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Controllable Rogue Waves in the Generalized Nonlinear Schrödinger Equations

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

We obtain the rogue waves with a controllable center in the generalized nonlinear Schrödinger equation by using a direct method. The position of these solutions can be controlled by varying different center parameters. We study the effects of different parameters on rogue waves and hence find that the nonlinearity parameter is responsible for the width of rogue waves. With the increase of the nonlinearity parameter, the rogue wave becomes wider. What is more, the negative nonlinearity parameter can yield some singular rogue waves.

Keywords: Generalized nonlinear; schrödinger equation; rogue wave; singular rogue wave.

1. INTRODUCTION

Rogue waves, are called freak waves, monster waves, killer waves, giant waves or extreme waves, Rogue waves are spontaneous nonlinear waves with amplitudes significantly larger (two or more times higher) than the surrounding average wave crests [1,2], What is more, they appear from nowhere and disappear without a trace.

It is a very meaningful work to search for rogue waves, which has been found in many different

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systems and has many important applications in some fields since they can signal fascinating stories [3,4].

In this paper, we study the generalized nonlinear cubic Schrödinger equation

$$\mathrm{i}\frac{\partial\psi}{\partial x}+\mathrm{A}\frac{\partial^2\psi}{\partial t^2}+\psi\left|\psi\right|^2=0, \tag{1}$$

where x is the propagation distance and t is the transverse variable. When A=0, equation (1) becomes the famous nonlinear cubic Schrödinger equation. Some rogue wave solutions of the nonlinear cubic Schrödinger equation have been found by taking limit of Akhmediev breather solutions [5,6] and Darboux transformation [7,8]. By a similarity transformation, rogue wave solutions to the generalized nonlinear Schrodinger equation with variable coefficients are obtained [9].

Using the (Exp(−φ (ξ))) -Expansion method, some new exact traveling wave solutions of the cubic nonlinear Schrodinger equation are given [10]. The center of these solutions is located at a fixed point (0, 0) on (x, t) plane. Basing on a simple assumption, WANG et al. [11] founded larger universality and applicability of rogue waves with a controllable center. The above method does not consider the effect of parameters on the waveform, which is our interest. More researches on rogue waves can be founded in Ref [12-21].

In this paper, our interests focus on two aspects:

(1) We want to determine rogue wave solutions of Eq. (1) with an arbitrary coefficient of nonlinearity;
(2) We want to know the role of the nonlinearity coefficient on the formation of rogue waves.

The organization of this paper is as follows. In Section 2, we obtain some special rogue waves with a controllable center by a direct method. In Section 3, we analyze the different controllability by numerical simulation. Conclusion will be given.

2. SOME SPECIAL ROGUE WAVES

By the similar method in Ref. [9], we assume rogue waves as follows

$$\psi_1=\left(1+\frac{p_1+iq_1}{h_1}\right)e^{ix} \tag{2}$$

With

$$p_1\left(x,t\right)=a_0+a_1x+a_2t, \tag{3}$$

$$q_1\left(x,t\right)=b_0+b_1x+b_2t, \tag{4}$$

$$h_1\left(x,t\right)=c_1\left(x-\alpha\right)^2+c_2\left(t-\beta\right)^2+c_3. \tag{5}$$

Here α_i, b_i (i = 0, 1, 2), c_j (j = 1, 2, 3), α, β are real parameters.

Substituting the function ψ_1 into Eq. (1) and setting different coefficient Lists to be zero. We obtain the following possible system of nonlinear algebraic equations with the aid of Maple.

$$\begin{gathered}
-3b_2{c_1}^2=0,\\
-3b_2{c_2}^2=0,\\
2a_2b_2c_2+a_1{c_2}^2=0,\\
8\alpha a_2c_1c_2-2b_2c_1c_2-6\alpha^2b_2c_1c_2-16\beta a_1c_2^2+12\beta b_0c_2^2-18\beta^2b_2c_2^2-6b_2c_2c_3=0, \quad (6)\\
-6a_0c_1c_2+12\alpha a_1c_1c_2+12\beta a_2c_1c_2-54\alpha^2c_1^2c_2-54\beta^2c_1c_2^2-18c_1c_2c_3=0,\\
-6a_1c_1c_2+36\alpha c_1^2c_2=0,\\
4a_1c_2^2-3b_0c_2^2+12\beta b_2c_2^2=0,\\
12\alpha a_2c_1c_2+8b_2c_1c_2+12\beta a_1c_2^2-72\alpha\beta c_1c_2^2=0,\\
\dots\dots\dots
\end{gathered}$$

From (6), we can have two classes of solutions:

Case 1.

$$c_3 \neq 0,\ a_0 = -4c_3,\ a_1 = 0,\ a_2 = 0,\ b_0 = 8c_3\alpha,\ b_1 = -8c_3,\ b_2 = 0,\ c_1 = 4c_3,\ c_2 = \frac{2c_3}{m}. \tag{7}$$

Substituting (7) into Eq. (1), we obtain

$$\psi_1 = \left(1 + \frac{-1 + i(2\alpha - 2x)}{(x-\alpha)^2 + \frac{1}{2m}(\mathrm{t}-\beta)^2 + \frac{1}{4}}\right)e^{ix} \tag{8}$$

Case 2

(i) $a_0 = 0,\ a_1 = 0,\ a_2 = 0,\ \alpha = \frac{-b_0 - \beta b_2}{b_1},\ m = \frac{-b_1^{\ 2}}{2b_2^2},\ b_0 \neq 0,\ c_1 = -b_1,$

$$m \neq 0,\ c_2 = -\frac{b_1}{2m},\ c_3 = 0. \tag{9}$$

(ii) $a_0 = 0,\ a_1 = 0,\ a_2 = 0,\ b_0 \neq 0,\ \alpha = -\frac{\beta b_2}{b_1},\ m = -\frac{\beta^2}{2\alpha^2},$

$$c_1 = -b_1,\ m \neq 0,\ c_2 = -\frac{b_1}{2m},\ c_3 = 0. \tag{10}$$

Substituting (9) and (10) into Eq. (1), we obtain

$$\psi_2 = \left(1 + \frac{i(b_0 + b_1 x + b_2 t)}{-b_1\left(x - \frac{-b_0 - \beta b_2}{b_1}\right)^2 + \frac{b_2^{\ 2}}{b_1}(t-\beta)^2}\right)e^{ix} \tag{11}$$

$$\psi_3 = \left(1 + \frac{i(b_0 + b_1 x + b_2 t)}{-b_1\left(x + \frac{\beta b_2}{b_1}\right)^2 + \frac{b_2^{\ 2}}{b_1}(t-\beta)^2}\right)e^{ix} \tag{12}$$

3. SOME PROPERTIES OF ROGUE WAVES

3.1 Width of Rogue Waves

It is well known that the parameter of the nonlinearity have a major impact on the forms of waves. We herein analyze the impact of rogue waves with the varying parameter of the nonlinearity. Given by different parameters of the nonlinearity, we draw the corresponding rogue waves and density pictures. It is easy to find that: (1) The nonlinearity parameter m has little effect on the height of rogue waves. That is, there is no change the height with different parameters of the nonlinearity. (2) The nonlinearity parameter m has more effect on the width of rogue waves. With the increase of m, the rogue waves becomes wider (in detailed see Figs. 1-3).

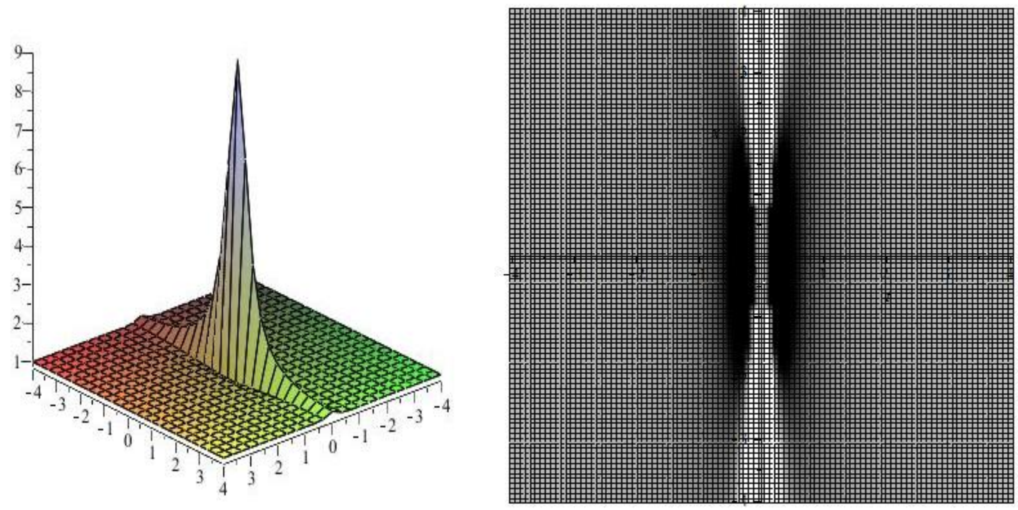
3.2 Rogue Waves with a Controllable Center

From (8), we find rogue waves will move when α, β are given by different values. When we study the situation before taking α definite values for d of m. The following, we consider wave changes under m taking a fixed value 0.5 and α, β varying. We find the following facts:

When α, β are given by different values, the central location of the rogue wave are different, namely, the rogue wave center is movable (see Figs. 4-7).

3.3 Singular Rogue Waves

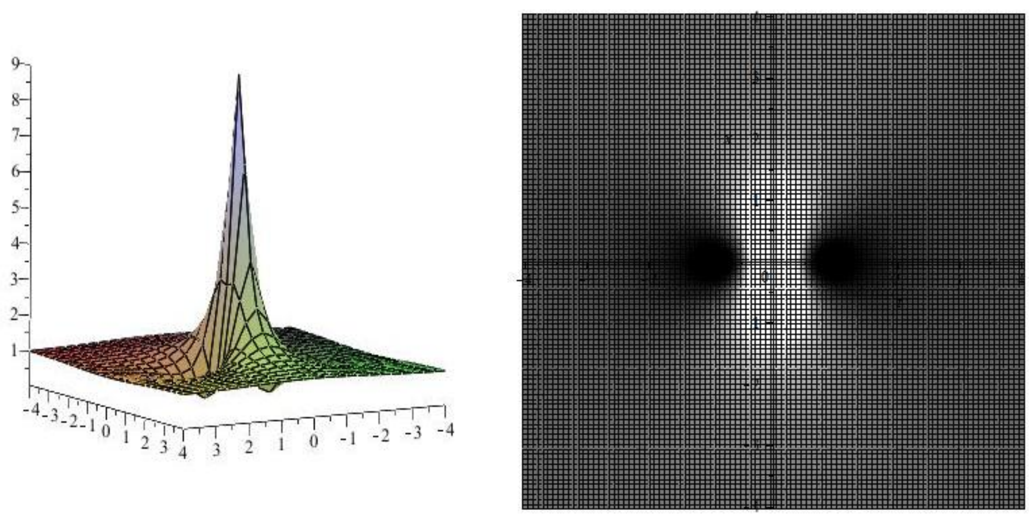
According to the analysis in Section 2, when m is a negative value, we find that the denominator value of obtained solutions (11)-(12) can be zero under some positions. So we can obtain some singular rogue waves see Figs. 8-11.



(a) (b)

Fig. 1. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for

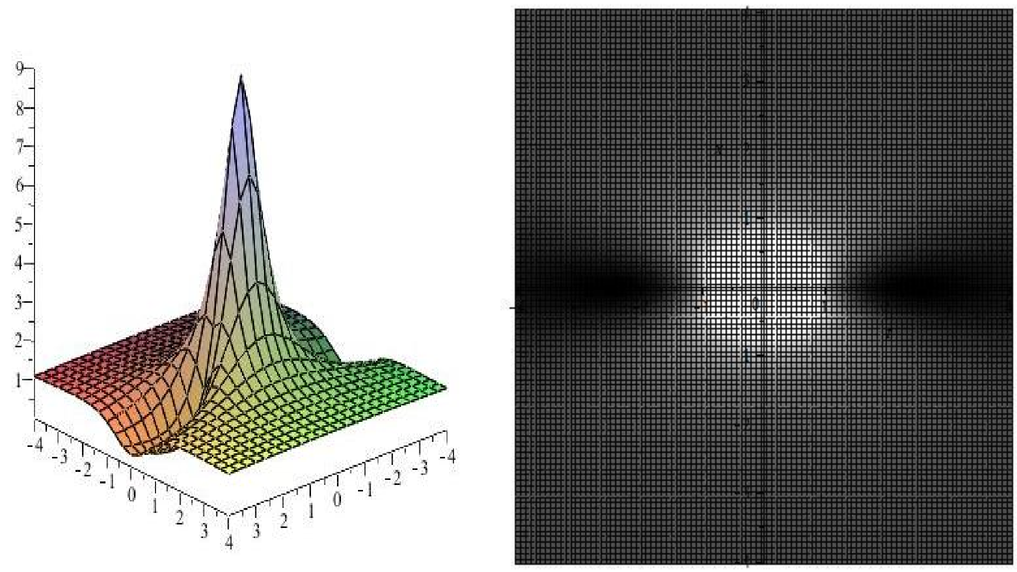
$m = 0.005, \alpha = 0$,



(a) (b)

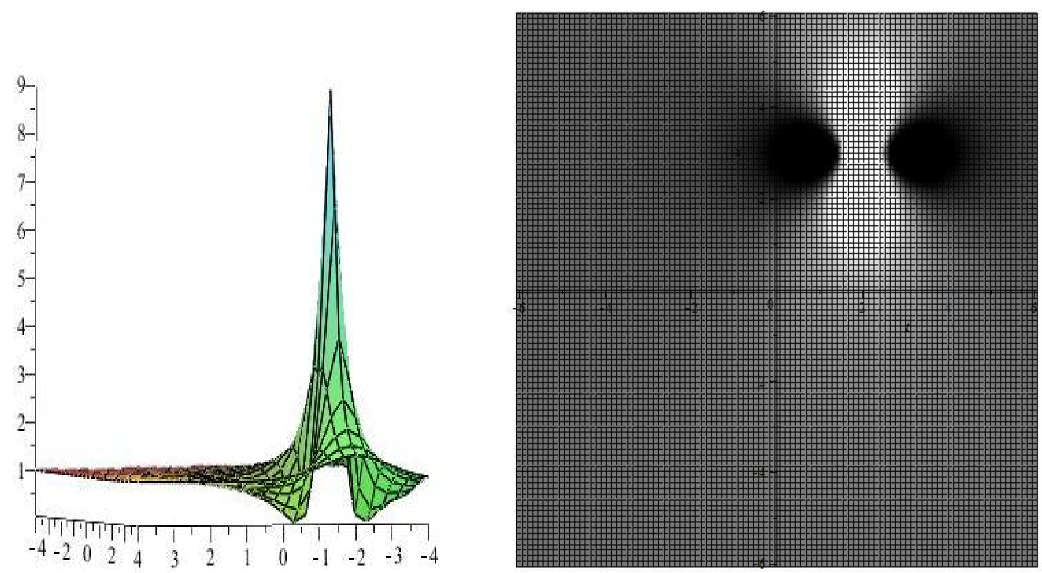
Fig. 2. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for

$m = 0.5,\ \alpha = 0$



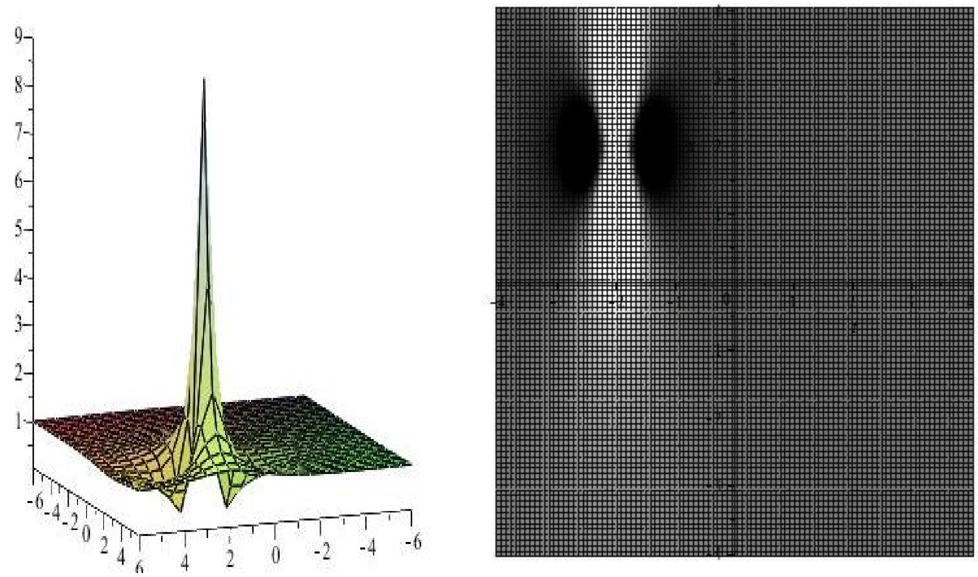
(a) (b)

Fig. 3. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for $m = 4, \alpha{=}0$



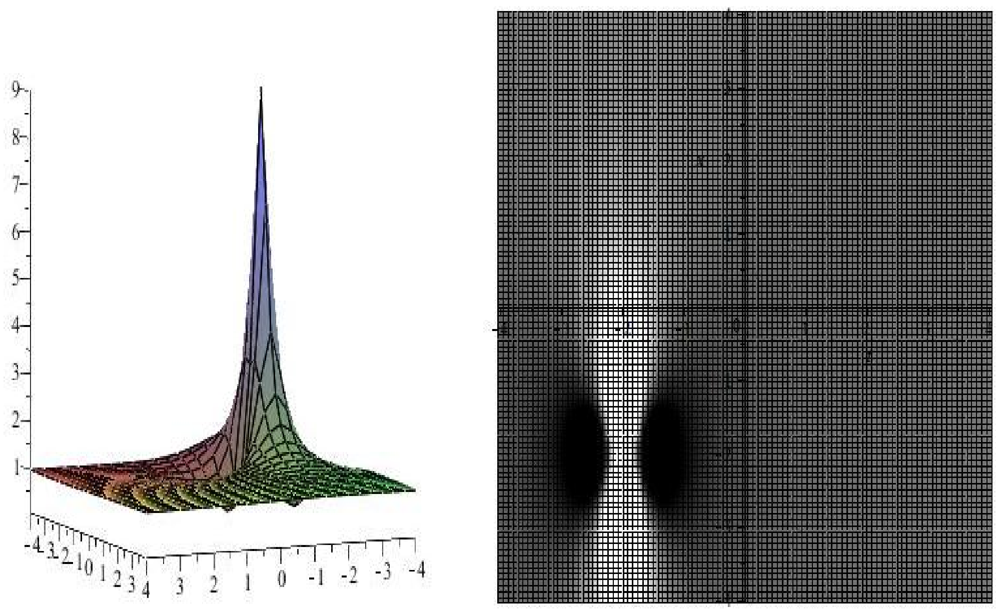
(a) (b)

Fig. 4. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for $m = 0.5$, $\alpha = 3, \beta = 2$



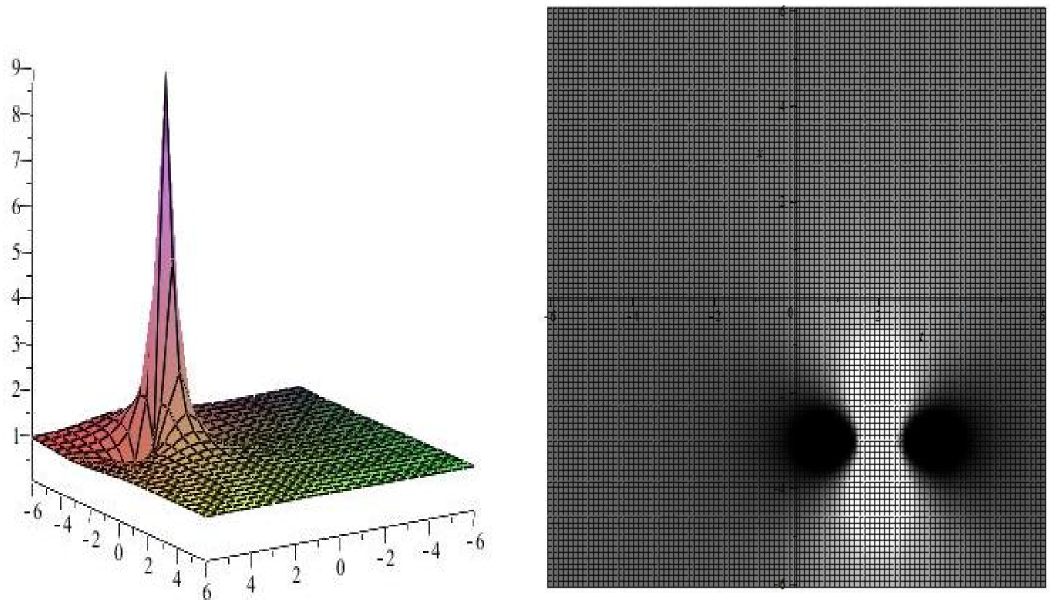
(a) (b)

Fig. 5. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for
$m = 0.5 , \alpha = 2, \beta = -2$



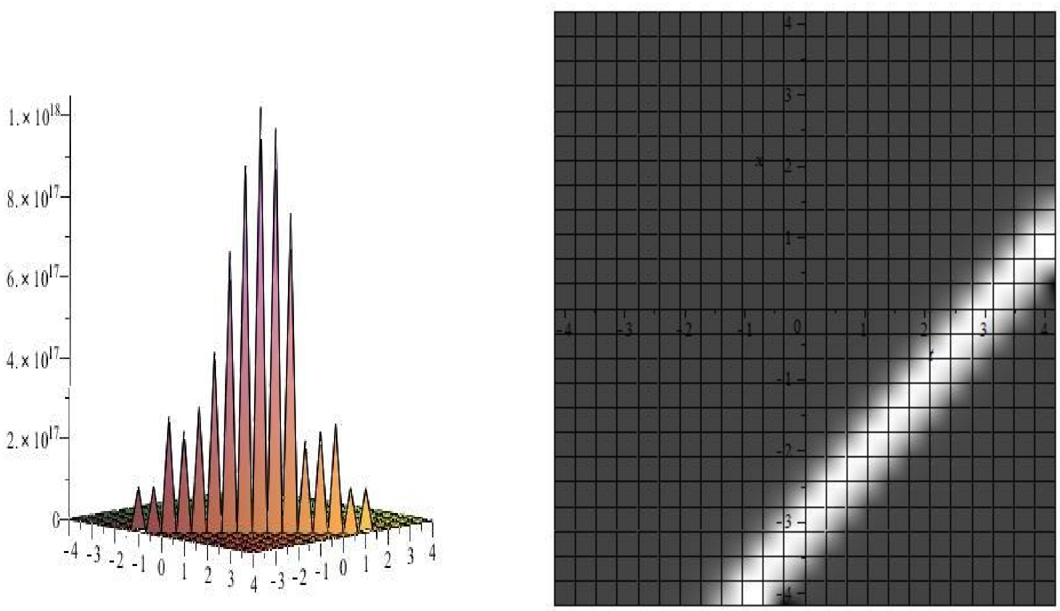
(a) (b) b

Fig. 6. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for
$m = 0.5 \ \alpha = -2, \beta = -2$.



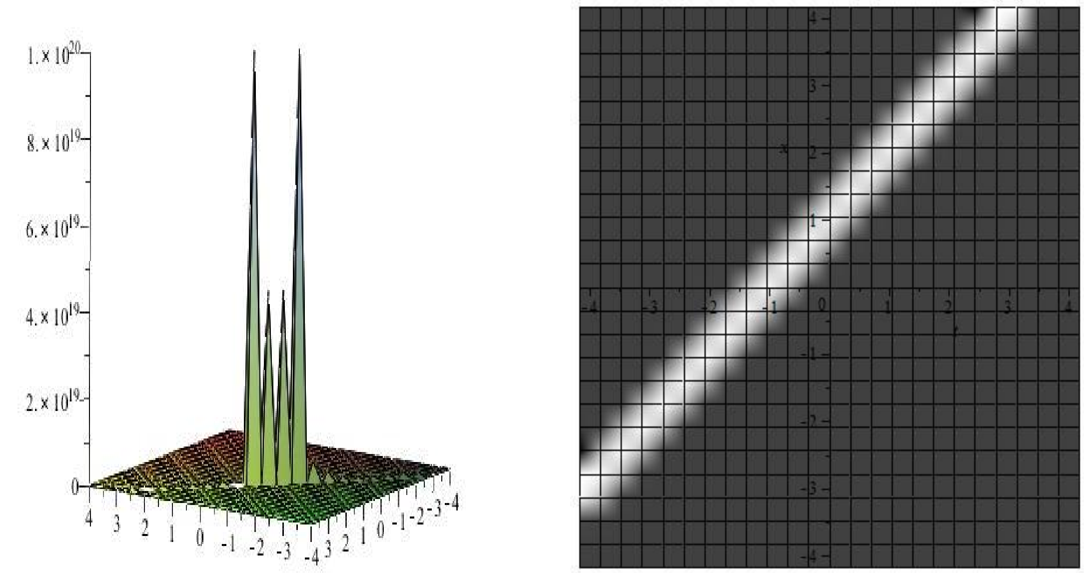
(a) (b)

Fig. 7. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for
$m = 4, \alpha=0$.



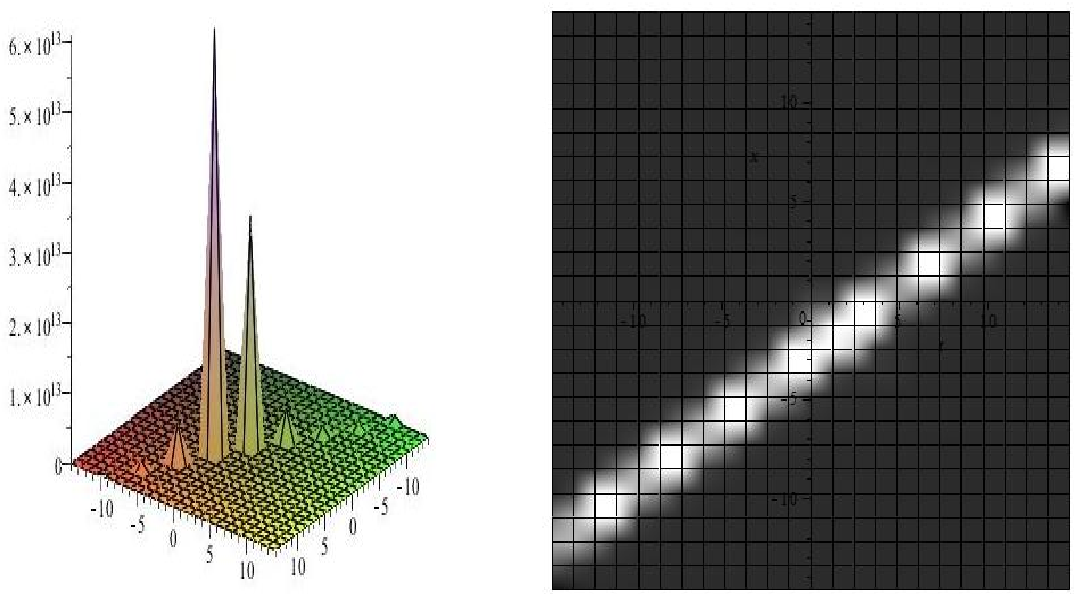
(a) (b)

Fig. 8. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ for
$b_0 = 1, b_1 = 1, b_2 = 1, \beta = 1.$



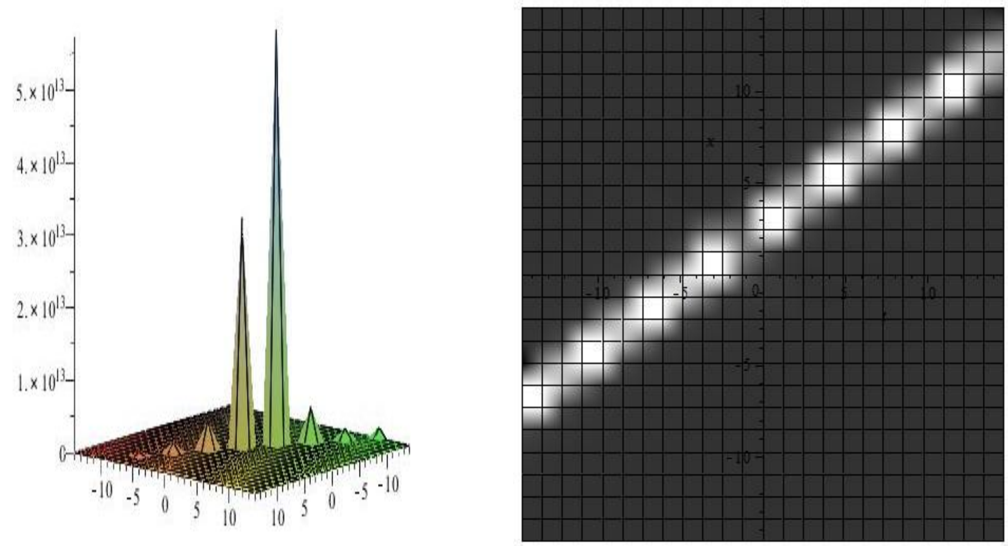
(a) (b)

Fig. 9. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ **for** $b_0 = 1,\ b_1 = 1,\ b_2 = 1,\ \beta = -1.$



(a) (b)

Fig. 10. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ **for** $b_0 = -1,\ b_1 = 3,\ b_2 = 2,\ \beta = 2.$



(a) (b)

Fig. 11. Rogue wave propagations (a) and contour plots (b) for the intensity $|\psi_1|^2$ **for** $b_0 = -1,\ b_1 = 3,\ b_2 = 2,\ \beta = -2.$

4. CONCLUSION

In this paper, we obtain some special rogue waves with a controllable center by a direct method and study the effects of different parameters on rogue waves. We find that the nonlinearity parameter is responsible for the width of rogue waves. In the future, we will study the effects of rogue wave solutions ψ_1 on NLS equations by similarity transformation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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