Controlled transport of matter waves in driven optical lattices

J. Abdullaev, E. A. Ostrovskaya, and Yu. S. Kivshar
Research School of Physics and Engineering, ACQAO, ANU

The idea of controlled manipulation of stable, spatially localized matter-wavepackets is attractive from the point of view of the developing atomic interferometry and precise measurement techniques based on the use of the Bose-Einstein condensates (BECs). In the recent years optical lattices were suggested as a means of achieving controlled transport of matter waves. In particular, theoretical studies of nonlinearly localized matter-wave solitons, loaded into a rapidly driven one-dimensional (1D) asymmetric optical lattice potential, have demonstrated that such an "optical ratchet" does not jeopardize the dynamical stability of the solitons and enables their mass-dependent transport [1, 2].

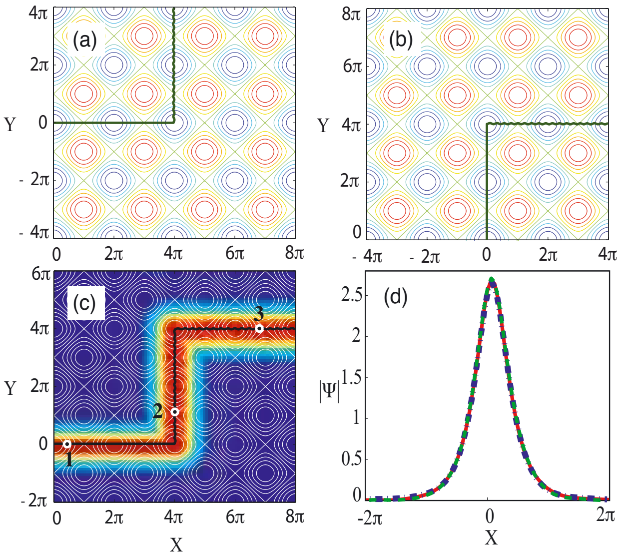

Figure 1: (a,b) Center of mass trajectory of a moving soliton in a rocking lattice potential, superimposed onto the contour plot of the potential at the initial time moment, and, in (c), onto the density profile of the moving soliton. Sharp turning points correspond to the switching of the directed mobility channels effectively created by driving. (d) The profiles of the moving soliton corresponding to the points 1 (solid), 2 (dashed), and 3 (dash-dotted) in (c).

Creation and transport of matter-wave solitons in a 2D or 3D trapping geometry is a more complex and challenging task, especially considering the instability of the condensate with the negative scattering length. Different methods of stabilization were suggested, many of them relying on the time-periodic management of the scattering length, or non-local interaction between ultracold atoms. Furthermore, various theoretical studies have established that stability of the nonlinear localized matter-wave can be greatly improved in an optical lattice, even in the case when the dimensionality of the soliton and the lattice do not coincide. However, an optical lattice potential may greatly inhibit the mobility of the localized states, and the main challenge is to suggest an efficient method for non-destructive, dynamically controlled transport of the stabilized wavepackets.

Here we present the theory of nonlinear dynamics, controlled transport, and "routing" of 2D matter-wave solitons, created in a BEC with a negative scattering length, by means of a driven "rocking" 2D optical lattice. This type of a dynamically reconfigurable lattice has been recently realized in experiments with ultracold atoms [3]. Our numerical analysis, based on the mean-field Gross-Pitaevskii model, and the theory based on the time-averaging approach, demonstrate that a fast time-periodic rocking of the 2D optical lattice enables efficient stabilization and manipulation of nonlinear localized matter wavepackets along dynamically created "mobility channels", as shown in Fig. 1 [4].

References

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