New Quantum Source for satellite-based QKD

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Satellite-based QKD

Free-space Quantum Key Distribution (QKD) is almost here for the future global quantum network!

So far China has successfully demonstrated a downlink (satellite → ground) QKD [1].

Image from CSA

However, uplink (ground → satellite) QKD is quite challenging to do as the atmospheric turbulences come into play more than in the downlink QKD. It would require a powerful quantum source that can generate a sufficient amount of quantum keys. ← ***goal***

Requirements and challenges

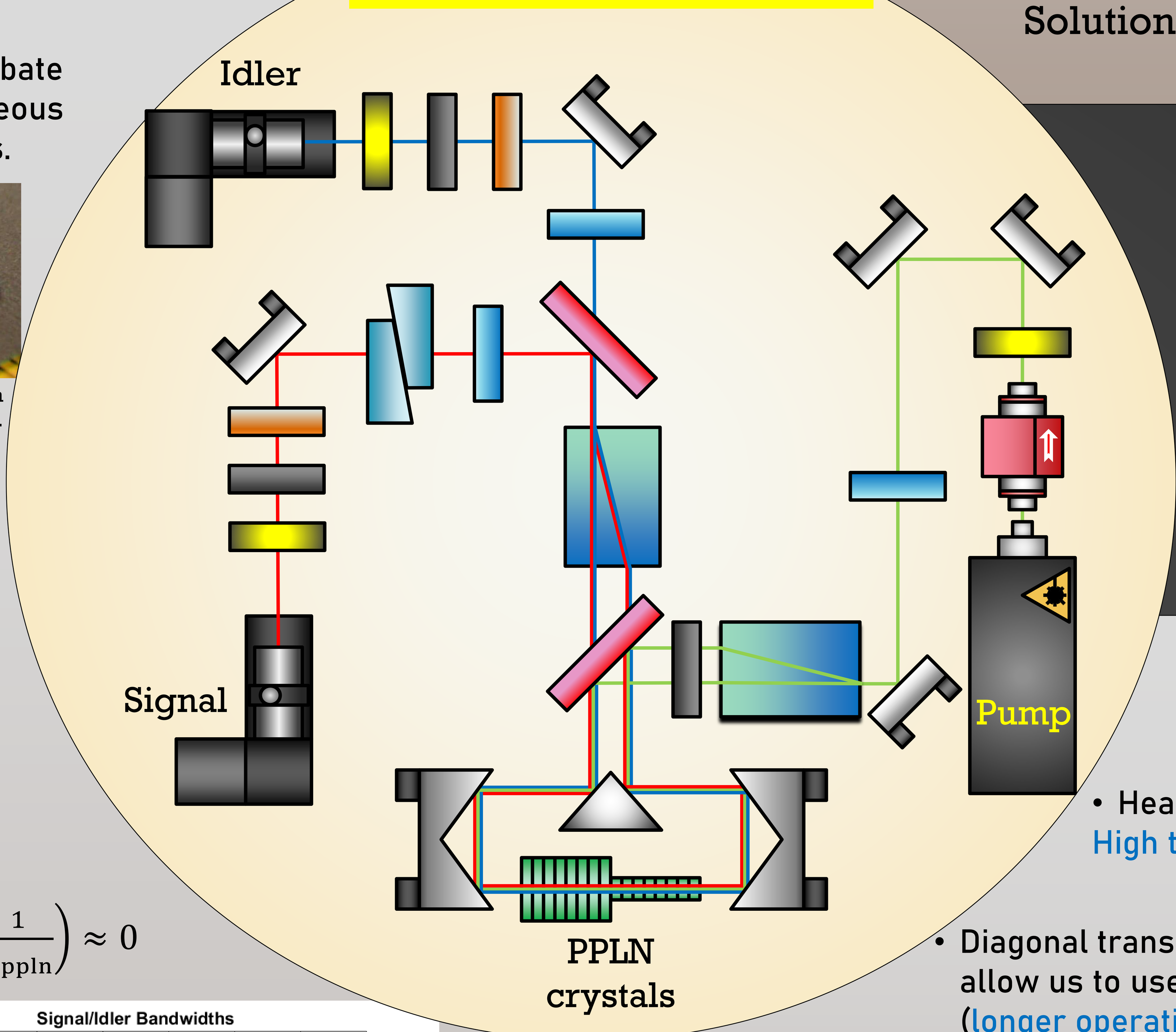
Earth atmospheres "well-transmit" photons only at certain wavelengths. Signal photon at 790nm was found to be suitable for the free-space transmission. On the other hand, Idler photon at 1550nm, which is a widely-used telecom wavelength was chosen for the ground transmission.

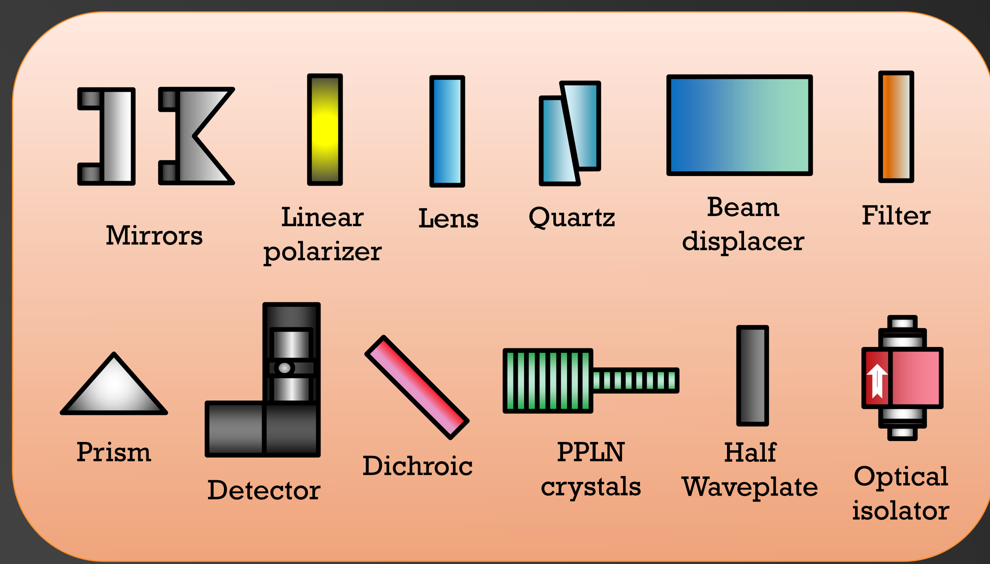
$$523\ nm \rightarrow 790\ nm + 1550\ nm$$

It is <u>difficult</u> to achieve entanglements using the currently available optics if the signal and idler wavelengths are <u>far separated.</u>

Solution : Beam Displacers + Sagnac loop

New QKD Source

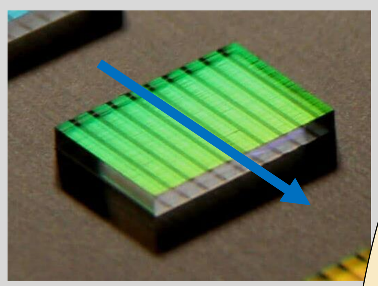




SPDC theory & results

5% MgO doped periodically poled Lithium Niobate (PPLN) crystal is used for the type0 spontaneous parametric down conversion (SPDC) process.

One of the nine different gratings (each corresponding to different poling periods) was arbitrarily selected for the test.



PPLN crystal - Image from Covesion Ltd.

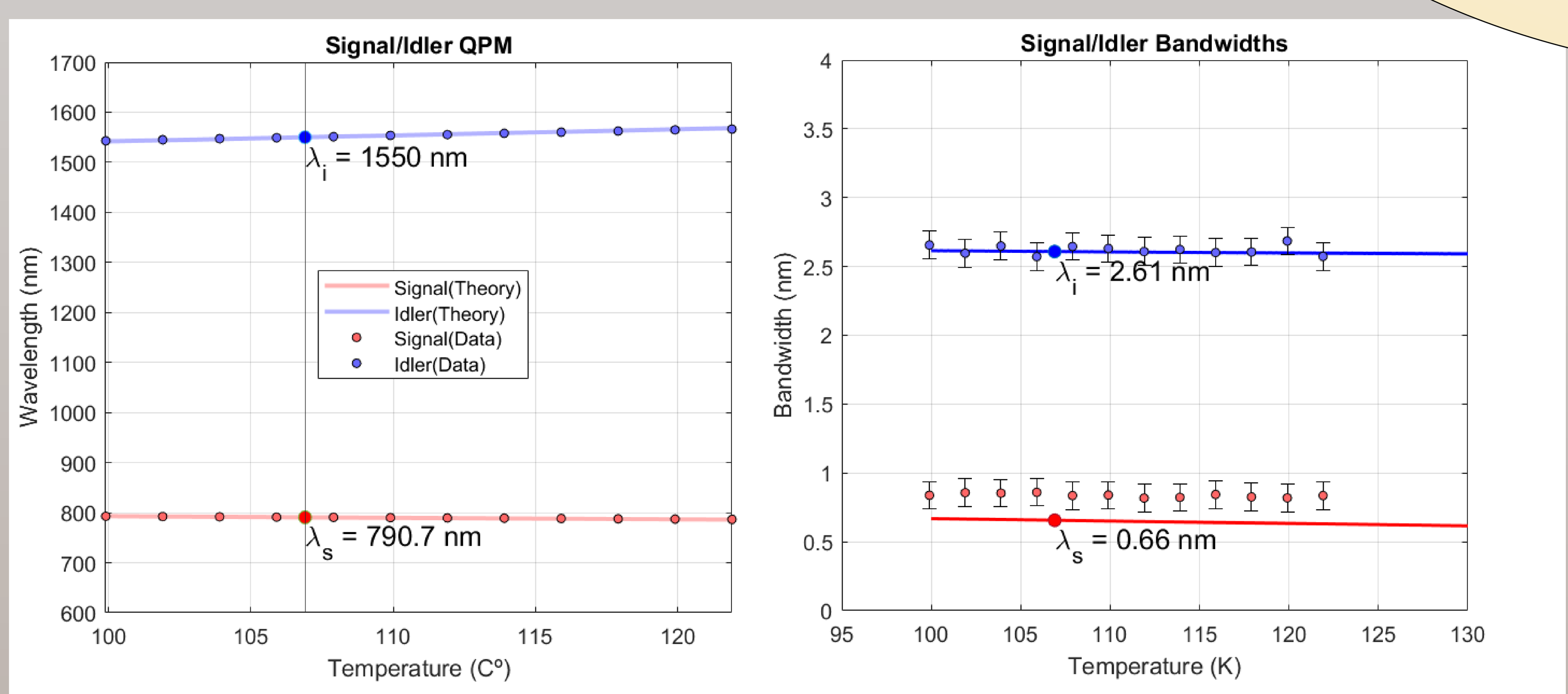
The experimental test has confirmed that PPLN crystal is suitable for the free-space QKD. The results are shown below.

<Quasi-Phase Matching (QPM)>

$$\Delta\lambda_{s,i} = \frac{\lambda_{s,i}^2}{c}\left(\frac{1}{L(\beta_i' - \beta_s')} - \frac{c\Delta\lambda_p}{\lambda_p^2}\frac{(\beta_p' - \beta_{i,s}')}{(\beta_i' - \beta_s')}\right)$$

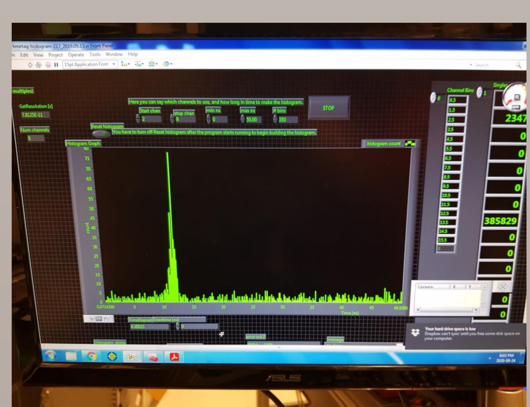
$$\Delta k = k_p(T) - k_s(T) - k_i(T) - \frac{2\pi}{\Lambda_{ppln}}$$

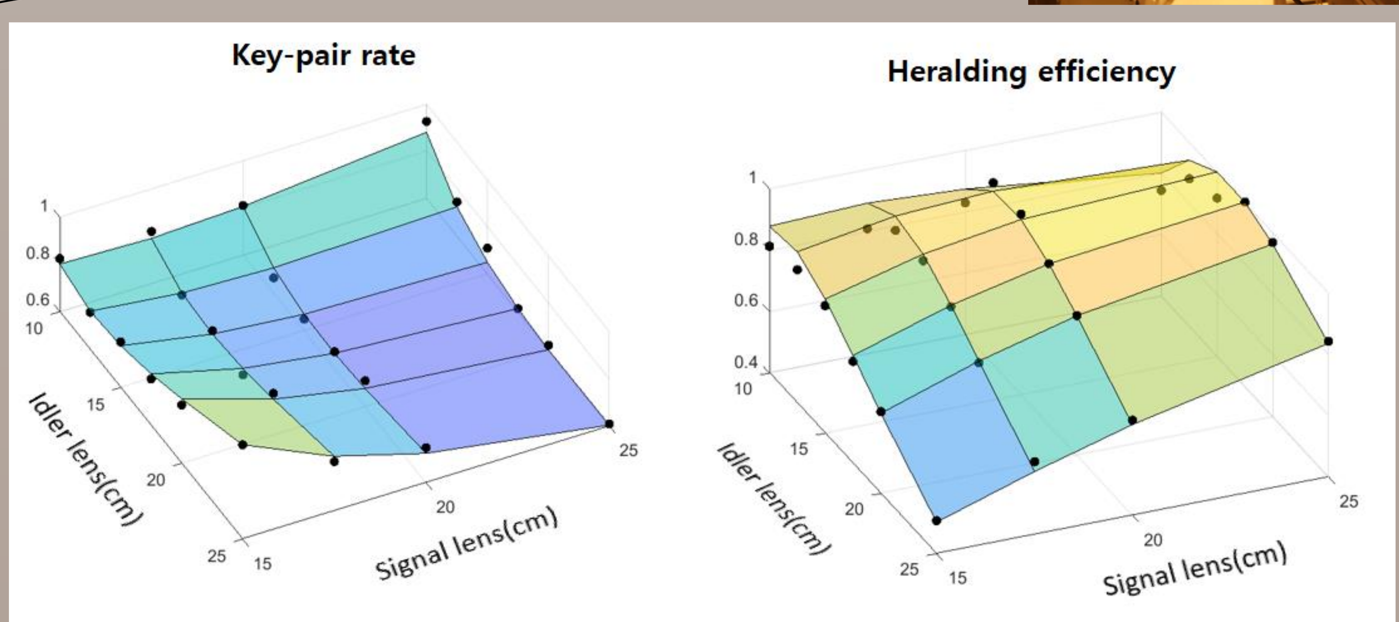
$$= 2\pi\left(\frac{n_p(\lambda_p,T) - n_i(\lambda_i,T)}{\lambda_p} + \frac{n_i(\lambda_i,T) - n_s(\lambda_s,T)}{\lambda_s} - \frac{1}{\Lambda_{\text{ppln}}}\right) \approx 0$$



<Pair rate>

$$R = (2d_{eff})^2\left(\sum_{m=0}^{M}\frac{2}{m\pi}\right)^2 \frac{128\pi^2\lambda_p}{|n_i - n_s|\,\epsilon_0\, n_p^2\, \lambda_s^2\, \lambda_i^2}\,\frac{\arctan(\gamma)}{AB}P$$

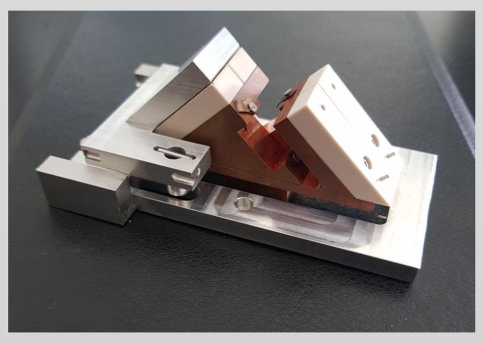




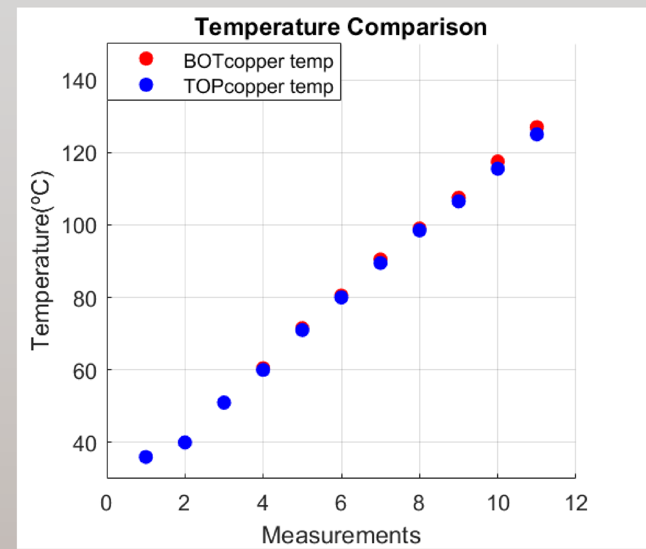
$\boldsymbol{A}, \boldsymbol{B}$ and γ depend on the focal lengths of the pump, signal and idler lenses! [2].

Found a lens combination for the optimal key-pair rate and its heralding efficiency

Design confirmation

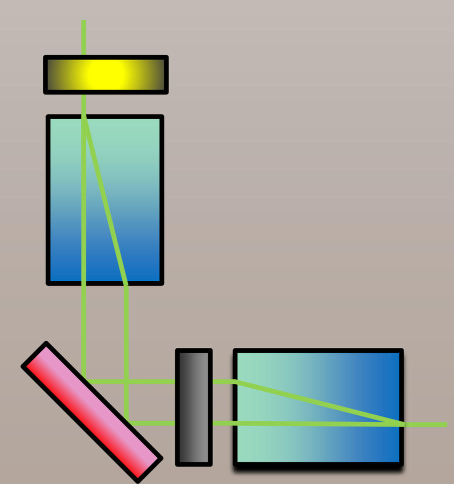


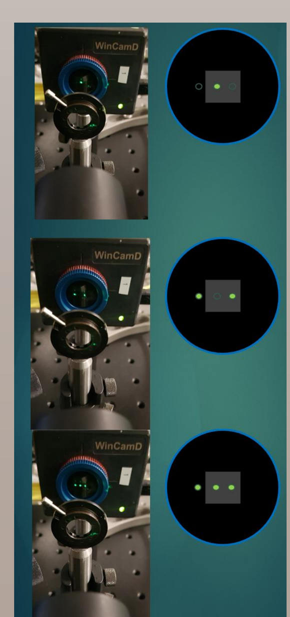
- Heat resistant : High thermal stability
- Diagonal translation feature : allow us to use all 9 gratings (longer operation)
- Operated by a single TEC device : Equal heat distribution on the two PPLN crystals (consistency and robustness)

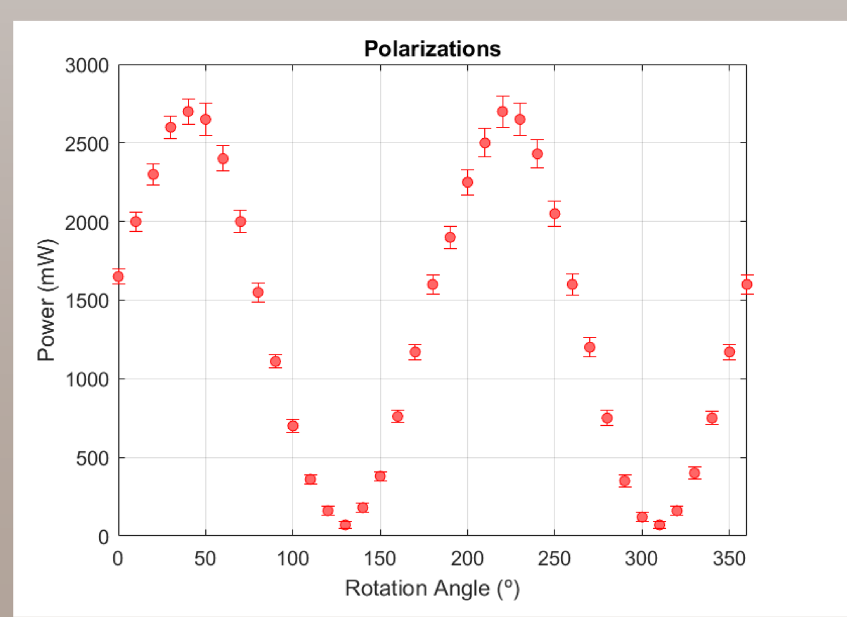


<Single photon interference>

$$P(\theta) = |\langle M|\psi\rangle|^2 = 1 + \sin(2\theta)$$







Visibility : $(94.9 \pm 1.6\ \%)$

Can be further improved!

QEYSSat mission (Canada)

Quantum Encryption and Science Satellite (QEYSSat) mission is led by Canadian Space Agency (CSA), and the satellite will be launched in early 2023.

In 2016, An airborne test supported by the National Research Council (NRC) successfully demonstrated free-space QKD.

We are currently in the progress of building a Quantum Optical Ground Station (QOGS) in the region of Waterloo, ON, Canada. The new quantum source will be installed in the ground station, to send encrypted keys to the satellite.

References

[1] SK. Liao et al, *Nature 549, 43-47* (2017).

[2] P.B. Dixon et al, *P.R.A. 90, 043804* (2014).

$$\gamma_{p,s,i} \equiv \frac{L}{k_{p,s,i}\, W_{p,s,i}^2} \quad A \equiv 1 + \frac{k_s\gamma_s}{k_p\gamma_p} + \frac{k_i\gamma_i}{k_p\gamma_p} \quad B \equiv \left(1 - \frac{\Delta k}{k_p}\right)\left(1 + \frac{(k_s + \Delta k)\gamma_p}{(k_p - \Delta k)\gamma_s} + \frac{(k_i + \Delta k)\gamma_p}{(k_p - \Delta k)\gamma_i}\right) \quad \gamma \equiv \frac{\gamma_s\gamma_i}{\gamma_p}\frac{B}{A}$$

$$n^2(\lambda, T) = a_1 + b_1 f + \frac{a_2 + b_2 f}{\lambda^2 - (a_3 + b_3 f)^2} + \frac{a_4 + b_4 f}{\lambda^2 - a_5^2} - a_6\lambda^2 \qquad \beta' = \left.\frac{\partial k}{\partial \omega}\right|_{\omega}$$

$$|\psi\rangle = \cos\theta|H\rangle + \sin\theta\,|V\rangle \quad |M\rangle = \cos\theta|H\rangle + \sin\theta\,|V\rangle$$

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