Dynamical or Landau Instability?

Recently Burger *et al.* [1] reported an observation of "dissipative dynamics of a Bose-Einstein condensate (BEC) in a periodic optical lattice." We here point out that the "dissipation" is caused mainly by the dynamical instability [2,3] induced by the optical lattice, not by Landau instability (fluid velocities being greater than the local speeds of sound) as claimed in Ref. [1].

By attributing this dissipative dynamics to Landau instability, Burger *et al.* presented a theory, which gives an excellent fit to the experimental data, as indicated in Fig. 4 of Ref. [1]. However, this theory was unable to explain their further experiments with decreased lattice strength V_0 and lower BEC densities. If Landau instability were the true cause of the dissipative dynamics, the dissipation would become more severe with lower densities of BEC (smaller speeds of sound). To the contrary, they "observed indications that the dissipation onset occurs at higher velocities for decreasing V_0 and that the BEC propagates without dissipation in a regime of very low atom number" [1]. As the density of BEC (interaction strength) and the lattice strength are two key parameters in this system, any complete theory should be able to predict what happens when these two parameters are changed.

In the experiment [1], after the preparation of a cigar-shaped BEC in a trap with the presence of an optical lattice, the trap was suddenly shifted by Δx along the longitudinal direction. The subsequent motion of the BEC is oscillatory when the displacement Δx is small, but becomes dissipative when Δx is big enough.

The dynamical instability of BEC Bloch waves is the main cause of this dissipation, and our theory [2] provides a good explanation of the experimental observations, including the change of BEC density and lattice strength. The BEC prepared is largely a Bloch state; after the shift of the trap center, the BEC not only oscillates in the real space, but also in the k space around the center of the Brillouin zone. As the shift Δx is increased, a larger portion of the Brillouin zone is swept, thus the oscillation can turn dissipative as a result of being affected by the dynamical instability existing in the outer region of the zone (dark areas of Fig. 1 in Ref. [2]).

As shown in Figs. 1 and 2 in Ref. [2], as the density of BEC is lowered, the dynamical instability is reduced both in terms of "dark area" and growth rates. This explains that "the BEC propagates without dissipation in a regime of very low atom number." The dynamical instability also becomes less severe as V_0 is decreased; it is consistent with "the dissipation onset occurring at higher velocities for decreasing V_0". For the typical case reported in Ref. [1], the growth rate is about 1.6 per ms. Therefore, a few milliseconds spent in the dangerous zone of dynamical instability means that only 1% of the system will remain in the initial state. The oscillation is destroyed.

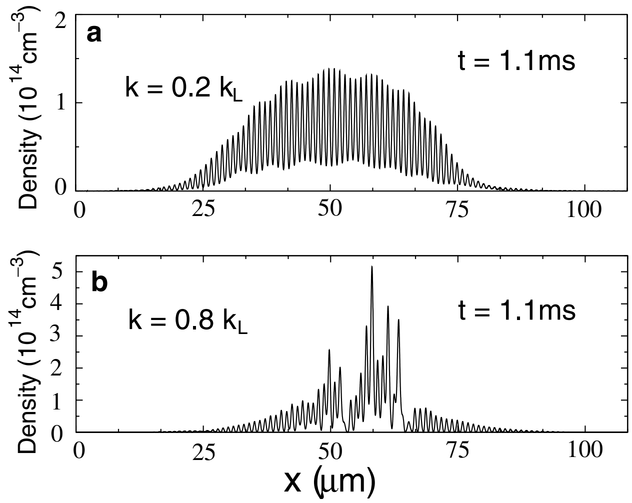

FIG. 1. Inhomogeneous BEC Bloch waves after evolving $t = 1.1$ ms. (a) Bloch wave number $k = 0.2k_L$; (b) $k = 0.8k_L$. The distorted and fragmented wave function signals the onset of dynamical instability.

The inhomogeneity of the BEC cloud in the experiment is not important. As shown in Fig. 1, the dynamical instability does not exist for the inhomogeneous Bloch waves near the center of the Brillouin zone and exists for ones at the outer region of the zone. This is the same as the homogeneous Bloch waves [2].

Our view is, in fact, strongly supported by the theoretical results presented in Ref. [1]. In Fig. 3 of Ref. [1], the experimental data are in remarkable agreement with the numerical results of the 1D Gross-Pitaevskii (GP) equation, where only dynamical instability is accounted. GP equations cannot simulate Landau instability since it does not allow energy dissipation. When Landau instability occurs, the system lowers its energy by emitting phonons. Finally, one may wonder if the very good fitting shown in Fig. 4 of Ref. [1], where only Landau instability is considered, can be found for other BEC densities and optical lattice strengths.

Biao Wu[1,2] and Qian Niu[1]
[1]Department of Physics, The University of Texas at Austin, Austin, Texas 78712-1081
[2]Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6032

Received 28 January 2002; published 2 August 2002
DOI: 10.1103/PhysRevLett.89.088901
PACS numbers: 03.75.Fi, 05.30.Jp, 67.40.Db, 73.20.At

[1] S. Burger *et al.*, Phys. Rev. Lett. **86**, 4447 (2001).
[2] B. Wu and Q. Niu, Phys. Rev. A **64**, 061603(R) (2001).
[3] J. C. Bronski *et al.*, Phys. Rev. Lett. **86**, 1402 (2001).

