From quantum science to quantum technologies

Tommaso Calarco
tommaso.calarco@uni-ulm.de
Basic science is motivated by the quest to understand the world

It is a long-term undertaking, but...

...it results in **transformative** (as opposed to incremental) changes in technology, and...

...it’s exactly these changes that define the modern society.

“quantum information is a radical departure in information technology, more fundamentally different from current technology than the digital computer is from the abacus”.

**W. D. Phillips**, 1997 Nobel laureate

member of the EU Integrating Project AQUTE
"But it could be that the most profound and mysterious feature of quantum mechanics, known as ‘quantum entanglement’ has not been exploited yet. Quantum entanglement opens the way to radically new ways of transmitting and processing information..."

Th. W. Hänsch, 2005 Nobel laureate member of the EU Integrating Project AQUTE

Information, its acquisition, storage, transmission and processing is fundamentally physics

Ultimate elements of processors will be of quantal size

Tremendous “speed-up” may be possible using quantum mechanical systems

Quantum techniques will have wide applications in science and technology
Europe is leading

- Roughly half of the world's publications in the field comes from EU based groups, funded through FET
- EU roadmap already in place; constant progress, milestones reached, gaps and challenges identified
- Many countries (Australia, China, Japan, Singapore, Russia, US) are developing their own research programs in the field

Overall, many branches of quantum technology have gone past the proof-of-principle phase
Further progress can only be achieved through the leap in resources and the long-term commitment coming with it.

"FET research on quantum technologies opened a new path to 100% secure communications, taken up by companies such as Siemens, Thales and the high tech SME idQuantique SA, a leader in this technology."

Commission Communication
Moving the ICT frontiers, a strategy for research on future and emerging technologies in Europe, COM(2009) 184
Next thing on the horizon (3-5 years)

**Impact:** Provide answers to problems that are fundamentally beyond classical computing capabilities

**Example:** The development of high-temperature superconductors via a quantum simulator would enable lossless electric transmission lines

"...trying to find a computer simulation of physics, seems to me to be an excellent program to follow out...and I'm not happy with all the analyses that go with just the classical theory, because nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem because it doesn't look so easy."

R. P. Feynman, 1965 Nobel laureate
Quantum Communication

- Already a real-world technology

Vision: **Consumer quantum cryptography**
- (quantum bank card/ATM, quantum door/car key...)

Security (e-commerce; smart grids...)

Challenges: **Continental-scale quantum communication** (**quantum repeaters**)
Quantum metrology and sensing

- Potential in many areas

Quantum-logic based metrology:
- ultra-precise **atomic clocks** for **navigation** (building on e.g. ESA Galileo satellites)

Sensing:
- sub-micron **imaging of tissues** for early detection and **diagnosis** of health problems
second quantum revolution
potential outcomes

- Ultrafast, “smart” computers
- Quantum internet (absolute security)
- Custom-designed quantum materials
- Quantum sensors
- Atomic clocks