Where Does Quantum Optics Go Next?

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Historically, quantum optics was shaped by the study of a few photons and their interactions with exquisitely controllable quantum systems, such as trapped atoms, cavities, and later quantum dots. In that setting, quantum optics became both a toolbox and a language: a framework for generating nonclassical states, engineering light–matter interactions, and describing coherence, squeezing, entanglement, and measurement with remarkable precision.

In recent years, however, quantum-optical concepts have begun to penetrate strong-field experiments, Floquet-driven non-equilibrium condensed-matter systems, and complex many-body platforms. This development raises a basic question: are there still conceptual advances to be made at the core of quantum optics?

In this talk, I will argue that quantum optics is entering a new phase, in which quantum mechanics is being brought into systems and scales long regarded as essentially classical. I will discuss several emerging frontiers through recent theoretical and experimental works. One example is free-electron quantum optics, where we recently introduced the first Bell-test protocol for free-electron pairs and proposed schemes in which electron entanglement can enhance spectroscopy and microscopy. A second example is X-ray quantum optics, where progress is still constrained by the weakness of X-ray nonlinearities. I will present a new direction based on quantum optomechanics with X-ray photons. I will conclude with a broader perspective on many-body quantum optics, where we have found special regimes in which even highly disordered quantum systems can sustain unexpectedly long-lived collective ”supercoherence”.

Together, these examples suggest that quantum optics is far from complete: its next conceptual breakthroughs may emerge precisely from pushing it into domains where quantum behavior was least expected.