Nonlinear dynamics in breathing-soliton lasers

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Our recent work demonstrates that lasers operating in the breathing-soliton regime[1] offer a powerful platform for investigating complex synchronisation and chaotic dynamics in nonlinear systems, all within a single oscillator—eliminating the need for external sources or coupled systems. In these lasers, harmonics of the breathing frequency can lock to the cavity repetition rate through competition between the system's two intrinsic frequencies. In this talk I will review the key findings of this research, which include higher-order Farey hierarchies and self-similar fractal dynamics (devil's staircases)[2], nonstandard synchronisation domains (unusual Arnold tongues)[3], a novel modulated subharmonic regime bridging synchrony and desynchrony[4], and a new route to chaos via modulated subharmonics[5].

References

1. J. Peng, S. Boscolo, Z. Zhao, and H. Zeng, "Breathing dissipative solitons in mode-locked fiber lasers," Sci. Adv., vol. 5, eaax1110, 2019.
2. X. Wu, Y. Zhang, J. Peng, S. Boscolo, C. Finot, and H. Zeng, "Farey tree and devil's staircase of frequency-locked breathers in ultrafast lasers," Nat. Commun., vol. 13, 5784, 2022.
3. X. Wu, J. Peng, B. Yuan, S. Boscolo, C. Finot, and H. Zeng, "Unveiling the complexity of Arnold's tongues in a breathing-soliton laser," Sci. Adv., vol. 11, eads3660, 2025.
4. X. Wu, J. Peng, S. Boscolo, C. Finot, and H. Zeng, "Synchronization, desynchronization, and intermediate regime of breathing solitons and soliton molecules in a laser cavity," Phys. Rev. Lett., vol. 131, 263802, 2023.
5. H. Kang et al., "Observation of optical chaotic solitons and modulated subharmonic route to chaos in mode-locked laser," Phys. Rev. Lett., vol. 133, 263801, 2024.