Long-range incoherent solitons

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The propagation of partially incoherent optical waves in nonlinear media is a subject of growing interest in different fields, e.g., incoherent solitons (IS), supercontinuum generation, random lasers or rogue waves [1]. In particular, the long term evolution of an incoherent optical wave is known to be characterized by a process of thermalization [2]. It refers to an irreversible evolution of the wave toward the thermodynamic equilibrium state that realizes the maximum of entropy - in complete analogy with the well-known thermalization of a gas system.

Here we consider the propagation of an incoherent wave in a nonlinear medium which is characterized by a highly nonlocal (or noninstantaneous) nonlinear response, which is encountered, e.g., in liquid crystals, thermal nonlinearities, photorefractives, ect... We show that a highly nonlocal (or noninstantaneous) nonlinearity deeply changes the behavior of the wave system. Contrary to the expected process of thermalization, the incoherent wave is shown to self-organize in a novel form of localized incoherent states, which may be termed *long-range incoherent solitons* [3,4]. The fact that a highly nonlocal (or noninstantenous) nonlinear response prevents the thermalization process can be interpreted intuitively by analogy with astrophysics, in which the *long-range* gravitational potential is known to prevent the thermalization of galaxies in the Universe. Long-range IS can thus be regarded as genuine *nonequilibrium stable states* of the incoherent optical wave. The properties of long-range incoherent nonlinear waves are described in detail by the wave turbulence theory on the basis of a recently derived Vlasov-like kinetic equation [3], which provides a deterministic description of the random system.

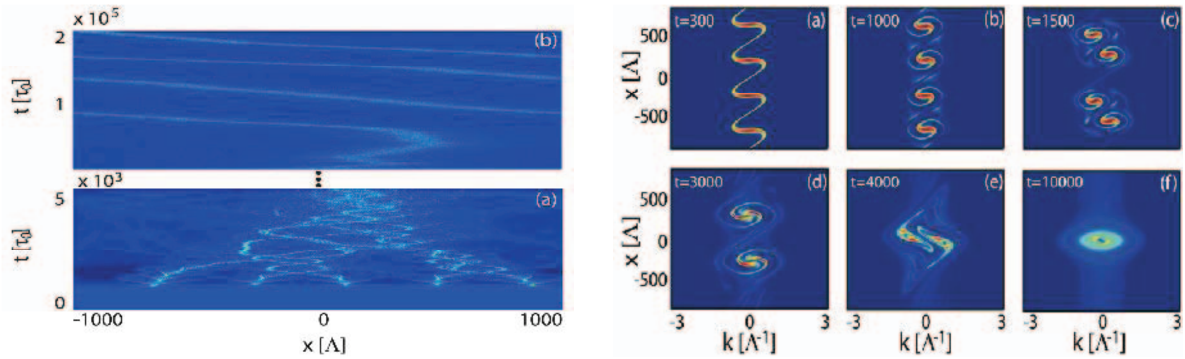

Fig. 1 Left panel: Numerical simulation of the spatial nonlocal NLS equation showing the formation of an IS starting from a homogeneous (coherent) plane wave: The modulational instability leads to the generation of five ISs, which eventually merge into a signle IS. Right panel: Simulation of the Vlasov equation showing the evolution of the *spectrogram* of the incoherent wave. The initial homogeneous spectrum exhibits an incoherent modulational instability: The corresponding four ISs slowly coalesce into two (d), and then into a single IS (f), in analogy with the NLS simulation (left pannel).

Long-range ISs exhibit fundamental different properties than conventional ISs in slowly responding photorefractives [1]. For instance, they are spontaneously generated from an initial coherent wave (see Fig. 1a) and they are characterized by a compactly supported spectral shape, which is in marked contrast with the thermal equilibrium spectrum of energy equipartition among the modes [2,3]. It can be shown that it is thermodynamically advantageous for the optical system to generate a long-range IS state, so as to increase the amount of disorder (entropy), in analogy with the conventional (i.e., coherent) soliton turbulence. In the temporal domain, the physical picture is more complicate because the nonlinear response function is constrained by the *causality condition*. The generation of long-range temporal ISs is counterintuitive: In the *focusing* regime (with anomalous dispersion) the incoherent wave packet experiences an unlimited temporal spreading, whereas in the *defocusing* regime the incoherent wave exhibits a phenomenon of IS self-trapping [4]. Moreover, in contrast with the expected Raman-like spectral red-shift due to a delayed nonlinear response, we show that a highly noninstantaneous response leads to a genuine modulational instability of the incoherent optical wave. All these properties are described in detail by the long-range Vlasov equation derived in Refs.[3,4].

References

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