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Spatiotemporal modulated solitons in a quasi-one-dimensional spin-1 Bose–Einstein condensates

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ABSTRACT

In this paper, we investigate the nonautonomous bright/dark solitons in a quasi-one-dimensional spi Bose–Einstein condensates through a three coupled Gross–Pitaevskii (GP) system with space–time-depend external potential and temporally modulated gain/loss distributions. Based on the Hirota bilinear method, analytically construct the bright soliton solutions when the coupled GP system exhibits attractive interactic while we obtain the dark soliton solutions when the coupled GP system exhibits repulsive interactic The influence of spatiotemporal modulated external potentials, such as the gain/loss distribution $\Gamma(t)$, bright/dark soliton dynamics is analyzed in detail via the analytical solutions. By taking different $\Gamma(t)$, obtain different types of bright solitons, including periodic, dromion-like and parabolic solitons, and a derive dark solitons on different backgrounds, such as periodic, parabolic and kink backgrounds. We anal the regulatory effects of different wavenumber ratios on the attraction and squeezing of bound-state solitc Through the asymptotic analysis, we find that the interactions between two solitons are elastic. In additi we conduct research on the forward and inverse problems of the above results via the parallel hard-constra physical informed neural network (phPINN) method. The predicted solitons and potential functions are in g agreement with the exact solitons and potential in the system.

1. Introduction

Bose–Einstein condensation (BEC) represents one of the most specific and fascinating quantum phenomena in nature [1]. In essence, it is a genuinely quantum-mechanical phase transition which is driven by the particle statistics and not by their interaction. Especially, a spinor BEC is a BEC with an internal atomic spin degree of freedom displaying a rich variety of magnetic effects [2]. In such interesting multi-component condensed system, there exist several phases below the transition temperature and the phases are dependent on the nature of the interaction. It should be mentioned here that in a conventional magnetic traps, the spin degrees of freedom are frozen and the BEC is described by a scalar order-parameter. In contrast, when the BEC is trapped using an optical potential, the spin of each atom is free to evolve due to the interparticle interaction. The order-parameter describing a BEC with spin internal degrees of freedom is referred to as a spinor BEC [3–6]. Usually, spinor BECs feature an intrinsic three component structure, which is due to the differences between differ hyperfine spin states of atoms [5]. It is also to be noted that such a I system has been first experimentally realized in a gas of ^{23}Na ato with hyperfine spin $F = 1$, in an optical dipole trap [4]. Moreover has been reported that due to the interparticle interaction, the direct of atomic spins can change, and therefore, spinor BECs exhibit cert spin textures [7–9]. Nowadays, spinor BECs have an important rol physics because the spin degrees of freedom can generate rich quant dynamics and abundant phenomena, including spin texture (i.e., spatial variation of the spin direction [2]), magnetic crystallization, fractional vortices [10–12]. Importantly, experimental and theoret studies on spinor BECs have revealed various interesting phen ena, such as quantum junction [13], polarity to ferromagnetic ph transition [14], condensation excited by Magnon [15], and vari nonlinear excitations composed of dark/bright solitons [16–23], ro waves [24], soliton complexes [25], vortices [26–28], etc..

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