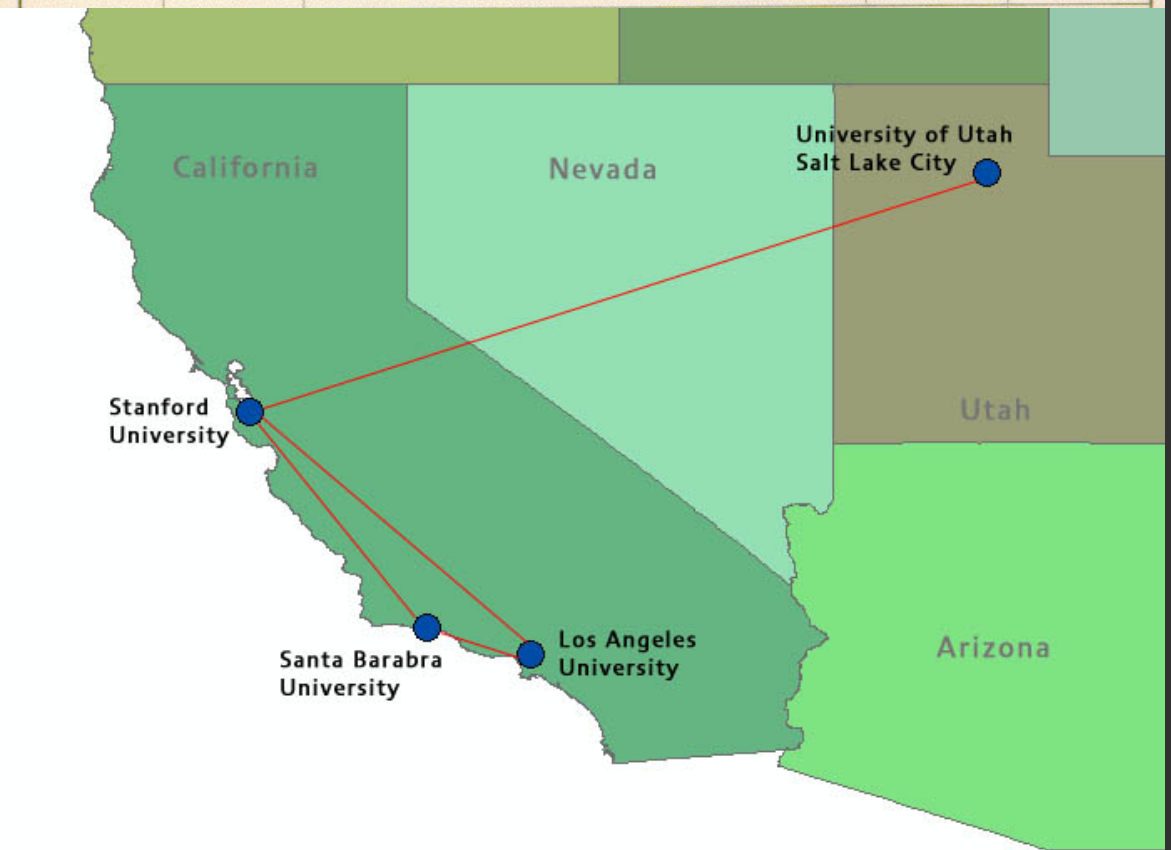
Quantum Internet

Stephanie Wehner

29 October 1969
LOGIN

29OCT69 2100 LOADED UP. PROGRAM (SK
FOR BEN BARKER
BBN

22:30 Talked to SRI (SK
Host to Host



We typed the L and asked on the phone: “Did you see the L?”

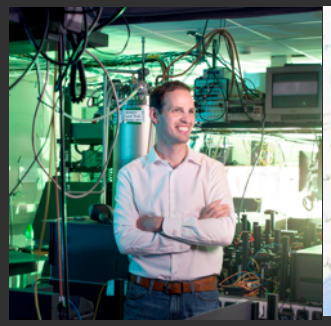
“Yes, we see the L!”

We typed the O and asked on the phone: “Did you see the O?”

“Yes, we see the O!”

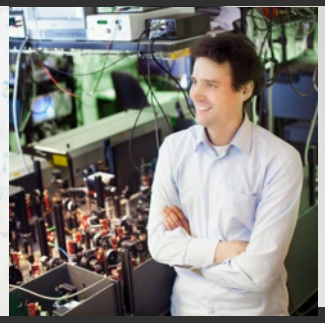
Then we typed the G and the System crashed…

Towards a quantum internet!



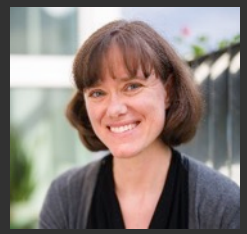
Ronald Hanson

Stephanie Wehner



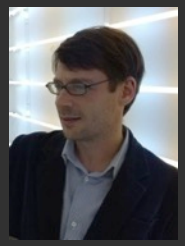
Tim Taminiau

David Elkouss

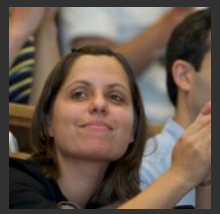


Northup (U. Innsbruck)

Chang (ICFO)

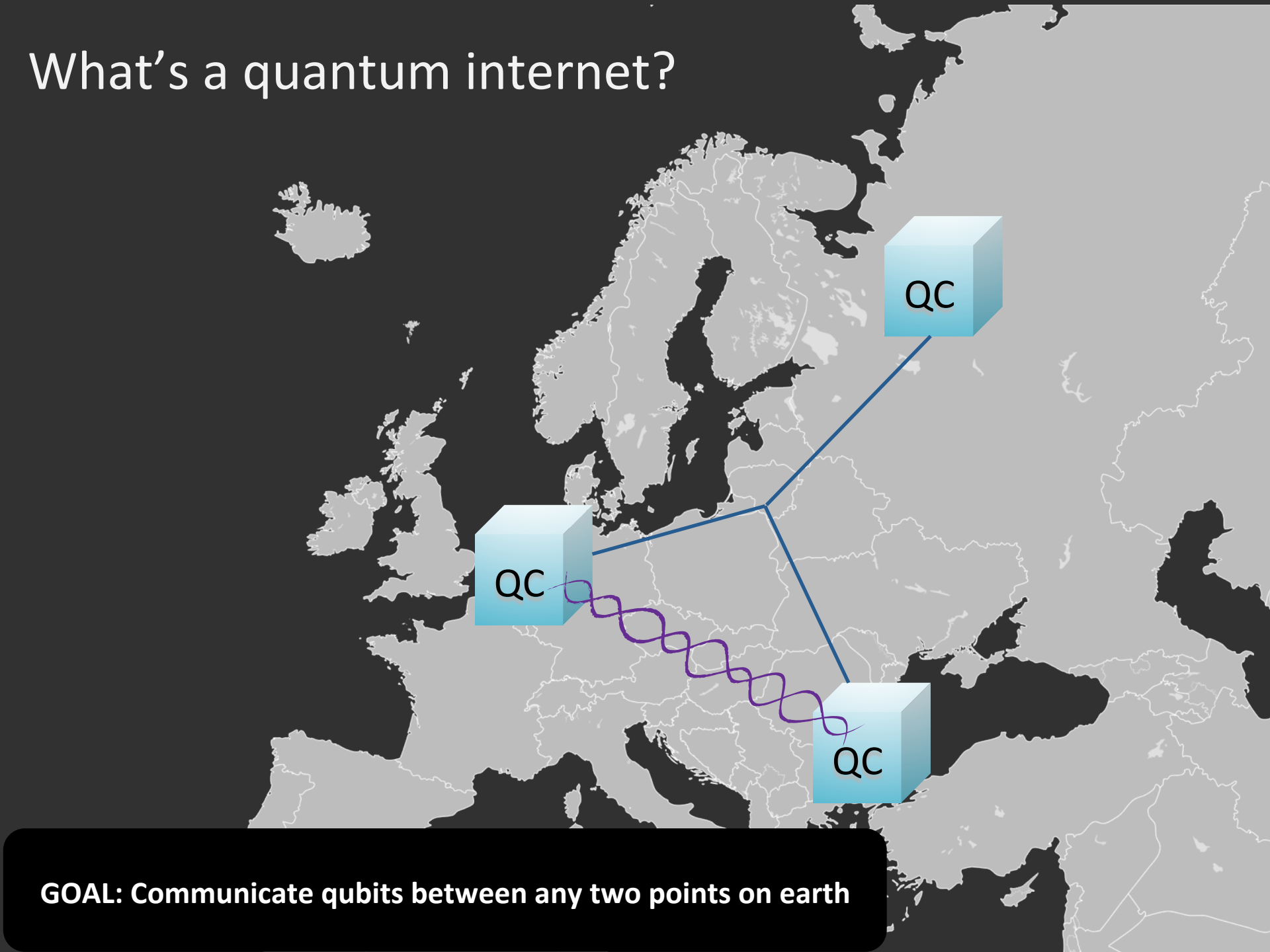


Kerenidis (PCQC)



Diamanti (Telecom PariTech)

What's a quantum internet?



GOAL: Communicate qubits between any two points on earth

Why construct a quantum internet?

For Quantum Communication

- Quantum secure communications
- Clock synchronization
- Combining telescopes
- Testing Physics
- Exponential savings in communication
- Cheating online games ☺
- ….

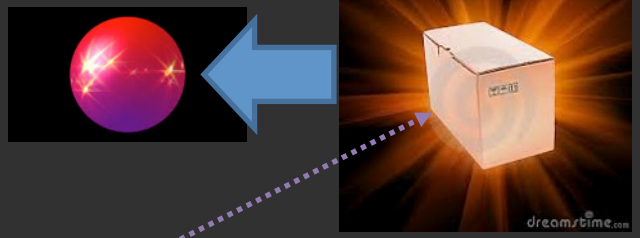
For Quantum Computation

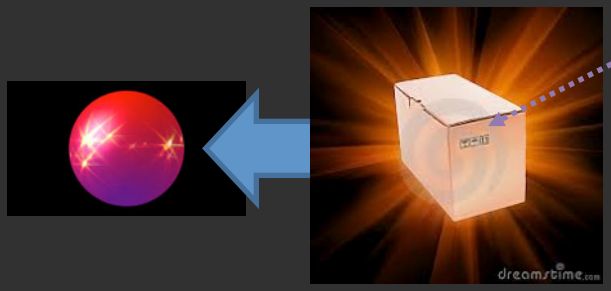
- Linking small quantum computers
- Access the quantum “mainframe”

Why does a quantum internet help here?

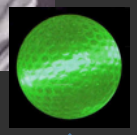
Entanglement:
No communication but maximal correlation!

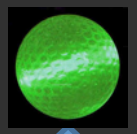
Entanglement allows much more coordination



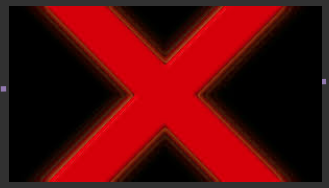


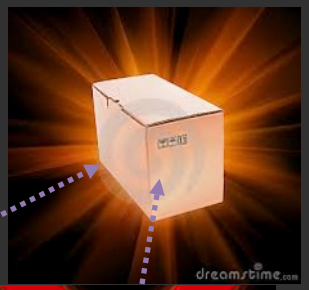
Entanglement allows much more coordination





Entanglement is inherently private





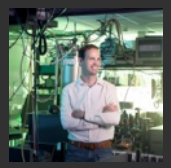
We can test for entanglement!

John Bell ‘63
(Reviews of Modern Physics, 86, 419, 2014)

Quantum key distribution in a nutshell:

- Generate end to end entanglement many times
- Test if Alice and Bob are maximally entangled using some of the entanglement.
- If test succeeds, measure to obtain a key.

First loophole free Bell test

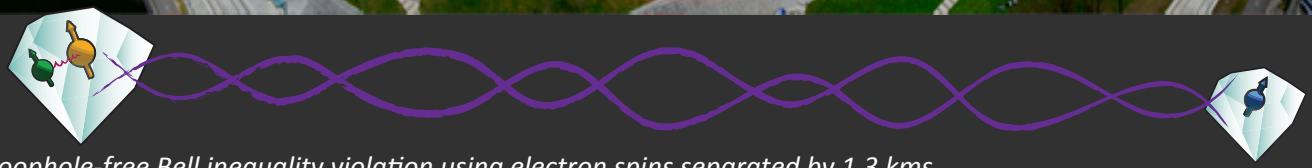

Hanson


Taminiau


Wehner


Elkouss

QuTech Quantum Internet Team



Loophole-free Bell inequality violation using electron spins separated by 1.3 kms
B. Hensen, H. Bernien, A. Dreau, A. Reiserer, N. Kalb, M. Blok, J. Ruitenberg, R. Vermeulen, R. Schouten, C. Abellan, W. Amaya, V. Pruneri, M. Mitchell, M. Markham, D. Twitchen, D. Elkouss,
S. Wehner, T. Taminiau, R. Hanson
Nature, 526, 682-686 (2015)

Science's Top 10 Breakthroughs of 2015
Nature's Science Events that shaped 2015.
New York Times (Front Page), The Economist, TIME, The Times, Huffington Post, New Scientist, Wired, Vice, and others.

nature International weekly journal of science

Quantum communication –state of the art

Quantum Cryptography (QKD) – non DI: Key Distribution

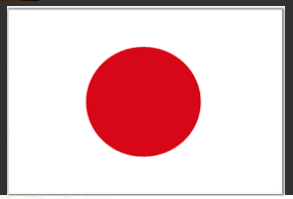
Status:

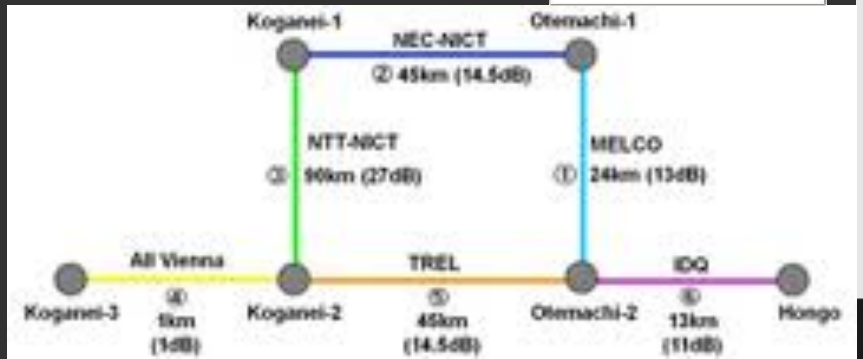
- Commercial at short (~100kms) distances (idQuantique, Huawei, Toshiba, NEC, Mitsubishi, ….)
- Lab ~300kms
- Grand Challenge: long distance quantum communication (Quantum Internet)

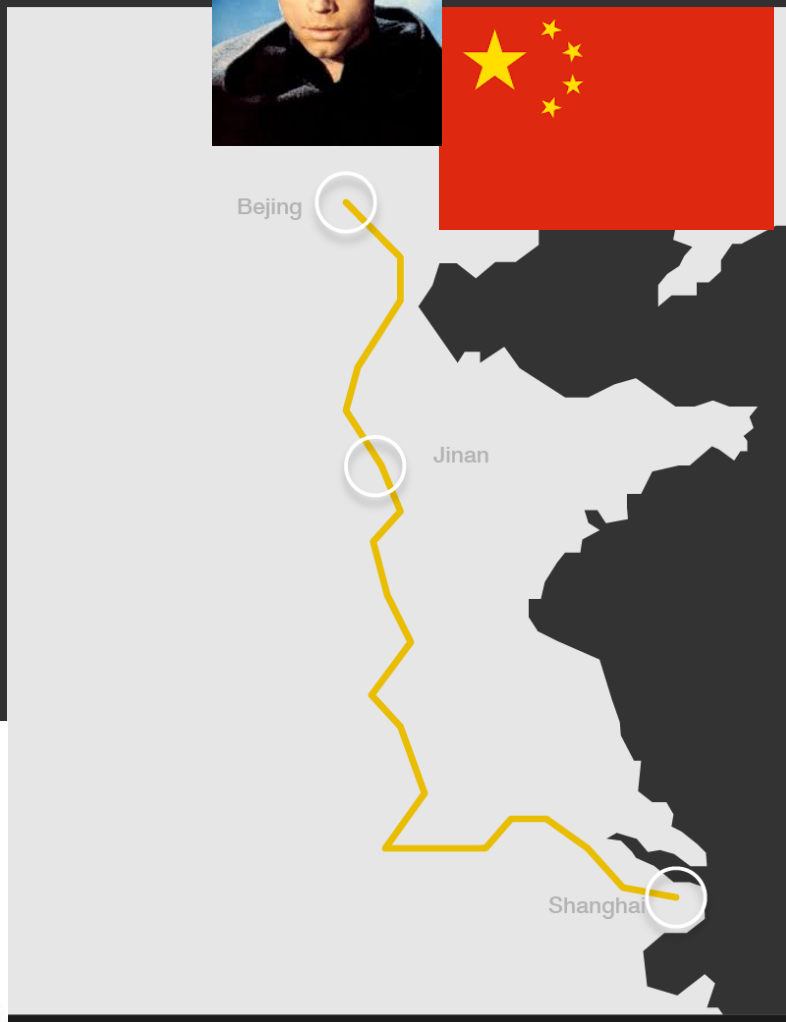
Quantum Cryptography (other protocols):

Status: In lab at short distances

Trusted repeater networks







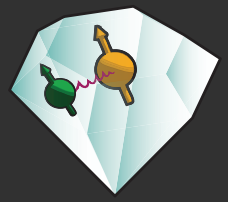
How to go beyond?

Why is long distance quantum communication difficult?

Cannot copy qubits!

Cannot try again!

Only few qubits at a time



Cannot do large scale error correction!

Quantum Teleportation

Useful trick: Quantum Teleportation – two ways to send qubits!

Direct transmission

$|\Psi\rangle$

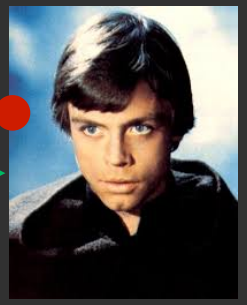
Quantum channel

Teleportation

$|\Psi\rangle$

Entanglement

Classical channel



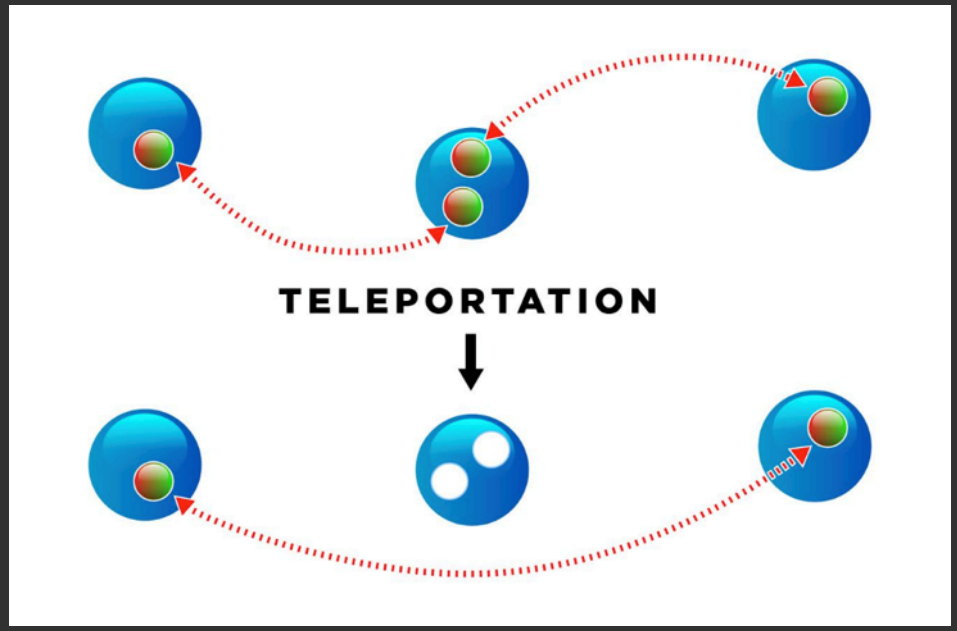
$|\Psi\rangle$

1. Measure qubit
+ her qubit of entanglement

2. Transmit measurement outcome

3. Apply correction according to outcome

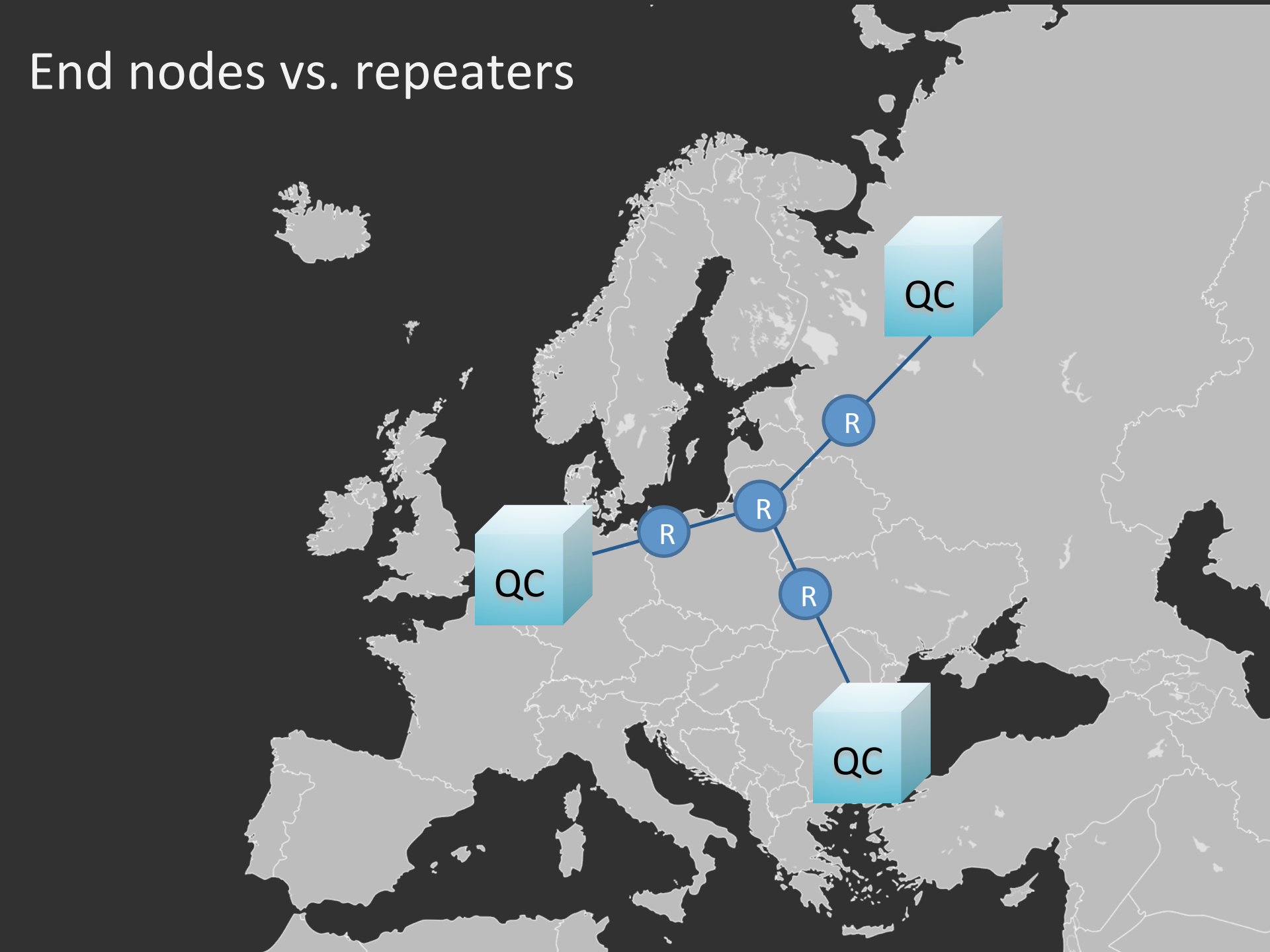
Quantum repeater – bridging long distances



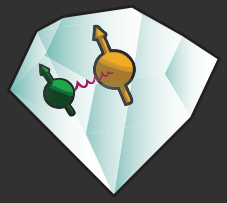
Nice Features

- Can try again if we fail to make entanglement!
- Simple operations

End nodes vs. repeaters



State of the Art



Small quantum computers
~ 6 qubits
~ 1s storage time
~ (future) entangling rate: hz (~10-60hz/40kms)
~ 97-99% gate fidelities

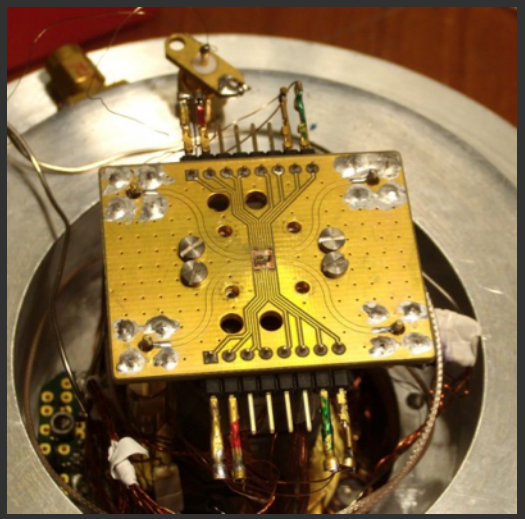
Others (nodes and repeaters):

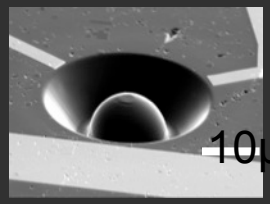
- NV in diamond (Mikhail Lukin, Dirk Englund)
- Ion traps (Chris Monroe, Tracy Northup)
- Silicon (Stephanie Simmons)
- …

Repeaters:

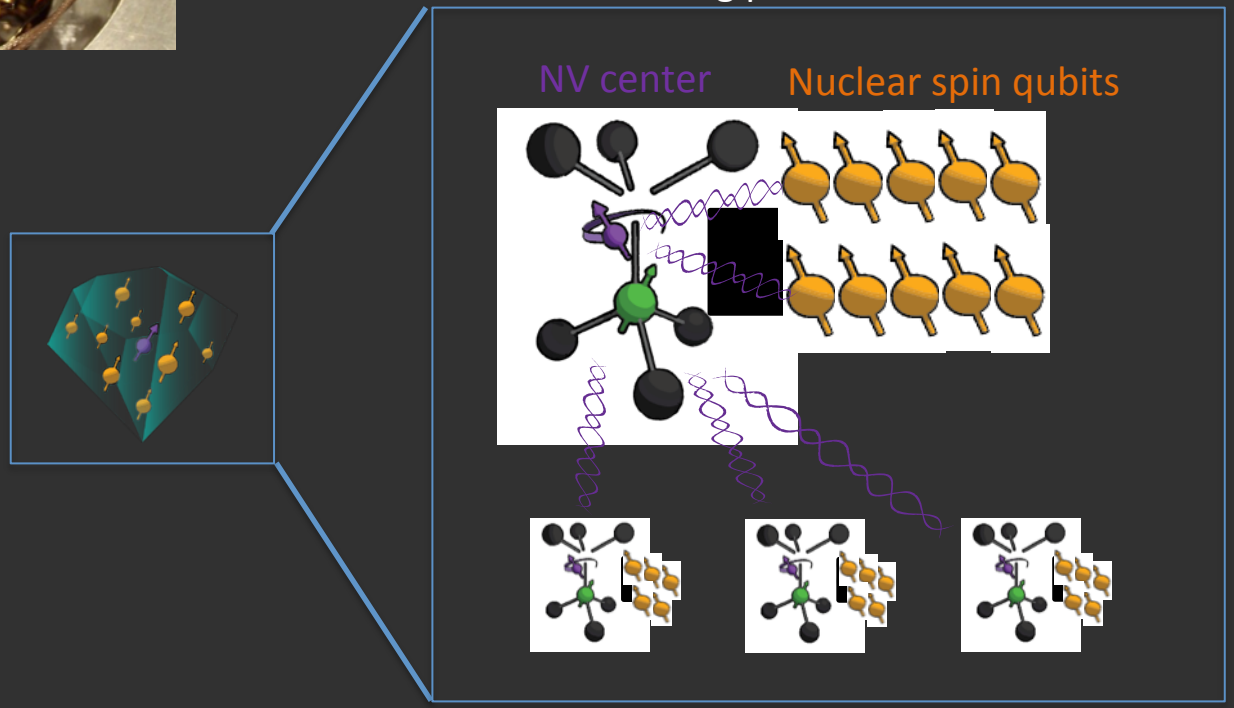
- Atomic ensembles (Hugues Riedematten, Wolfgang Tittel,..
- Theory: All photonic repeaters – Azuma, Tamaki, Lo, Nat. Comm, 2015

Quantum network nodes in Delft





Processing power in each node



What is QuTech?

- Research institute collaboration TU Delft and TNO
- National Icon of the Netherlands
- Goal: Realize quantum computer and quantum internet
- QuTech Academy
  - For master students at TU Delft
- Quantum Campus

STATION Q

Microsoft

intel

Learn more?

- Quantum internet open day 22nd june- stay tuned!
  - Visit QuTech
  - Beta release of simulaQron – program applications on a quantum network simulator
- edX MOOC QuCryptoX – running again in fall!
- More info:
  - QuTech http://www.qutech.nl
  - Quantum Internet Alliance: http://quantum-internet.eu