Thermalization of light waves in multimode optical fibers: Negative temperatures equilibrium states and the role of disorder - INVITED

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1 Introduction

Different studies on wave turbulence revealed that purely classical waves can exhibit a process of condensation that originates from the thermalization of the waves toward the Rayleigh-Jeans (RJ) equilibrium distribution [1]. Recently, the observation of RJ thermalization and condensation of light waves has been reported in multimode optical fibers (MMFs) [2-4], in relation with the discovery of the phenomenon of spatial beam cleaning [5-6]. More recently, RJ thermalization has been extended by including the conservation of orbital angular momentum [7].

In this contribution we present two recent developments: (i) The observation of RJ thermalization to negative temperatures equilibrium states [8]. (ii) The study of the impact of strong disorder (strong random mode coupling) on RJ thermalization [9].

2 Negative temperatures equilibriums

Because of the presence of a finite number of modes supported by the MMF, the propagation constants of the fiber exhibit both lower and upper bounds for the energy levels. Such a bounded spectrum, combined to the nonlinear four-wave interaction, are responsible for the process of RJ thermalization to negative temperature equilibrium states [10]. We report in Fig. 1 the experimental modal distributions for different values of kinetic energy ($E$), or equivalently different temperatures $T$. The modal distribution peaked on the lowest mode for $T > 0$ (a), gets inverted for $T < 0$ (b-f). The fiber modes are sorted from the fundamental one ($\beta_0$) to the highest mode group (nine-fold degenerate with $\beta_{\text{max}} = 9 \beta_0$). Degenerate modes are equally populated at equilibrium, leading to a staircase distribution $n_{\beta \text{RJ}}$. From Ref.[8].
3 Impact of strong disorder

In order to study the impact of strong disorder on light propagation in MMFs, we have extended the wave turbulence theory by numerical simulations of the nonlinear Schrödinger equation and the derived kinetic equation, which are found in quantitative agreement with experimental data. Our experiments show that negative temperature speckle beams are featured, in average, by a temperature distribution averaged over a large number of realizations (the radius 

Fig. 3.

4 Conclusion

The interplay between disorder and nonlinearity reveals that a nonequilibrium process of thermalization can take place in the presence of strong disorder, see Fig. 3b), during the realizations (the radius

The strongly populated (Fig. 1a), for negative temperature equilibriums where the fundamental mode is.

Among non-degenerate modes, which unexpectedly exhibit an incipient process of RJ thermalization and, strong random mode coupling has not been the subject of detailed investigations among the modes (Fig. 1b).

For short propagation length, the power equipartition among non-linear modes are more populated than low temperatures modes (Fig. 1a).

While the impact of weak disorder prevents the conservation of the kinetic energy (Hamiltonian), strong disorder prevents thermalization to the RJ distribution, and, evidence the process of thermalization in strong disorder, see Fig. 3. The strongly randomized (Fig. 1a), for negative temperature speckle beams are featured, in average, by a temperature distribution averaged over a large number of realizations (the radius

Experimental

3 Impact of strong disorder

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