

# Ultrafast Bright Quantum Light

D SELETSKIY<sup>1,2</sup>, G DEMONTIGNY<sup>2</sup>, AND S VIRALLY<sup>2</sup>

<sup>1</sup>*Physics and Astronomy, University of New Mexico, Albuquerque NM, USA*

<sup>2</sup>*Engineering Physics, Polytechnique Montréal, Montréal, Canada*

Contact Email: denisel@unm.edu

Nonclassical light sources that are simultaneously bright, ultrafast, and mode-pure open qualitatively new possibilities for quantum-enhanced sensing, nonlinear quantum optics, and time-domain studies of entanglement. I will present recent progress on two fronts: the engineering of single spatio-temporal mode bright twin-beam sources spanning the near- and mid-infrared, and the first temporally resolved observation of entanglement in macroscopic light fields.

In the first part, I describe a bright twin-beam source based on type-0 parametric down-conversion in periodically poled lithium niobate, generating strongly non-degenerate output with signal at  $1.37\ \mu\text{m}$  and idler at  $4.0\ \mu\text{m}$ . Two independent diagnostics confirm near-single spatio-temporal mode operation over three orders of magnitude in brightness, up to  $10^8$  signal photons per pulse: photon-number statistics yield a linear entanglement entropy  $S_L = 0.05$  (a linearized version of von Neumann entropy), and singular-value decomposition of the reduced spectral density matrix yields  $S_L = 0.03$ . Vanishing linear entropy ensures that the bipartite entanglement of the twin-beam state is fully accessible without mode-selective detection. We further identify pump pulse duration as a deterministic control parameter for modal purity, consistent with a space-time volumetric amplification picture in which the number of amplified temporal modes is set by the ratio of the pump temporal window to the inverse phase-matching bandwidth.

In the second part, I turn to the temporal structure of entanglement itself. Working with few-cycle bright entangled beams (BTBs) containing approximately  $10^8$  photons per pulse at near-unity Schmidt number, we perform simultaneous single-shot, phase-sensitive detection of both daughter beams. The near-unity mode number establishes a direct mapping between spectral and temporal quadratures, granting access to the quantum electric field in the time domain. Individually, each beam displays the featureless statistics of thermal light in both amplitude and phase. Yet the joint field reveals a striking temporal signature: subcycle oscillations between squeezing and anti-squeezing modulated at the pump carrier frequency. This structured noise pattern persists after the twin beams propagate independently over approximately  $10^6$  coherence times, during which their individual field statistics fully thermalize. No classical mechanism acting during this propagation can establish correlated oscillations on few-femtosecond timescales. The temporal pattern is a direct, field-resolved fingerprint of the entanglement created in the nonlinear crystal.

Together, these results establish a practical and deterministic route to engineering the mode structure of bright quantum light and demonstrate that the time domain provides a qualitatively new window onto quantum correlations in macroscopic fields. I will conclude with an outlook on applications ranging from quantum-enhanced mid-infrared spectroscopy and nonlinear interferometry to strong-field quantum optics driven by non-classical light.