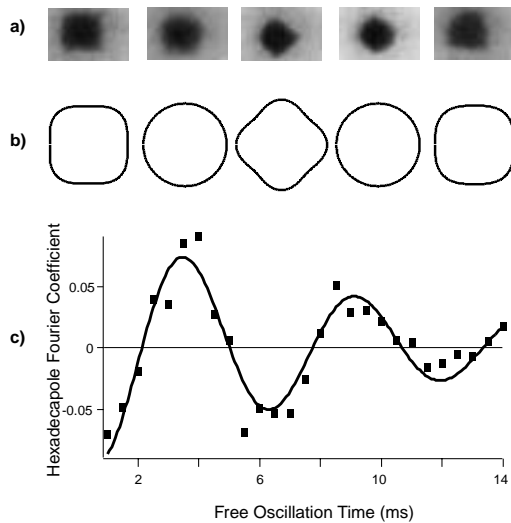


Surface excitations in a Bose-Einstein condensate

Collective modes which have no radial nodes and are localized close to the surface of the condensate are called surface modes. In a semiclassical picture these excitations can be considered the mesoscopic counterpart to tidal waves at the macroscopic level. Those excitations are of special interest since they show a crossover between collective and single-particle behavior, which is crucial for the existence of a critical rotational velocity. Furthermore, they probe the surface region of the condensate where the density of the thermal cloud is peaked, and should be sensitive to the interactions between condensed and non-condensed atoms [1].



Observation of a standing hexadecapolar excitation of a Bose-Einstein condensate. Absorption images of a condensate driven to excite the $m=4$ mode for various hold times (1, 2, 3.5, 4.5 and 6.5 ms from left to right) in the magnetic trap (a). The shape oscillations of a pure $m=4$ mode are schematically depicted in (b) for one cycle. The contours of images like those in Fig. a were Fourier analyzed. Fig. c shows the oscillation of the $m=4$ Fourier coefficient

Since these modes don't have cylindrical symmetry, they cannot be excited by modulating currents in the coils of a dc magnetic trap. We have therefore developed a method to create perturbations with high spatial and temporal control [2]. Excitations were driven by the optical dipole force of a far-off-resonant focused laser beam which was controlled by a two-axis acousto-optical deflector. A rapid scan created a pattern of two or four points which had the correct symmetry to excite quadrupolar or hexadecapolar surface oscillations. A temporal modulation of the intensity or a rotation of the whole pattern resulted in standing and rotating waves, respectively (see figure).

This novel method should be useful for exciting even higher-lying excitations. It was subsequently used to impart angular momentum to the whole condensate which resulted in vortex formation [3].

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