Deterministic optical rogue waves

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Rare extreme events can be observed in different systems in nature. A typical example are rogue waves observed in the oceans, where waves higher than 30 meters are more or less common phenomena. This fact is in contradiction with the Gaussian models often used to describe fluctuations of the wave height in the sea[1,2]. Scientific interest on extremely high waves increased substantially during the last decade not only in oceanographic studies but also in other systems such as capillary waves[3] and optical waves[4–7]. Both, from the theoretical and from the experimental points of view there are several questions still remaining unsolved. The physical mechanisms that originate them, the way they develop, the probability for them to occur , the type of system able to generate such extreme events, and the connections between extreme events in systems which are apparently completely different, are being the subjects of intensive research.

In this work we investigate, both experimentally and theoretically, the appearance of rare giant pulses or rogue waves in a semiconductor laser subject to optical injection. We perform a detailed experimental characterization of the parameter region where rogue waves appear, and compare the experimental observations with numerical results from the simplest rate-equation model.

A typical experimental time series, where a sporadic large intensity pulse is observed, is shown in Fig. 1(a). Figure 1(b) shows a numerical time series obtained for the laser model, in a good qualitative agreement with the experiment. To investigate the rarity of the large pulse events, histograms for the laser intensity were measured, as shown in Fig. 2. Figure 2(a) shows a typical histogram for a time series without rogue waves and Fig. 2(b) shows an histogram with rogue waves. In this case, the probability distribution function of the pulse amplitude displays clear non-Gaussian features, with a long tail and an abnormality index that confirm the rogue wave character of the intensity pulsations.

The analysis of the theoretical model allows to discuss the main mechanisms associated with the appearance of rogue waves. Parameter regions where rogue waves occur are identified and is shown that the rogue waves can be understood as a result of a deterministic nonlinear process. The role of noise in the system is investigated and its influence to induce or inhibit rogue waves is discussed.

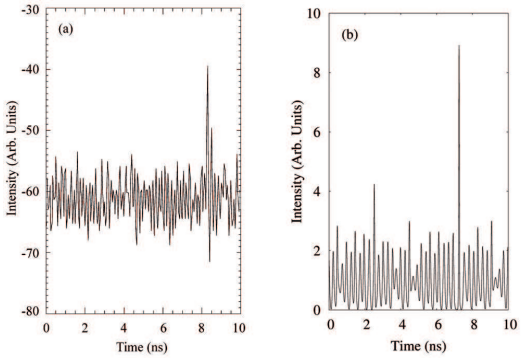

Figura 1. Time trace for the laser intensity showing the occurrence of a large rare event obtained by (a) measuring experimentally the laser intensity and (b) simulating the theoretical model.

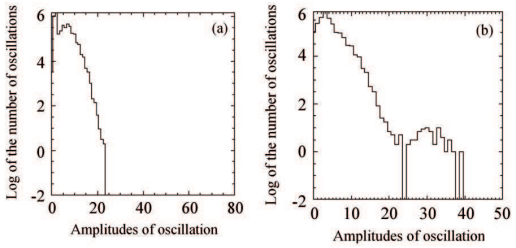

Figura 2. Experimental histograms obtained for the laser intensity showing the cases (a) without rogue waves and (b) with rogue waves.

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