

Topological effects in active media

Henning Schomerus,

Department of Physics, Lancaster University, Lancaster, LA2 4YB, UK

Abstract

Many prospective applications of topological photonics involve intrinsically nonlinear media with gain and loss, such as encountered in lasers, plasmonic structures, or excitonic condensates. I describe how symmetries known from the linear context extend to these situations. This allows us to define topologically protected, dynamically stable states, including stationary states replicating zero modes and power-oscillating states. These considerations also determine the quantum-limited noise in the system.

Electronic topological systems such as insulators or superconductors depend on the interplay of three fundamental symmetries—time-reversal symmetry, chiral symmetry and charge-conjugation symmetry—as well as the number of spatial dimensions in which the system is realized. The last decade has seen considerable efforts to formulate a photonic counterpart of this framework. The main complications—gain and loss that change the particle number, as well as interactions and nonlinearities—have only been tackled incompletely. First, while the same three symmetries mentioned above still play an important role in nonconserving media, their interplay is much richer. This leads to a very large class of possible scenarios, in which topological phases also involve the lifetime of the modes [1]. As a consequence one can encounter topological effects that only appear beyond a threshold value of gain and loss (hence do not have an electronic counterpart) [2]. For many of these effects only spectral characterizations exist, while the status of the bulk-boundary principle (which underpins much of the research in the electronic setting) is unclear. Secondly, a similar emergence of new topological effects also appears from nonlinearities, such as induced by bosonic interactions or gain saturation [3].

After motivating these complications by the cited examples, I will argue that topological lasers and condensates provide a concrete physical platform for which some practical progress can be made. For such systems the lifetime of modes has a direct bearing on the mode competition, while nonlinearities are essential to stabilize the systems at their working point. It turns out that the charge-conjugation symmetry—originally encountered in superconducting settings—naturally extends to these cases. In the linear setting one obtains a mode competition in which topologically protected modes can be naturally favoured [1, 4]. For this one exploits that the topological modes break a symmetry in a very concrete manner [5], which tells us how to distribute the gain. Furthermore, as the charge-conjugation symmetry preserves the arrow of time it can be extended into a dynamical symmetry [3, 6], which allows precise definitions of symmetry-protected stationary modes (which do have a linear counterpart) and symmetry-protected nonstationary modes (which do not have a linear counterpart, and turn out to be automatically periodic). Topological lasers and condensates that operate by these principles have been realized in a range of recent experiments [7].

- [1] H. Schomerus, *Topologically protected midgap states in complex photonic lattices*, Opt. Lett. **38**, 1912 (2013).
- [2] S. Malzard, C. Poli, and H. Schomerus, *Topologically Protected Defect States in Open Photonic Systems with Non-Hermitian Charge-Conjugation and Parity-Time Symmetry*, Phys. Rev. Lett. **115**, 200402 (2015).
- [3] S. Malzard, E. Cancellieri, and H. Schomerus, *Topological dynamics and excitations in lasers and condensates with saturable gain or loss*, Opt. Express **26**, 22506 (2018).
- [4] C. Poli, M. Bellec, U. Kuhl, F. Mortessagne, and H. Schomerus, *Selective enhancement of topologically induced interface states in a dielectric resonator chain*, Nat. Commun. **6**, 6710 (2015).
- [5] S. Barkhofen, L. Lorz, T. Nitsche, C. Silberhorn, and H. Schomerus, *Supersymmetric Polarization Anomaly in Photonic Discrete-Time Quantum Walks*, Phys. Rev. Lett. **121**, 260501 (2018).
- [6] S. Malzard and H. Schomerus, *Nonlinear mode competition and symmetry-protected power oscillations in topological lasers*, New J. Phys. **20**, 063044 (2018).
- [7] P. St-Jean et al., Nat. Photon. **11**, 651 (2017); H. Zhao et al., Nat. Commun. **9**, 981 (2018); M. Parto et al., Phys. Rev. Lett. **120**, 113901 (2018); C. E. Whittaker et al., Phys. Rev. Lett. **120**, 097401 (2018); Y. Ota et al., Commun. Phys. **1**, 86 (2018); R. Yao et al., arXiv:1804.01587; C. E. Whittaker et al., Phys. Rev. B **99**, 081402 (2019).