

Full Spectral and Temporal Correlation Measurement at the Single-Photon Level

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Capturing full temporal and spectral dynamics is a major endeavor in optics. This is challenging because many phenomena, such as the motion of charges, radiative recombination of excitons and polaritons in semiconductors, are governed by processes occurring at picosecond time scales [1-3]. Capturing these events requires tools that can resolve not only each photon's arrival time, but also its wavelength. Time-resolved photon-correlation techniques have provided profound insight into these dynamics, revealing how quantum systems emit, interact, and fluctuate. Yet existing approaches face a fundamental constraint: experiments must choose between temporal precision and spectral resolution. State-of-the-art single-photon detectors offer outstanding timing jitter down to a few picoseconds [4-7] but require narrow spectral filtering, forcing sequential measurements of each optical transition. Conversely, semiconductor-based detectors provide optical spectra but lack the sensitivity and timing accuracy needed to detect and correlate individual photons [8]. This trade-off has limited the ability to observe correlated spectro-temporal behavior, the key indicator of coherent evolution, coupling, or entanglement in complex emitters.

In this talk, we present the “Quantum Spectrometer” that bridges this divide. By combining a spectrally dispersive optical element with an array of superconducting nanowire single-photon detectors, the device records the spectral and temporal structure of light simultaneously, at the single-photon level. It transforms each detection event into a point in a joint “time–wavelength” map, enabling direct visualization of correlations between spectral channels with picosecond precision. We demonstrate this capability using a single quantum dot emitting in the telecommunication C-band [9,10], capturing its emission lines and mutual second- and higher-order correlations in a single measurement. This proof of concept establishes a powerful new platform for ultrafast optical science, extending photon-correlation spectroscopy from a sequential task to a single-shot multidimensional measurement, opening the door to real-time studies of quantum dynamics across disciplines.

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