Extracting energy from a quantum battery

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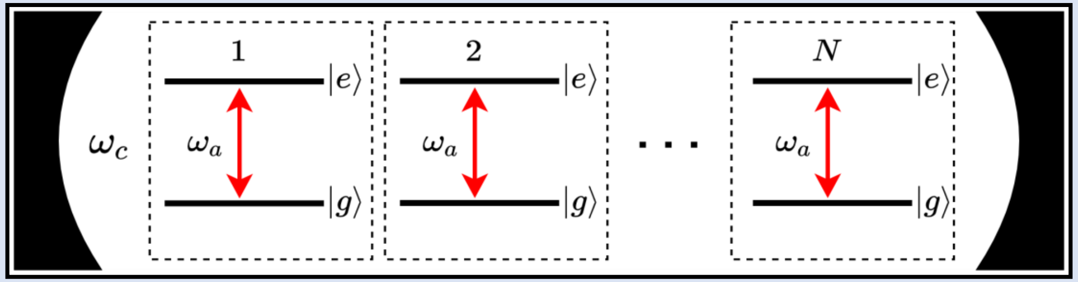
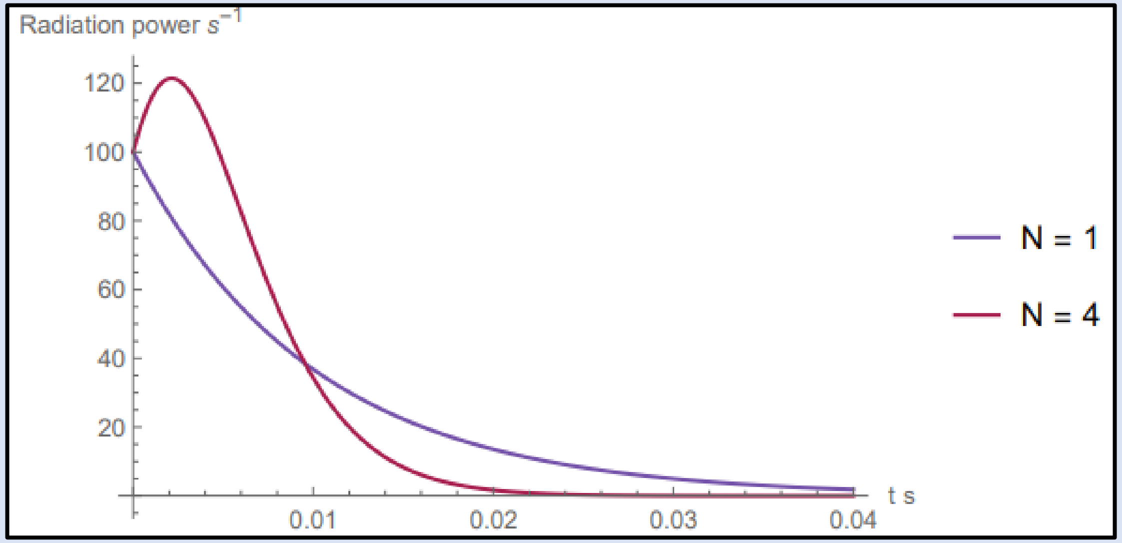
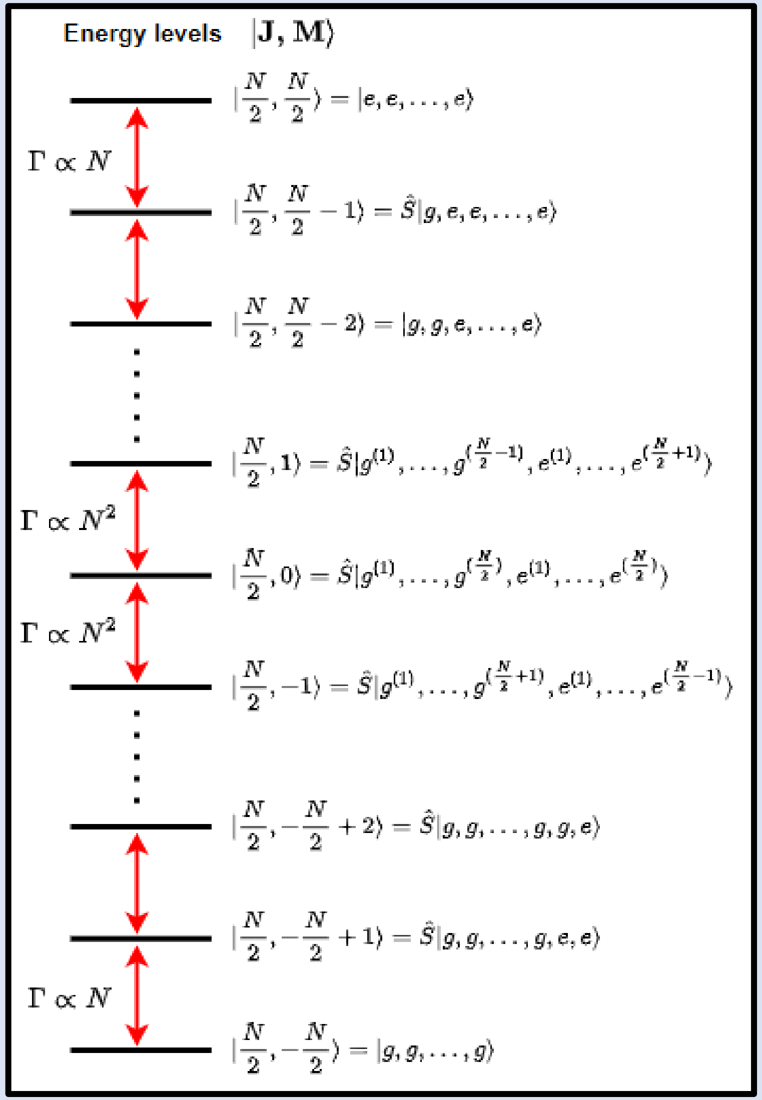
Background & Model



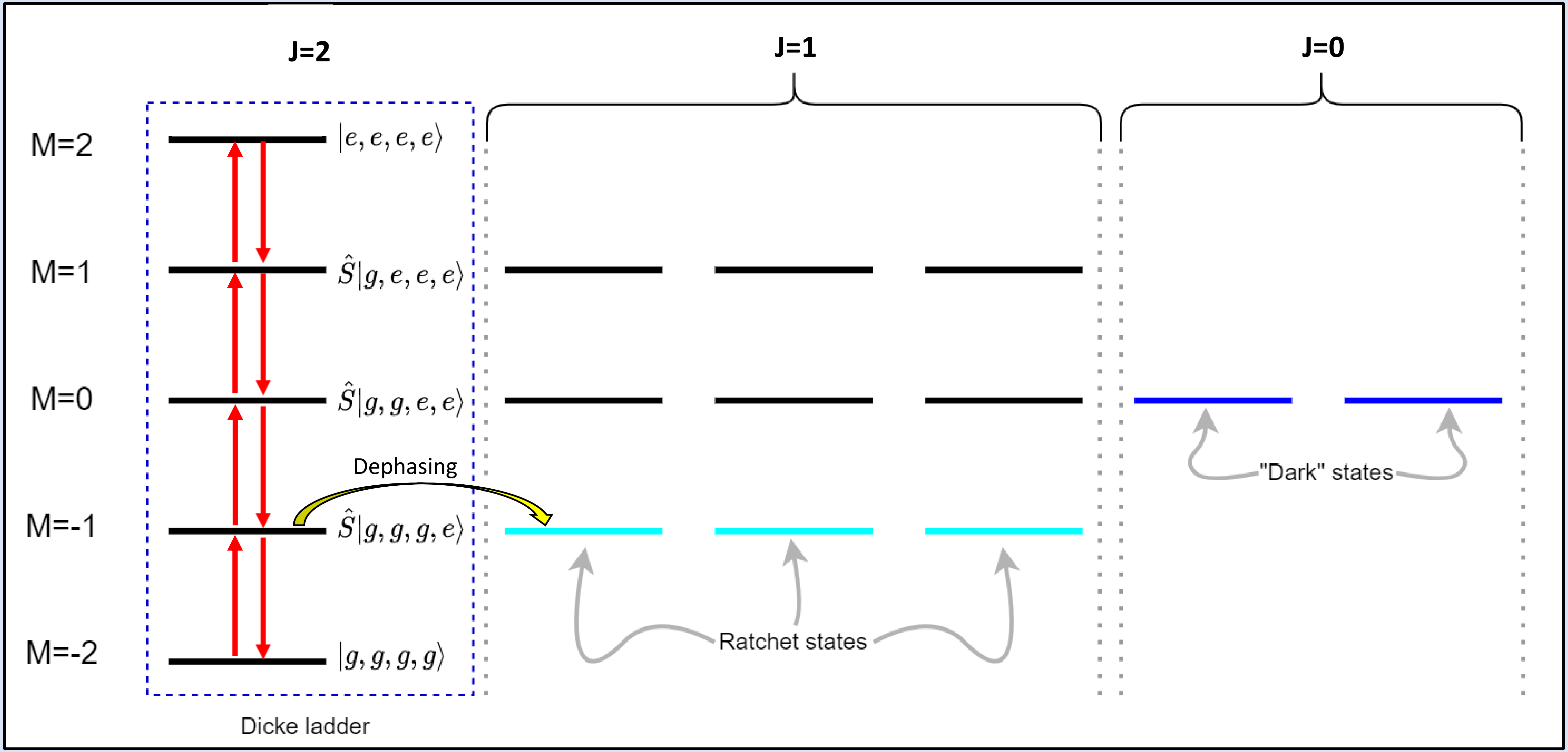
N two-level atoms (of freq ω_a) coupled to a cavity (of freq $\omega_c = \omega_a$)



Rate at which excitations are emitted from a single atom that is apart of a 4-atom coupled system (N = 4) and from a single atom which is isolated (N = 1)



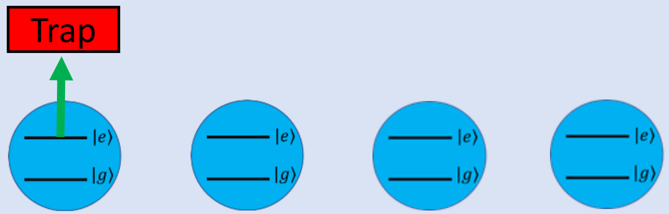
Dicke ladder of symmetric $|J,M\rangle$ states with $J = \frac{N}{2}$.

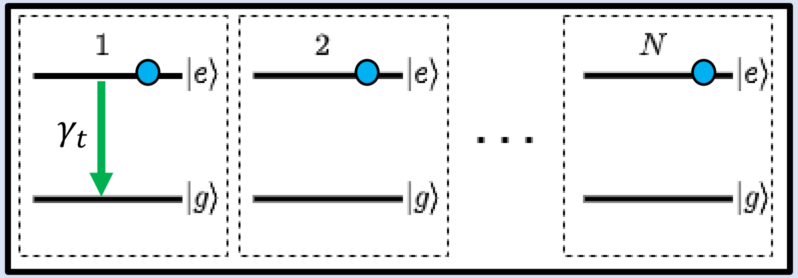


$|J, M\rangle$ states for a 4-atom system represented by spin ½ particles, $|\uparrow\rangle = |e\rangle$ and $|\downarrow\rangle = |g\rangle$.

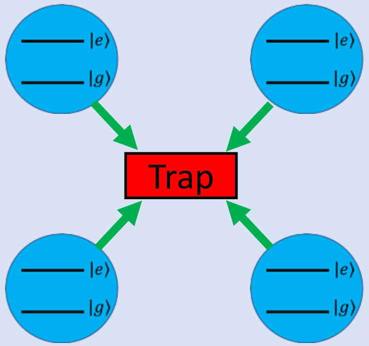
Trap coupling

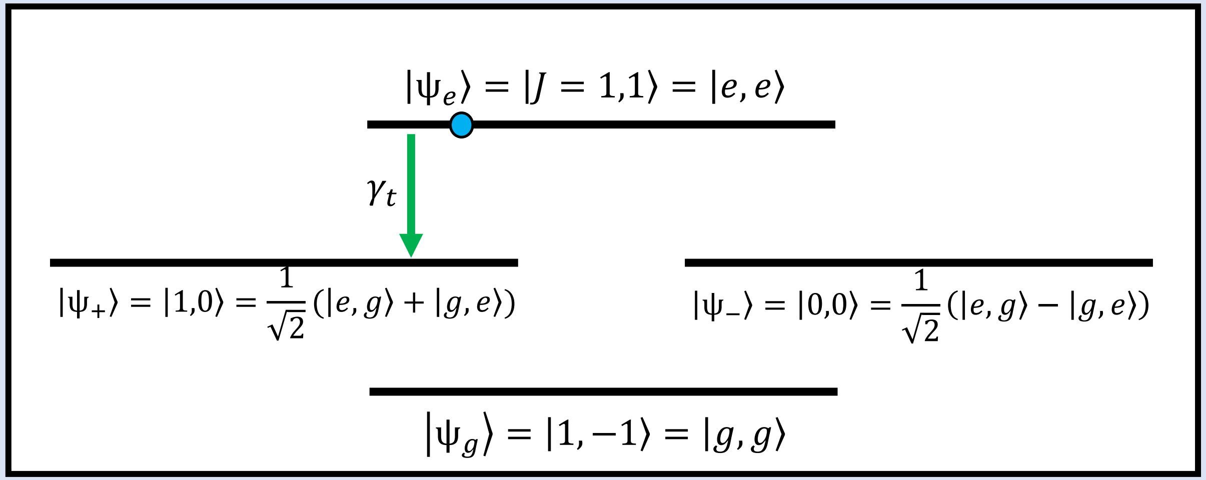
- Singular trap (trap 1)





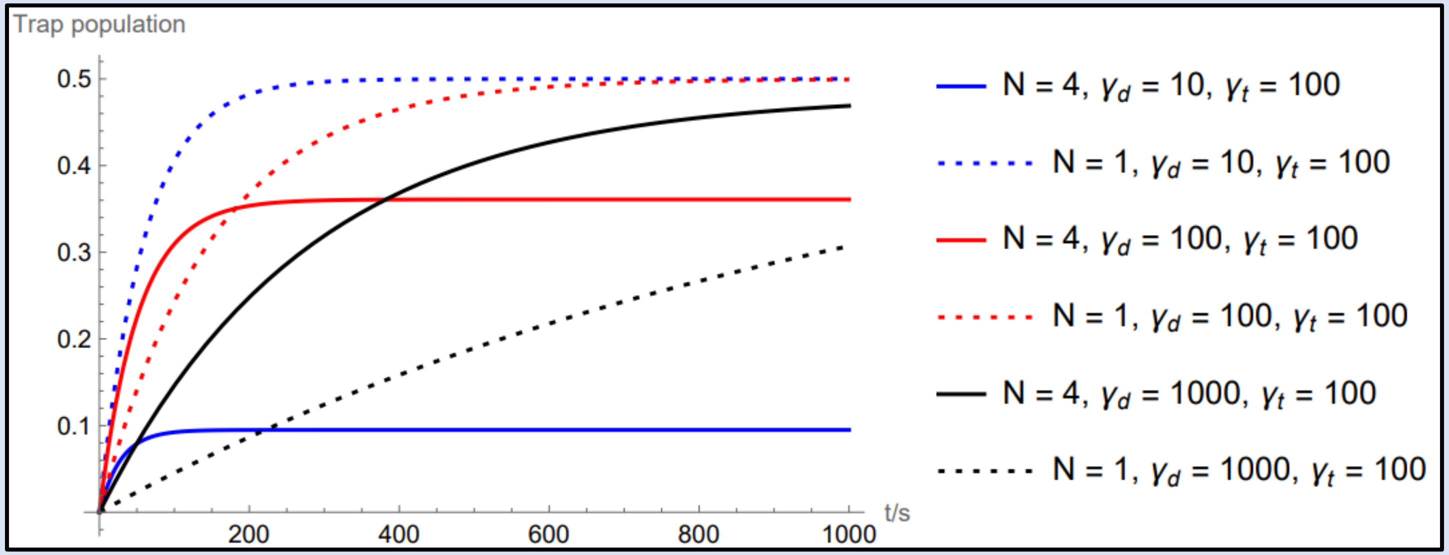
- Collective trap (trap 2)



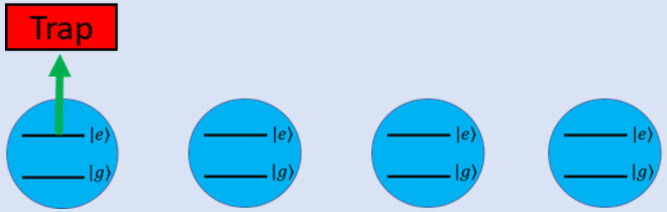


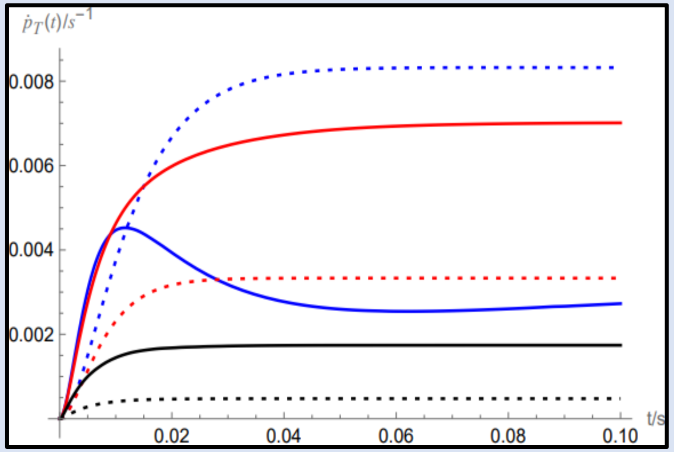
Energy levels of a two-atom system

Singular trap: Dephasing

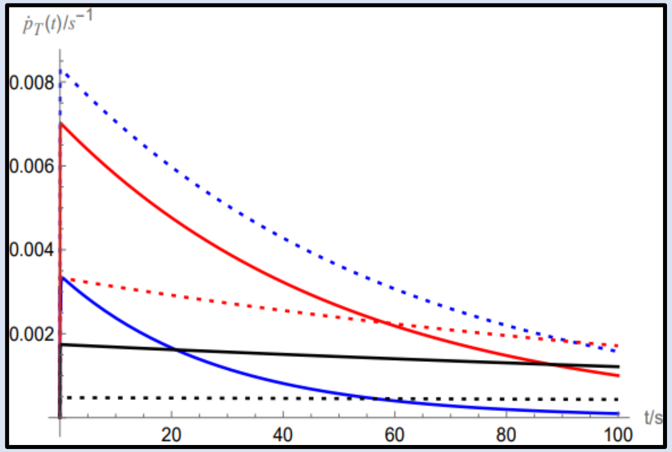


Trap population of coupled system (N=4) and individual atoms (N=1) for different dephasing rates. ($\gamma_t = 100, \gamma_o = 100$).





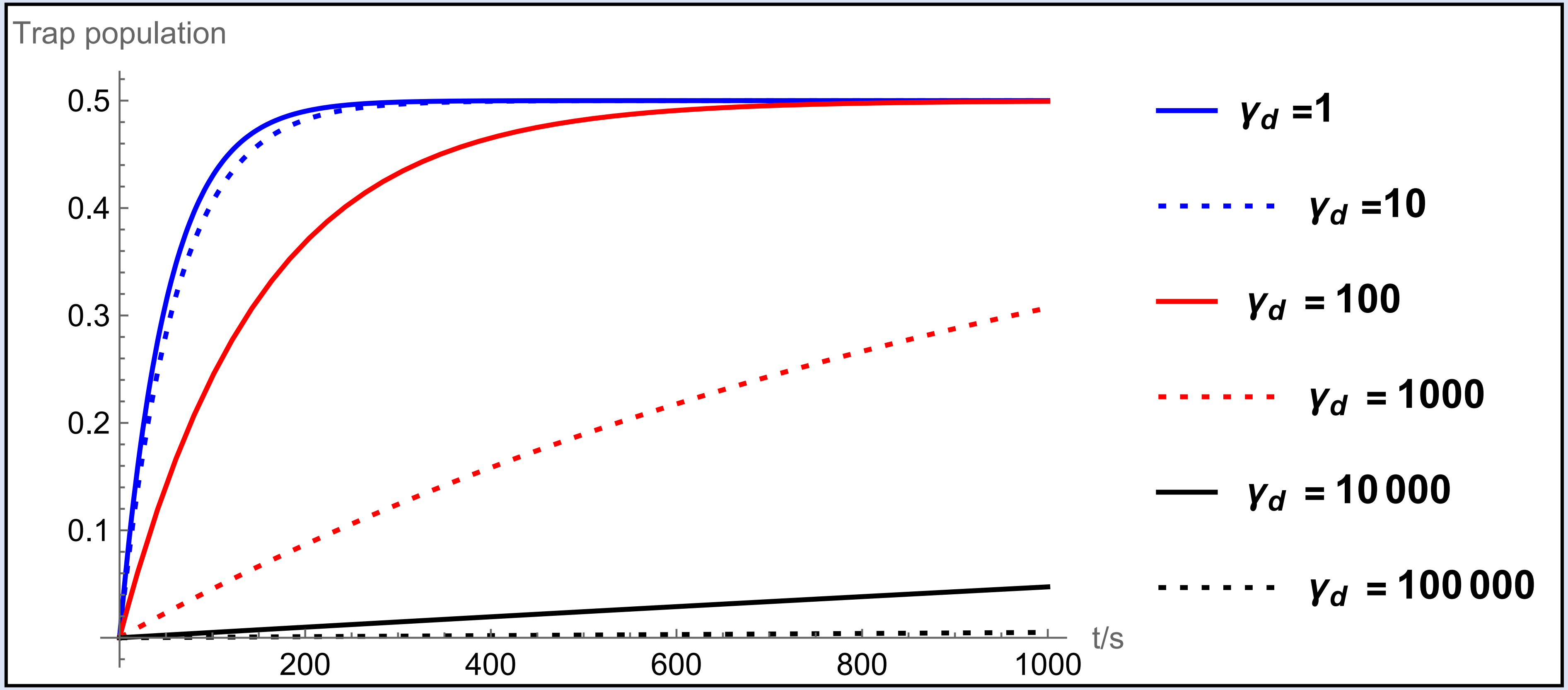
Trap charging rate (for small times)



Trap charging rate (for large times)

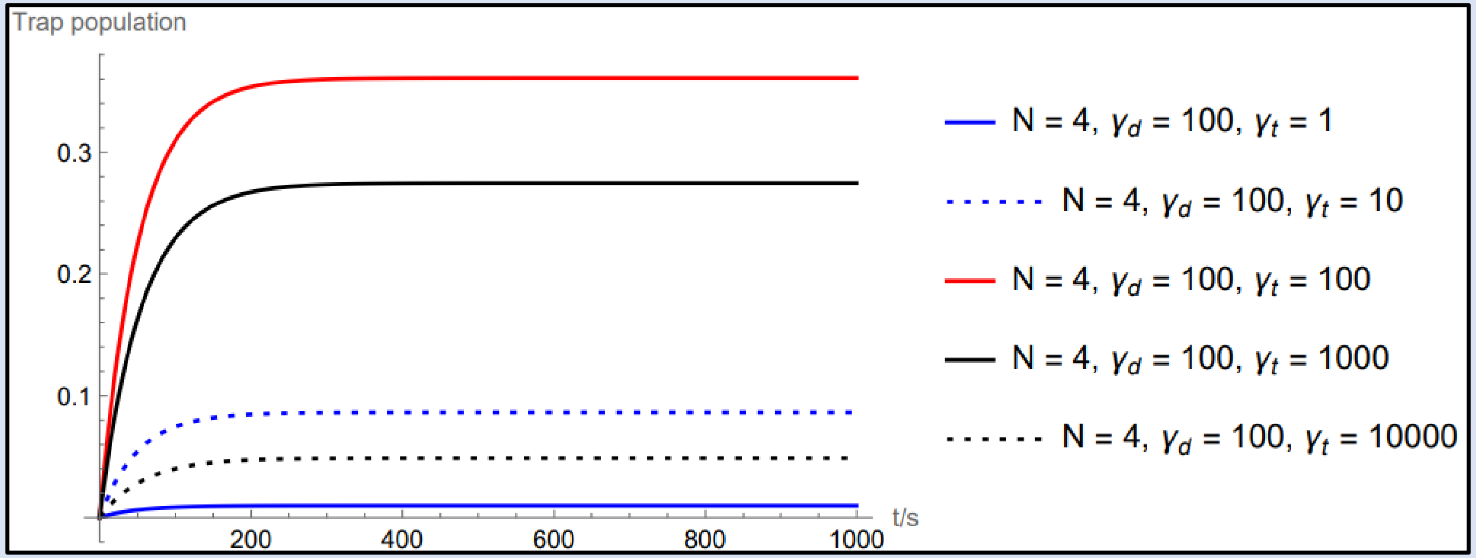
All rates defined relative to the atom light coupling constant, g (10 neV). So, $\gamma_d = 100$ is really $\gamma_d = 100g$.

Bleaching

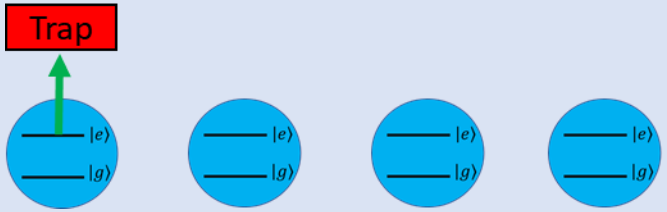


Trap population for a trap coupled to a single independent atom for different dephasing rates. $\gamma_t = 100, \gamma_o = 100.$

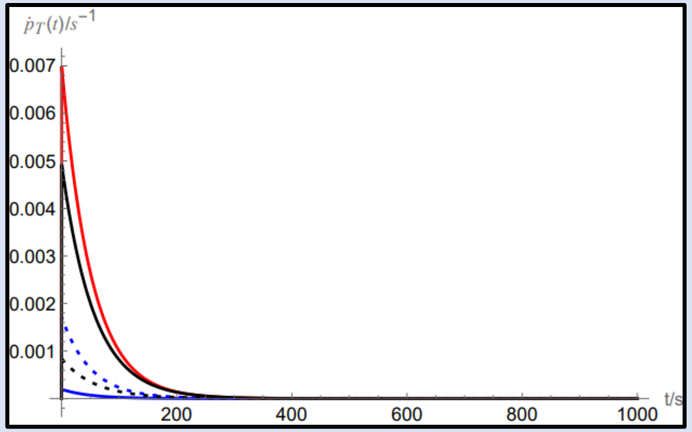
Singular trap: Extraction rate



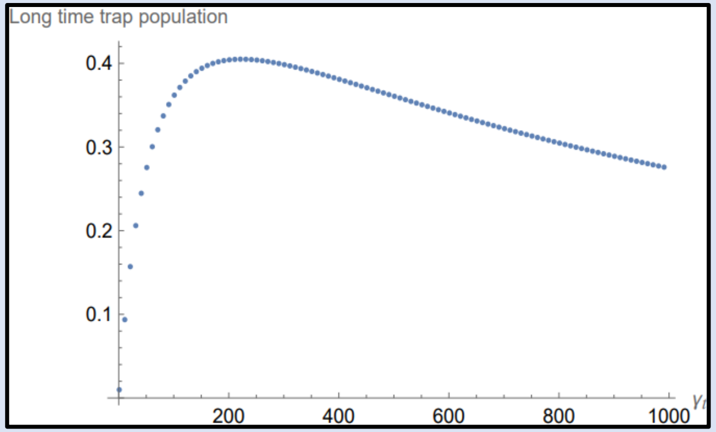
Trap population of coupled system for different extraction rates. ($\gamma_d = 100, \gamma_o = 100$).



Quantum Zeno effect



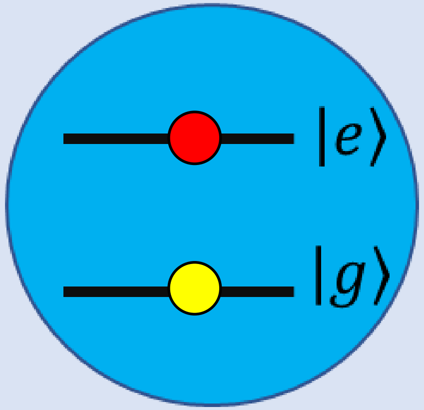
Trap charging rate



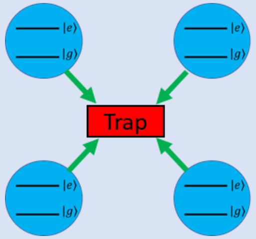
Long time trap population (max pop) as a function of γ_t

Quantum Zeno effect

- The continuous observation of a system forces the system to remain in the same state. Therefore, not allowing it to evolve.



Collective trap: Extracting excitations



From a single atom: $\boxed{\hat{\sigma}_+\hat{\sigma}_-}$

From system collectively: $\hat{J}_+\hat{J}_-$

where, $J_+ = \sum_i \sigma_+^i$ and $J_- = \sum_i \sigma_-^i$

$$J_+J_- = \sum_{i,j} \sigma_+^i \sigma_-^j = \sum_i \boxed{\sigma_+^i \sigma_-^i} + \sum_{i \neq j} \sigma_+^i \sigma_-^j$$

Energy levels of a 2-atom system:

$|\psi_e\rangle = |e,e\rangle$

$|\psi_+\rangle = \frac{1}{\sqrt{2}}(|e,g\rangle + |g,e\rangle)$ $\quad$ $|\psi_-\rangle = \frac{1}{\sqrt{2}}(|e,g\rangle - |g,e\rangle)$

$|\psi_g\rangle = |g,g\rangle$

Dicke ladder

$$\langle\psi_e|J_+J_-|\psi_e\rangle = 2$$

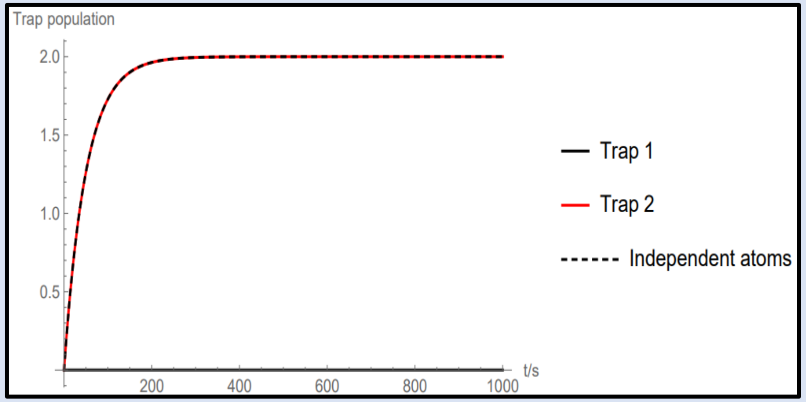
$$\langle\psi_g|J_+J_-|\psi_g\rangle = 0$$

$$\langle\psi_-|J_+J_-|\psi_-\rangle = 0$$

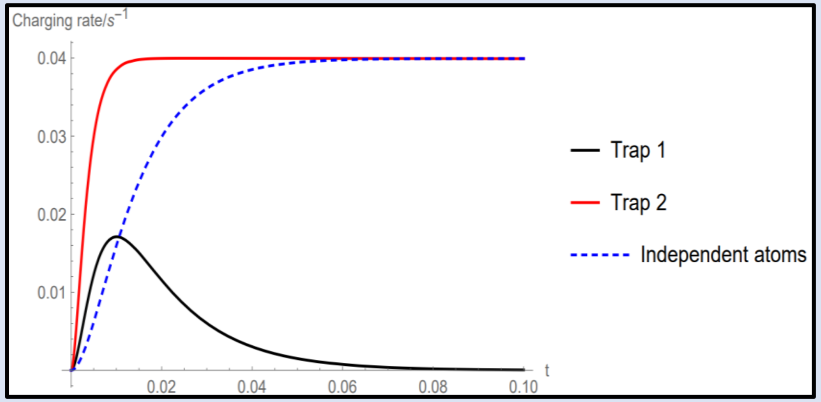
$$\langle\psi_+|J_+J_-|\psi_+\rangle = 2$$

Singular (trap 1) vs Collective (trap 2)

$\gamma_d = 0$

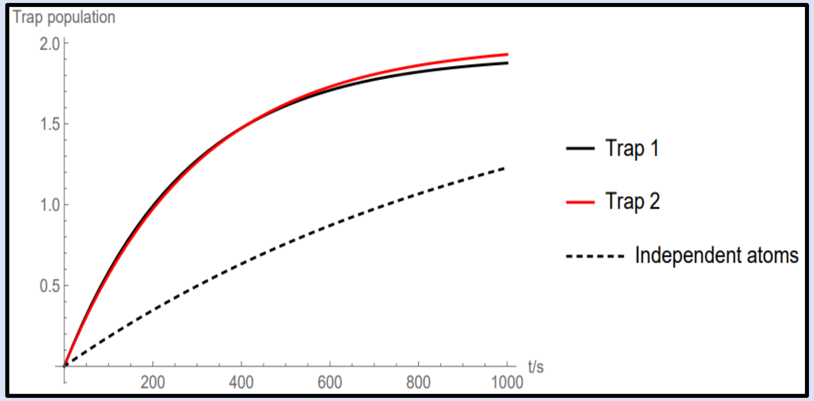


Trap population

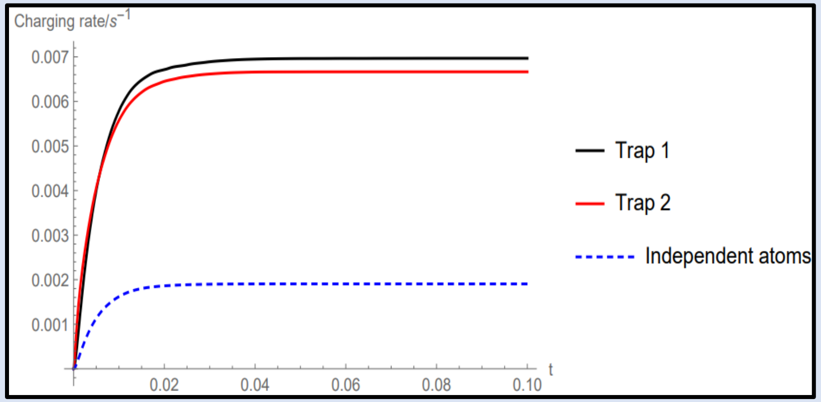


Trap charging rate (for small times)

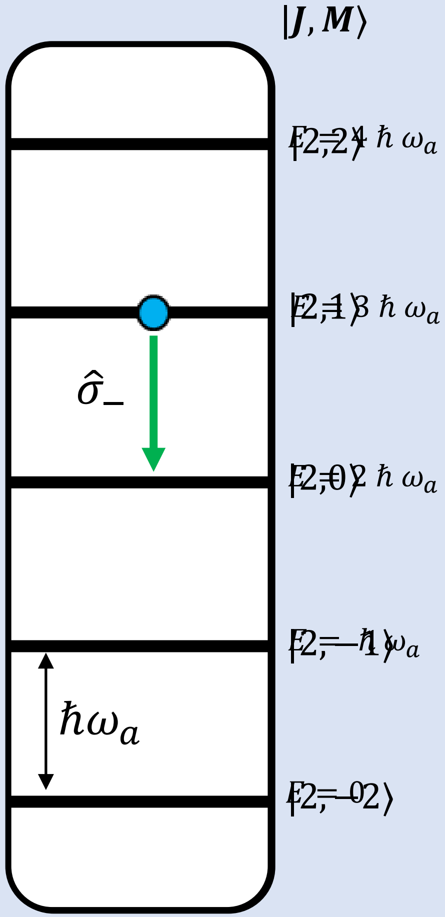
$\gamma_d = 1000$



Trap population

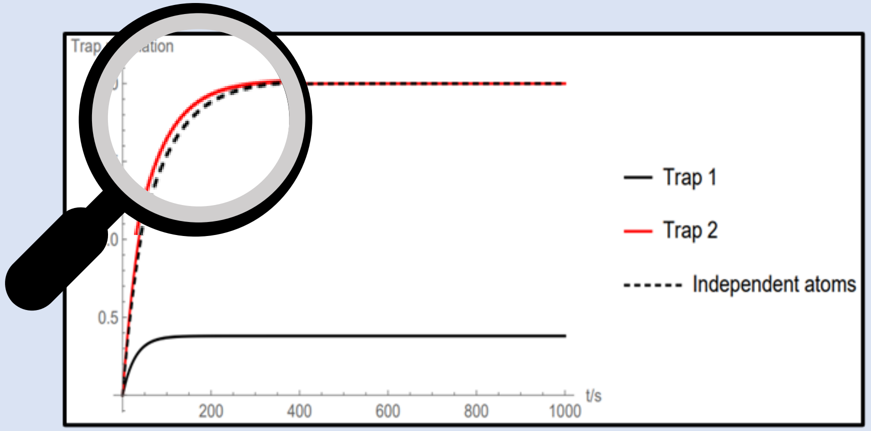


Trap charging rate (for small times)

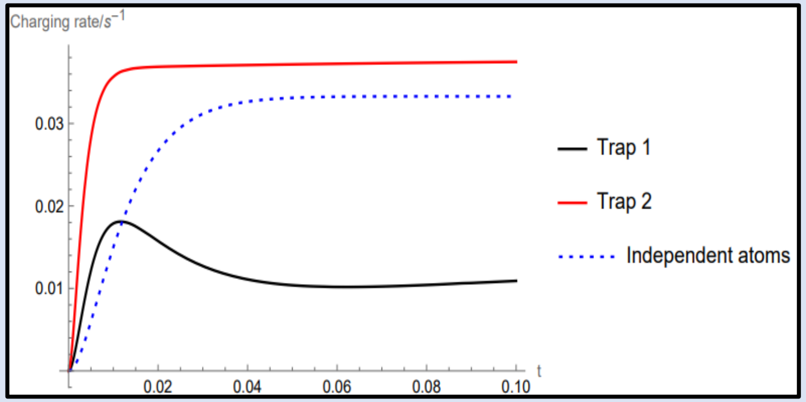


Singular (trap 1) vs Collective (trap 2)

$\gamma_d = 10$

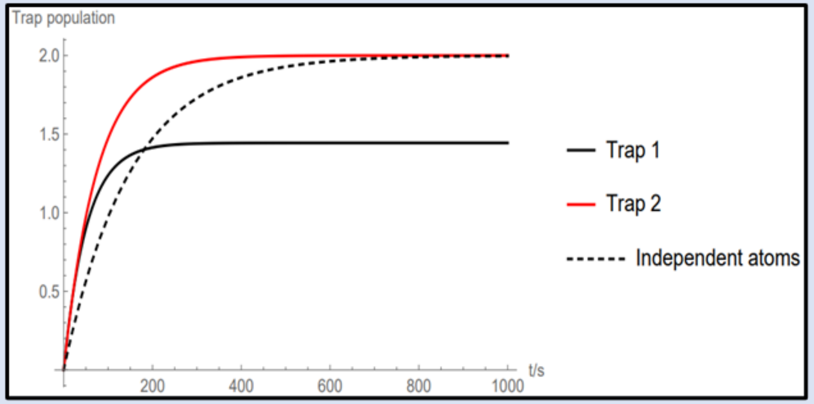


Trap population

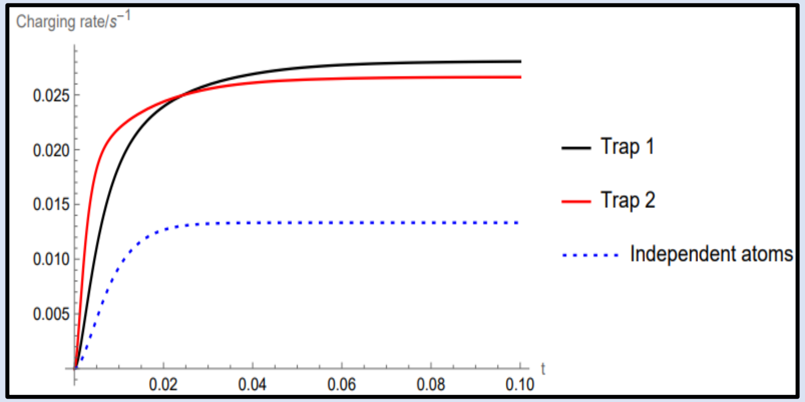


Trap charging rate (for small times)

$\gamma_d = 100$

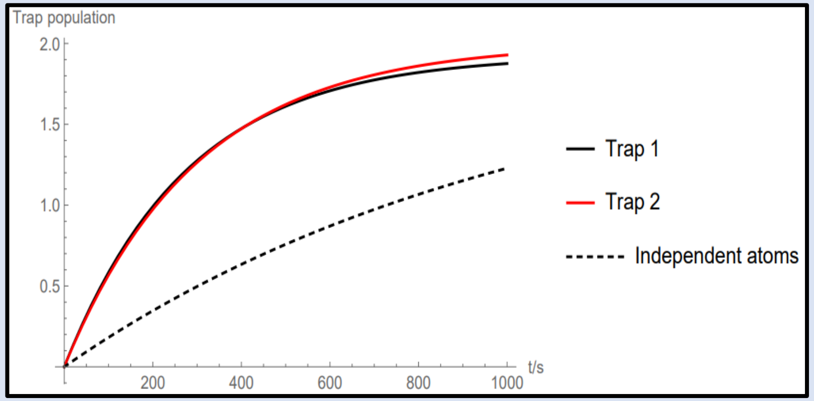


Trap population

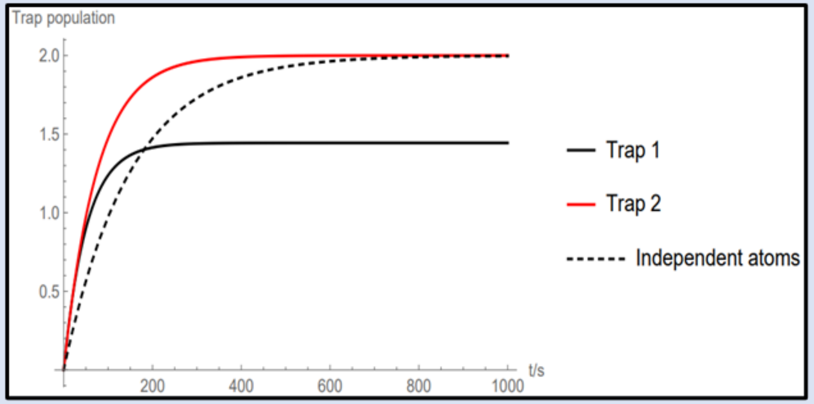


Trap charging rate (for small times)

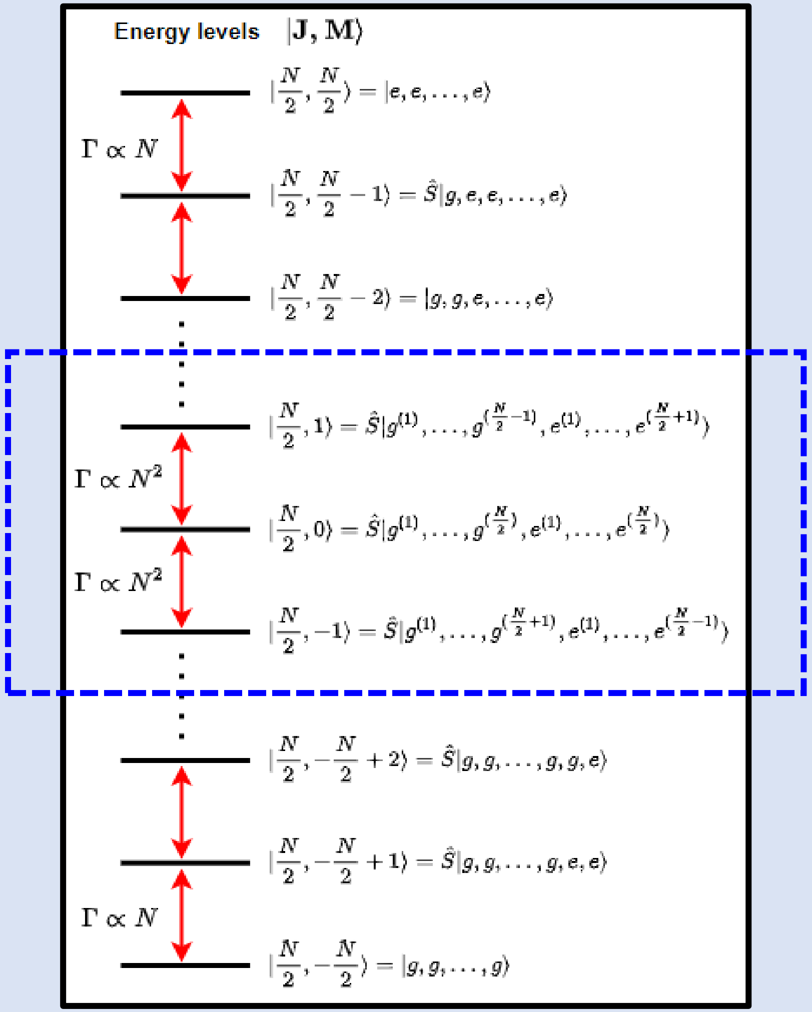
Conclusion



Trap population for larger dephasing ($\gamma_d = 1000$)



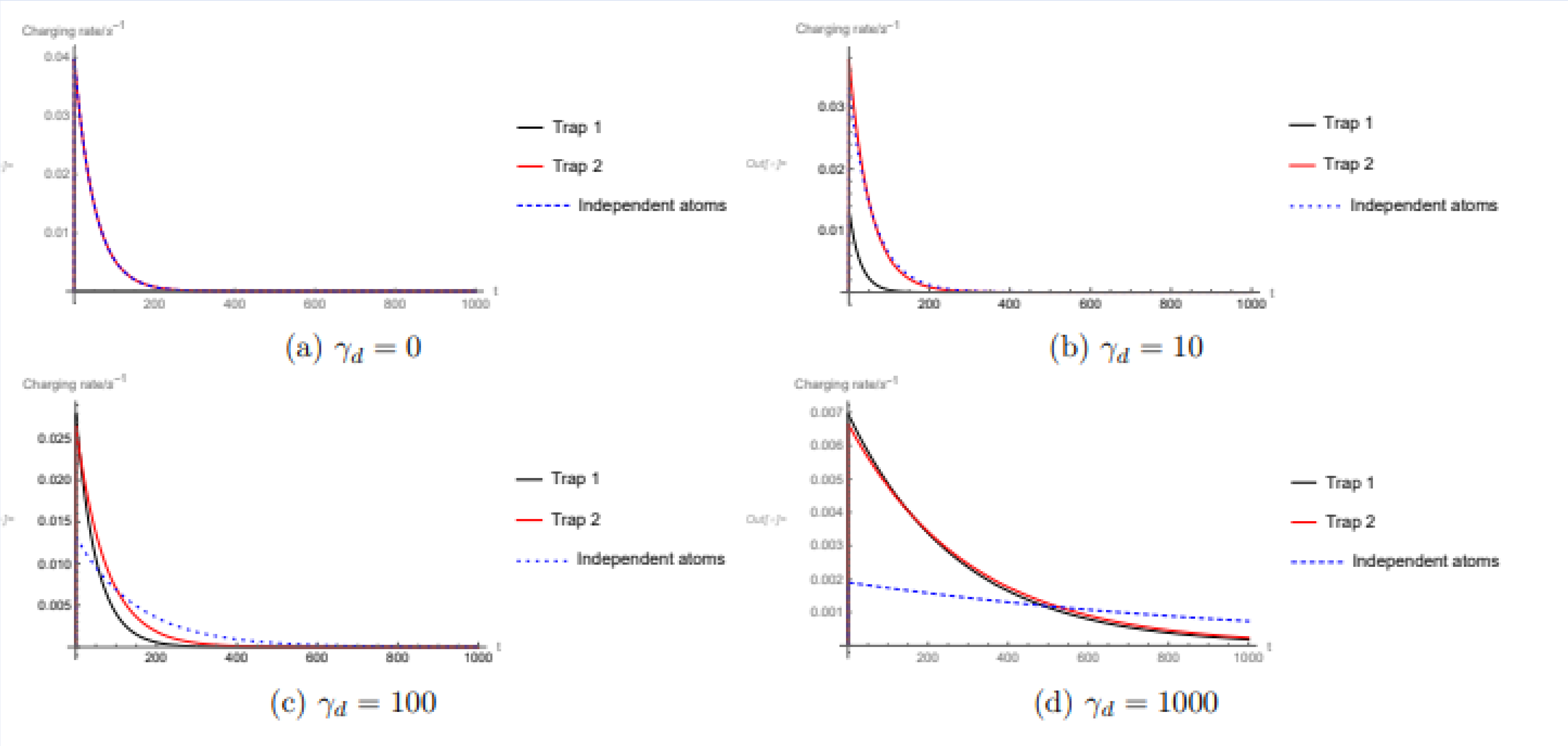
Trap population for $\gamma_d = 100$



Dicke ladder

See : Higgins, K. et al. Superabsorption of light via quantum engineering. Nature communications 5, 4705 (2014). https://doi.org/10.1038/ncomms5705

Degree = fin



(a) $\gamma_d = 0$

(b) $\gamma_d = 10$

(c) $\gamma_d = 100$

(d) $\gamma_d = 1000$

Rate of emission for $|J = \frac{N}{2}, M\rangle$ state, $\Gamma = \Gamma_0 \left(\frac{N}{2} + M\right)\left(\frac{N}{2} - M + 1\right)\hbar^2$, where Γ_0 is the emission rate of a single two-level atom.