Extreme waves in complex scattering media in the linear and nonlinear regimes

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Ocean rogue or freak waves are huge waves that appear in relatively calm seas in a very unpredictable way. Numerous naval disasters leading to ship disappearance under uncertain conditions have been attributed to these waves. Since sailors are well known story makers these monster, distractive waves that were in naval folklore perhaps for thousands of years penetrated the realm of science only recently and after quantitative observations. Since then, they seem to spring up in many other fields including optics, BEC and matter waves, finance, etc. Unique features of these waves, contrary to other solitary waves, are both their extreme magnitude but also their sudden appearance and disappearance.

In this work we focus on photonic extreme waves in strongly scattering optical media that consist of Luneburg-type lenses randomly embedded in the bulk of glasses. Spherical or cylindrical Luneburg lenses (LLs) have very strong focusing properties directing all parallel rays impinging on them to a single spot on the opposite side surface. The index variation is very large, viz. of the order of 40% and thus a medium with a random distribution of Luneburg-type lenses departs strongly from the Anderson regime.

We observe the appearance of extreme waves and study the role of linear and nonlinear contributions in their statistics. In the purely linear regime the coalescence of light channels, introduced by the strongly scattering system, and the resulting complexity leads to the appearance of extreme, transient waves. There is a clear departure from the Rayleigh law in large intensities where rogue waves are produced. We also show both experimentally and numerically that the medium nonlinearity does not destroy the rogue wave statistics but rather enhances events that are nucleated in the linear regime. Nevertheless, at higher nonlinearities, where nonlinear defocusing terms counterbalance the focusing one, the rogue wave statistics are destroyed since many small waves are amplified to large clamped amplitudes. Thus, we conclude that optical extreme events in scattering media are generated by the complexity of the medium that drives interference and wave coalescence.