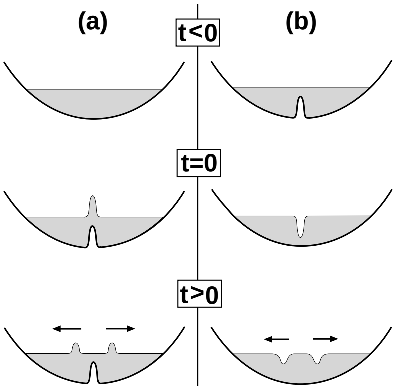
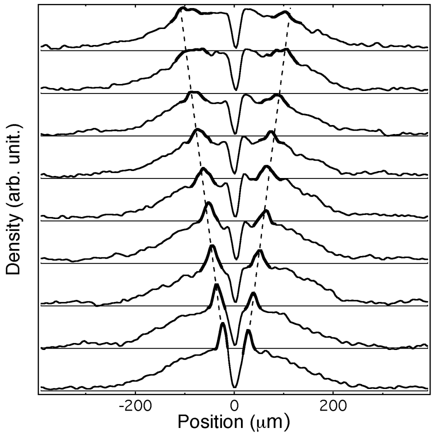
Propagation of sound in a Bose-Einstein condensate

The study of quantum liquids has revealed a wealth of physics such as superfluidity, second sound, and quantized vortices. A microscopic picture of these macroscopic quantum phenomena was developed based on elementary excitations and quantum hydrodynamics. For a long time such studies were limited to He-3 and He-4. The realization of Bose-Einstein condensation in atomic vapors has provided a new class of macroscopic quantum fluids which are dilute gases. An important issue, which applies both to quantum liquids and quantum gases, is the characterization of the system by its collective excitations.

Previous experiments on Bose condensed clouds had focused on the lowest collective excitations [1, 2]. They showed a discrete spectrum due to the small size of the trapped clouds, in contrast to the continuous spectrum of quantum liquids, which is phonon-like at low frequencies. In this study, we observed sound propagation in a Bose condensate [3]. Localized density perturbations, much smaller than the condensate, were induced by suddenly modifying the trapping potential using the optical dipole force of a focused laser beam (see figure). The resulting propagation of sound was directly observed using a novel technique, rapid sequencing of non-destructive phase-contrast images (see figure). The speed of sound was found to be consistent with the predictions of Bogoliubov theory [4], which were formulated 50 years ago, but had not yet been directly tested.



Excitations of wave packets in a Bose condensate. A condensate is confined in the potential of a magnetic trap. At time t=0, a focused, blue-detuned laser beam is suddenly switched on (a) or off (b) and, by the optical dipole force, creates respectively two positive or negative perturbations in density which propagate at the speed of sound.



Observation of sound propagation in a condensate by non-destructive rapid phase-contrast imaging. Shown are axial density profiles of the condensate, taken every 1.3 ms, beginning 1 ms after switching on the argon ion laser. Two pulses traveled outward with the speed of sound (compare with figure above).

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