Quantum Key Distribution

Google CTF 2019 Qualifiers

ilm0

Agenda

1. Understanding the challenge

2. Solving the challenge

3. How could it affect you?

The challenge

Crypto

134 solves

92/500 points

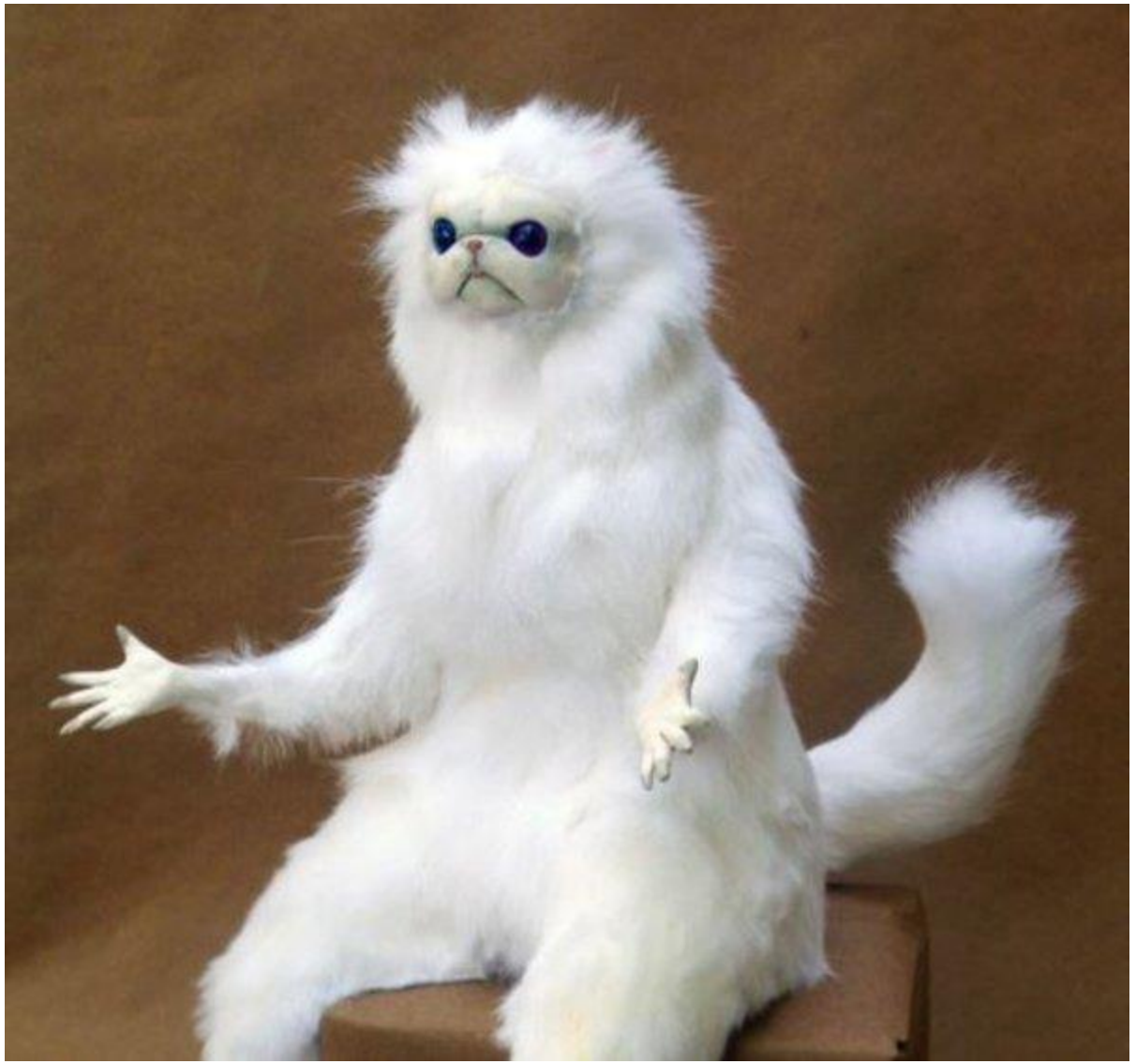
The challenge

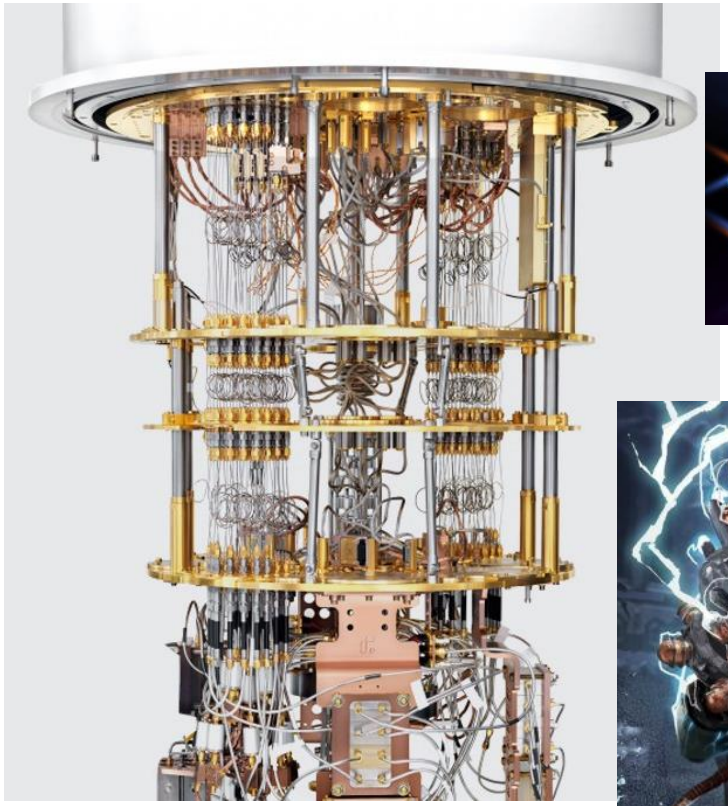
Crypto

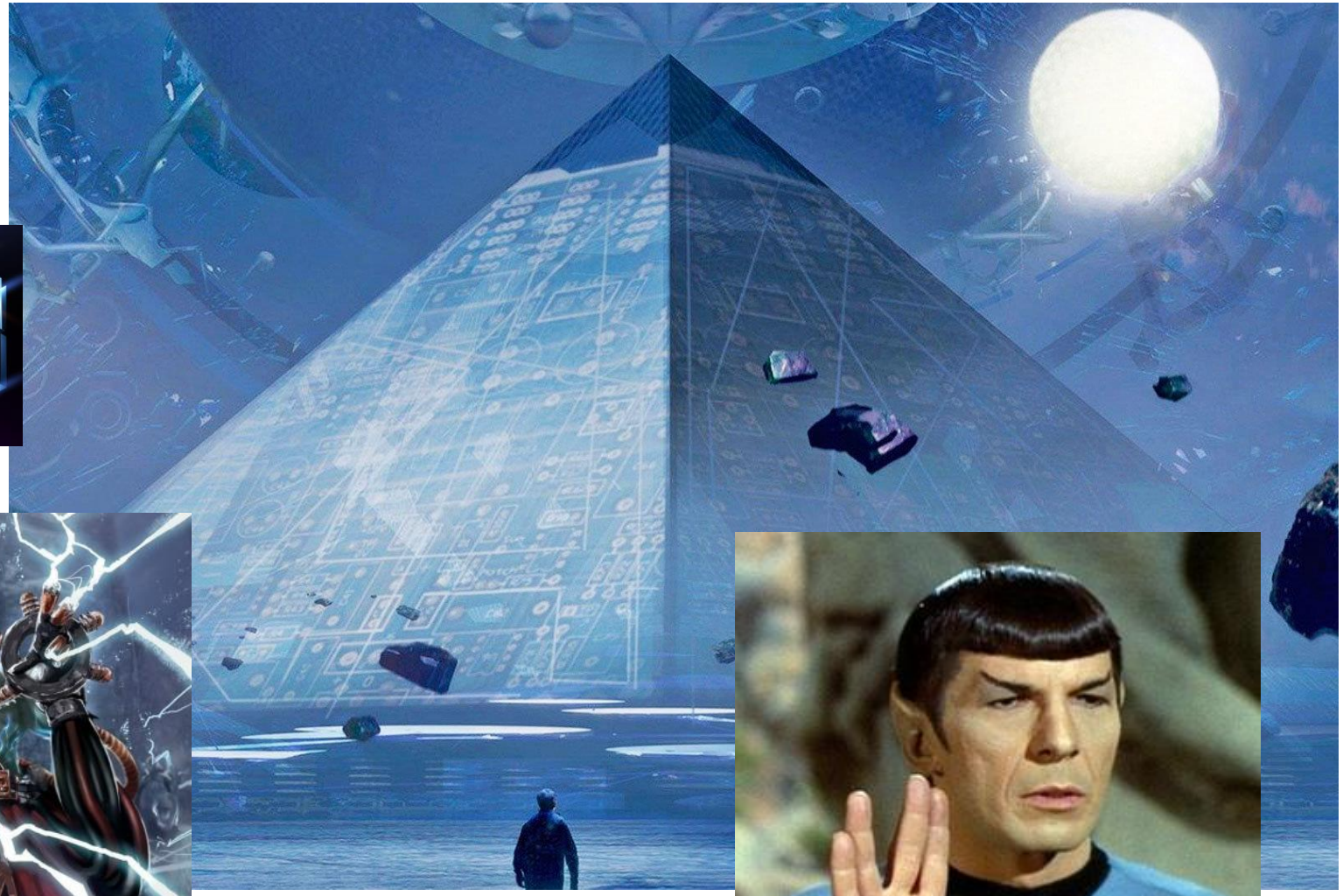
134 solves

92/500 points

But *quantum*?







A closer look

We are simulating a quantum satellite that can exchange keys using qubits implementing BB84. You must POST the qubits and basis of measurement to '/qkd/qubits' and decode our satellite response, you can then derive the shared key and decrypt the flag. Send 512 qubits and basis to generate enough key bits.

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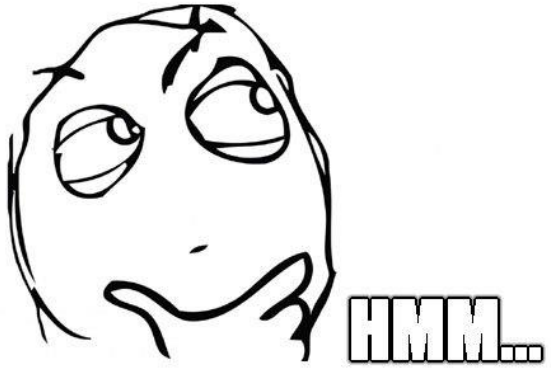
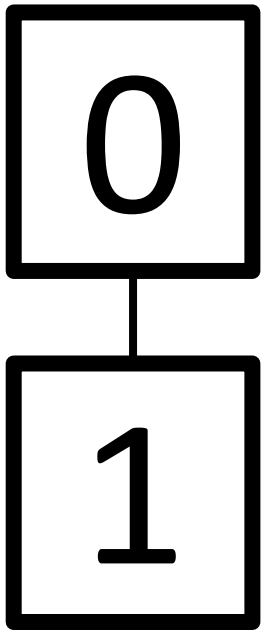


Quantum computing 101

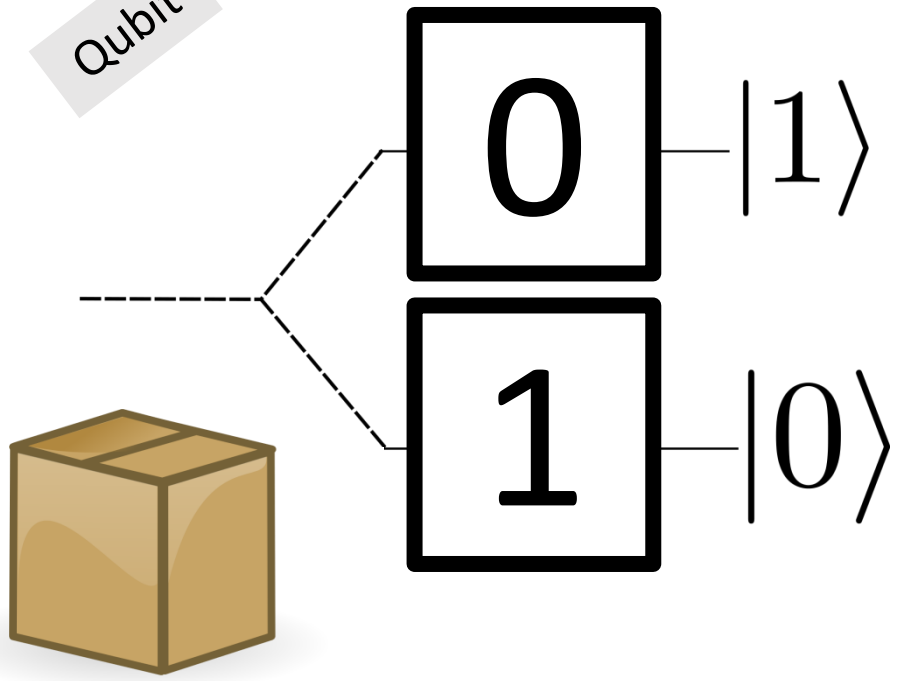
Classical CS

Bit



Quantum CS

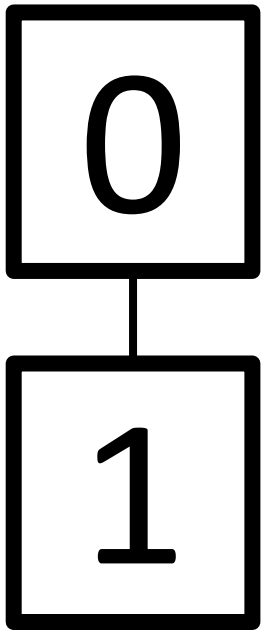
Qubit



Quantum computing 101

Classical CS

Bit



Quantum CS

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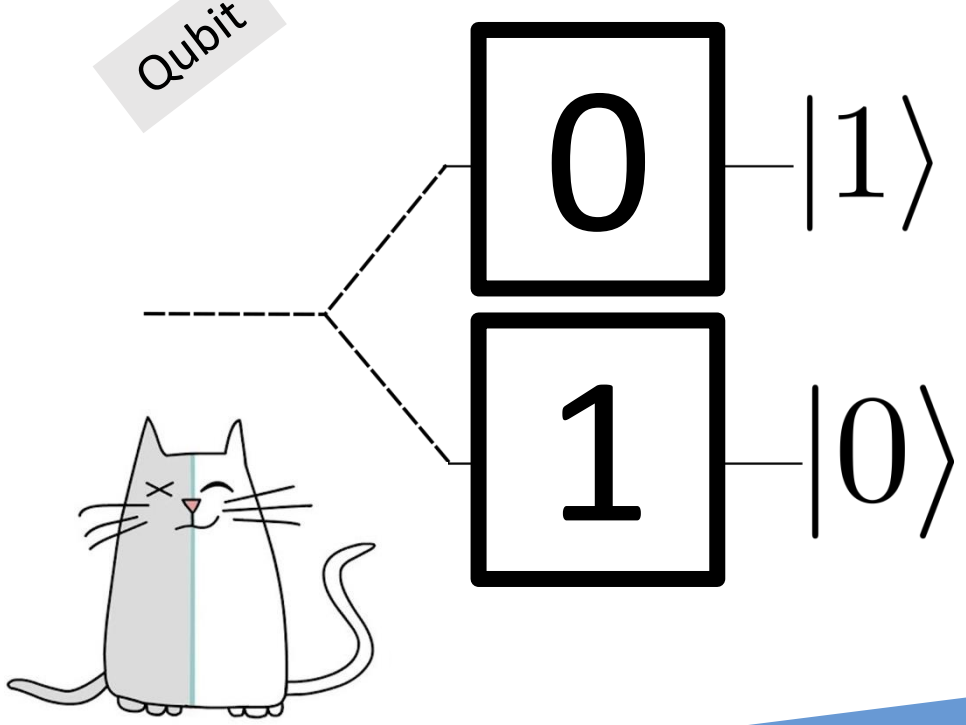


Qubits

$\alpha, \beta \in \mathbb{C}$

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$|\alpha|^2 + |\beta|^2 = 1$$

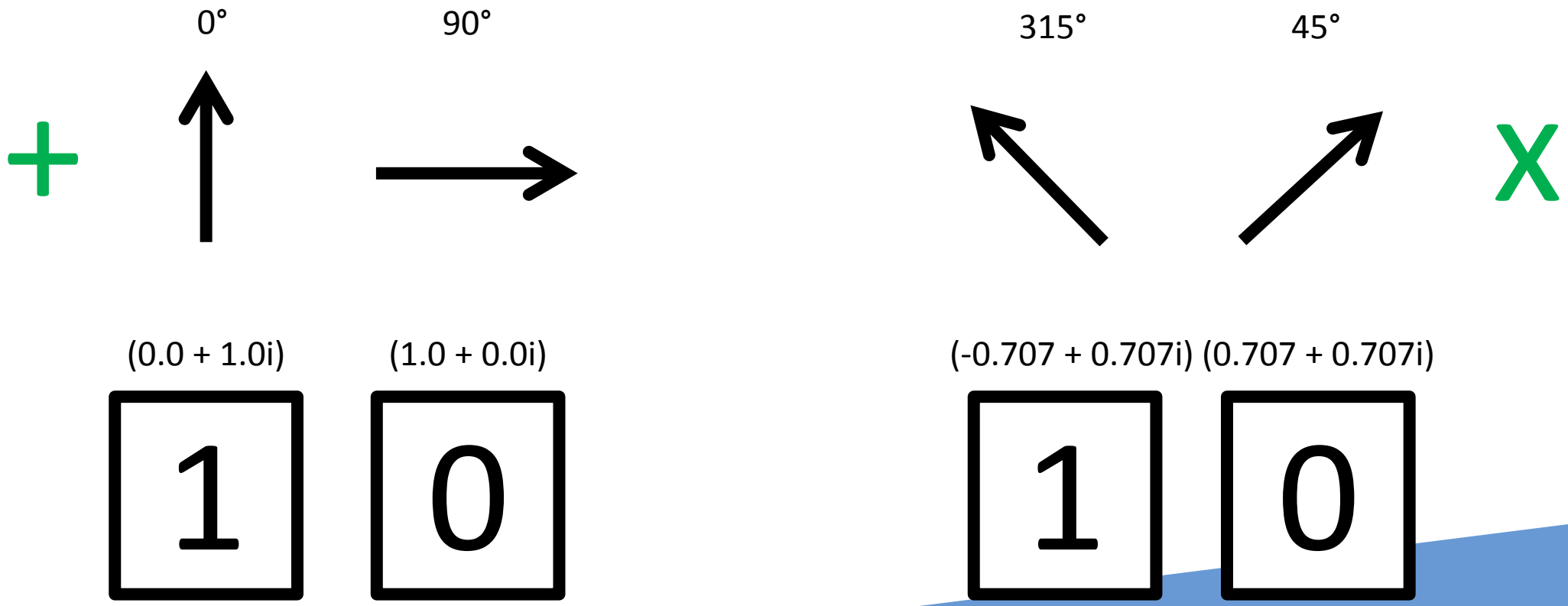
BB84

BB84

- Key distribution scheme cf. Diffie-Hellman
- Derive private key for one-time pad
- Works with 2 channels – 1 quantum, 1 traditional (authenticated)
- Uses photon polarization states

BB84

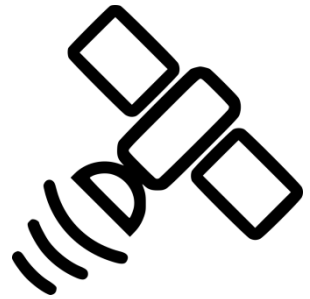
Photons → qubits
Information → polarization



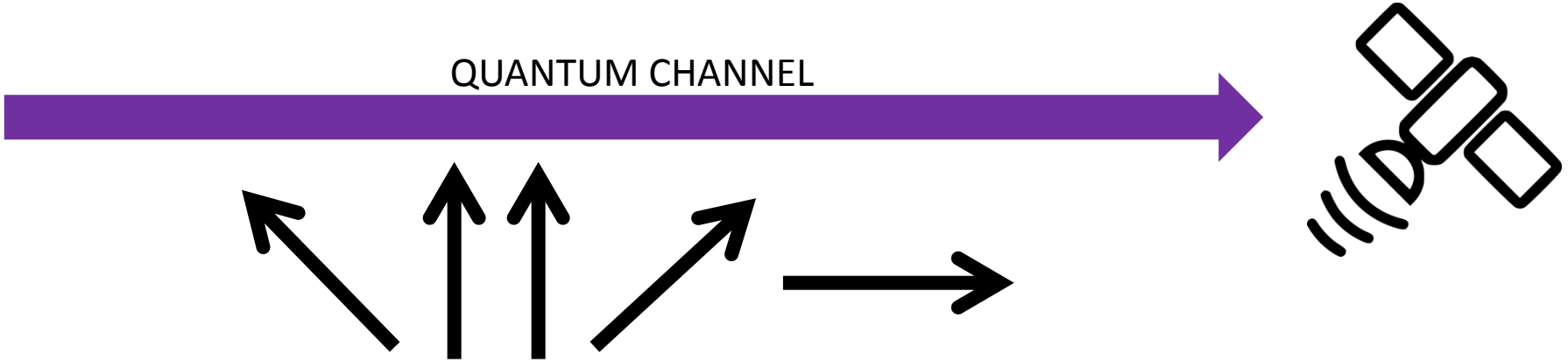
BB84

11100

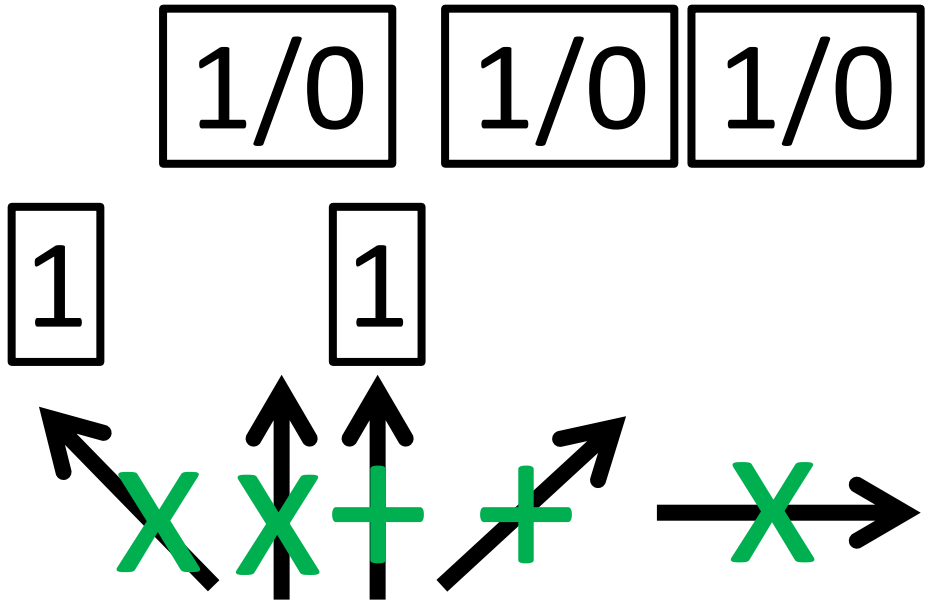
x+-x+



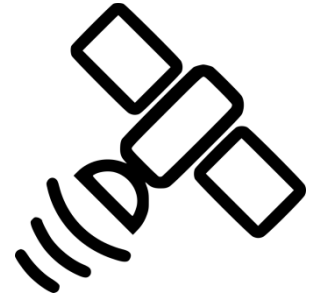
BB84



BB84



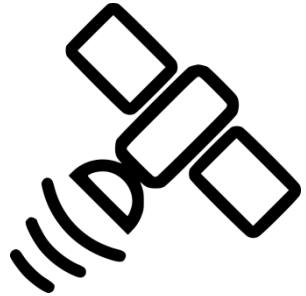
QUANTUM CHANNEL



BB84

TRADITIONAL AUTHENTICATED CHANNEL

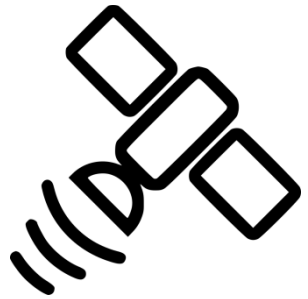
X X + + X



BB84

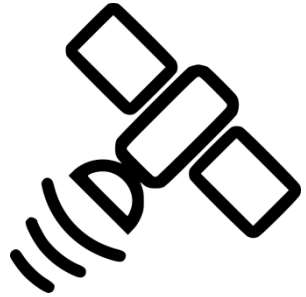
TRADITIONAL AUTHENTICATED CHANNEL

1st:OK 3rd:OK



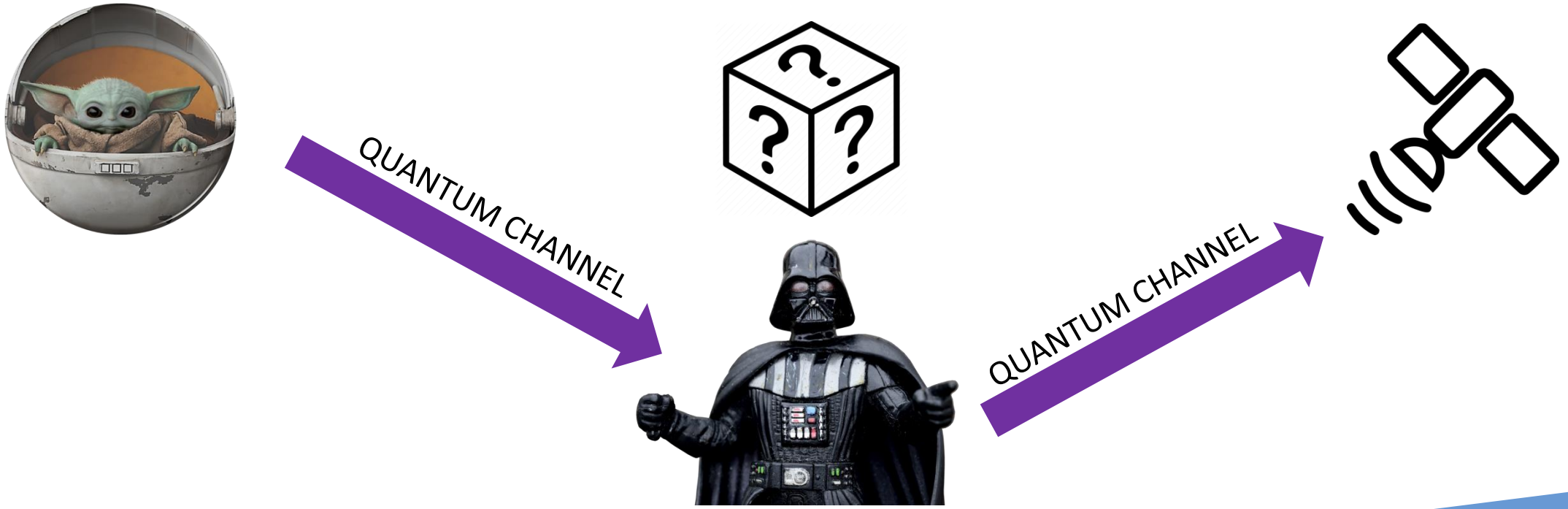
BB84

11



11

BB84 with eavesdropper



BB84 with eavesdropper

TRADITIONAL AUTHENTICATED CHANNEL

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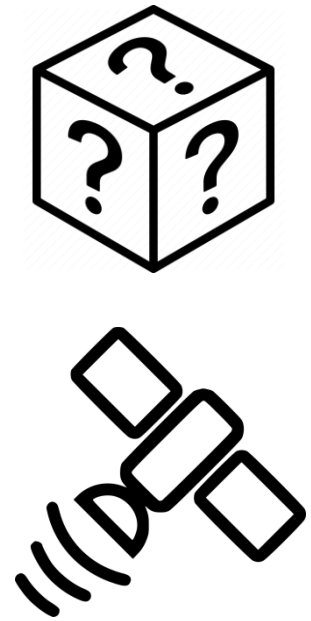
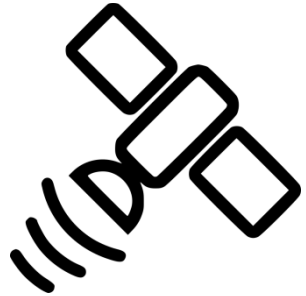


BB84 with eavesdropper

TRADITIONAL AUTHENTICATED CHANNEL

2nd:OK 3rd:OK



BB84

TRADITIONAL AUTHENTICATED CHANNEL

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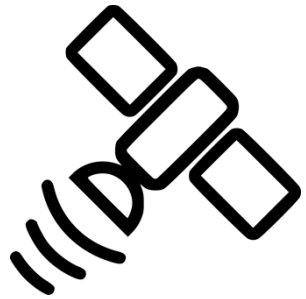


BB84

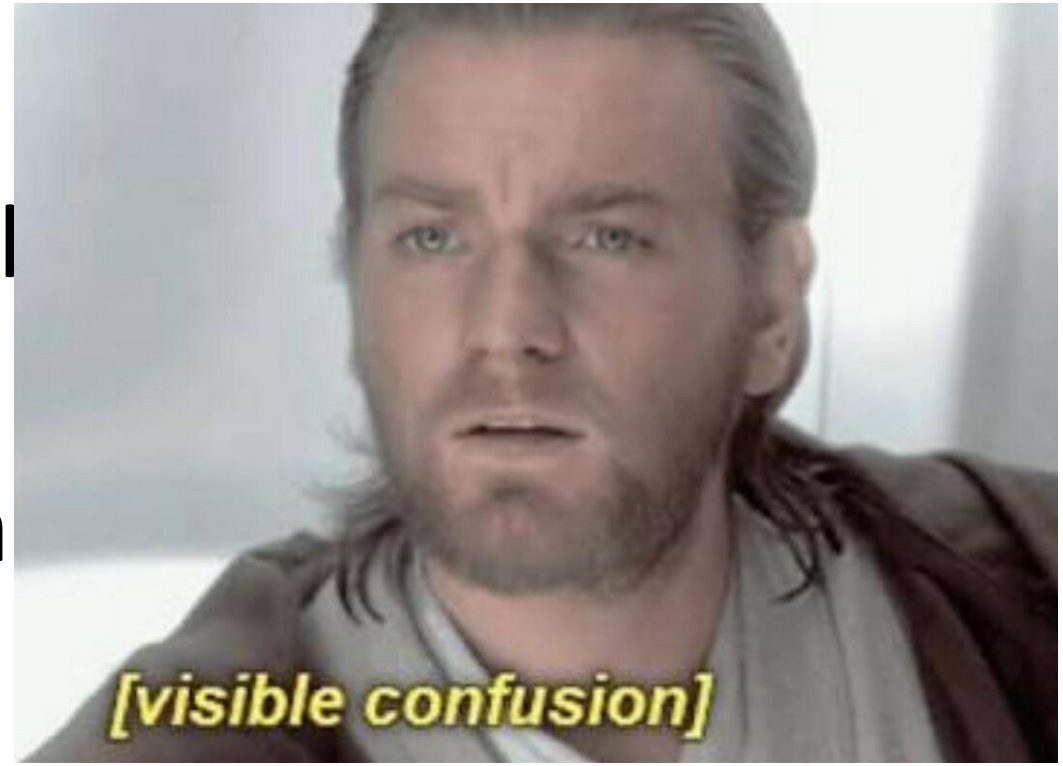
How do I make qubits?

I dont have any quantum channels!

BB84

How do I mal

I dont have a



A closer look /2

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Cyphertext

Flag (base64)

```
U2FsdGVkX19OI2T2J9zJbjMrmI0YSTS+zJ7fnxu1YcGftgkeyVMMwa+NNMG6fGgjROM/hUvvUxUGhctU8fqH4titwti7HbwNMxFxfIR+lR4=
```

Example decryption with hex key 404c368bf890dd10abc3f4209437fcbb:

```
echo "404c368bf890dd10abc3f4209437fcbb" > /tmp/plain.key; xxd -r -p
/tmp/plain.key > /tmp/enc.key echo


"U2FsdGVkX182ynnLNxv9RdNdB44BtwkjHJpTcsWU+NFj2RfQIOpHKYk1RX5i+jKO" |
openssl enc -d -aes-256-cbc -pbkdf2 -md sha1 -base64 --pass file:/tmp/enc.key
```

Satellite server

```
# Receive user's qubits and basis, return the derived key and our basis.
def perform(rx_qubits, rx_basis):
  random.seed()
  # Multiply the amount of bits in the encryption key by 4 to obtain the amount of basis.
  sat_basis = [random.choice('+x') for _ in range(len(current_app.config['ENCRYPTION_KEY'])*16)]
  measured_bits = measure(unmarshal(rx_qubits), sat_basis)
  binary_key, err = compare_bases_and_generate_key(rx_basis, sat_basis, measured_bits)
  if err:
    return None, None, err
  # ENCRYPTION_KEY is in hex, so multiply by 4 to get the bit length.
  binary_key = binary_key[:len(current_app.config['ENCRYPTION_KEY'])*4]
  if len(binary_key) < (len(current_app.config['ENCRYPTION_KEY'])*4):
    return None, sat_basis, "not enough bits to create shared key: %d want: %d" % (len(binary_key),
      len(current_app.config['ENCRYPTION_KEY']))
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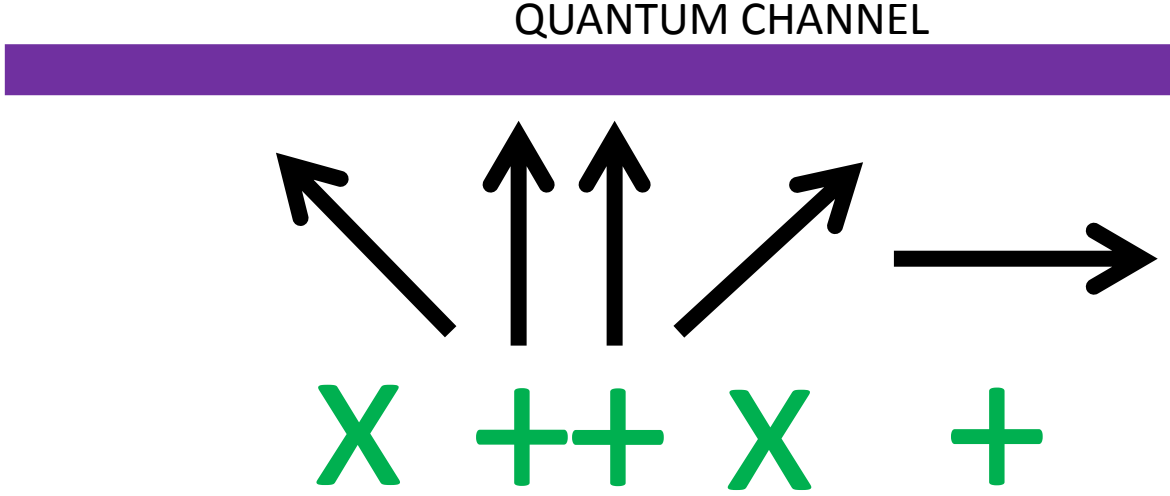
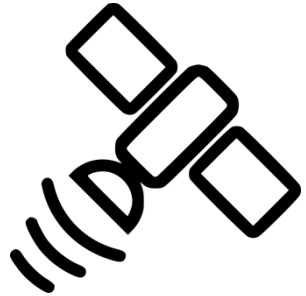
Solving the challenge

First try





Generate key

```
def compare_bases_and_generate_key(tx_bases, rx_bases, measure):
  """Compares TX and RX bases and return the selected bits."""
  if not (len(tx_bases) == len(rx_bases) == len(measure)):
    return None, "tx_bases(%d), rx_bases(%d) and measure(%d) must have the same length." %
(len(tx_bases), len(rx_bases), len(measure))
  ret = ''
  for bit, tx_base, rx_base in zip(measure, tx_bases, rx_bases):
    if tx_base == rx_base:
      ret += bit
  return ret, None
```

Mighty XOR

- One time pad uses XOR
- But what should I XOR?
- Involutory function
  XOR(k, XOR(k, x)) = x

Can all this affect you?
Should you care?

3

What can quantum computers do?

- Only run probabilistic algorithms
- Physical and financial modelling
  ↳ Predictions
- Searching an unstructured database
  - Grover's algorithm

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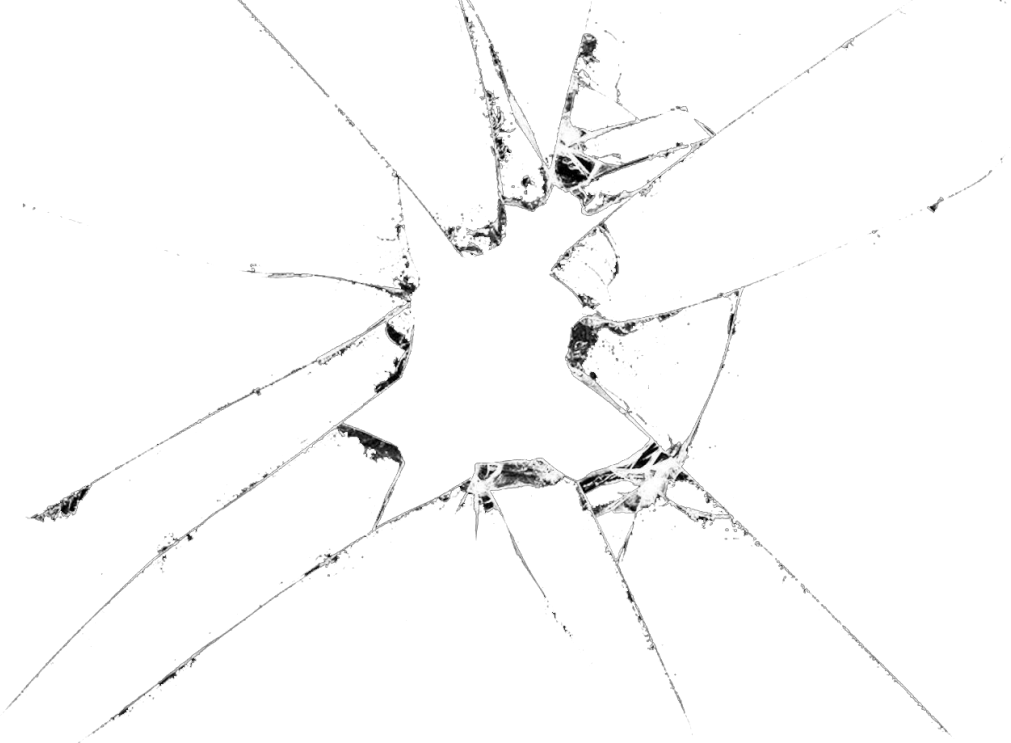
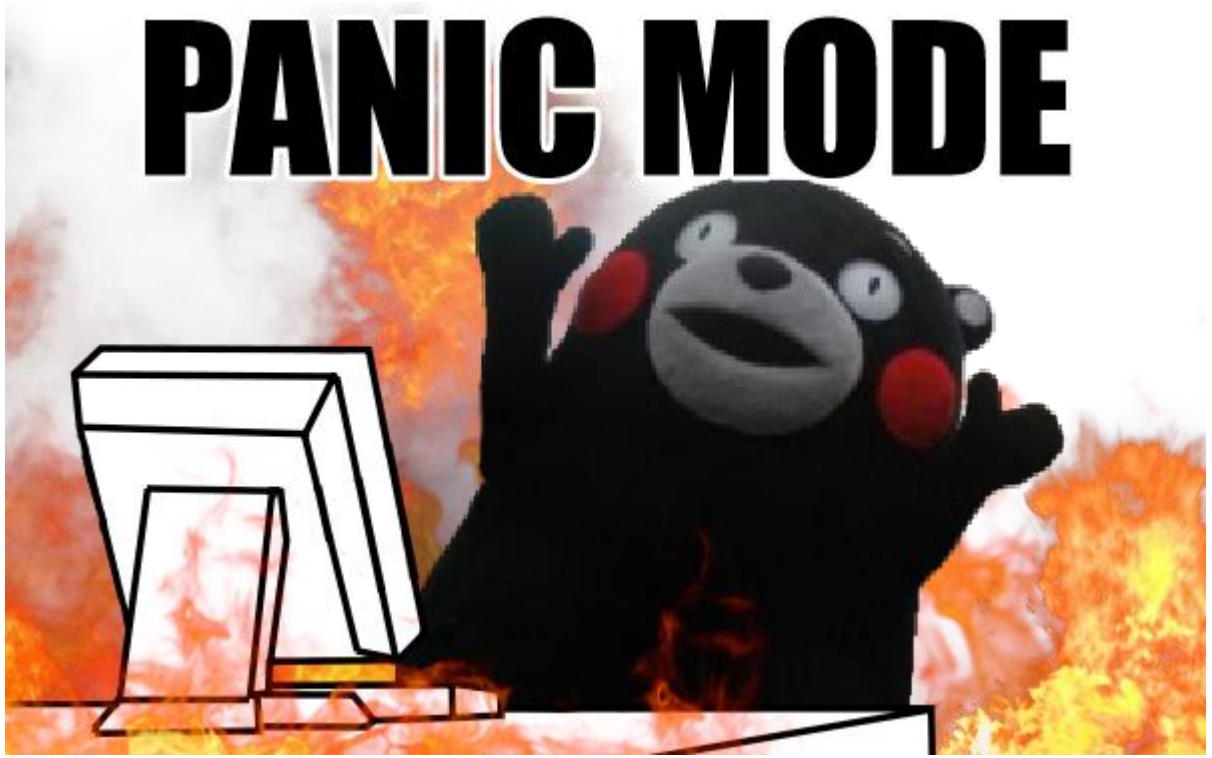
- Integer factorization → Shor's algorithm

Post quantum cryptography



Integer factorization
Discrete log problem

RSA, Diffie-Hellman and ECDSA



PANIC?!

How to prepare

Table 1: Security Comparison						
Type of Attack	Symmetric Encryption			Public Key Encryption		
		Key Length	Bits of Security		Key Length	Bits of Security
Classical Computers	AES-128	128	128	RSA-2048	2048	112
	AES-256	256	256	RSA-15360	15,360	256
Quantum Computers	AES-128	128	64	RSA-2048	2048	25
	AES-256	256	128	RSA-15360	15,360	31

- Several families of quantum-resistant PKC
  - ↳ Lattice-based, code-based, hash-based and multivariate

- Use strong symmetric crypto

Where is quantum now?

- Big claims, little results 
- Quantum supremacy
- Many sceptics, even more obstacles
- Use cases very targeted → not a replacement, but complement

Lessons learned

- Understanding key concepts of a challenge is essential before 'getting dirty'
- Crypto basics aswell
- Possibility of post-quantum crypto

Thank you for your attention!


OH ALICE... YOU'RE THE ONE FOR ME
BUT BOB... IN A QUANTUM WORLD HOW CAN WE BE SURE
ψ^+ or ψ^- ?

Questions?