

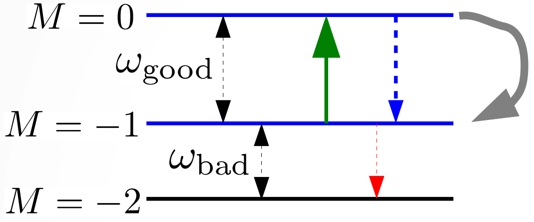
Ideal result:

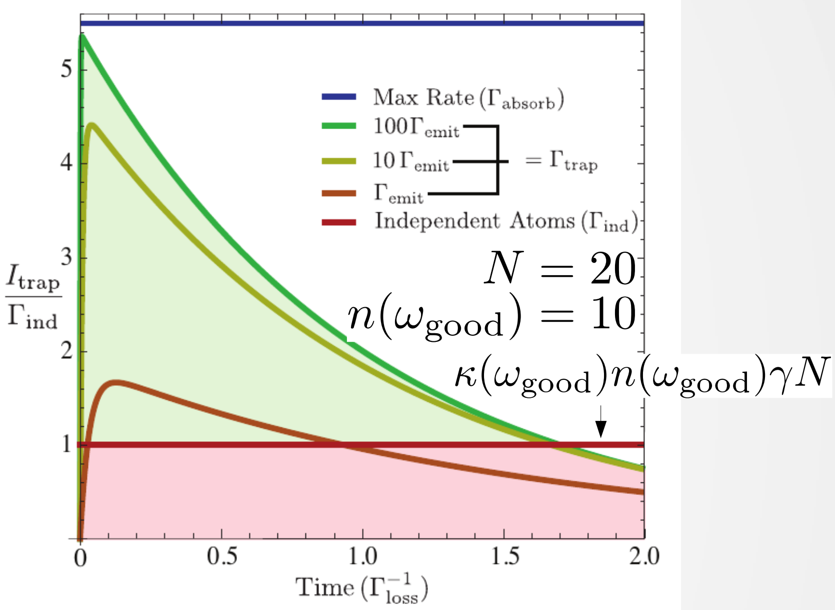
$$\Gamma_{\text{loss}} = \kappa(\omega_{\text{bad}})[n(\omega_{\text{bad}})+1]\Gamma_{-1\to-2} = 0$$

$$\Gamma_{\text{trap}} \gg \Gamma_{\text{emit}} = \kappa(\omega_{\text{good}})[n(\omega_{\text{good}})+1]\Gamma_{0\to-1}$$

$$\Rightarrow\; I_{\text{trap}} = \Gamma_{\text{absorb}} \overset{N\gg 1}{\approx} \gamma\kappa(\omega_{\text{good}})n(\omega_{\text{good}})\left(\frac{N}{2}\right)^2$$

Results for finite Γ_{loss}





1. Assuming ideal optimal feedback

$$I_{\text{trap}} = \Gamma_{\text{absorb}} - \Gamma_{\text{loss}} = (\mu-\sigma)\left(\frac{N}{2}\right)^2 + 2\sigma$$

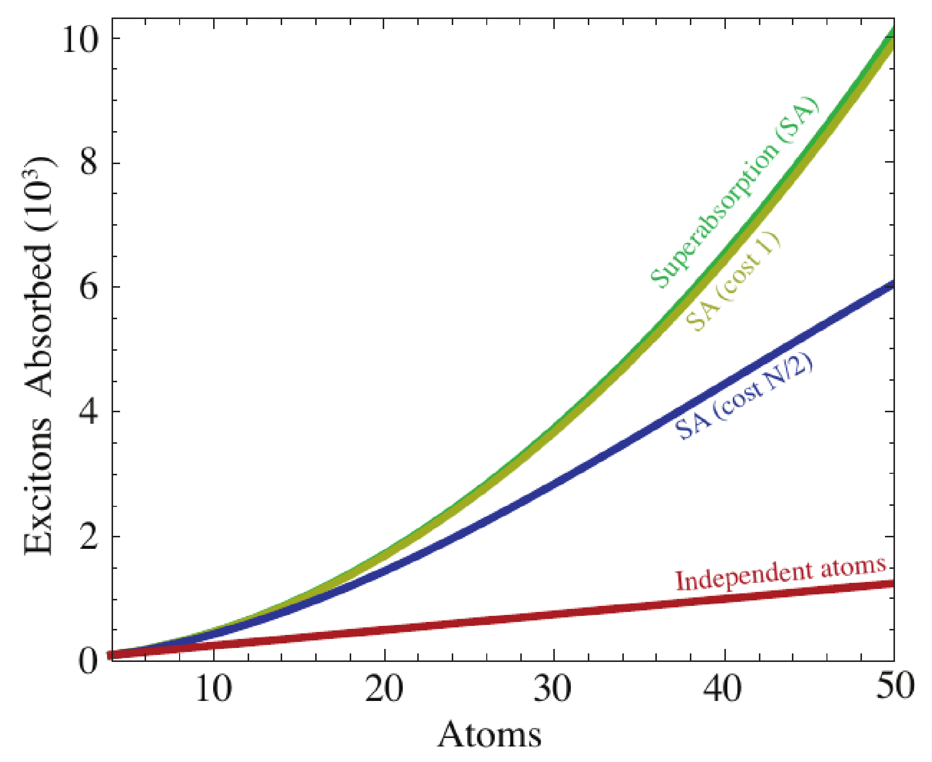
$$\mu = \gamma\kappa(\omega_{\text{good}})n(\omega_{\text{good}})$$

$$\sigma = \gamma\kappa(\omega_{\text{bad}})[n(\omega_{\text{bad}})+1]$$

$\Longrightarrow$ Superabsorption for $\mu > \sigma$

Results for finite Γ_{loss}

2. Reinitialization after $\Gamma_{\text{loss}}^{-1}$



Potential systems and applications

- Molecular rings
- Quantum dots
- Circuit QED
- BEC, optical lattices

- Light harvesting (solar cells)
- Ultra-sensitive optical or microwave sensors