Storage and release of light in subradiant excitations of dense atomic clouds

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Collective decay in dense atomic clouds

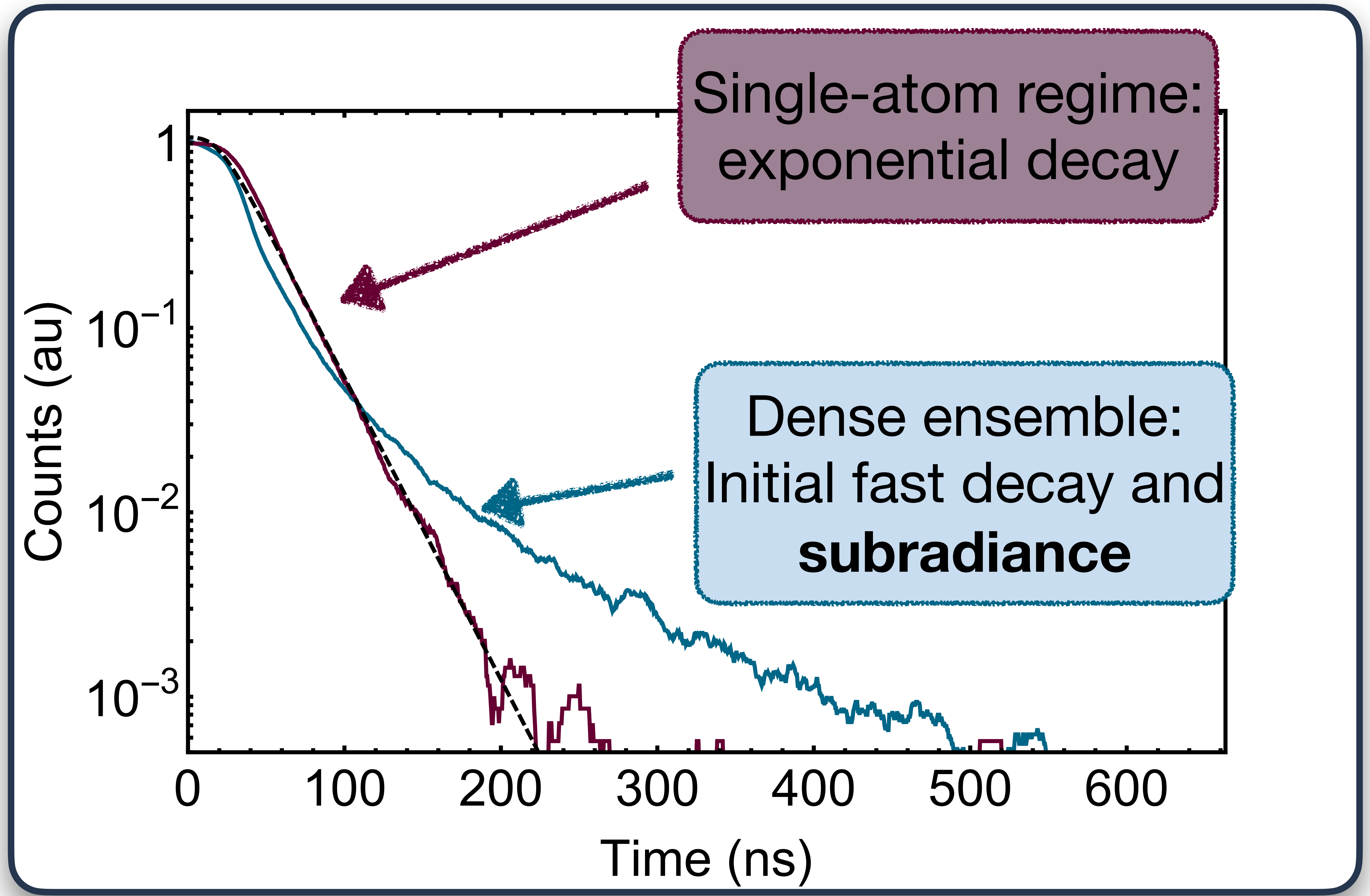
^{87}Rb, on the D2 line λ_0 = 780 nm, Γ_0 = 6 MHz

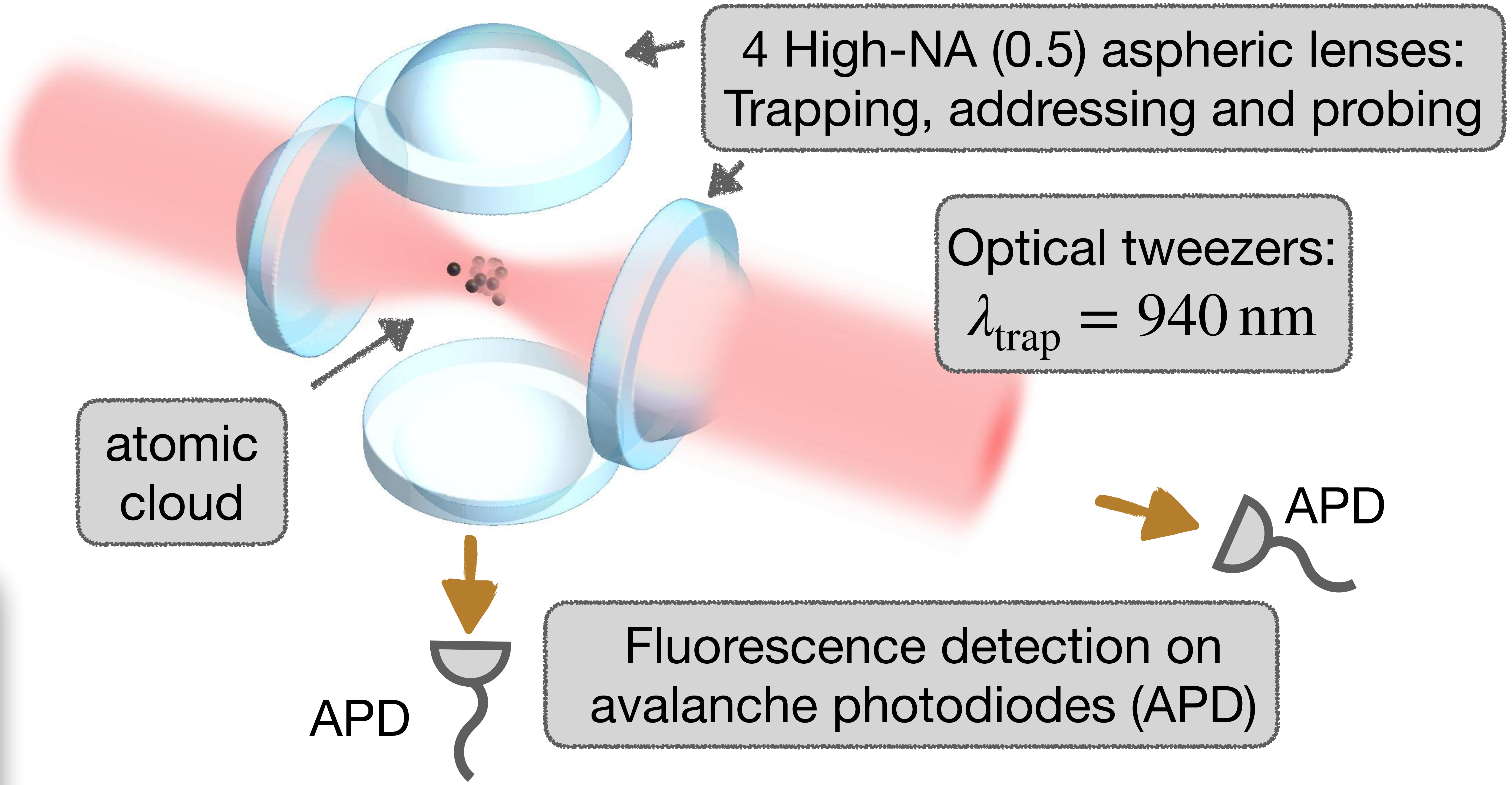
Λ-enhanced gray molasses loading

Dipole trap, tuneable waist (~1.8 - 3.5 µm)

Clouds of N = 100 - 5000 atoms

Density from $\sim 5 \times 10^{12}$ up to $\sim 10^{15}\,\mathrm{cm}^{-3}$

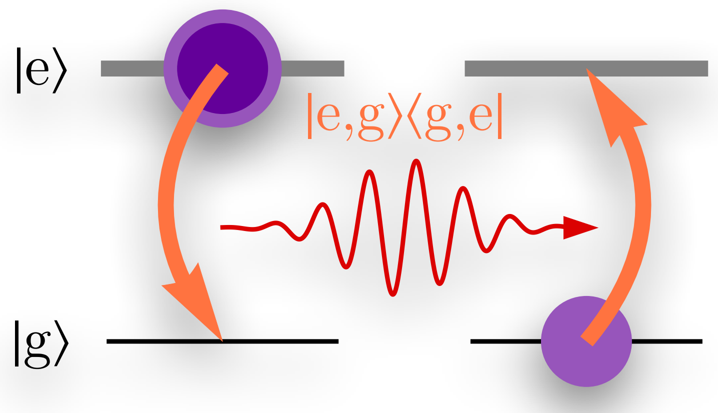




High density $(n/k_0^3 > 1)$: **strong coupling.**

Small sizes $(\sigma_r/\lambda_0 \simeq 0.5,\ \sigma_z/\lambda_0 \simeq 5)$: **Dicke's regime.**

Light-induced resonant dipole-dipole interaction

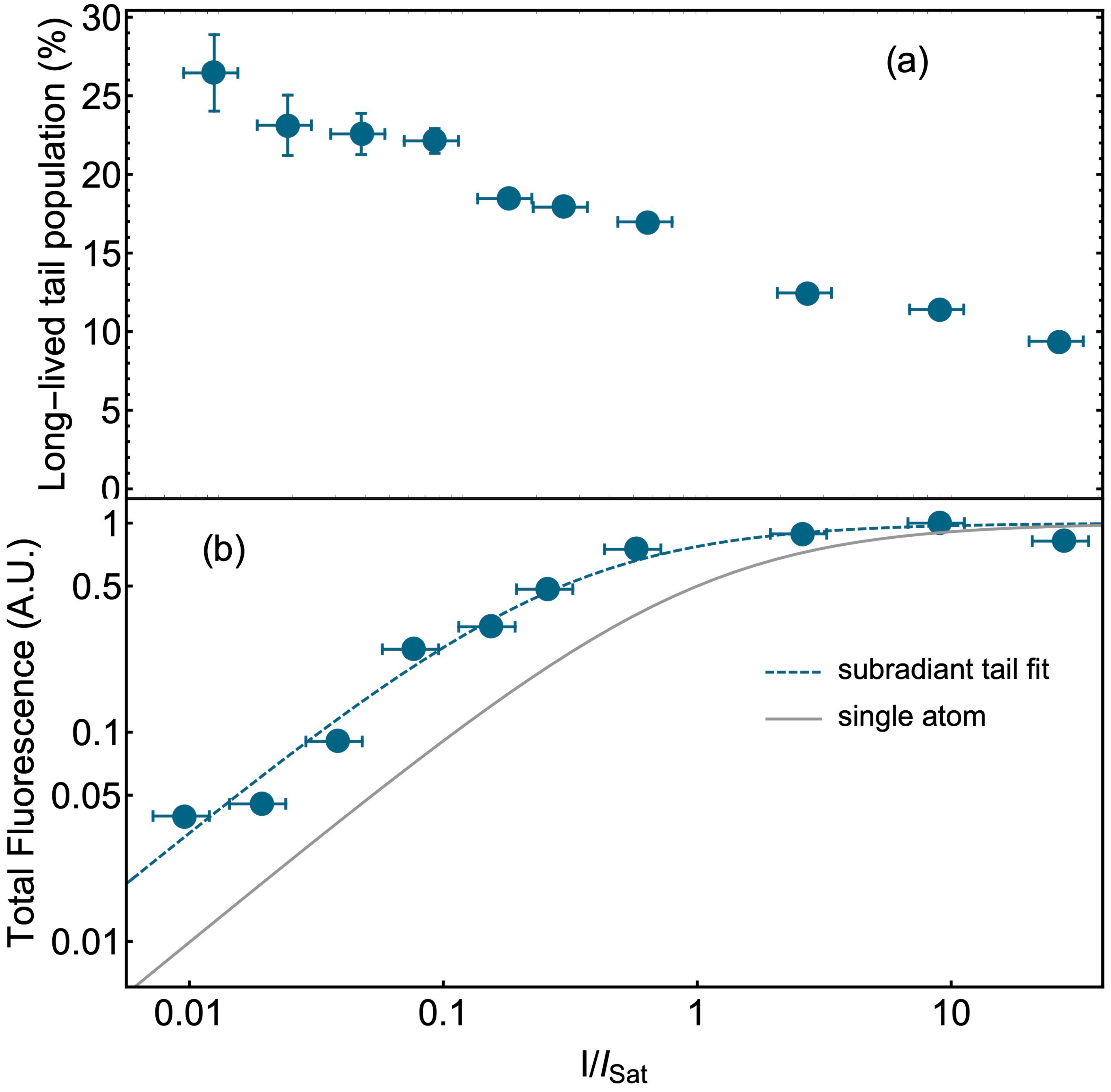


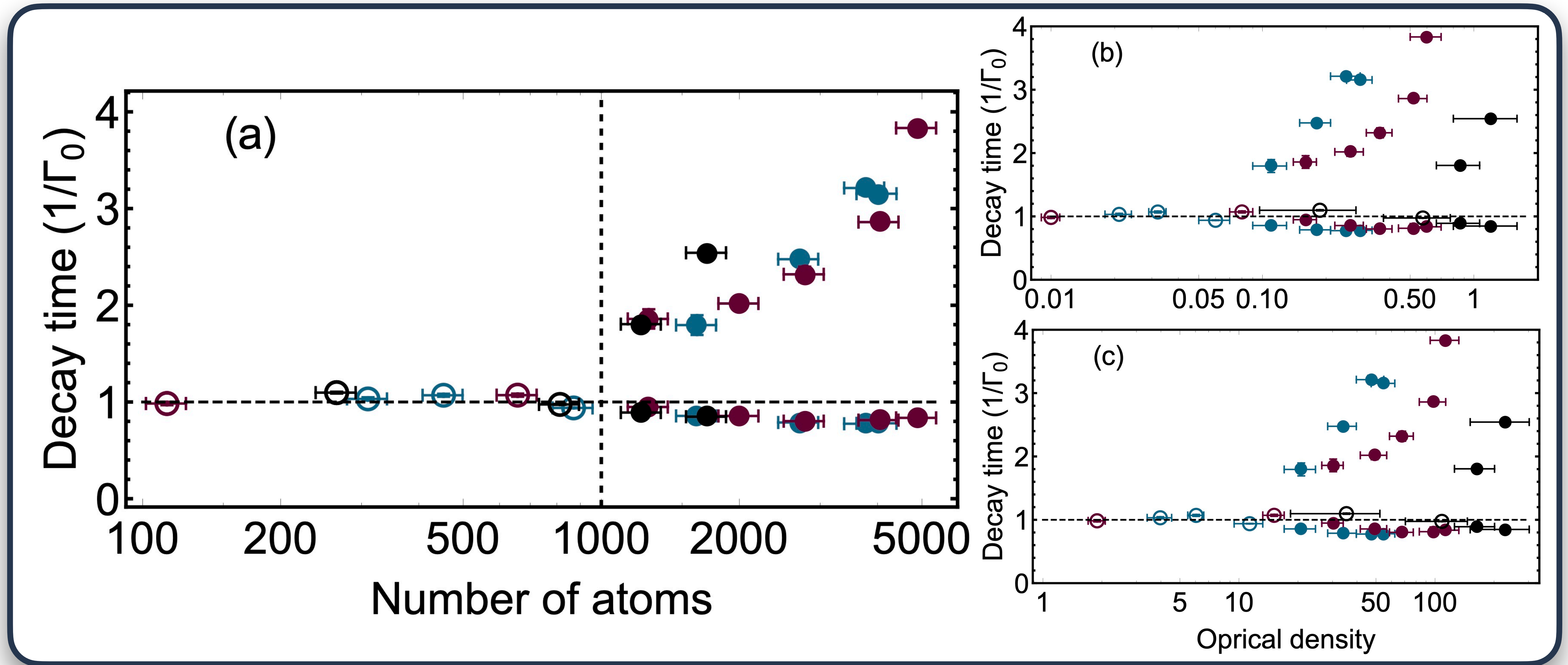
$$\frac{1}{k_0 r},\ \frac{1}{(k_0 r)^2},\ \frac{1}{(k_0 r)^3}$$

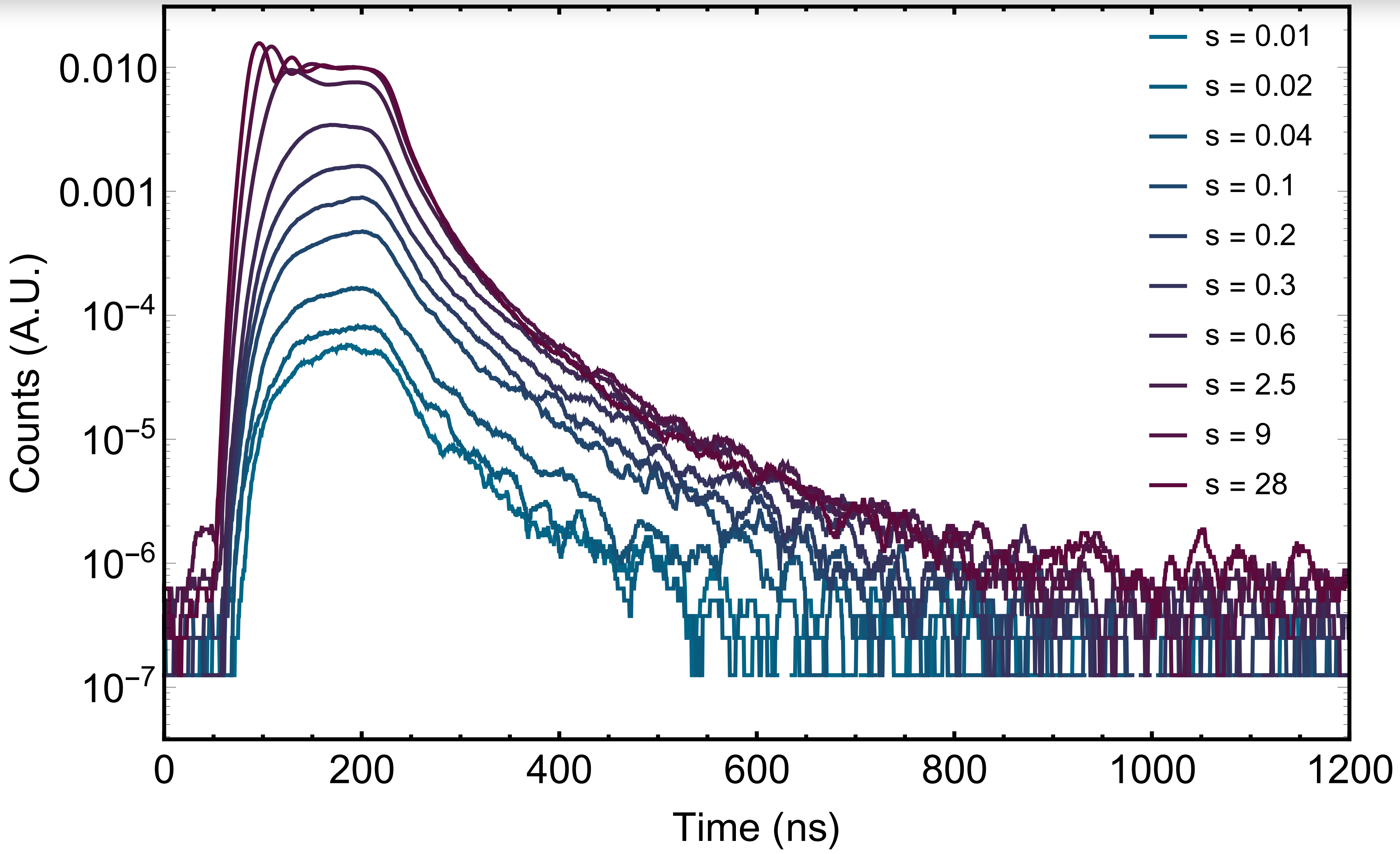
Subradiance close to Dicke's regime

Cooperativity parameter: atom number N
Signature of Dicke's regime (scattering in a few modes)

Photon mean free path $l = \dfrac{1}{n\,6\pi\,k_0^{-2}} \ll n^{-1/3}$

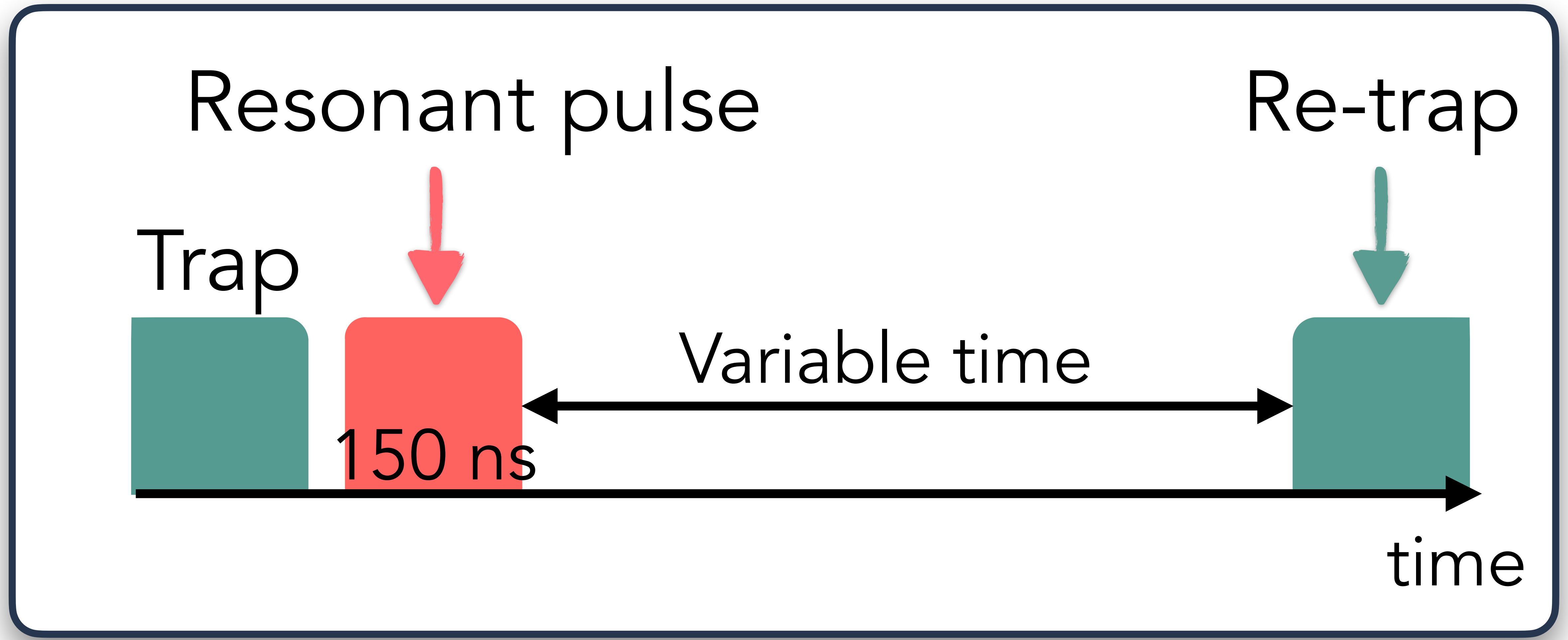


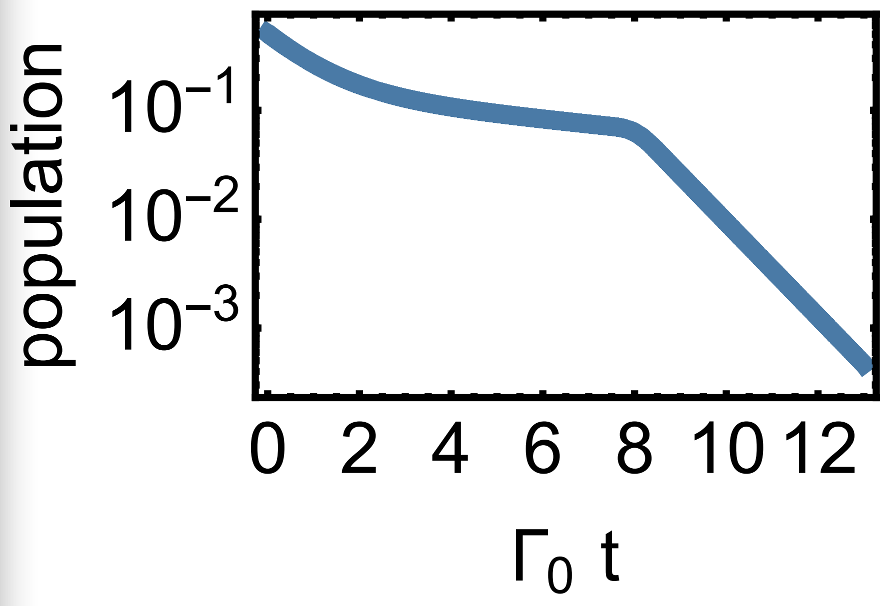




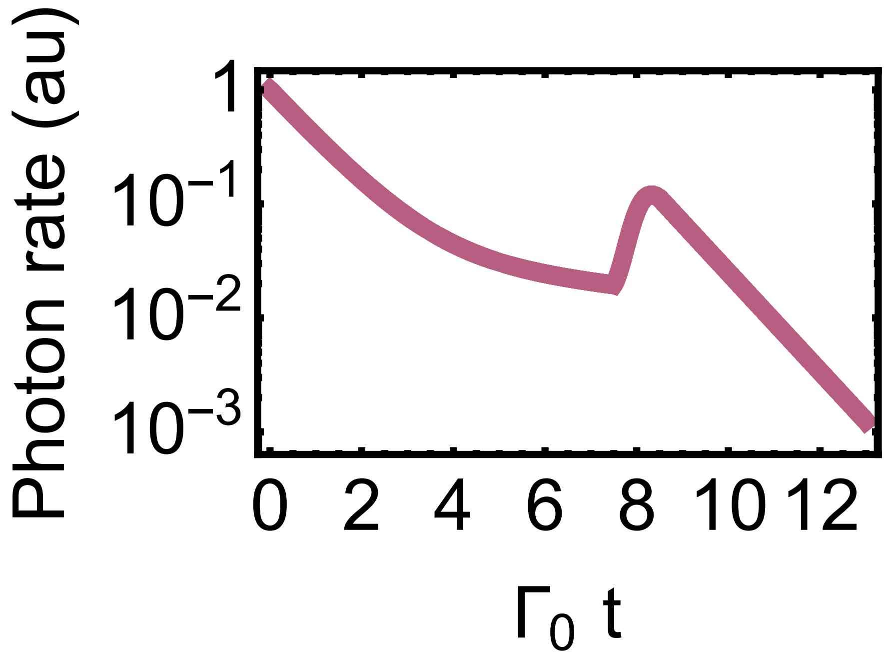
Versus pulse intensity (I/Isat): Saturation of subradiance

Storage and release of an excitation





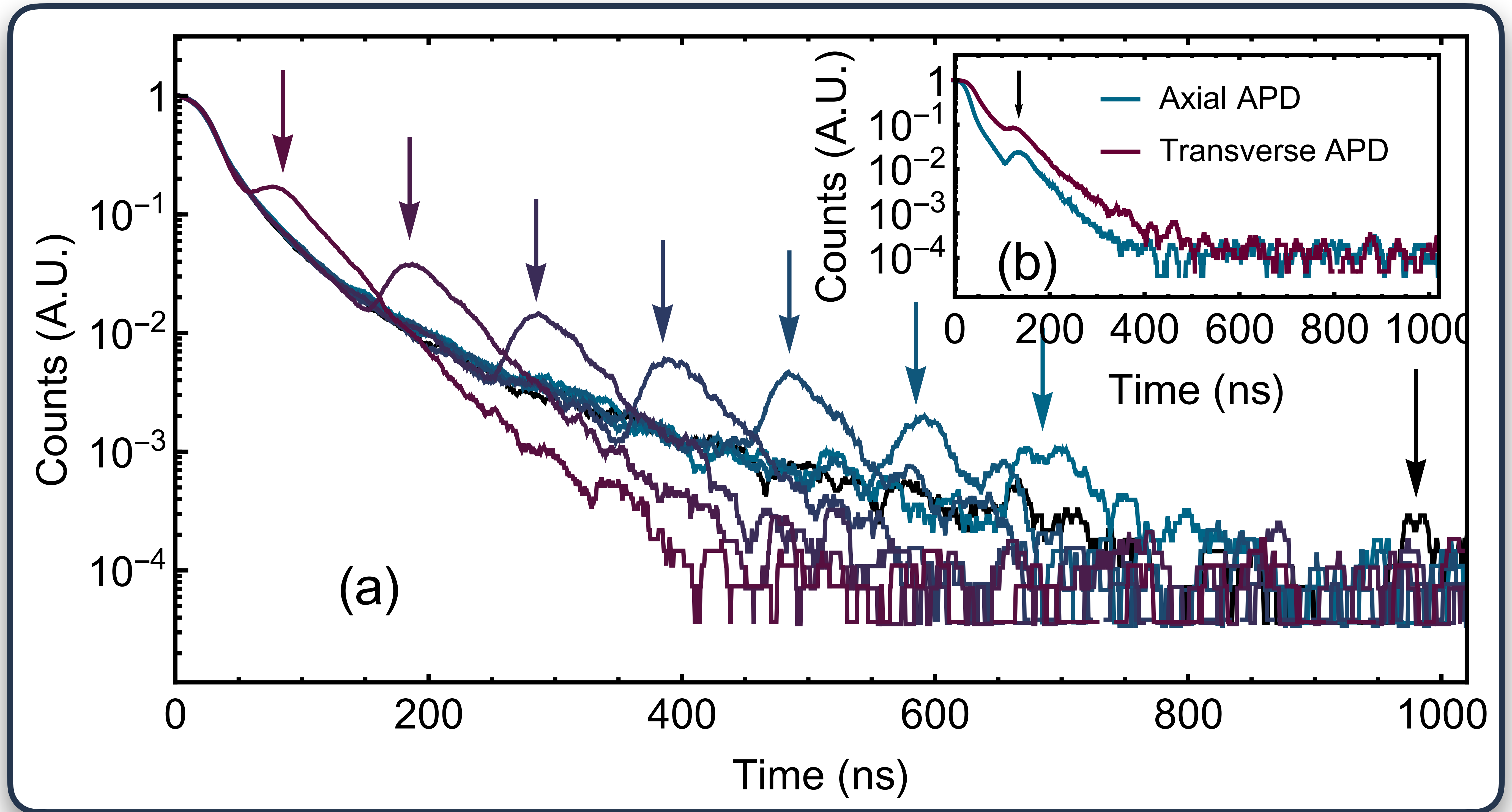
$$I \propto \frac{d\rho_{ee}}{dt}$$



Trap induces strong **inhomogeneous broadening**

Cancels interactions:
Back to independent decay

Induces a controlled, directional **pulse of light**



Theory?

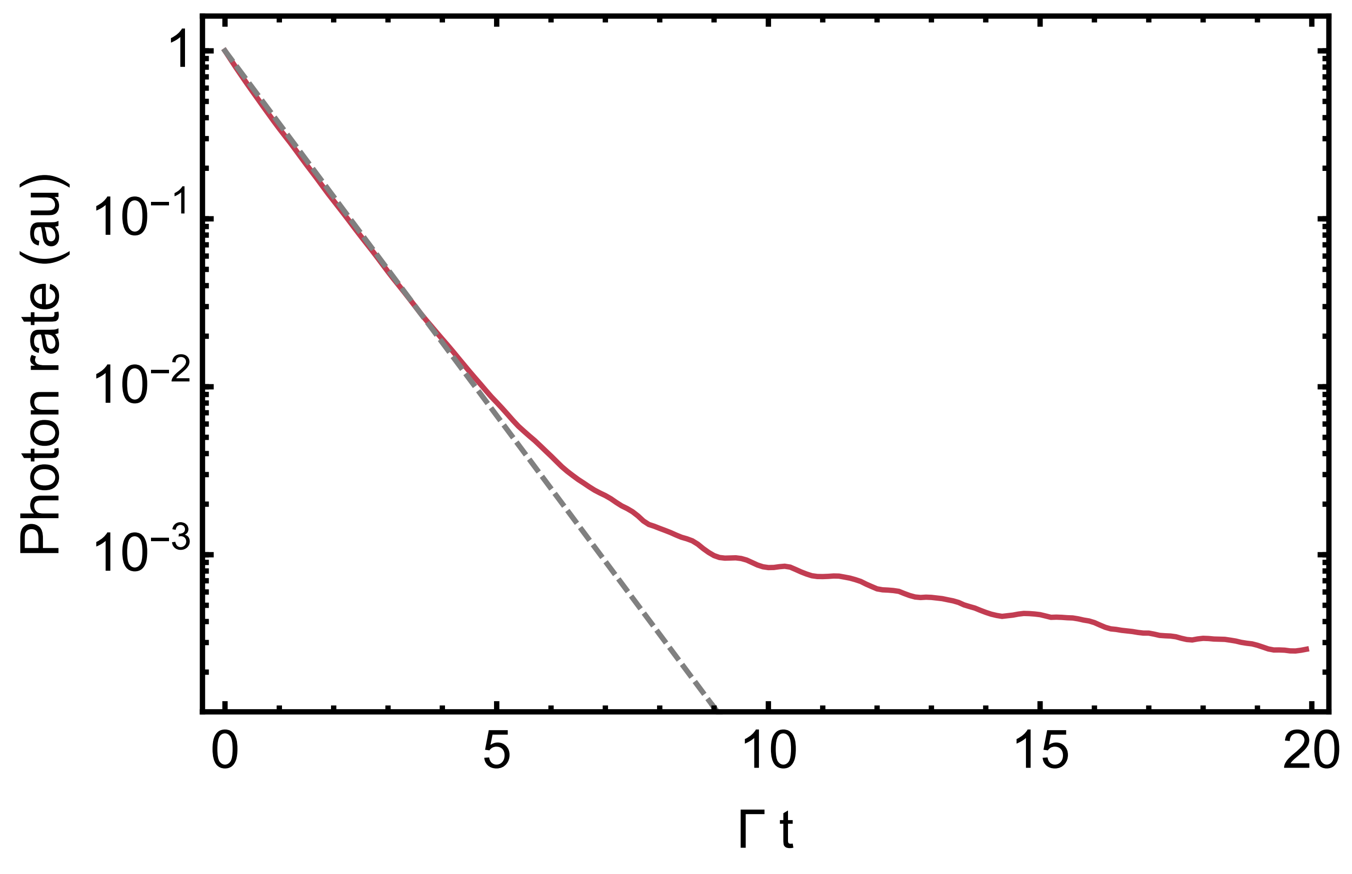
Full master equation undoable for more than ~20 atoms…

Mean-field model (coupled optical Bloch equations) fails at high saturation…

$$\frac{d\rho_{ee}^{(n)}}{dt} = -\Gamma_0\,\rho_{ee}^{(n)} + \frac{i}{2}\left(\Omega^{(n)}\rho_{ge}^{(n)} - \Omega^{(n)*}\rho_{eg}^{(n)}\right)$$

$$\frac{d\rho_{eg}^{(n)}}{dt} = \left(i\Delta - \frac{\Gamma_0}{2}\right)\rho_{eg}^{(n)} - i\frac{\Omega^{(n)}}{2}\left(\rho_{ee}^{(n)} - \rho_{gg}^{(n)}\right)$$

$$\Omega^{(n)} = \Omega_{las} + \sum_{m\neq n} G(\boldsymbol{r}_m - \boldsymbol{r}_n)\rho_{eg}^{(m)}$$



Qualitative agreement

Outlook: superradiance in Dicke’s regime

- **Many-body model??**
- Collective Rabi oscillations
- Superradiant decay in inverted systems