Effects of inhomogeneities and drift on the dynamics of temporal solitons in fiber cavities and microresonators

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In this work we describe the dynamics induced by inhomogeneities and drift on solitons in the framework of temporal systems, in particular in the case of fiber cavities and microresonators when they are pumped synchronously.

In [1] we introduced a mechanism that allows to generate oscillatory and excitable soliton dynamics. That mechanism was based on the competition between a pulling force due to drift and a pinning force due to spatial inhomogeneities. In the present work [2] we study the effects of drift and inhomogeneities on temporal solitons and their corresponding Kerr frequency combs in fiber cavities and microresonators, as described by the Lugiato-Lefever equation (LLE) with periodic boundary conditions. In particular we consider the case of a synchronously pumped fiber cavity like the one in Fig.1a), in the presence of a drift force, that could be originated by a third order chromatic dispersion or any other phenomenon.

The dynamics of such system can be model by the modified LLE

$$\partial_t u = -(1 + i\theta)u + i\partial_\tau^2 u + c\partial_\tau u + iu|u|^2 + u_0(\tau)$$

where, t is the slow-time describing the evolution of the intracavity field $u(t, \tau)$ at the scale of the cavity photon lifetime, while τ is a fast-time that describes the temporal structure of that field along the resonator roundtrip. The first term on the right-hand side describes cavity losses; θ is the cavity detuning between the frequency of the input driving field and the nearest cavity resonance; the cubic term represents the Kerr nonlinearity in the self-focusing case; $u_0(\tau) = u_0 + b(\tau)$ represents the synchronously pumped driving field composed by a sequence of pulses of width σ and hight h injected at every roundtrip, that can be approximated by the Gaussian $b(\tau) = hexp(-(\tau - \tau_0)^2/\sigma^2)$. Without loss of generality we decided to use a gradient term as the drift term. In the following we fix the parameters θ and u_0 in a region of existence of solitons and we consider the strength of the drift c and the amplitude of the injected pulses h as control parameters of the system.

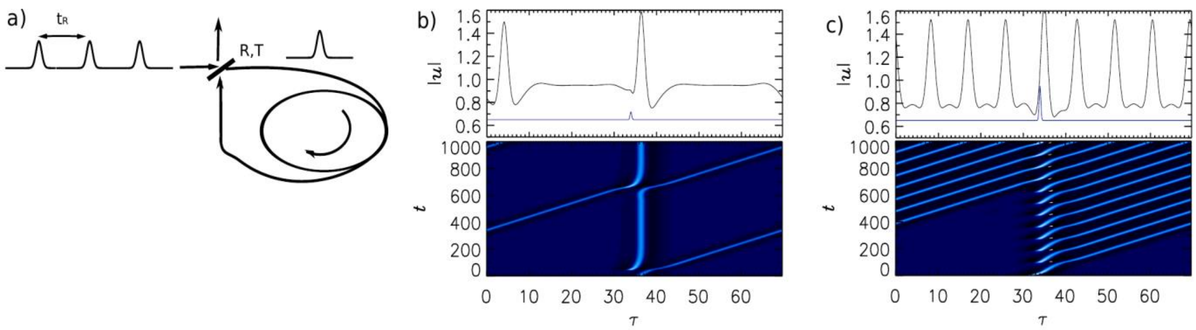

Fig. 1 a) A synchronously pumped fiber cavity. R and T are the reflection and transmission coefficients of the beam splitter. L is the length of the fiber. b) Newton cradle in the region of excitability. c) Oscillatory state. Taken from [2].

For a low frequency detuning, the competition between inhomogeneities and drift leads to similar dynamics at the defect location as shown in [1]. In fact, comparing Fig.1 and Fig.2 in [1] with Fig.3 and Fig.5 of [2], we see that the bifurcation diagrams are equivalent. This agreement is a confirmation of the generality of the mechanism inducing oscillations and excitability. Although the system can be locally excitable, the intrinsic periodic nature of ring cavities and microresonators introduces interesting differences in the final global states. For example, Fig.1b) shows the temporal evolution of a perturbed soliton in the region where, in case of absorbent boundary conditions, we would expect excitability. However, due to the periodicity, the emitted pulse reenters the domain colliding elastically with the pinned one, generating a kind of Newton cradle. Another example of such differences can be observed in Fig.1c). In this case a soliton is perturbed close to the oscillatory regime. Because of that it starts to emit a sequence of pulses described as train of solitons in [1], but in this case the oscillatory solution fills up all of the domain.

References

[1] P. Parra-Rivas, D. Gomila, M. A. Matías and P. Colet, " Dissipative soliton excitability induced by spatial inhomogeneities and drift", Physical Review Letters **110**, 064103 (1-5) (2013).

[2] P. Parra-Rivas, D. Gomila, M. A. Matías , P. Colet and L. Gelens, "Effects of inhomogeneities and drift on the dynamics of temporal solitons in fiber cavities and microresonators", Optics Express **22**, 30943-30954 (2014).