Spectral Statistics and Fractional Transport in Aperiodic Optical Nanostructures

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Aperiodic optical media generated by mathematical rules, known as deterministic aperiodic structures, have recently attracted significant attention in the optics and electronics communities due to their simplicity of design, fabrication, and compatibility with current material deposition and device fabrication technologies.[1,2] Deterministic aperiodic structures support distinctive optical responses that are absent in either periodic or random systems, such as fractal mode spectra with controllable anomalous transport behavior, and a rich spectrum of optical modes that manifest various degrees of spatial localization, known as *critical modes*. Critical modes feature highly fragmented multi-fractal envelopes with a power-law decay and found recent applications in aperiodic lasing, optical sensing, photo-detection, and nonlinear optical devices[1].

In addition to its technological importance, the study of deterministic aperiodic structures is a highly interdisciplinary and fascinating research field conceptually rooted in several branches of pure and applied mathematics, such as number theory, symbolic dynamics, and computational geometry (i.e., tiling and tessellation theory, point patterns and graph theory). As a result, the study of wave propagation and light scattering in deterministic aperiodic media can stimulate numerous cross-disciplinary and exciting research opportunities that only recently began to be actively pursued in the engineering disciplines.

The goal of this talk is to introduce to the mathematical community some of the latest developments and research grand challenges associated with the study of wave phenomena in aperiodically ordered media. In particular, I will discuss the relationship between structural and spectral properties of a new type of arrays of scattering particles, referred to as Complex Primes Arrays (CPAs), which are created based on the aperiodic distribution of prime numbers in complex quadratic fields. In our work, we apply the vector Green's matrix method [2], which has been extensively utilized in conjunction with Random Matrix Theory (RMT) for the study of scattering resonances in open random media, to systematically investigate the spectral statistics and localization properties of classical waves in the proposed structures. As a second example I will discuss the fractional transport of photons through primary examples of periodic, quasi-periodic and pseudo-random photonic structures and demonstrate the occurrence of largely tunable anomalous photon transport, including logarithmic Sinai sub-diffusion of photons, in deterministic aperiodic systems with multifractal energy spectra [3]. This will allow me to emphasize the fruitful connection between fractional transport equations, particularly the distributed-order fractional diffusion model, and optical photon transport in deterministic aperiodic media.

References

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