



DEPARTMENT OF
NETWORKED SYSTEMS
AND SERVICES

Possibilities and challenges of the new quantum era

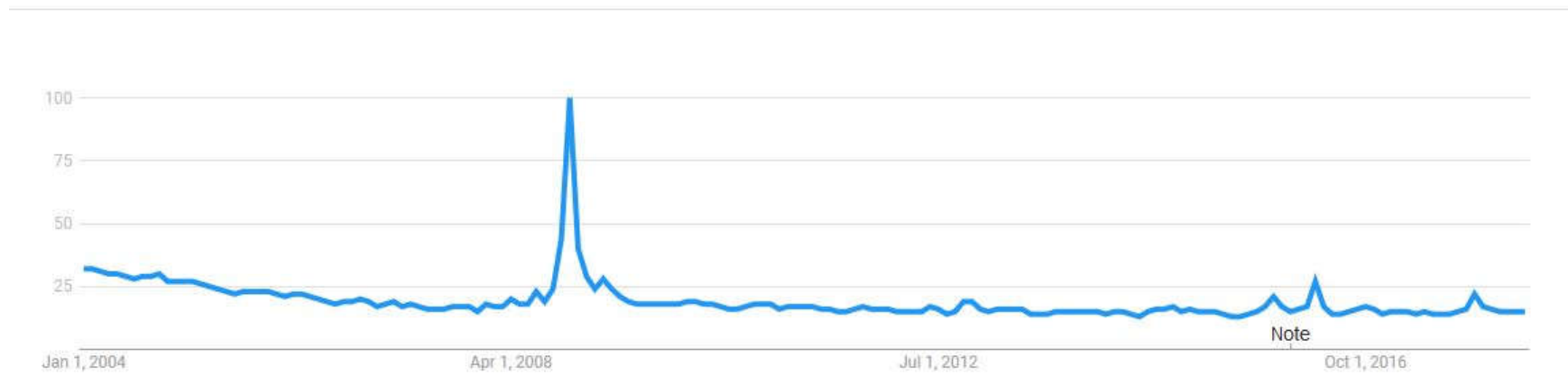
László Bacsárdi, PhD

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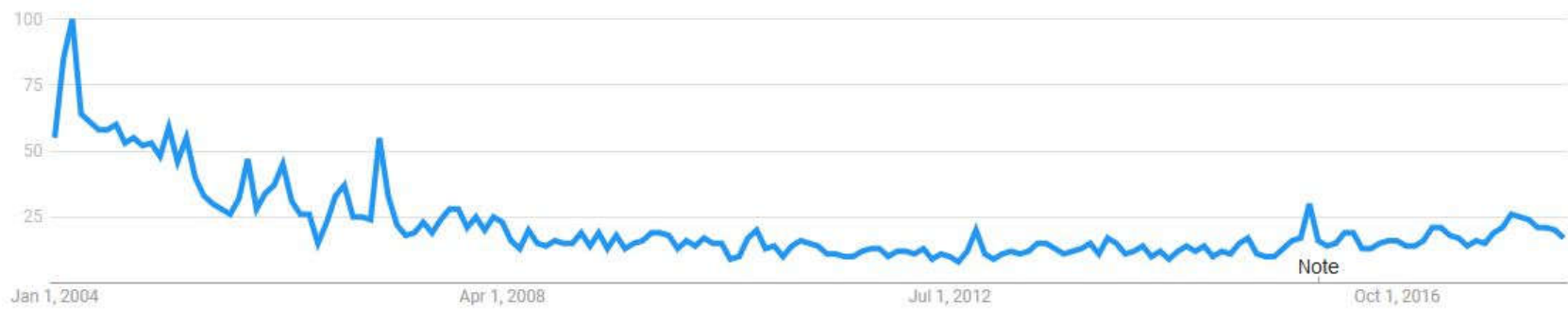
e-IRG Workshop,
Sofia, Bulgaria
May 14, 2018



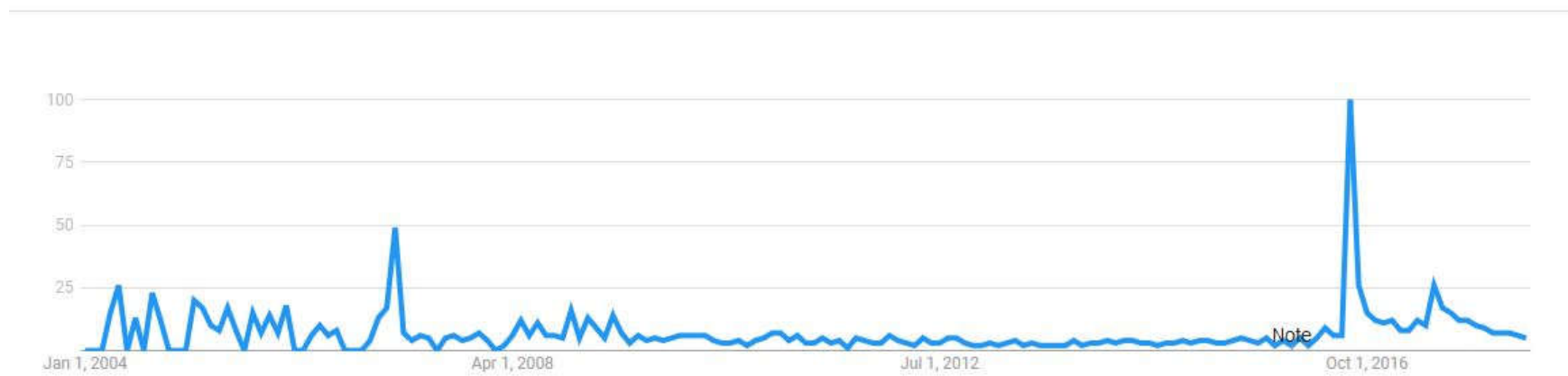




Data Source: Google Trends



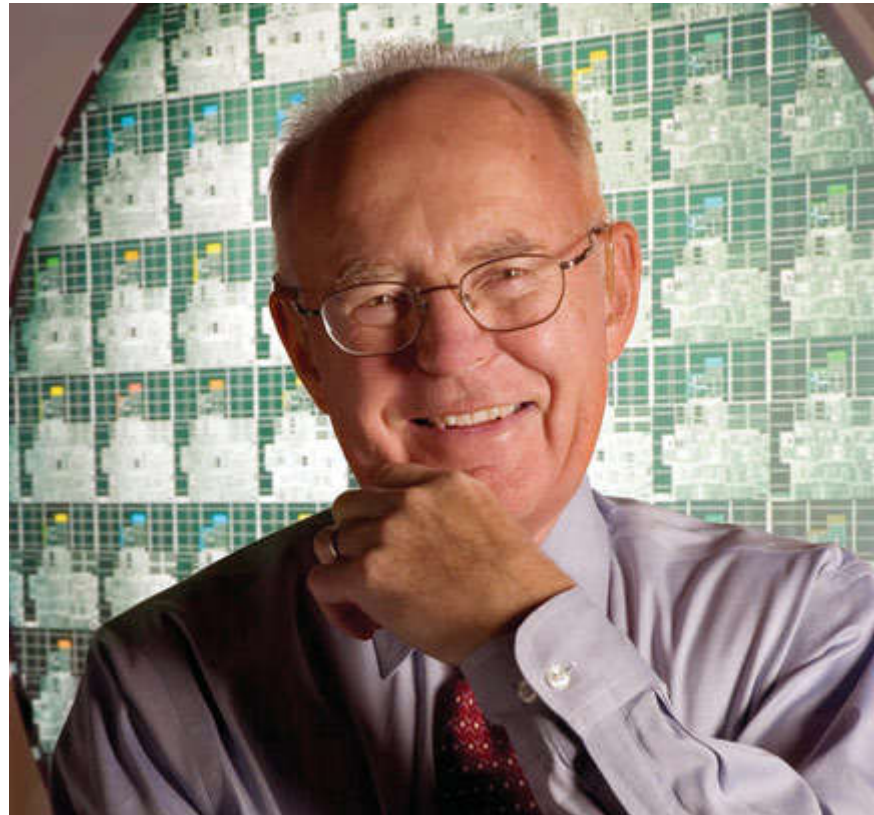
Data Source: Google Trends



Data Source: Google Trends

THE MOORE'S LAW

- Information is stored in a physical medium, and manipulated by physical processes
- The laws of physics dictate the capabilities of any information processing device



Source: Founder of Intel: Gordon Moore
<http://www.entrepreneursstartup.com/2011/02/founder-of-intel-gordon-moore/>

0

1

0 and 1

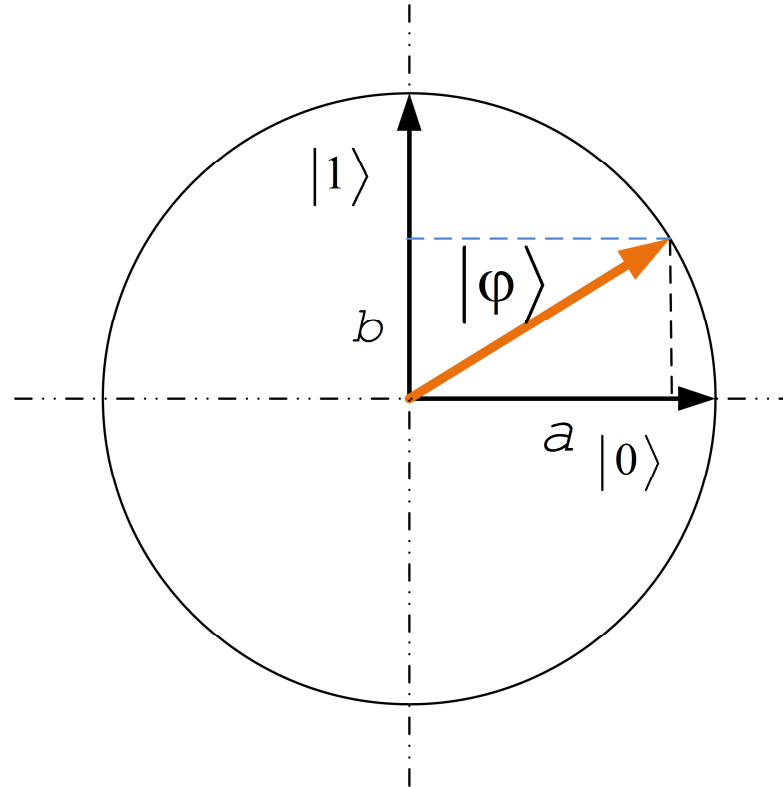
SUPERPOSITION

0 and 1

QUANTUM BIT

$$|\varphi\rangle = a|0\rangle + b|1\rangle$$

$$|a|^2 + |b|^2 = 1 \quad a, b \in \mathbb{C}$$



QUBIT

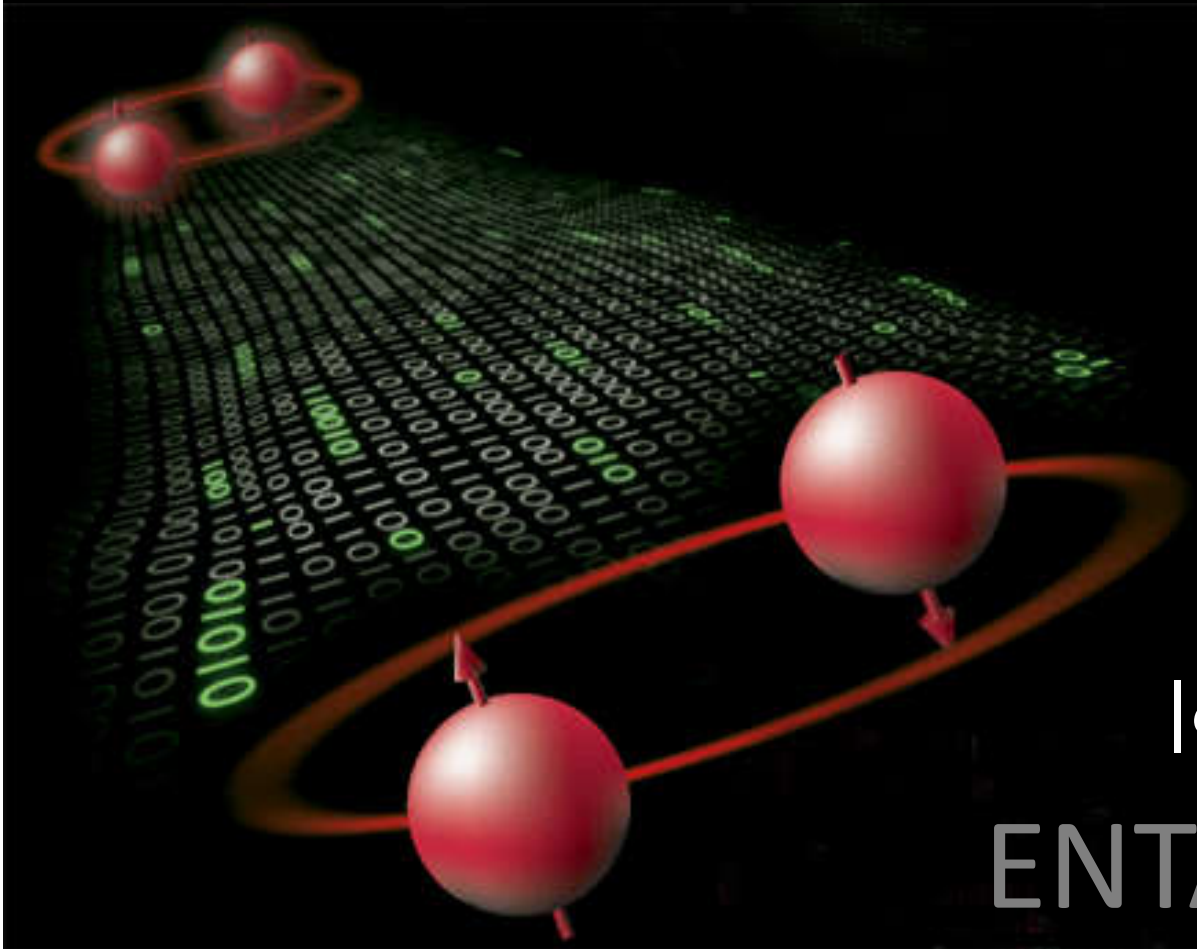
QUANTUM REGISTER

$$|\varphi\rangle = a|0\rangle + b|1\rangle$$

$$|\varphi\rangle^{\otimes 2} = a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle$$

$$|\varphi\rangle^{\otimes 4} = a|0000\rangle + b|0001\rangle + \dots + o|1110\rangle + p|1111\rangle$$

QUREGISTER

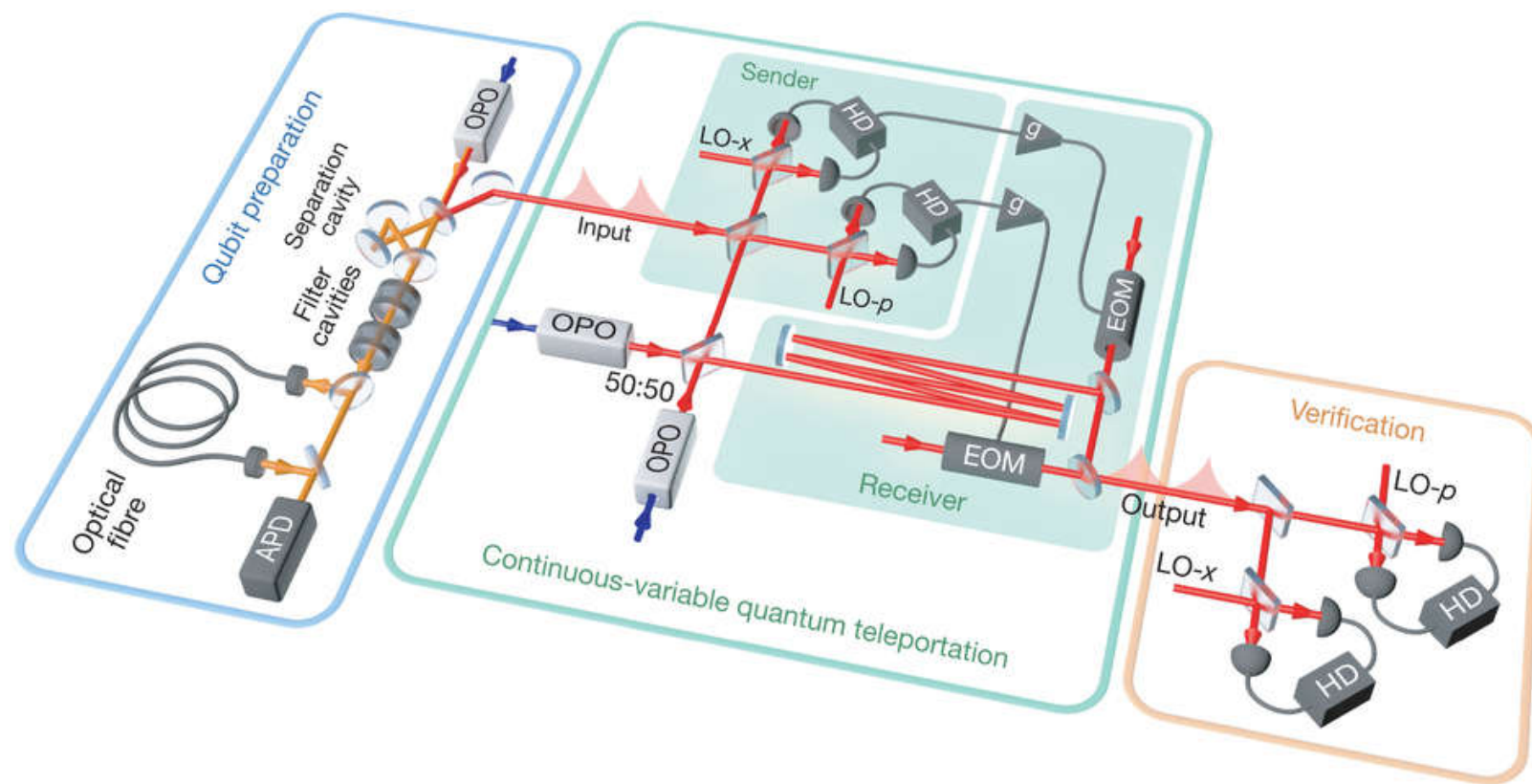


$$|\varphi\rangle = a|00\rangle + b|11\rangle$$

ENTANGLEMENT



KEEP
CALM
AND
BEAM
ME UP
SCOTTY





Afaljd

Open Question

[Show me another »](#)

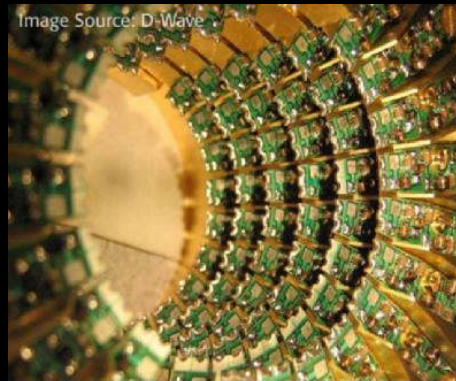
Is teleportation allowed in table tennis or ping pong?

What if the opponent hits it really far back and I can't reach it and so I decided to shift/teleport into that location that I couldn't quickly reach and then return the ball? So is teleportation allowed?

3 days ago - 1 day left to answer.

 [Report Abuse](#)

[Answer Question](#)



30 Qubit Computer
10 teraFLOPS



30 Bit Computer
~0.5 megaFLOPS

**Quantum computers perform
2 million times faster**



QUANTUM COMPUTERS

$$f(x) = ? \text{ (for all possible } x\text{)}$$

CLASSICAL COMPUTERS

QUANTUM COMPUTERS

$$f(x) = ? \text{ (for all possible } x\text{)}$$

n step (e.g., for $i=1$ to n)

CLASSICAL COMPUTERS

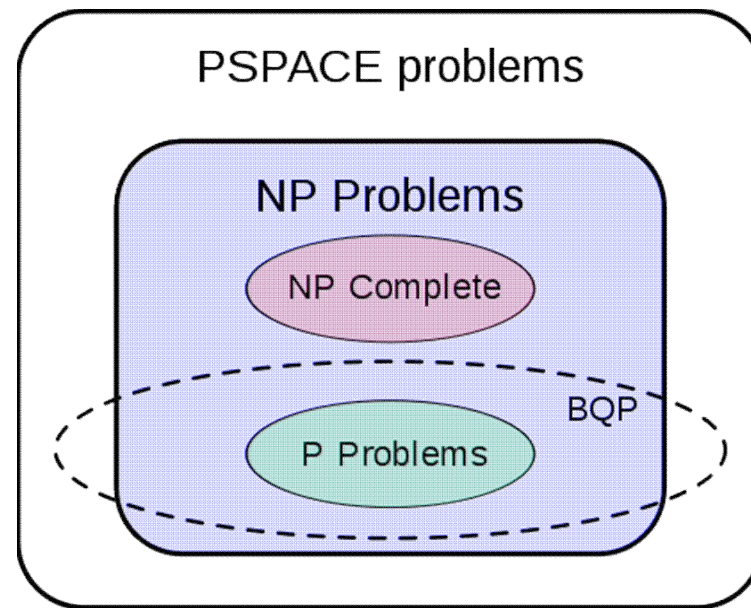
QUANTUM COMPUTERS

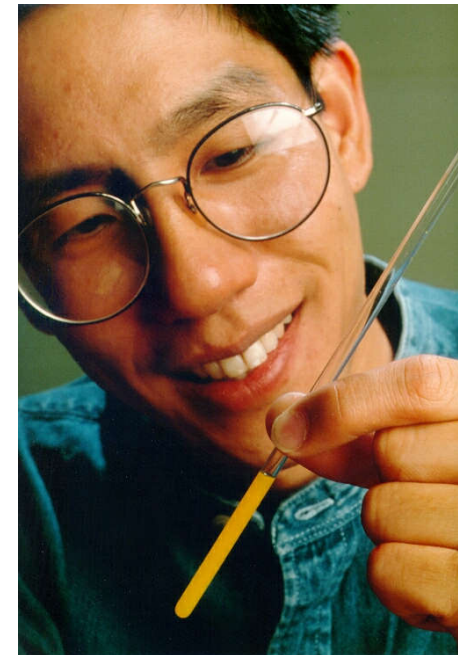
1 step

$$f(x) = ? \text{ (for all possible } x\text{)}$$

n step (e.g., for $i=1$ to n)

CLASSICAL COMPUTERS



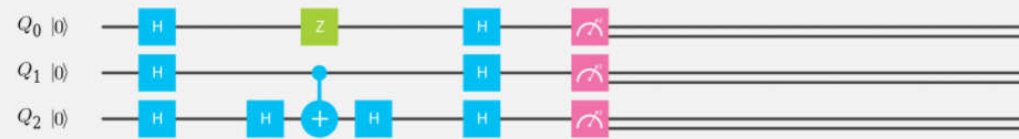


Source of images: *IBM's Almaden Research Center (San Jose, CA.),*



Source: Wired Magazine / IBM

DJ N=3 Example



[Open in Composer](#)

DJ N=3 Constant



[Open in Composer](#)

Get started with quantum development

The Microsoft Quantum Development Kit is the fastest path to quantum development.

[Download for Windows >](#)

[Download for macOS and Linux >](#)

```
/// A qubit initially in the |0> state that we want to send
/// the state of msg to.
operation Teleport(msg : Qubit, there : Qubit) : () {
    body {

        using (register = Qubit[1]) {
            // Ask for an auxiliary qubit that we can use to prepare
            // for teleportation.
            let here = register[0];

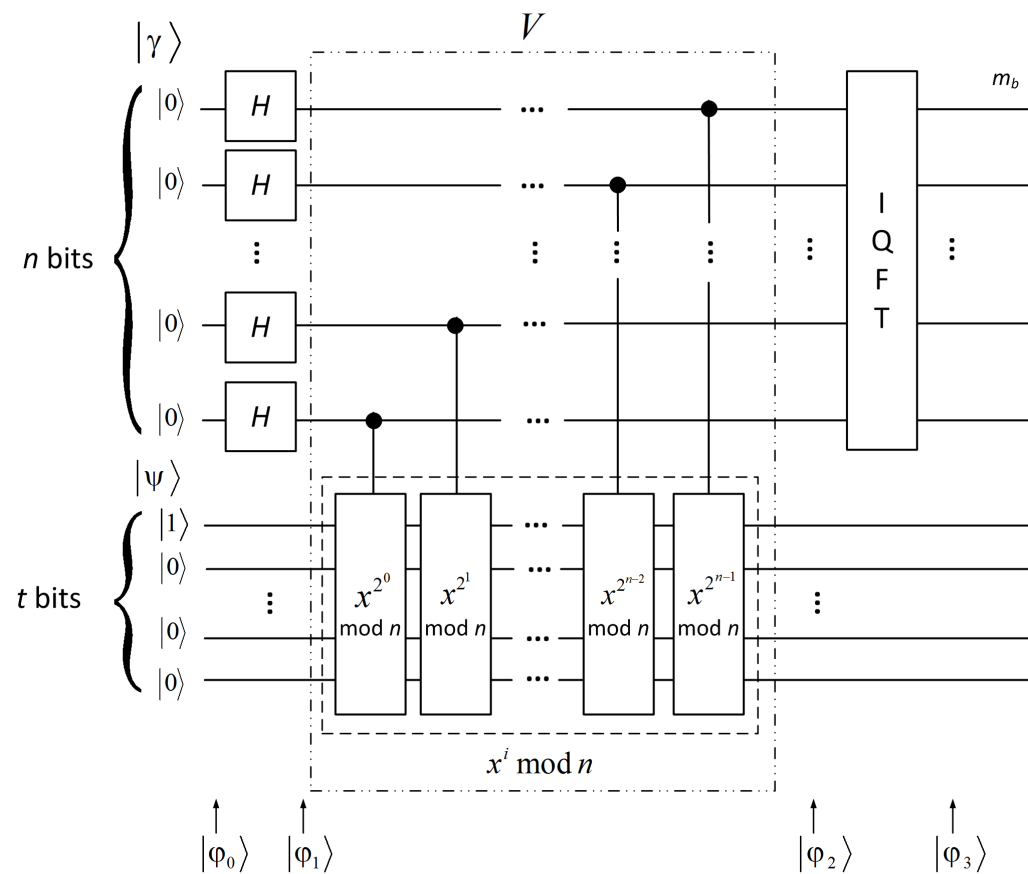
            // Create some entanglement that we can use to send our
            M(here);
            CNOT(here, there);

            // Move our message into the entangled pair.
            CNOT(msg, here);
            M(msg);

            // Measure out the entanglement.
            if (M(msg) == One) { Z(there); }
            if (M(here) == One) { X(there); }

            // Reset our "here" qubit before releasing it.
            Reset(here);
        }
    }
}
```





SHOR's ALGORITHM

15

21

143

Martín-López, Enrique et al. „Experimental realization of Shor's quantum factoring algorithm using qubit recycling”, Nature Photonics 6, 773–776, (2012)

Nanyang Xu, Jing Zhu, Dawei Lu, Xianyi Zhou, Xinhua Peng, and Jiangfeng Du, Quantum Factorization of 143 on a Dipolar-Coupling Nuclear Magnetic Resonance System, Phys. Rev. Lett. 108, 130501 (2012).

SHOR's ALGORITHM

15

21

143

56153

Martín-López, Enrique et al. „Experimental realization of Shor's quantum factoring algorithm using qubit recycling”, Nature Photonics 6, 773–776, (2012)

Nanyang Xu, Jing Zhu, Dawei Lu, Xianyi Zhou, Xinhua Peng, and Jiangfeng Du, Quantum Factorization of 143 on a Dipolar-Coupling Nuclear Magnetic Resonance System, Phys. Rev. Lett. 108, 130501 (2012).

Nikesh S. Dattani and Nathaniel Bryans. "Quantum factorization of 56153 with only 4 qubits." arXiv:1411.6758 [quant-ph]

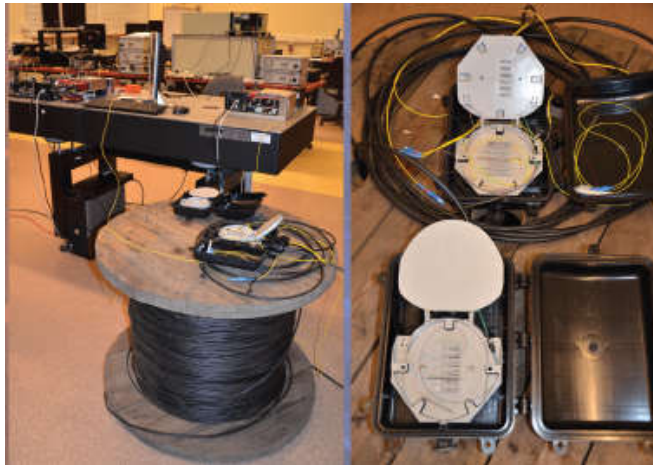
- Gate Model (*Google, Intel, Alibaba*)
 - Analogues to Boolean logic circuits
 - Difficult to scale, requires massive qubit overhead for error correction
- Topological (*Microsoft*)
 - Like gate model but without need for error correction
 - needs exotic quasi-particle which robustness is now in dispute
- Annealing (*D-Wave*)
 - Using quantum tunneling
 - Resilient to noise
 - Currently not universal

- „More efficient” solution for classical problems
 - Searching in an unsorted database
 - Factoring
 - Order finding
 - Simulation of complex systems
 - Optimization problem and applications
 - Routing in network
 - Supply chain management
 - Matching of molecular structures
 - Production planning
 - ...
- Different protocols
 - Superdense coding
 - Quantum teleportation
 - Quantum Key Distribution (BB84, B92, S09, E91)

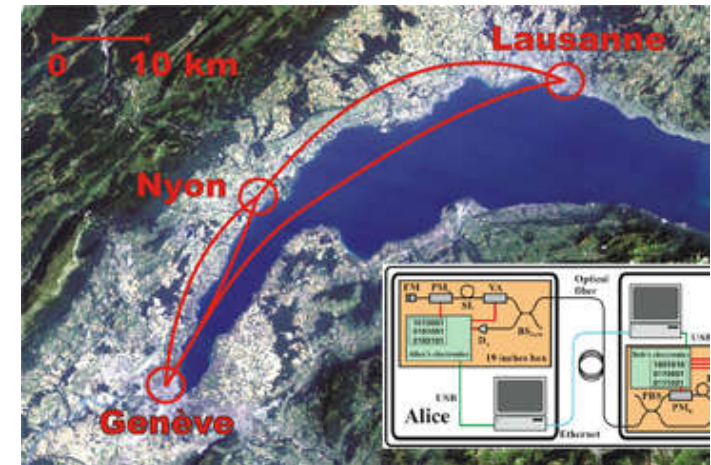




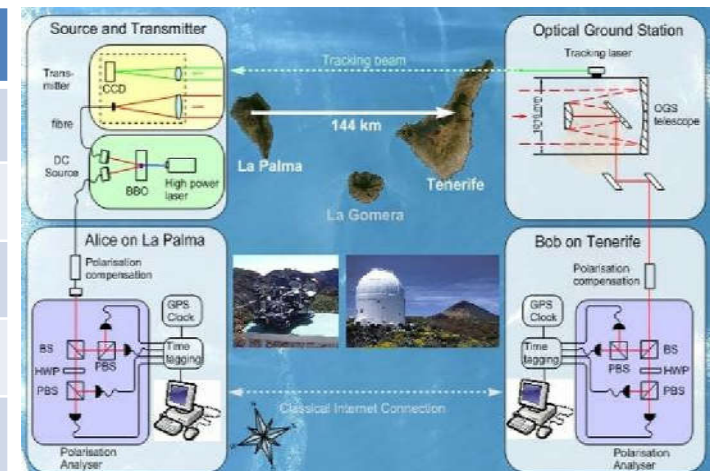
Distances...



1989/91	0,3 m
1993	1100 m
1995	23 km
2007	67 km
2016	404 km



1991	0,3m
1996	75 m
1998	1 km
2002	10 km
2006/2007	144 km
2016	space



[Space.com](#) > [Tech](#)

China Launches Pioneering 'Hack-Proof' Quantum-Communications Satellite

By Mike Wall, Space.com Senior Writer | August 16, 2016 06:13pm ET

f 385

54

g+ 19

37

1388

MORE ▼



China launched the first-ever quantum-communication satellite, known as QUESS, atop a Long March-2D rocket from the Jiuquan Satellite Launch Center on Aug. 15, 2016 (Aug. 15 local time).

Credit: Xinhua/Jin Liwang

Source of image: <http://www.space.com/33760-china-launches-quantum-communications-satellite.html>

'Much better than expected': Chinese 'hack-proof' quantum communication satellite put into service

Published time: 19 Jan, 2017 04:43

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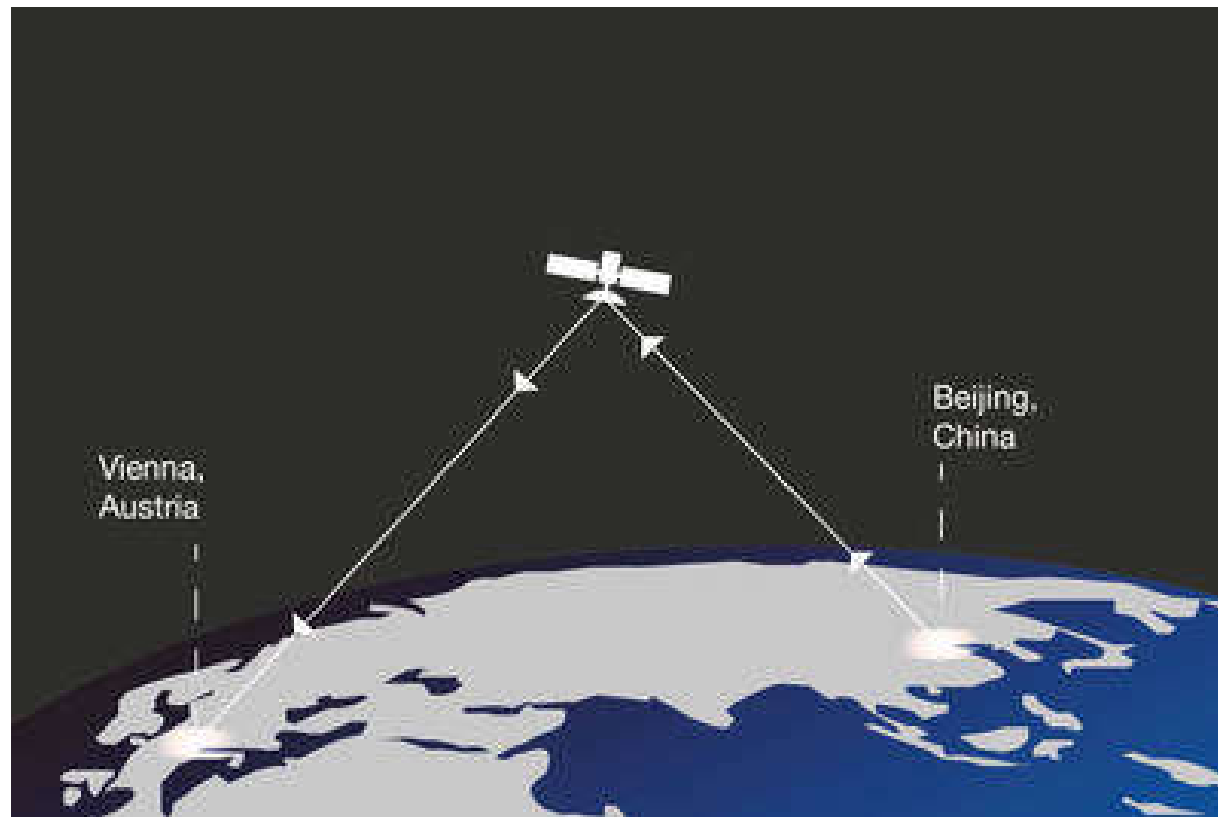


Beijing Aerospace Control Center. © Ju Zhenhua / Xinhua / Global Look Press via ZUMA Press



The world's first quantum communication satellite is now officially operational following months of in-orbit testing, the Chinese Academy of Sciences (CAS) announced, saying that performance of the device is "much better" than was initially expected.

Source of image: <https://www.rt.com/news/374167-china-quantum-satellite-operational/>





The future is Quantum.

The Second Quantum Revolution is unfolding now, exploiting the enormous advancements in our ability to detect and manipulate single quantum objects. The Quantum Flagship is driving this revolution in Europe.

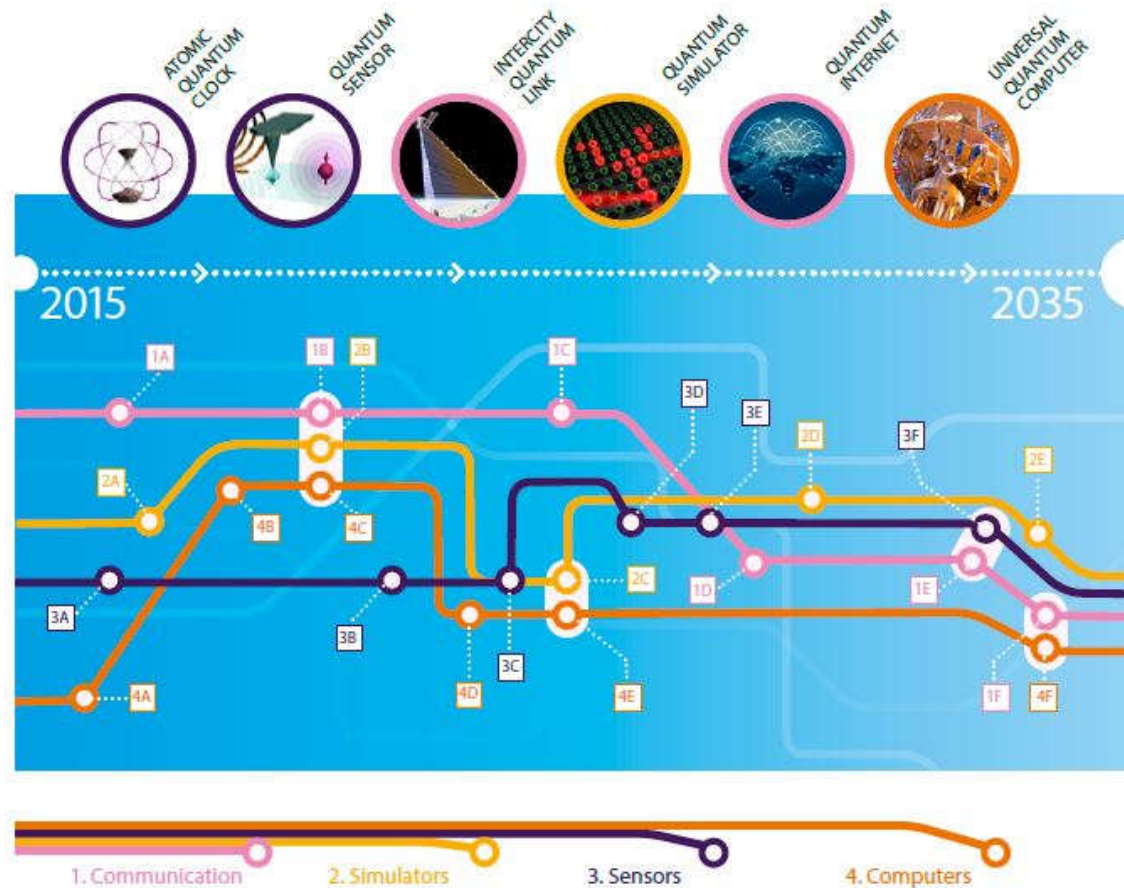
[LEARN MORE](#)

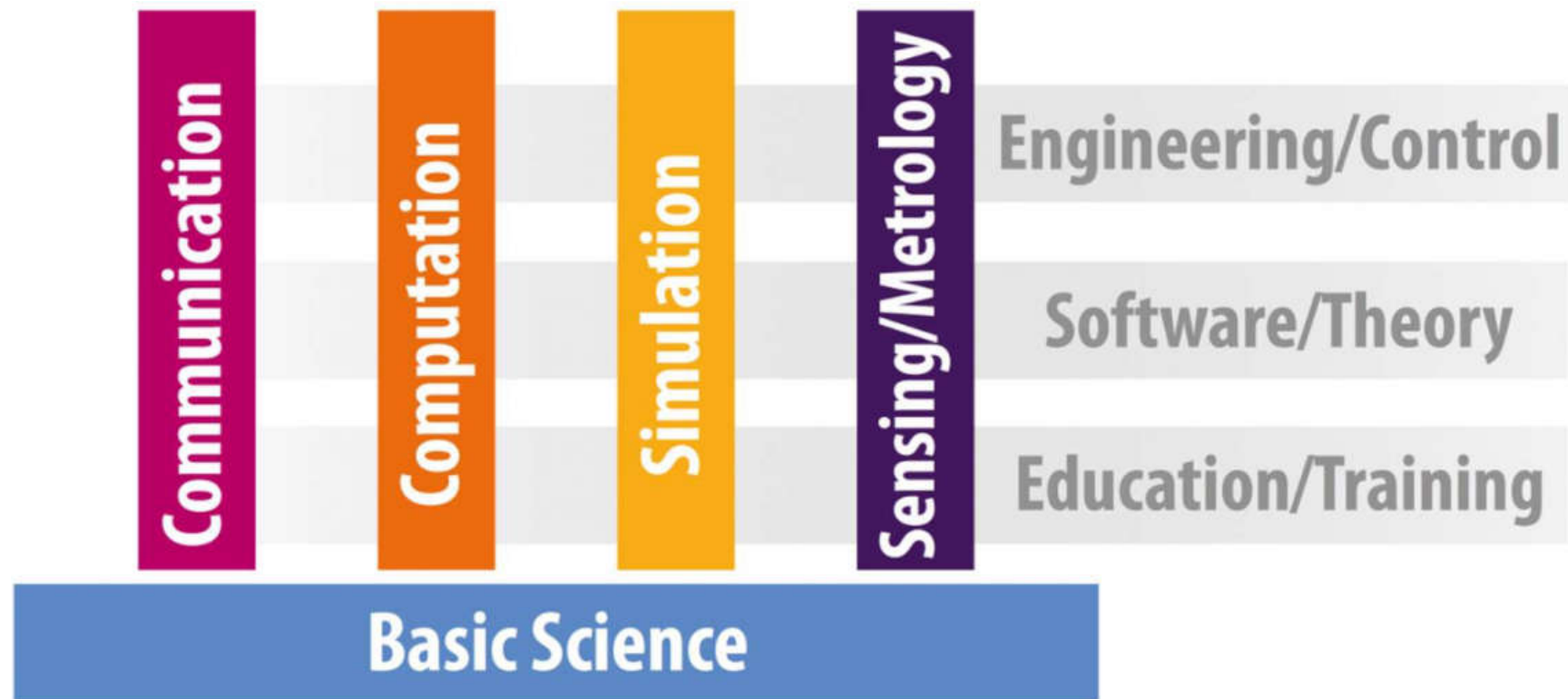
QuantumManifesto

A New Era of Technology

May 2016

Quantum Technologies Timeline





QTS

QUANTUM TECHNOLOGIES IN SPACE

The scientific and technological legacy of the 20th century includes milestones such as **quantum mechanics** and **pioneering space missions**. Both endeavours have opened new avenues for the furthering of our understanding of Nature, and are true landmarks of modern science. Quantum theory and space science form building blocks of a powerful research framework for exploring the **boundaries of modern physics** through the unique working conditions offered by experimental tests performed in space.

Long free-fall times enable **high-precision tests** of general relativity and tests of the **equivalence principle** for quantum systems.

Harnessing microgravity, high vacuum and low temperature of deep space promises allowing the study of **deviations from standard quantum theory** for high-mass test particles. Space-based experiments of metrology and sensing will push the **precision of clocks**, mass detectors and transducers towards the engineering of **novel quantum technologies**.

Secure
Communication

Time and
Frequency Services

Earth Sensing and
Observation

Fundamental
Physics

Research & Development



Metropolitan Quantum Communication

Using coherent quantum communication to enhance the security of intra-city cryptography. Coherent Quantum Key Distribution Our quantum key distribution systems are based on coherent telecommunication technology. Quantum states are distributed with state-of-the-art rates of 10 Gbaud via an optical fiber link,...

Satellite Quantum Communication

We use quantum-enhanced satellites to provide quantum communication on a global scale. Quantum Communication on a global scale Current quantum communication technologies are limited by a fixed amount of tolerable loss for the quantum signals. In fibers, this loss scales...

Quantum Random Number Generation

Harnessing the power of quantum mechanics to generate true and unique, high-speed random numbers. Quantum random numbers from the vacuum While a coin toss or the casting of a die may seem random, short-term behaviour is very predictable when for example...

Quantum Encryption and Science Satellite (QEYSSat)



Principal Investigator Professor Thomas Jennewein

Institute for Quantum Computing (IQC) researcher Thomas Jennewein is pioneering new applications for quantum technologies, in particular quantum communications networks in space.



Recent media

04/27/17 - [Press release](#) from Innovation, Science and Economic Development Canada

02/02/17 - [Wired article](#) by Sophia Chen

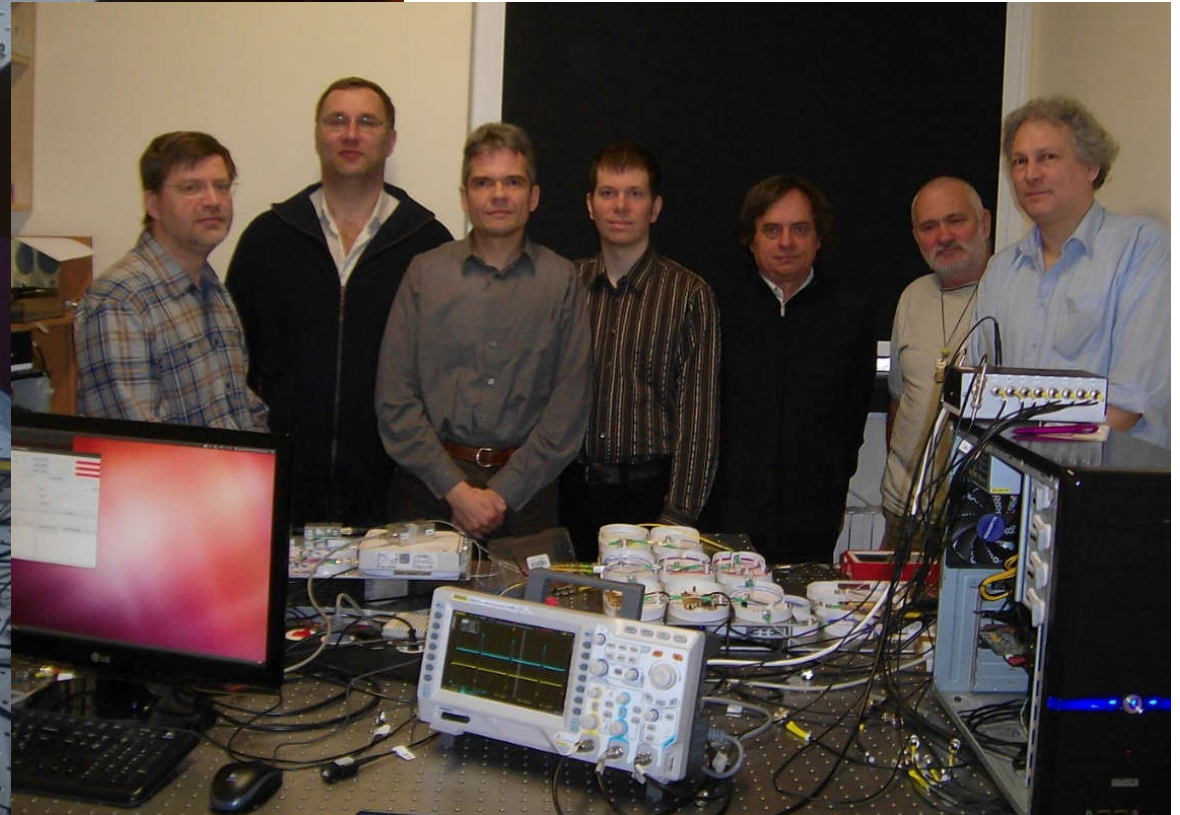
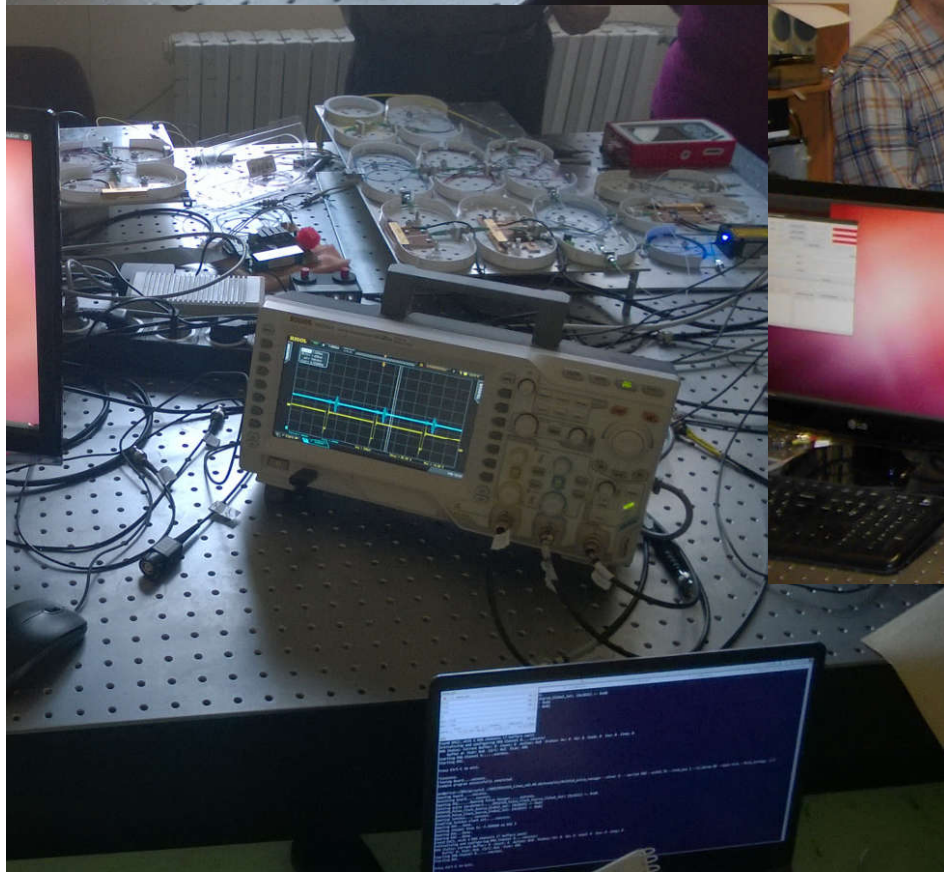
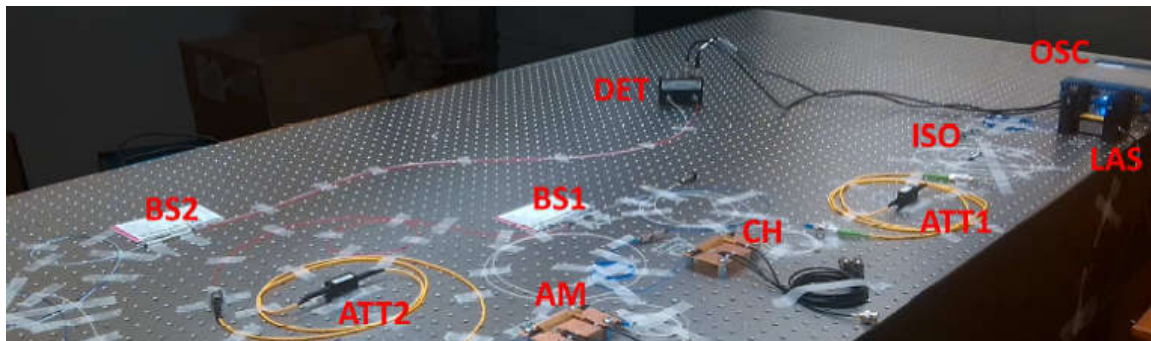
12/22/16 - ["We've got photons!"](#)

12/21/16 - [Researchers successfully demonstrate prototype for space-based quantum-secured communication](#)

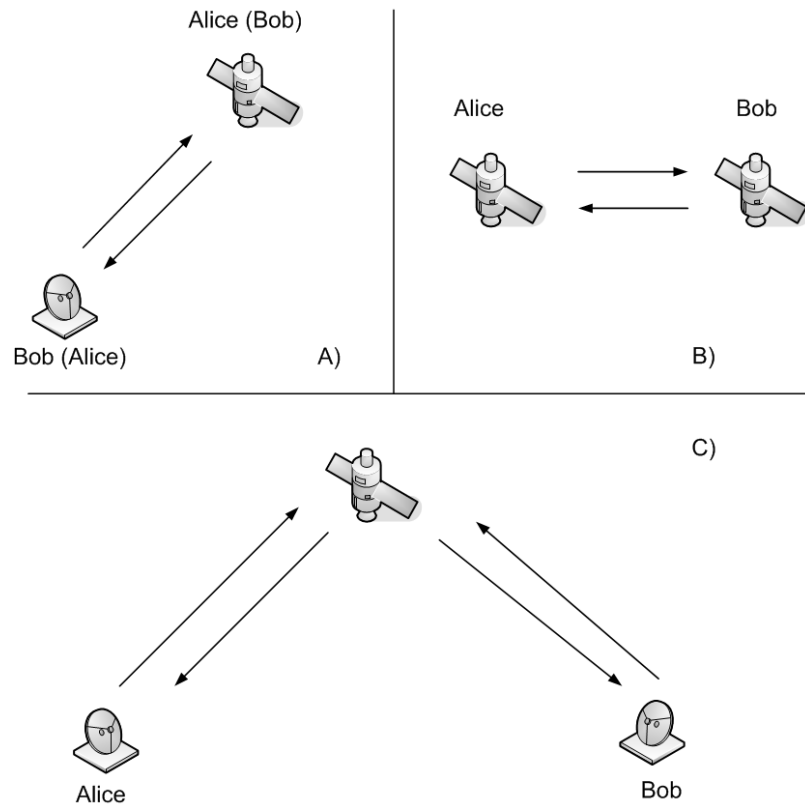
12/20/16 - [Globe and Mail article](#) by Ivan Semeniuk

09/12/16 - [IQC researchers successfully conduct airborne demonstration of quantum key distribution](#)

05/05/16 - [IQC researcher awarded CSA grant to demonstrate quantum communications technologies aboard student space mission](#)

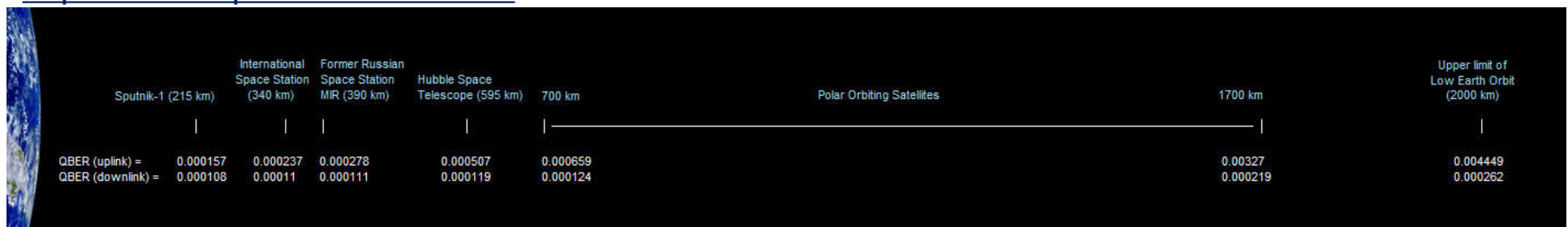


QKD



L. Bacsardi, „On the way to Quantum Based Satellite Communication”,
IEEE Communications Magazine, 51:(08) pp. 50-55.

The latest version of the Quantum Satellite Communication Simulator is available:
<http://mcl.hu/quantum/simulator/>







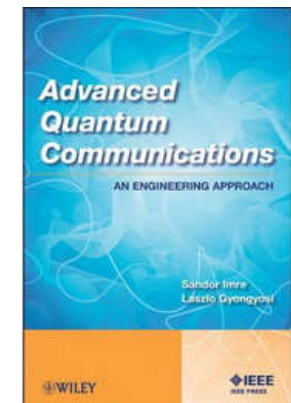
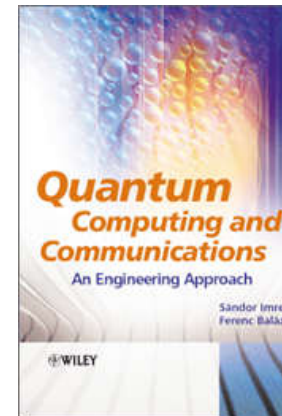
bacsardi@hit.bme.hu

Quantum Technology Flagship: <http://qt.eu>

Quantum Technology in Space: <http://qtSPACE.eu>

Hungarian Quantum Technology Flagship:
<https://wigner.mta.hu/quantumtechnology/en>

Our website: <http://mcl.hu/quantum>





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