Dynamics of matter-wave solitons in a ratchet potential

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The ratchet effect, i.e. rectified average current induced by an asymmetric potential and unbiased zero-mean driving force, has been extensively studied in various physical contexts due to its relevance to biological systems and nanotechnology [1]. The theory predicts that, in order for a ratchet to work, the space-time symmetry of the driving potential should be broken and the experiments with cold atoms and Bose-Einstein condensates (BECs) in optical ratchet potentials (see, e.g., [2]) have confirmed this prediction. These experimental advances coincide with the growing interest in the effect of interaction on ratchet transport. As a physical system with intrinsically present nonlinear interactions due to atomic scattering, a BEC supports the existence of spatially localized, particle-like collective excitations - *matter-wave solitons*. It is therefore natural to consider the possibility that a ratchet potential can not only provide the means to transport the condensate bulk, but also to control a directed motion of individual matter-wave solitons.

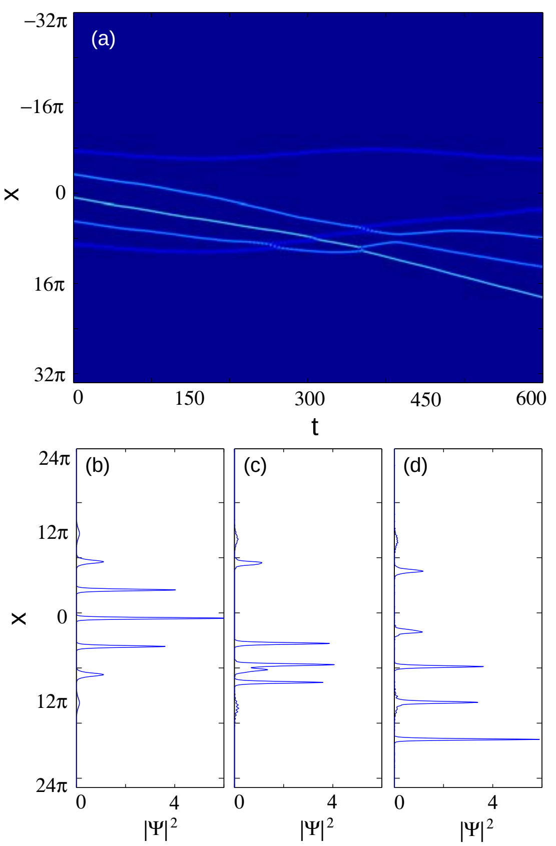

Fig. 1: Dynamics of an array of bright solitons in a ratchet potential. Larger solitons move faster, which results in spatial separation of solitons with different masses.

Recently we have studied the dynamics and transport of bright matter-wave solitons in a weak flashing optical ratchet potential [3, 4]. The important feature of the ratchet-induced transport is the dependence of the soliton cumulative velocity on both number of atoms and the initial position of the soliton. For small atom numbers the soliton transport occurs in one direction only, while larger solitons may be transported in either direction. As a result, the averaging over all initial positions results in a strong ratchet effect for solitons with small peak densities. The results obtained by direct numerical integration of the one-dimensional mean-field model show good qualitative agreement with the effective-particle approximation. Finally, we have investigated the scattering of the matter-wave solitons moving under the influence of a ratchet potential. Depending on the size of the interacting solitons, their collisions can cause either gradual or instantaneous transitions between transporting and non-transporting trajectories in the phase space. We have demonstrated that for multiple solitons of different sizes, initially formed in a harmonically trapped condensate, this effect could result in directed transport or spatial filtering of solitons.

References

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