Multitel Applied Photonics

FIBRE LASERS

A Source of Single Photons for Quantum Key Distribution in Space

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Introduction

Quantum Key Distribution (QKD) is a secure cryptographic information transmission method that relies on quantum properties of photons. QKD in space imposes challenges: absorption and turbulence. We address these problems with a heralded single-photon source with signal photons in the C band for transmissivity [1] and polarisation encoding because of the robustness in the atmosphere [2]. The photons are produced via Degenerate Four-Wave Mixing (FWM) in a Photonic Crystal Fibre (PCF).

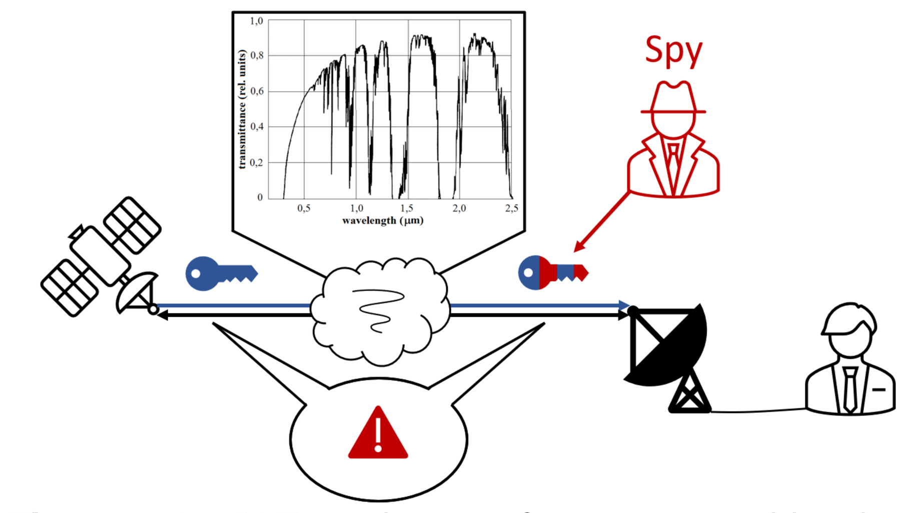

Fig. 1: A QKD scheme for space with the atmospheric transmittance over the wavelength [1].

Methods

Constraints of space

- Polarisation of photons is robust against atmospheric turbulence [2]
  - ➢ Polarisation encoding as end objective
- The atmosphere absorbs some wavelengths (cf. Fig. 1)
  - ➢ Focus on producing signal photons in the optical C band

Degenerate FWM in optical fibres

Heralded single-photon source to monitor the generation of a signal photon with correlated idler photon [3] via Degenerate FWM in optical fibres. This phenomenon:

- Requires high nonlinearity of the fibre and high input power
  - ➢ PCF + High amplification of a laser
- Imposes to optimise all optical stages carefully because:
  1. PCF dispersion profiles are decisive for phase matching to drive FWM (cf. Fig. 2)
  2. Raman effect and non-degenerate FWM driven by nonlinearity and detrimental to performance
  3. High peak powers prevent from employing certain optical components such as filters or gratings

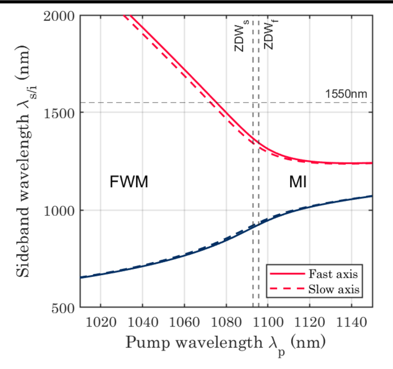

Fig. 2: Calculated phase-matching condition for the experimental fibre.

Set-up (Fig. 3)

- Pulsed laser-diode source at 1064 nm (50 ps)
- Series of optimised Yb fibre amplifiers
- PCFs (experimental fibre and commercial NKT Photonics LMA5) with lengths of 40-60 cm
- Comparison of the FWM performance between the NKT LMA5 and the experimental fibre

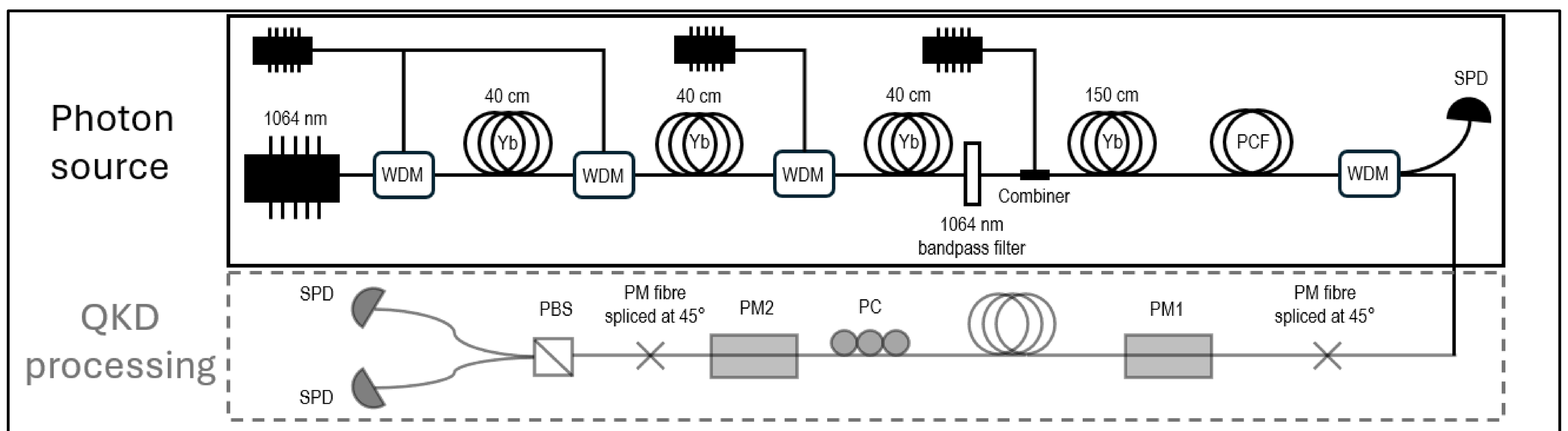

Fig. 3: Top: a fibred set-up for generation of single photons via degenerate FWM with an optimised amplification stage; bottom: possible implementation of BB84 QKD encoding and decoding in a fibred set-up (cf. [4]). WDM: wavelength division multiplexer, Yb: ytterbium-doped fibre, PCF: photonic crystal fibre, SPD: single-photon detector, PM: polarisation modulator, PC: polarisation controller, PBS: polarisation beamsplitter.

Theoretical modelling and simulations

- Coupled Generalised Nonlinear Schrödinger equations (GNLS) including dispersion and nonlinearity wavelength-dependent profiles, Raman and Kerr effects
- Two polarisation states (slow and fast axis) (cf. [5])

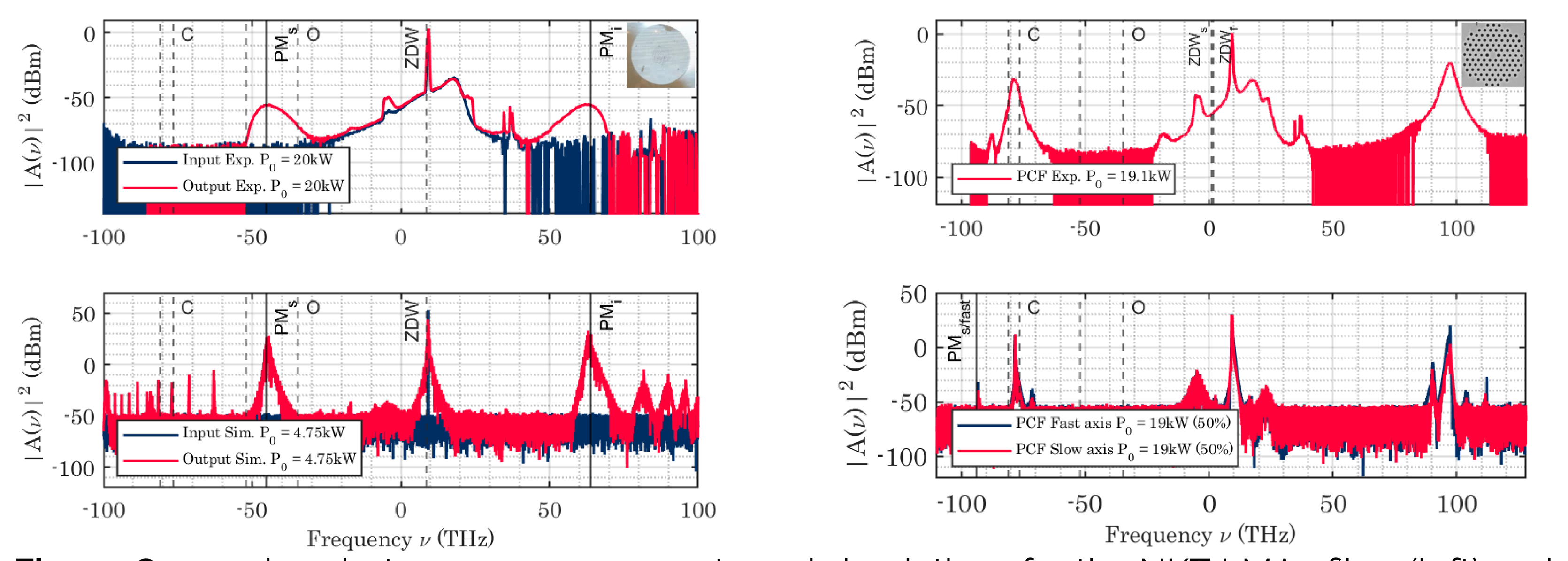

Fig. 4: Comparison between measurements and simulations for the NKT LMA5 fibre (left) and the experimental fibre (right). Left inset: NKT LMA5 cross section; right inset: experimental fibre cross section [5].

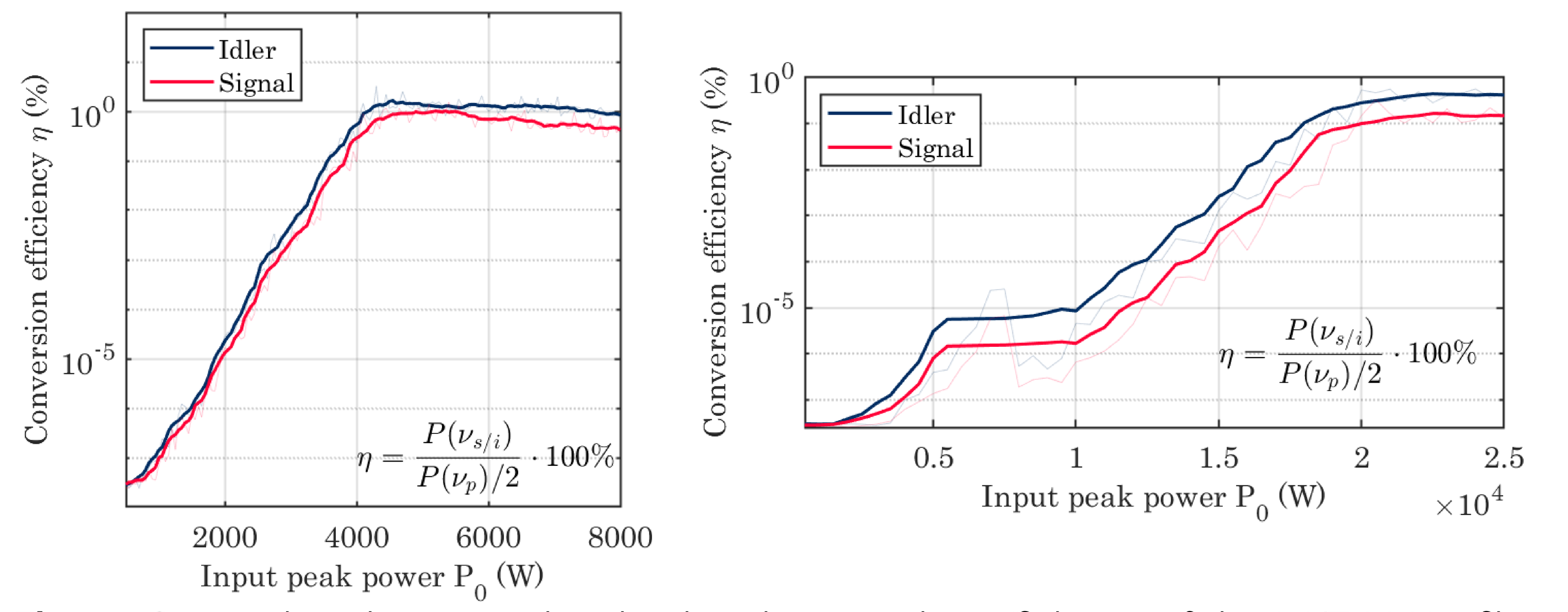

Fig. 5: Comparison between the simulated conversion efficiency of the NKT LMA5 fibre (left) and the experimental fibre (right) with a length of 45 cm.

Results, Conclusions and Perspectives

Modelling and simulations

- Very good agreement between simulations and experiments
- Conversion efficiency of 0.17% (signal) and 0.44% (idler) for the fast axis, similar for slow axis (cf. Fig. 5)

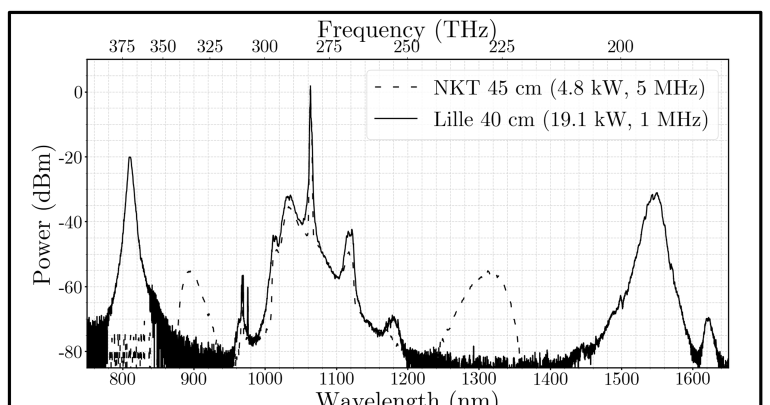

Fig. 6: Comparison between spectra for the NKT LMA5 and the experimental fibre.

Amplifier stages

- Optimised to achieve low-level Raman and low-level ASE with highest possible amplification given fibre lengths and filters

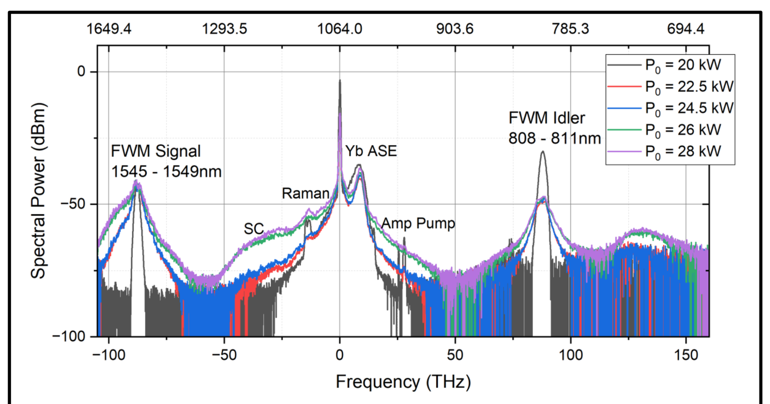

Fig. 7: Experimental fibre spectra for various input peak powers.

Comparison NKT LMA5 and experimental fibre

- NKT LMA5: signal in O band
- Experimental fibre: signal in C band with high-level conversion efficiency

Conclusions

- We built a fully fibred heralded photon source based on degenerate FWM to produce signal photons in the optical C band
- A commercial and an experimental PCF are compared for the application of space QKD with simulations and experimentation
- Experimental PCF spectrum is adapted for atmospheric transmission

Challenges and outlook

- Need to understand the rich dynamics of the experimental fibre
- Optimisation of the PCF input power for QKD
- Measurement of yield and correlation of signal and idler photons
- Implementation of a BB84 QKD protocol

References

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