Exceptional points in exciton-polariton systems: from universal neighborhood topology in the nonlinear regime to functional photonics and sensing

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Exceptional points (EPs) of n^{th}-order are singularities in the parameter space of non-Hermitian systems at which n eigenvalues and their corresponding eigenvectors coalesce [see Fig. 1(a)]. Over the last decade, EPs have attracted significant attention with their intriguing spectral topology, with potential applications in sensing driving much of the current research in this field [1]. In the last few years, there has been a growing interest in the interplay of nonlinearities and EPs. A promising platform to systematically study EPs in the nonlinear regime is exciton-polariton condensates. Exciton polaritons are hybrid light-matter quasiparticles that form due to strong light-matter coupling, pairing finite lifetimes and thus non-Hermiticity with strong nonlinearity [2,3]. Under non-resonant optical excitation, spontaneous macroscopic coherence can form, known as polariton condensation. With the possibility to control loss, gain and nonlinearity by optical means, this system allows for a comprehensive analysis of the interplay of nonlinearities with topological properties and non-Hermiticity [e.g., in the setup shown in Fig. 1(b)].

With sensing applications in mind, we show that nonlinearities can significantly alter the eigenvalue splitting close to a single EP and shift it in parameter space. However, we also find that nonlinear systems can pose a challenge when it comes to the systematic localization and characterization of EPs [4]. To address this issue, we use a subfield of bifurcation theory and show that an isolated linear EP is the organizing point of a universal elementary bifurcation (elliptic umbilic) in the nonlinear parameter space [5]. This clarifies not only the EP neighborhood's topology, but also its geometric shape [see Fig. 1(c)]. This shape comprises two quasi-deltoid cones, the ribs of which are third-order EPs, which are connected by smooth surfaces of second-order EPs. The cross sections consist of cusps and folds, Fig. 1(d). The results are of very general nature and can be applied to a wide range of nonlinear non-Hermitian systems [5]. These fundamental insights on universal topological structures and phase boundaries accompanying EPs in nonlinear physical systems will pave the way for the purposeful design of such systems with novel functionalities and control possibilities. The topology of EPs found here also offers new possibilities for the design of advanced sensors and the study of phase transitions in the vicinity of nonlinear EPs. Here, we will discuss specific applications of this topology to the exciton-polariton system.

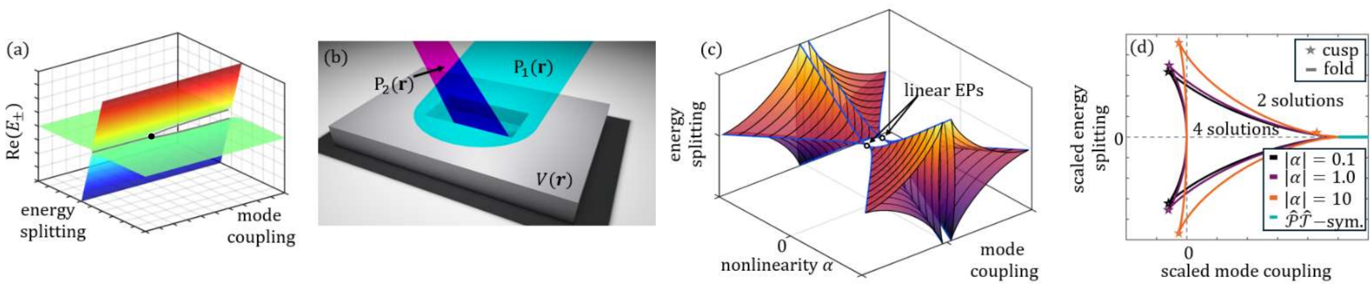

Figure 1: (a) Real part of a Riemann surface close to a linear EP (black dot). (b) Potential V(**r**) and pump setup P(**r**) to investigate an EP in a nonlinear polariton condensate [4]. (c) Universal EP singularity set (non-equilibrium phase boundaries) in nonlinear systems [5]. (d) Cross sections of nonlinear EP surface to illustrate the cusp points and fold lines for different nonlinearities.

References

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