Engineering quantum states of light using superradiance

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Motivation – generating quantum light

Quantum light with *many photons* is key for technologies such as quantum sensing, cryptography and computation [1,2] but is difficult to create in the optical range.

Schrodinger cat states: $\sim|\alpha\rangle + |-\alpha\rangle$ **can be used to encode a qubit.**

NOON states: $\mathbf{1/\sqrt{2}(|N\rangle|0\rangle + |0\rangle|N\rangle)}$ **Can be used to measure phase with *Heisenberg limited sensitivity.***

Superradiance

Superradiance is the process by which multiple emitters correlate with one another while spontaneously decaying, resulting in a *short and intense emission* [3,4].

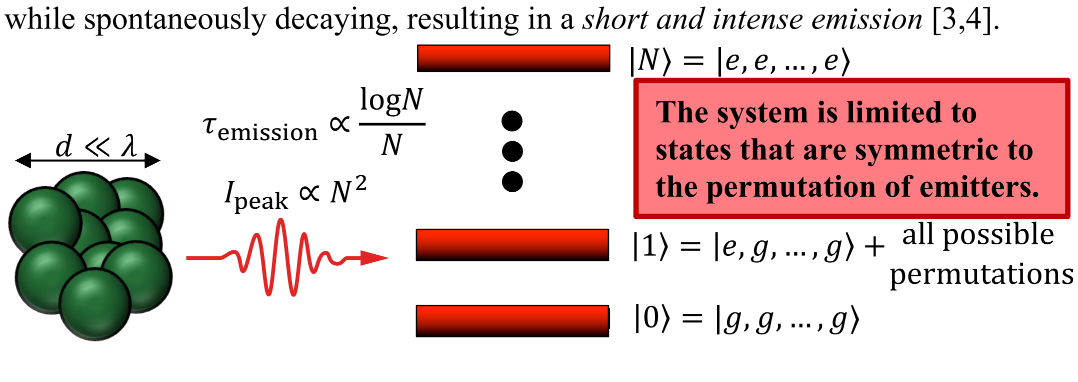

Fig. 1. Superradiance

A correlated state of emitters will emit correlated quantum light.

Superradiance transfers atomic correlations to the light

Our theory of superradiant light emission:

$$H = \hbar\Omega_0 S_z + \sum_\omega \hbar\omega a_\omega^\dagger a_\omega + \hbar g_\omega S_- a_\omega^\dagger + \hbar g_\omega^* S_-^\dagger a_\omega$$

a_ω - annihilation operator for mode ω; S_- - lowering operators for atomic system, ; S_z - collective Pauli operator

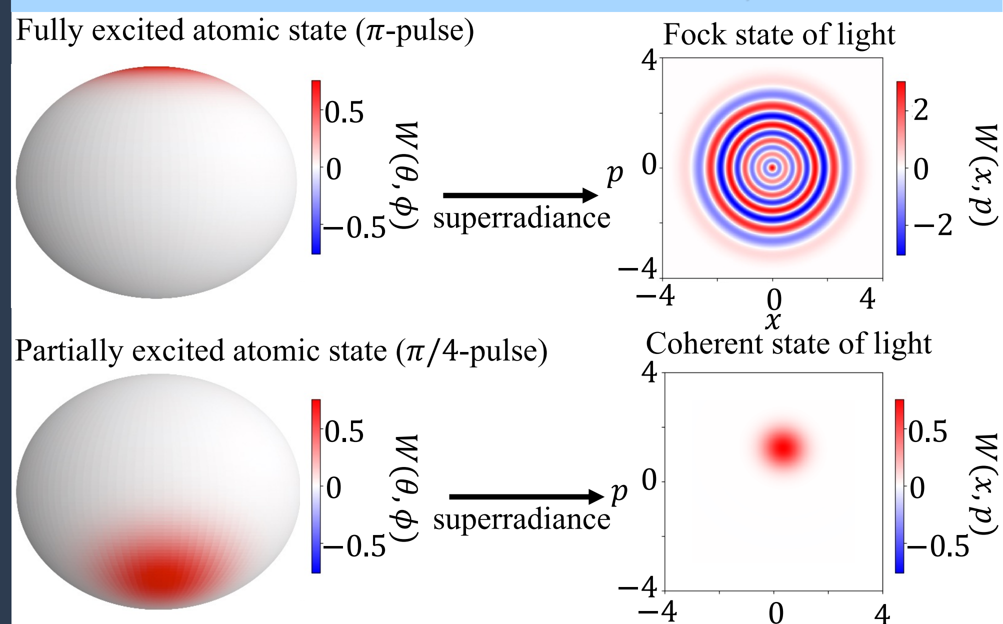

Fig. 2. The quantum state of light in superradiance

Protocols for creating quantum light with superradiance

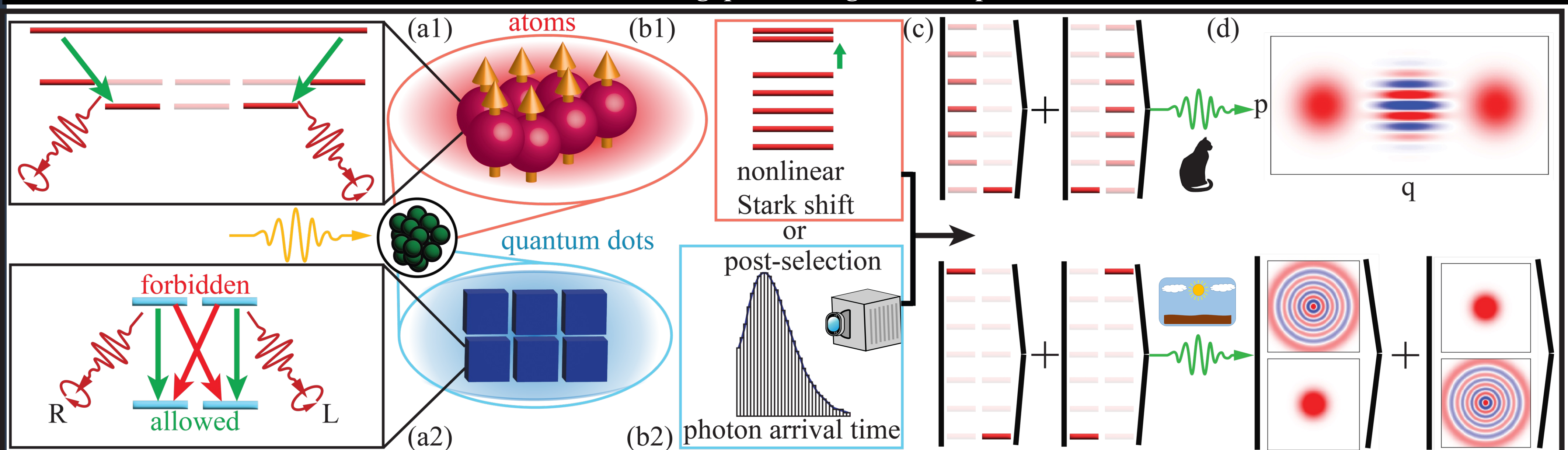

Fig. 3. Protocols for creating NOON and Schrodinger cat states

Emitters with degenerate energy levels are set in a superposition. → The emitters are shaped into a *correlated state* using either measurement and post selection or nonlinearity. → Superradiance transfers the correlations to the light, creating NOON and Schrodinger cat states.

Results

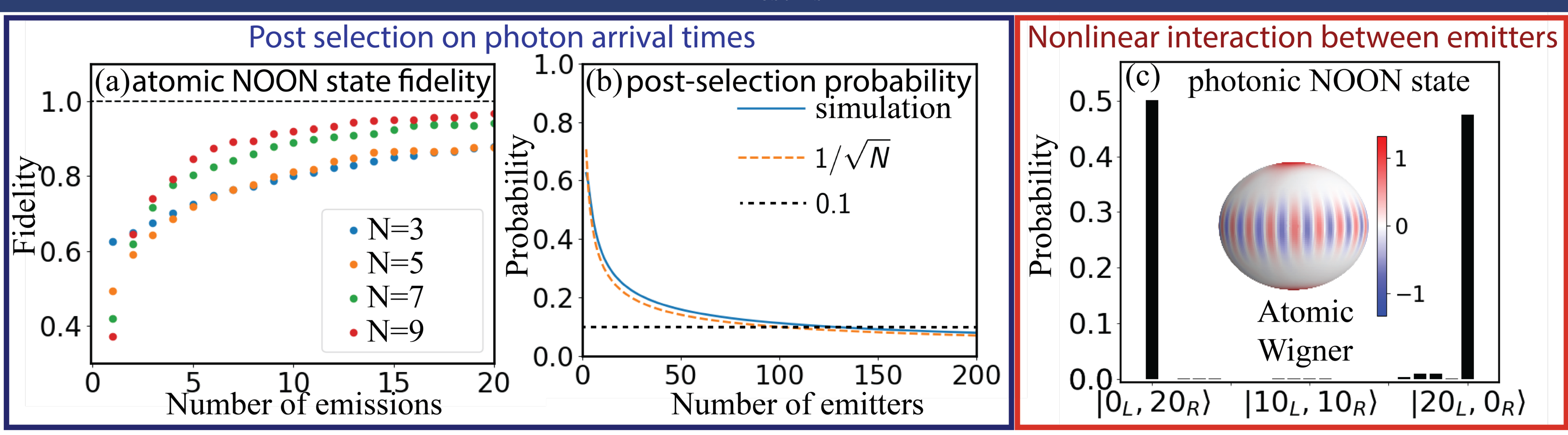

Fig. 4. The generated quantum states of light

The fidelity of the atomic NOON states converges to 1 after many emissions

Surprisingly, the probability for post-selection scales as $1/\sqrt{N}$ (rather than exponentially) in the number of emitters N.

Utilizing a *nonlinear Stark shift* [5], a NOON state with 95% fidelity can be achieved.

Conclusions

- **Superradiance can be used to transfer atomic correlations to make quantum light.**
- **To create atomic correlations, emitters with degenerate energy levels are a useful tool.**
- **Using measurement and post selection on the result, or nonlinearity in the interactions between emitters, it is possible to shape the atomic system such that it will emit NOON and Schrodinger cat light states.**

References

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