Sequential Parametric Amplification: Quantum Technology with Multimode Light

Teams

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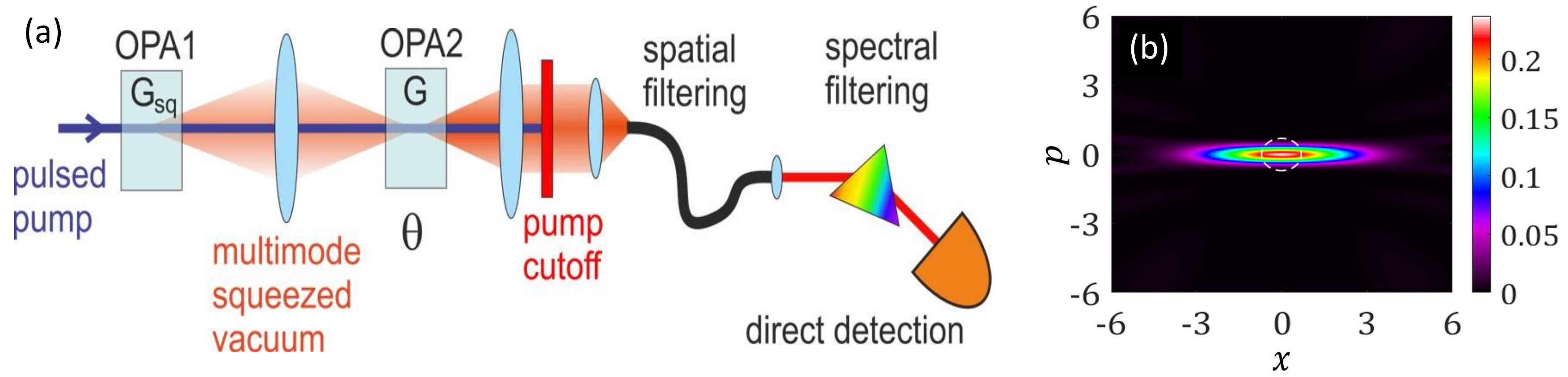
Objectives

O1. Sub-shot-noise imaging and spectroscopy tolerant to inefficient detection.
O2. Squeezing-enhanced Raman spectroscopy.
O3. Wide-field squeezing-enhanced Raman microscopy.
O4. Quantum sensing and communication with multimode light..
O5. Generation and measurement of multimode non-Gaussian states for quantum sensing.

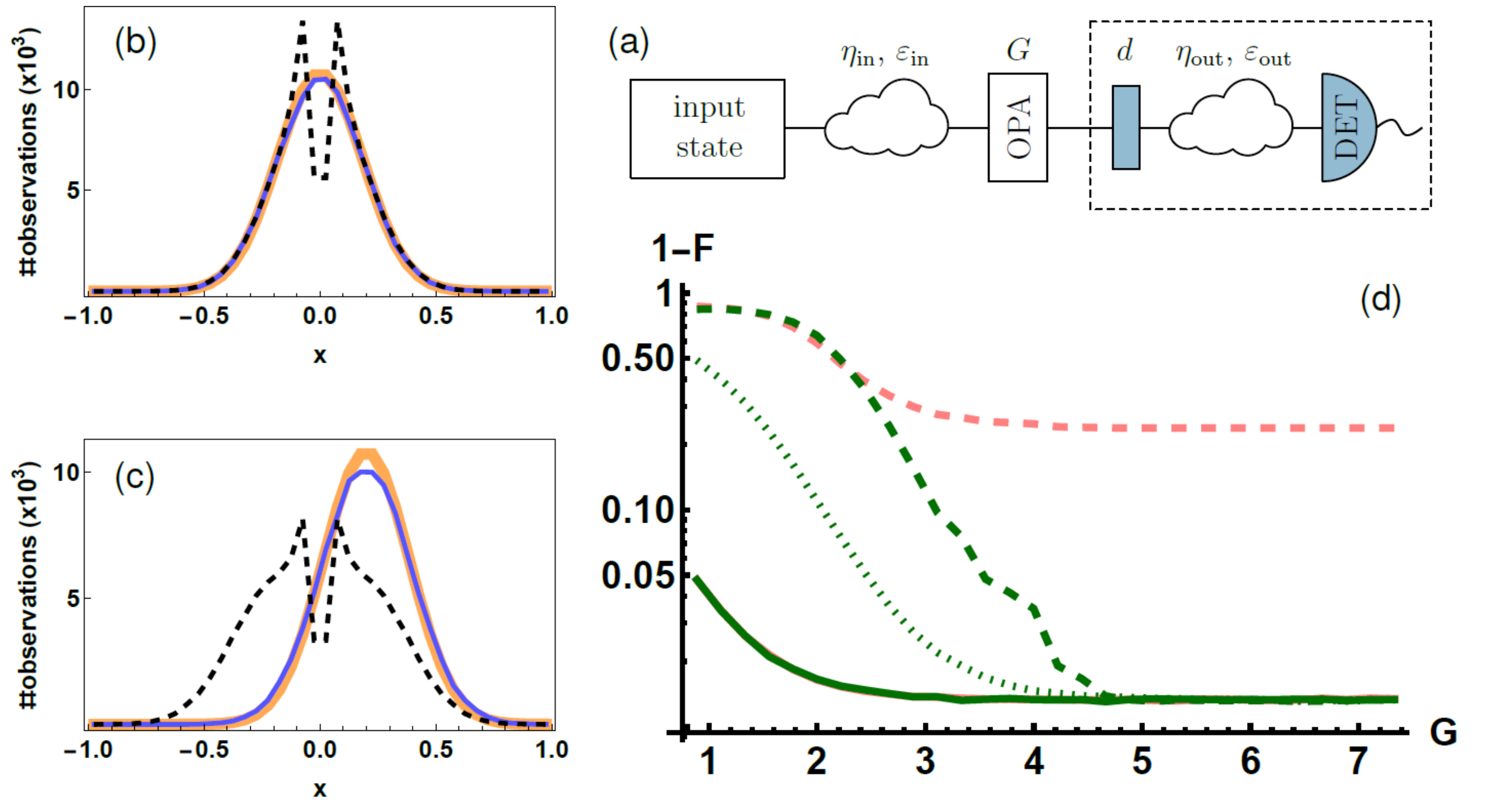
Abstract

Squeezing is a valuable quantum resource, which enables sensitive optical measurements by overcoming the shot noise – the noise stemming from the photon structure of light. At the same time, squeezing is susceptible to optical loss and inefficient detection, which limits its use in technology. SPARQL will apply multimode parametric amplification to make this resource loss-tolerant. This step will open practical applications for sub-shot-noise quantum imaging, microscopy, and spectroscopy. It will also protect from loss extremely fragile multimode non-Gaussian states. Moreover, by implementing two stages of parametric amplification in sequence, SPARQL will apply multimode squeezing to wide-field Raman spectroscopy and quantum key distribution.

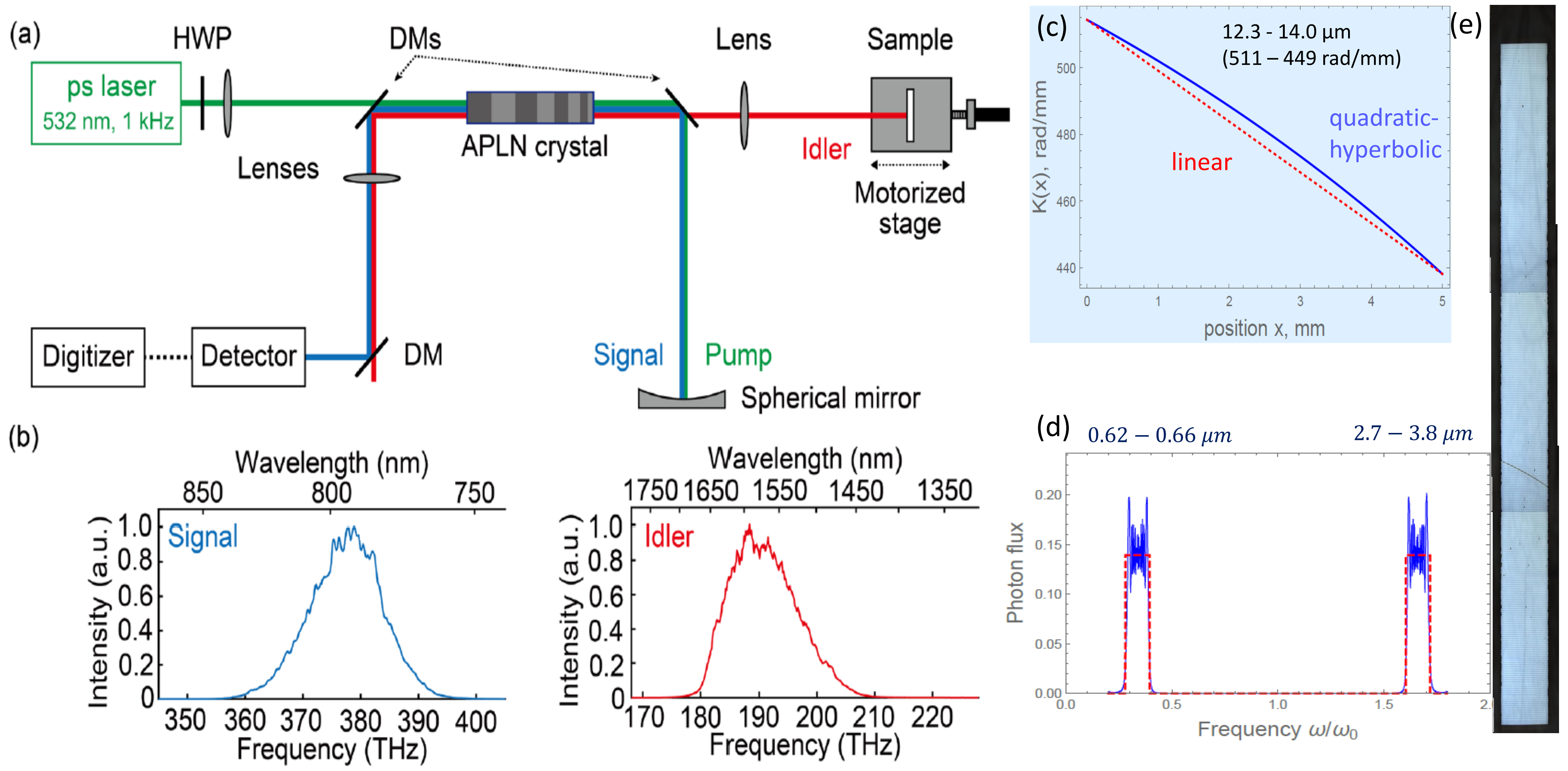
Mid-term results



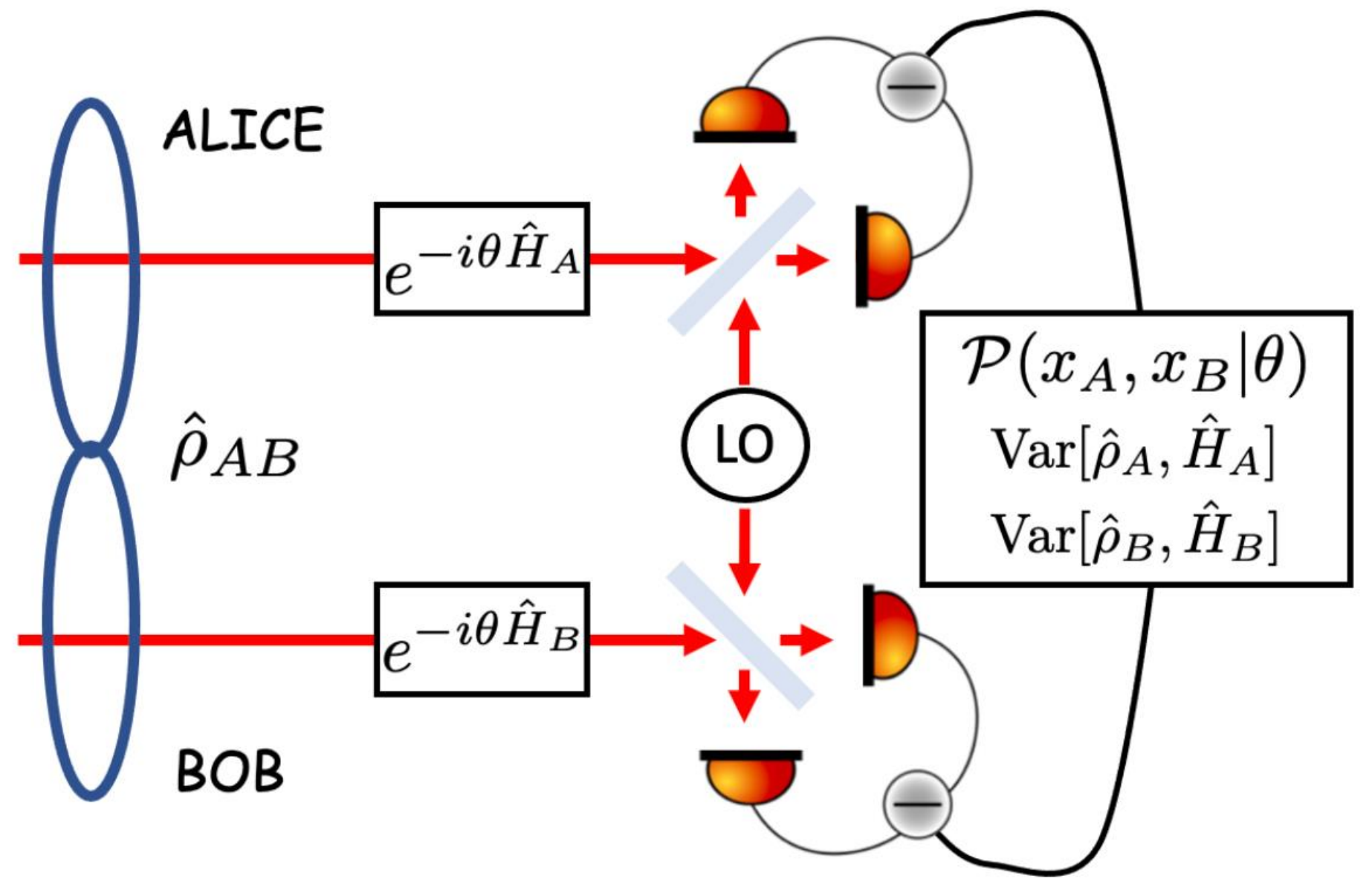
Wigner-function tomography of a single mode filtered out of a highly multimode squeezed-vacuum state using parametric amplification followed by direct detection [1]: (a) the principal scheme of the experiment and (c) the reconstructed Wigner function measured with detection loss >90% [2]. White dashed circle shows the vacuum state Wigner function at 1/e level. The squeezing is 7.5 dB and the purity is 93%.



Proposal of advanced OPA tomography [4]. (a) The scheme uses parametric amplification (G) and displacement (d). (b,c) The reconstructed quadrature distributions of squeezed vacuum (b) and displaced squeezed (c) states. Insufficient amplification and the detector noise cause a distortion around zero. Orange: input state; black dashed: original scheme; blue: improved scheme. (d) Infidelity of the estimation versus the amplification strength. Dashed lines: original scheme; solid lines: improved scheme, dotted lines: homodyne detection with the same detection efficiency (10%). Green: squeezed vacuum state; pink: displaced squeezed state



We use aperiodically poled (chirped) crystals to broaden the spectrum of for their use in optical coherence tomography (OCT) and Fourier-transform infrared spectroscopy (Ftwin beams TIR) 'with undetected photons'. (a) Setup for OCT and FTIR with NIR 'undetected photons' [3]. (b) spectra of signal and idler photons achieved by aperiodically poling lithium niobate [3]. (c) Variation of the inverse grating vector along the KTP crystal for OCT and FTIR with MIR 'undetected photons' and (d) calculated resulting spectra for signal and idler photons. (e) Different regions of the fabricated KTP crystal.



Proposed metrological protocol for entanglement detection. Alice and Bob share a quantum state $\hat{\rho}_{AB}$. They jointly estimate a parameter θ generated by two local Hamiltonians $\hat{H}_{A,B}$. Using two homodyne detectors with a common phase reference, Alice and Bob can retrieve the parameter-dependent jointprobability distribution $P(x_A, x_B|\theta)$, and thus the Fisher information related to this parameter estimation, and the local variances of the Hamiltonians $\hat{H}_{A,B}$. With this in hand, Alice and Bob can jointly compute the metrological witness of entanglement.

Further steps

Towards O1: implement OCT and FTIR with undetected photons under strong parametric amplification in mid-infrared spectral range; apply optical parametric amplification before detection to sub-shot-noise absorption measurements.

Towards O2: complete the experimental configuration for squeezing-enhanced Raman spectroscopy, both spontaneous and stimulated [5].

Towards O3: combine the wide-field interferometer with the quantum Raman setup and build a quantum-enhanced Raman microscope.

Towards O4: extend the OPA tomography and its theoretical description to the case of multiple spatial modes; based on it, develop quantum sensing and processing applications.

Towards O5: OPA tomography of non-Gaussian states: first of a single photon, then of a squeezed single photon. Extend such schemes to quantum sensing with non-Gaussian states. Study non-Gaussian entanglement criteria using quantum metrology formalism, apply it to 1- and 2-photons subtracted states.

References

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