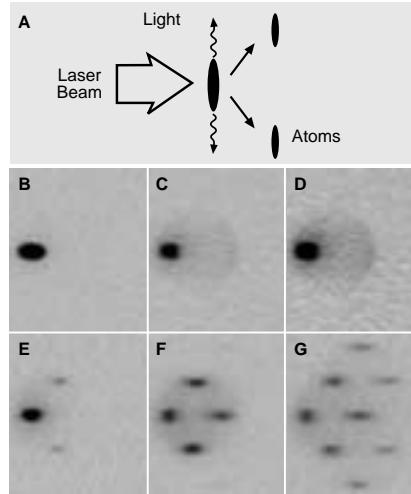


## ***Superradiant Rayleigh scattering from a Bose-Einstein condensate***

We have discovered a new phenomenon in the scattering of light by a condensate: highly directional, “superradiant” scattering of light and atoms [1]. This phenomenon is deeply rooted in the long coherence time of a condensate. When a condensate has scattered light, an imprint is left in the form of long-lived excitations. This “memory” accelerates the scattering of further photons into the same directions. It provides a gain mechanism for the generation of directed beams of atoms and light.



Observation of superradiant Rayleigh scattering. (a) A cigar-shaped condensate is illuminated with a single off-resonant laser beam. Collective scattering leads to photons scattered predominantly along the axial direction, and atoms at 45 degrees. (b-g) Absorption images after 20 ms time-of-flight show the atomic momentum distribution after exposure of the atoms to a laser pulse of variable duration. When the polarization is parallel to the long axis, superradiance is suppressed, and normal Rayleigh scattering was observed (b-d). For perpendicular polarization, directional superradiant scattering of atoms was observed (e-g), and evolved to repeated scattering for longer laser pulses (f,g). The pulse durations are 25  $\mu$ s (b), 100  $\mu$ s (c,d), 35  $\mu$ s (e), 75  $\mu$ s (f), 100  $\mu$ s (g). The field of view of each image is 2.8 mm x 3.3 mm. The scattering angle appears to be larger than 45 degrees due to the angle of observation. All images use the same gray scale except for (d), which enhances the small signal of Rayleigh scattered atoms in (c).

This phenomenon is fairly dramatic. When a condensate was illuminated with a single weak laser beam, it randomly scattered light into all directions (with the well-known dipolar pattern – this is ordinary Rayleigh scattering). However, above a certain threshold intensity, the condensate produced two highly directional beams of light. Such highly directional light scattering was accompanied by the production of highly directional beams of recoiling atoms (see figure). These beams of atoms were shown to build up by matter wave amplification. The condensate acted as an amplifier for a recoiling atom and “amplified” it to about a million atoms. If one had collected the light in an optical cavity, one would have realized an optical laser. Therefore, the simultaneous superradiant emission of light and atoms emphasizes the symmetry between atom lasers and optical lasers.

1. S. Inouye, A.P. Chikkatur, D.M. Stamper-Kurn, J. Stenger, D.E. Pritchard, and W. Ketterle, *Science* **285**, 571 (1999).