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GALICIA SUPERCOMPUTING CENTER

Nueva línea de comunicaciones cuánticas Santiago-Vigo

David Barral
Técnico coordinador de proyecto PCCC

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Plan de Recuperación, Transformación y Resiliencia

Cryptography

Confidential communication through cipher techniques

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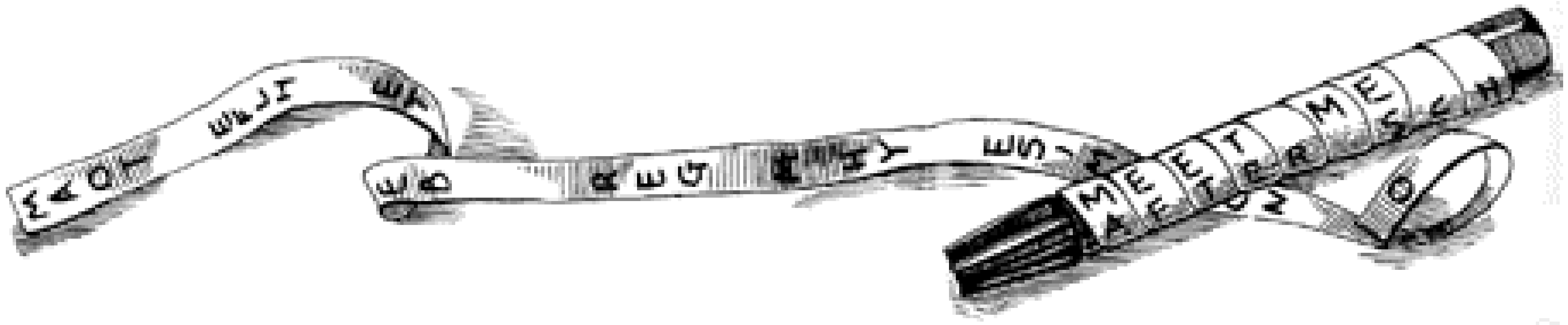
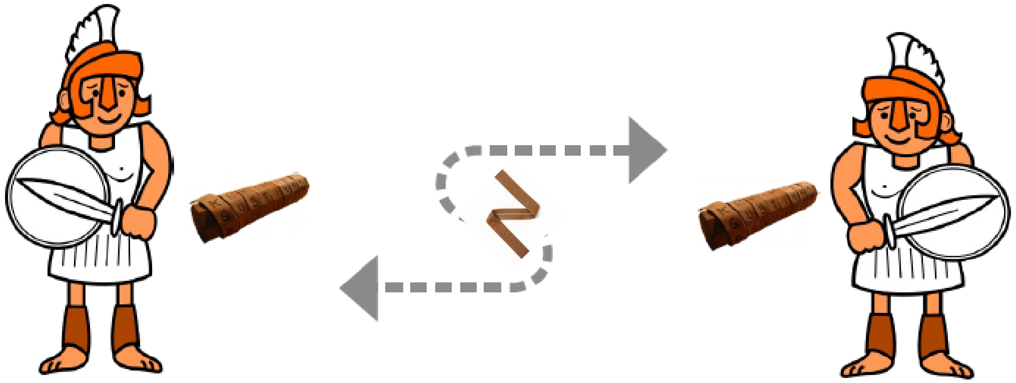
Scytale

(7th century B.C.)





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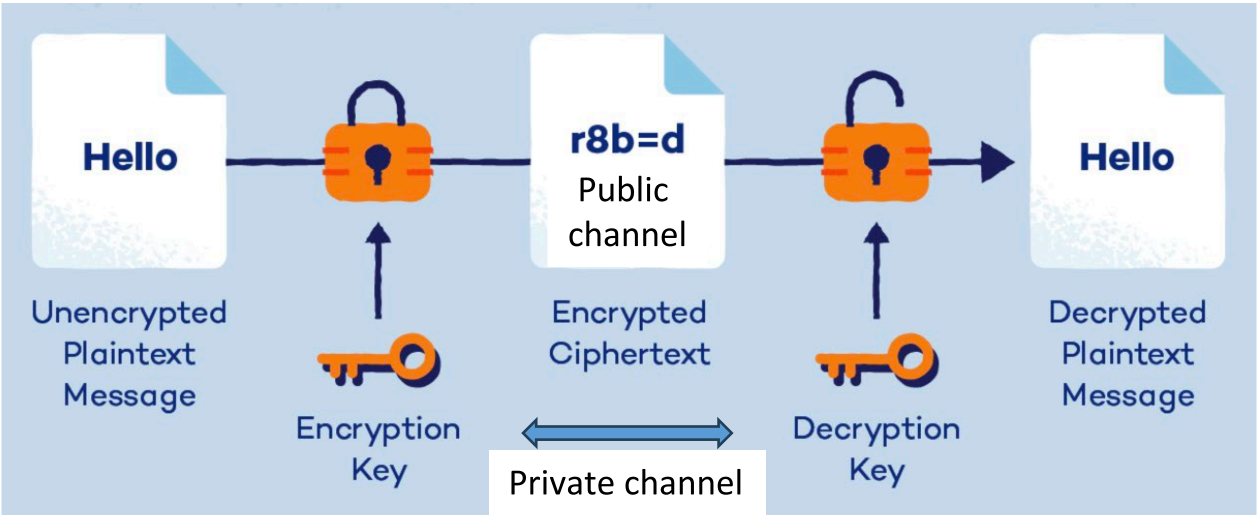

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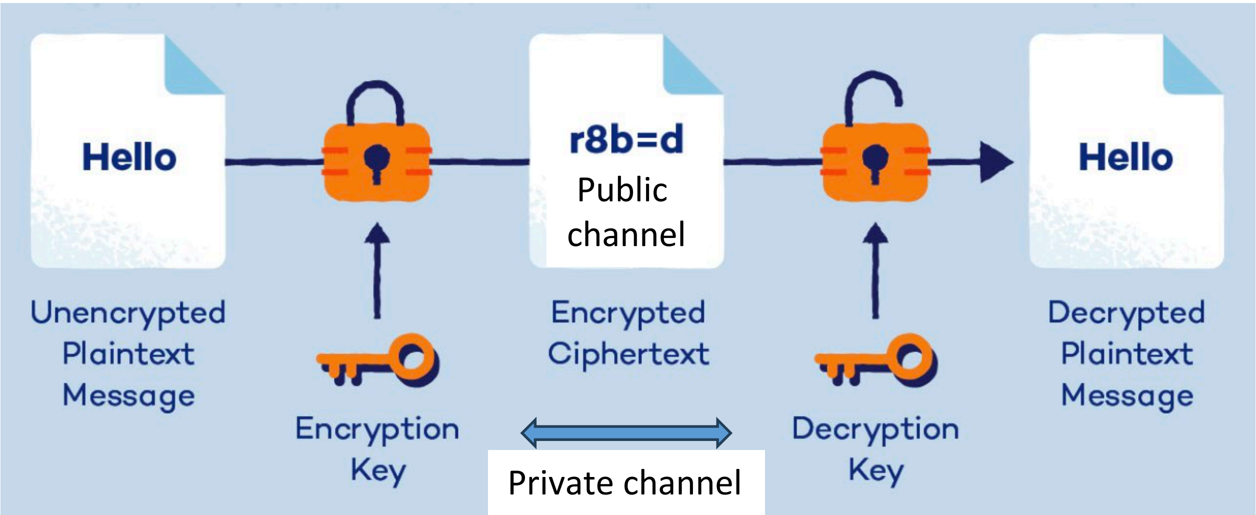
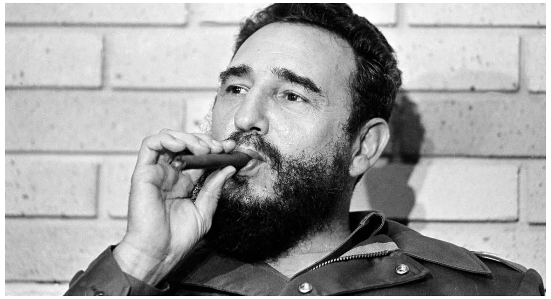
One time pad

(20th century)



Public channel

Private channel



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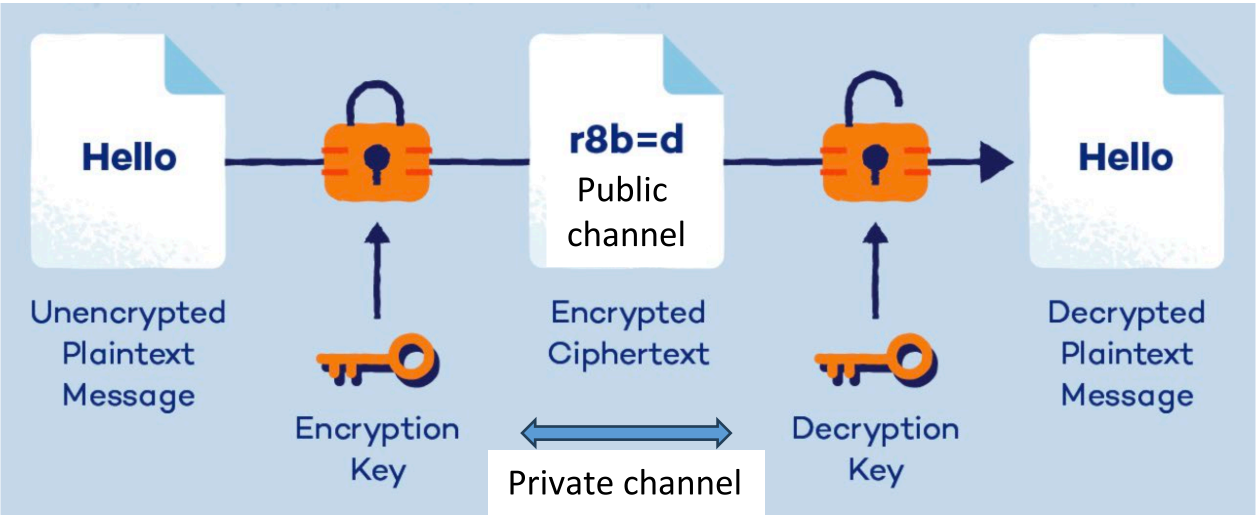
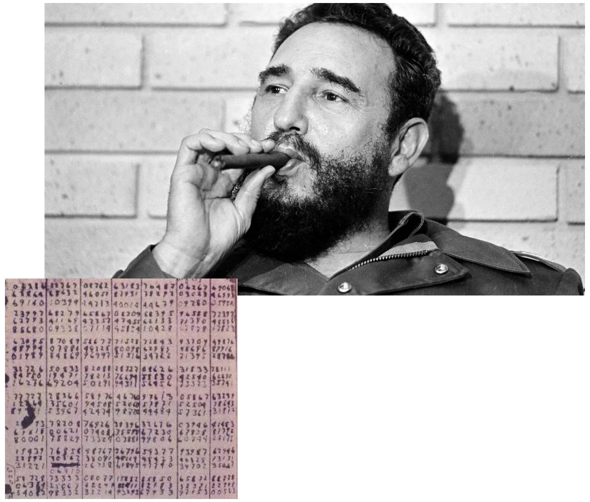


Public channel

Private channel



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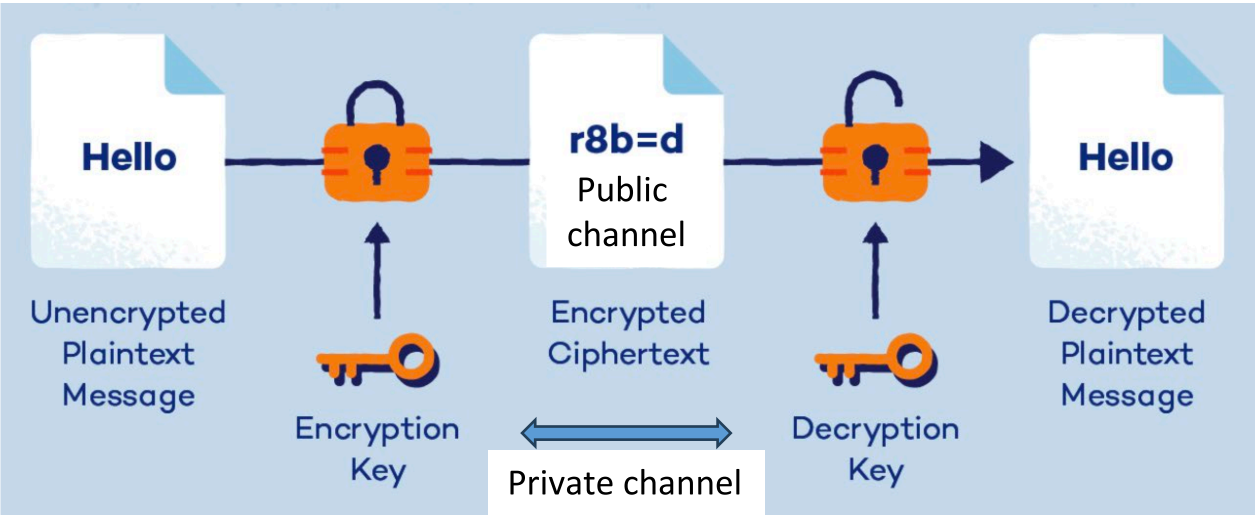

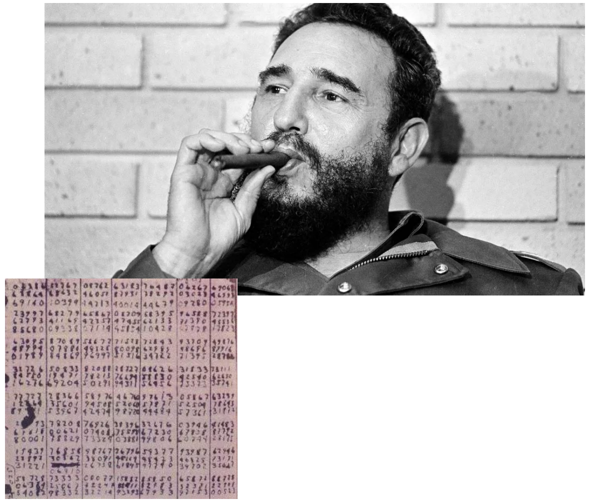

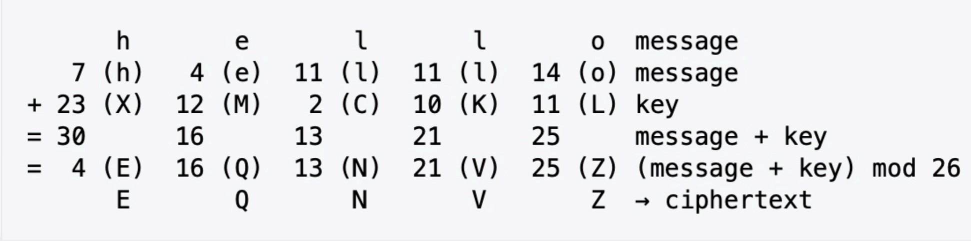

```
       h        e        l        l        o  message
    7 (h)    4 (e)   11 (l)   11 (l)   14 (o)  message
+ 23 (X)   12 (M)    2 (C)   10 (K)   11 (L)  key
= 30       16       13       21       25      message + key
=  4 (E)   16 (Q)   13 (N)   21 (V)   25 (Z)  (message + key) mod 26
       E        Q        N        V        Z  → ciphertext
```

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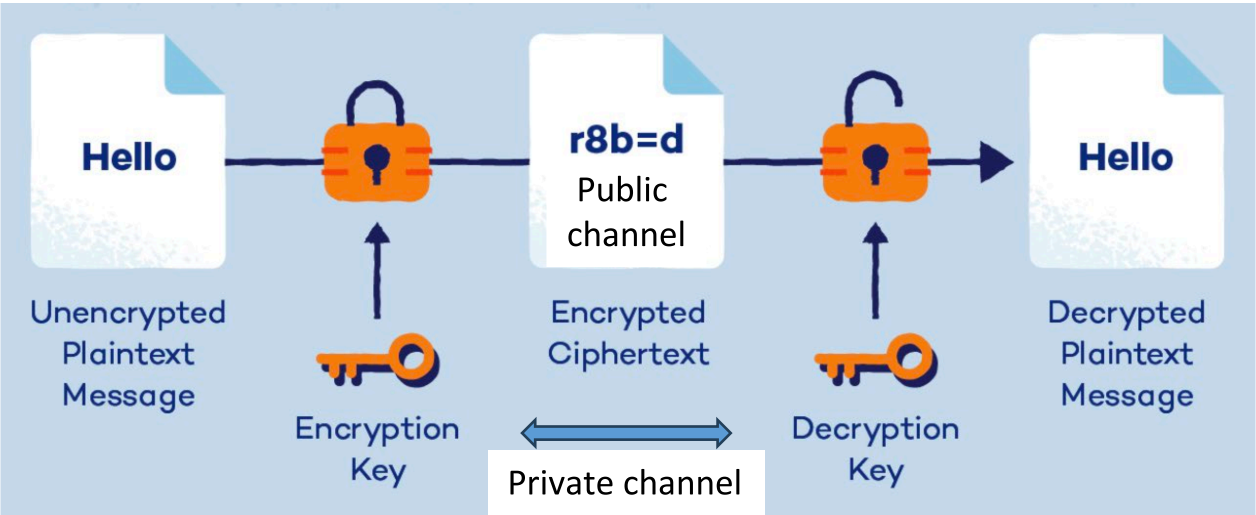

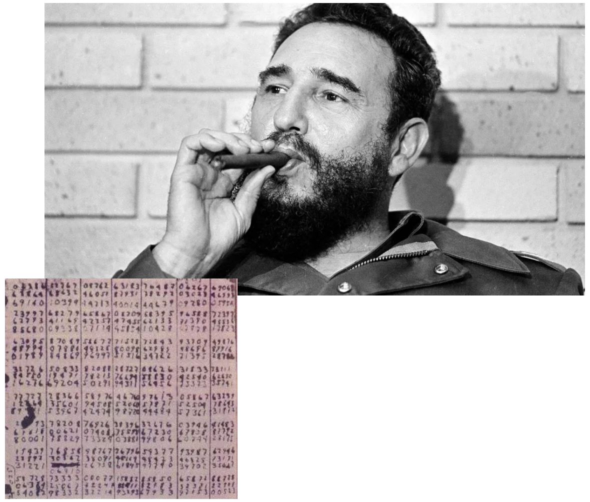

```
     h       e       l       l       o  message
   7 (h)   4 (e)  11 (l)  11 (l)  14 (o) message
+ 23 (X)  12 (M)   2 (C)  10 (K)  11 (L) key
= 30      16      13      21      25     message + key
=  4 (E)  16 (Q)  13 (N)  21 (V)  25 (Z) (message + key) mod 26
     E       Q       N       V       Z  → ciphertext
```

```
       E       Q       N       V       Z  ciphertext
    4 (E)  16 (Q)  13 (N)  21 (V)  25 (Z) ciphertext
−  23 (X)  12 (M)   2 (C)  10 (K)  11 (L) key
= −19       4      11      11      14     ciphertext − key
=   7 (h)   4 (e)  11 (l)  11 (l)  14 (o) ciphertext − key (mod 26)
       h       e       l       l       o  → message
```

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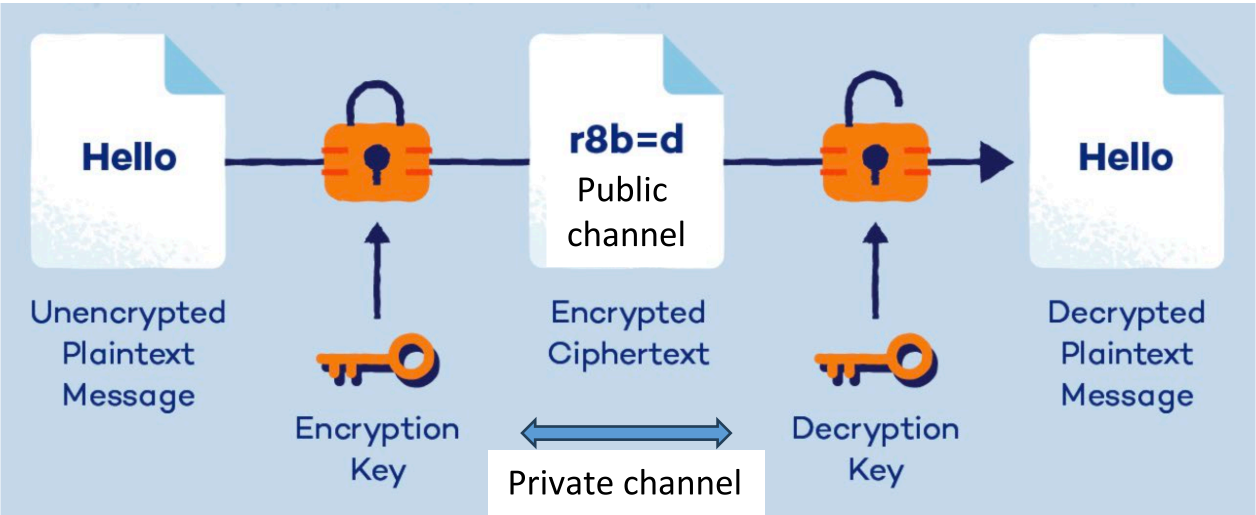
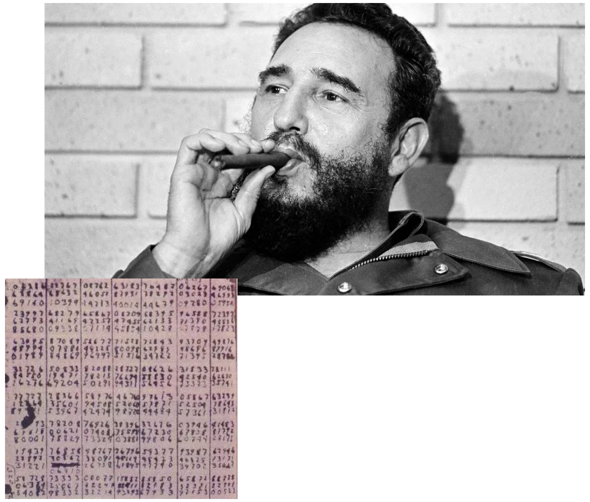
One time pad

(20th century)





```
     h       e       l       l       o   message
   7 (h)   4 (e)  11 (l)  11 (l)  14 (o) message
+ 23 (X)  12 (M)   2 (C)  10 (K)  11 (L) key
= 30      16      13      21      25     message + key
=  4 (E)  16 (Q)  13 (N)  21 (V)  25 (Z) (message + key) mod 26
     E       Q       N       V       Z   → ciphertext
```

```
      E       Q       N       V       Z   ciphertext
    4 (E)  16 (Q)  13 (N)  21 (V)  25 (Z) ciphertext
−  23 (X)  12 (M)   2 (C)  10 (K)  11 (L) key
= −19       4      11      11      14     ciphertext − key
=   7 (h)   4 (e)  11 (l)  11 (l)  14 (o) ciphertext − key (mod 26)
      h       e       l       l       o   → message
```

Weakness: key transmission

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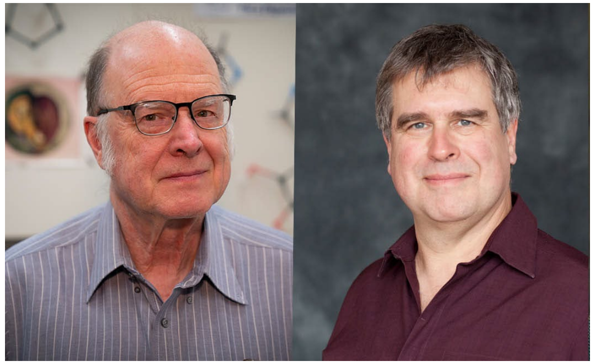
Quantum key distribution (QKD)

Secure key transmission (guaranteed by the laws of nature)

Proposed by Ch. Bennett and G. Brassard in 1984



Two quantum-mechanical ingredients:

- Quantum uncertainty
- No-cloning theorem

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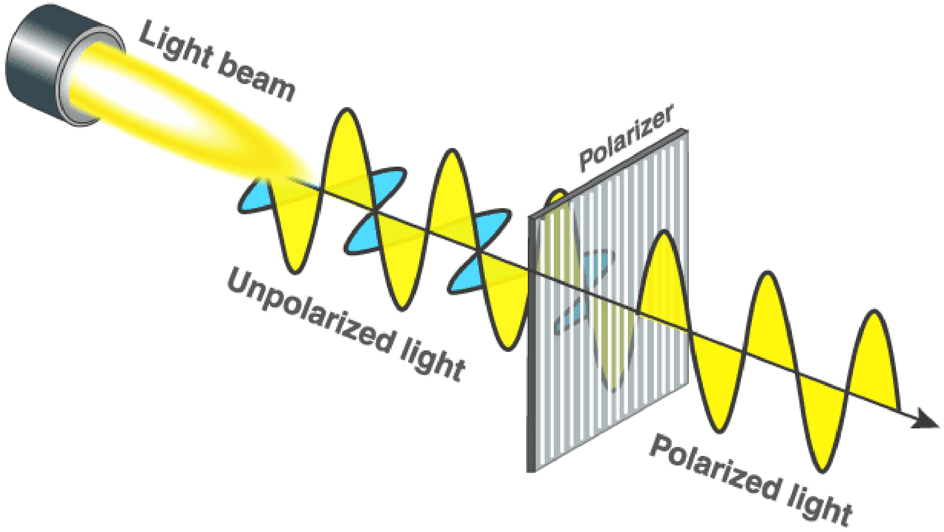
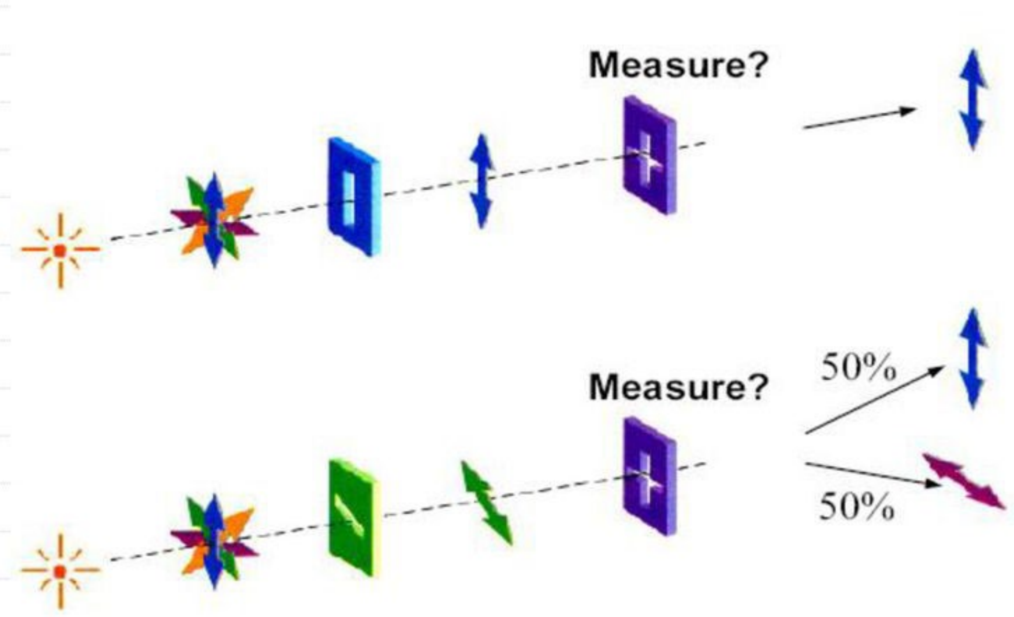
Quantum key distribution (QKD)

A photon is a wave and a particle

Wave: polarization

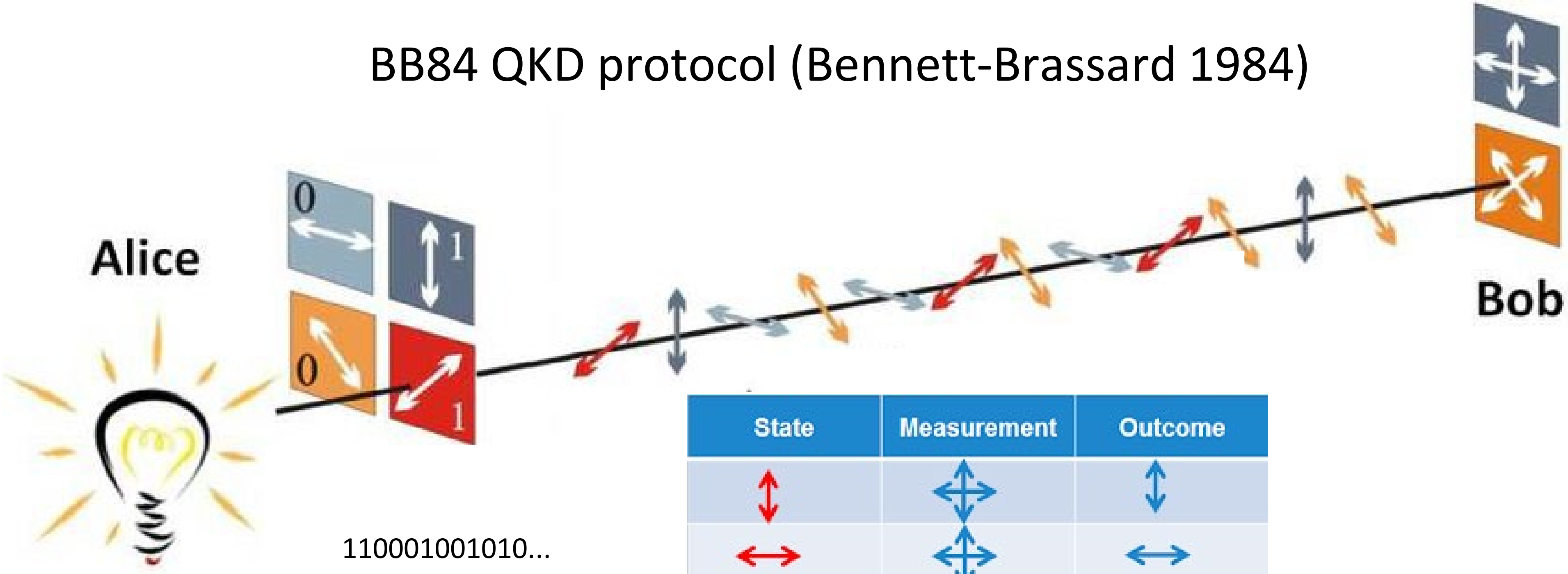


Particle: one "path" or "the other"



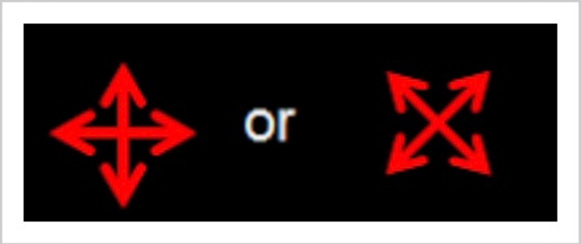
Quantum key distribution (QKD)

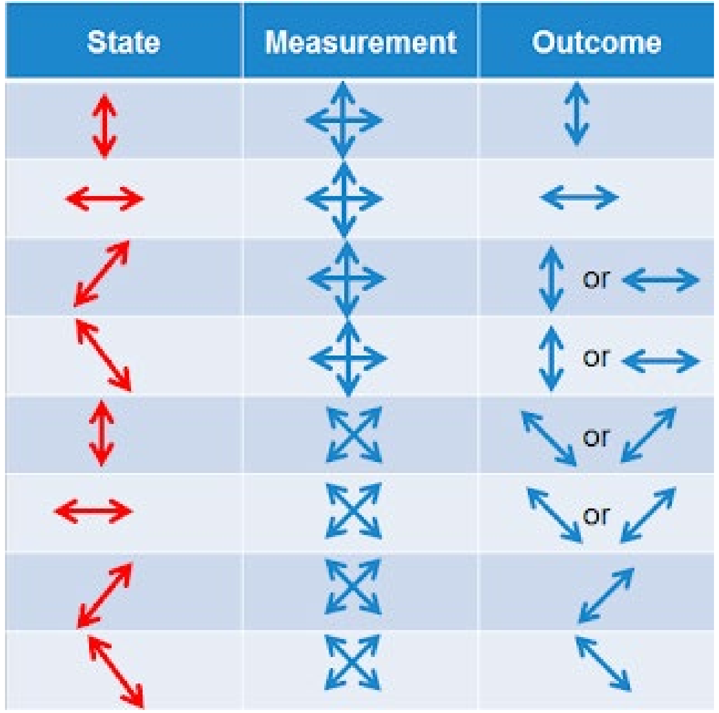
BB84 QKD protocol (Bennett-Brassard 1984)



110001001010...

1. Alice chooses a random sequence of bits and encodes each one using either:

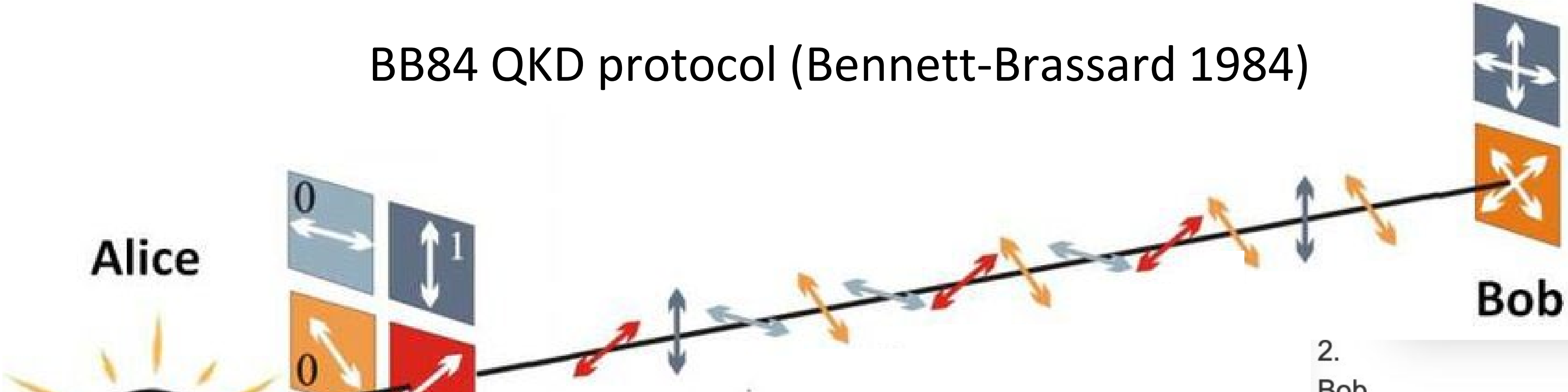




State	Measurement	Outcome
↕	✛	↕
↔	✛	↔
⤢	✛	↕ or ↔
⤡	✛	↕ or ↔
↕	✕	⤡ or ⤢
↔	✕	⤡ or ⤢
⤢	✕	⤢
⤡	✕	⤡

Quantum key distribution (QKD)

BB84 QKD protocol (Bennett-Brassard 1984)



110001001010...

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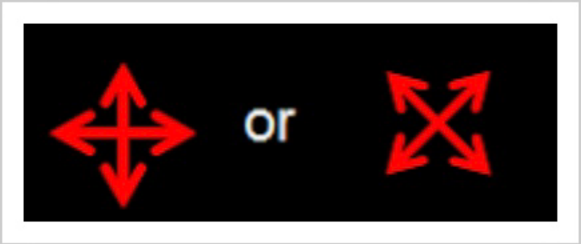

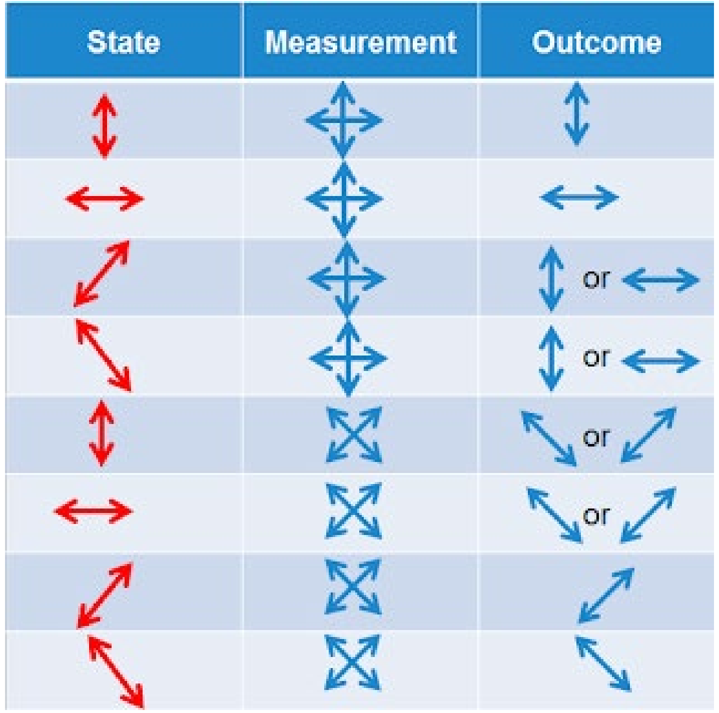

State	Measurement	Outcome
↕	✥	↕
↔	✥	↔
⤢	✥	↕ or ↔
⤡	✥	↕ or ↔
↕	✕	⤡ or ⤢
↔	✕	⤡ or ⤢
⤢	✕	⤢
⤡	✕	⤡

2. Bob randomly chooses to measure with either:

Quantum key distribution (QKD)

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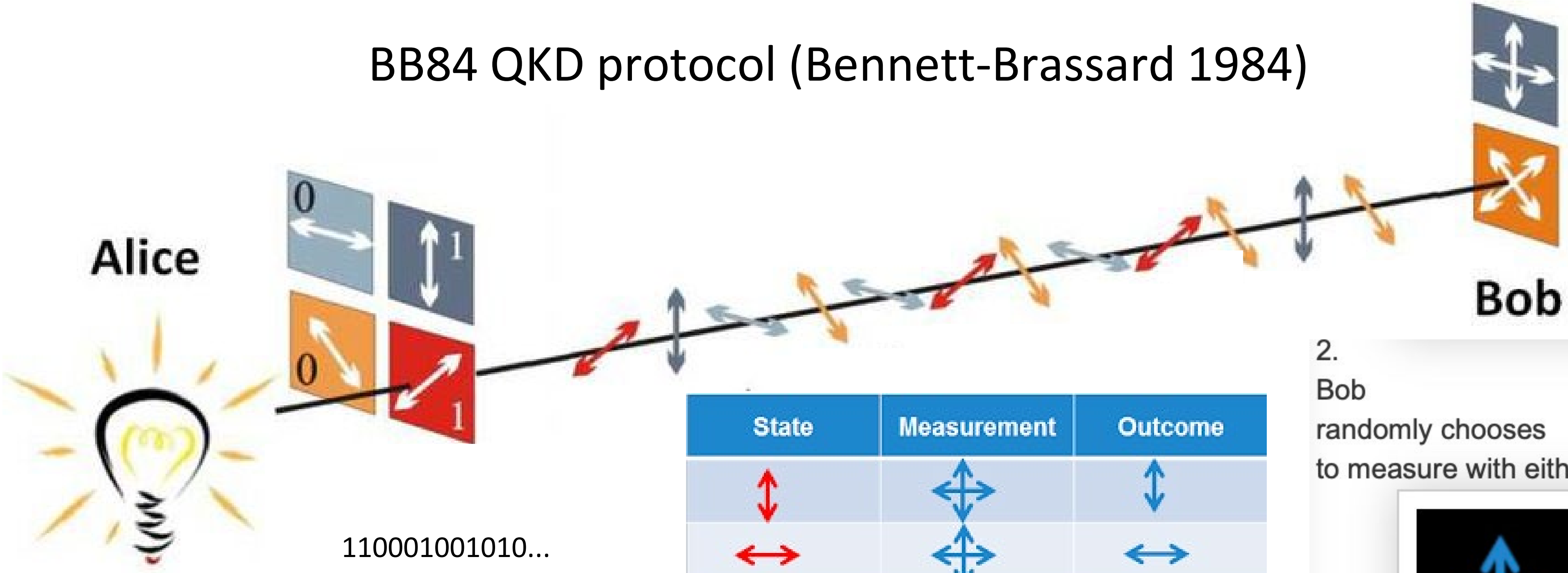
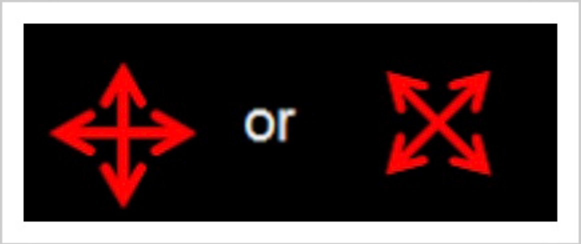


1. Alice chooses a random sequence of bits and encodes each one using either:



State	Measurement	Outcome
↕	✥	↕
↔	✥	↔
⤢	✥	↕ or ↔
⤡	✥	↕ or ↔
↕	⤧	⤡ or ⤢
↔	⤧	⤡ or ⤢
⤢	⤧	⤢
⤡	⤧	⤡

2.
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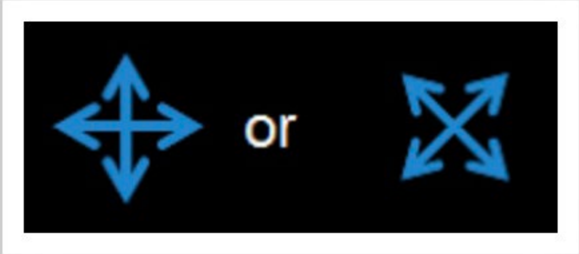
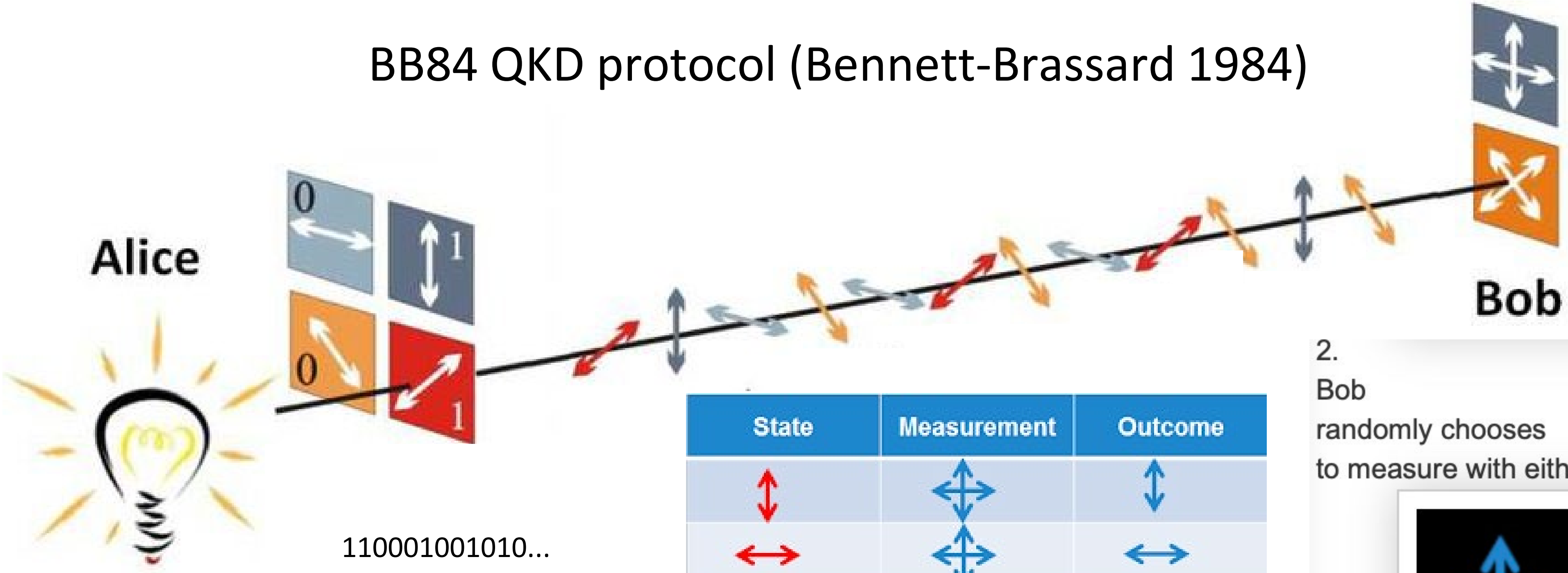
randomly chooses
to measure with either:



3.They publically reveal their choice of axes and discard pairs that don’t match.

Quantum key distribution (QKD)

BB84 QKD protocol (Bennett-Brassard 1984)



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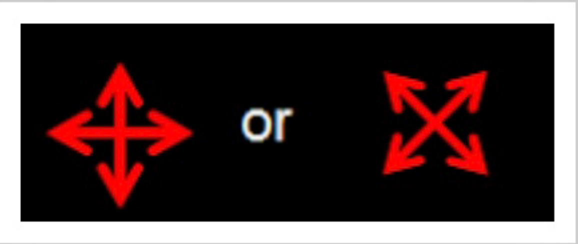

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⤡	✛	↕ or ↔
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⤡	✕	⤡

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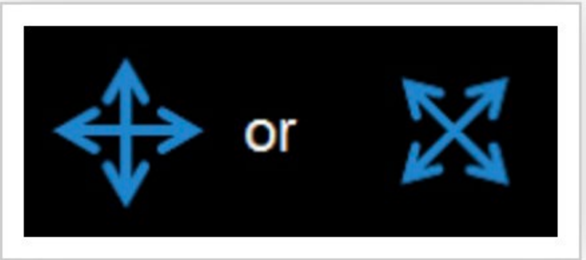
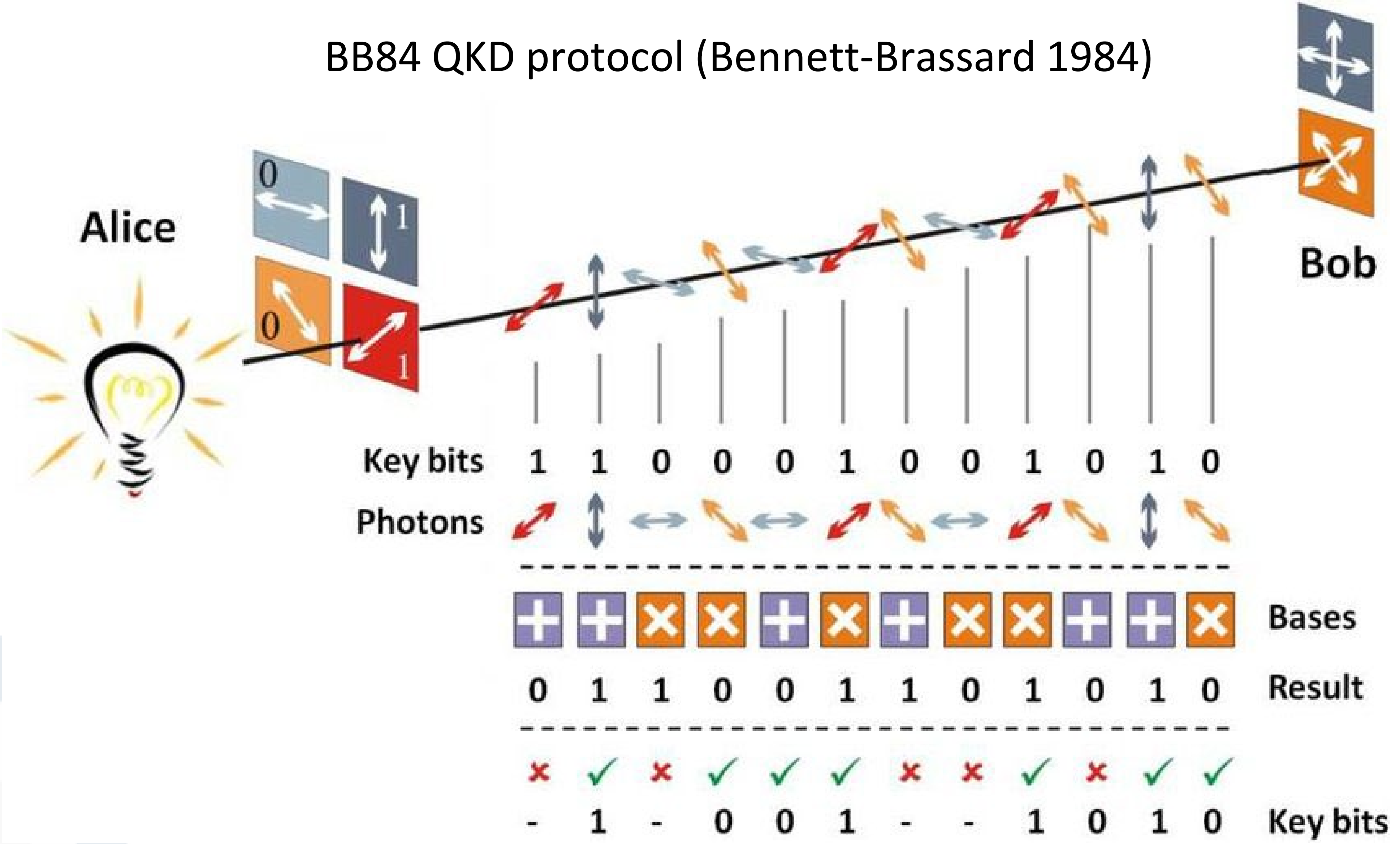


3. They publically reveal their choice of axes and discard pairs that don't match.

4. If remaining bits are perfectly correlated, then they are also secret.

Quantum key distribution (QKD)

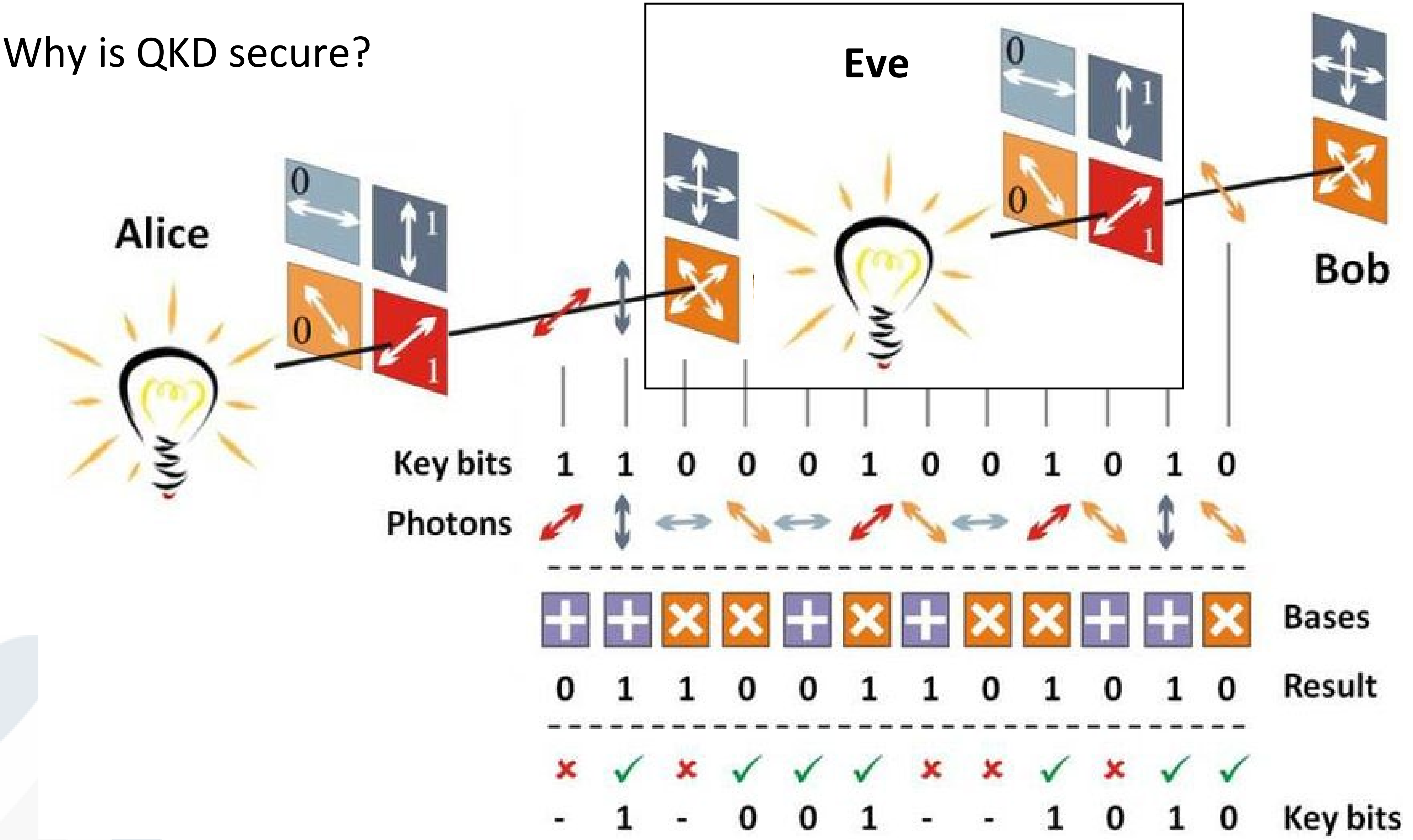
BB84 QKD protocol (Bennett-Brassard 1984)



Key bits	1	1	0	0	0	1	0	0	1	0	1	0
Photons	⤢	↕	↔	⤡	↔	⤢	⤡	↔	⤢	⤡	↕	⤡
Bases	+	+	×	×	+	×	+	×	×	+	+	×
Result	0	1	1	0	0	1	1	0	1	0	1	0
	✗	✓	✗	✓	✓	✓	✗	✗	✓	✗	✓	✓
Key bits	-	1	-	0	0	1	-	-	1	0	1	0

Quantum key distribution (QKD)

Why is QKD secure?



Key bits	1	1	0	0	0	1	0	0	1	0	1	0
Photons	⤢	↕	↔	⤡	↔	⤢	⤡	↔	⤢	⤡	↕	⤡
Bases	+	+	×	×	+	×	+	×	×	+	+	×
Result	0	1	1	0	0	1	1	0	1	0	1	0
	✗	✓	✗	✓	✓	✓	✗	✗	✓	✗	✓	✓
Key bits	-	1	-	0	0	1	-	-	1	0	1	0

Spanish plan on Quantum Communications

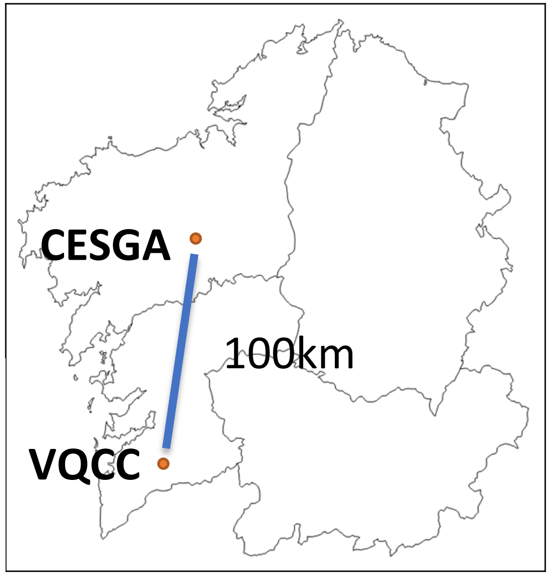
- **Goals**

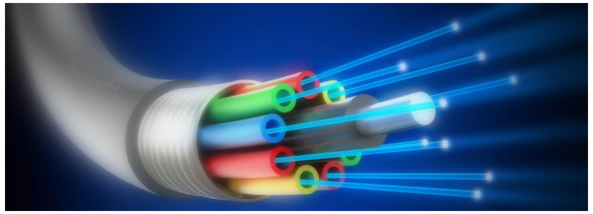
  1. **Set up a QKD fibered link between Santiago and Vigo**

     Current status:

     – Fibers VQCC-CESGA: up for tender
     – QKD equipment: preparing tender

Single long link





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Spanish plan on Quantum Communications

- **Goals**

1. **Set up a QKD fibered link between Santiago and Vigo**

   Current status:

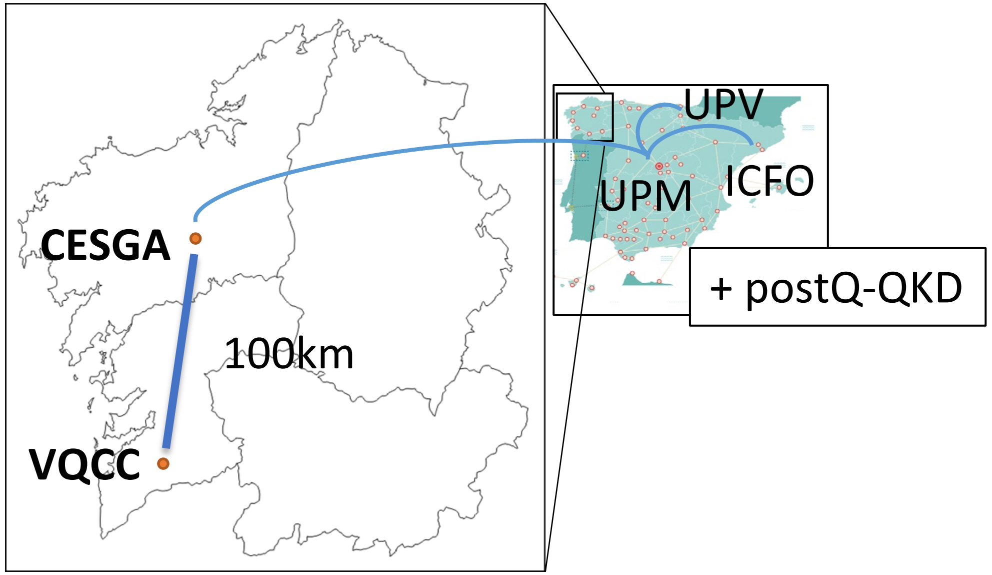
   – Fibers VQCC-CESGA: up for tender
   – QKD equipment: preparing tender

2. **Demostrate one use case**

   Currently exploring:

   i. GRADIANT: 5G/drones
   ii. UPM: transnational QKD+postquantum link

Single long link



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Juan Villasuso

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Madrid, 19-21 de septiembre de 2023
Organizado por la Universidad Politécnica de Madrid
POLITÉCNICA

Iago Fernández

David Barral

Natalia Costas