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Dispersive optical nonlinearities using cold Rydberg atoms

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We study dispersive optical nonlinearities arising from Rydberg interactions in cold atomic gases. In a resonant, dispersive regime such systems have recently been used as single-photon sources, whereas in the off-resonant, dispersive case they could ultimately allow one to realize two-photon quantum logic gates. We experimentally measure the optical dispersion of a cold atomic cloud inside an optical cavity using a weak probe laser, in presence of a strong control beam driving off-resonant transitions to highly excited Rydberg states. We find that the non-linear response of the system is considerably stronger than for non-interacting atoms, and that the nonlinearity increases with the Rydberg interactions and with the atomic density following the expected scaling laws. We show that this non-linearity can be explained by a "blockade" phenomenon, where an excited Rydberg atom prevents the excitation of its neighbors, thereby modifying their optical response. To investigate the behavior of the system in the quantum regime, we show that in the resonant case the cloud acts as "quantum scissors," deterministically transforming a weak coherent excitation in a non-classical state. We find a range of parameters where this state can be efficiently retrieved and characterized in a homodyne measurement.