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PhD THESIS DEFENSE: Heating and decoherence due to light scattering in atomic media

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10:30

ICFO Auditorium and Online (Teams)

Cold atom platforms have become central to quantum technologies such as information processing, simulation, and metrology. Their versatility and high degree of control make them especially powerful. A key breakthrough in the field was the ability to trap individual atoms using light. Far-off-resonant optical dipole traps-like optical tweezers and lattices-enable precise positioning of atoms in diverse geometries, from simple 2D arrays to complex 3D structures.

Another major advantage of cold atoms is their ability to mediate interactions between photons, which do not naturally interact in free space. Cold atomic ensembles act as a nonlinear medium, enabling strong interactions even at the two-photon level. Using collective atom-photon coupling and Rydberg-state excitations, they allow for

photon-photon gates and the creation of non-classical states of light. These two features-strong optical nonlinearities and precise atomic positioning-make cold atoms a leading platform for quantum networks, quantum simulations, and studies of light-matter interaction.

A phenomenon common to both platforms is photon scattering, which can either be of an intended or unintended nature. Up until recently, simple theories of scattering were sufficient for the community. However, the advance of atomic platforms now requires more nuanced and sophisticated theories to understand scattering and their consequences on applications. This constitutes the main theme of the thesis.

In the application of atom trapping, in many practical situations atoms may experience state-dependent potentials. The potential mismatch can lead to excess heating and reduced elastic scattering of light, as compared to well-known limits like an atom in i¿½magic-wavelengthi¿½ traps or a trapped ion. In the first part of the thesis, we devel p a model to analyze these effects, which can have important consequences in quantum op ics or in atom imag

ng. In the second part of the thesis, we investigate how Rydberg spin waves decohere in the presence of light scattering, within the context of Rydberg Electromagnetically Ind ced Transparency (EIT). Within Rydberg EIT, an initial photon is stored as a coherent, exte ded superposition across atoms. This initial photon can strongly modify the propagatio of subsequent photons, leading to large nonlinearities, but the scattering of subseq ent photons can reveal information about where the first photon was stored, leadin to decoherence of the initial superposition state. This in turn can lead to decreased utilit or ability to retrieve the first photon. Here, we elucidate the nature of decoherence, an in particular for the first time we take fully into account the three-dimensional nature of the ensemble and its multiple scattering of light. We find regimes in which multiple scatte ing might offer additional protection from decoherence, as compared to previous simpli ied theor

es. Overall, this thesis makes new advances in understanding the nature of microsc pic atom-light interactions and scattering, and connects this fundamental physics to key consequences in real-life applicati

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