Automating physical intuition in nonlinear fibre optics

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An especially exciting area of work in machine learning (ML) is the development of new techniques to "discover" new physical laws from data and to "automate" physical intuition. One of the richest areas of nonlinear dynamics in physics is the study of pulse propagation in optical fibre governed by the generalised nonlinear Schrödinger equation (GNLSE), and in this paper we describe a fully unsupervised dominant balance ML method [1] that algorithmically interprets GNLSE dynamical interactions [2].

We consider propagation in space ξ and time τ of a pulse envelope $\psi(\xi,\tau)$ governed by the normalised GNLSE: $i\psi_\xi + \psi_{\tau\tau} + i\delta\psi_{\tau\tau\tau} + |\psi|^2\psi + \rho\psi\,(h_\mathrm{R} * |\psi|^2) = 0$, including second- and third-order dispersion $\psi_{\tau\tau}$ and $\psi_{\tau\tau\tau}$ ($\delta = 0.05$), Kerr nonlinearity $|\psi|^2\psi$, and Raman effects (h_R is the silica Raman response function, $\rho = 0.54$). The concept of dominant balance is to identify regions in (ξ,τ) where only a subset of terms plays a dominant role in satisfying the mathematical condition that the sum of the different differential and nonlinear terms in GNLSE must equal zero. To achieve this, our algorithm combines statistical Gaussian mixture model clustering with a combinatorial threshold. Figure 1(a) shows results for soliton fission dynamics in temporal and spectral domains. In a completely automated manner, Fig. 1(b) shows that the algorithm correctly and autonomously isolates the relevant interaction physics associated propagation, revealing the particular time- and frequency-domain signatures associated with dispersive wave emission, soliton ejection and third-order dispersion (TOD) perturbation of the Raman soliton [3].

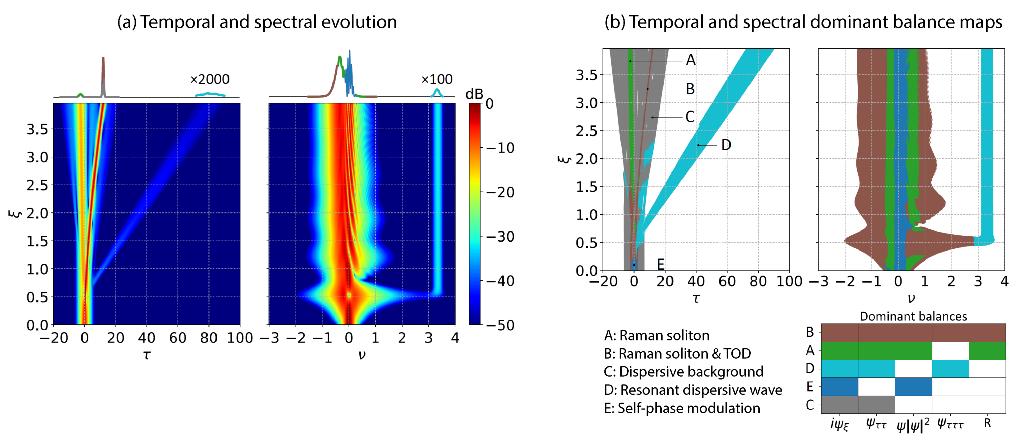

Figure 1. Temporal and spectral maps of (a) evolution and (b) dominant balance. The colour key shows combinations of different physical processes that dominate propagation. R is the Raman term $\rho\psi\,(h_\mathrm{R} * |\psi|^2)$.

This algorithmic perspective on nonlinear and dispersive evolution offers a novel and exciting way of interpreting phenomena that may seem well-established and suggests opportunities to apply approximate theoretical methods to identify asymptotic limiting regimes. Crucially, the method is not restricted to nonlinear fibre optics but is applicable to any system described by differential equations.

References

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