EIT in Rydberg gases: From classical nonlinearities to two-photon interactions and quantum many-body physics with light.

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In this talk we will discuss some theoretical concepts for the description of light propagation through a cold gas of Rydberg atoms under conditions of electromagnetically induced transparency (EIT). Starting from a brief overview of the unique properties of atomic Rydberg states, we first consider the optical response of such systems to classical light fields. An analytical treatment in the limit of weak Rydberg excitation illustrates the emergence of large nonlocal nonlinearities due to the interplay of EIT and the strong van der Waals interactions between Rydberg states. At high atomic densities, the resulting nonlinearities can be sufficiently large to operate on a few-photon level, thereby enabling basic applications to optical quantum information processing. We will demonstrate these opportunities by studying the dynamics of two interacting photons. Finally, we will expand such settings to multi-photon fields and elucidate the transition from classical to quantum nonlinear optics. In the strongly nonlinear regime, numerical simulations suggest a rich spectrum of correlated phases of photons, atoms or both. When possible, the described theoretical approaches will be linked to recent observations and potential future experiments.