Dark solitons in Bose-Einstein condensates

S. Burger, K. Bongs, S. Dettmer, W. Ertmer, and K. Sengstock

Institut für Quantenoptik, Universität Hannover
Welfengarten 1, D-30167 Hannover, Germany
Tel +49-511-762 -2231, Fax +49-511-762 -2211
E-mail: ertmer@iqo.uni-hannover.de, Website: http://www.iqo.uni-hannover.de

One of the most striking aspects of Bose-Einstein condensates (BEC) of weakly interacting gases are the nonlinear properties of these systems. Of particular interest are macroscopically excited states, such as solitons and vortices. Solitons, as particle-like excitations of matter wave fields, provide a link from condensate physics to fluid mechanics, nonlinear optics and fundamental particle physics.

Dark solitons in matter waves are characterized by a local density minimum and a steep phase gradient of the wavefunction at the position of the minimum. The shape of the soliton is preserved due to the balance between the repulsive interparticle interaction (seeking to fill the minimum) and the phase gradient (seeking to enhance the gap).

We report on the experimental investigation of dark solitons in BEC's of ^{87}Rb. A highly anisotropic confining potential (see [1]) allows us to be close to the (quasi) 1D situation where dark solitons are expected to be dynamically stable [2]. Low lying excited states are produced by the method of phase imprinting [3]. By monitoring the evolution of the density profile we study the dynamics of the wavefunction.

The evolution of density minima travelling at a smaller velocity than the speed of sound in the trapped condensate is observed. By comparison to analytical and numerical solutions of the 3D Gross-Pitaevskii equation for our experimental conditions we identify these density minima to be moving dark solitons [4].

We have studied in detail the creation and the dynamics of dark solitons as a function of evolution time and imprinted phase distribution. Fig.1 shows the density profiles of atomic clouds for different evolution times in the magnetic trap, t_{ev}. In agreement with numerical solutions of the 3D Gross-Pitaevskii equation, the minimum moving slowly (in comparison to the speed of sound) to the positive z-direction can be identified as a moving dark soliton. An additional structure is attributed to a density wave created in the phase imprinting process in combination with more complex dynamics during an additional free evolution time t_{TOF}. The results of the experiment also show clear signatures of the presence of dissipation originating from the interaction of the soliton with the thermal cloud. As predicted by theory, we see no indication for dynamical instability in the experiment. As the lifetime of the soliton is sensitive to the gas temperature, the studies of dissipative dynamics of solitons will offer a unique possibility for thermometry of BEC's in the conditions where the thermal cloud is not discernible.

We present first results on the interaction of two counterpropagating dark solitons, and we report on results of spectroscopic measurements of dark soliton states using Bragg-diffraction

[5, 6]. The study of dark solitons in a 1D geometry, created by a far blue-detuned doughnut-mode potential will be discussed.

This work is supported by the SFB 407 of the *Deutsche Forschungsgemeinschaft.*

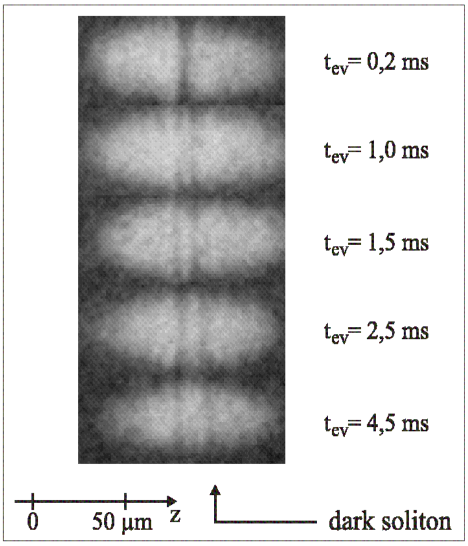

Figure 1: Images of BEC's after phase imprinting, varying evolution times in the magnetic trap, and a time-of-flight of 4ms. For short evolution times the density profile of the BEC shows a pronounced minimum. The dark soliton appears as a minimum travelling in positive z-direction.

[1] K. Bongs, S. Burger, G. Birkl, K. Sengstock, W. Ertmer, K. Rzążewski, A. Sanpera, and M. Lewenstein, *Phys. Rev. Lett.* **83**, 3577 (1999).

[2] A. E. Muryshev, H. B. van Linden van den Heuvell, and G. V. Shlyapnikov, *Phys. Rev. A.* **60**, R2665 (1999).

[3] Ł. Dobrek, M. Gajda, M. Lewenstein, K. Sengstock, G. Birkl, and W. Ertmer, *Phys. Rev. A.* **60**, R 3381 (1999).

[4] S. Burger, K. Bongs, S. Dettmer, W. Ertmer, and K. Sengstock, A. Sanpera, G. V. Shlyapnikov, and M. Lewenstein, *Phys. Rev. Lett.* **83**, 5198 (1999).

[5] M. Kozuma, L. Deng, E. W. Hagley, J. Wen, R. Lutwak, K. Helmerson, S. L. Rolston, and W. D. Phillips, *Phys. Rev. Lett.* **82**, 871 (1999).

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