Characterizing the complex dynamics of a semiconductor laser with optical feedback and modulation.

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The task of infering signatures of determinism in a complex system, by means of analyzing aperiodic, noisy time series, is recurrent in the study of nonlinear systems. Recently, methods to distinguish signatures of determinism that employ ordinal patterns analysis have received considerable attention for being computationally fast, conceptually simple, and for maintaining their usefulness even in the presence of high levels of noise[1–3].

One longstanding discussion about the roles of stochastic and deterministic processes, and where their detection and distinction are crucial, comes from semiconductor laser dynamics[4]. Semiconductor lasers subject to optical feedback and/or injection are paradigmatic nonlinear systems. They have been studied for decades and are still object of intense investigation, allowing experimental observation of a great variety of nonlinear behaviors. One of the most remarkable phenomena observed in a semiconductor laser under optical feedback are the low-frequency fluctuations (LFFs). LFFs are irregular, sudden power dropouts followed by a gradual stepwise recovery, that occur for moderate feedback levels near the laser's solitary threshold. This dynamical regime is of widespread interest in complex systems, as it involves the interplay of nonlinearity (light-matter interactions), time-delayed feedback and noise that induces this dynamics, ingredients which are ubiquitous in nature.

One particular configuration where a semiconductor laser with feedback results of special interest is when the laser is submitted to a external periodic forcing, as it is very useful in telecommunications and new phenomena manifest[5]. Also, many other dynamical systems tend to appear in nature subjected to an external modulation: electronic circuits, neuronal networks, metabolic system[6], ..., increasing the interest in characterizing the dynamics of nonlinear oscillators under an external periodic forcing.

We characterize the dynamics of a semiconductor laser subjected to optical feedback and modulation of the injection current. We measure the experimental power output of the laser in the LFF regime (see Fig. 1(a)) and compute the inter dropout intervals. We transform the time series into sequences of ordinal patterns (words of dimension 2, labelled as '01' and '10'), and compute the probability of each word, and the transition probabilities (see figure 1(b)) versus the modulation amplitude, to distinguish signatures of determinism and stochasticity in the dynamics of the system. We detect transitions in its dynamics as the amplitude of the modulation is varied, and we unveil a structure in the underlying dynamics of the IDIs, in good agreement with previous works and with the Lang-Kobayashi model[7].

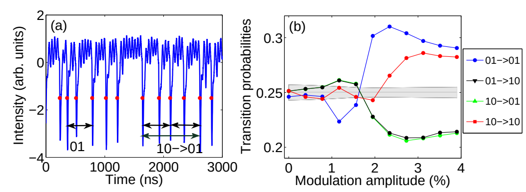

FIG. 1. (a) Experimental time series of the intensity of the laser with feedback and modulation. One word ('01') and one transition ('10− > 01') are shown as examples. (b) Transition probabilities of the different ordinal patterns are depicted versus the modulacion amplitude.

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