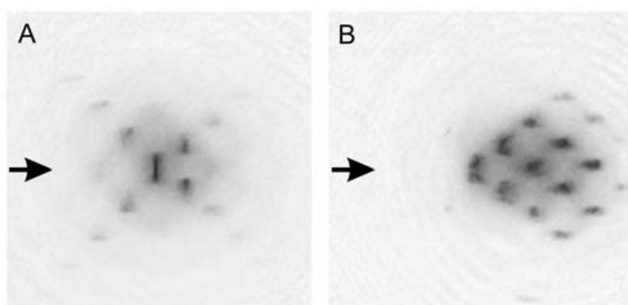
The onset of matter-wave amplification in a superradiant Bose-Einstein condensate

We have studied the interaction of short and strong laser pulses with an atomic Bose-Einstein condensate [1]. Light at low intensity is scattered into all directions – this is the well-known case of Rayleigh scattering. Stronger laser pulses can give rise to collective "superradiant" light scattering. In the case of elongated Bose-Einstein condensates, the light is predominantly emitted along the long axis of the condensate in the so-called endfire modes [2]. The recoiling atoms appear as distinct peaks in momentum space corresponding to the momentum transfer of an absorbed pump photon and a superradiantly scattered photon.

Short and intense laser pulses were found to generate patterns of recoiling atoms that were strikingly different from those seen in previous experiments [1]. Superradiantly emitted photons were reabsorbed and re-emitted into the pump beam, leading to atoms, which were recoiling out of the condensate with a velocity component antiparallel to the pump beam. Since this process is non-resonant, it occurs only for short pulse durations. These experiments show that the previous description of superradiance as atomic stimulation was incomplete and that optical stimulation plays a crucial role. The reabsorption of superradiant photons implies that matter wave amplification in superradiant Bose-Einstein condensates is suppressed at early times. Our experiments elucidate the nature of bosonic stimulation in the four-wave mixing of light and atoms and the interplay of optical and atomic stimulation.



Superradiant scattering of a laser beam (arrow) from a Bose-Einstein condensate in the short-pulse (A)and long-pulse (B)limit. Absorption images of the atomic density distribution were taken after 30 ms of ballistic expansion. In case A, the detuning was 420 MHz and the pulse duration was 6 μs. In case B, the detuning was -4400 MHz and the pulse duration was 800 μs. The field of view of both images is 2.0 mm by 2.0 mm, and that of the inset is 120 μm by 270 μm.

1. D. Schneble, Y. Torii, M. Boyd, E.W. Streed, D.E. Pritchard, and W. Ketterle, *The Onset of Matter-Wave Amplification in a Superradiant Bose-Einstein Condensate*, Science **300**, 475 (2003).
2. S. Inouye, A.P. Chikkatur, D.M. Stamper-Kurn, J. Stenger, D.E. Pritchard, and W. Ketterle, *Superradiant Rayleigh scattering from a Bose-Einstein condensate*, Science **285**, 571 (1999).