QUCODE: a robust encoder for alignment-free satellite QKD

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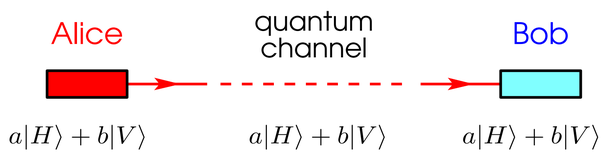
Free-space QKD

Satellite-based QKD [1]: key element for a future quantum internet; first quantum satellite launched by China (August 2016)

Problem: *basis alignment*, i.e., maintain a shared reference frame between parties. This is critical in space-based scenarios (ground-to-satellite, satellite-to-satellite), since parties are moving at high speed

- Solution 1: **active alignment** involves extra resources (lasers, detectors, control electronics, actuators) $\Rightarrow$ increased weight and complexity
- Solution 2: **encoding in rotationally-invariant states** [2, 3]

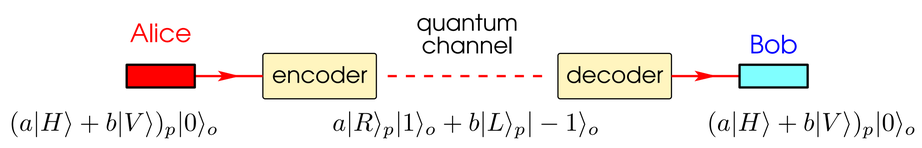
1. Active alignment



requires *active basis alignment* in real time

$\Rightarrow$ need fast measurement, control electronics, actuators etc

2. Encoding



alignment-free operation

Encode states in 2 d.o.f. of a single photon, **polarization** *p* and **OAM modes** *o* [2, 3]:

$$(a|H\rangle + b|V\rangle)_p|0\rangle_o \longrightarrow a|R\rangle_p|1\rangle_o + b|L\rangle_p|-1\rangle_o \qquad (1)$$

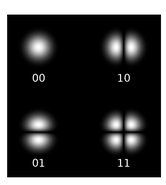
polarization : $|L\rangle_p$, $|R\rangle_p$
OAM : $|0\rangle_o$, $|\pm 1\rangle_o$

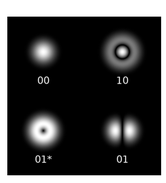
What are OAM states?

$$|\ell\rangle_o, \quad \ell = 0, \pm 1, \pm 2, \ldots$$

– linear combinations of HG_{mn} modes

– carry $\ell\hbar$ units of orbital angular momentum (OAM)

HG modes : 

LG modes : 

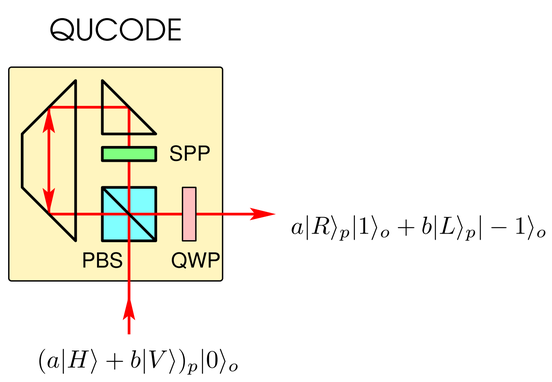
How to generate rotationally-invariant states (1)*?*

1. ***q*-plate**: anisotropic, birefringent, liquid-crystal wave-plate [4, 5]

drawbacks: needs fine-tunning (voltage & temperature control etc) $\Rightarrow$ not suitable for space-based platforms

2. **QUCODE**

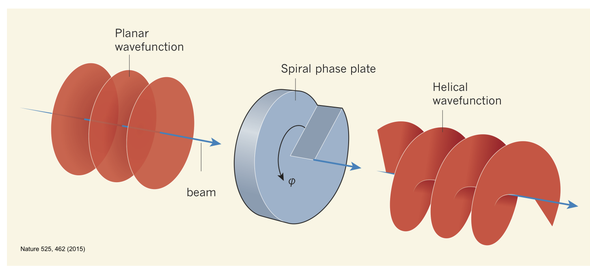
passive optics, robust, stable $\Rightarrow$ suitable for satellite operation



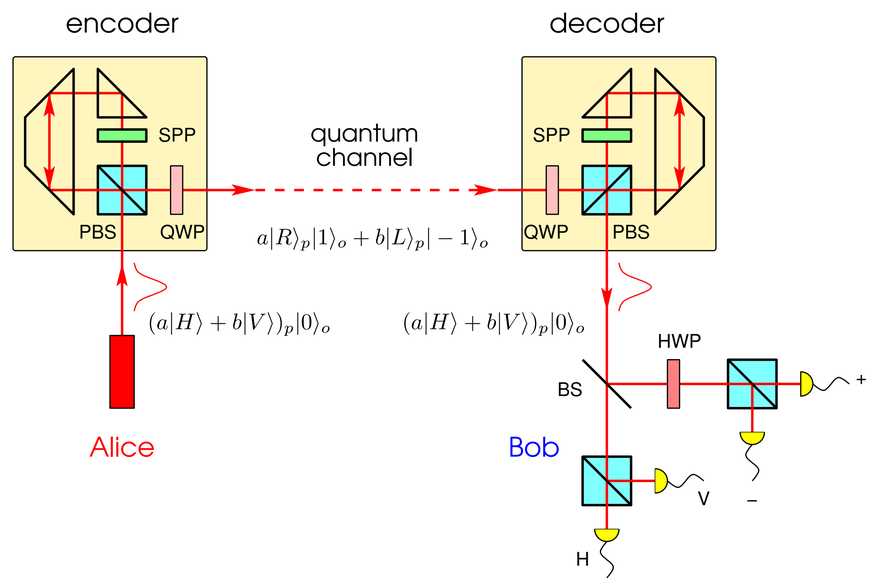
Spiral phase-plate (SPP)

SPP (in)(de)creases orbital angular momentum:

$$|0\rangle_o \xrightarrow{SPP \pm 1} |\pm 1\rangle_o$$



Full setup



Discussion

- **symmetry**: QUCODE is both encoder & decoder $\Rightarrow$ reduced footprint
- **stability**: the Sagnac setup is intrinsically stable
- **no active control**: passive optics makes QUCODE simpler and robust, better for space operation (in contrast to the *q*-plate)
- **plug-and-play operation**: QUCODE can upgrade a free-space QKD system into an alignment-free system
- **future challenge**: design a chip-based QUCODE

References

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