

Subradiance via entanglement in atoms with several independent decay channels

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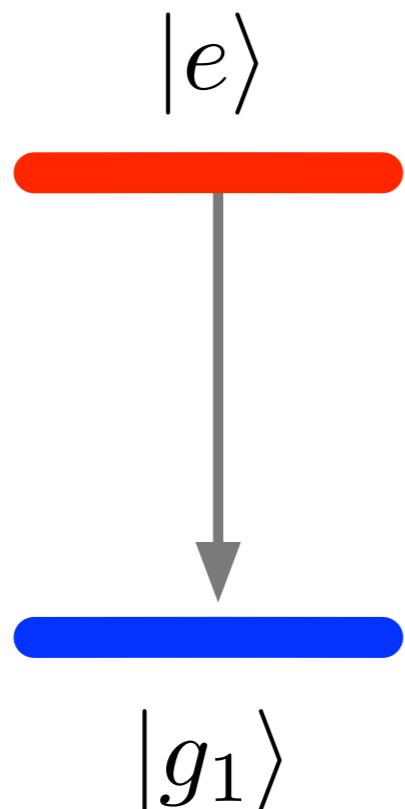
Der Wissenschaftsfonds.



Outline

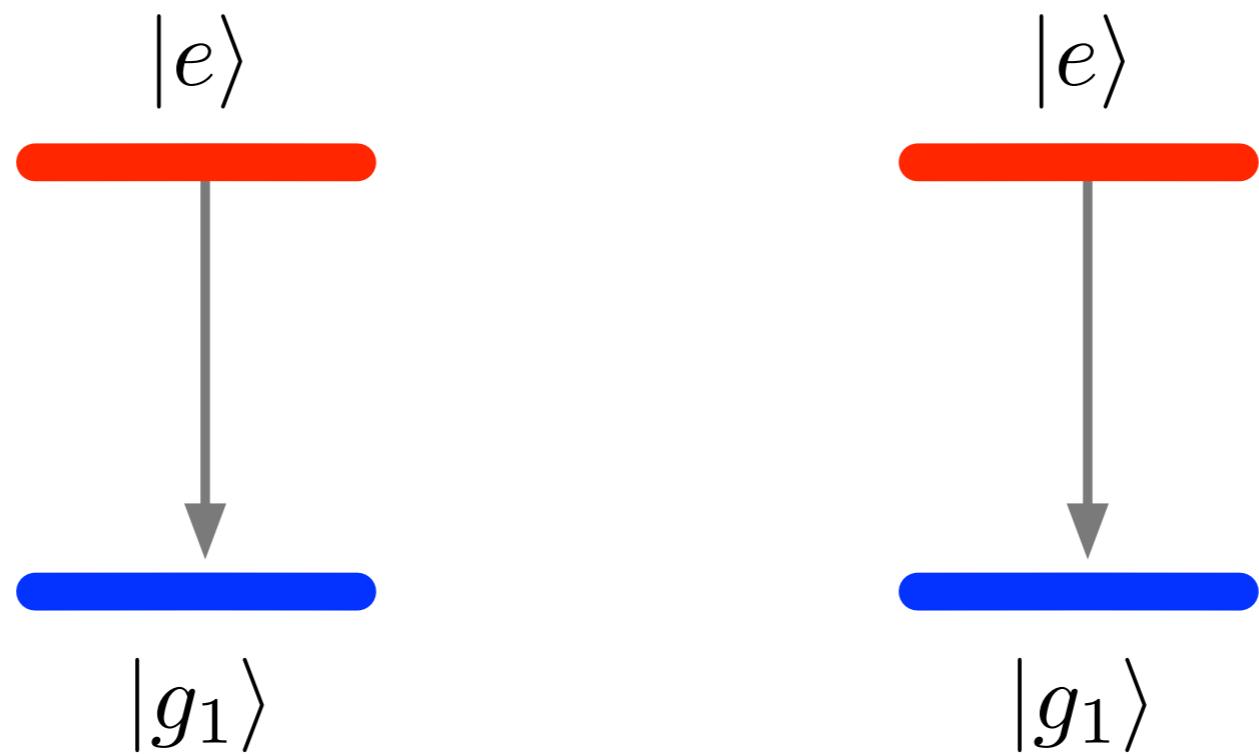
- Multilevel Dark States
- Mathematical Properties
- Preparation

Spontaneous Emission

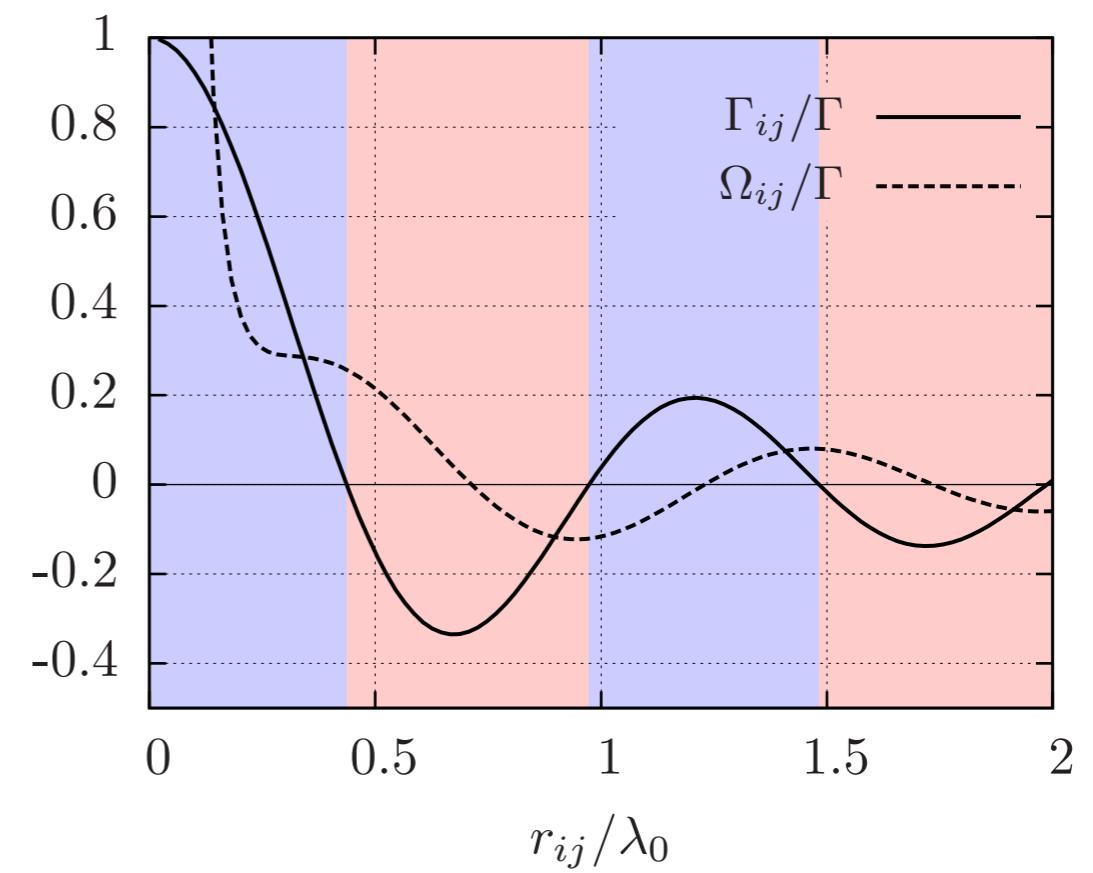
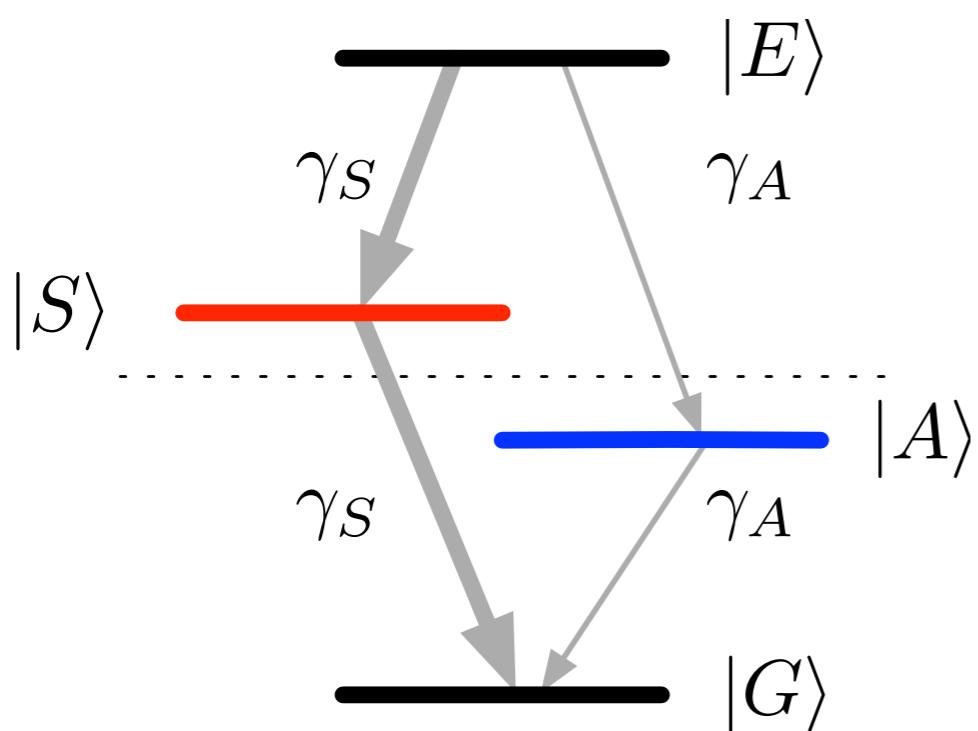


$$\Gamma = \frac{\omega^3 \mu^2}{3\pi\epsilon_0 c^3}$$

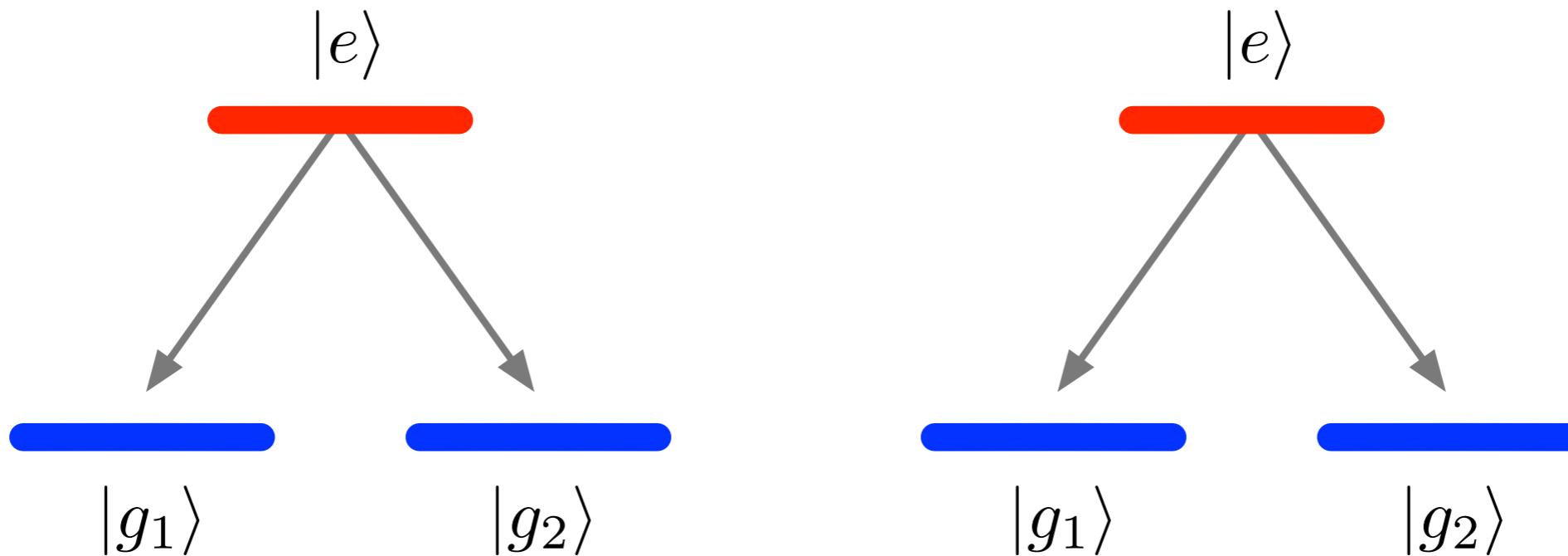
Two Atoms



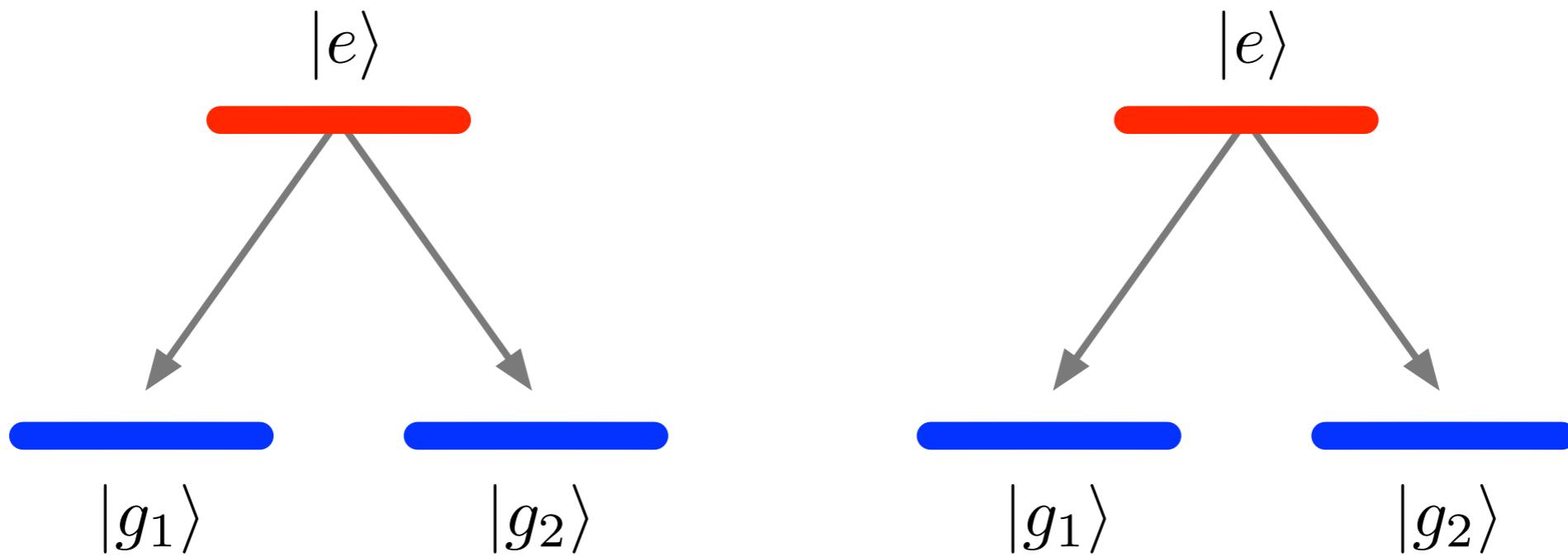
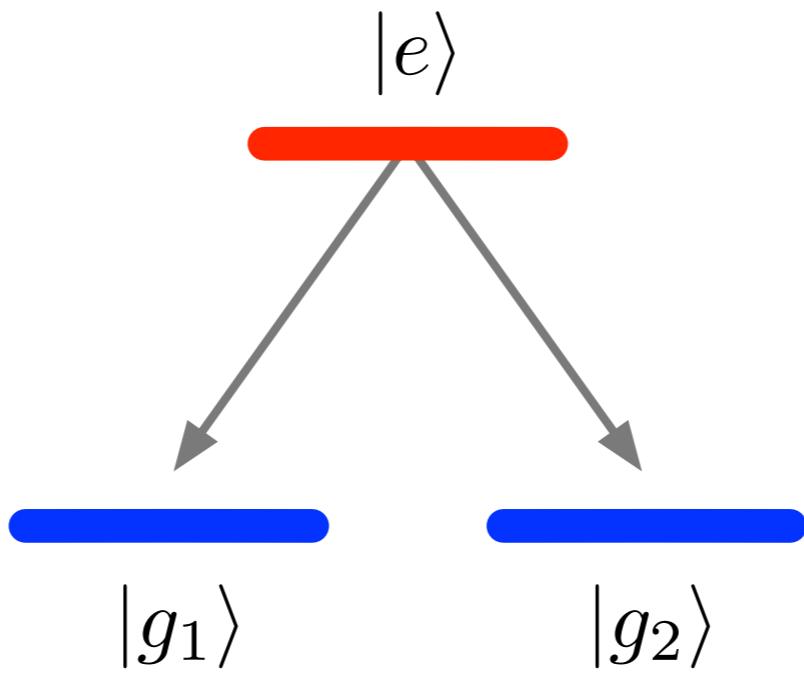
Two Atoms



Two Atoms

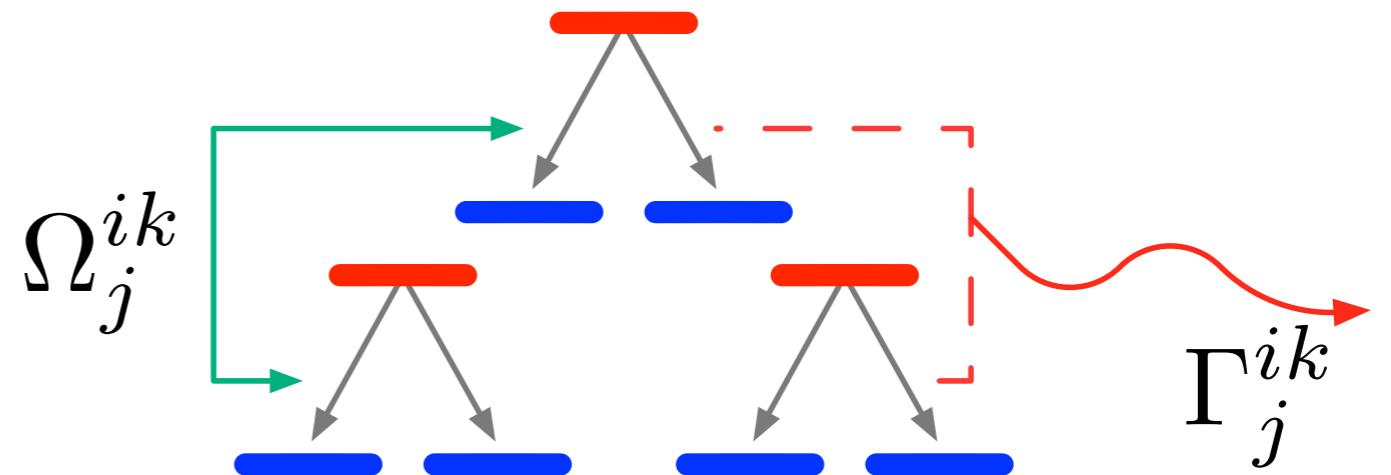


No dark state is known.



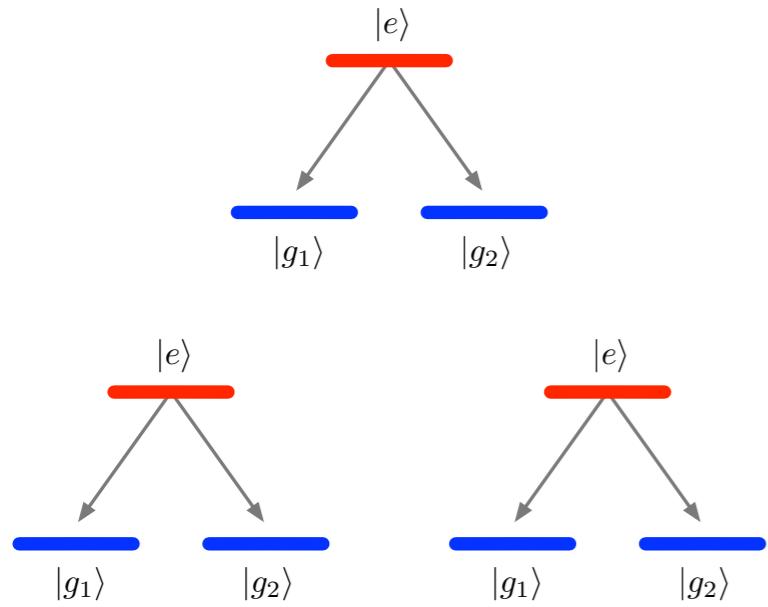
Dynamics

$$\dot{\rho} = i [\rho, H] + \mathcal{L} [\rho]$$



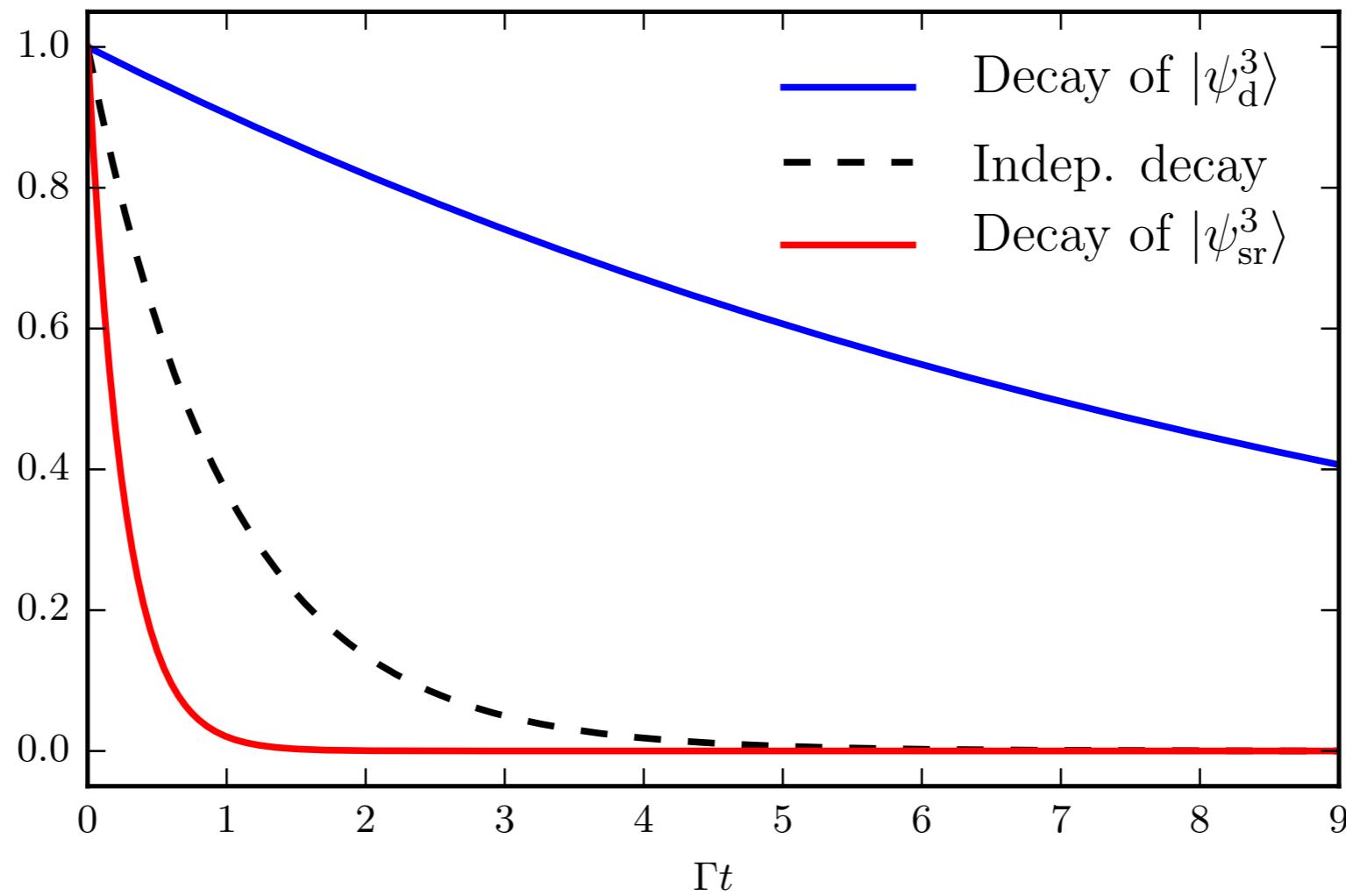
$$H = \sum_{i,j} -\omega_j^i \sigma_j^i - \sigma_j^i + + \sum_{i \neq k} \sum_j \Omega_j^{ik} \sigma_j^i + \sigma_j^k -$$

$$\mathcal{L}[\rho] = \frac{1}{2} \sum_{i,k,j} \Gamma_j^{ik} [2\sigma_j^i - \rho \sigma_j^k + - \sigma_j^i + \sigma_j^k - \rho - \rho \sigma_j^i + \sigma_j^k -]$$



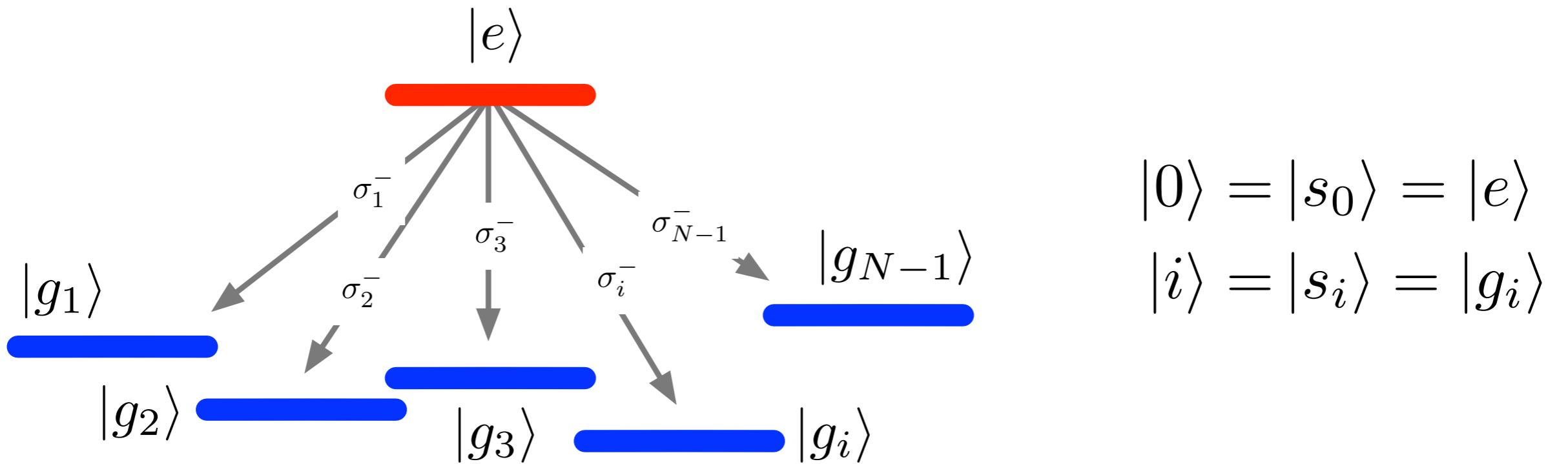
$$|\psi_d^3\rangle = \frac{1}{\sqrt{6}} \{ |eg_1g_2\rangle + |g_1g_2e\rangle + |g_2eg_1\rangle - |eg_2g_1\rangle - |g_2g_1e\rangle - |g_1eg_2\rangle \}$$

Decay of single excitations in a triangular array



Generalization

$$|\psi_d^N\rangle = \frac{1}{\sqrt{N!}} \sum_{\pi \in S_N} \text{sgn}(\pi) \bigotimes_i |s_{\pi(i)}\rangle$$



Math. Properties

- Dipole moments vanish

$$\langle \mu_j \rangle = 0$$

- Bipartite entanglement is maximal

$$\rho_1 \propto 1$$

- No individual information: Subradiance is purely non-classical and non-local

Math. Properties

- Invariant under any invertible single-atom operator

$$|\psi_d^N\rangle \propto S^{\otimes N} |\psi_d^N\rangle$$

→ announce measurement, create

$$|\psi_d^{N-1}\rangle$$

deterministically by LUs only

Preparation

- Deterministically (3 atoms)

$$\frac{1}{\sqrt{2}}(|01\rangle - |10\rangle) \otimes |2\rangle$$

$$\exp\left(-i\frac{2\pi}{9}(X \otimes X \otimes X + \text{h.c.})\right)$$

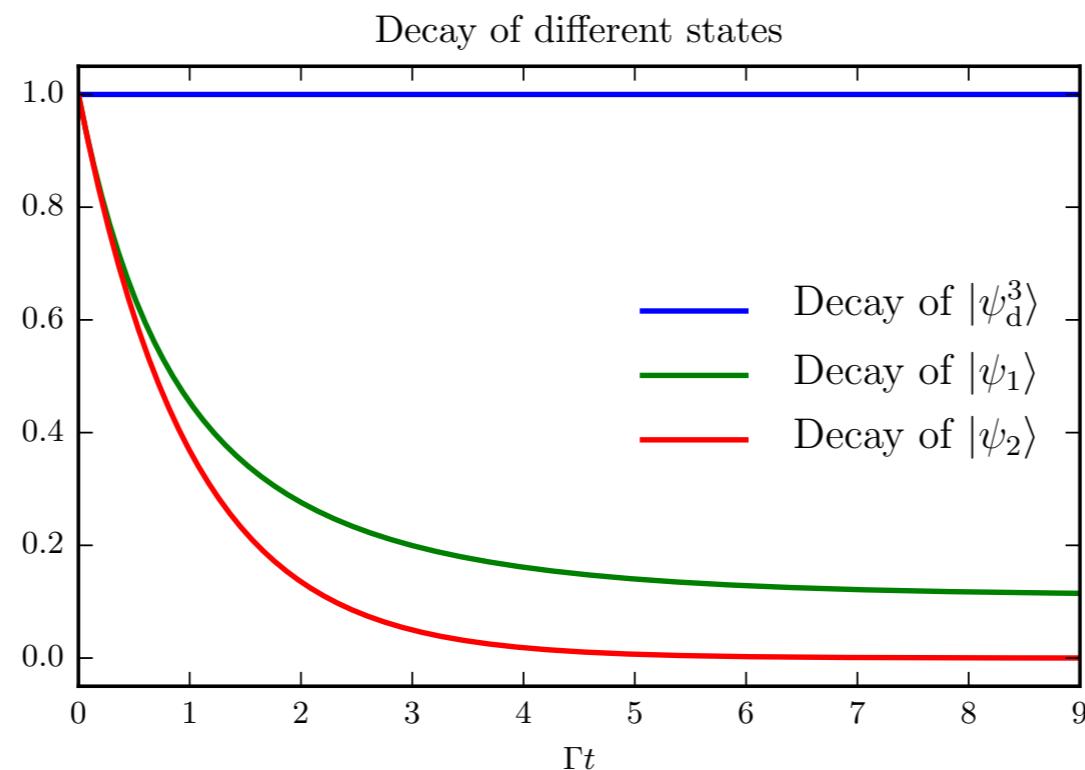
$$X = |1\rangle\langle 0| + |2\rangle\langle 1| + |0\rangle\langle 2|$$

Preparation

- Probabilistically (3 atoms)

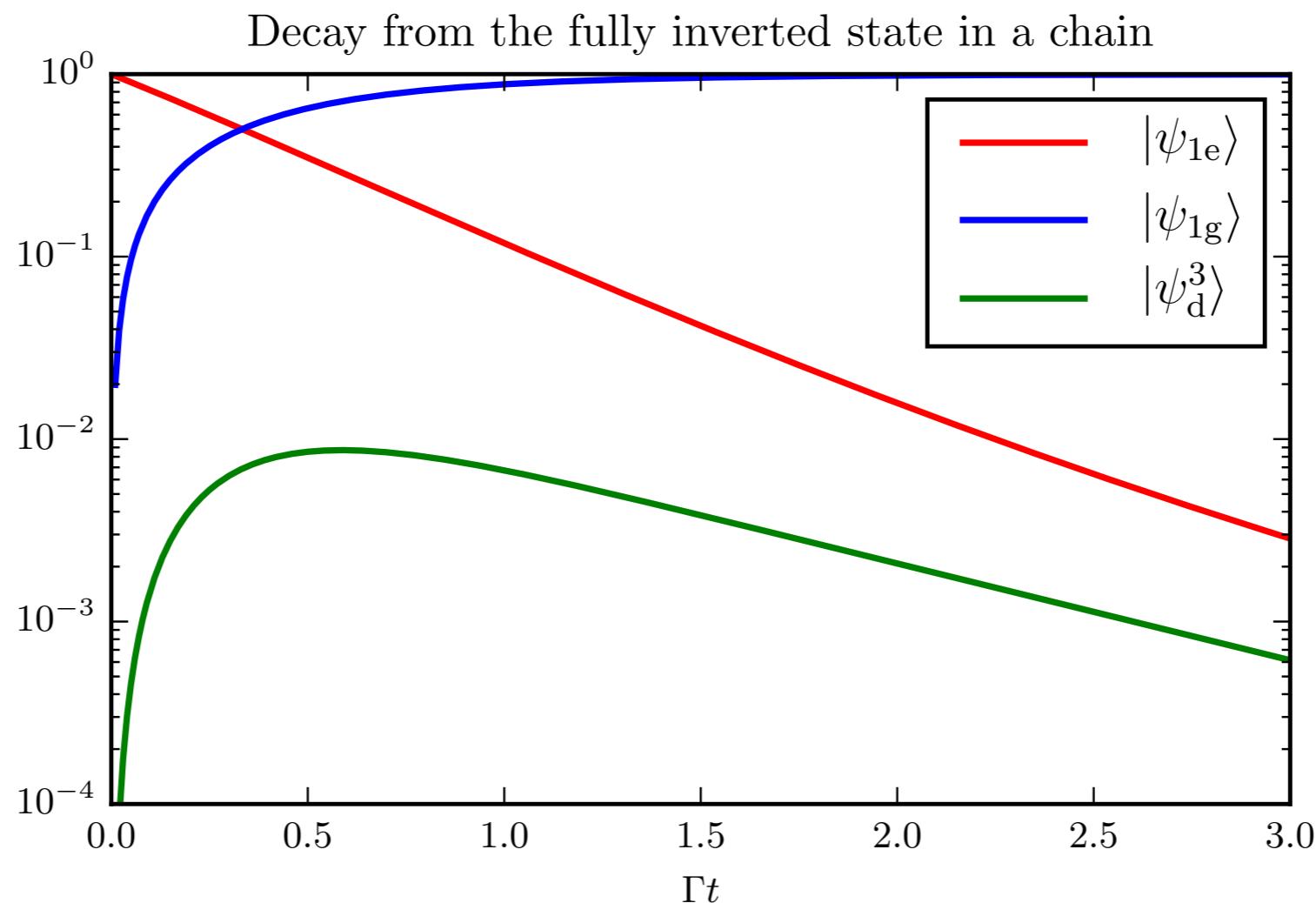
$$|\psi_1\rangle = \frac{1}{\sqrt{2}} (|eg_1\rangle - |g_1e\rangle) \otimes |g_2\rangle$$

$$|\psi_2\rangle = \frac{1}{\sqrt{2}} (|eg_1\rangle - |g_1e\rangle) \otimes |g_1\rangle$$



Preparation

- Probabilistically (3 atoms)



Conclusions

- Subradiance persists for more than one decay channel per atom
- Anti-symmetric, highly entangled multi-partite states
- Deterministic & probabilistic preparation

The screenshot shows a web browser window with the URL "qojulia.org" in the address bar. The page content is as follows:

QuantumOptics.jl

A Julia Framework for Open Quantum Dynamics

QuantumOptics.jl is a numerical framework written in the [Julia](#) programming language that makes it easy to simulate various kinds of open quantum systems. It is inspired by the [Quantum Optics Toolbox](#) for MATLAB and the Python framework [QuTiP](#).

Performance

QuantumOptics.jl optimizes processor usage and memory consumption by relying on different ways to store and work with operators.

Usability

The framework comes with a plethora of pre-defined systems and interactions making it very easy to focus on the physics, not on the numerics.

Reliability

Every function in the framework has been severely tested with all tests and their code coverage presented on the framework's [GitHub page](#).

www.qojulia.org

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