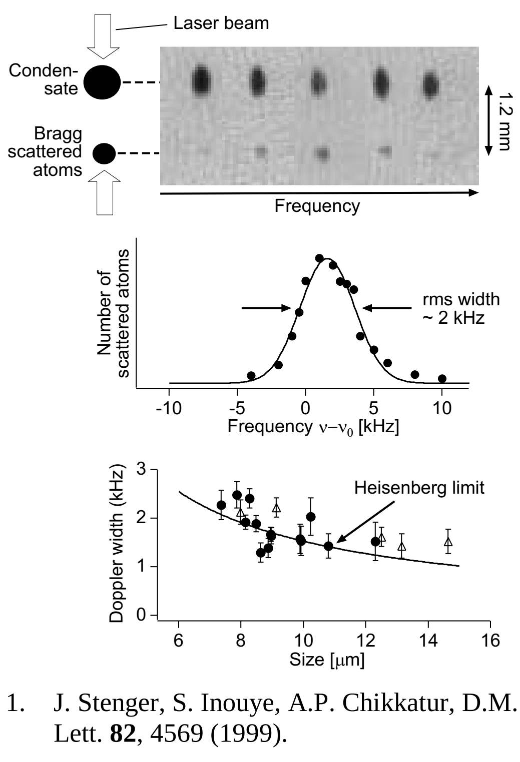
Bragg spectroscopy of a Bose-Einstein condensate

The first evidence for Bose-Einstein condensation in dilute gases was obtained by a sudden narrowing of the velocity distribution as observed for ballistically expanding clouds of atoms. However, the dominant contribution to the observed momentum distribution of the expanding condensate was the released interaction energy (mean-field energy) resulting in momentum distributions much broader than the zero-point motion of the ground state of the harmonic trapping potential. Since the size of a trapped condensate with repulsive interactions is larger than the trap ground state, the momentum distribution should be considerably narrower than in the trap ground state. We could measure the momentum distribution of a trapped condensate with Doppler velocimetry using two-photon Bragg scattering. We observed that the momentum distribution was Heisenberg uncertainty limited by its finite size, i.e. the coherence length of the condensate was equal to its size [1].

A shift of the narrow Bragg resonance was caused by the repulsive interactions within the condensate resulting in a spectroscopic measurement of the mean-field energy. More generally, we have established Bragg scattering as a spectroscopic technique to probe properties of the condensate. It can be used to map out the density fluctuations of the system and thus to measure directly the dynamic structure factor $S(q, \omega)$, which is the Fourier transform of the density-density correlation function and is central to the theoretical description of many-body systems.



Bragg spectroscopy of a trapped condensate. A condensate was exposed to two counterpropagating laser beams and analyzed using time of flight absorption imaging (upper part). The number of Bragg scattered atoms showed a narrow resonance when the difference frequency between the two laser beams was varied (upper and middle part). The width of the resonance was studied for various radial sizes of the condensate. The solid line (lower part) compares the experimental results with the prediction for the momentum uncertainty due to the finite size.

1. J. Stenger, S. Inouye, A.P. Chikkatur, D.M. Stamper-Kurn, D.E. Pritchard, and W. Ketterle, Phys. Rev. Lett. **82**, 4569 (1999).