Automating physical intuition in nonlinear fibre optics

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Data-drive dominant balance search algorithm

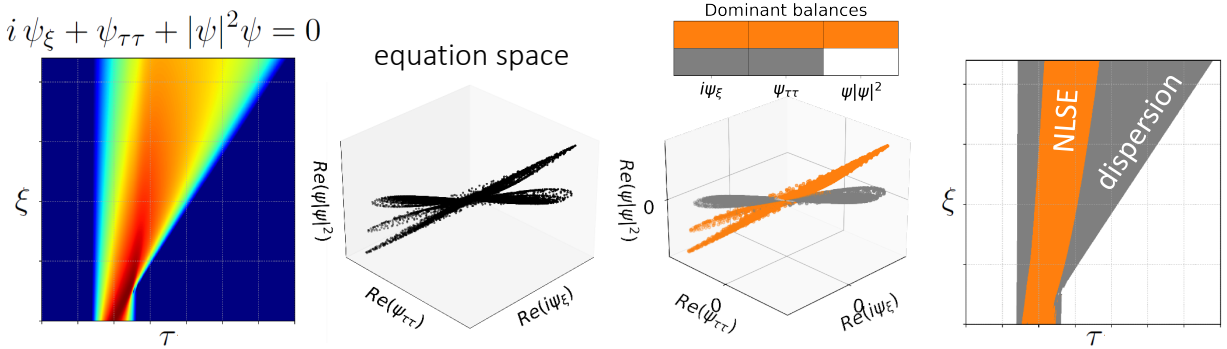
The concept of **dominant balance** is that whilst for any differential equation, the sum of terms will always equal zero,

$$\sum_{k=1}^{K} f_k(\psi, \psi_\xi, \psi_\tau ..., \psi^2, \psi\psi_\xi, \psi\psi_\tau, ..., \psi_{\xi\xi}, \psi_{\tau\tau}, ...) = 0$$

different combinations of terms may dominate the equality in different spatio-temporal regions.

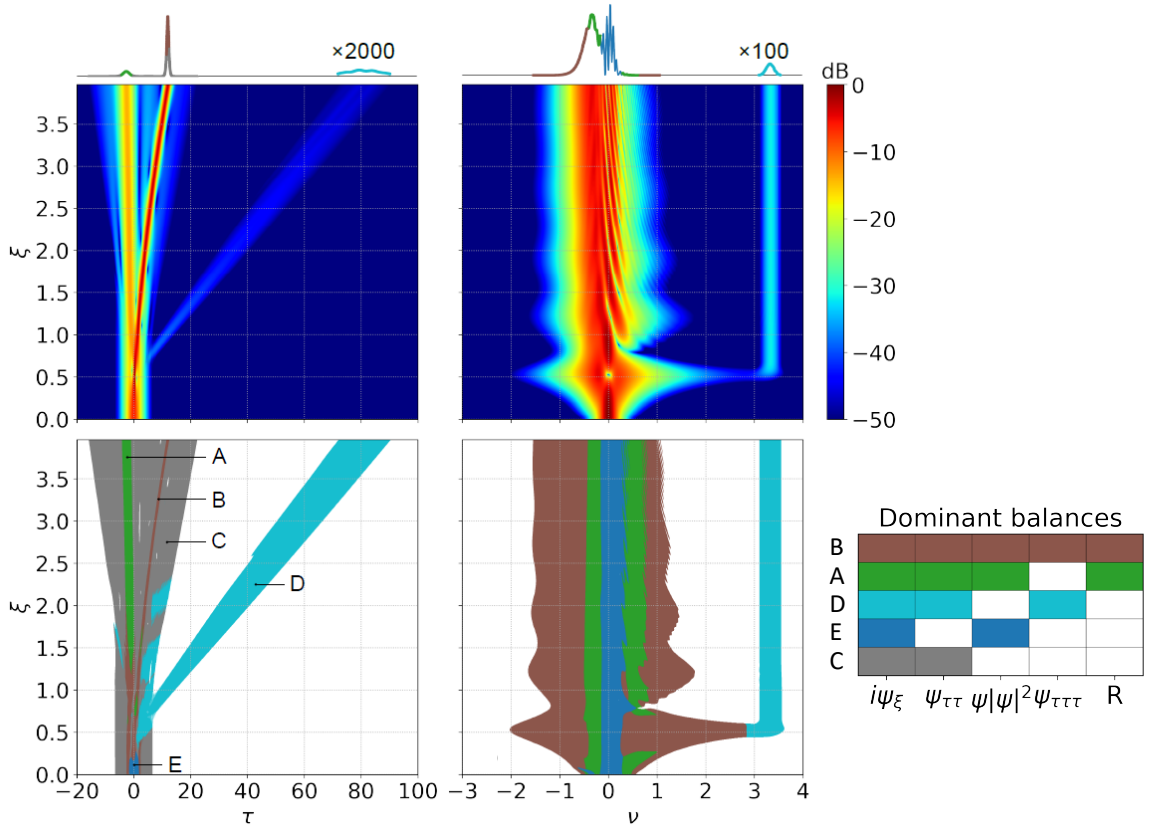
Machine learning framework:

(1) Computing the spatio-temporal evolution in the term-by-term “equation space”
(2) Partition of the dynamics via Gaussian mixture model clustering
(3) Sparse principal component analysis / Combinatorial model selection
(4) Re-mapping the identified dominant balances to the original domain



An example – soliton fission dynamics

$$i\psi_\xi + \psi_{\tau\tau} + i\delta\psi_{\tau\tau\tau} + |\psi|^2\psi + \rho\psi\,(h_R * |\psi|^2) = 0$$



Other examples:

- Optical wave breaking
- Riemann wave propagation
- Soliton fission induced by third order dispersion

References

1. J. L. Callaham, J. V. Koch, B. W. Brunton, J. N. Kutz, S. L. Brunton, Nat. Com., 12, 1016 (2021)
2. A. V. Ermolaev, C. Finot, G. Genty, J. M. Dudley, Opt. Lett., 49, 4202-4205 (2024)
3. J. M. Dudley, G. Genty, S. Coen, Rev. Mod. Phys., 78, 1135-1184 (2006)