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Advances in free-space Quantum Key Distribution

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Abstract

As modern societies rely on digital communications, the necessity for security becomes increasingly pressing. Nowadays, security is ensured thanks to complex mathematical operations that modern computers struggle to solve. However, the imminent emergence of quantum computers is suspected to change this situation. Among the different countermeasures, Quantum Key Distribution yields promising results. Quantum Key Distribution relies on the quantum properties of photons to distribute secured encryption keys between two parties. Many obstacles lie ahead towards global Quantum Key Distribution networks. This work introduces many of the challenges in implementing the technique widely, with a particular interest in free space operation

The present work explains the basic principles of Quantum Key Distribution and provides a presentation of its practical implementations. A review of optical fibre Quantum Key Distribution and its hurdles are introduced before considering free space as a transmission medium. Based on a thorough literature review, this study examines technical challenges and promising solutions for free-space Quantum Key Distribution from the photon source to the detectors. Afterwards, this thesis provides an analysis of the Chinese satellite Micius and the experiments conducted with it.

Following this discussion, this work presents an experimental photon source for Quantum Key Distribution. This study establishes the theoretical elements driving the design, from the non-linear optics considerations to the optics selection and including the laser source amplification. Then, this paper briefly questions the transposability of this source to space.

In light of the different aspects presented, this work discusses the current state of the technology and its feasibility on a large scale. This study concludes that provided some advances in the envisioned solutions to the current limitations, free-space Quantum Key Distribution is a promising technique that shows the potential to oppose the increased computing abilities of quantum computers and ensure global security.

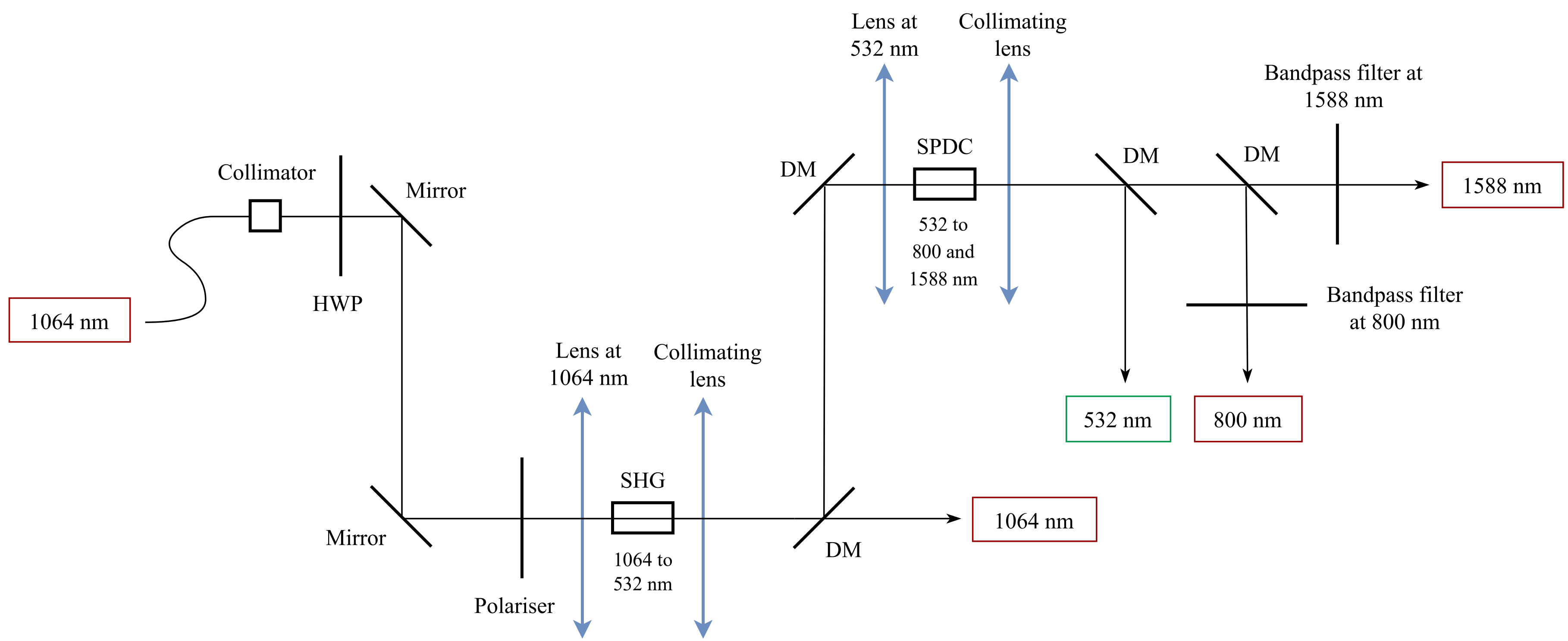

Figure 0.1: Conceptual optical design. The purpose of the setup is to focus the laser beam in the crystals at their centre. To guarantee the appropriate polarisation, a half-wave plate is used with a polariser. After each focusing, the output beams are collimated with converging lenses. The dichroic mirrors filter the output signal after the crystals. HWP: Half-wave plate. DM: Dichroic mirror

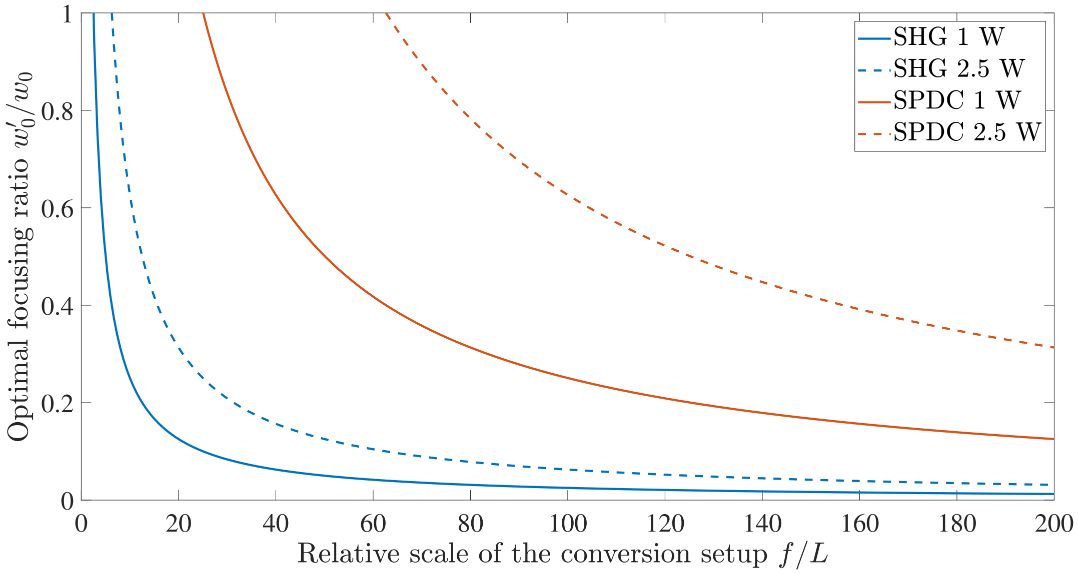

Figure 0.2: Optimal focusing ratio of the lens with respect to the scale of the conversion crystal expressed as the ratio of the focal length on the length of the crystal. The focusing ratio is the ratio of the targeted waist size in the crystal imposed by the material on the size of the beam at the focusing lens. The focusing ratio is optimal because the waist size in the crystal is the critical limit of the material.

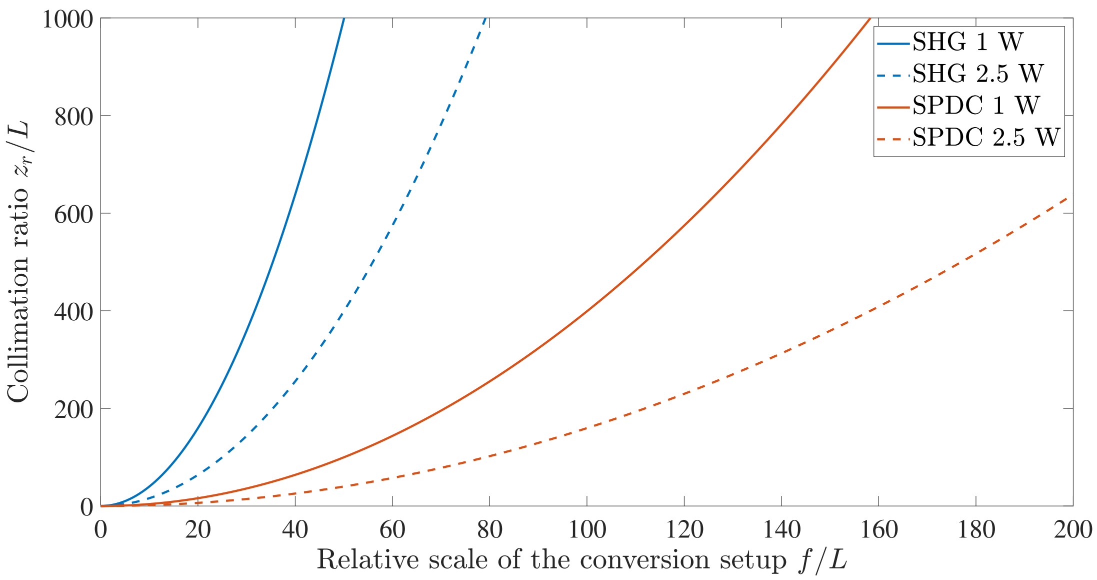

Figure 0.3: Rayleigh range of the collimated beam of adequate size as a function of the scale of the conversion module expressed as the ratio of the focal length on the length of the crystal. The waist used to compute the Rayleigh range is the optimal waist such that the focused spot size is exactly equal to the limit of the material.