Going to 2.1 µm for Space Quantum Key Distribution

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Quantum key distribution (QKD) is a secure communication method that relies on the laws of quantum mechanics. After the success of the Micius satellite in 2016 [1], the EU started the development of Eagle-1, the first European QKD satellite. It will pave the way for the IRIS^2 QKD satellite network, to be operational by 2030 [2]. The choice of wavelength is a fundamental question for the future of space QKD [3].

We developed a comprehensive model to simulate a link between a ground station and a satellite at an arbitrary location on its orbit. This broadband model incorporates effects such as beam divergence, atmospheric absorption, solar noise, and more, to find the optimal wavelength regarding the signal-to-noise ratio (SNR) at the receiver telescope for given losses. For both uplink and downlink scenarios, we found the ∼2 to ∼2.5 µm atmospheric window to be by far the most promising, with the lowest atmospheric losses near 2.1 µm. Fig. 1(a) shows the numerical results obtained with our model. Although technologies for this atmospheric window are less efficient than for shorter wavelengths [4], our study shows that going above 2 µm can bring non negligible advantages.

To validate our model, we present a tunable heralded single-photon source. Fig. 1(b) shows the experimental set-up. It utilises a mode-locked pulsed fibre laser (7.9 ps pulses, 32.45 MHz repetition rate) at 1064 nm (∼300 pm linewidth), that is first frequency doubled in a periodically poled lithium niobate (PPLN) crystal C1, with an efficiency of 15% at 455 mW input power. Subsequently, the output of C1 is exploited for Type-0 spontaneous parametric down-conversion (SPDC) in the seven-grating PPLN crystal C2. Fig. 1(c) shows experimentally obtained spectra of SPDC idler photons at 713 nm and 805 nm when launching green light in the first grating at 25°C, and in the fifth grating at 121°C. The corresponding signal photons lie at 2.1 µm and 1570 nm respectively.

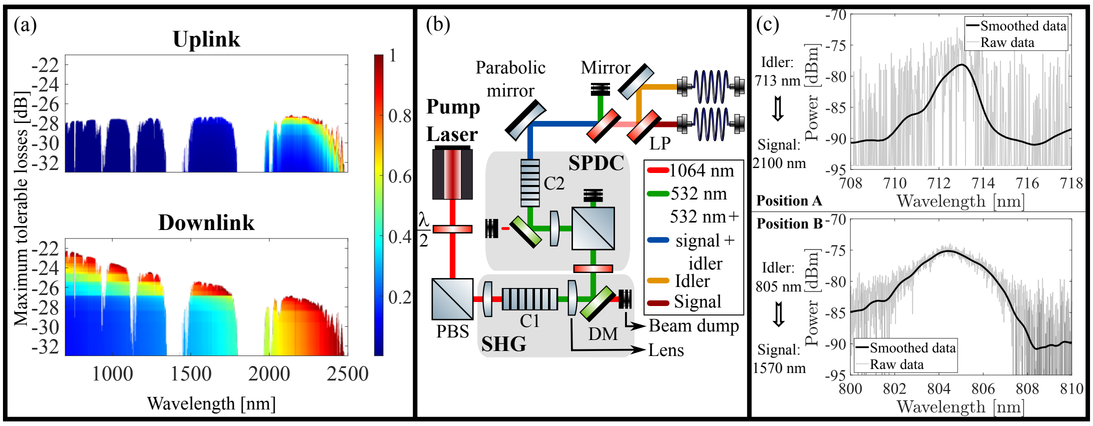

Fig. 1 (a): Normalized SNR for each wavelength assuming any tolerable losses for a satellite at zenith at 500 km, (b): Schematic representation of the experimental set-up. PBS: polarisation beamsplitter, SHG: second-harmonic generation, C1: PPLN crystal, DM: dichroic mirror, C2: multi-grating PPLN crystal, SPDC: spontaneous parametric down-conversion, LP: longpass filter. (c): output spectra of idler photons in two different positions of the crystal C2.

As a next step, we will focus on improving both the model and the source in parallel. Our model already highlights the interest of using longer wavelengths for optical communications, but is currently solely based on classical physics. We will thus refine the model by incorporating a computation of the Quantum Bit Error Rate (QBER) to assess the interest of these wavelengths in a quantum communication context. As for the experimental set-up, our source will allow to study the propagation of the correlated photon pairs with signal photons from 1064 to 2300 nm in free-space. Our study of the source will be expanded to quantum physics by optimising and characterising its output in terms of photon statistics and heralding efficiency. We will first focus on the range accessible by the detectors currently available in the lab (< 1700 nm) and expand the wavelength range afterwards with superconducting nanowire single-photon detectors.

References

[1] J. Yin et al., “Satellite-based entanglement distribution over 1200 kilometers,” Science **356**, 1140-1144 (2017).
[2] Press release dated 16 December 2024 on “Commission takes next step to deploy the IRIS^2 secure satellite system,” `https://ec.europa.eu/commission/presscorner/detail/en/ip\_24\_6439` (accessed 16 January 2025).
[3] R. N. Lanning et al., “Quantum Communication Over Atmospheric Channels: A Framework for Optimizing Wavelength and Filtering,” Physical Review Applied 16, 044027 (2021).
[4] S. Prabhakar, “Two-photon quantum interference and entanglement at 2.1 µm,” Science advances **6**, eaay5195 (2020).