Embedded Scattering Eigenvalues: Light Trapping in 2D and 3D Systems

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Light confinement and localization are of fundamental importance in modern science and technology. In many bounded and unbounded electromagnetic systems, the presence of highly confined modes manifests itself in the reflection, transmission, or scattering signature, as asymmetric Fano resonances with narrow bandwidths. A typical example of this response is represented by resonant Wood's anomalies in diffraction gratings, which have been shown to arise from the excitation of guided complex modes, i.e., leaky modes, supported by the periodic structure (A. Hessel and A. A. Oliner, Appl. Opt. 4, 1275, 1965). Their asymmetric Fano lineshape is due to the interference between a non-resonant reflection background and a discrete resonant state, i.e., the leaky mode, which corresponds to a transverse resonance of the open wave-guiding structure. By using a rigorous coupled-wave analysis, it is possible to observe that, while resonant Wood's anomalies typically have narrow bandwidths, their Q factor can never truly diverge for conventional grating geometries (except for normal plane-wave incidence under specific conditions). This behavior is expected since, if there are outgoing waves that fulfill phase matching with a guided mode of the structure (or one of his space harmonics), the mode is expected to couple to free-space radiation, resulting in a scattering resonance with finite Q factor. Surprisingly, however, it has recently been found that different geometries, e.g., double gratings, or photonic crystal slabs, can actually sustain Fano resonances with diverging Q factors, as the leaky mode supported by the structure becomes uncoupled from free-space radiation, ideally bound despite the presence of available and compatible outgoing waves (D. Marinica, et al., Phys. Rev. Lett. 100, 183902, 2008; C. W. Hsu, et. al., Nature 499, 188, 2013). Such a bound state has been denoted as an "embedded eigenvalue", which can exist within the continuum of radiation modes. In our talk, we will provide physical insights into this behavior, investigating why and how it occurs for specific grating geometries, and we will discuss the possibility of controlling and tuning embedded eigenvalues by suitably changing the property of the periodic structure.

Given the analogy between leaky modes in open guiding structures and damped resonances in open cavities, Fano resonances are also frequently observed in the scattering spectra of bounded 3D structures, such as plasmonic nanoparticles and nanoclusters (F. Monticone, et. al., Phys. Rev. Lett. 110, 113901, 2013). In our talk, we will demonstrate that, also in the 3D scenario, the Q factor of such Fano resonances can diverge, as an eigenmode of the structure becomes ideally confined, with zero fields in the external region. Interestingly, we will show that the realization of an embedded eigenvalue in a bounded structure necessary involves extreme material or geometrical properties (M. G. Silveirinha, Phys. Rev. A 89, 023813, 2014; F. Monticone and A. Alù, Phys. Rev. Lett. 112, 213903, 2014). At the conference, we will further discuss the connections between embedded eigenvalues in bounded/unbounded structures and the established concepts of Fano resonances, Wood's anomalies, and leaky wave theory. Deeper understanding of bound states in open systems may allow establishing a new route for efficient light trapping in 2D and 3D geometries.