Quantum Cryptography: 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: atmospheric absorption and turbulence. Motivated by a comprehensive model to simulate a satellite-to-ground link, we address these problems with a tunable heralded single-photon source with signal photons ranging from 1064 to 2300 nm in free-space. The photons are produced via spontaneous parametric down-conversion (SPDC) in a seven-grated periodically poled lithium niobate (PPLN) crystal.
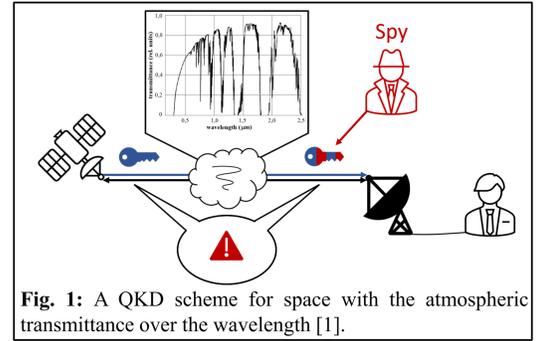

Fig. 1: A QKD scheme for space with the atmospheric transmittance over the wavelength [1].

Methods

Atmospheric model
- Broadband model
- Includes gaussian beam divergence, atmospheric absorption, turbulence and beam wandering, beam expansion, scattering, solar noise…
- Simulates a satellite-to-ground link in uplink and downlink configurations (cf. Fig. 2)
- Predicts for a given affordable loss the best wavelength in terms of Signal-to-Noise ratio (SNR) (cf. Fig. 3).
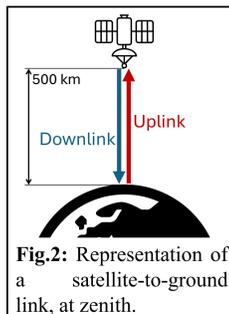

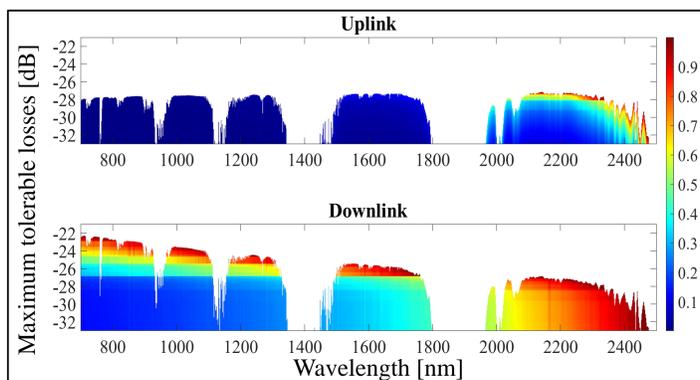**Fig.2:** Representation of a satellite-to-ground link, at zenith.

Fig. 3: Normalised SNR for each wavelength assuming any tolerable losses for a satellite at zenith at 500 km. The outline of the curves is the intrinsic atmospheric loss specific to each wavelength. The colour map indicates the most interesting wavelength provided a given level of loss in the optical link.

> ➢ **The 2 µm atmospheric window is advantageous**

Type-0 SPDC in a PPLN crystal
- Heralded single-photon source to monitor the generation of a signal photon with correlated idler photon [2]
- Conversion of incident photons into pairs composed of an idler and a signal photon
- Amplified pulsed mode-locked laser source at 1064 nm (7.9 ps, 32.45 MHz, 300 pm linewidth)
- Frequency doubling of the laser into 532 nm laser in C1 before SPDC in seven-grating crystal C2 (cf. Fig. 4)
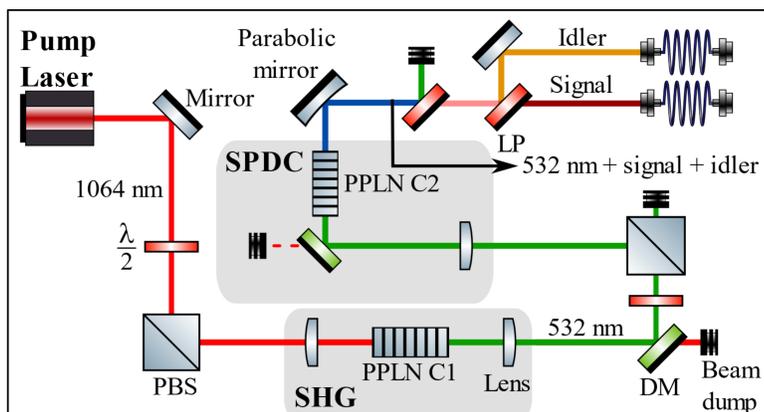

Fig. 4: Schematic representation of the optical set-up. PBS: polarisation beamsplitter, SHG: second harmonic generation, C1: PPLN crystal, DM: dichroic mirror, C2: multi-grating PPLN crystal, SPDC: spontaneous parametric down-conversion, LP: longpass filter.
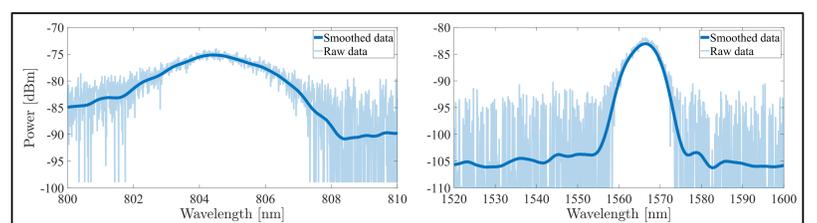
Results

Fig. 5: Output spectra of the idler and signal photon after the fourth channel of the crystal C2. The central wavelength of the idler and signal photons are about 805 and 1565 nm respectively.

Generated photons spectra
- Depend on the temperature of the crystal (cf. Fig. 6)
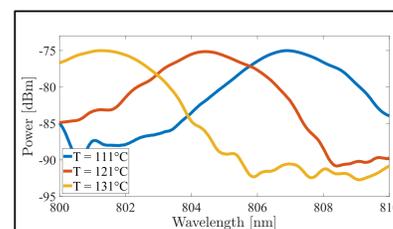- Depend on the grating that is illuminated (cf. Fig. 7)

Fig. 6: Spectrum of the idler photon out of the fourth channel of C2 at different temperatures.
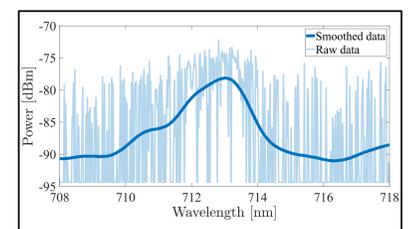

Fig. 7: Spectrum of the idler photon out of the seventh channel of C2 at ambient temperature.

> ➢ **The source can generate signal photons between 1064 and 2300 nm**

Conclusions and Perspectives

- Very good agreement between the simulations from the theoretical tool "SPDCalc" and the measured spectra [3]
- We built a free space heralded photon source able to generate signal photons in a wide range
- Our source can help us study further wavelengths than usual, with a focus on 2.1 µm, motivated by our atmospheric model

Challenges and outlook
- Optimisation of the input power to reach the single photon regime
- Quantum characterisation of the source in terms of heralding efficiency and photon statistics thanks to single-photon detectors
- First focus on detectors available in the lab (<1700 nm) and extension to further wavelengths later

References

[1] M L Belov et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 450 022018, doi: 10.1088/1757-899X/450/2/022018
[2] S. A. Castelletto and R. E. Scholten, Eur. Phys. J. Appl. Phys. 41, 181-194 (2008), doi: 10.1051/epjap:2008029.
[3] 'SPDCalc'. Accessed: Jan. 29, 2025. [Online]. Available: https://spdcalc.org/