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Recent advances in quantum metamaterials

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Metamaterials – artificially crafted media where effective material properties emerge from the structure of its constituents – have provided access to light-matter interactions at spatial, strength and temporal scales that would not be possible in free space. A similar evolution is expected to take place in the field of quantum optics, where the multiple degrees of freedom offered by metamaterials might be harnessed to engineer photon statistics and quantum correlations. In turn, metamaterials have the potential to further advance quantum technologies, including secure communication systems, sensing beyond the standard quantum limit, quantum computing and quantum simulation of complex systems in chemistry, solid-state and high-energy physics.

In our invited talk, we will review our latest advances in the field of quantum metamaterials. In particular, we will show how metamaterials enable strengthened light-matter interactions beyond the weak coupling regime [1]. Such strengthened interactions facilitate the exploration of nonperturbative decay dynamics, including effects such as the transition from unstable poles (exponential decay) to real poles (long-lived bound states), as well as fractional decay dynamics associated to the contribution of branch-cut singularities [1]. Metamaterials can also act as the interface between physically different quantum systems. We will discuss how metamaterial dispersion engineering enables control over magnon-optical photon coupling [2-3]. In particular, we will show how epsilon-near-zero (ENZ) media empowers strong magnon-optical photon coupling [2], a key property for the reversible exchange of excitations needed for the deterministic conversion of quantum information between different physical systems. Furthermore, metamaterials offer a finer control over material absorption. Such control can be utilized in the design of more complex devices and optical networks, where dissipation can be utilized as a resource in quantum state engineering [4].

1. I. Liberal and R.W. Ziokowski, "Nonperturbative decay dynamics in metamaterial waveguides," *Applied Physics Letters*, **118**, 2021, p. 111103, doi: 10.1063/5.0044103.

2. V. Bittencourt, I. Liberal, S.V. Kusminskiy, "Optomagnonics in dispersive media: magnon-photon coupling enhancement at the epsilon-near-zero frequency," arXiv preprint arXiv:2110.02984, 2021.

3. V. Bittencourt, I. Liberal, S.V. Kusminskiy, "Light propagation and magnon-photon coupling in optically dispersive magnetic media," *Physical Review B* **105**, 2022, 014409, doi: 10.1103/PhysRevB.105.014409

4. O. Hernández and I. Liberal, "A generalized approach to quantum interference in lossy N-port devices via a singular value decomposition," arXiv preprint arXiv:2108.12160, 2021.