Photonic Time Crystals: Transport, Emission, Squeezing

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Photonic time crystals (PTCs) offer unique opportunities to manipulate photonics via time-periodic modulation, but a cohesive theory uniting their classical and quantum regimes has been lacking. This work delivers a comprehensive framework across three pillars. First, we resolve the paradox of superluminal Floquet dispersion, proving that the cycle-averaged energy velocity remains rigorously bounded by the medium's phase velocity. Second, we show that time-modulation reshapes light–matter interactions; spontaneous emission is strongly enhanced in the momentum gap due to Floquet-mode non-orthogonality, a signature we confirm experimentally in microwave platforms. Third, we uncover a direct classical–quantum correspondence, demonstrating that the classical Petermann factor quantitatively governs the quantum squeezing scale and vacuum population. Ultimately, these results unify transport, emission, and squeezing, positioning PTCs as continuum SU(1,1) parametric amplifiers in momentum space.