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Short communication

The rogue waves with quintic nonlinearity and nonlinear dispersion effects in nonlinear optical fibers

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ABSTRACT

We study on rogue waves in a nonlinear fiber with cubic and quintic nonlinearities, linear and nonlinear dispersion effects. We find the rogue wave with these higher order effects has identical shape with the well-known one in nonlinear Schrödinger equation. However, the quintic nonlinear term and nonlinear dispersion effect affect the velocity of rogue wave, and the evolution of its phase.

1. Introduction

Rogue wave (RW) phenomena in the ocean, are reported to have disastrous consequence, such as destroy ships, oil platform, etc. [1,2]. To avoid its negative effects, people need to know its character, mechanism, even find the ways to control it. Recently, scientists have done lots of studies on them [3]. It is shown that it possesses many exceptional properties, such as much higher than surrounding waves, abrupt appearance and disappear without any trace, etc. Between the studies, the nonlinear theory have been paid much attention [4–8]. It has been found that the dynamics equations for RW in ocean, Bose–Einstein condensate, plasmas, and nonlinear optical fibers are identical fundamentally. Therefore, the studies on RW in nonlinear fibers would help us to understand the ones in other systems [9]. It is well known that the nonlinear Schrödinger equation (NLSE)

$$i\psi_z + \psi_{tt} + 2|\psi|^2\psi = 0, \qquad (1)$$

which describes the optical pulse propagation in optics fibers when the pulse width is greater than 100 femtosecond [10–12], Where $\psi = \psi(t,z)$ is the slowly varying amplitude of the pulse envelope, z represents the distance along the direction of propagation and t is the retarded time. It is shown that the rational form solution of the NLSE, could be used to describe RW well [8]. Furthermore, RW has been observed recently in one-mode nonlinear fibers experimentally [10,11], which would highly stimulate RW studies in a lot of nonlinear systems.

However, the dynamics of these nonlinear systems is significantly more complicated than the one modeled by the simple NLSE. For example, for femtosecond optical pulse, higher-order terms that take into account third-order dispersion, self-steepening and other nonlinear effects have to be added to this equation [13]. Thus, a question arises: do rogue wave solutions exist for these more complicated equations? Considering third-order dispersion and delayed nonlinear response

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effects, RW in Hirota equation have been studied in [14,15]. Distinct from them, we study RW for the integrable Kundu–Eckhaus (KE) equation as following [16–19],

$$i\psi_z + \alpha\psi_{tt} + \gamma|\psi|^2\psi + 4\beta^2|\psi|^4\psi - 4i\beta(|\psi|^2)_t\psi = 0, \tag{2}$$

where the subscripts represent the partial derivatives, α is the group velocity dispersion coefficient, γ is the nonlinear parameter responsible for the self-phase modulation, β^2 is the quintic nonlinearity coefficient, the last term is a nonlinear term which results from the time-retarded induced Raman process. Eq. (2) has been derived in [16,17] and possesses some applications in the nonlinear optics [21], quantum field theory [20] and weakly nonlinear dispersive matter waves [22].

In this letter, we present exact rational solution for the KE model through Darboux transformation. It is found that properties of the rational solution are similar to RW's. Therefore, it could be used to describe RW in the model as the previous works [6,7]. We find that the quintic nonlinear coefficient and nonlinear dispersion effect affect the velocity of rogue wave, and change the evolution of its phase, under the integrable condition, which is the additional requirement on the coefficients to solve it analytically. Interestingly, the rogue wave with these higher order effects has identical shape with the well-known one of the simplified NLSE which just cubic nonlinearity and linear group velocity dispersion effects.

2. Exact rational solution and rogue waves

The Eq. (2) has been solved to get soliton solution on trivial background through Darboux transformation (DT) method in [19]. As done in NLSE, one can get rational solution on nonzero plane wave background. We perform the DT method to derive

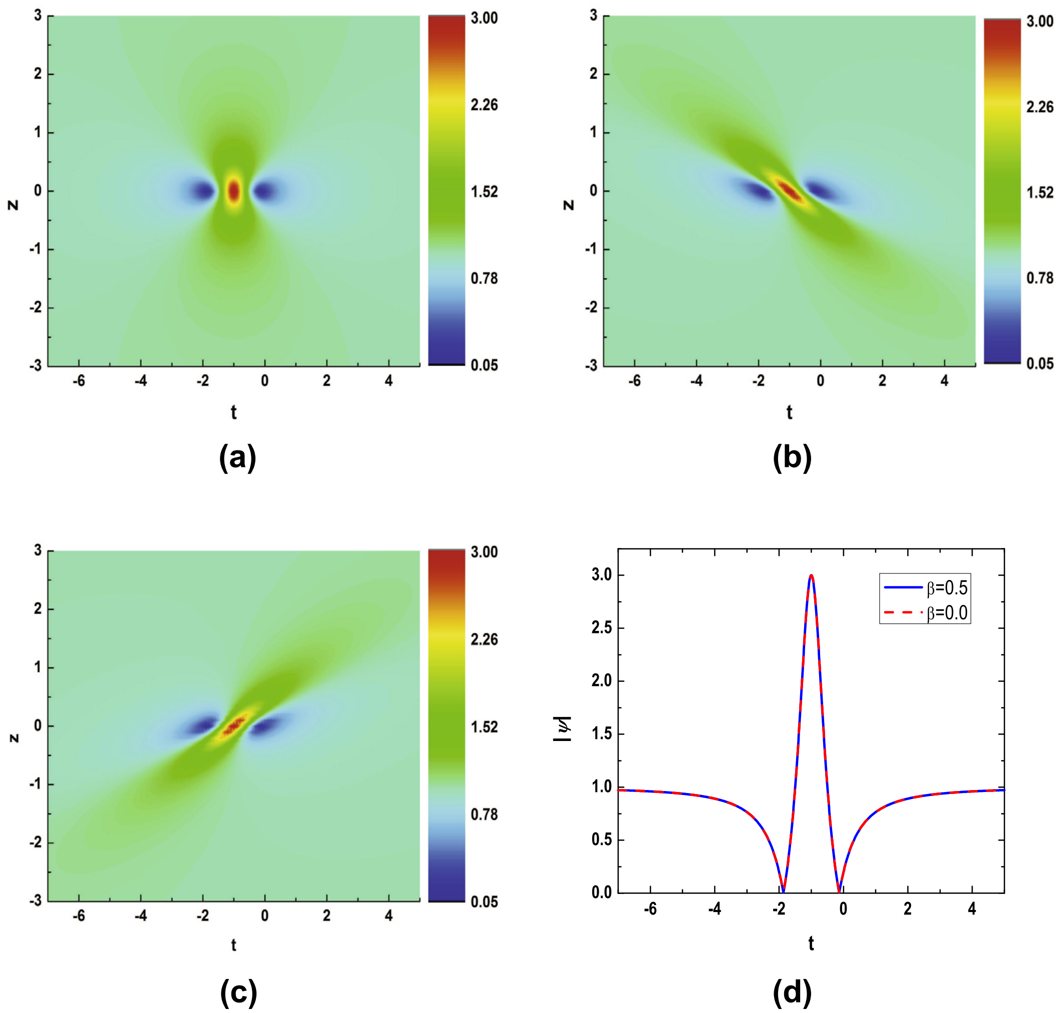

Fig. 1. The evolution of RW with different nonlinear parameters β. (a) $\beta = 0$; (b) $\beta = 0.5$; (c) $\beta = -0.5$; and (d) the density distribution of RW with different β at $z = 0$ (the red dashed one with $\beta = 0$, and the blue one with $\beta = 0.5$). It is shown that the density distribution on time are unchanged with β, and the parameter β just affect its velocity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)