Quantum Communications at NASA Glenn Research Center

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Motivation

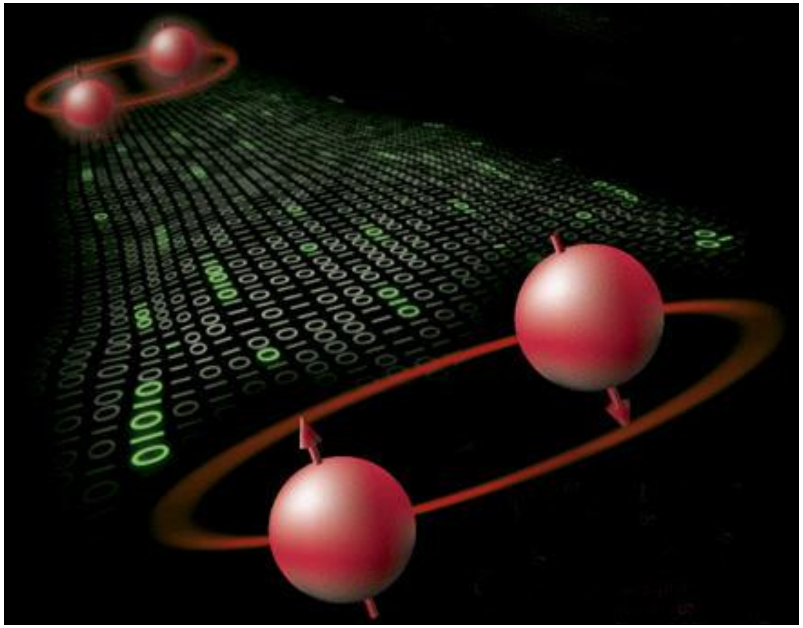
- Current secure communication algorithms involve finding prime factors of very large integers.
- These algorithms will be ineffective when a practical quantum computer is developed.
- Rupak Biswas* predicts usable quantum computer by end of this decade.
- Solution: Quantum Key Distribution (QKD) which enables unconditionally secure communication.
- However QKD data rate very low (estimated 120 photons/sec/receiver from Earth to low earth orbit based on Ursin, 2007).

[source: www.itvpartner.com]

** Deputy Director of Exploration Technology, NASA Ames [www.scientificcomputing.com/articles/2014/04/nasa's-rupak-Biswas-sees-usable-quantum-computing-end-decade]*

Quantum Entanglement

- Einstein, Podolsky, and Rosen (1935) : If quantum mechanics is correct, two particles could be linked (entangled) such that a measurement of one would affect both it and its partner instantaneously – "spooky action at a distance".
- Quantum entanglement experimentally demonstrated by Aspect (1981).
- Basis for absolutely secure communications : quantum key distribution (QKD)



(source: nature.com)

Quantum Key Distribution (QKD)

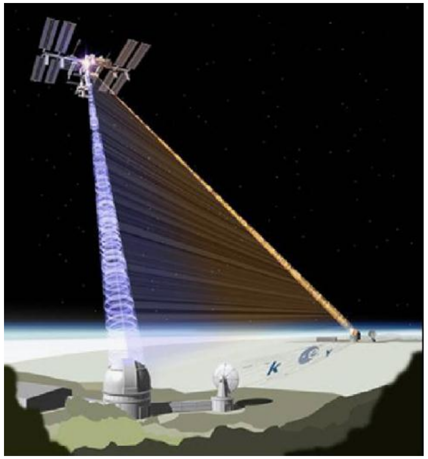
- Sender (Alice) creates quantum entangled photon pairs with randomized polarizations and sends one of each pair to receiver (Bob): ↑→↑↑→→→↑→↑.
- This sequence of randomized polarizations constitutes a coding ‘key’.
- If an eavesdropper (Eve) measures a photon, it and its partner will change state and Alice will be able to detect. Corrupted parts of key discarded.
- After uncorrupted part of key received by Bob, coded signal is sent via conventional channel.

Signal	1	0	1	1	0	0	0	1	0	1
Key	1	1	0	1	1	0	0	0	1	1
Coded Signal	0	1	1	0	1	0	0	1	1	0

Free Space QKD

- Austrian group demonstrated free space QKD over 144 km at ground level in Canary Islands (Ursin, 2007).
- Attenuation approximately that from Earth to low earth orbit.
- Source: Beta-Barium Borate (BBO) nonlinear crystal with 1M photons/sec generation rate.
- Received: 120 photons/sec/receiver.
- Loss of 39 dB (1/8300 photons detected at receiver).

2007 Canary Islands Experiment
[source: phys.org]



Proposed ISS Experiment
[source: Armengol,2008]

GRC Quantum Communications History

2002-2008: GRC develops quantum communications expertise and laboratory specifically for ultra low power robotic planetary rover communications (see J. Lekki references).

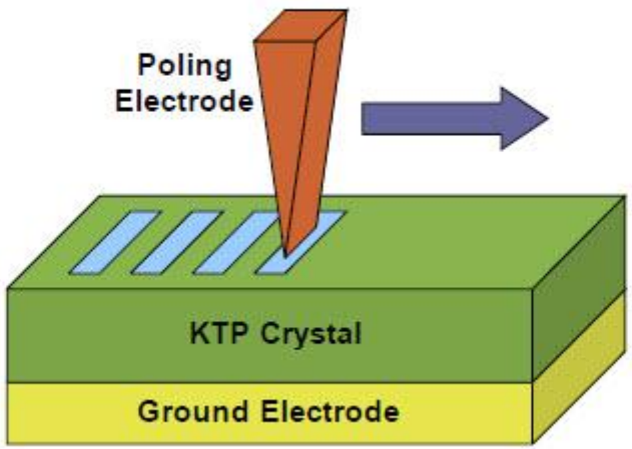
11/2009: GRC begins management of SBIR Phase 1 award to AdvR, Inc. for "High Fidelity Down-Conversion Source for Secure Communications Using On-Demand Single Photons."

6/2014: GRC accepts delivery of and tests SBIR Phase 2 entangled photon waveguide source.

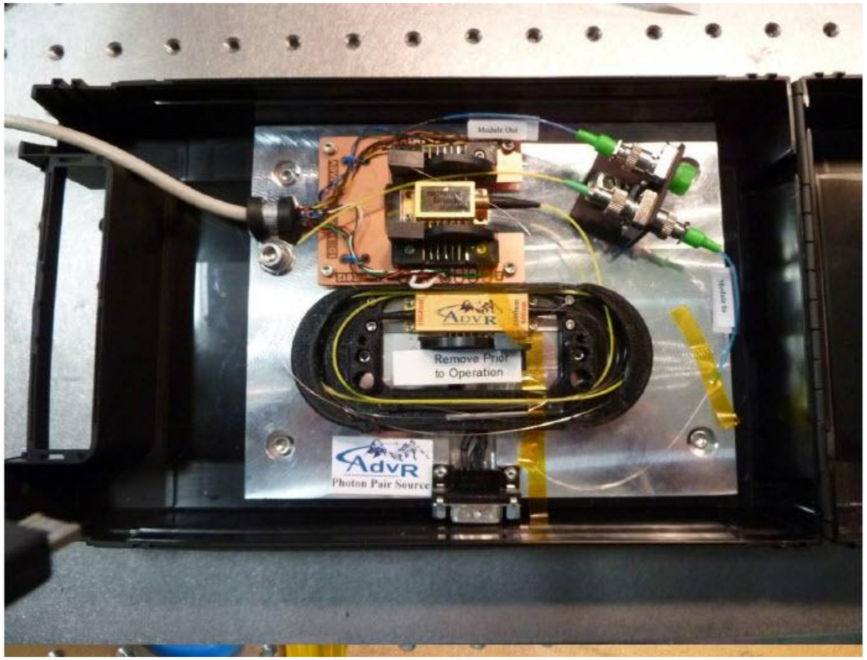
6/2015: GRC accepts delivery of and is testing SBIR Phase 3 entangled photon waveguide source.

10/14/2015: GRC Center Innovation Fund proposal "Quantum Illumination for Space Communications" approved.

AdvR Entangled Photon Source



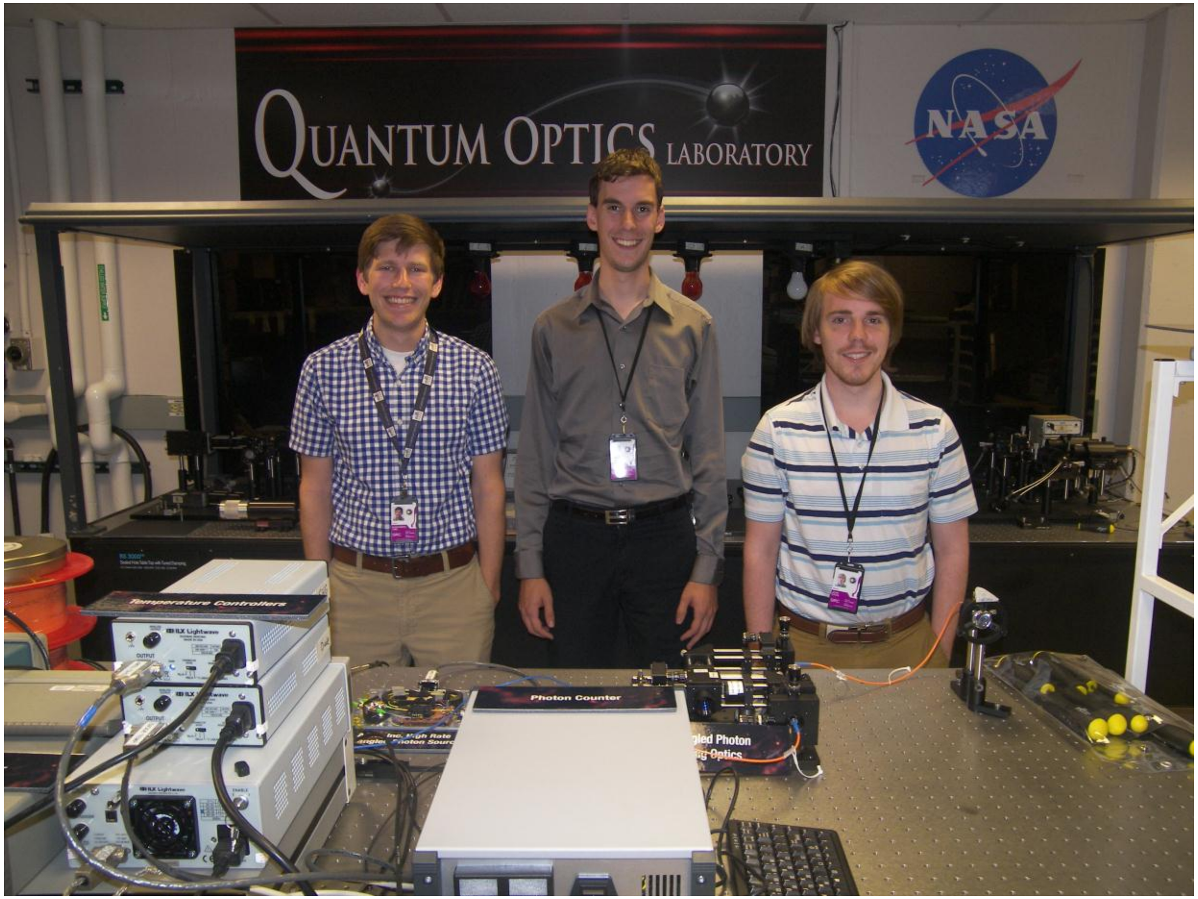
AdvR Poling Technique to Create Alternating Ferroelectric Domains in KTP Crystal



AdvR SBIR Phase 3 Entangled Photon Source Delivered to GRC 6/1/2015

- Source creates 800 nm and 1600 nm photons, entangled by polarization, through quasi-phase matching in potassium titanyl phosphate crystal.
- Measurements indicate 56 MHz entangled photon generation (potential 6.7 kbit/sec earth to low earth orbit link).

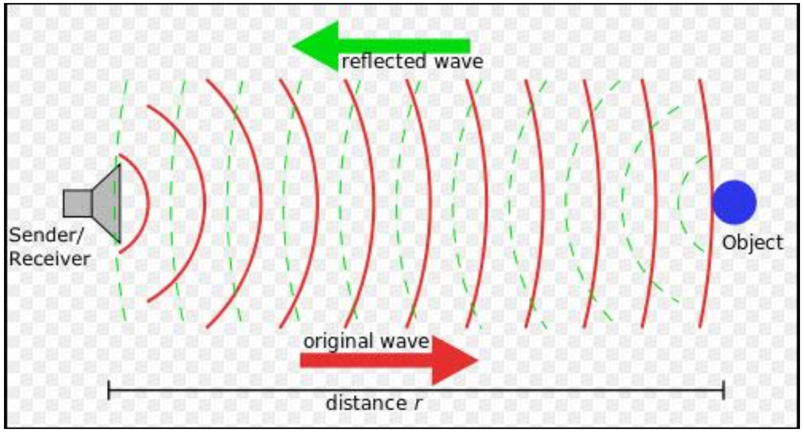
GRC Quantum Optics Lab



2015 SCaN Interns Alex Lind, Spencer Helmick, and John Cavin

Quantum Illumination (Q. I.)

- Originally conceptualized for high resolution imaging (Lloyd, 2008).
- Transmitter sends out entangled photons, keeps twins.
- Receiver matches up returning photons with entangled twins.
- If a received photon does not have a twin, it is noise and is discarded.
- Potential to enable high resolution imaging in a noisy environment.

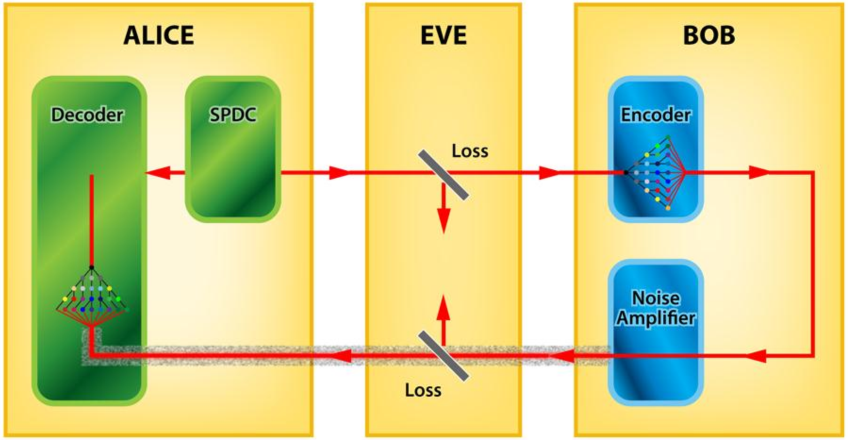


Q.I. for Imaging [wikipedia.org]

Q.I. for Secure Communications

Q.I. proposed for secure communications (Zhang, 2013):

- Alice prepares pairs of entangled photons. She keeps one of each pair and sends the others to Bob.
- Bob breaks the entanglement with a noise amplifier and sends the photons back to Alice.
- However, the photons still have a significantly higher correlation with each other than photons which were never entangled.
- This enables Alice and Bob, but not Eve, to determine which are the photons carrying the key.



Schematic of Q.I. for secure communications with sender 'Alice', receiver 'Bob', and eavesdropper 'Eve' [from Ralph and Lam, 2013].

NASA GRC Center Innovation Fund

NASA GRC Center Innovation Fund proposal "Quantum Illumination for Secure Space Communications" awarded 10/14/2015:

(1) Characterize AdvR high generation rate entangled photon source.

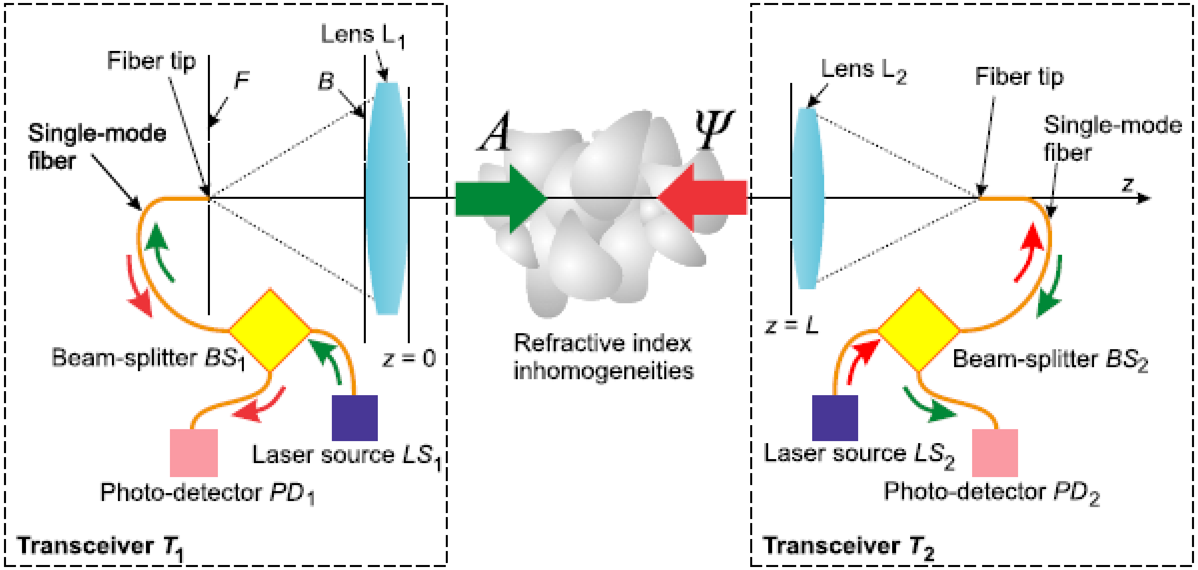
(2) Develop computational models of QI and alternative quantum communication protocols.

(3) Compare the advantages and disadvantages of QI with other quantum communication protocols.

(4) Utilize AdvR photon source to experimentally demonstrate and optimize free-space QI or a superior protocol in the lab.

Turbulence-Enhanced Communication (TECOM) Security

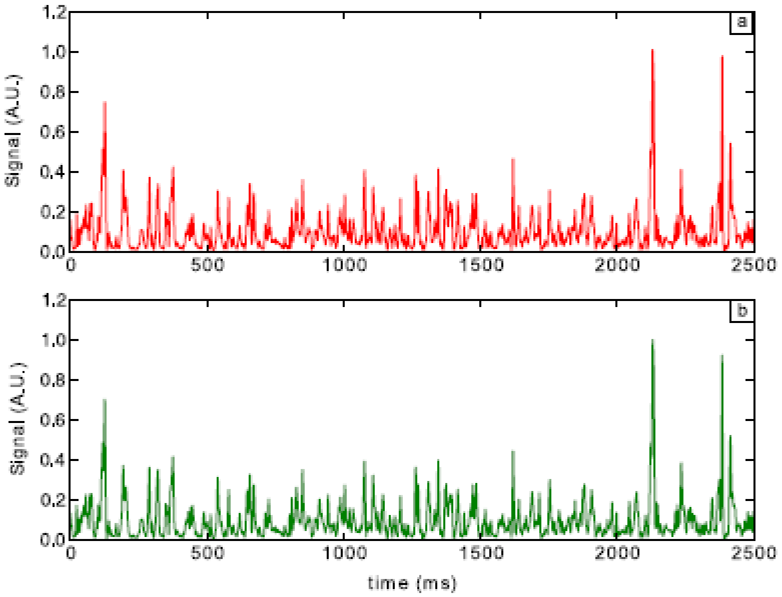
- Visited University of Dayton in September 2015, including the Intelligent Optics Laboratory of Professor Mikhail Vorontsov.
- Used 7-km free space optical link between buildings to explore Turbulence-Enhanced Communication (TECOM) Security concept.*



* J. Minet, M. Vorontsov, E. Polnau, and D. Dolfi, "Enhanced correlation of received power-signal fluctuations in bidirectional optical links," J. of Optics **15** (2013).

TECOM cont.

- Two laser transceivers simultaneously send beams to each other.
- Since each wave propagates through the same turbulence-induced inhomogeneities, the power levels as a function of time at each transceiver can be matched.
- A threshold value of power is defined and the key will consist of only those bits which are propagated when the threshold value is exceeded.
- Could be a simpler, cheaper, higher key bit rate alternative to QKD.



Measured signal power for sender and receiver at opposite ends of 7-km free space link (from Minet, et al., 2013)

Potential Research Areas

- On-demand entangled photon sources (ferroelectric waveguide, nitrogen vacancy center, quantum dot, micro-ring resonators).
- Novel techniques for improving efficiency of single photon receivers.
- Novel quantum key distribution protocols (decoy states, squeezed light) for increasing key data rate.
- Microwave quantum illumination for quantum radar.
- Hyper-entanglement and super-dense coding for enhanced data rates.
- Techniques to improve quantum memory time.
- Turbulence-enhanced communication security.

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