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Leaky Modes, Resonances, and Transmission Channels in Open Disordered Systems

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In this talk, a brief review of the state of the art in investigating the transmission through media with fluctuating parameters is presented. The expansion in a series of leaky (quasi-normal) modes is the most efficient tool in analytical study of wave properties of open physical structures (microwave waveguides, optical fibers, resonators, quantum cavities, etc.), as well as in the inverse scattering theory. Mathematically, these modes are the natural generalization of the eigen functions of well-known self-adjoined problem for conservative systems and can be found as solutions of the corresponding non-Hermitian equation with the outgoing boundary conditions. In the past few years, leaky modes have become an important area of research in mathematics and theoretical physics. Since the first mathematical proof of existence of transmission eigenvalues in 2008, the interest in the transmission eigenvalue problem has increased, resulting in a number of important applications in the classical wave theory and quantum mechanics.

Of particular interest are the properties of the quasi-normal modes (QNMs) in disordered non-conservative structures, where the interference of the randomly scattered waves not only significantly enhances the leakage to the outside, but also reshapes the spatial distribution of the field inside a disordered sample. While in regular open systems each QNM generates a transmission resonance (TR), in a case of weak disorder, there exist two types of the eigenstates: ordinary QNMs, associated with a TR, and "hidden" QNMs, which do not exhibit peaks in transmission or within the sample. The distinctive feature of the hidden modes is that, unlike ordinary ones, in a wide range of the disorder strengths their lifetimes remain constant, or even decrease (depending on the coupling with the leads) as the disorder becomes stronger. Hidden modes have been experimentally found in microwave measurements in quasi-1D open disordered samples.

Contrary to the common believe that electromagnetic radiation disperse homogeneously in a diffusive medium, quite recently, it was understood that it is significantly structured, concentrating in relatively narrow non-interacting transmission eigenchannels (TEs). Each TE is uniquely characterized by the input wave front, which maintains its shape through the sample; and by the transmission coefficient, whose probability distribution is bimodal, with peaks corresponding to highly transparent and reflecting channels. This property opens up outstanding possibilities to control wave propagation in disordered environment, in particular, to tailor the flux distribution and to focus it through scattering media by wave-front shaping. Remarkably, it suggests that a diffusive medium can enhance spatial resolution, potentially surpassing the diffraction limit.