Quantum Teleportation - from polarisation to images

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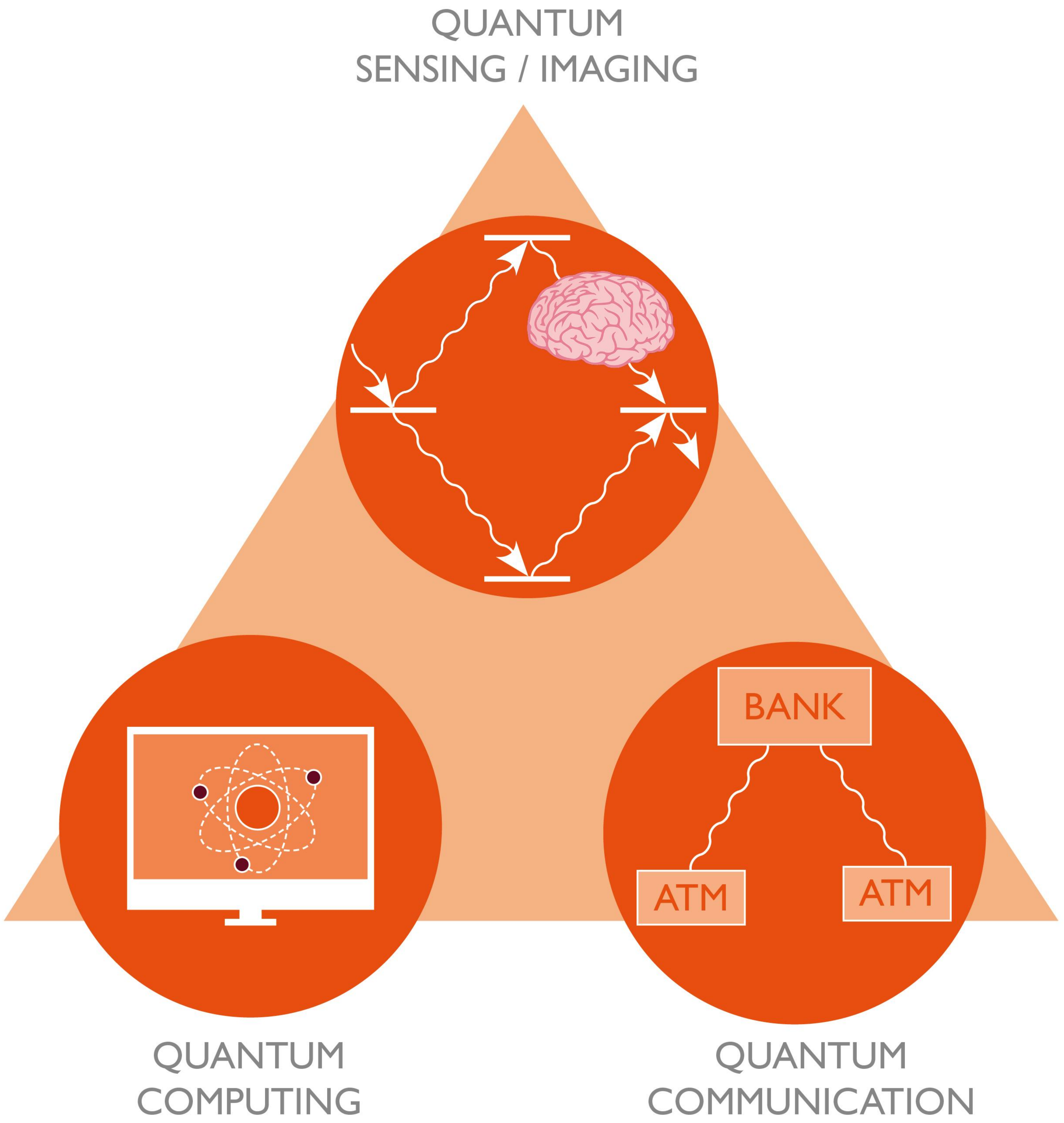
2025 International Year of Quantum Science and Technology

Quantum Technology: Threat or Opportunity?

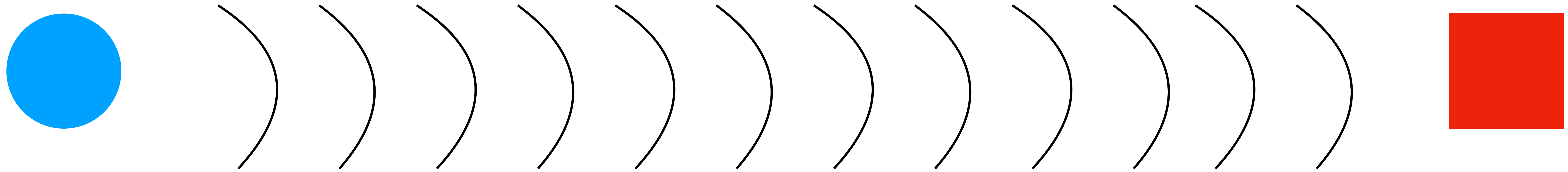
- **How can we understand Quantum Technology?**
- **What is Quantum Teleportation?**
- **How to teleport images?**

QUANTUM TECHNOLOGY



Information Theory

Sender **Receiver**



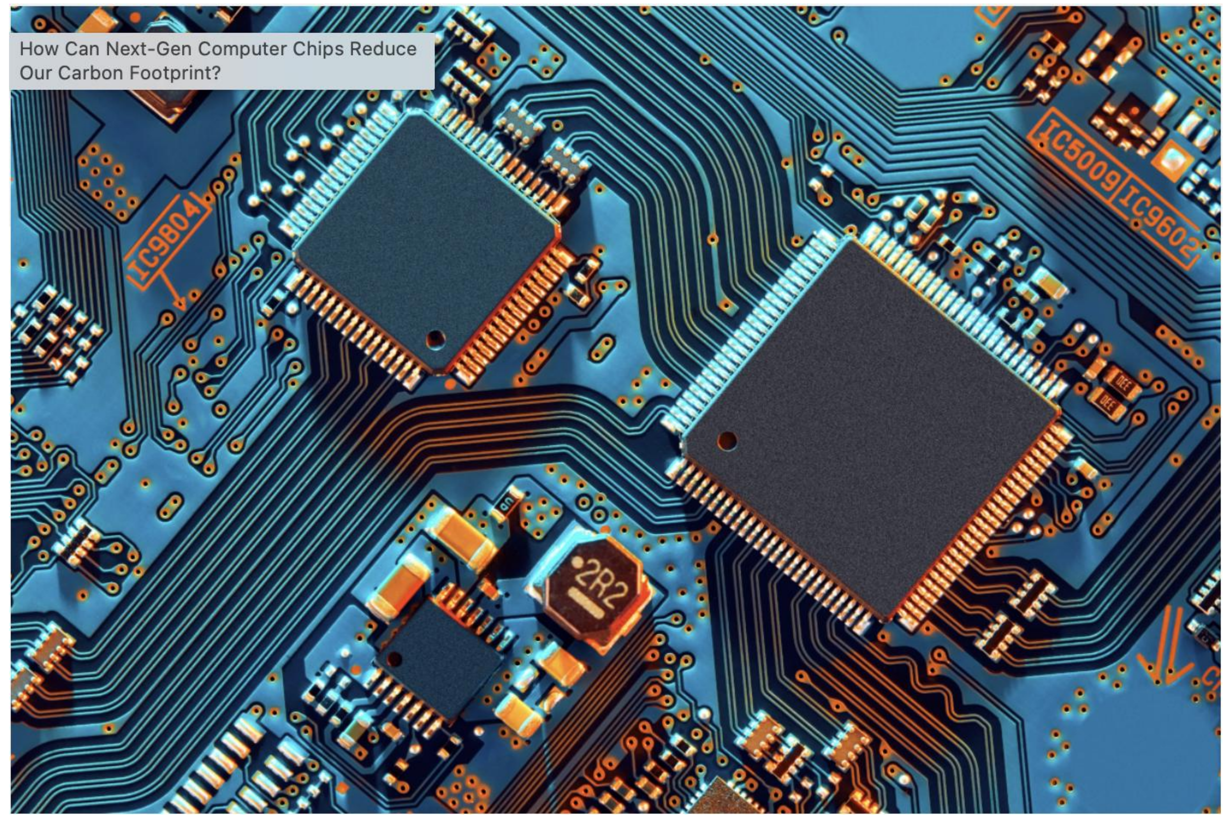
Message	**Probability**
A	**P1**
B	**P2**
C	**P3**

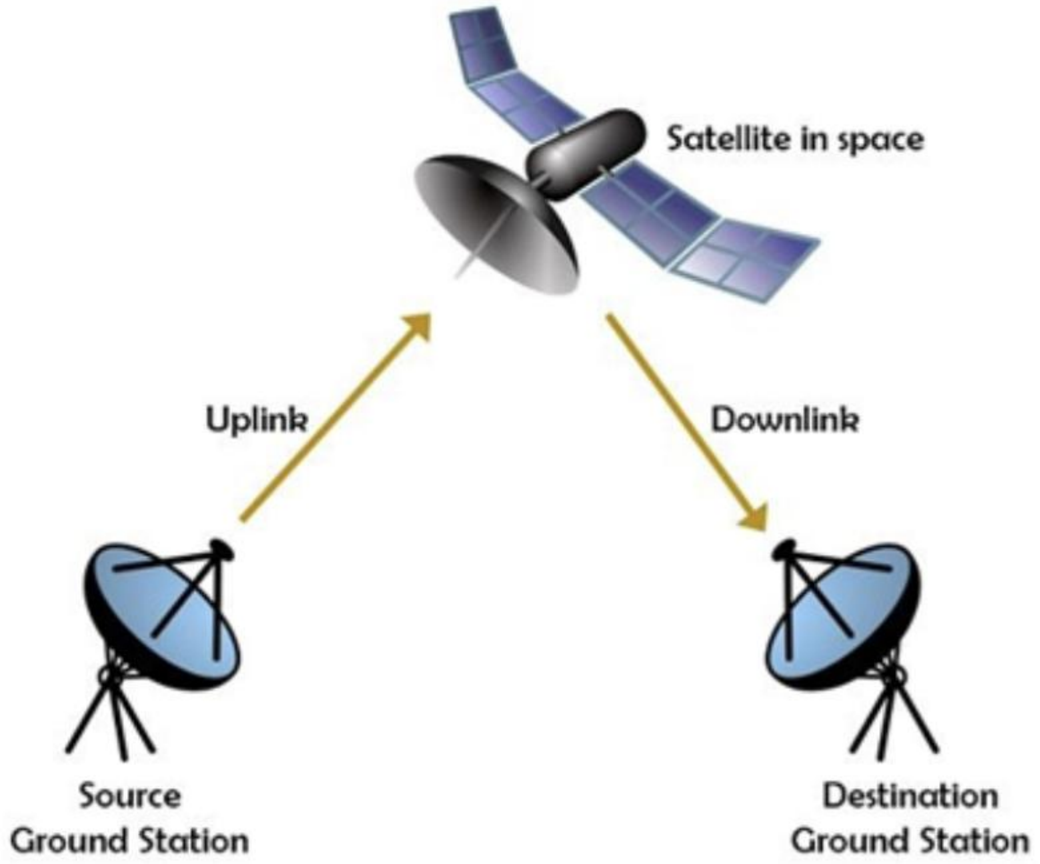
How much information does A contain?

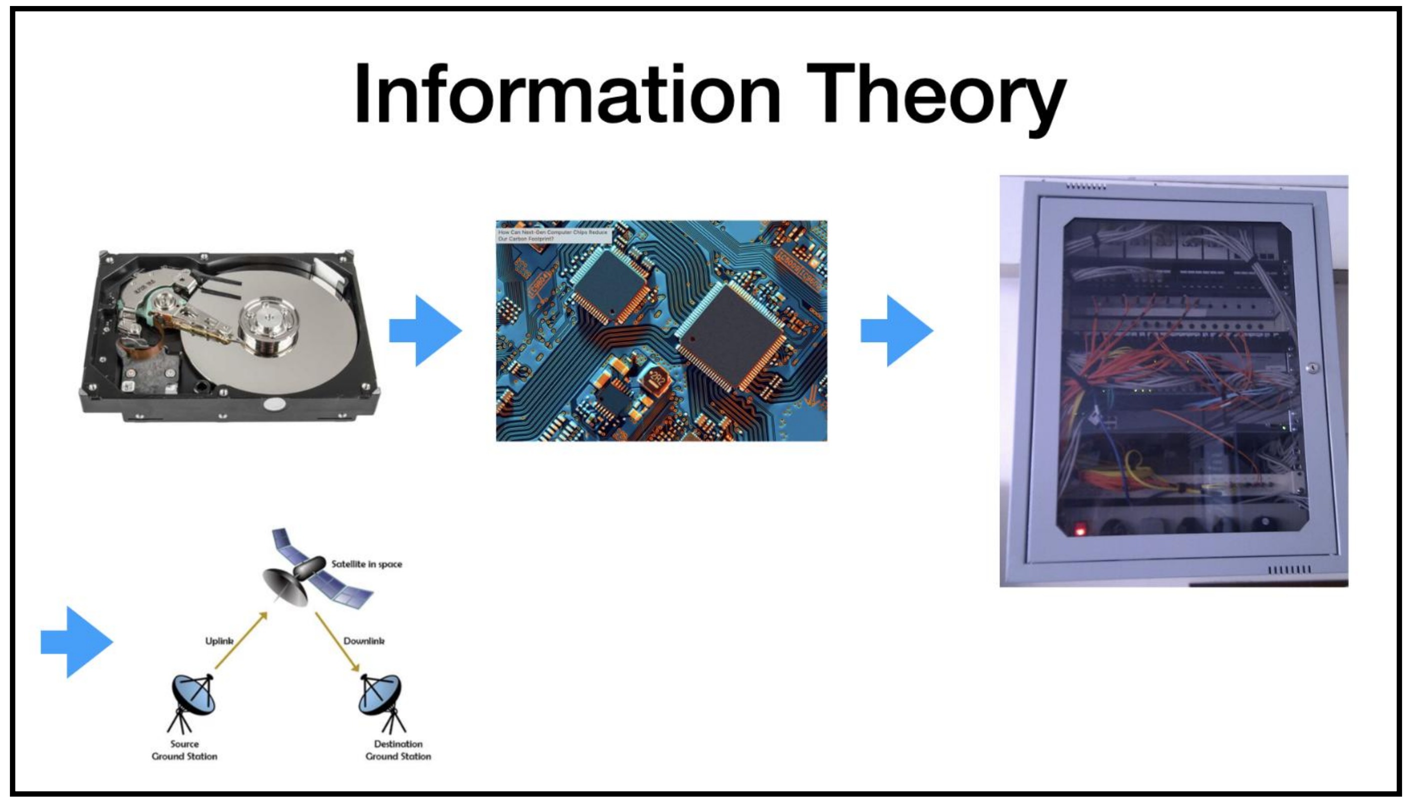
The smaller the probability, the more information!

The Information content does not depend on the meaning of the message

Information Theory







Information Theory

Information ca

ysical carriers

The laws of

sical carrier

What about

tion carriers?

Quantum system

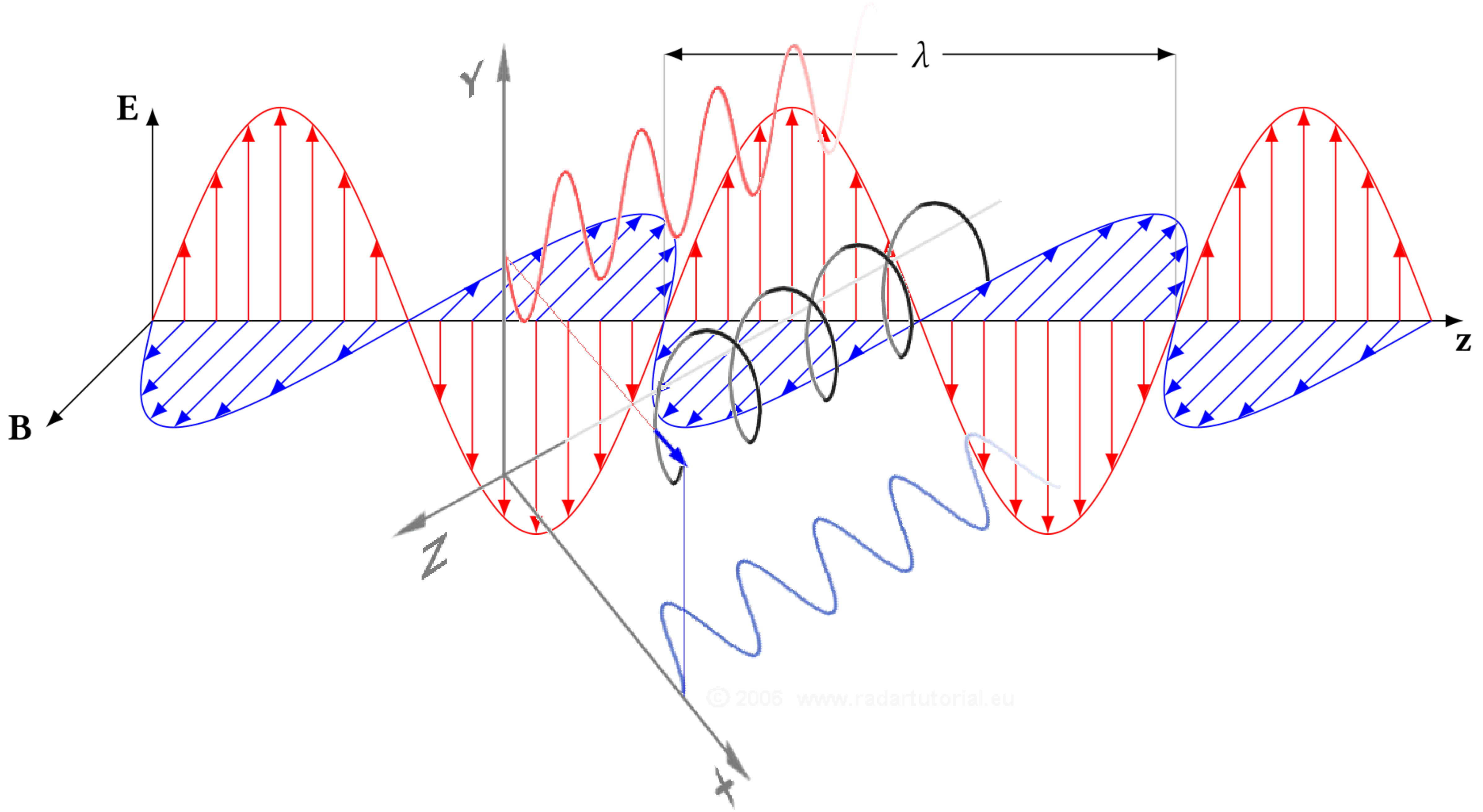
Quantum system

If this would work withou

Theory would not exist!!!

How do we understand quantum information

A photon is an elementary excitation of a light wave

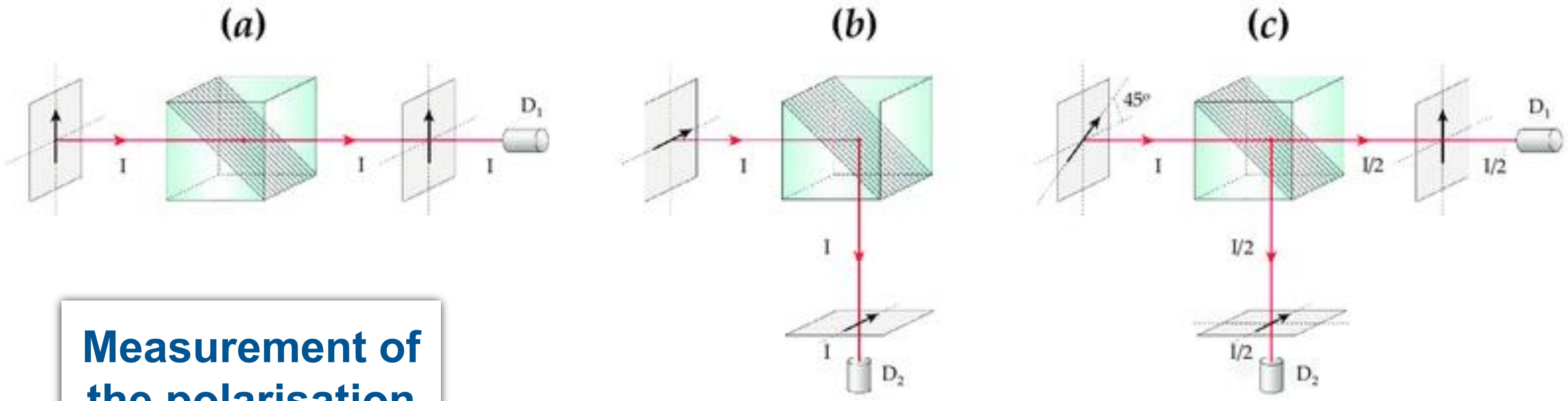


How do we understand quantum information

Can send V (“0”) or H (“1”), or “superposition” of V (“0”) and H (“1”).

A photon is an elementary excitation of a light wave

Quantum Bit $0 + 1$

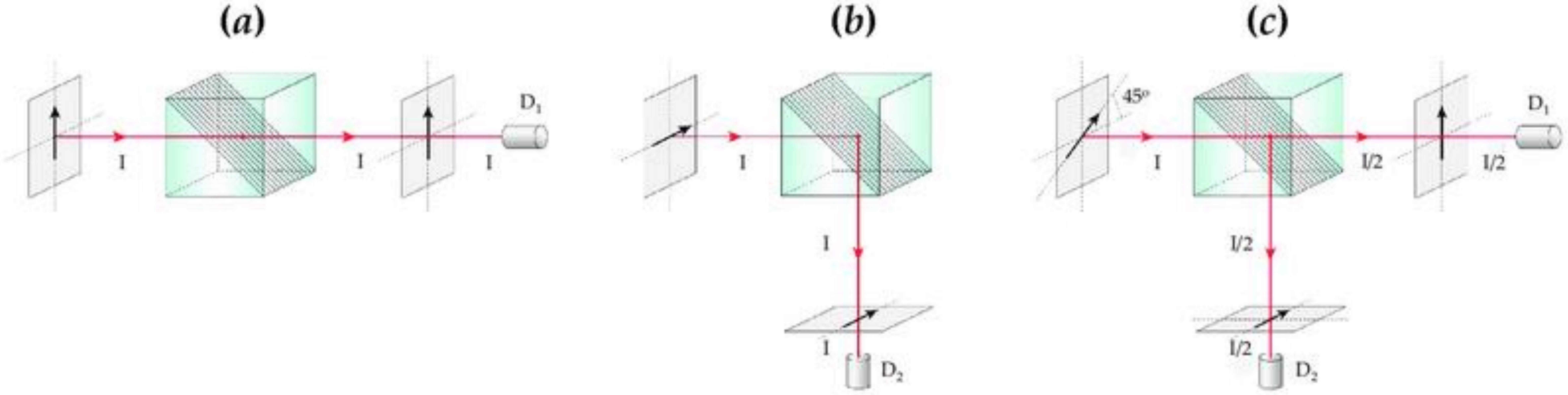


Measurement of the polarisation

How do we understand quantum information

Can send V (“0”) or H (“1”), or “superposition”of V (“0”) and H (“1”).

Quantum Bit $|0\rangle + |1\rangle$

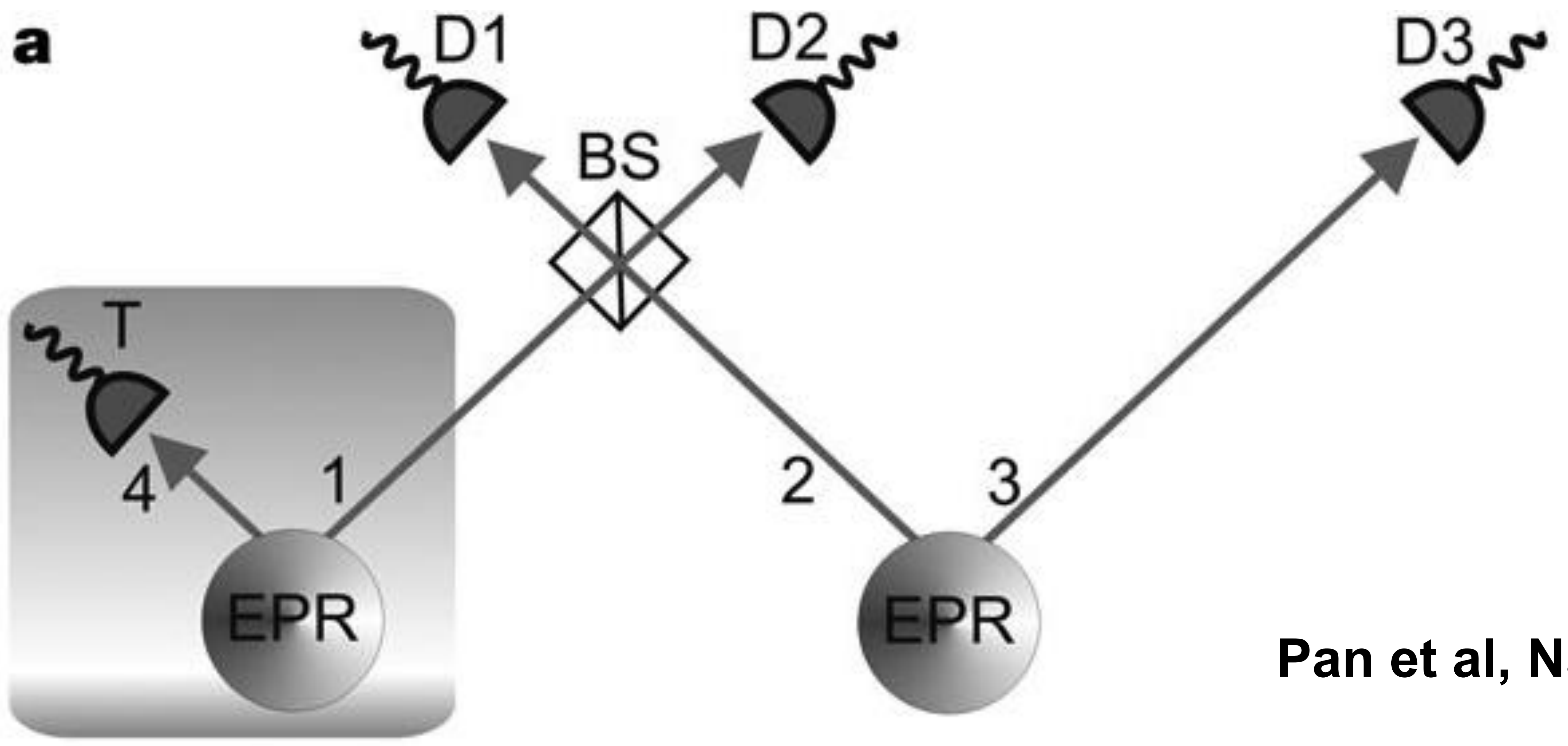


Can detect only $|0\rangle$ or $|1\rangle$, not $|0\rangle + |1\rangle$

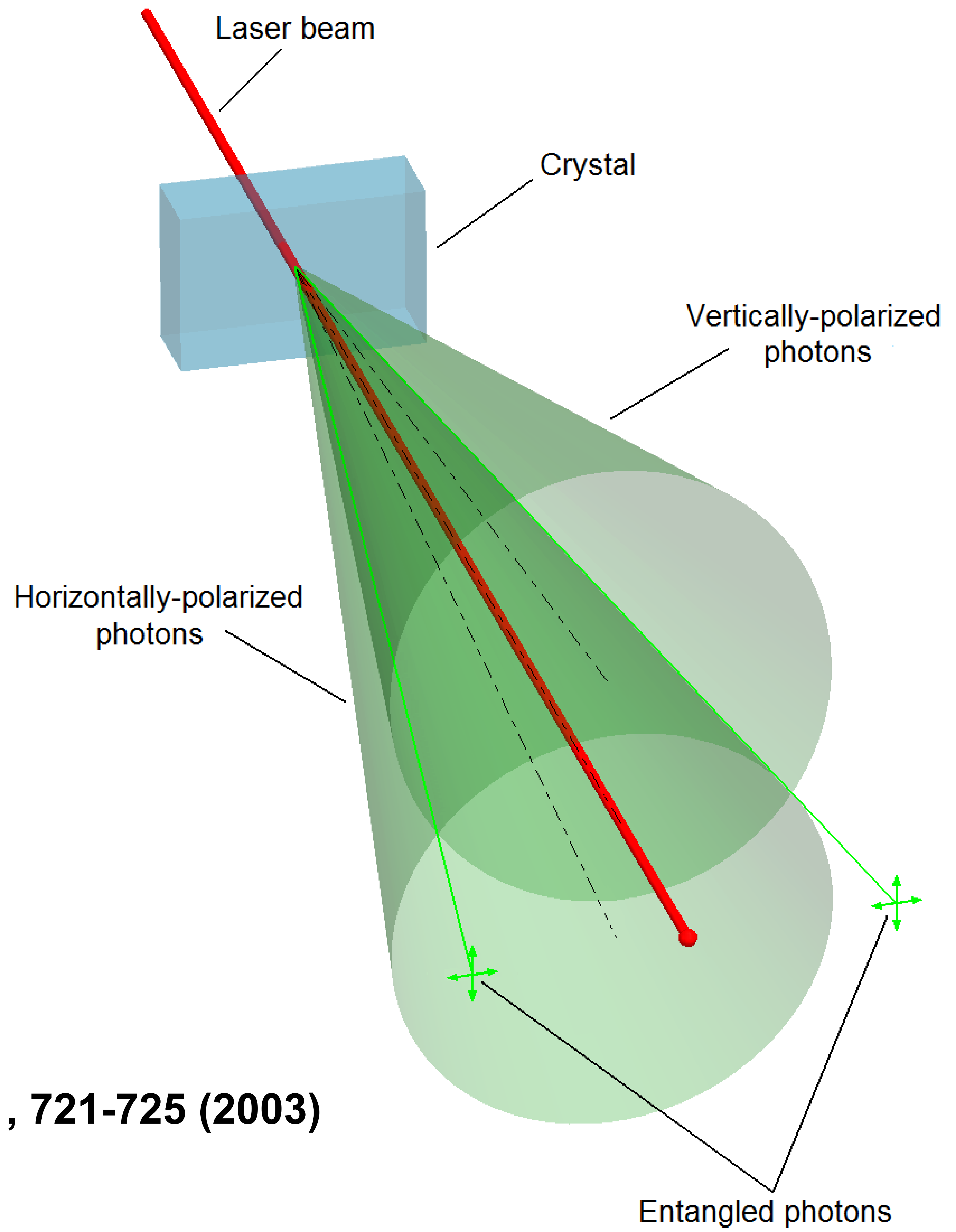
Ho do we understand quantum information

Quantum Bit $|0\rangle + |1\rangle$

Entanglement $|0\rangle\,|1\rangle + |1\rangle\,|0\rangle$



Pan et al, Natue 421, 721-725 (2003)



Quantum Information Theory

- Quantum Information = state of quantum system, superposition allows to store and process “0” and “1” simultaneously, measurement results shows real randomness!

➡ **Quantum computing, simulation of complex systems, random number generation**

- Quantum information in single quantum system cannot be detected nor copied

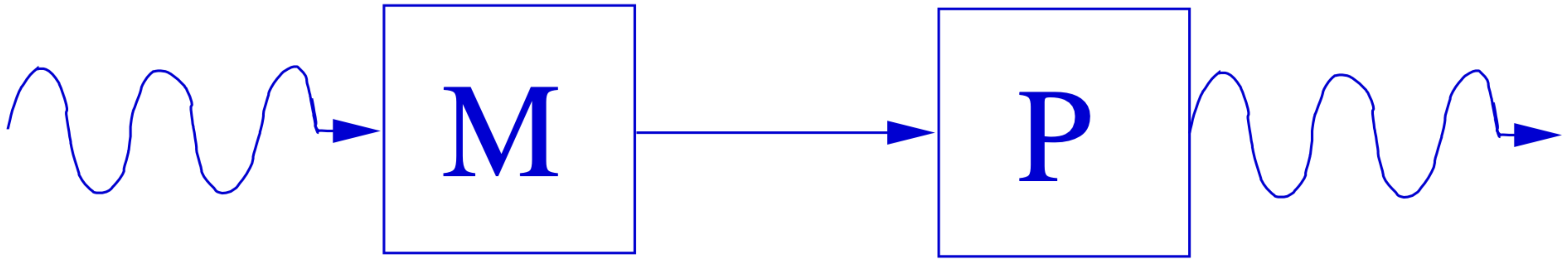
➡ **Quantum Cryptography**

- Quantum correlations “Entanglement”

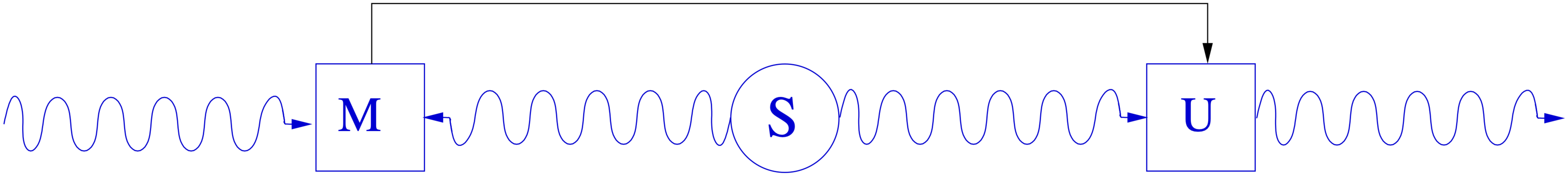
➡ **Quantum teleportation, quantum key distribution, quantum imaging, quantum metrology super dense coding,**

Classical Teleportation

not possible!



Quantum Teleportation



works!

Andrew Forbes

Published: May 2007

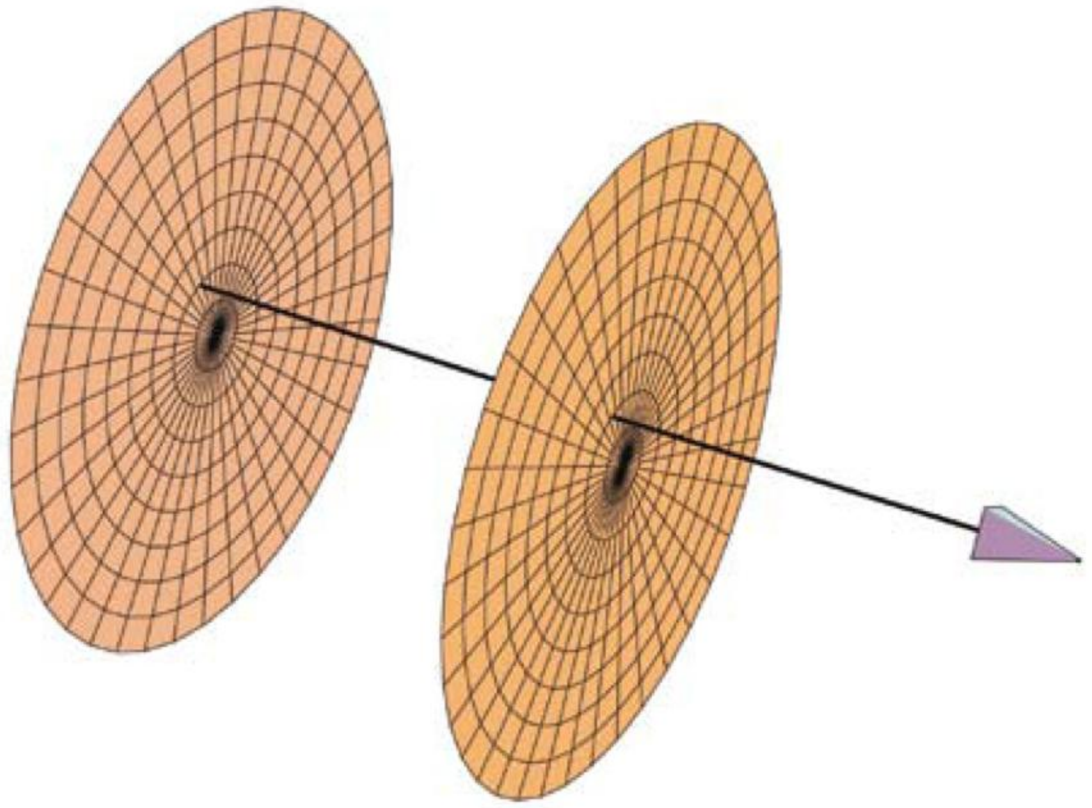
Twisted photons

Gabriel Molina-Terriza, Juan P. Torres & Lluis Torner

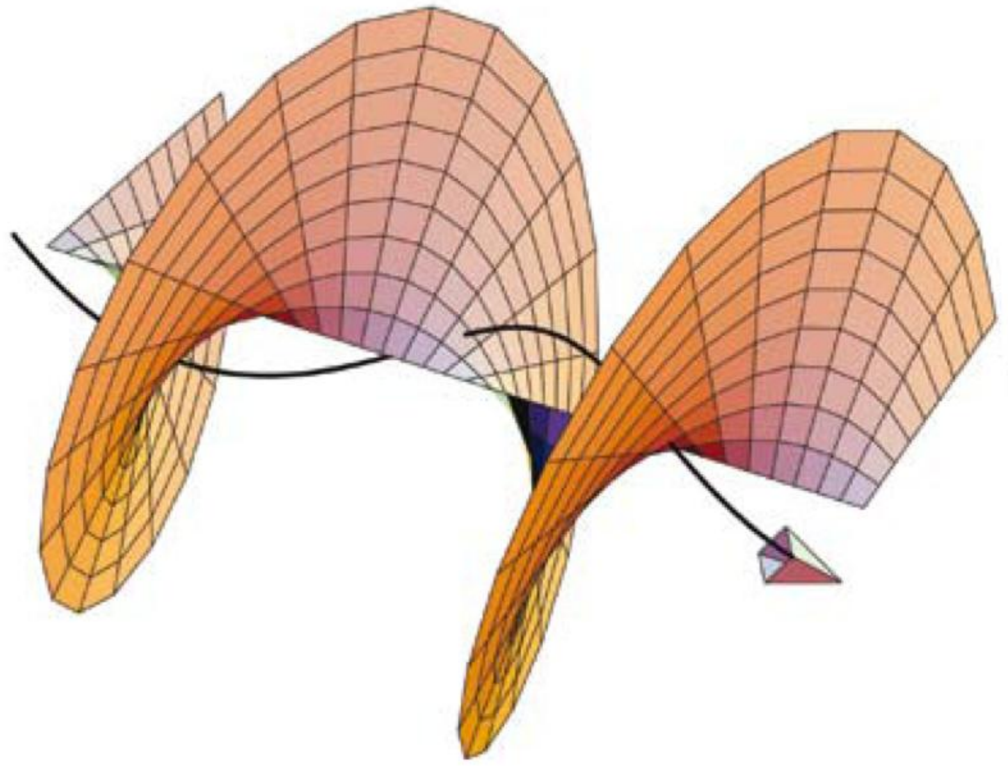
Nature Physics **3**, 305–310 (2007) | Cite this article

Abstract

The orbital angular momentum of light represents a fundamentally new optical degree of freedom. Unlike linear momentum, or spin angular momentum,

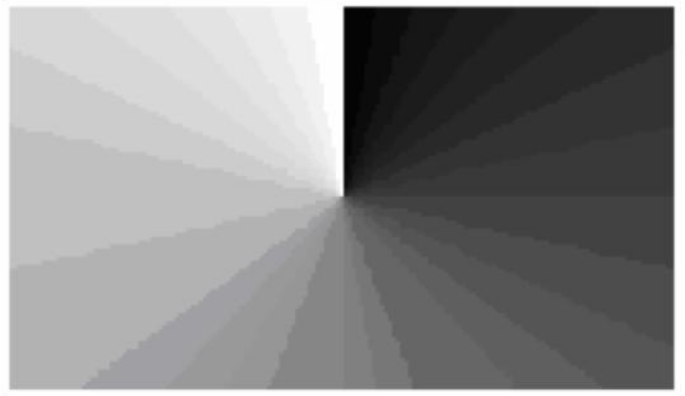


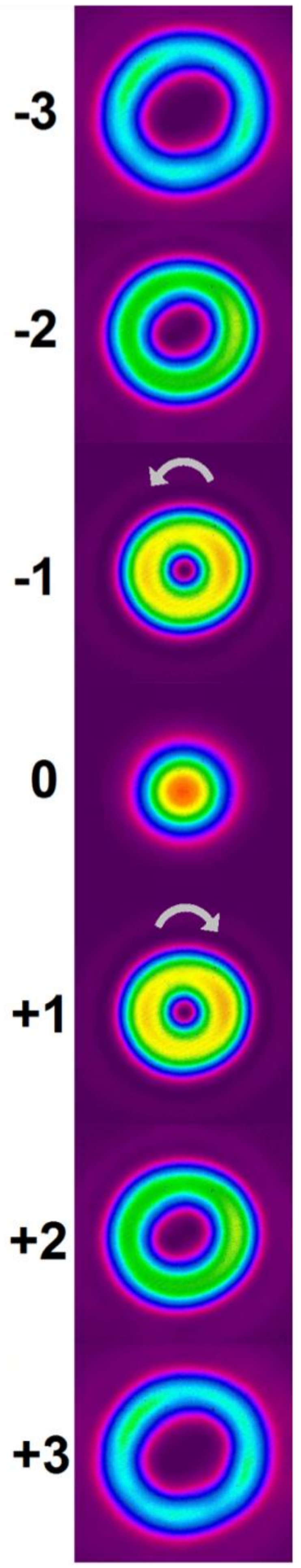
plane wave front

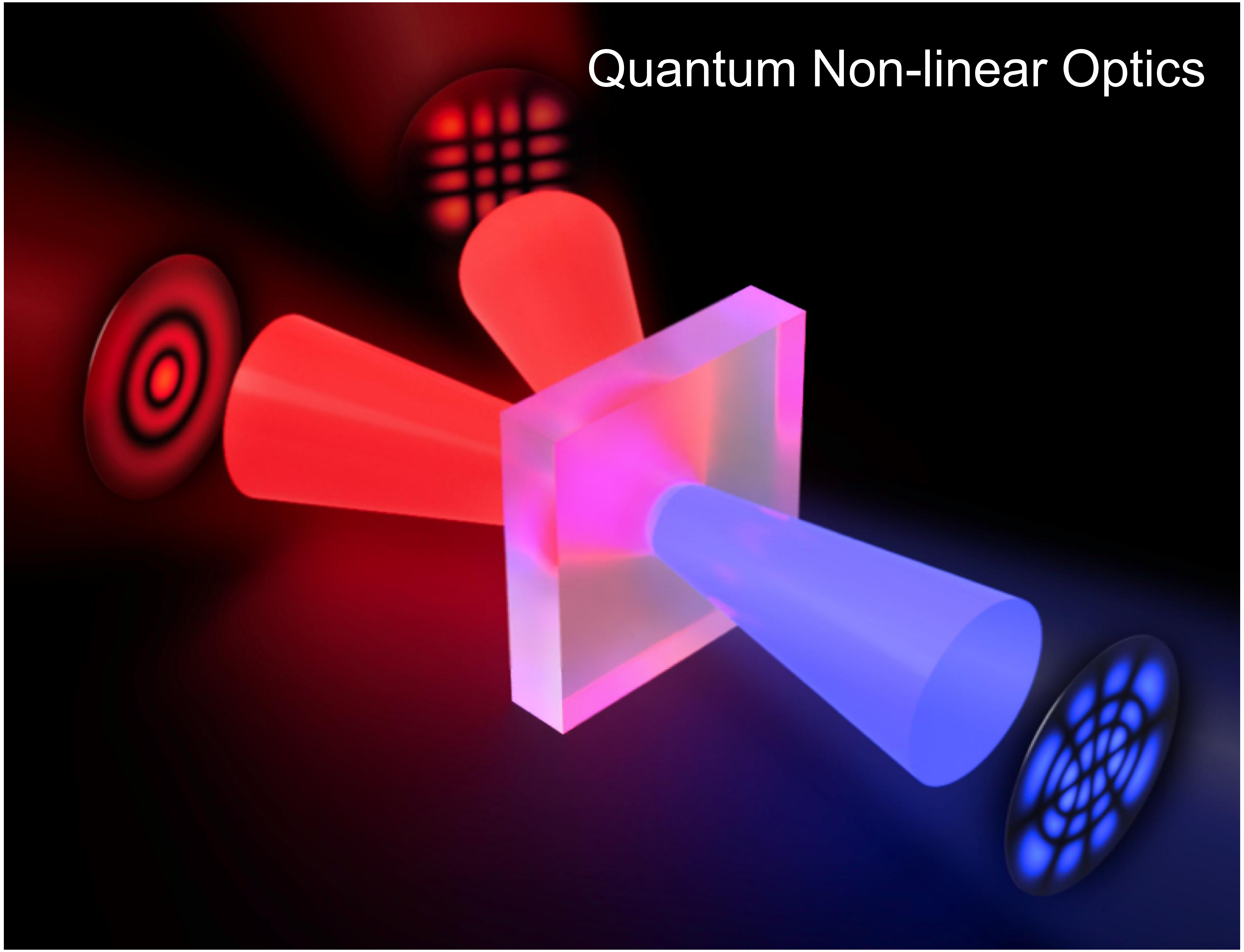


OAM wave front

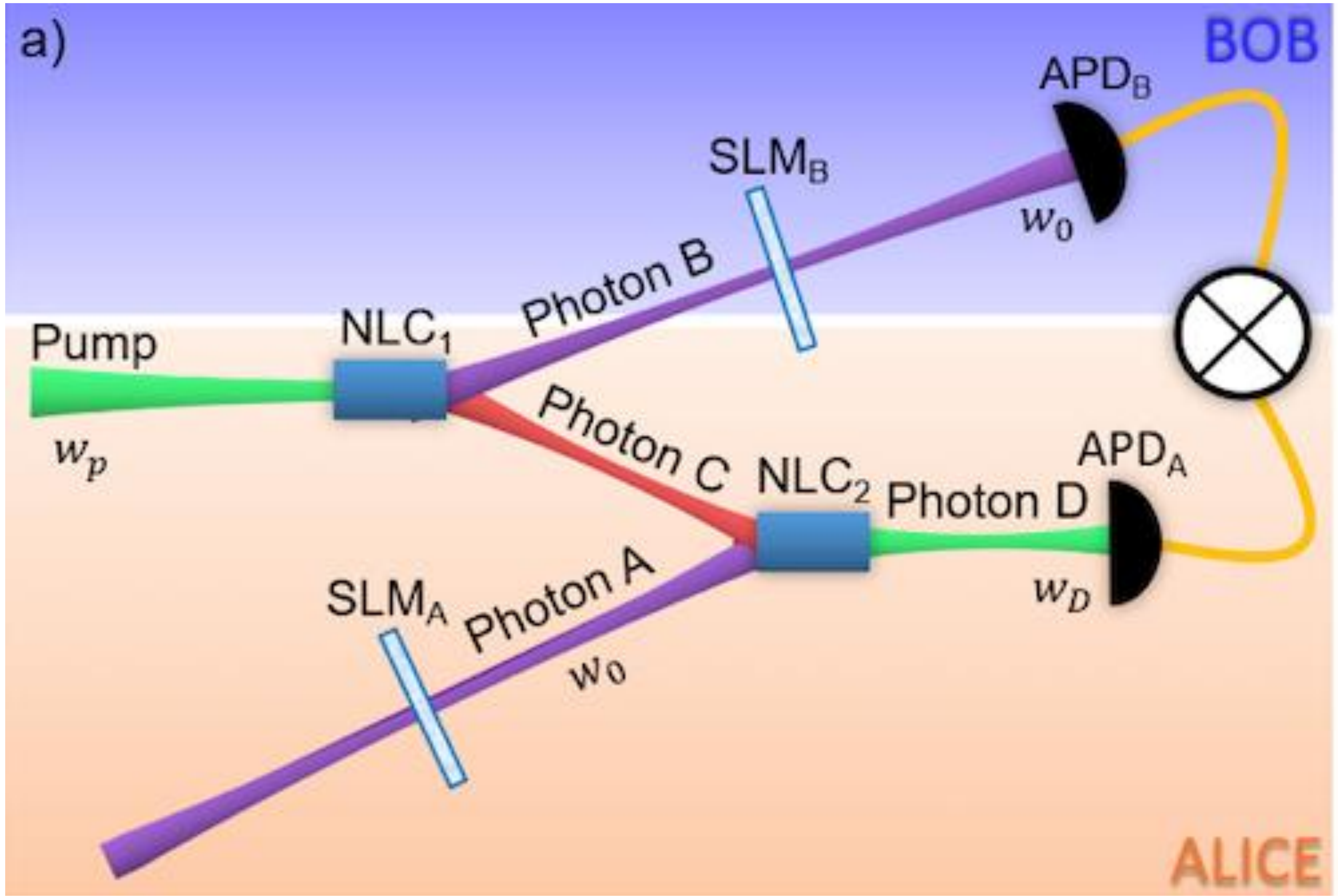
apply position-dependent phase shi



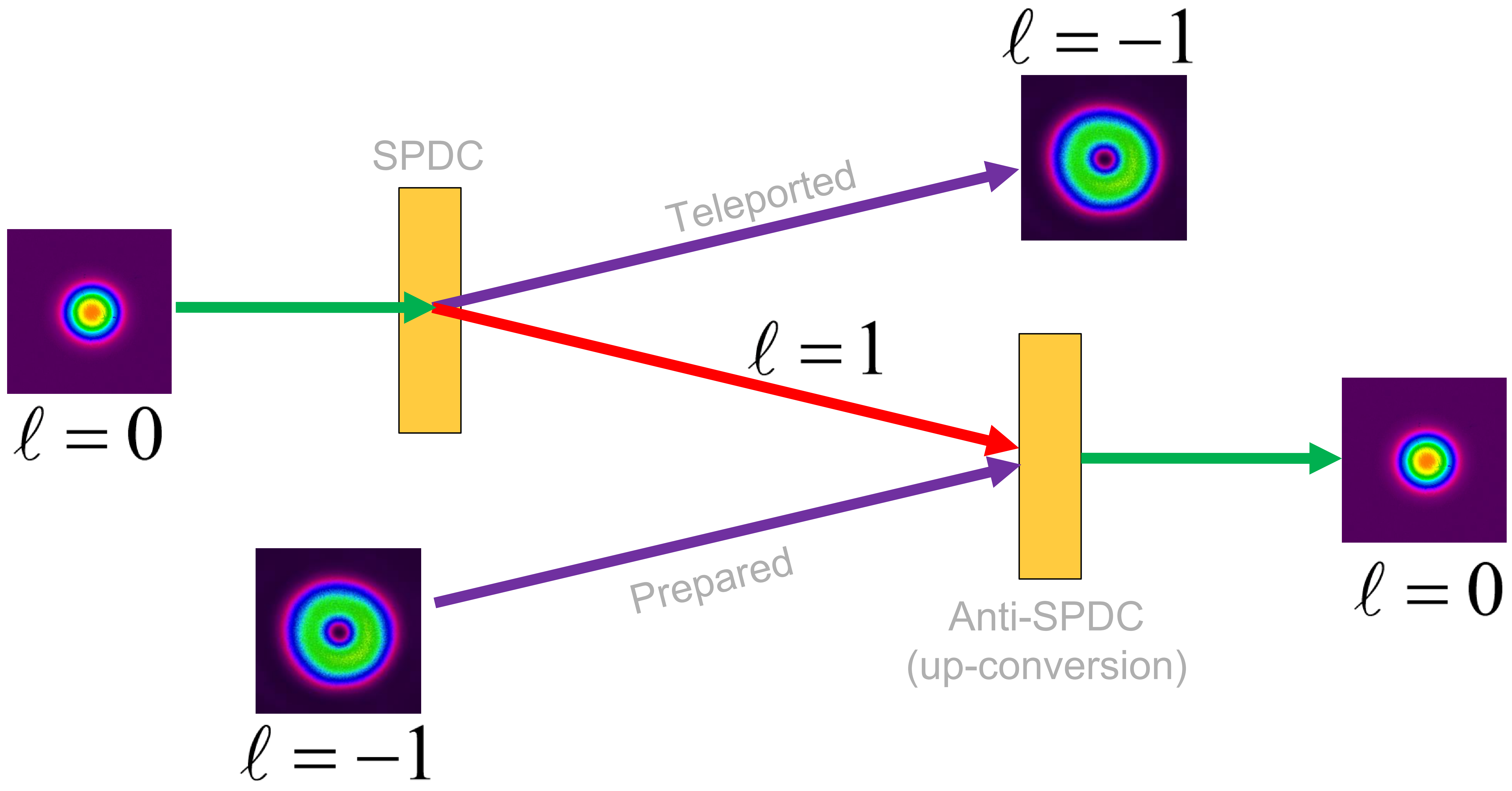



Quantum Non-linear Optics

Quantum Teleportation with non-linear optics

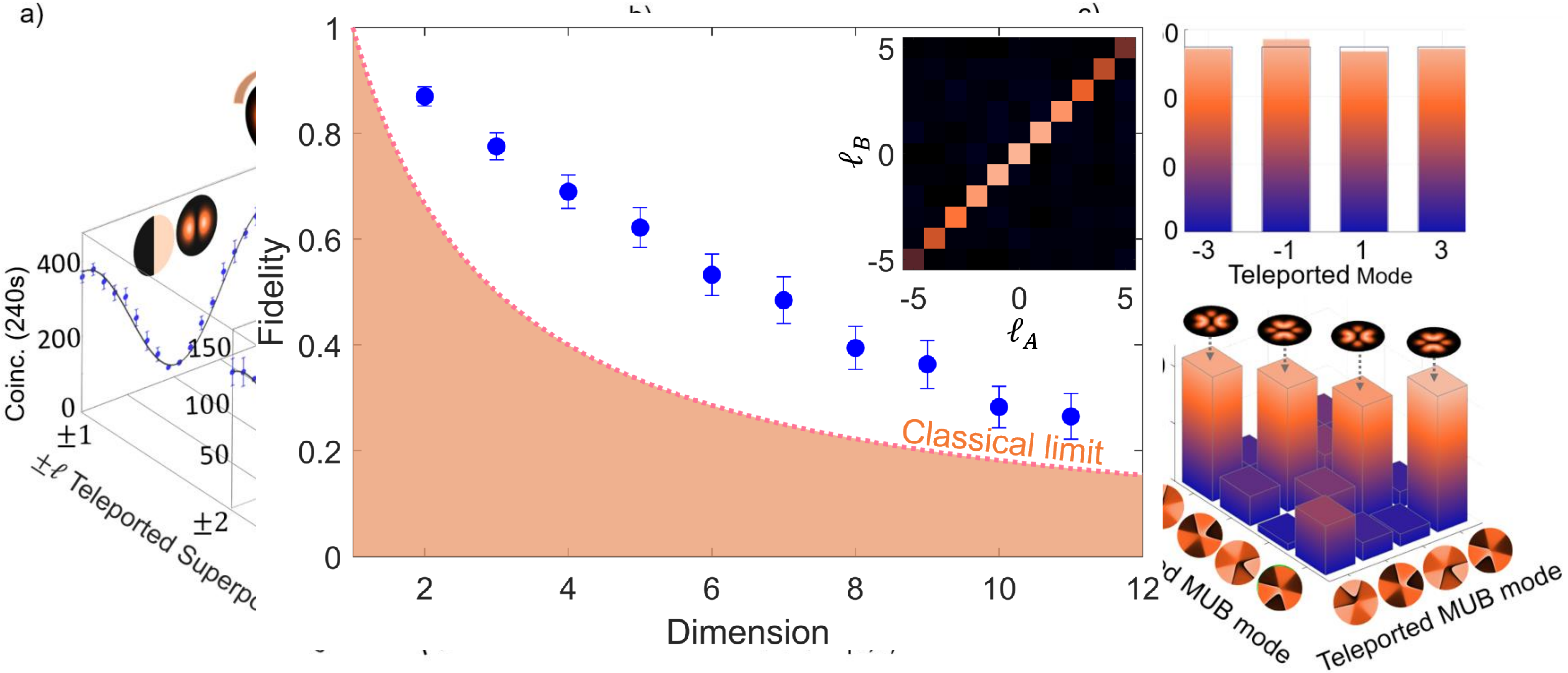


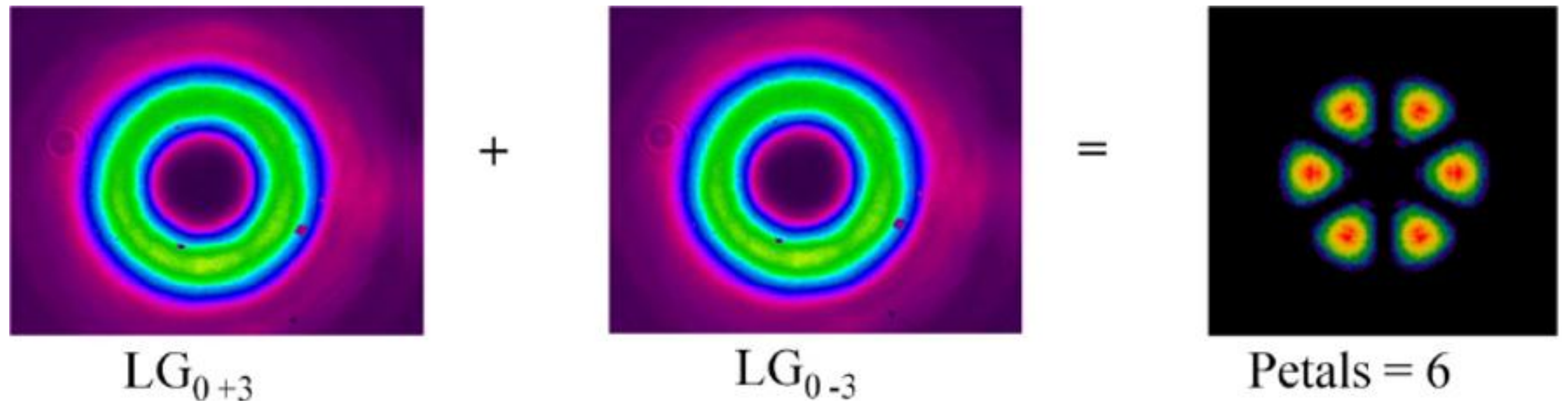
Teleportation with a non-linear optical detector

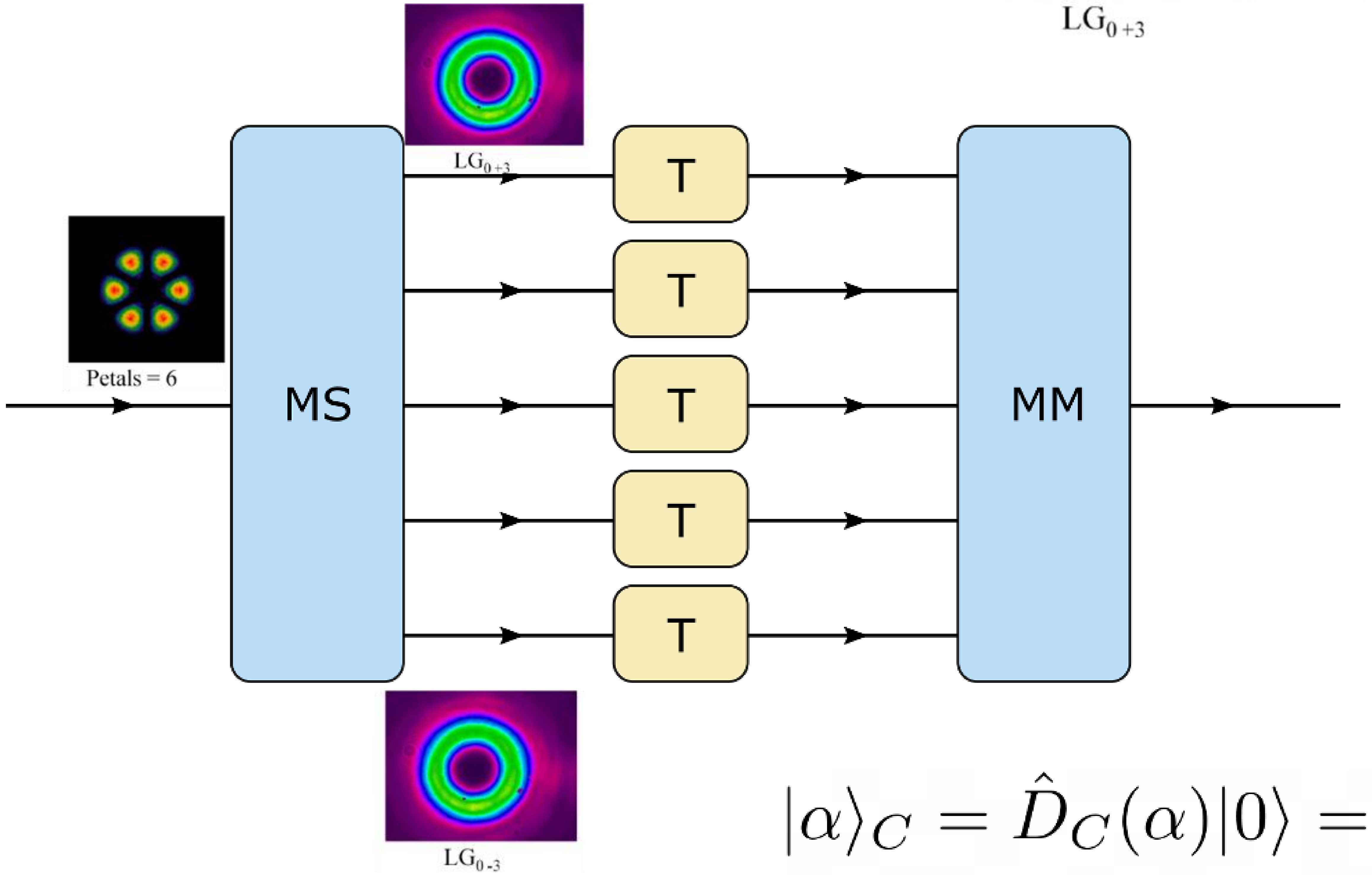


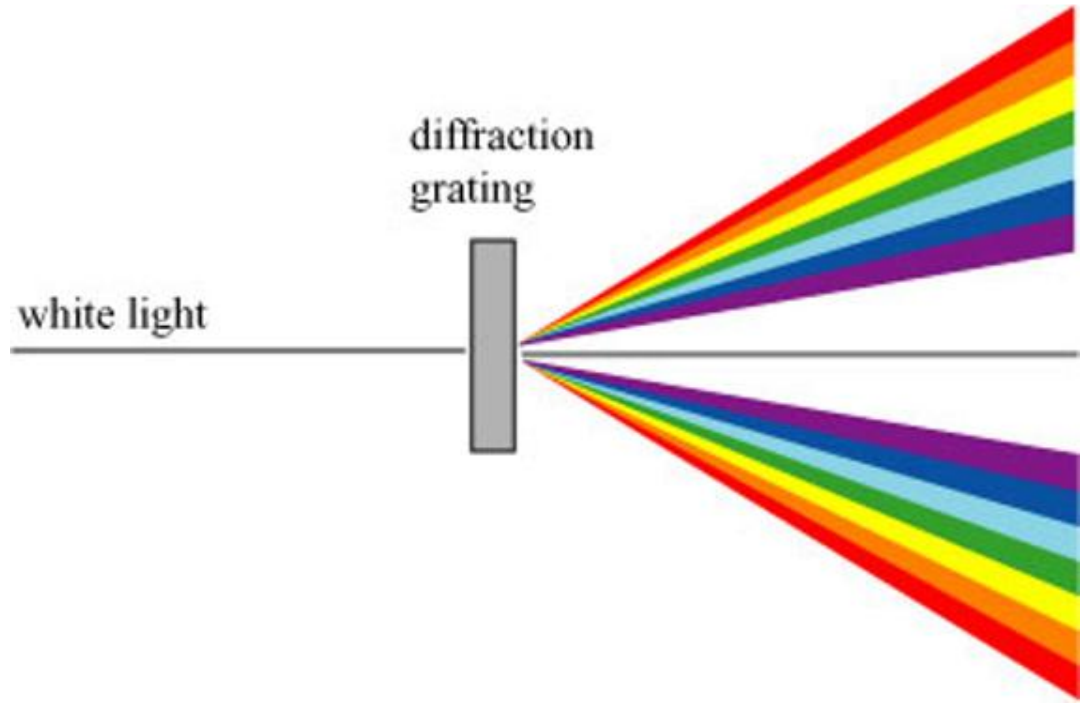
Slide: curtesy A. Frobes

Teleportation in any dimension and any spatial basis without ancillary photons









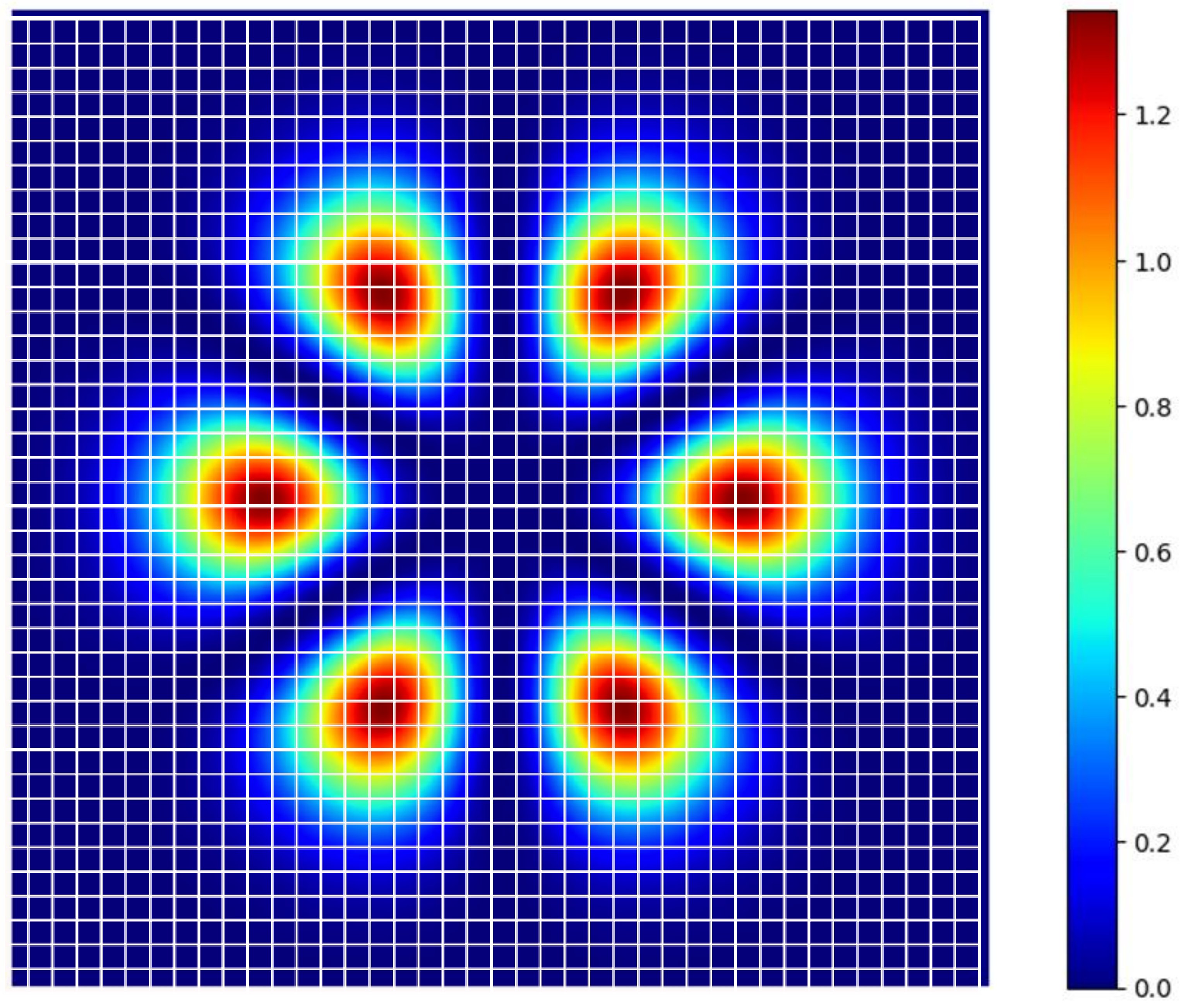
$$
\begin{aligned}
|\alpha\rangle_C &= \hat{D}_C(\alpha)|0\rangle = \exp(\alpha \hat{a}_{\mathrm{C}}^\dagger - \alpha^* \hat{a}_{\mathrm{C}})|0\rangle \\
&= \exp\left(\alpha \sum_j \gamma_j \hat{a}_j^\dagger - \text{h.c.}\right)|0\rangle \\
&= \prod_j \exp\left(\alpha\gamma_j \hat{a}_j^\dagger - \text{h.c.}\right)|0\rangle = \bigotimes_j |\alpha\gamma_j\rangle_j
\end{aligned}
$$

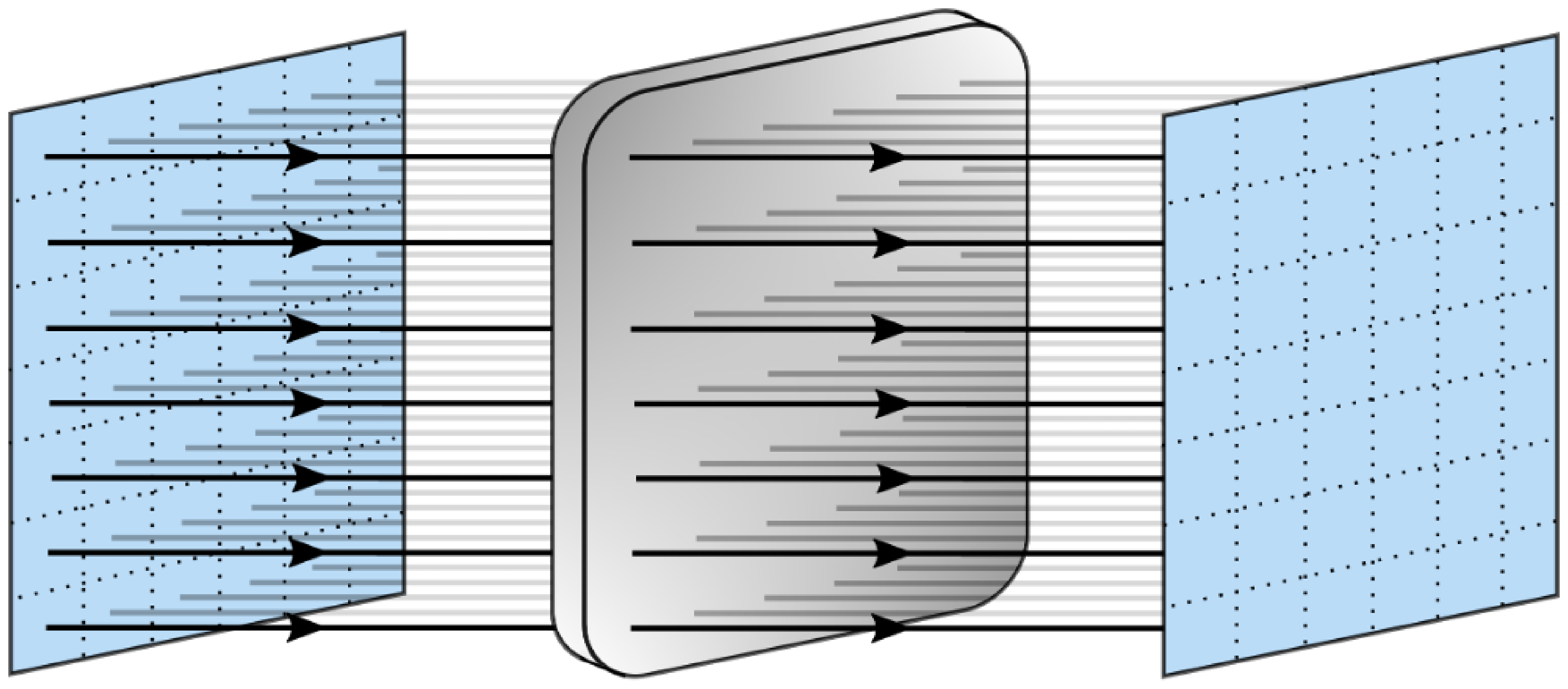
Pixel Modes

$$\tilde{f}_j(\mathbf{x}) = \begin{cases} \frac{1}{\sqrt{A}} & \text{if } \mathbf{x} \in A_j \\ 0 & \text{outside} \end{cases}$$

$$c(\mathbf{x}) = c_j$$

$$c(\mathbf{x}) = \sum_j \gamma_j f_j(\mathbf{x}) \qquad \text{with } \gamma_j = c_j A^{1/2}$$





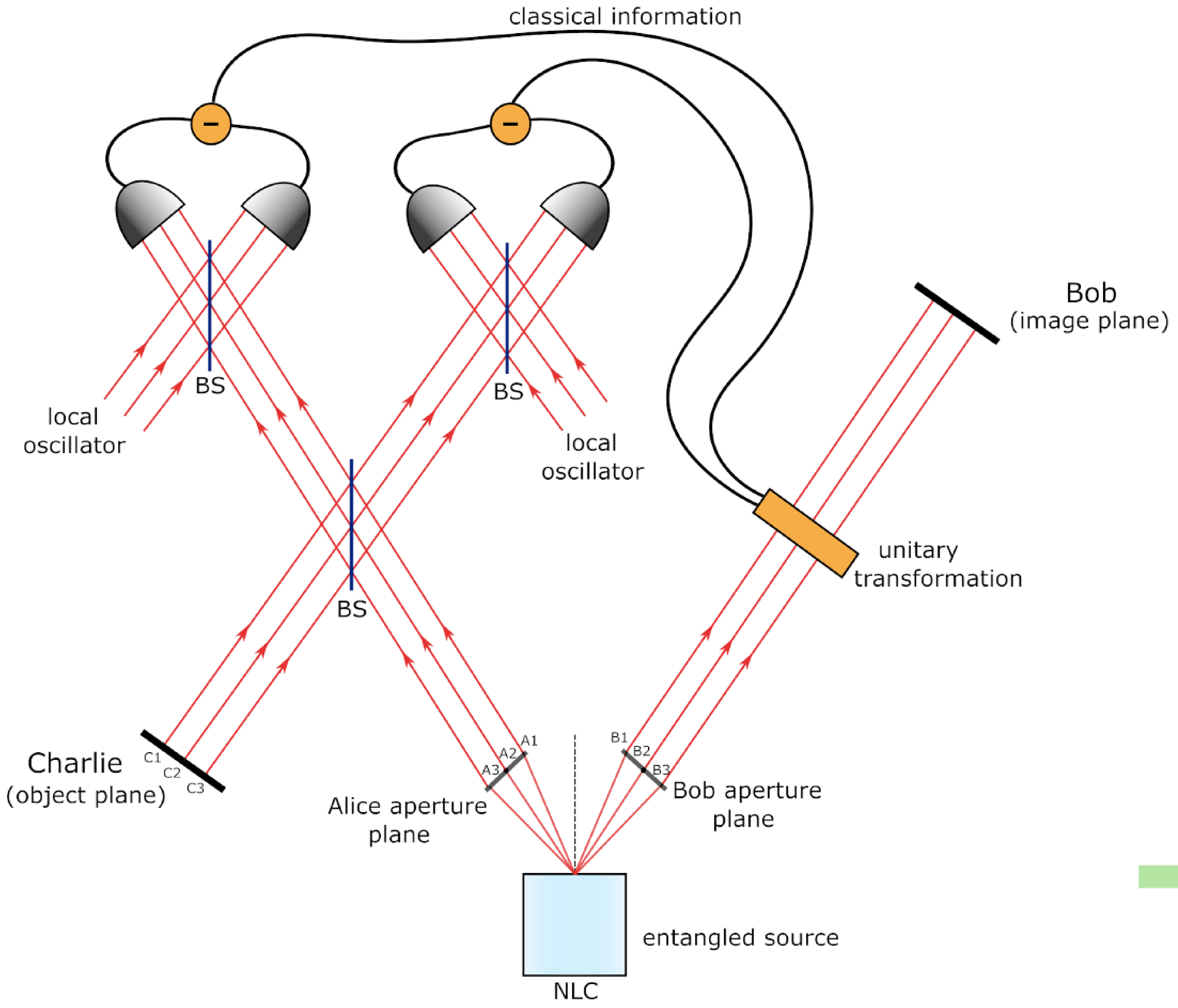
T

$$|\alpha\rangle_C = \hat{D}_C(\alpha)|0\rangle = \exp(\alpha \hat{a}_C^\dagger - \alpha^* \hat{a}_C)|0\rangle$$

$$= \exp\left(\alpha \sum_j \gamma_j \hat{a}_j^\dagger - \text{h.c.}\right)|0\rangle$$

$$= \prod_j \exp\left(\alpha\gamma_j \hat{a}_j^\dagger - \text{h.c.}\right)|0\rangle = \bigotimes_j |\alpha\gamma_j\rangle_j$$

Teleportation Scheme



where $\tilde{\alpha} \equiv \alpha\gamma_j$

$$|\Psi_{\text{init}}\rangle_{ABC} = |\Phi\rangle_{AB} \otimes |\tilde{\alpha}\rangle_C$$

-Generalised Bell measurement

$$|\Psi(\beta)\rangle_{AC} = \frac{1}{\sqrt{\pi}} \sum_s \hat{D}_C(\beta)|s\rangle_A|s\rangle_C$$

$$\rightarrow \quad |\tanh(r)(\tilde{\alpha} - \beta)\rangle_B$$

-Unitary transformation

$$\hat{D}(\beta)$$

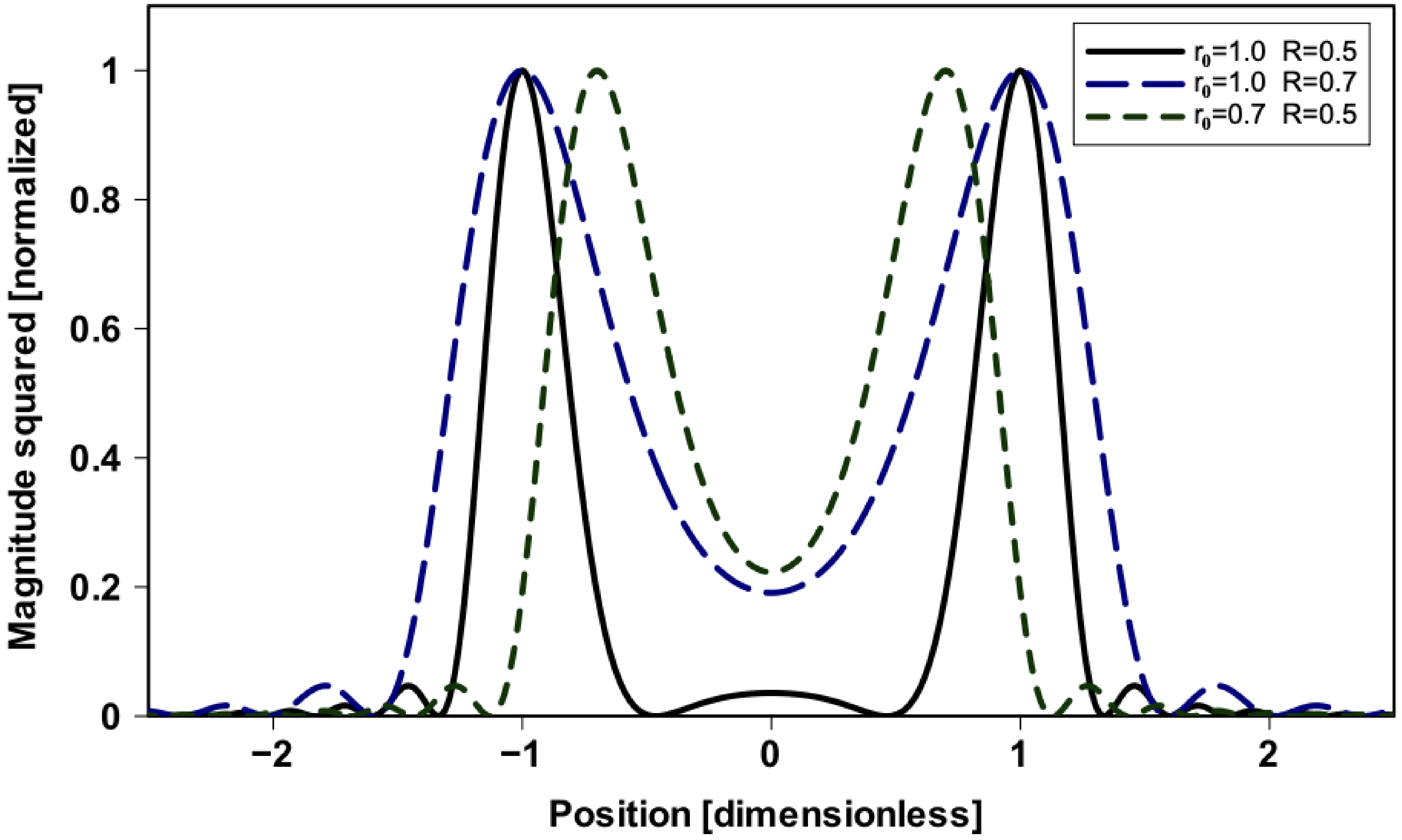
Bob's output state

$$\rightarrow \quad |\tanh(r)\tilde{\alpha} + (1 - \tanh(r))\beta\rangle_B$$

Fidelity

Fidelity for single pixel teleportation

$$F_j = \frac{1 + \tanh(r_j)}{2}$$

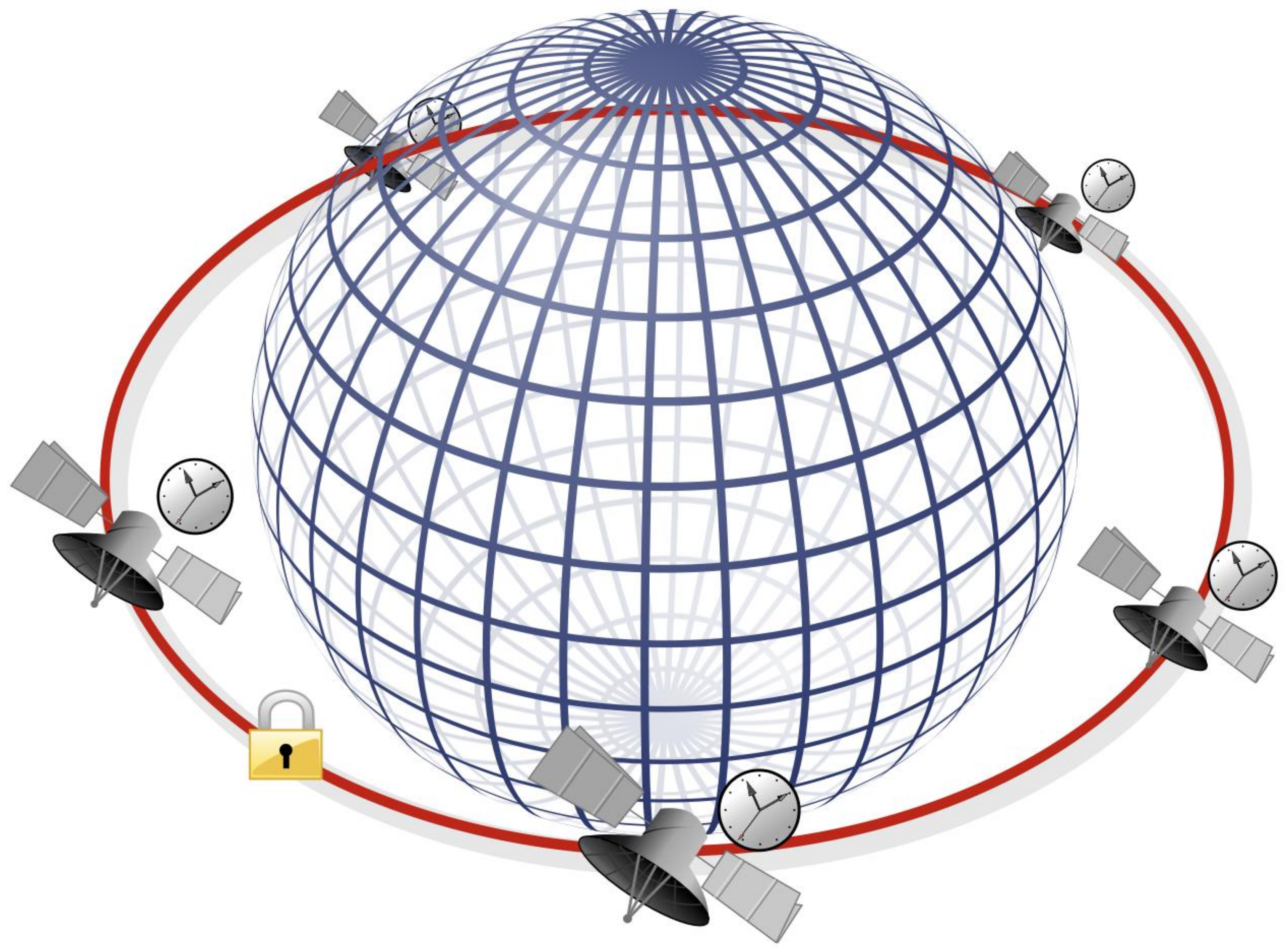


Average pixel fidelity for N pixels

$$F_{\text{image}} = \frac{1}{N}\sum_j F_j = \frac{1}{N}\sum_j \left(\frac{1 + \tanh(r_j)}{2}\right)$$

https://arxiv.org/abs/2502.18204

Future of Quantum Sensing

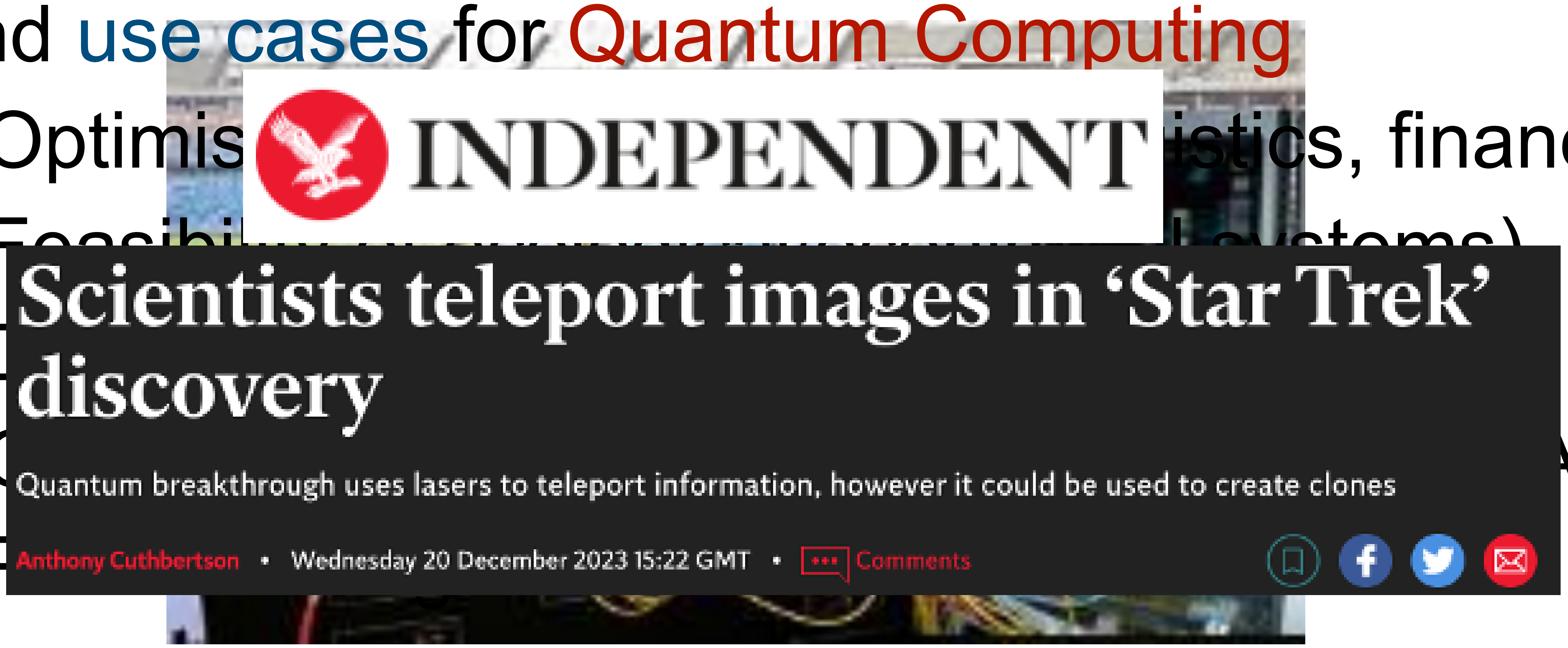


Kómár, P., et al., A quantum network of clocks. Nature Physics, 2014. 10(8): p. 582-587.

Realization of a real-time single international time scale (world clock) with unprecedented stability and accuracy.

What can we do with QT in Durban ?

Find use cases for Quantum Computing

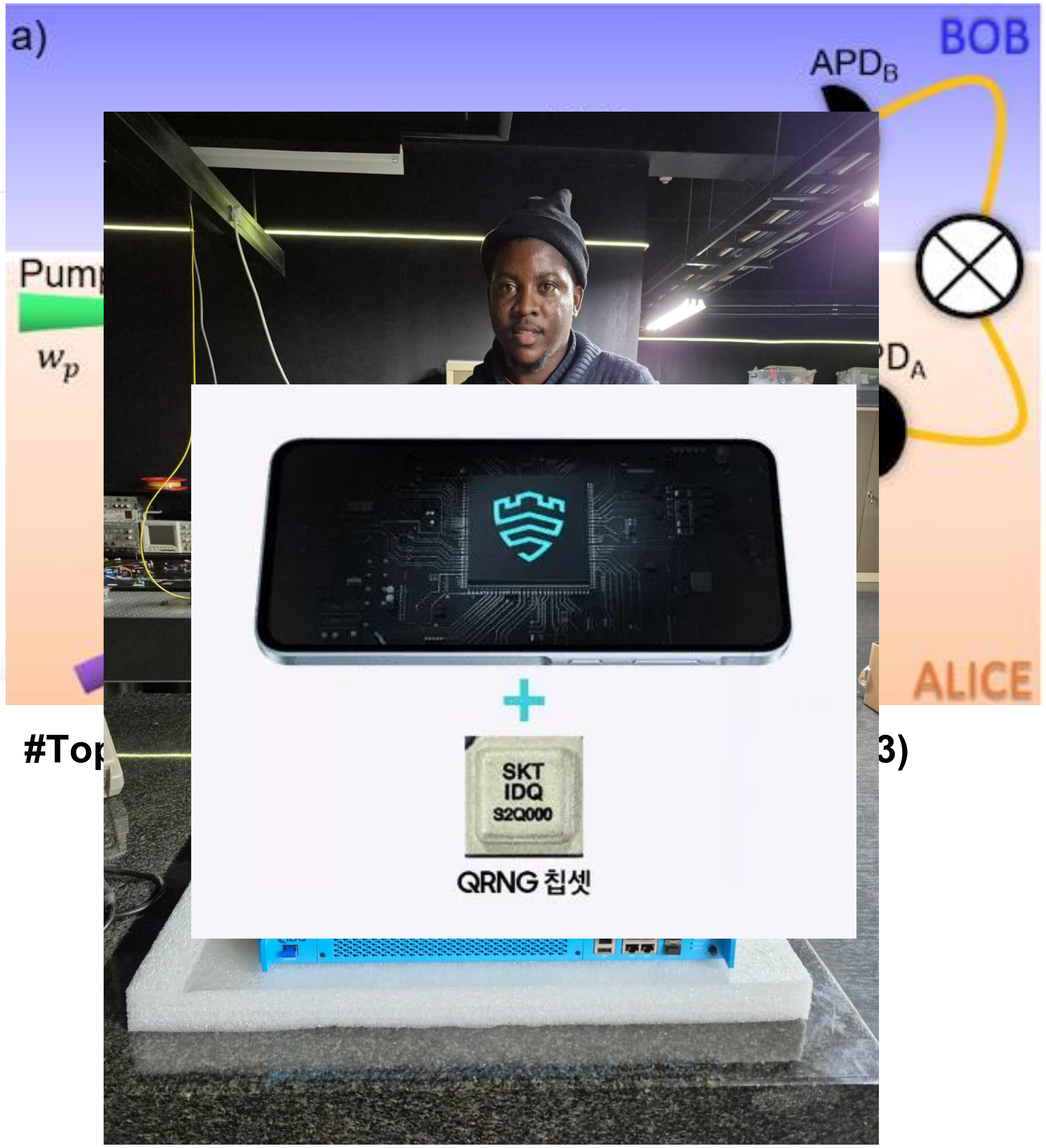

INDEPENDENT

Scientists teleport images in 'Star Trek' discovery

Quantum breakthrough uses lasers to teleport information, however it could be used to create clones

Anthony Cuthbertson • Wednesday 20 December 2023 15:22 GMT • Comments

- Optimis… istics, finance)
- Feasibi… l systems)
- D…
- C… AI)
- P…



Commercial Quantum Communication

- Resell quantum key distribution (QKD) systems
- Assemble QKD devices
- Design and develop QKD devices
- Design Post-Quantum Solutions for Industry

CQCtec

Centre for Quantum
Computing & Technology

Established by UKZN
Council on the 23rd
June 2025

AfriQA

Thank you!

CQCtec
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RESEARCH & INDUSTRY ENGAGEMENT:
Quantum Technology

NITheCS

SA QuTI
South African
Quantum
Technology
Initiative

Squeezed state factorise

Squeezing kernel: $h(\mathbf{k}_1, \mathbf{k}_2) = \xi (2\pi)^2 \delta(\mathbf{k}_1 + \mathbf{k}_2)$

$$\int \hat{a}^\dagger(\mathbf{k}_1) h(\mathbf{k}_1, \mathbf{k}_2) \hat{b}^\dagger(\mathbf{k}_2) \frac{\mathrm{d}^2\mathbf{k}_1 \, \mathrm{d}^2\mathbf{k}_2}{(2\pi)^4}$$
$$= \xi \int \sum_j \hat{a}^\dagger(\mathbf{k}_1) F_j(\mathbf{k}_1) F_j(\mathbf{k}_2) \hat{b}^\dagger(\mathbf{k}_2) \frac{\mathrm{d}^2\mathbf{k}_1 \, \mathrm{d}^2\mathbf{k}_2}{(2\pi)^4}$$
$$= \xi \sum_j \hat{a}_j^\dagger \hat{b}_j^\dagger.$$

$$(2\pi)^2 \delta(\mathbf{k}_1 + \mathbf{k}_2) = \sum_j F_j^*(-\mathbf{k}_1) F_j(\mathbf{k}_2).$$
$$= \sum_j F_j(\mathbf{k}_1) F_j(\mathbf{k}_2).$$

$$\hat{S}_{A,B}|0\rangle = \exp\left[\xi \textstyle\sum_j \left(\hat{a}_j \hat{b}_j - \hat{a}_j^\dagger \hat{b}_j^\dagger\right)\right] |0\rangle$$
$$= \textstyle\prod_j \exp\left(\xi \hat{a}_j \hat{b}_j - \xi \hat{a}_j^\dagger \hat{b}_j^\dagger\right) |0\rangle$$
$$= \textstyle\bigotimes_j \ \mathrm{sech}\xi \ \sum_{n_j=0}^{\infty} (\tanh\xi)^{n_j} |n_j\rangle_{A_j} |n_j\rangle_{B_j}$$

CV Teleportation of coherent states

Coherent States

$$\hat{a}|\alpha\rangle = \alpha|\alpha\rangle$$
$$\langle\alpha|\hat{a}^\dagger = \alpha^*\langle\alpha|$$

$$\hat{D}(\alpha)|0\rangle = \exp\left(\alpha\hat{a}^\dagger - \alpha^*\hat{a}\right)|0\rangle$$
$$= \exp\left(-|\alpha|^2/2\right)\sum_{n=0}^{\infty}\frac{\alpha^n}{\sqrt{n!}}|n\rangle = |\alpha\rangle$$