Universal Peregrine Soliton structure in optical fibre soliton compression

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Following its first observation in optics in 2010, the Peregrine soliton (PS) is now recognized as one of the seminal solutions of the nonlinear Schrödinger equation (NLSE) [1]. Although it is widely believed that the PS is uniquely associated with the process of plane wave modulation instability (MI), recent theory has shown that it actually appears more generally as a universal localized structure emerging during high power nonlinear pulse propagation [2]. Some evidence for this has already been seen in partially coherent nonlinear propagation in optical fibers [3], but in this paper, we use frequency-resolved optical gating to fully characterize an evolving high-order optical soliton around the first point of compression, and quantitatively confirm theoretical predictions that the properties of the compressed pulse and pedestal can indeed be interpreted in terms of the PS solution.

We first show numerical simulations in Fig. 1 comparing: (a) the initial propagation (compression) of a higher-order soliton, and (b) a Peregrine soliton for the normalized NLSE $i\,\psi_\xi + 1/2N\,\psi_{\tau\tau} + N|\psi|^2\psi = 0$ where the soliton order N appears as an NLSE parameter and the initial condition is $\psi(0,\tau) = \mathrm{sech}(\tau)$. There is clear qualitative similarity in pulse evolution up to the compression point ξ_m, and this is seen more quantitatively in Fig. 1(c) which shows how the compressed pulse profile at $\xi = \xi_m$ is very well fitted locally across the temporal centre by the scaled theoretical PS solution $\psi_{PS} = a_0\,[1 - 4/(1+4a_0^2N^2\tau^2)]$.

We confirmed these simulations experimentally by injecting N = 6 soliton pulses ($P_0 = 26.3$ W, $\Delta\tau = 1.1$ ps) into highly nonlinear fibre ($\beta_2 = -5.23$ ps^2 km^{-1}, $\gamma = 18.4$ W^{-1}km^{-1}) and using frequency-resolved optical gating (FROG) to measure intensity and phase about the point where simulations indicated pulse compression would occur ($z \sim 10.3$ m). Fig. 1(d) shows these results comparing the measured characteristics of the compressed pulse (black) with NLSE simulations (red) and the theoretical PS solution (dashed). There is excellent agreement in intensity and phase, and we remark the agreement in the π phase jump which is a particular signature of the PS.

These results clearly show how the PS arises as the compressed pulse shape associated with higher order soliton compression in the NLSE, and confirm predictions of its universality beyond the specific case of MI. The results also provide a physical interpretation to the longstanding observation that soliton compression is associated with a broad deleterious pedestal, which we can now associate with the Peregrine soliton background.

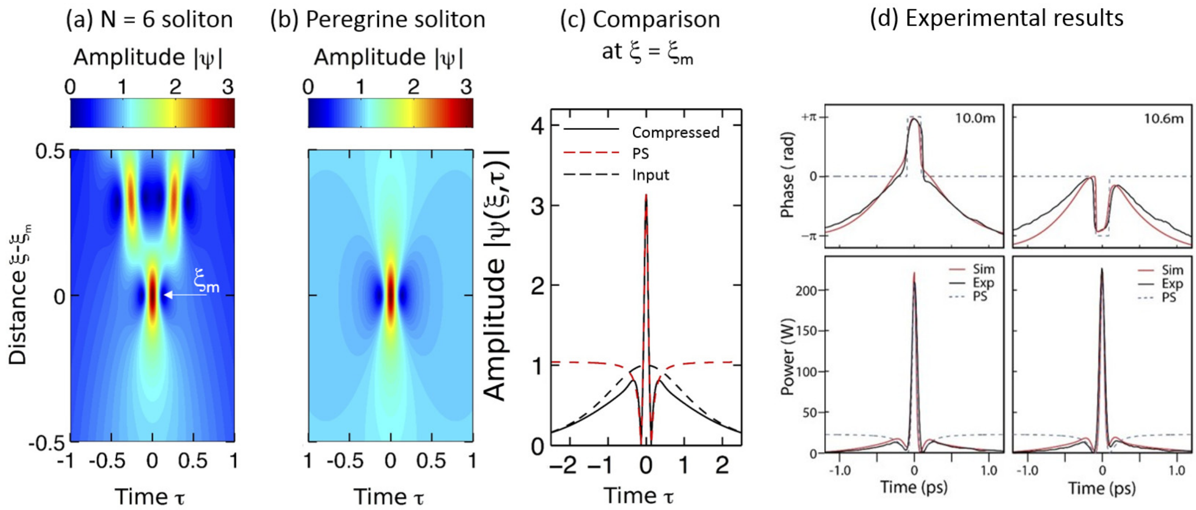

Fig 1. (a) N= 6 soliton compression and (b) PS evolution. (c) Amplitude of compressed pulse (black), Peregrine soliton (red dashed) and input (black dashed). (d) Experimental results from FROG showing intensity and phase characteristics about compression point. Experiment (black) is compared with simulation (red) and ideal PS (black dashed)

References

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