

# Background

- PhD in Geneva with Nicolas Gisin ~5 years
  - Joint Theory / experimental group in quantum information theory
    - Theory: Quantum entanglement, nonlocality, QKD protocols, ...
    - Experiment: Quantum nonlocality, teleportation, QKD, single photon detectors, ...
- Postdoc in Barcelona - ICFO with Antonio Acin
  - Theory group in quantum information theory
- Worked on:
  - Quantum correlations in networks
  - Quantum certification
  - Quantum foundations

# Now: lead Inria PhiQus project team

- CPJ Inria since Feb 23
- PhiQuS
  - New team (Aug 25) <https://team.inria.fr/phiqus/>
  - Joint Inria – Ecole Polytechnique - CNRS
  - 3 permanents: Filippo Vicentini, Titouan Carette, MOR
  - ~10 PhDs, 5 PostDocs, visitors
- Research objectives:
  - Elucidate opportunities offered by the manipulation of quantum information
  - For computing, distributed and simulation problems
  - Using Computer Science, Physics, Optimization and Machine Learning methods and concepts
- Partnerships: Nokia Bell Labs



# What are the fundamental laws ruling information carried by physical systems?

➤ Depends on the physical theory ruling the systems :  
Classical, quantum, beyond quantum (?)

1. What operational differences?

2. Basic principles explaining these differences?

3. These differences are useful for what?

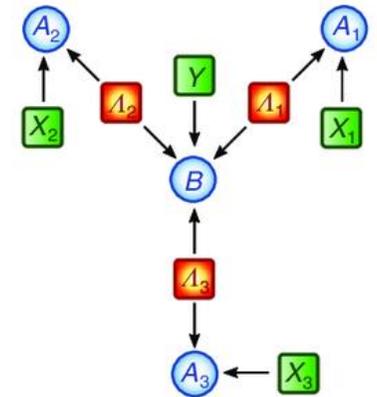
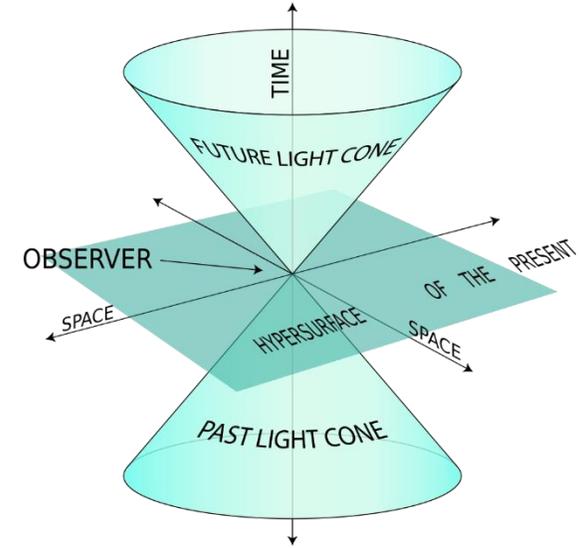
Example:

1. Quantum key distrib, Shor algorithm, Bell theorem, quantum advantages in general, ...
2. No cloning of quantum information
3. ...

Important:

Scenario, what do we trust ? measurement apparatus, circuit depth, no faster than light signaling, ...

➤ Most conservative: **no faster than light signaling / where were the systems sent?** (can be any dimension)



# Project 1

## Fermionic Information Theory > Quantum Information Theory

### Context

Information = boxes containing (“1”) or not (“0”) particles

- Classical particle: bit 0 or 1
- Distinguishable quantum particles: qubit  $|0\rangle, |1\rangle$
- Fermionic particle: febits  $|0\rangle, |1\rangle$

Different:  $|11\rangle_{12} = -|11\rangle_{21}$

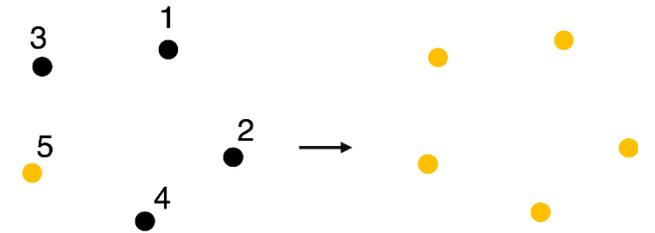
### Goal

Prove that qubits  $\ll$  febits

- Similarly: Bell theorem shows bits  $\ll$  qubits

### SotA

- Trivial: qubits  $\lesssim$  febits
- Computing with febits  $\approx$  computing with qubits
  - Replace  $X_k^{(f)}$  by  $Z_1^{(q)} \dots Z_{k-1}^{(q)} X_k^{(q)}$ : *this is nonlocal!*

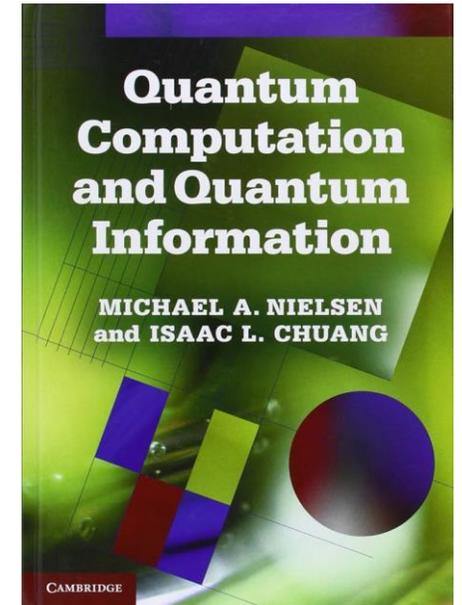


# Project 1

## Fermionic Information Theory > Quantum Information Theory

### Impact: why does it matter?

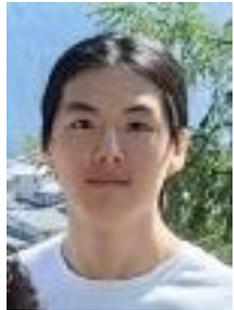
- Standard textbooks are “wrong”
  - Computer Scientist newly interested in quantum distributed computing
  - Take Nielsen and Chuang to understand what quantum can do
  - Wrong! Febits might do better
- New “distributed fermionic Shor algorithm”



# Project 1

## Fermionic Information Theory > Quantum Information Theory

Who?



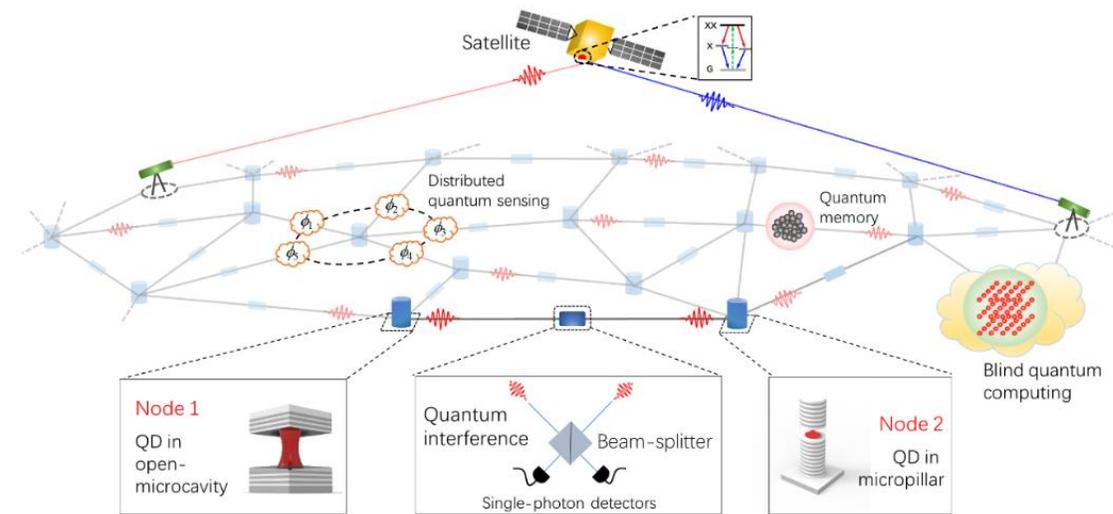
+

Sadra Boreiri (PhD Geneva)  
Salman Beigi (Prof IPM Theran)  
Tommaso Guaita (PostDoc Berlin)



# Project 2

## Network Scenarios: Distributed Algorithm



### Quantum networks

- Large systems of geographically distributed, interconnected quantum information processing devices:
  - Photons carrying information
  - Optical fibers, satellite connections

# Project 2

## Network Scenarios: Distributed Algorithm

### Goal

Understand bits  $\ll$  qubits in a realistic distributed system context

### SotA

Physicists:

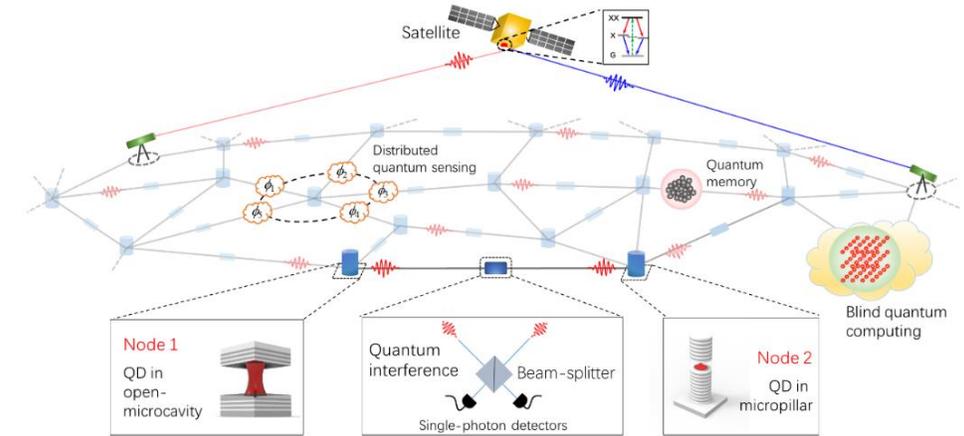
- Naïve models (“network nonlocality”)
- Advanced tools (“inflation”)
- Good quantum understanding

Computer scientists:

- Advanced models (maybe too focused?)
- Advanced similar tools (“Round Elimination”) discovered in parallel
- Bad quantum understanding

### Our projects:

- Find qubit advantages in CS advanced models
- Find bounds on qubit advantages in CS advanced models
- Understand new difference and basic principles invisible in the Bell scenario



# Project 2

## Network Scenarios: Distributed Algorithm

### Impact: why does it matter?

Practical (maybe one day). With a 'quantum network':

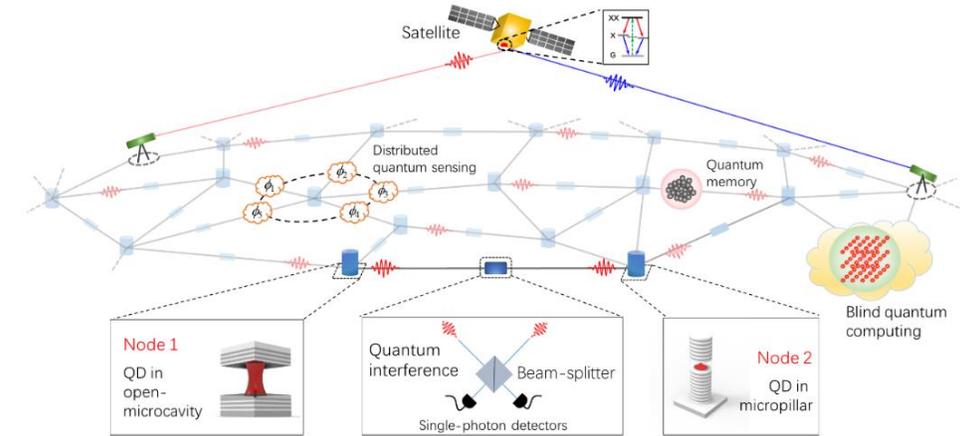
- What can't you do?
- What can you do?
- What capabilities do you need to do it?

Fundamental understanding of 'Information'

- Model much closer to reality

### Beyond:

- Understand qubits  $\ll$  febits in CS advanced models
- Still open: algorithm to solve "show that this cannot be done by qubits"



# Project 2

## Network Scenarios: Distributed Algorithm

Who?



Ludovic

Rémi

Sébastien

Jukka Sumela's team (Aalto Finland)

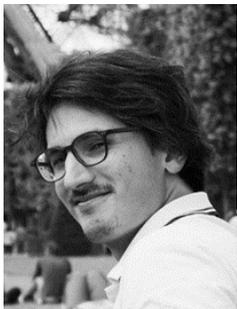
Xavier Coiteux Roy (Calgary Canada)

Sebastien Brandt (CISPA Saarbruecken)

Dennis Oliveti, Alkida Balliu (GSSI Italie)

Vaclav Rozhon (Prague)

Francois Le Gall (Nagoya)



# Project 3

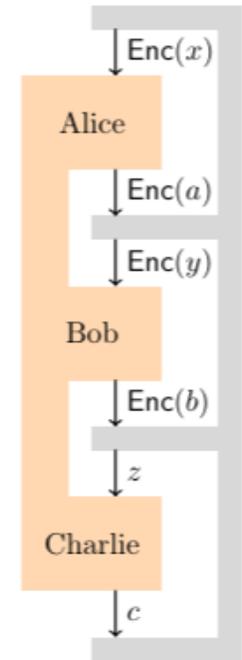
## Quantum Cryptographic Protocols

### Goal

Re-understand quantum protocols / find new protocols based on cryptographic primitives

### Impact: why does it matter?

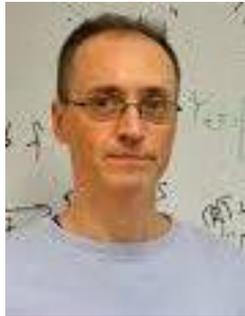
- New ways to obtain proof of quantumness
- Reformulate quantum protocols with new hypothesis
- Related to important crypto problems (e.g., blind delegated quantum computing)



# Project 3

## Quantum Cryptographic Protocols

Who?



Ivan Supic (CNRS Grenoble)  
Matilde Baroni, Dominik Leitch (LIP6)  
Connor Paddock (Calgary Canada)  
Simon Schmidt (Bochum)  
Yuming Zhao (QMATH Copenhagen)

# Toolbox

## C\* Algebras / Noncommutative Polynomial Optimization for Quantum Information

### Goal

Understand qubits capabilities when

- No restriction is made on the system dimensions (e.g., Bell)
- Infinitely many systems (e.g., condensed matter thermodynamic limit)

### SotA

Methods based on “C\* algebras”

Well understood in the Bell scenario / condensed matter

Not well understood beyond

### Our projects:

- Find C\* algebraic formulas / characterization of our problems
- Find algorithms corresponding to these formulas
- Prove the convergence of these algorithms
  - Non commutative version of the Lasserre hierarchy, convergent SDP relaxations of polynomial optimization problems

### Who?

Almost everyone

# Project 4

## Certified algorithms for condensed matter problems

### Goal

Condensed matter: huge, central problem in physics

- Collective effects -> supraconductivity, ...
- Dimension problem:  $n \sim 10^{23}$  particules, Hilbert space dimension  $d \sim 2^n$

### SotA

Many nonconvex / ML/ ... optimization methods

- Noncertified, several example of “failures”
- Some problems are proven undecidable

### Our projects:

Find certified / converging algorithms for condensed matter problem

- Based on C\* algebraic formalism / noncommutative Lasserre

### Impact: why does it matter?

Theoretical: understand what problem admit algorithms solving them

Practical: run these algorithms

# Project 4

## Certified algorithms for condensed matter problems

Who?



Omar Fawzi (Inria Lyon)  
Victor Magron (LAAS Toulouse)  
Jie Wang (Beijing)  
Antonio Acin (ICFO Barcelona)