Quantum Science & Technology (at the UofC)

Wolfgang Tittel

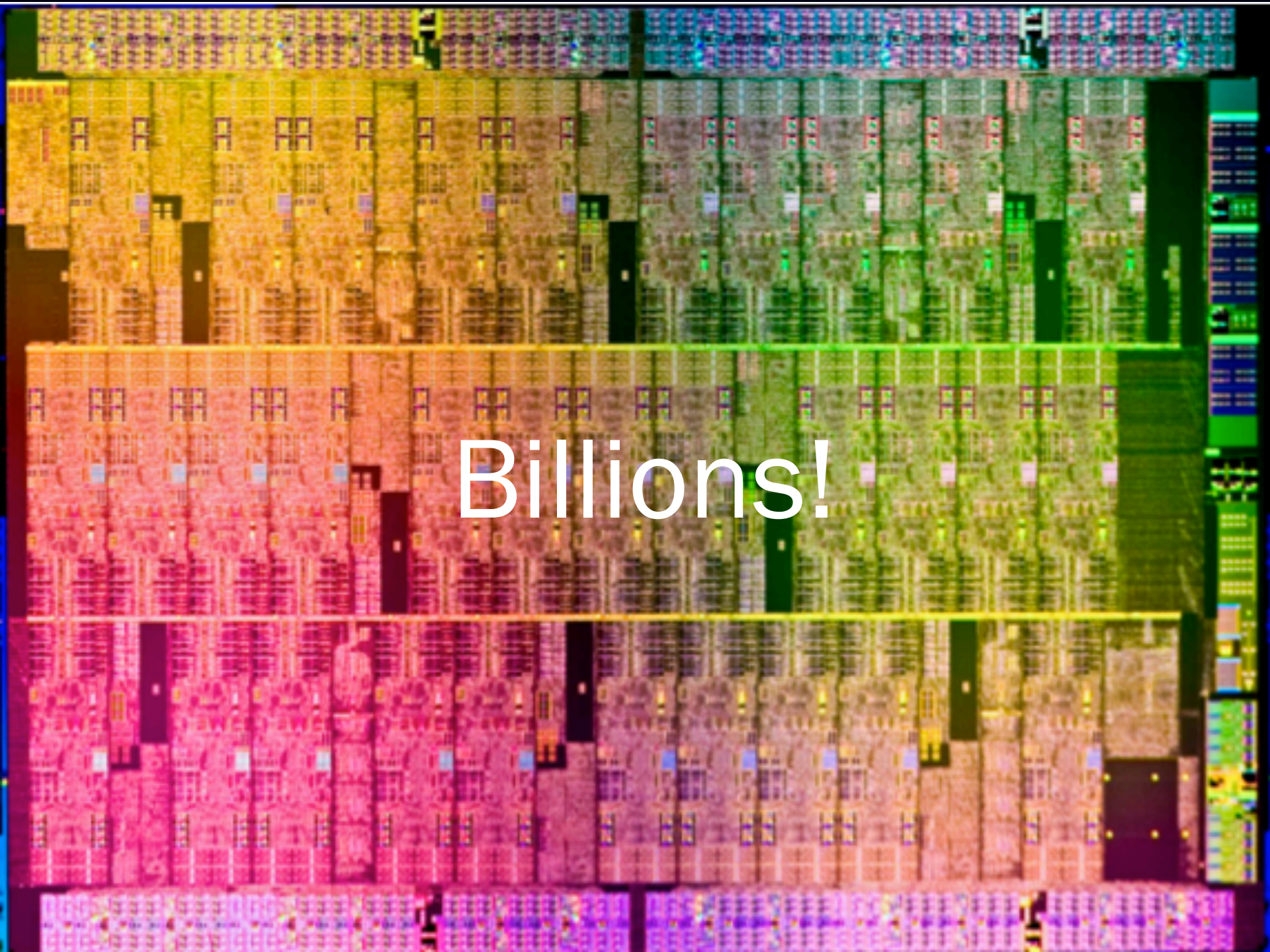
"The twenty-first century will be the quantum age" – P.C.W. Davies

Quantum mechanics?

Oxford dictionary: The branch of mechanics that deals with the mathematical description of the motion and interaction of subatomic particles, ...

Quantum mechanics?

How many devices we use every day are based on this (abstract) theory?


Billions!


intel


And a few more

History has proven the importance to understand interactions on the quantum level*,

Transistor

Laser

Atomic clocks

Magnetic Resonance Imaging (MRI) Scanner

Superconducting Quantum Interference Devices (SQUIDS)

Computer hard drives and memory

Chemical/biochemical reaction rates[1]

...

**The goal of the founders of quantum theory was to understand nature, not to create a 300 billion/year industry*

[1]Pharmacompanies claim that 50% of all new pills are based on quantum-chemical computer simulations

…but more is to be explored and expected

quantum information science, computing and communication

nano-scale materials

quantum chemistry & spectroscopy of exotic materials

quantum biology

…

the task: understand, control and exploit the quantum world in a multi-disciplinary approach to the benefit of our society

Quantum information science, computing & communication

classical bits

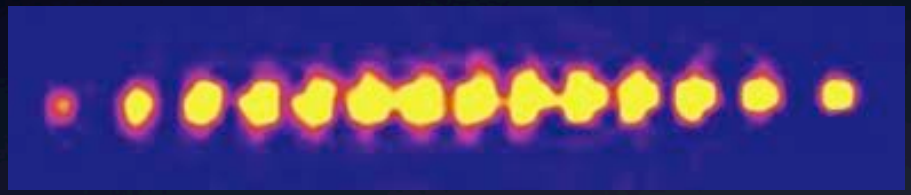
- 1 bit: either 0 or 1
- 2 bits: either 00, or 01, or 10, or 11
- n bits represent one n-bit number
- calculations generally simple (one input, one output)
- some calculations not known to be feasible
- classical bits can be copied perfectly

quantum bits (qubits)

$\Sigma_i |c_i|^2=1$

- 1 qubit: $c_1|0\rangle+c_2|1\rangle$
- 2 qubits: $c_1|00\rangle+c_2|01\rangle+c_3|10\rangle+c_4|11\rangle$
- n qubits can be in a superposition of 2^n n-qubit states (entanglement)
- impossibility to calculate quantum evolutions on a classical computer
- quantum algorithm (Shor, Grover)
- qubits can generally not be copied perfectly (QKD)

Quantum information science, computing & communication

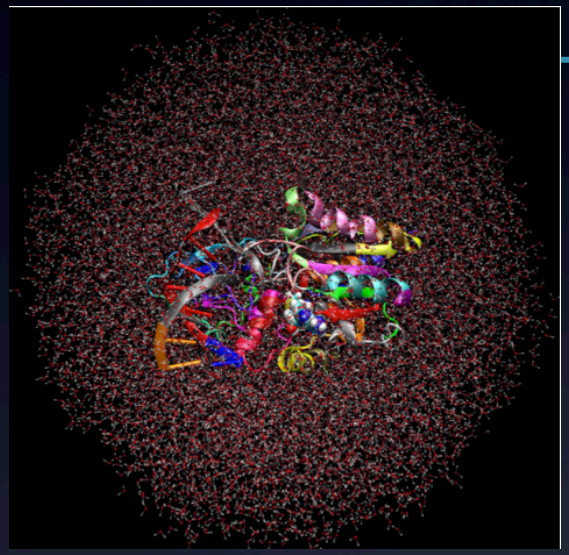




Some examples of current research:

- quantum algorithms (type, approach)
- quantum cryptography protocols (key distribution, bit commitment, coin flipping, private database queries, etc.)
- characterization and best use of resources
- proof-of-principle demonstrations of algorithms/protocols in various systems
- transition to viable technology

Quantum chemistry and spectroscopy of exotic materials



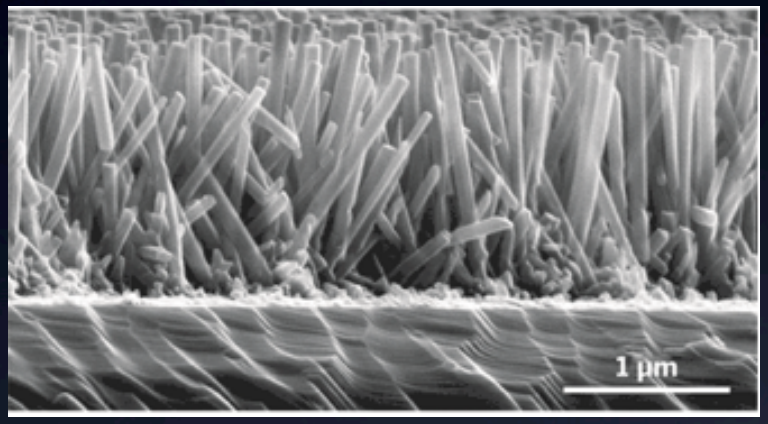


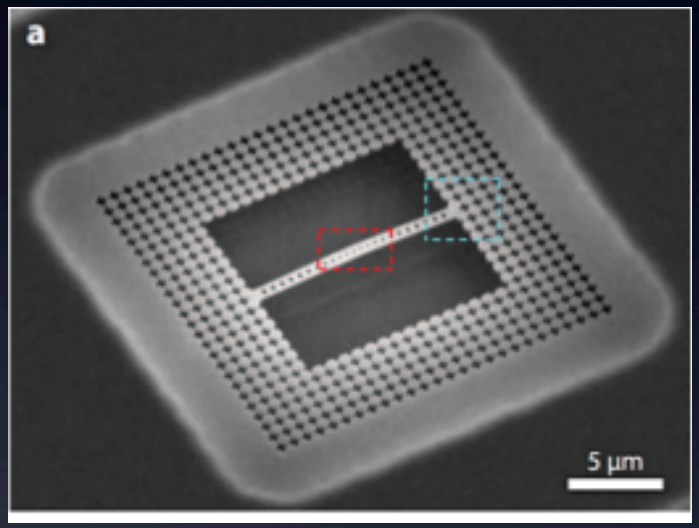
Some examples for current research:

- investigate, understand, and control quantum systems and processes that are far more complex than isolated atoms, or those governing the behavior of isolated atoms

- verify fundamental physical laws

nano-scale materials





Some examples of current research:

- nano-scale systems for enhanced photo-voltaic efficiency
- nano-scale sensors for enhanced sensitivity (magnetometers)
- study of the interaction between light and nano-scale systems (single atoms & electron spins in NV centers in nano-resonators, nano-mechanical oscillators)

Quantum biology





Some examples of current research:

- quantum effects in living (hot) systems
- efficient photosynthesis in marine algae employing quantum random walks
- entanglement-based magneto-reception in European Robins

QST worldwide

15 Nobel Prices awarded since 1995

Academic clusters all around the world (USA, Austria, Switzerland, Germany, GB, Singapore, China)

Significant research funding

A lot of R&D in Industry

Quantum Science & Technology is a strategic priority in many countries

QST in Canada

Three of the 2010 Canada Excellence Research Chairs in quantum programs

DRDC has prioritized quantum computation and cryptography

Nanotech programs

CIFAR Programs (Nanoelectronics, Quantum Materials, & Quantum Information)

NSERC QuantumWorks Innovation platform

MITACS Quantum Information Program

PIMS (Mathematics of Quantum Information)

NSERC Solid Oxide Fuel Cells Canada (SOFCC) Strategic Research Network

Steacie Institute for Molecular Sciences (NRC)

Institute for Quantum Computing (UofW)

Institute for Transdisciplinary Research in Quantum Computing (INTRIQ)

Institute for Quantum Information Science (UofC)

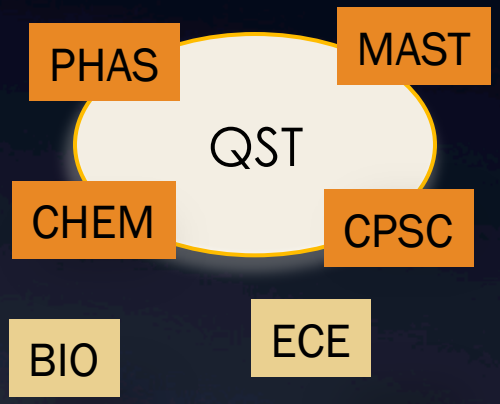
Canadian Light Source & TRIUMPF

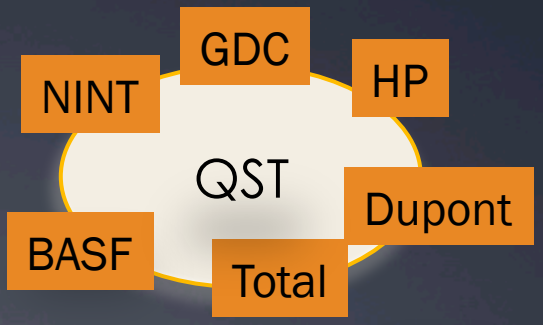
Compute Canada/Westgrid

infrastructure & support available

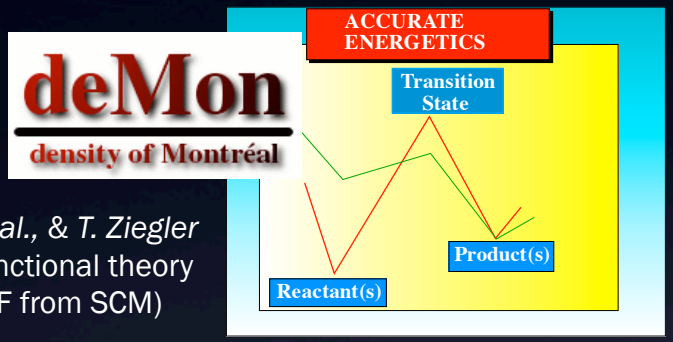
QST in Calgary/core team

Paul Barclay	PHAS/IQIS
David Feder	PHAS/IQIS
Gilad Gour	MAST/IQIS
Peter Høyer	CPSC/IQIS
Peter Kusalik	CHEM
Alex Lvovsky	PHAS/IQIS
Nasser Moazzen Ahmadi	PHAS
Dennis Salahub	CHEM/IBI/ISEEE
Barry Sanders	PHAS/IQIS
Yujun Shi	CHEM
Christoph Simon	PHAS/IQIS
Robert Thompson	PHAS
Wolfgang Tittel	PHAS/IQIS
Simon Trudel	CHEM/NANS
Tom Ziegler	CHEM

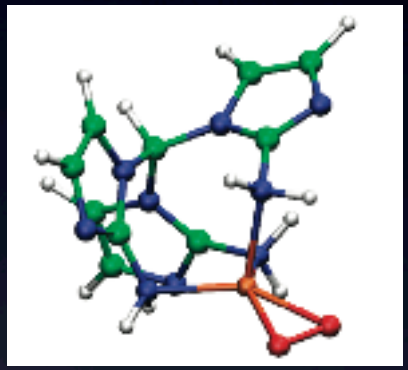




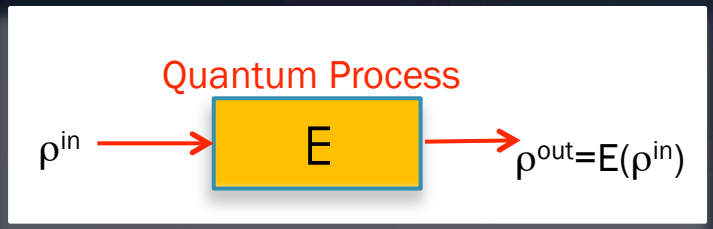
A few research highlights



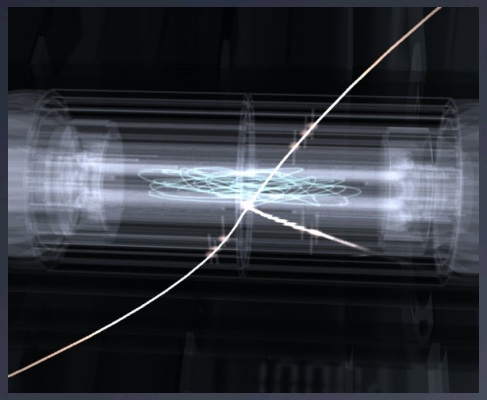
D.R. Salahub *et al.*, & *T. Ziegler et al.*, density functional theory (deMon, & ADF from SCM)



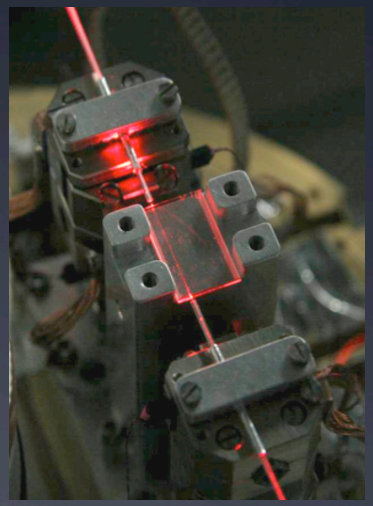
B.C. Sanders, D.R. Salahub *et al*., Transmision coefficients for chemical reactions with multiple states: the role of quantum decoherence. ***J. Am. Chem. Soc***., (2011). Related work by P. Kusalik *et al*., Impacts of Quantization on the Properties of Liquid Water, ***J. Phys. Chem***. A (2005).



A. Lvovsky, B.C. Sanders *et al.* Complete characterization of quantum-optical processes, ***Science*** (2008)

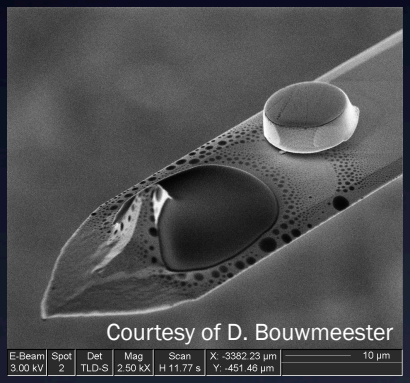


R. Thompson *et al.*, Trapped antihydrogen, ***Nature*** (2010), Nature Physics (2011)

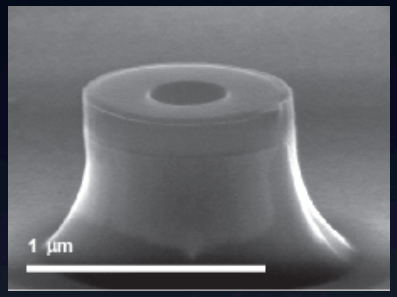


W. Tittel *et al.*, Broadband quantum memory for entangled photons, ***Nature*** (2011)

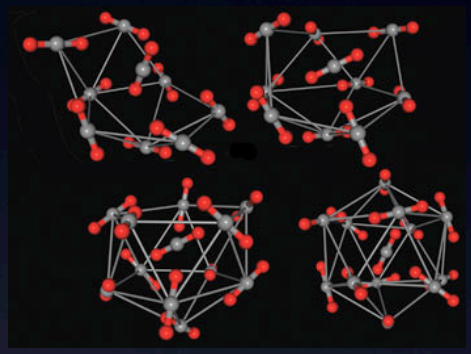
More research highlights



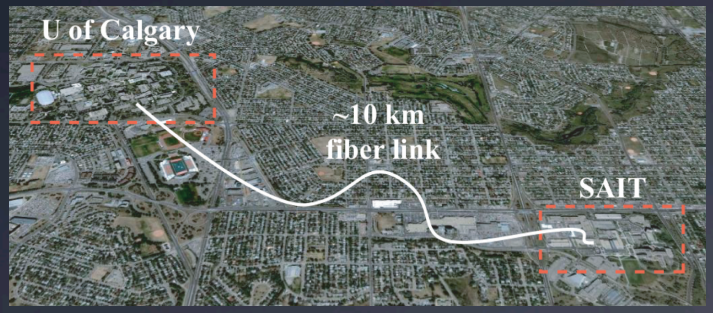
C. Simon *et al.*, Towards quantum superpositions of a mirror, ***Phys. Rev. Lett.*** (2003)



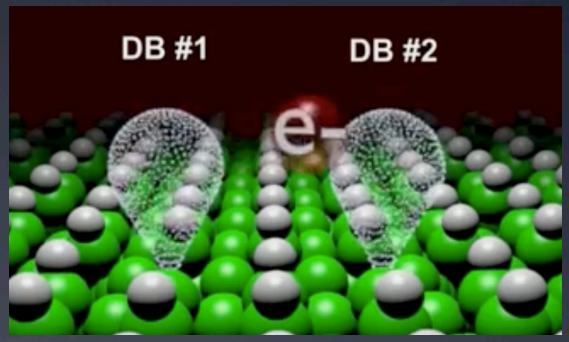
P. Barclay *et al.*, Resonant enhancement of the zero-*phonon emission from a colour centre in a diamond cavity, Nature Photonics (2011)*



N. Moazzen-Ahmadi *et al*, Spectroscopic identification of carbon dioxide clusters: $(CO_2)_6$ to $(CO_2)_{13}$, ***Phys. Chem. Chem. Phys.*** *(2011)*

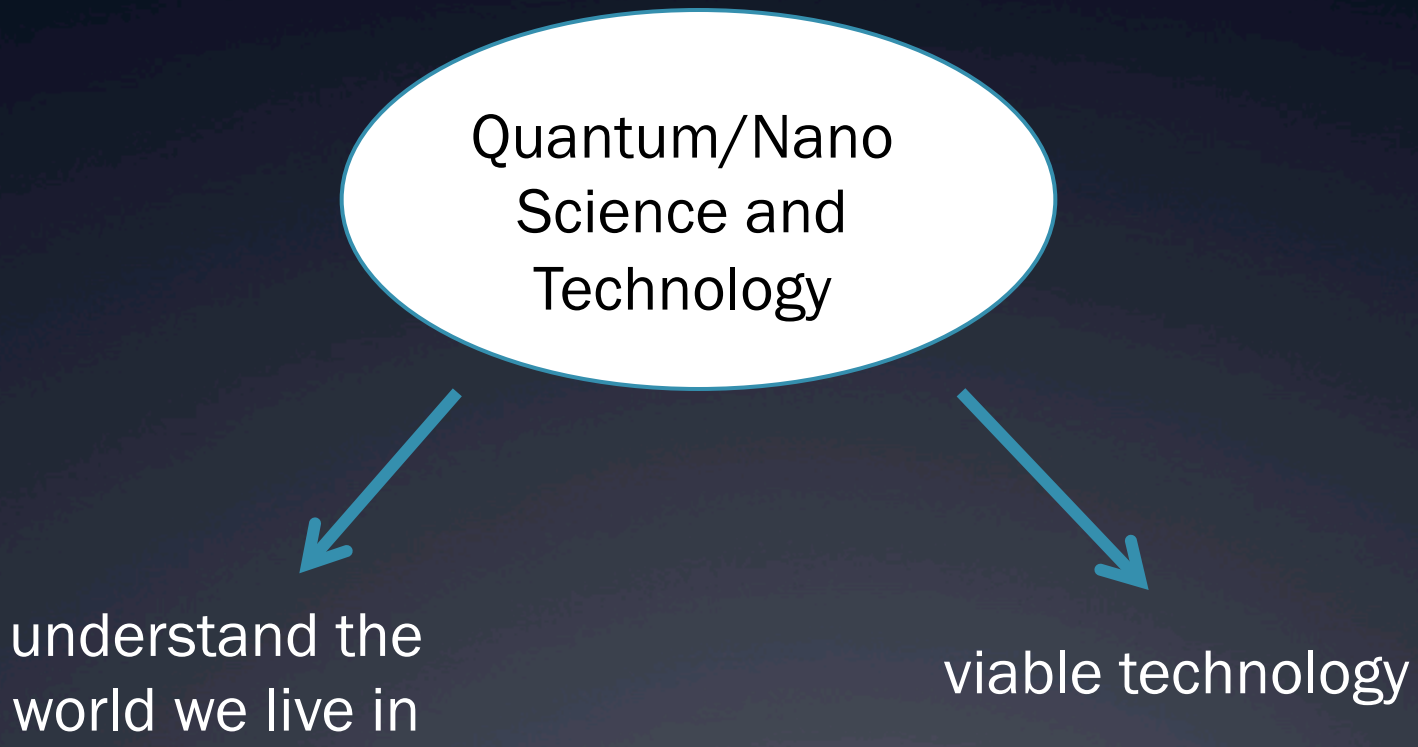


W. Tittel *et al.*, GDC-UofC-SAIT Quantum Crypto link



Dangling-bond charge qubit on a silicon surface, B.C. Sanders & R.A. Wolkow, ***New J. Phys., IOP select*** (2011)

QNST – an interdisciplinary meeting point at the nexus between fundamental research and applications



Thank you