Panorama des Technologies Quantiques

- Où en est-on aujourd'hui ?
- Quelles sont les feuilles de route technologique et industrielle ?

Comité de pilotage

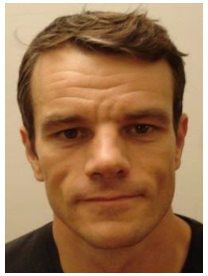
Minalogic Team


ATOS Team




QEI

CNRS



CEA Team


La semaine quantique grenobloise

Le programme

☕ **08h30-09h00 Accueil Café** ☕

- **09h00-09h05** Allocution de bienvenue par **Tony Maindron**, Directeur Micro/nano/électronique / Minalogic
- **09h05-10h05** Keynote introductive - Un an d'évolutions dans les technologies quantiques
  Maud Vinet, Quantum computing program manager / CEA-LETI
  Olivier Ezratty, Auteur et expert quantique
- **10h05-10h25** Informatique quantique à base de photons chez Quandela
  Shane Mansfield, Chercheur en informatique quantique / **Quandela**

10:25-10h45 Pause Café / Networking

- **10h45-11h05** Si spin-based quantum computing
  Tristan Meunier, Senior CNRS researcher / **CNRS / QCosmos**
- **11h05-11h25** Quantum interconnects for scaling-up quantum technologies
  Tom Darras, CEO **/ WeLinQ**
- **11h25-11h45 Les défis de l'informatique quantique dans un monde bruité**
  Alastair Abbott, Chargé de recherche / **INRIA**
- **11h45-12h15 Les opportunités de financement nationales**
  Neil Abroug, Coordinateur national pour la stratégie quantique / SGPI

12:15-13h45 Déjeuner / Networking

- **13h45-14h10 Quantum Programming: A programming shift**
  Olivier Hess, Atos Quantum Computing Leader / **ATOS**
- **14h10-14h35 L'initiative HQI - France Hybrid HPC Quantum Initiative**
  Sabine Mehr, Responsable Calcul Quantique / **Genci**
- **14h35-15h00 IDQ's technologies for mobile phones security and optical quantum simulation**
  Gaëtan Gras, R&D Scientist / **ID Quantic**
- **15h00-15h25 Composants et circuits intégrés photoniques pour les communications et le calcul quantique**
  Ségolène Olivier, Integrated Quantum Photonics Program Manager / **CEA-LETI** et **Jean-Michel Gérard**, Directeur de recherche / **CEA-IRIG**

15:25-15h45 Pause Café / Networking & Session Posters

- **15h45-16h15 L'apport des technologies quantiques pour les capteurs de Thales**
  Cédric Demeure, VP Research and Technology / **Thales**
- **16h15-17h00 Table ronde autour des capteurs quantiques**
  Modérateur : **Audrey Bienfait**, CNRS Researcher at ENS de Lyon
  Participants
  Agustin Palacios-Laloy, PhD, CTO / **Mag4Health**
  Dimitri Labat, Co-founder & CTO / **Chipiron**
  Jessica Bousquet, PhD Engineer, **Diamfab**
  Cédric Demeure / VP Research and Technology / **Thales**
- **17h00-17h20 Conclusion : Le quantique à Grenoble**
  Thierry Chanelière, Scientific Researcher CNRS, Institut Néel
  Anna Minguzzi, Directrice de recherche au CNRS
  Andrea Busch, Head of inward Investment, Invest in Grenoble Alpes

Panorama des technologies quantiques

Keynote introductive

Un an d’évolutions dans les technologies quantiques

Maud Vinet, CEO, **Qcosmos**
Olivier Ezratty, Consultant et auteur

MINALOGIC
Auvergne-Rhône-Alpes

un an d'évolutions des technologies quantiques

maud vinet
CEO, Qcosmos
maud.vinet@cea.fr

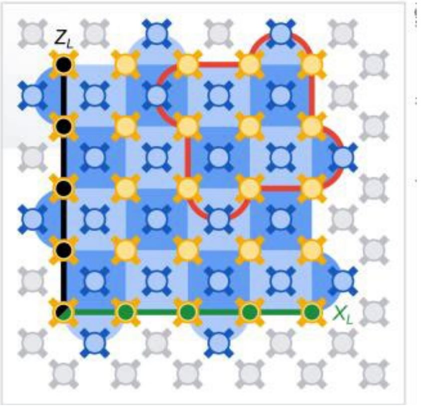
olivier ezratty
consultant et auteur
olivier@oezratty.net www.oezratty.net

Journée Thématique Panorama des Technologies Quantiques, Grenoble, 4 octobre 2022

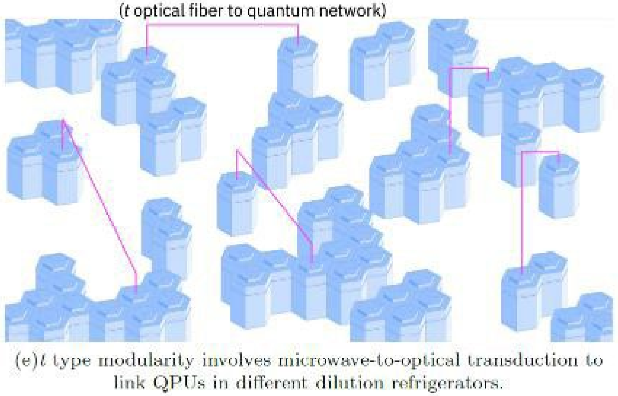
agenda

		october 2021		october 2022	
# operational qubits	supra	65 IBM	→	127	
	cold atoms	N/A / 256	→	100 / 324 PASQAL	
	ions	11 IONQ	→	22 IONQ, 20 AQT, 20 QUANTINUUM	
	silicon spin	4 QuTech	→	6 QuTech	
	photons	113 中国科学院	→	216 XANADU	boson sampling photon modes
2-qubit gate fidelities	supra	99.1% IBM	→	99.99% IBM	with 27 qubits
	ions	99.76% QUANTINUUM	→	99.81% QUANTINUUM	with 12 qubits
	cold atoms	97.4% HARVARD	→	99.4% ColdQuanta	with 100 qubits
	silicon spin	98% QuTech	→	>99% UNSW, QuTech, RIKEN	with 2 Si & SiGe qubits

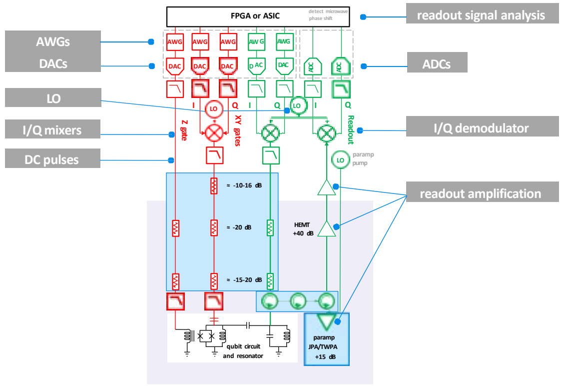
actualité des qubits



correction et mitigation d'erreurs



scale-in et scale-out



technologies habilitantes

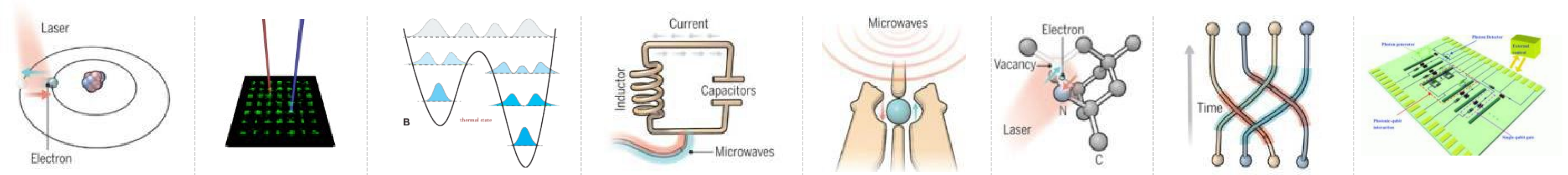
scène entrepreneuriale

#QEI

the quantum energy initiative

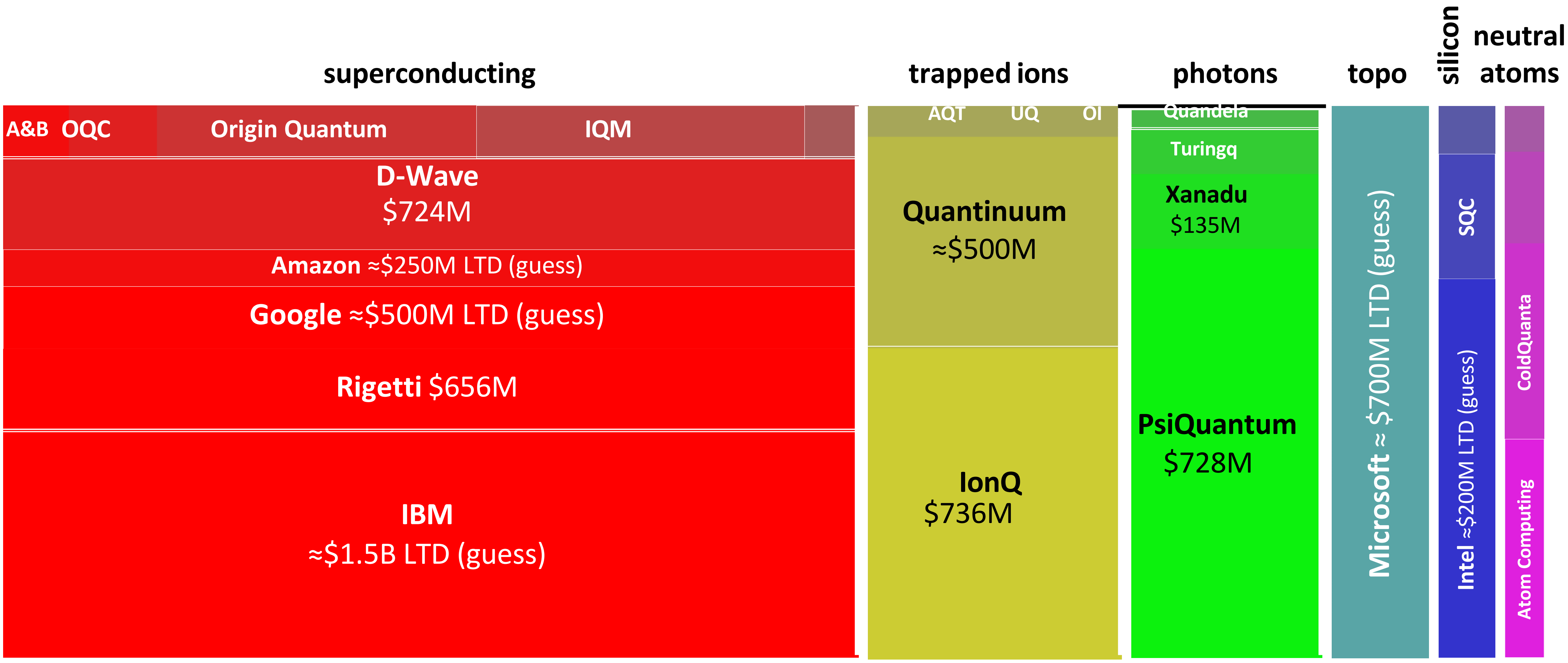
innovation responsable

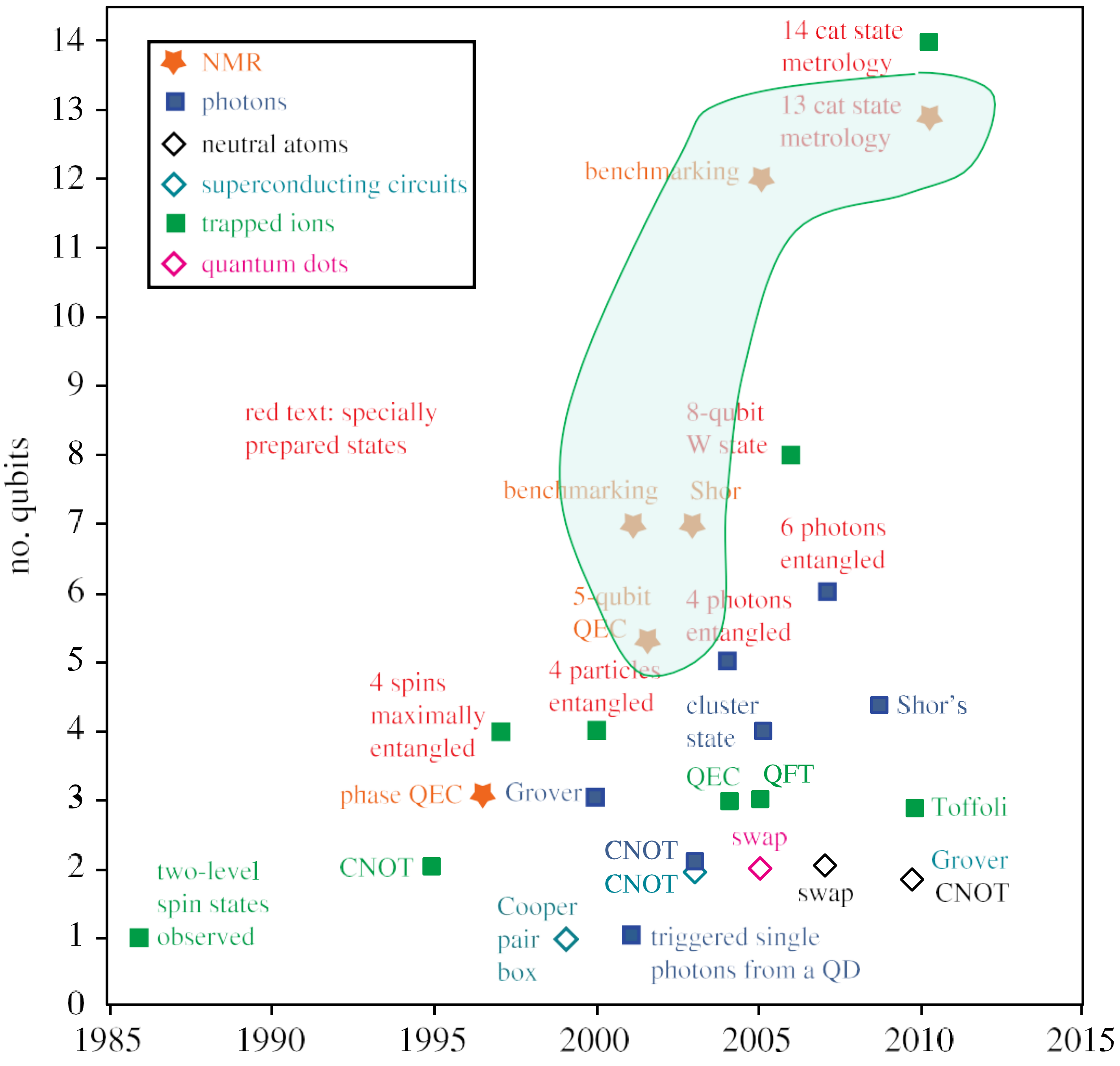
atoms		electron *superconducting loops & controlled spin*					photons



	trapped ions	cold atoms	quantum annealing	super-conducting	silicon	spin vacancies	topological	photons
vendors	IONQ, AQT, OXFORD IONICS, eleQtron, FOXCONN	PASQAL, ColdQuanta, ATOM COMPUTING, QuEra, COMPUTING INC., planqc	D-WAVE The Quantum Computing Company, QILIMANJARO QUANTUM TECH, NEC	IBM, rigetti, amazon, Google, OQC, qci, Nord Quantique, OXFORD QUANTUM, IQM, ALICE & BOB, ANYON, Alibaba, ATLANTIC, 本源量子 Origin Quantum, EeroQ, Baidu, bleximo, FUJITSU	QUANTUM MOTION, QCOSMOS, intel, C12, Silicon Quantum Computing, NTT, diraq, equal1.labs, QπAI, QuTech, ARCHER	TURING, QUANTUM BRILLIANCE, photonic, XEED The Quantum Transcendence	Microsoft, NOKIA	PsiQuantum, XANADU, ORCA Computing, QBoson, QUANDELA, DUALITY QUANTUM PHOTONICS, QUIX QUANTUM, BardeenQ LABS, QCI Ready-to-Run Quantum Systems, TUNDRASYSTEMS GLOBAL LTD
labs (*)	IQST, University of Maryland, MIT, KIT Karlsruher Institut für Technologie, IQI, universität innsbruck, Sandia National Laboratories, JGU Johannes Gutenberg Universität Mainz, NIST, HARVARD UNIVERSITY, US University of Sussex	CNRS, Institut d'Optique Graduate School, HARVARD, Caltech, JÜLICH Forschungszentrum, PennState, EPFL, The Ohio State University	NEDO, Stanford University, MIT, KIT Karlsruher Institut für Technologie, MCQST, ETH zürich	cea, CNRS, MIT, Inria, UCSB, QuTech, UMassAmherst, MCQST, ETH zürich, Universität des Saarlandes, Berkeley University of California, Yale, Caltech, 東京大学 The University of Tokyo	cea, CNRS, University of Bristol, University of Oxford, UNSW Sydney, Yale, HRL Laboratories, ETH zürich, The University of Wisconsin Madison, EPFL, RIKEN, Princeton University	cea, CNRS, MIT, University of Maryland, TU Delft, HARVARD UNIVERSITY, Universität Stuttgart, The University of Chicago	cea, CNRS, University of Maryland, UCSB, TU Delft, QuTech, Niels Bohr Institutet, The University of Sydney	CNRS, University of Bristol, University of Oxford, universität wien, 東京大学 The University of Tokyo

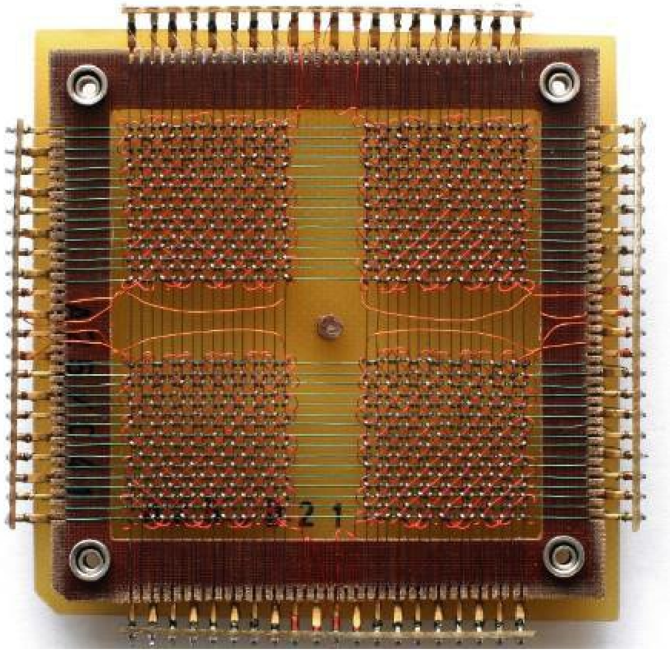
(*) non exhaustive inventory, missing Chinese labs among others


superconducting
trapped ions
photons
topo
silicon
neutral atoms
A&B
OQC
Origin Quantum
IQM
D-Wave $724M
Amazon ≈$250M LTD (guess)
Google ≈$500M LTD (guess)
Rigetti $656M
IBM ≈$1.5B LTD (guess)
AQT
UQ
OI
Quantinuum ≈$500M
IonQ $736M
Quandela
Turingq
Xanadu $135M
PsiQuantum $728M
Microsoft ≈ $700M LTD (guess)
SQC
Intel ≈$200M LTD (guess)
ColdQuanta
Atom Computing

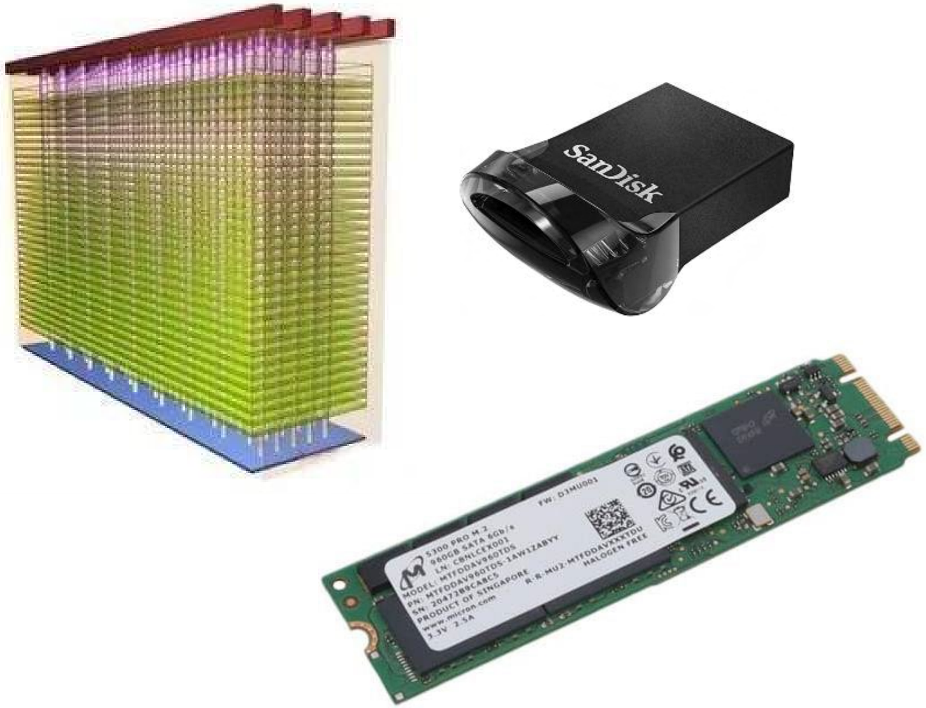


a chart with number of qubits per technology and year, as of 2015. It gave the impression, back then, that **NMR qubits** were the most scalable. They are not! Source: Recent advances in nuclear magnetic resonance quantum information processing by Ben Criger, Gina Passante, Daniel Park and Raymond Laflamme, The Royal Society Publishing, 2015 (16 pages).

early classical memory technologies



magnetic core memory 1954-1975
1μs - 6μs access times
non volatile, 128 bytes
used in IBM 705 and DEC PDP-1



flash memory 2022
512 GB in a single chipset
20ns - 70 ns access times

qubits figures of merits progress

		october 2021		october 2022	
# operational qubits	supra	65 IBM	→	127 IBM	
	cold atoms	N/A / 256	→	100 / 324 PASQAL	
	ions	11 IONQ	→	22 IONQ, 20 AQT 20	
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	cold atoms	97.4% HARV	→	99.4% ColdQuanta	with 100 qubits
	silicon spin	98% QuTech	→	>99% UNSW QuTech RIKEN	with 2 Si & SiGe qubits

superconducting qubits

127 qubits
november 2021

scale-out roadmap
may 2022

Sycamore 72 qubits
july 2022

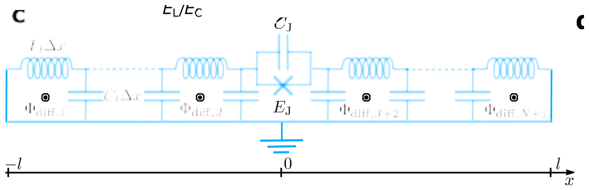
>100s T_1
march 2022

raised 27M€
march 2022

raises £38M
august 2022

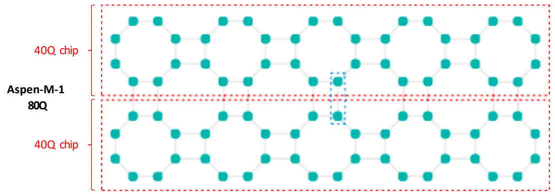
Unimon qubits
march 2022

raises 128M€
july 2022



80 qubits Aspen M-1
late 2021

$345M SPAC
march 2022



quantum dots spins qubits

diraq

Andrew Dzurak's team proposes a simpler system to feed qubits with microwaves

february 2021

Silicon Quantum Computing

« first processor »

new funding round launched

2022

QCOSMOS

Startup launched in October 2022

intel®

Improving qubit manufacturing

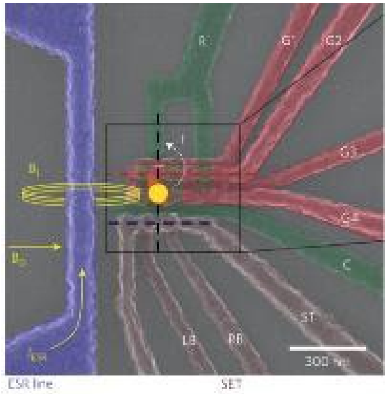
March 2022

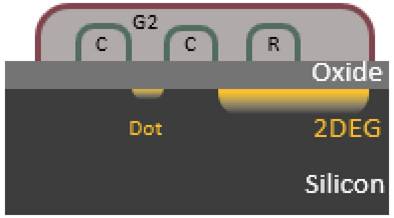
quantum dots (spin) qubits

players		technology	patents	total funding
intel		Intel leverages its mainstream Finfet technology	>100	
QCOSMOS		leverages FDSOI technology	24*(42**)	fund raising
QUANTUM MOTION		uses spin qubits fabricated by EU RTOs (Leti and IMEC)	10*	$9.8M
diraq		recently incorporated after having separated from SQC. No prefered relation with foundry yet.	7* (28**)	AUS $20M
Silicon Quantum Computing		relies on deterministic ion implantation thanks to STM Ambition to build their own fabrication facilities	5*	~AUS $90M
equal1.labs		charge-based qubits wilingness to stay with plain existing technologies	3*	$11.3M
photonic		uses defects in silicon (impurities) optically addressed, no deterministic pathway yet to position these impurities	6*	>$20M

different electron spin qubits platforms

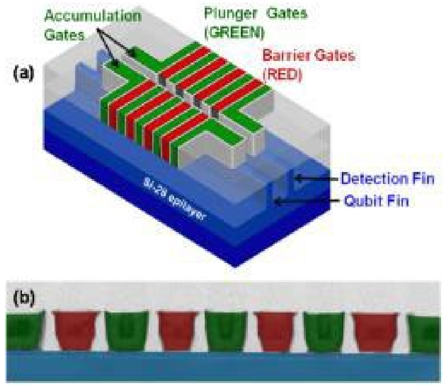
Si-MOS





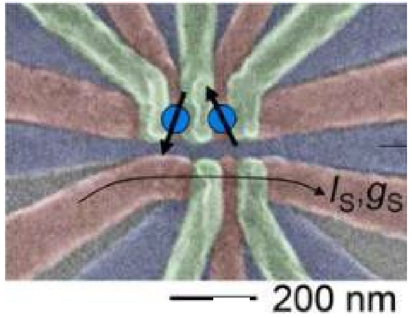
UNSW, Sandia Labs, CEA-Leti

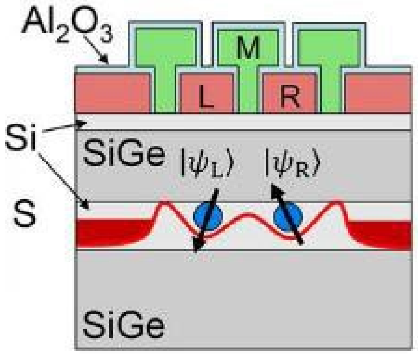
Fin-FET



Intel, TU Delft

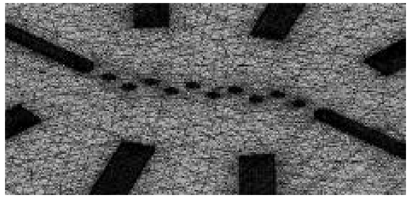
Si/SiGe

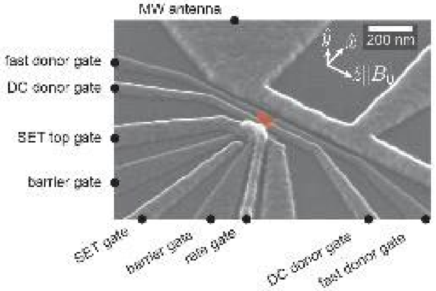




Princeton, RIKEN, TU Delft

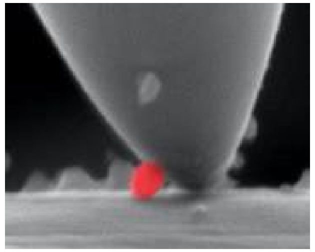
donors

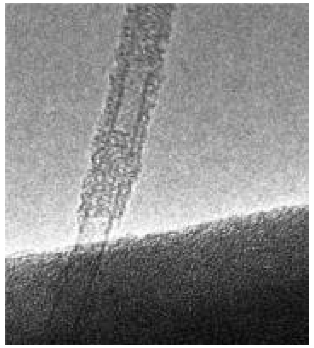




UNSW, SQC

carbon
nanotubes/spheres



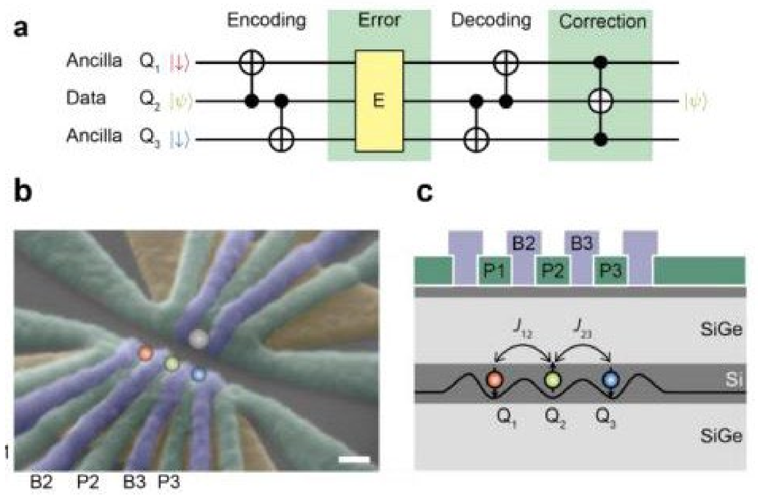


C12 Quantum Electronics, Archer Materials

quantum dots spin scientific news

towards large scale quantum computing

fFirst PoC of error correction (Seigo Tarucha @ Tokyo)



long distance quantum information transfer

nature

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Article | Published: 25 December 2019

Resonant microwave-mediated interactions between distant electron spins

F. Borjans, X. G. Croot, X. Mi, M. J. Gullans & J. R. Petta

Nature **577**, 195–198 (2020) | Cite this article

SpinQubit5

fabs

research fabs

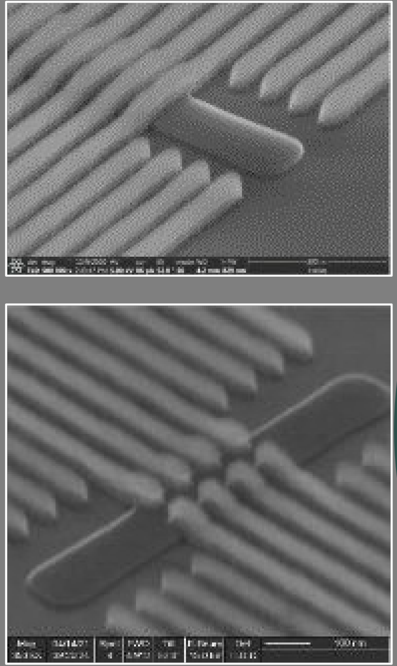
pre-industry research fabs

foundry vendors

in-house vendor fabs

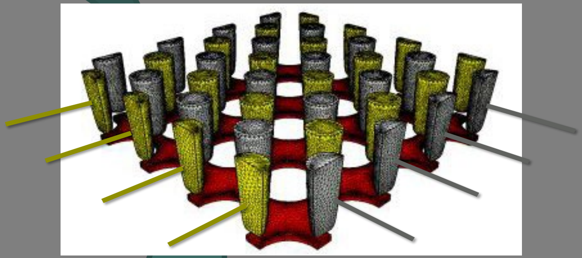
manufacturing foundations

fabrication

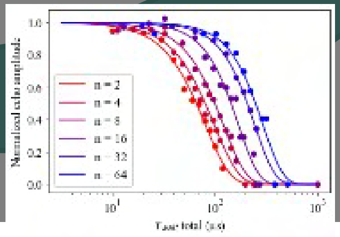


statistical characterization

modelling and simulation

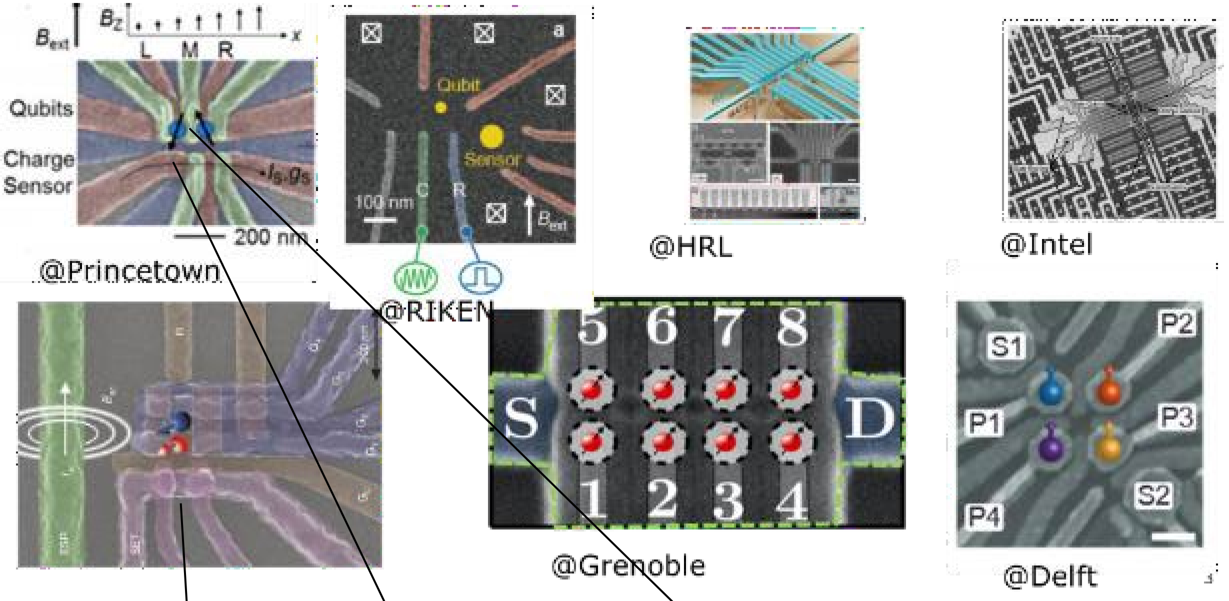


physics understanding

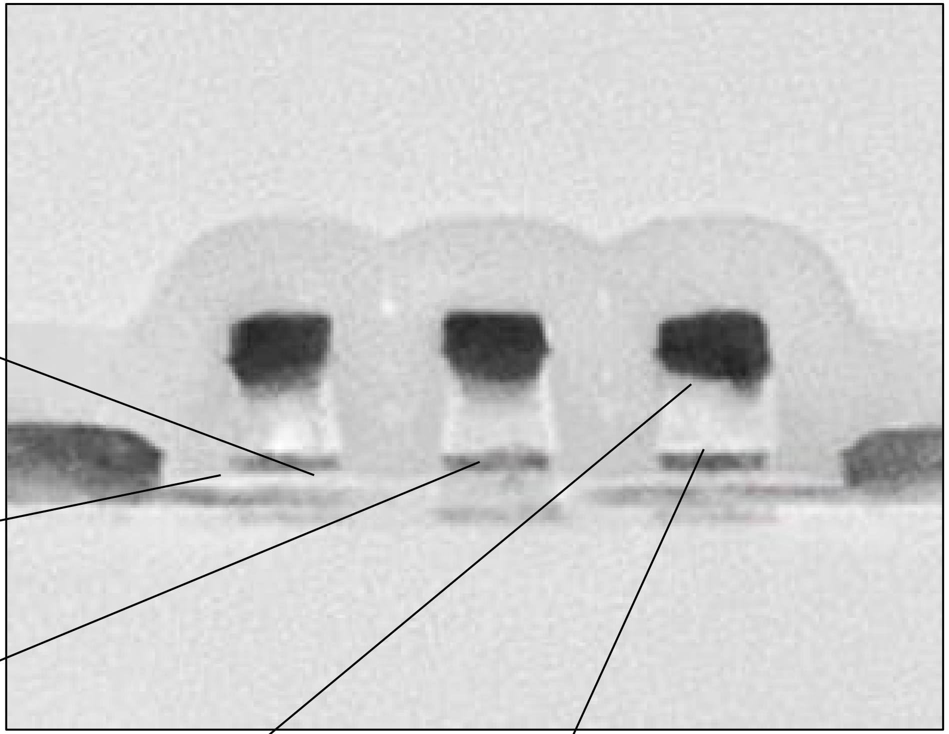


what choices are there?

layout



stack



timely moment for EU manufacturing

Le Monde

Consulter le journal | Se connecter

ACTUALITÉS | ÉCONOMIE | VIDÉOS | DÉBATS | CULTURE | M LE MAG | SERVICES

ÉCONOMIE · TECHNOLOGIES

Semi-conducteurs : GlobalFoundries et STMicroelectronics annoncent la construction d'une usine à Grenoble

Cette nouvelle usine devrait créer environ mille emplois supplémentaires, pour un investissement estimé à 5,7 milliards d'euros.

Le Monde avec AFP

Publié le 11 juillet 2022 à 09h27 · Mis à jour le 11 juillet 2022 à 10h29 · Lecture 1 min.

FRANCE 2030 — La France de demain commence aujourd'hui.

STRATEGIE NATIONALE QUANTIQUE

QUANTUM FLAGSHIP

KDT JU — Key Digital Technologies Joint Undertaking

EUROPEAN CHIPS ACT

trapped ions qubits

IONQ

May 3, 2022 | Investigative report by Scorpion Capital | www.scorpioncapital.com

IONQ (NYSE: IONQ)

The "World's Most Powerful Quantum Computer" Is A Hoax With Staged Nikola-Style Photos – An Absurd VC Pump With A Recent Lock-Up Expiration Takes SPAC Abuses To New Extremes

- A part-time side-hustle run by two academics who barely show up, dressed up as a "company"
- A useless toy that can't even add 1+1, as revealed by experiments we hired experts to run
- Fictitious "revenue" via sham transactions and related-party round-tripping
- A scam built on phony statements about nearly all key aspects of the technology and business
- CEO appears to be making up his MIT educational credentials

$1.6B market cap | $8/share | ADV 6.4MM shares | Short interest 7mm shares

Scorpion Capital report

march 2022

22 qubits online

2022

HQS M&A with CQC becomes Quantinuum

november 2021

12 qubits online

2022

QUANTINUUM

AQT

20 qubits

2022

photon qubits

QUANDELA

Perceval qubit emulation software

march 2022

XANADU

programmable GBS

march 2022

QBoson 玻色量子

1000 operational photon qubits in a laboratory (supposedly)

coherent Ising machine

july 2021

QuiX

THE FASTEST WAY TO A QUANTUM FUTURE

programmable photonic circuit with 20 qubits

2022

QCi Ready-to-Run Quantum Systems

Qphoton acquisition

2022

exotic qubits

MAY 20, 2022

Unique quantum material could enable ultra-powerful, compact computers

by Ellen Neff, Columbia University Quantum Initiative

qubits, gates and entanglement not mentioned in the paper!

OCTOBER 12, 2021

Researchers unlock secret path to a quantum future

by Rachel Berkowitz, Lawrence Livermore National Laboratory

ensemble of NV centers, very hard to control and entangle

MAY 4, 2022

Building a better quantum bit: New qubit breakthrough could transform quantum computing

by Bill Wellock, Florida State University

electron on solid neon

Breakthrough offers new route to large-scale quantum computing

by John Sullivan, Office of Engineering Communications

Nov. 27, 2012, midnight

first Princeton realization of quantum dots spin qubits in … 2012 !

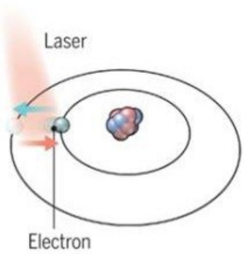
[Submitted on 25 Apr 2022]

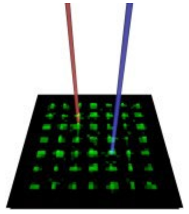
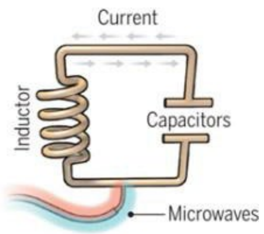
Quantum supremacy with spin squeezed atomic ensembles

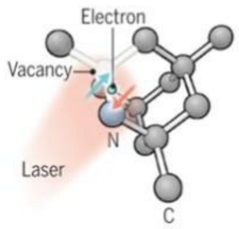
Yueheng Shi, Junheng Shi, Tim Byrnes

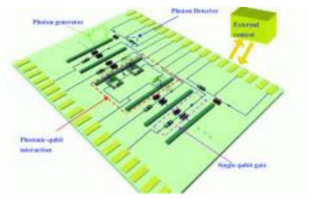
We propose a method to achieve quantum supremacy using ensembles of qubits, using only spin squeezing, basis rotations, and Fock state measurements. Each ensemble is assumed to be controllable only with its total spin. Using a repeated sequence of random basis rotations followed by squeezing, we show that the probability distribution of the final measurements quickly approaches a Porter-Thomas distribution. We show that the sampling probability can be related to a #P-hard problem with a complexity scaling as $(N+1)^M$, where N is the number of qubits in an ensemble and M is the number of ensembles. The scheme can be implemented with hot or cold atomic ensembles. Due to the large number of atoms in typical atomic ensembles, this allows access to the quantum supremacy regime with a modest number of ensembles or gate depth.

conceptual proposal with spin ensembles







	atoms		superconducting & controlled spin			photons
quantum objects	**trapped ions**	**cold atoms**	**super-conducting**	**quantum dots spins**	**cavity spins (NV, SiC)**	**photons**
gate-based computing						
quantum simulation						
quantum annealing						
quantum memory					in repeaters	with cold atoms
quantum telecoms & QKD					in repeaters	
quantum sensing			SQUIDs			

QEM vs QEC

QEM

quantum error mitigation

↓

NISQ

reduces errors with classical post-processing techniques, circuits modifications & several runs and results average

uses machine learning techniques

QEC

quantum error correction

↓

FTQC / LSQ

create longer lifetime logical qubits with apparent lower error rates

physical/logical qubit ratios

surface codes, color codes, LDPC codes, Floquet codes, etc.

fault-tolerant error correction

qubits for FTQC?

>100 logical qubits with 10^{-8} to 10^{-15} error rates

- >50 useful logical qubits for Hilbert space over 2^{50} (equiv to > 72 PB RAM)
- +≈50 additional ancilla qubits required with most algorithms (QFT, …)
- for ↘RSA 2048 keys, ≥4098 logical qubits are needed target error rate ≈ 1/# gates in algorithm

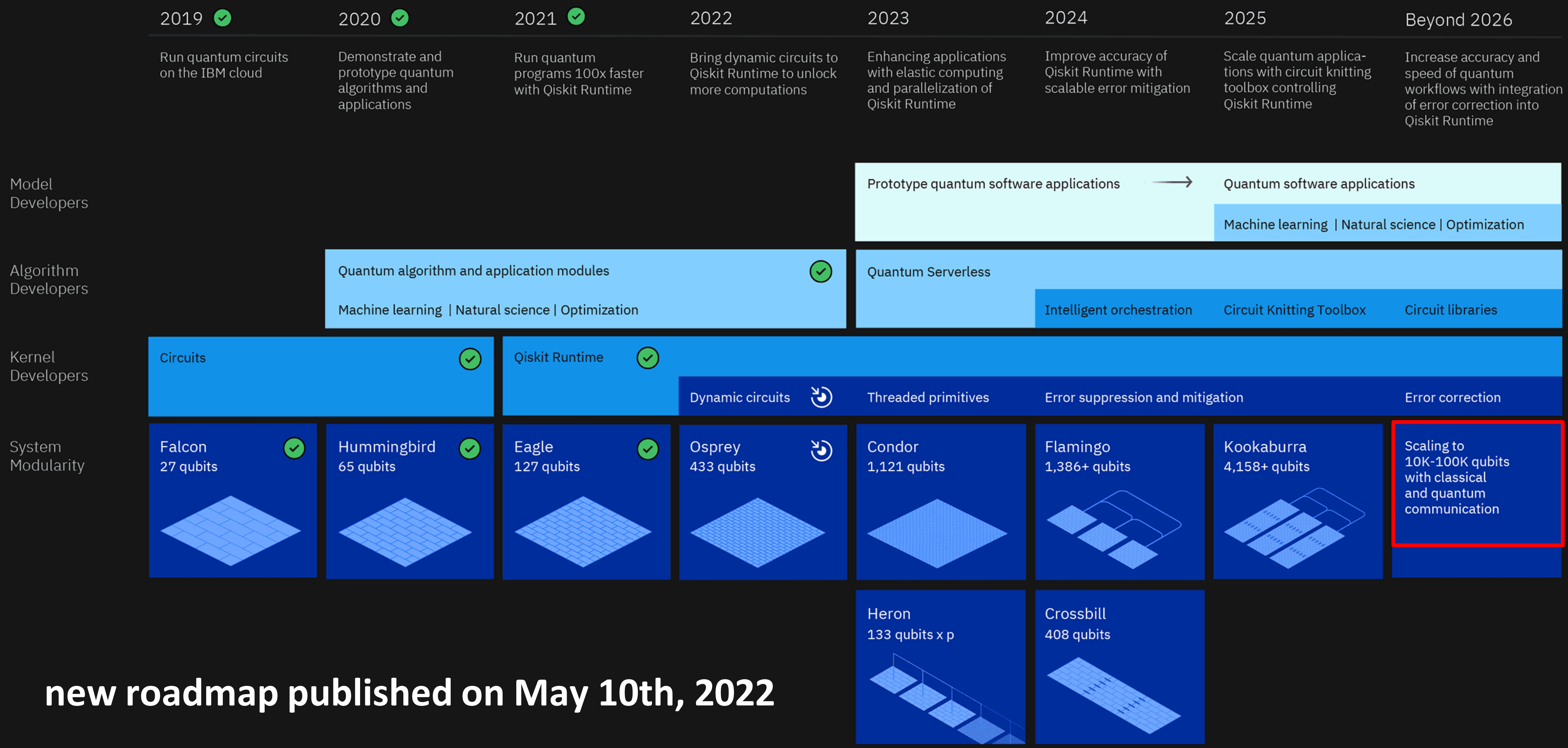
physical/logical qubit rates varies

- 1000-10000 estimates by Google/IBM/PsiQuantum => 1M qubits
- 30 estimate by Alice&Bob & 10^{-8} error rate => 3000 qubits
- 16-32 estimates by IonQ => 3200 qubits (but scaling > 40 qubits?)

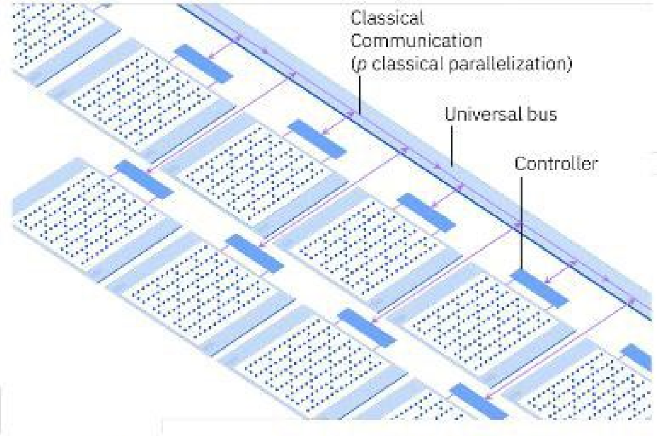
Development Roadmap

Executed by IBM
On target

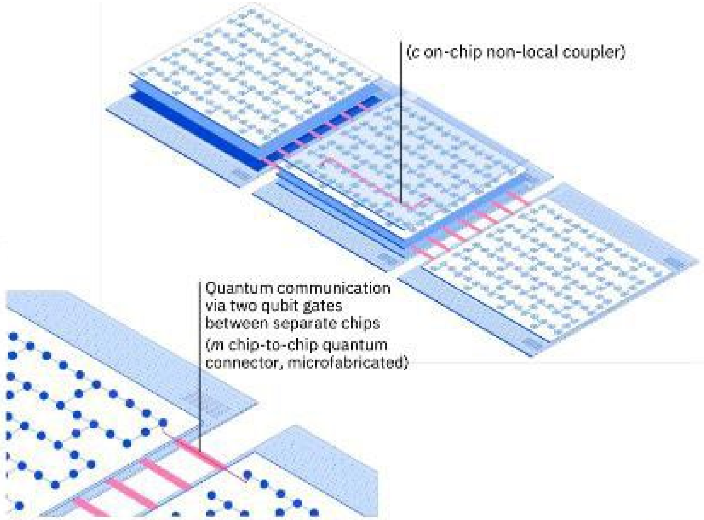
IBM **Quantum**



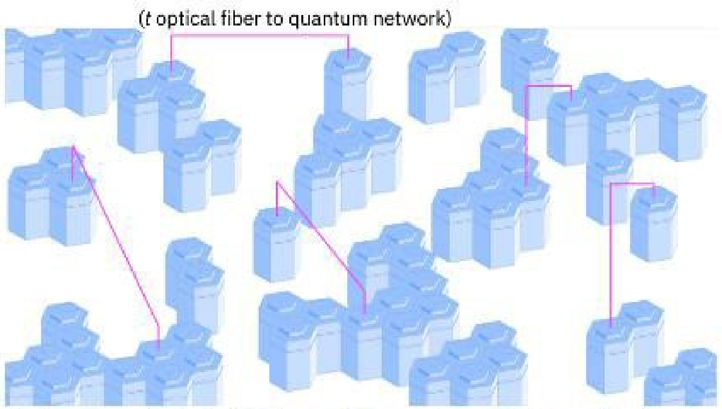
new roadmap published on May 10th, 2022



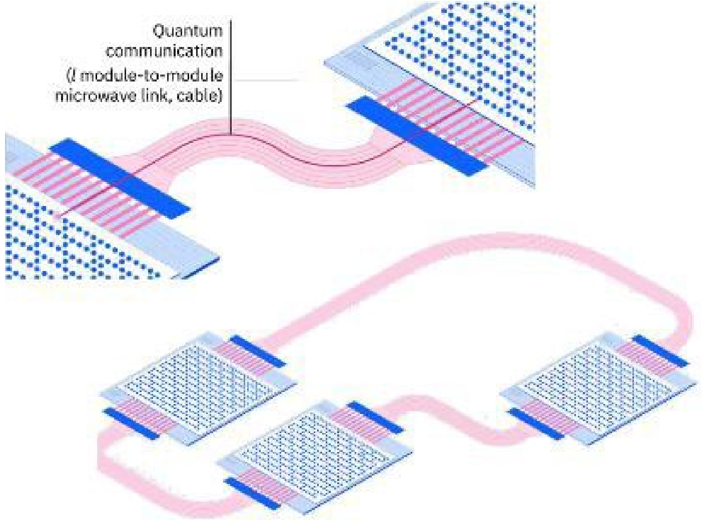
(a)p type modularity for classical parallelization of QPUs



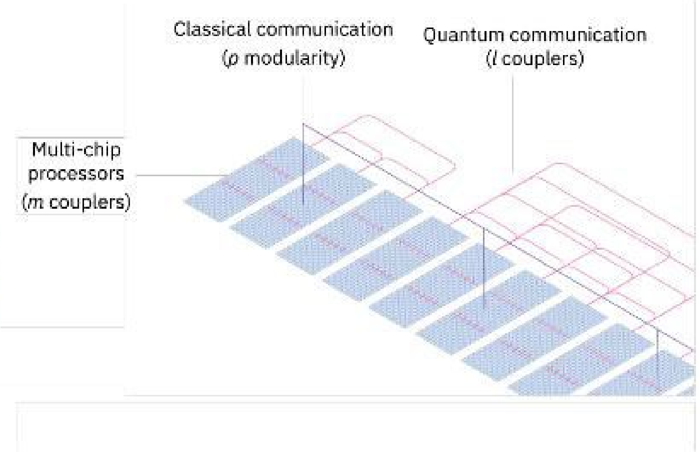
(b)Dense modularity m and on-chip non-local couplers c for LDPC codes for creating a single QPU from multiple chips



(e)l type modularity involves microwave-to-optical transduction to link QPUs in different dilution refrigerators.



(c)Long-range l type modularity to enable quantum parallelization of multiple QPUs



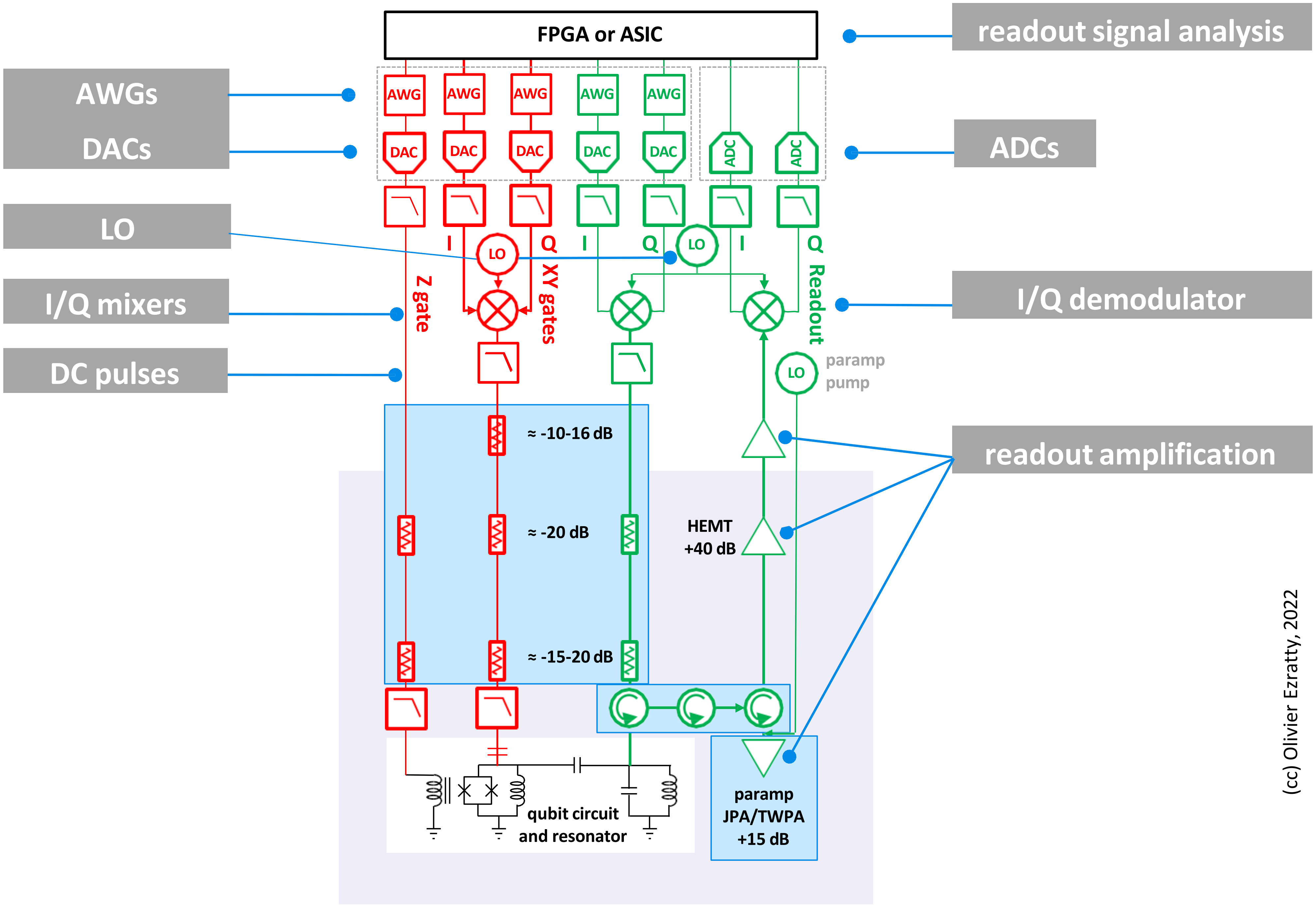
(d)l, m, p schemes can be combined to extend the scale of hardware to thousands of qubits.

IBM

source: The Future of Quantum Computing with Superconducting Qubits by Sergey Bravyi, Oliver Dial, Jay M. Gambetta, Dario Gil and Zaira Nazario, IBM Quantum, September 2022 (20 pages)

scale-in vs scale-out

scale-in	scale-out
SILENT WAVES	WeLinQ
ATEM customized connectivity	QPHOX
Radiall	NEXT GENERA QU
	BOHR QUANTUM



FPGA or ASIC
readout signal analysis
AWGs
DACs
AWG
DAC
ADC
ADCs
LO
I
Q
Z gate
XY gates
Readout
I/Q mixers
I/Q demodulator
DC pulses
paramp
pump
≈ -10-16 dB
≈ -20 dB
≈ -15-20 dB
HEMT
+40 dB
readout amplification
qubit circuit
and resonator
paramp
JPA/TWPA
+15 dB

	DC pulses	LO	AWG	DAC	I/Q mixers	I/Q demod	readout parametric amplification	readout ADC	readout signal analysis	temp	power / qubit
Google - Bardin 2019			for X and Y gates	yes	yes					3K	2 mW
Microsoft/Sydney /Purdue, FD-SOI 28 nm, 2019	yes	yes	only external signal routing to qubit							100 mK	N/A, low power
CEA List/Leti FD-SOI 28 nm 2020	Yes	yes					Yes TIA amplification			110 mK	295µW
QuTech& Intel FinFET 22 nm 2020			Yes, 8-10 bits	Yes	yes						12 mW
HorseRidge 2 FinFET 22 nm, Intel 2021	yes		yes, 14-bit	yes	Yes	yes	only LNA between paramp and HEMT	yes		4K	27 mW (to check)
EPFL, CMOS 40 nm 2021						yes	time and frequency domain readout signal multiplexing			50 mK	
POSTECH Korea CMOS 40 nm 2022		2	yes, 4 bits	yes, 4 bits	yes	yes	LNA	yes		3.5K	15 mW
IBM, FinFET 14 nm 2022			Yes		Yes					3.5K	23 mW
SeeQC, SFQ 2019 **DigiQ**, USC, Chicago, Nvidia 2022 (*)	yes		replaced by series of single amplitude pulses				yes			3K/600 mK (SFQ copro) & 20 mK (DQM)	0,24 mW (*)
IBM QEC, SFQ 2022									partial surface code QEC	4K	10µW to 500µW per logical qubit

algorithms figures of merit

provable speedup vs classical algorithms

and/or

other quantitative advantages: precision, error rates for quantum machine learning, energy consumption.

relative small-size data output since N qubits generate only N useful bits of information.

correctness guarantee on the results.

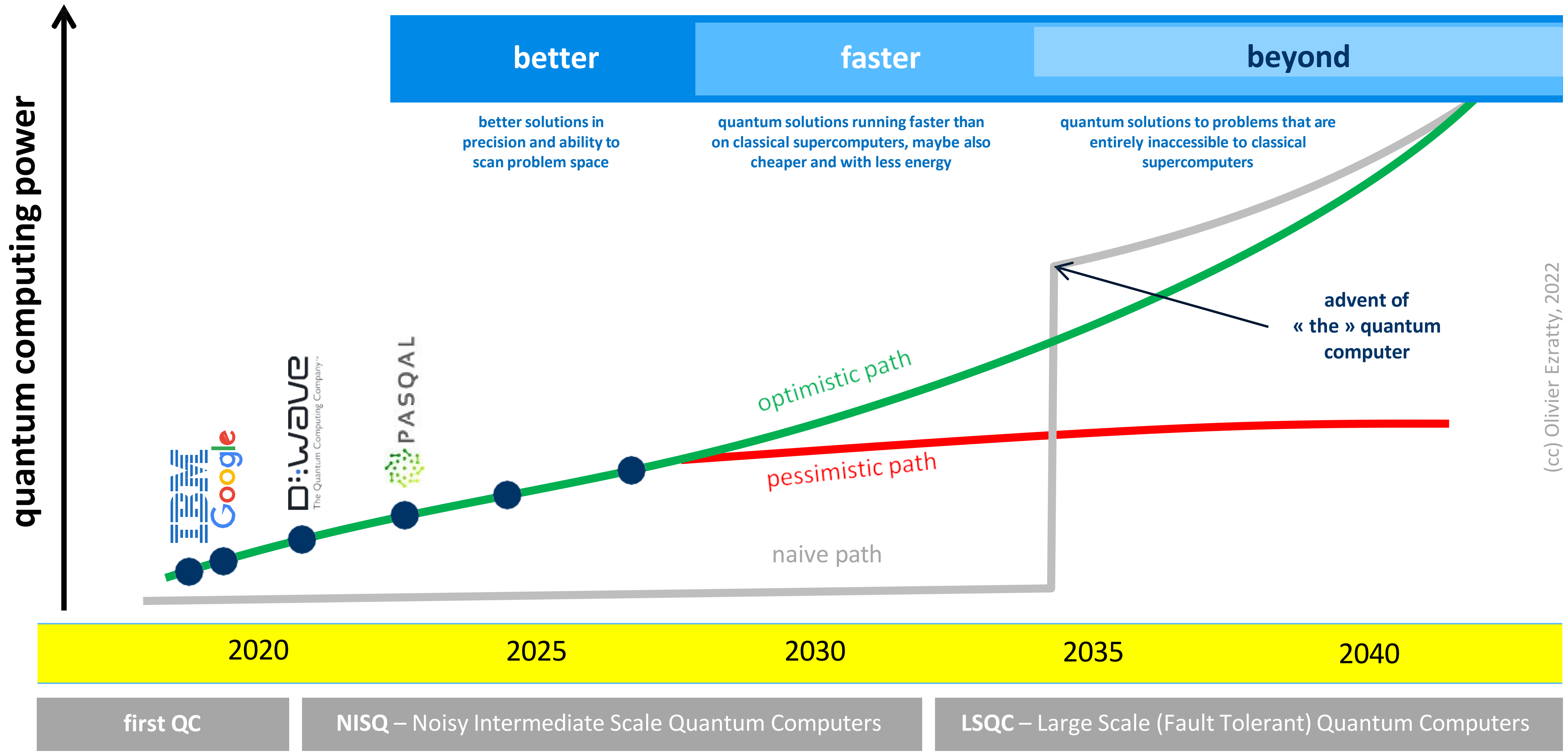
solve some useful problem.

shallow depth circuit (not many quantum gate cycles).

resilience to qubit noise.

} NISQ

when will we have 'a' quantum computer ?



quantum computing cloud offerings

	hybrid computing centers	OVHcloud	IBM	aws	Microsoft	Google
emulation	40 qubits Atos	Atos	36 qubits	34-50 qubits	30 qubits	40 qubits
computing	hybrid quantum TGCC JÜLICH LUMI in 2023	PASQAL 100 qubits (quantum simulation) …	IBM 5 to 127 qubits	D:Wave 5000 qubits IONQ 32 qubits rigetti 80 qubits OQC 8 qubits (**) QuEra Computing Inc. XANADU	PASQAL 100 qubits (q. simulation) IONQ 32 qubits rigetti 80 qubits QUANTINUUM 12 qubits	IONQ 11 qubits

et aussi…

D:Wave
QCWARE
XANADU
Quantum Inspire - By QuTech

industry vendors ecosystem

computing

PASQAL

C12

QCOSMOS

QUANDELA

Atos

software

Qubit pharmaceuticals

Atos

QuantFi

QbitSoft
Quantum as a Service

VeriQloud

ColibrITD

AQEMIA

cybersecurity

CRYPTONEXT SECURITY

Crypto Experts

ravel

SECURE-IC
THE SECURITY SCIENCE COMPANY

sensing

THALES

iXblue PHOTONICS

wainvam

Syrlinks

orolia

chipiron

MAG4Health

cryogeny

Air Liquide

CryoConcept

INNOVATIVE SOLUTIONS ABSOLUT SYSTEM

MYCRYOFIRM
CRYOGENIC SOLUTIONS

electronics

SILENT WAVES

WeLinQ

Radiall

ATEM

SILENTSYS
ultralow noise systems

photonics

cailabs
SHAPING THE LIGHT

Lytid

iXblue PHOTONICS

SPARK LASERS

LUMIBIRD

AUREA TECHNOLOGY

AZURLIGHT SYSTEMS

GLOphotonics

QUANDELA

manufacturing

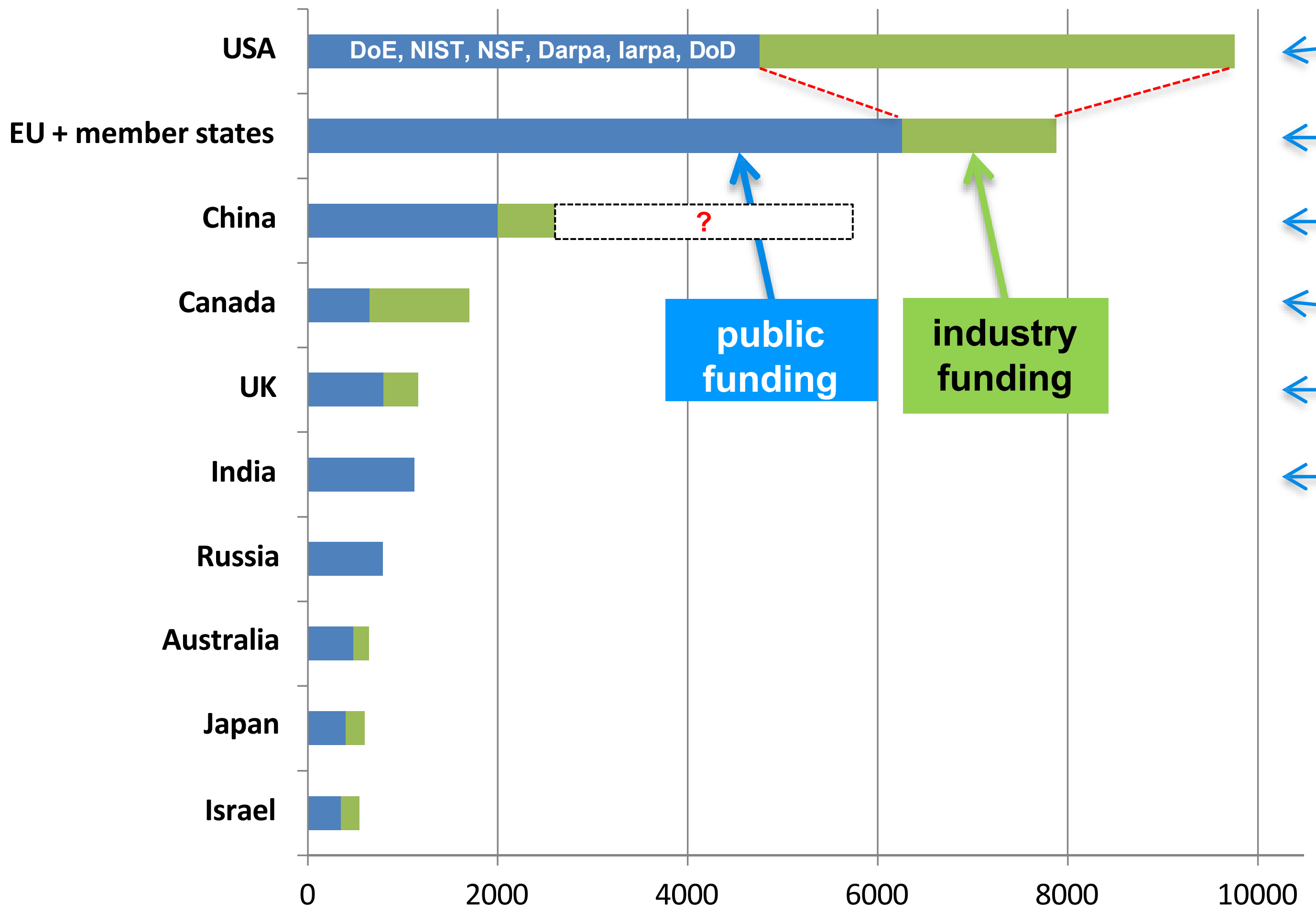
PLASSYS

RIBER

isotopes

orano

the « true » global investments



IonQ & Rigetti SPAC, PsiQuantum, Quantinuum, other startups, IBM, Google, Amazon, Intel, Microsoft, Raytheon, $4.76B Federal.

EU Flagship, Germany's 2.6B€ (not including legacy investments), France 1.8B€, Netherlands 900M€, optimistic guesstimate of private sector funding.

<$3B since 2011, poor (visible) startups investments, includes Alibaba, Huawei, Baidu, Tencent

D-Wave, Canada and regions plans, IBM investment in Bromont and Sherbrooke.

£1.2B over 8 years

need to check the practicality of their $1.12B 5Y plan

source: Olivier Ezratty compilation, August 2022, on a 5 year period, past, present or future depending on the country. Euro/$ parity.

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a Physical Review journal

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Perspective Open Access

Quantum Technologies Need a Quantum Energy Initiative

Alexia Auffèves
PRX Quantum **3**, 020101 – Published 1 June 2022

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

Quantum technologies are currently the object of high expectations from governments and private companies, as they hold the promise to shape safer and faster ways to extract, exchange, and treat information. However, despite its major potential impact for industry and society, the question of their energetic footprint has remained in a blind spot of current deployment strategies. In this Perspective, I argue that quantum technologies must urgently plan for the creation and structuration of a transverse quantum energy initiative, connecting quantum thermodynamics, quantum information science, quantum physics, and engineering. Such an initiative is the only path towards energy-efficient, sustainable quantum technologies, and to possibly bring out an energetic quantum advantage.

- Is there a **quantum energy advantage** as the processors scale up?
- How different is it from the **quantum computational advantage**?
- What is the fundamental **minimal energetic cost** of quantum computing?
- How to **avoid energetic dead-ends** on the road to LSQ? Create optimization tools for qubit technology, enabling technologies and software engineering.
- Propose **energy-based benchmarks**.
- Foster a **cross-disciplinary** research-industry collaboration.

Quantum Energy Initiative – quar

quantum-energy-initiative.org

#QEI

the quantum energy initiative

WELCOME MANIFESTO FAQ CONTACT

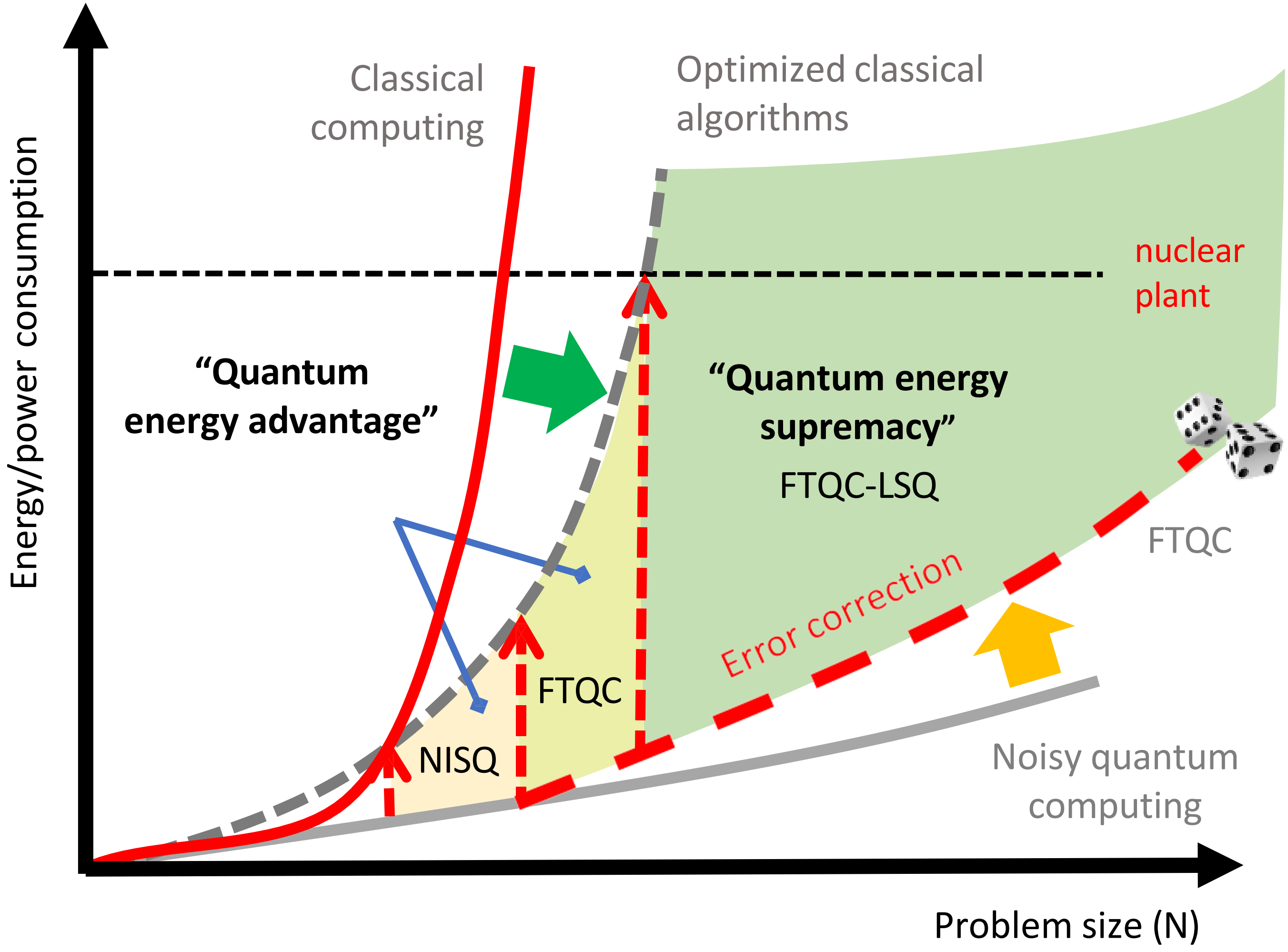
Manifesto

As quantum technologies drive strong expectations from governments and industries, we believe a responsible way of deploying them must include the study of their potential for energy savings and contained environmental footprint. At the present time, reduced energy consumptions have been noticed on various NISQ processors over the world (trapped ions, superconducting qubits, neutral atoms…). While these observations seem to point toward an energetic advantage of quantum nature, the physical mechanisms behind them are barely understood: how does energy consumption scale with the processor size? How does it relate to the computational performance or the qubit technology? How does it compare to classical processors? Beyond quantum computing, the understanding must include quantum communication, quantum sensing and metrology.

In the quest for energy savings, efficiencies are precious beacon lights. Defined as the ratio of the performance over the energy cost, they are bound to become major figures of merit in our finite world: indeed, increasing them holds the promise to implement identical tasks with fewer physical resources.

In quantum technologies, the performance of quantum processes is optimized at the quantum level. One natural way is to mitigate noise: these efforts involve a large range of expertise, from qubits fabrication, quantum thermodynamics, quantum control, thermo-electricity, reservoir engineering, to quantum information sciences

promises of quantum advantage(s)



"Quantum energy supremacy": when a quantum computer solves a problem no classical computer could do with **accessible** energy (and *btw*, time).

"Quantum energy advantage": when a quantum computer solves a problem with less energy than best in-class classical computers and algorithms.

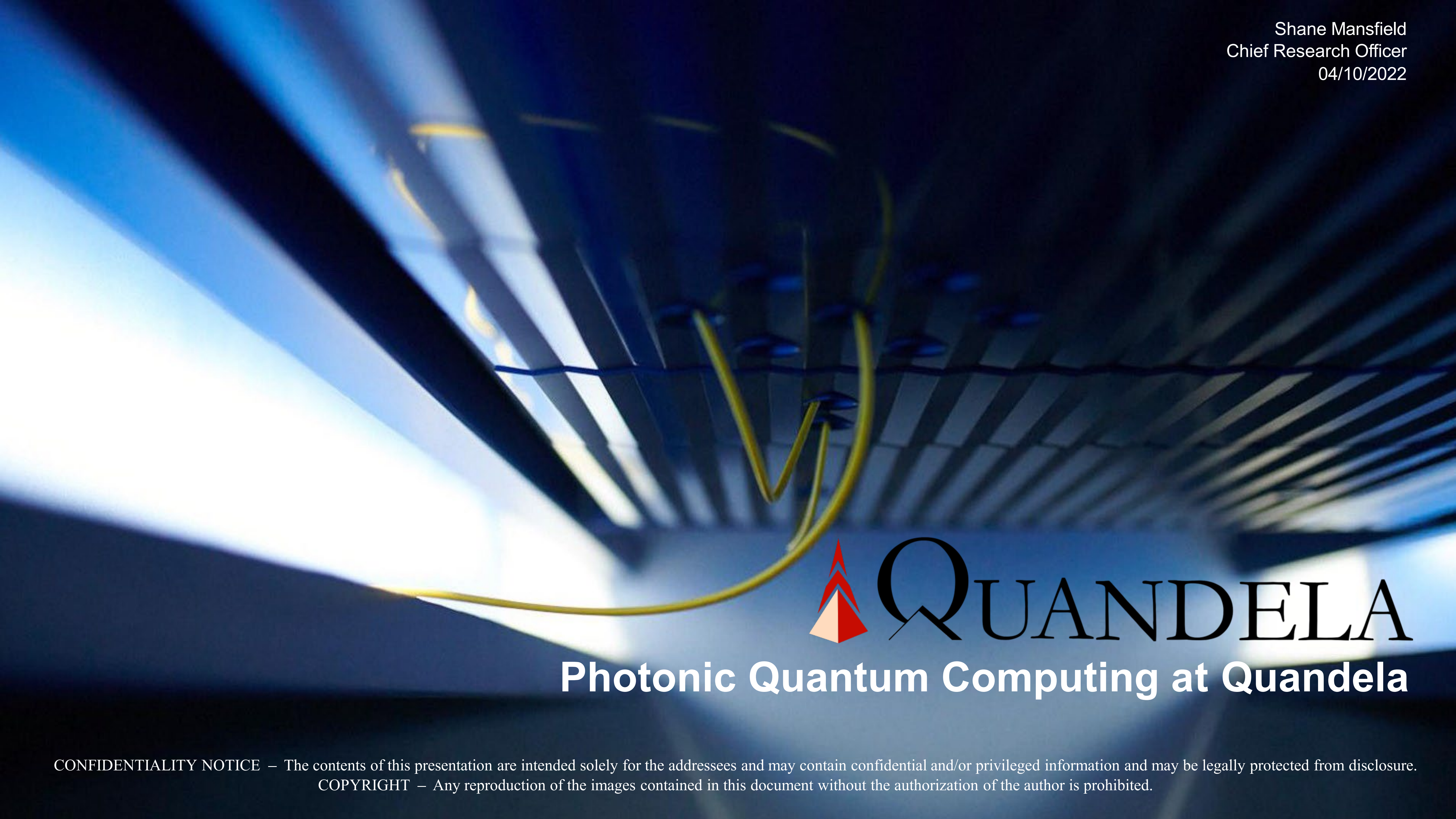
Panorama des technologies quantiques

MINALOGIC
Auvergne-Rhône-Alpes

Informatique quantique à base de photons chez Quandela

Shane Mansfield, Chercheur en informatique quantique / **Quandela**

Shane Mansfield
Chief Research Officer
04/10/2022



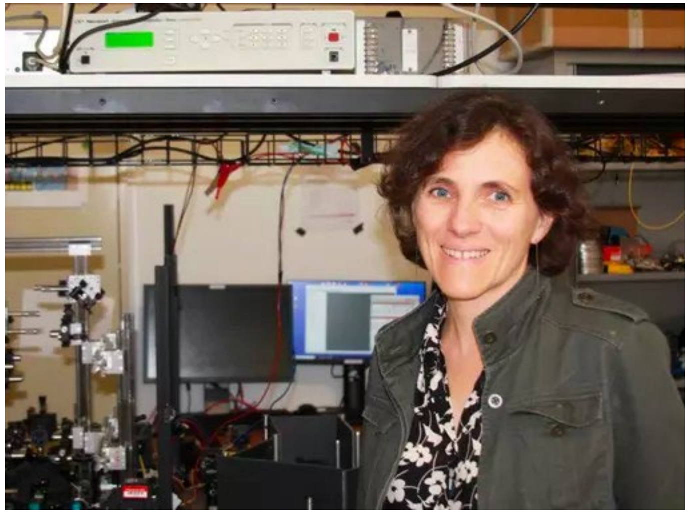
QUANDELA

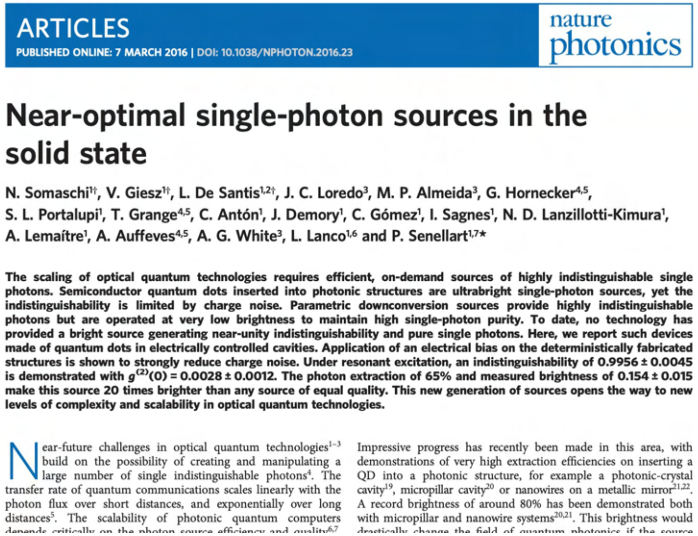
Photonic Quantum Computing at Quandela

2017
Founded by Prof Pascale Sennelart [right], Niccolo Somaschi & Valérian Giesz

Commercialise single-photon sources for quantum technologies

[Centre for Nanosciences and Nanotechnologies Paris-Saclay]





ARTICLES
PUBLISHED ONLINE: 7 MARCH 2016 | DOI: 10.1038/NPHOTON.2016.23
nature photonics

Near-optimal single-photon sources in the solid state

N. Somaschi[1†], V. Giesz[1†], L. De Santis[1,2†], J. C. Loredo[3], M. P. Almeida[3], G. Hornecker[4,5], S. L. Portalupi[1], T. Grange[4,5], C. Antón[1], J. Demory[1], C. Gómez[1], I. Sagnes[1], N. D. Lanzillotti-Kimura[1], A. Lemaítre[1], A. Auffeves[4,5], A. G. White[3], L. Lanco[1,6] and P. Senellart[1,7]*

The scaling of optical quantum technologies requires efficient, on-demand sources of highly indistinguishable single photons. Semiconductor quantum dots inserted into photonic structures are ultrabright single-photon sources, yet the indistinguishability is limited by charge noise. Parametric downconversion sources provide highly indistinguishable photons but are operated at very low brightness to maintain high single-photon purity. To date, no technology has provided a bright source generating near-unity indistinguishability and pure single photons. Here, we report such devices made of quantum dots in electrically controlled cavities. Application of an electrical bias on the deterministically fabricated structures is shown to strongly reduce charge noise. Under resonant excitation, an indistinguishability of 0.9956 ± 0.0045 is demonstrated with $g^{(2)}(0) = 0.0028 \pm 0.0012$. The photon extraction of 65% and measured brightness of 0.154 ± 0.015 make this source 20 times brighter than any source of equal quality. This new generation of sources opens the way to new levels of complexity and scalability in optical quantum technologies.

Near-future challenges in optical quantum technologies[1–3] build on the possibility of creating and manipulating a large number of single indistinguishable photons[4]. The transfer rate of quantum communications scales linearly with the photon flux over short distances, and exponentially over long distances[5]. The scalability of photonic quantum computers depends critically on the photon source efficiency and quality[6,7].

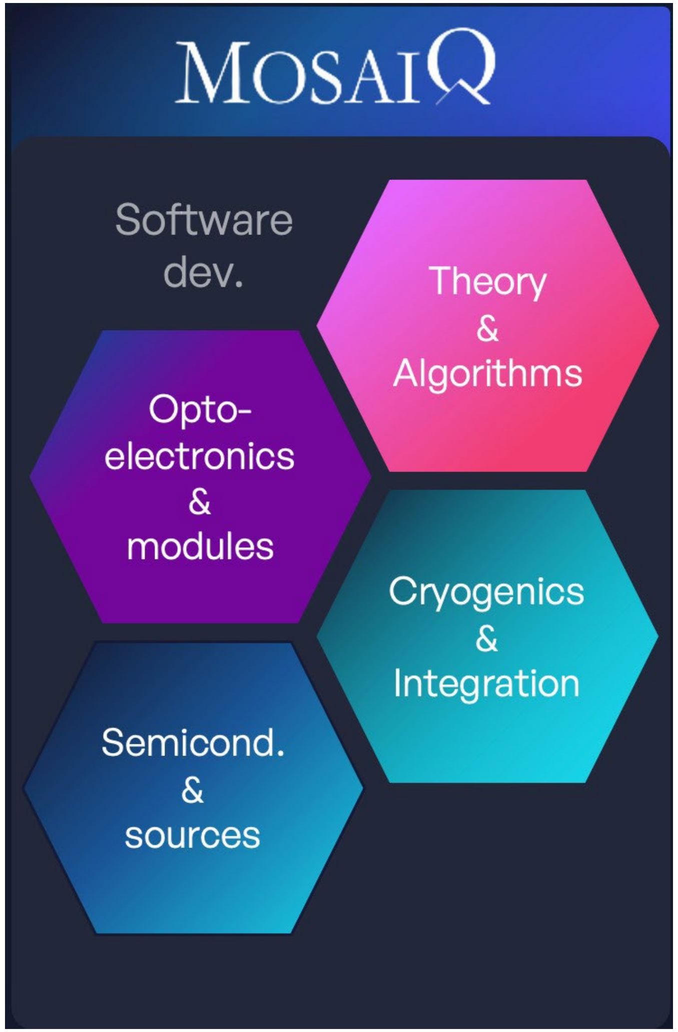
Impressive progress has recently been made in this area, with demonstrations of very high extraction efficiencies on inserting a QD into a photonic structure, for example a photonic-crystal cavity[19], micropillar cavity[20] or nanowires on a metallic mirror[21,22]. A record brightness of around 80% has been demonstrated both with micropillar and nanowire systems[20,21]. This brightness would drastically change the field of quantum photonics if the source

Since 2020

Full-stack Quantum Computing

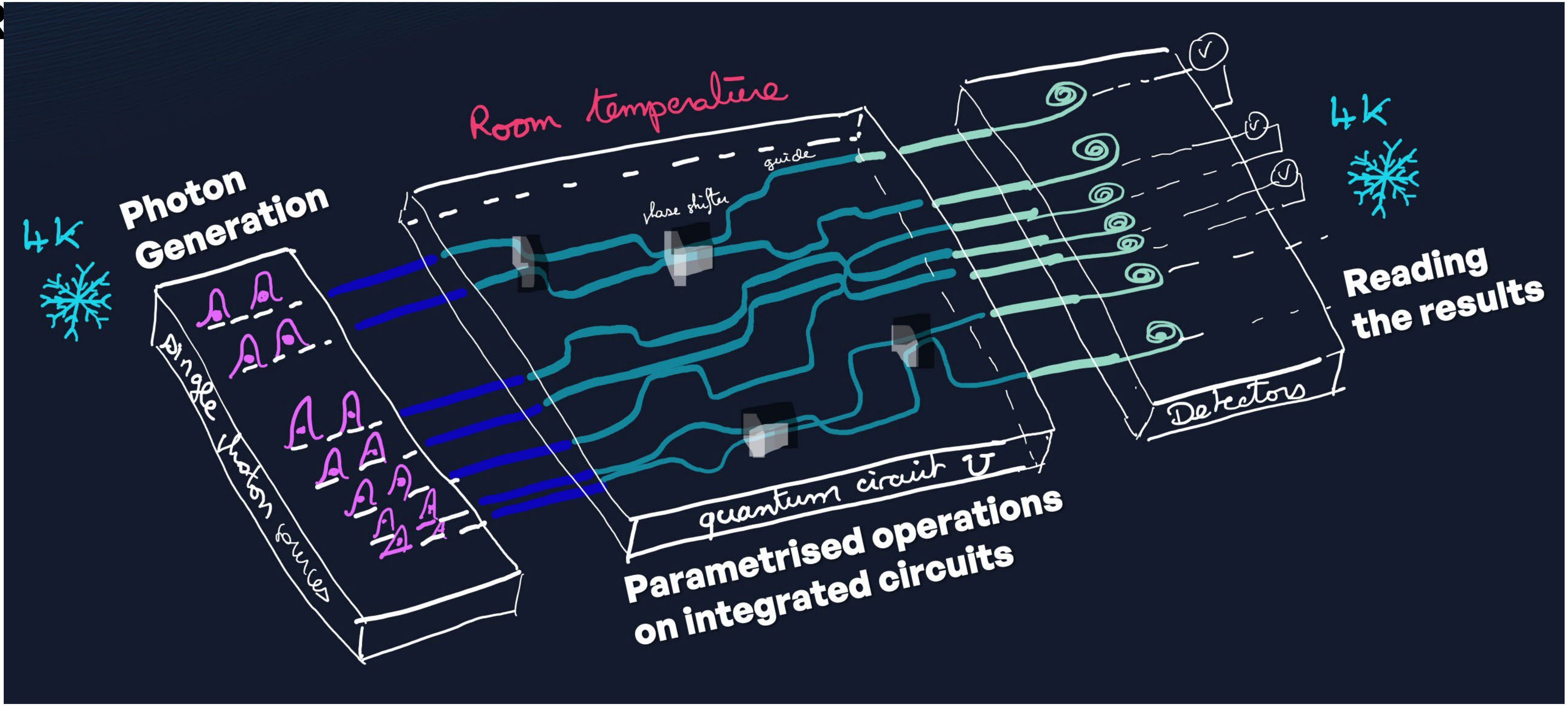
2022

6 photon quantum computing platform **MOSAIQ** available on the cloud



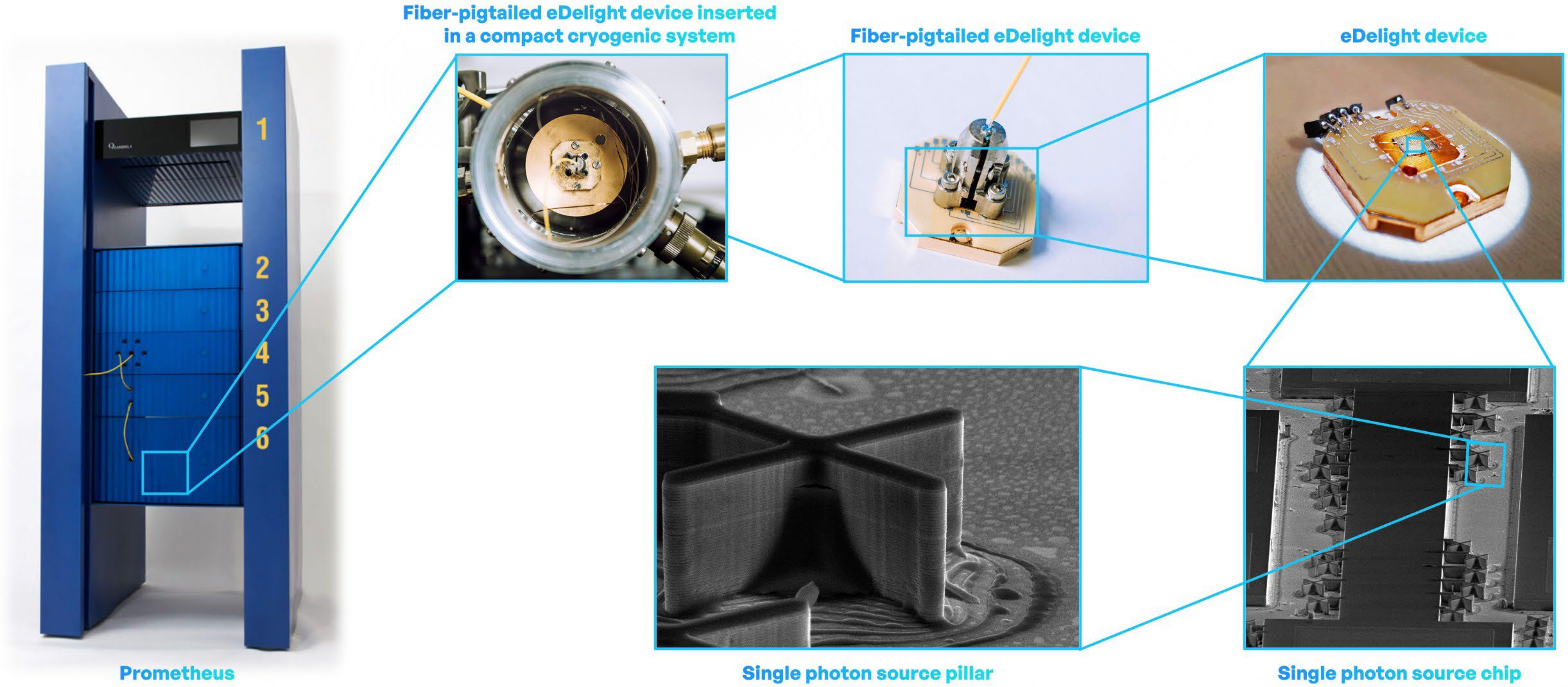
A Photonic Quantum Computing Platform

R



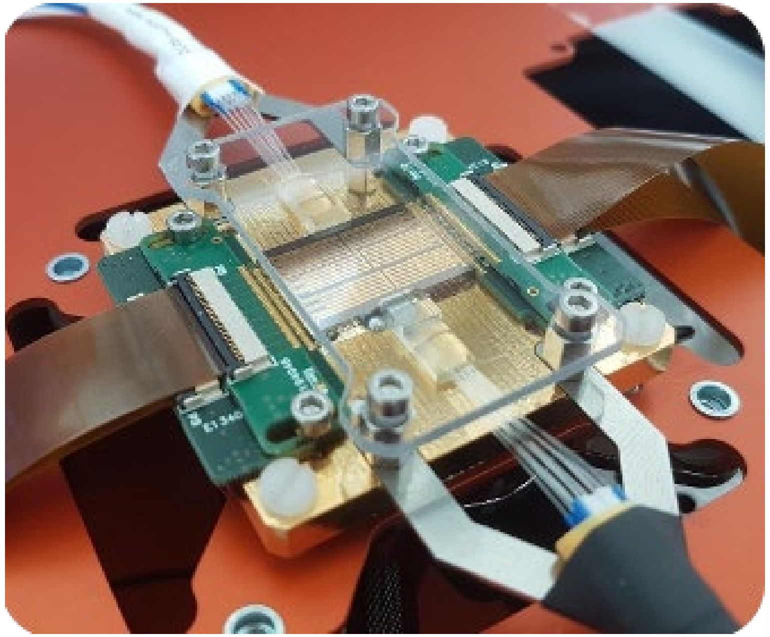
Photonic Qubit Generation

Zoom on Quandela's



MosaiQ

Quandela's Modular QC Platform



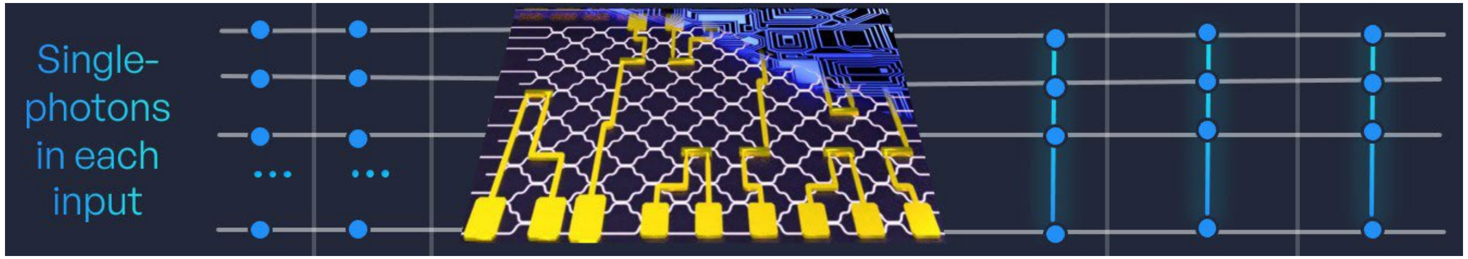
1. Classical computer
2. Lasers and electronics
3. Integrated photonic circuit [top left]
4. Control module
5. Active demultiplexer
6. Cryogenically cooled sources [bottom left] and detectors

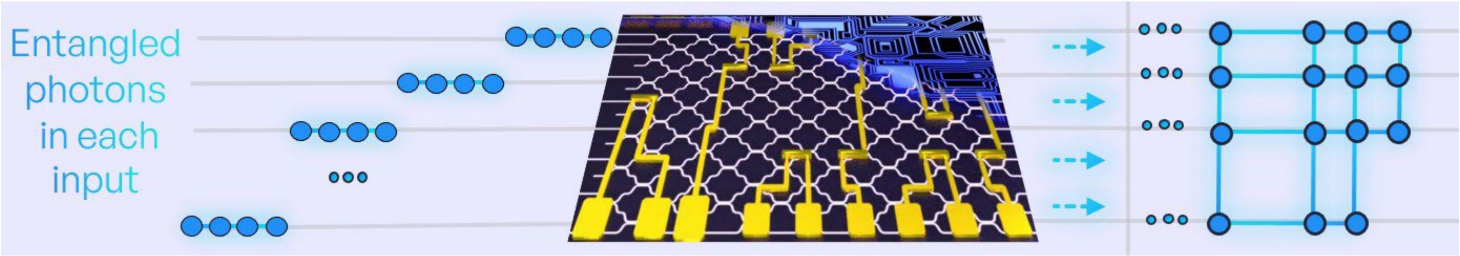
Quantum Computing

A Closer Look at Photonic Information Processing

At Source

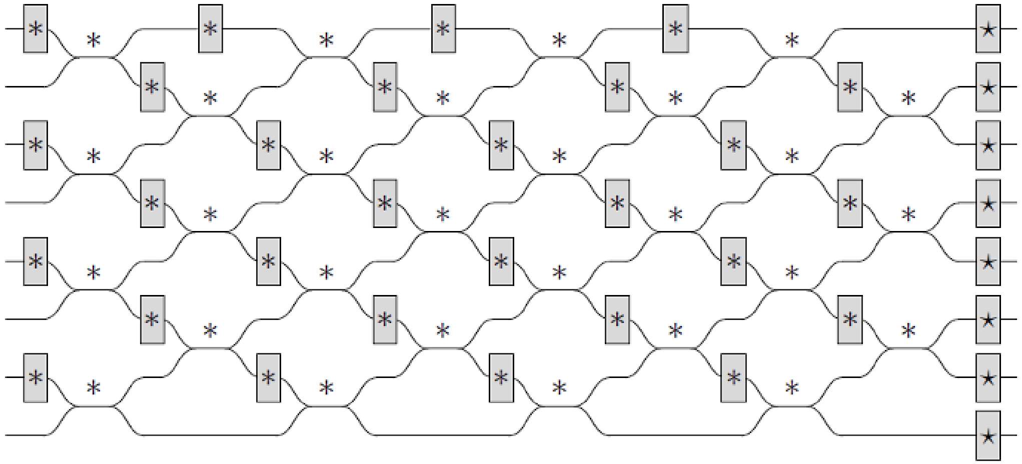
- Single photons
- Entangled photons*





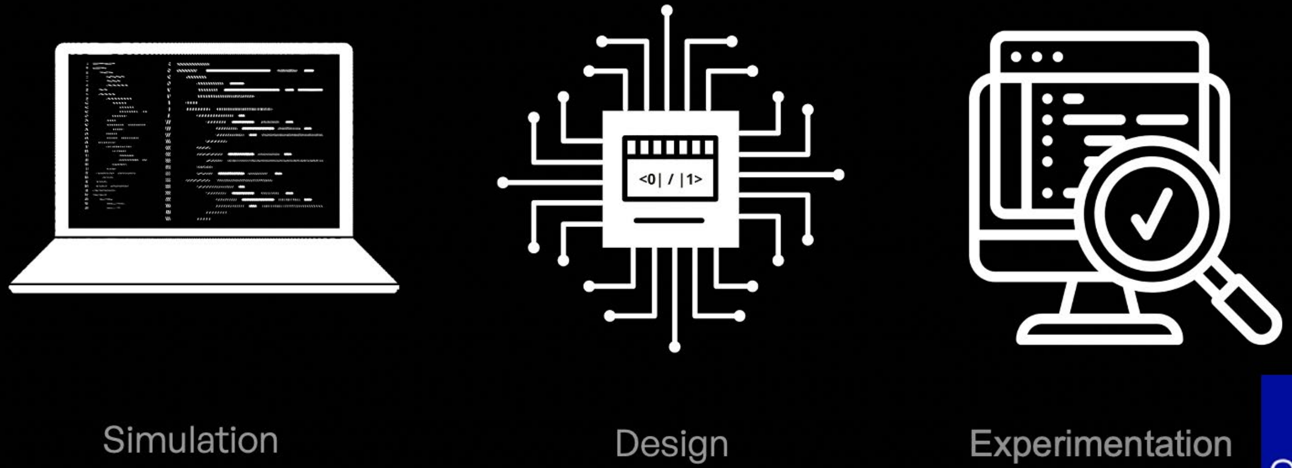
On Chip

- Linear optical components;
  i.e. beamsplitters, phaseshifters, …



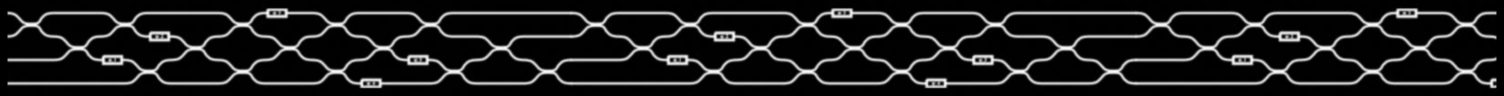
*Linear cluster states: N. Coste, P. Senellart at al, arxiv2207.09881

Perceval:
A Software Platform for Discrete-Variable Photonic Quantum Computing



OVHcloud

Documentation: https://perceval.quandela.net



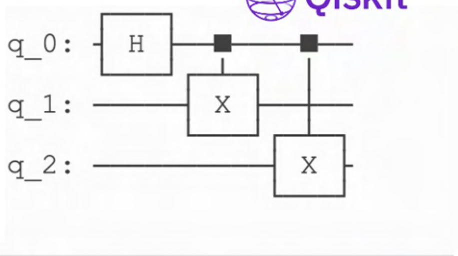
PERCEVAL

- Open-source, collaborative and evolutive
- Define photonic circuits
- Run on a variety of backends
- perceval.quandela.net
- State-of-the-art simulation algorithms arXiv:2206.10549
- Graphical rewriting (LOv calculus) arXiv:2204.11787

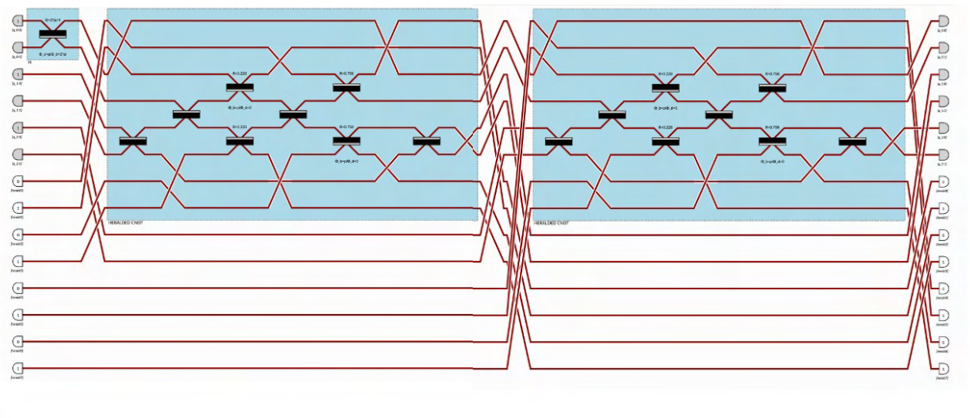
Perceval

Convert Qubit to Photonic Circuits or Simulate Photonic Experiments

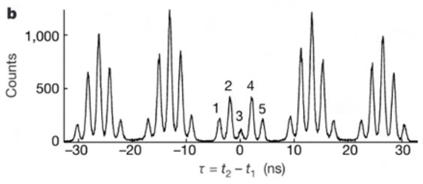
Qiskit



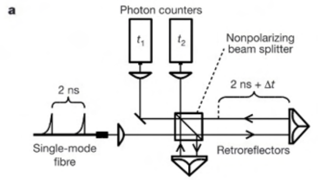

```
qiskit_converter = QiskitConverter(phys)
quantum_processor = qiskit_converter.convert(circuit, heralded=True)
pcvl.pdisplay(quantum_processor, recursive=True)
```



Experimental Results



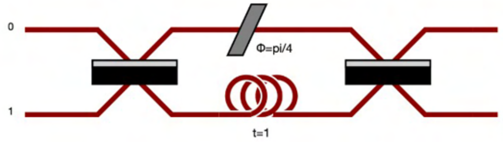
Experimental Set-up



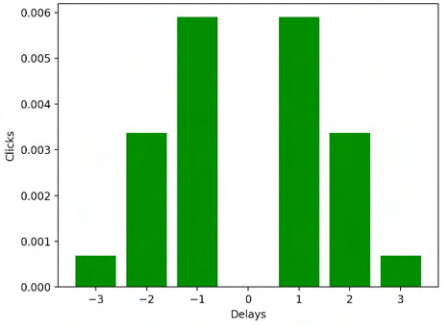
Perceval Implementation

```
c = pcvl.Circuit(2) // comp.SimpleBS() // comp.PS(np.pi/4) // (1, comp.TD(1)) // comp.SimpleBS()
```

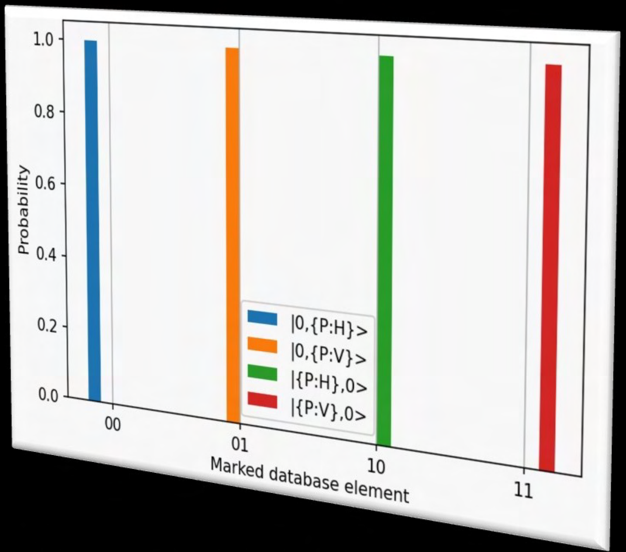
```
pcvl.pdisplay(c)
```



Perceval Simulation



2-mode Grover's search algorithm



We implement in this notebook a 2-mode optical realization of Grover's search algorithm following *Kwiat et al. (2000). Grover's search algorithm: An optical approach. Journal of Modern Optics, 47(2–3), 257–266*. https://doi.org/10.1080/09500340008244040

Motivation

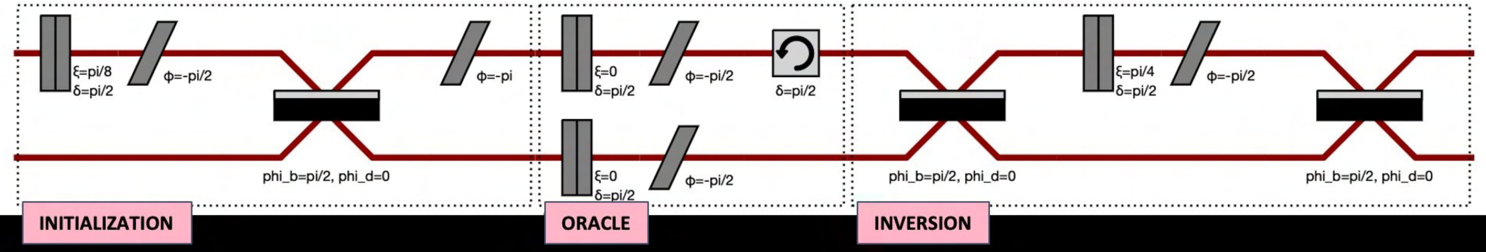
Searching for a specific item in an unstructured list of N items will classicaly necessitate $\mathcal{O}(N)$ function calls. Grover showed in 1996 that is possible for a quantum computer to achieve this using only $\mathcal{O}(\sqrt{N})$ iterations.

Algorithm breakdown

Suppose we are implementing Grover's algorithm with NN qubits. The algorithm's first part consists in setting each of these qubits in a quantum superposition $\frac{|0>+|1>}{\sqrt{2}}$. Then, a so-called oracle is applied on the qubits.

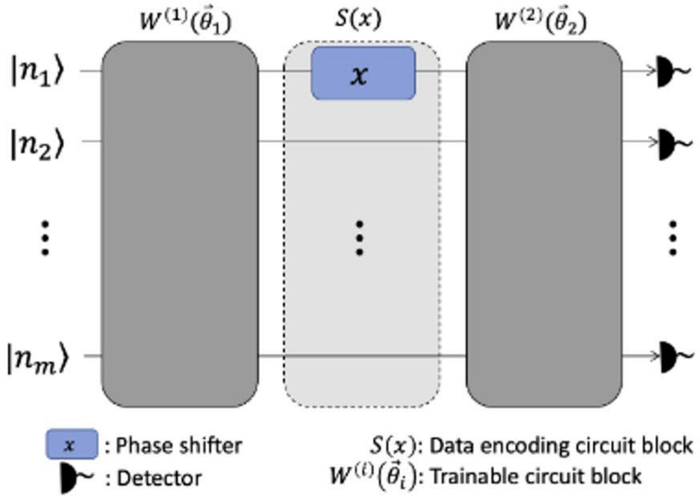
```python
def grover_circuit(n):
    """Returns grover circuit which selects output n, where n is 0, 1, 2 or 3."""
    grover_circuit = pcvl.Circuit(m=2, name='Grover')
    grover_circuit.add((0,1), init_circuit).add((0,1), oracle(n))\
                  .add((0,1), inversion_circuit)
    return grover_circuit

pcvl.pdisplay(grover_circuit(0), recursive=True)
```



A NISQ Application
Clustering

- Trainable circuit(1)

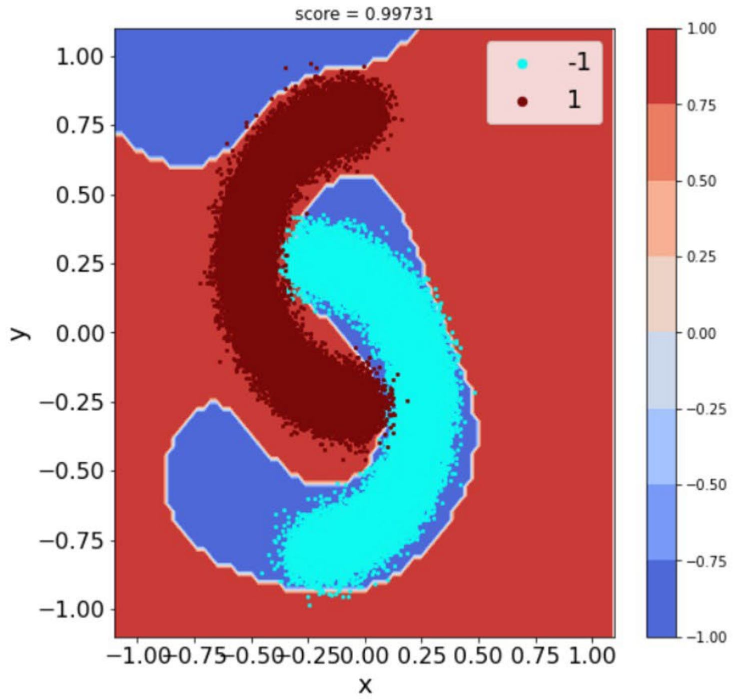


- Machine Learning model:

$$f^{(n)}(\boldsymbol{x},\boldsymbol{\theta},\boldsymbol{\lambda}) = \langle \mathbf{n}^i | U^\dagger(\boldsymbol{x},\boldsymbol{\theta}) Meas(\boldsymbol{\lambda}) U(\boldsymbol{x},\boldsymbol{\theta}) | \mathbf{n}^i \rangle$$

- Classification: sign of the model $f^{(n)}(-,\boldsymbol{\theta},\boldsymbol{\lambda})$

Possible improvement to learn faster or from less data



Simulation with 10 photons

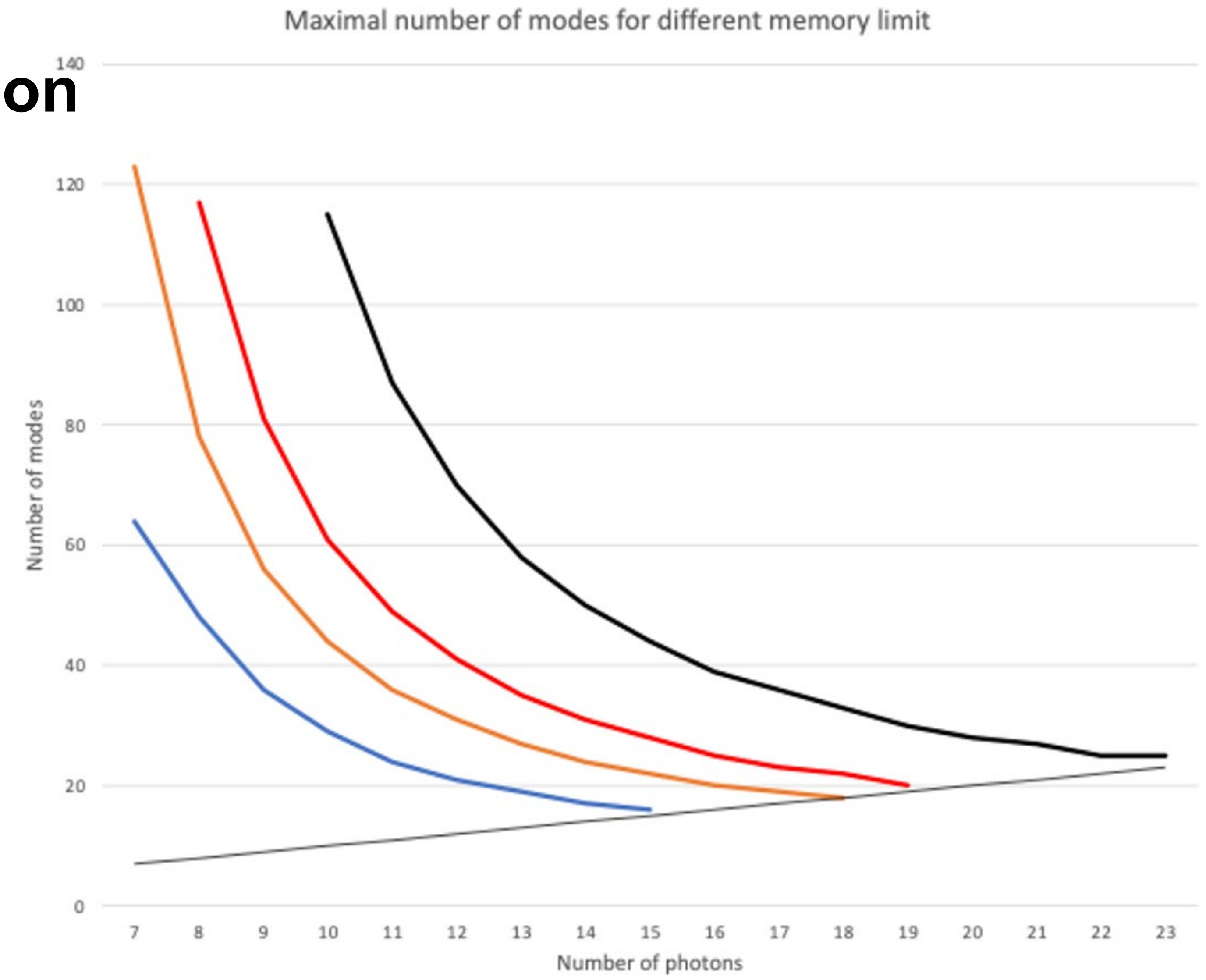
(1) Gan et al. "Fock State-enhanced Expressivity of Quantum Machine Learning Models", arXiv:2107.05224

Towards Quantum Advantage

The Limits of Classical Simulation

RAM usage

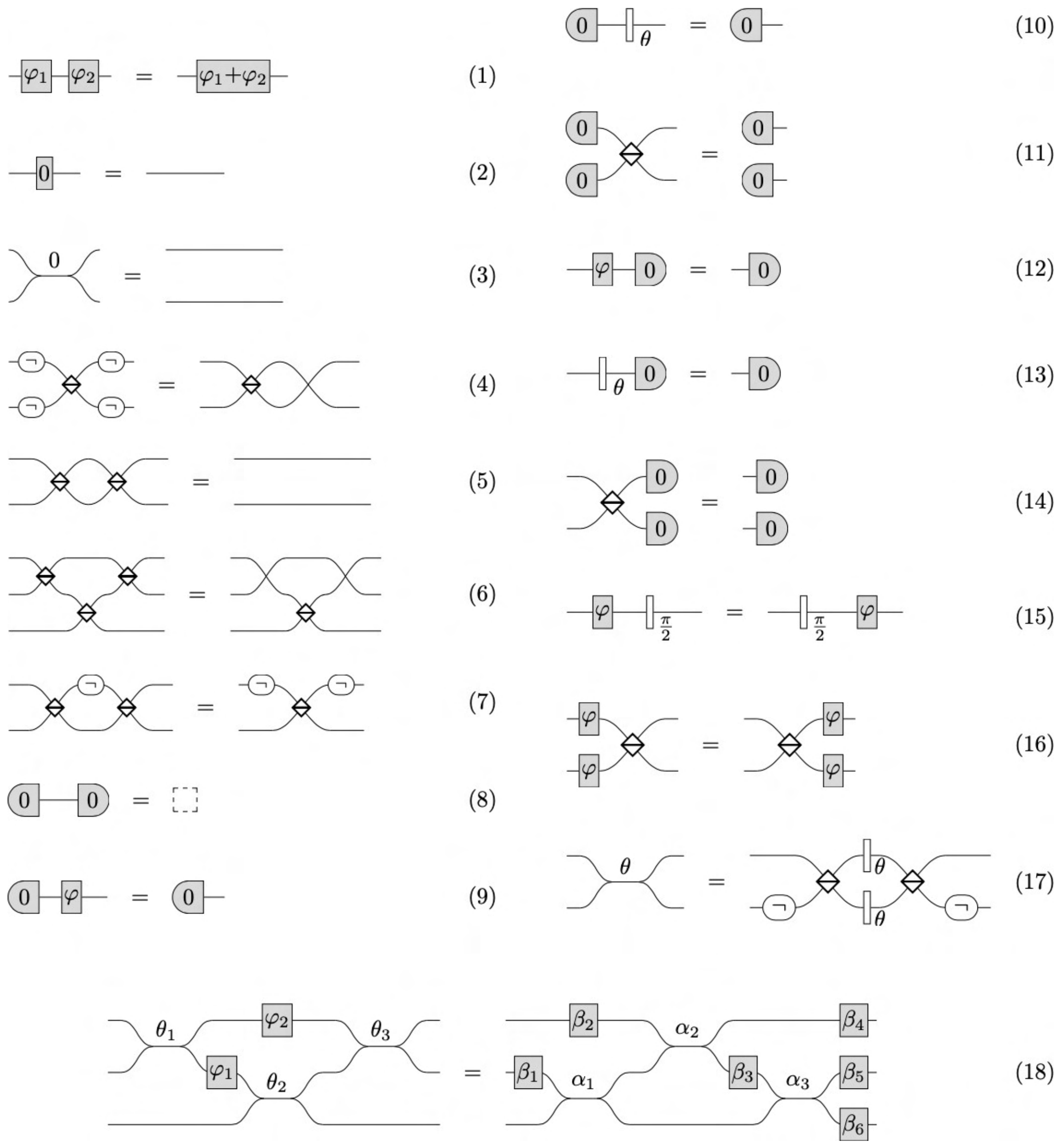
8Gb
256Gb
4Tb
1Pb



LOv Calculus

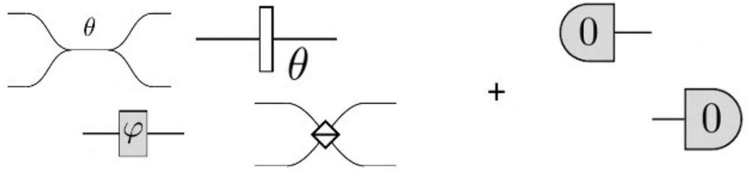
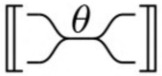
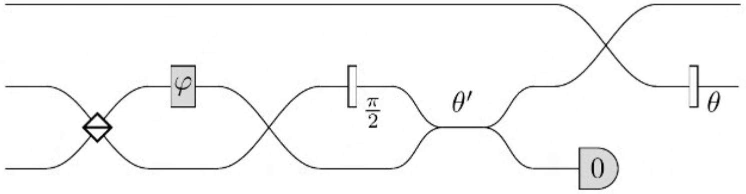
A Graphical Language for Linear Optics

- A formal system of reasoning about linear optical processes
- Rewrite, simplify, check equivalences of circuits
- Human-readable, visual and intuitive
- Provides powerful tools both for linear optical and qubit circuits
- Solved a longstanding problem:
  A Complete Equational Theory for Quantum Circuits
- LOv appeared at MFCS 2022
- Joint work with Nicolas Heurtel (Quandela) Benoît Valiron (CentraleSupelec), Simon Perdrix (INRIA) and Alexandre Clément (LORIA)



LOv Calculus

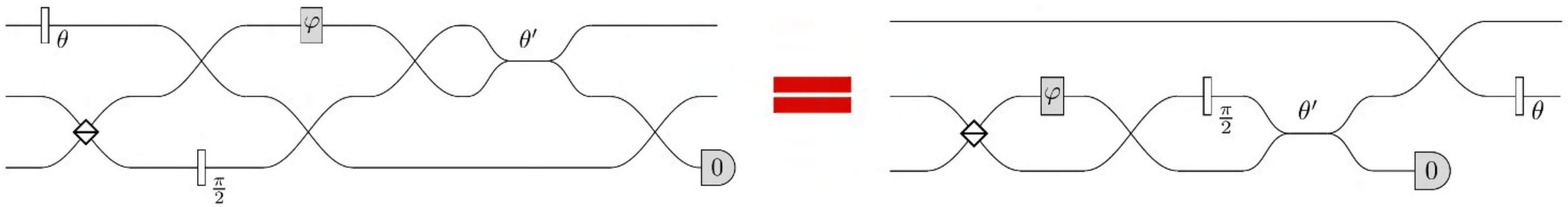
As A Graphical Language

Language / Made of	English	LOv
Generators	Words *Cat, table, enjoy, quantum, …*	LO-components 
Semantics	Definitions *Cat: superposition of cute and evil pet, …*	Matrices $[\![$  $]\!]_{pp} = \begin{pmatrix} \cos(\theta) & i\sin(\theta) \\ i\sin(\theta) & \cos(\theta) \end{pmatrix}$
Elements	Sentences *"A quantum cat is on the table", …*	LO-circuits 

LOv Calculus
Graphical Reasoning

- We'd like to compare the elements of our language

"On the table, there is a quantum cat" — "A quantum cat is on the table"



- Compare the elements without using the semantics !

LOv Calculus

A Complete Language for Linear Optics

Completeness: Given any two equivalent LO-circuits with phase shifters and beamsplitters, we can always rewrite one into the other

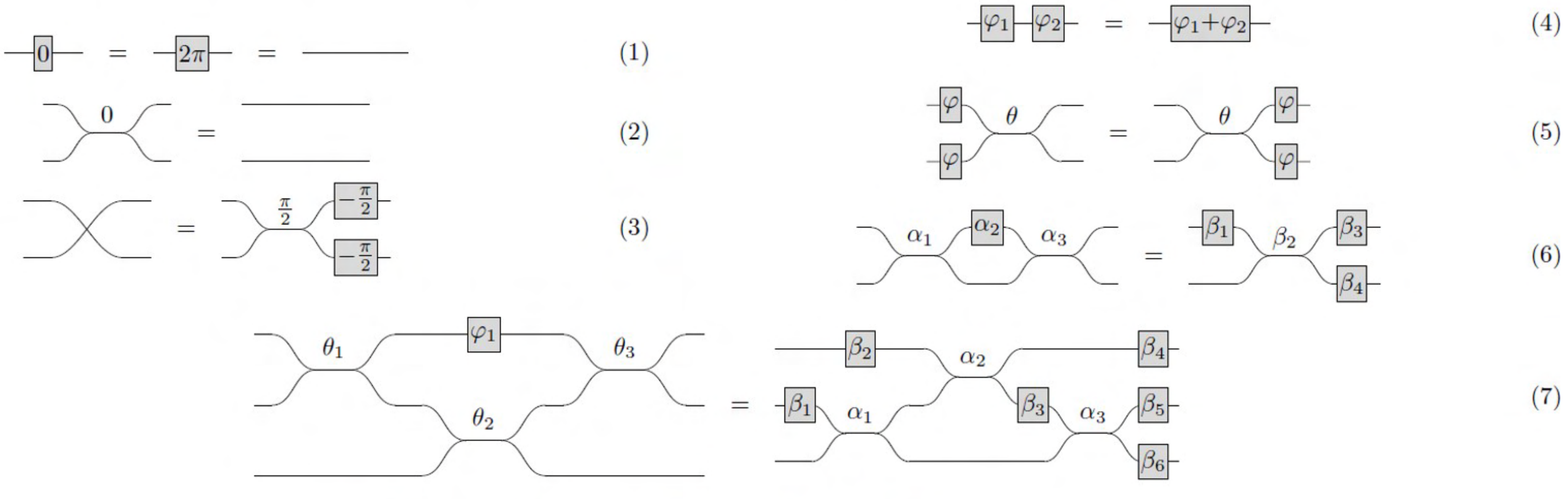
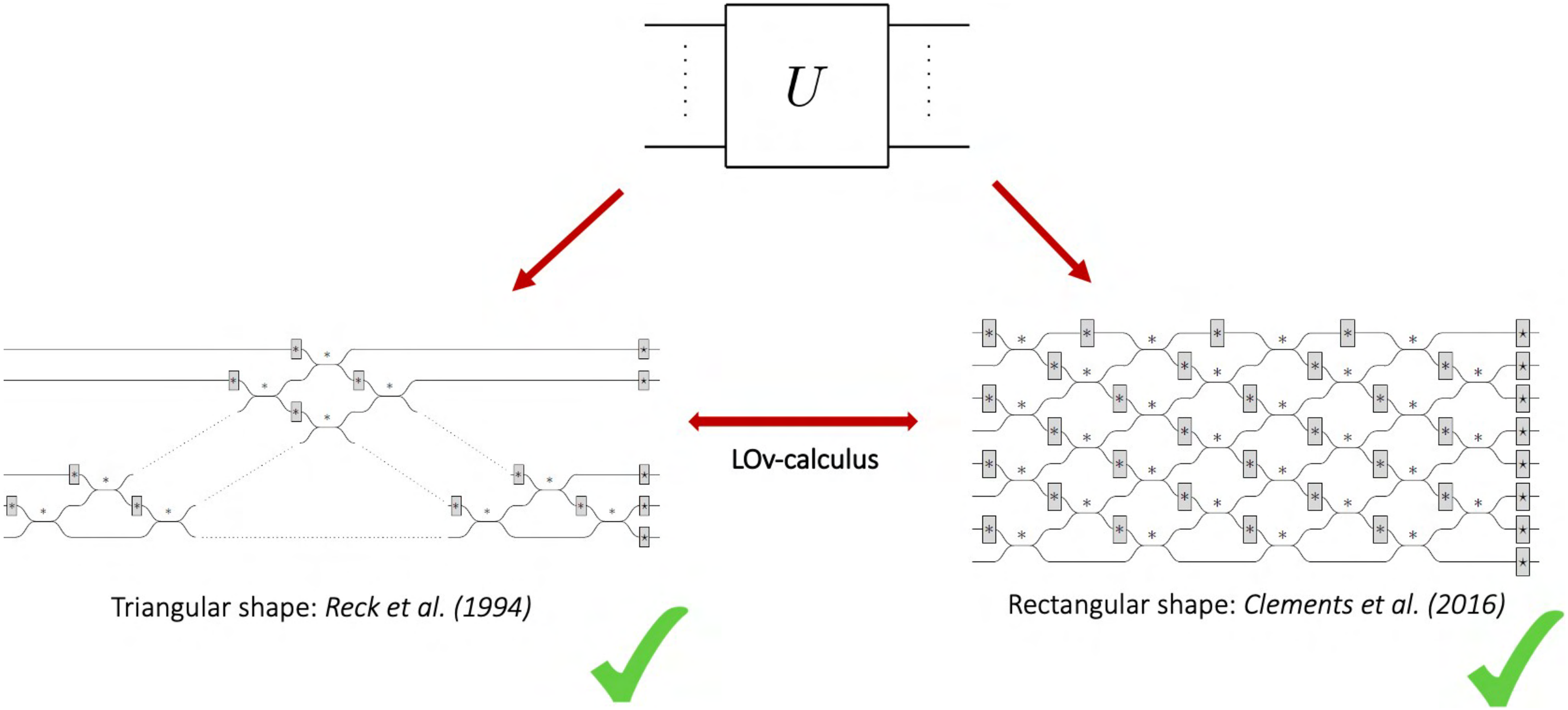


Figure 1: Axioms of the LOPP-calculus.

LOv Calculus

Example



7-9 Nov. 22'
Paris

(Sorbonne Université)

At the Crossroads of
Physics and Software!

LOQCathon

Powered by Quandela with a partnership of QICS (Quantum Information Center Sorbonne)

Panorama des technologies quantiques

MINALOGIC Auvergne-Rhône-Alpes

Si spin-based quantum computing

Tristan Meunier, Senior CNRS researcher / CNRS / **QCosmos**

Spin Qubit Quantum Computing effort

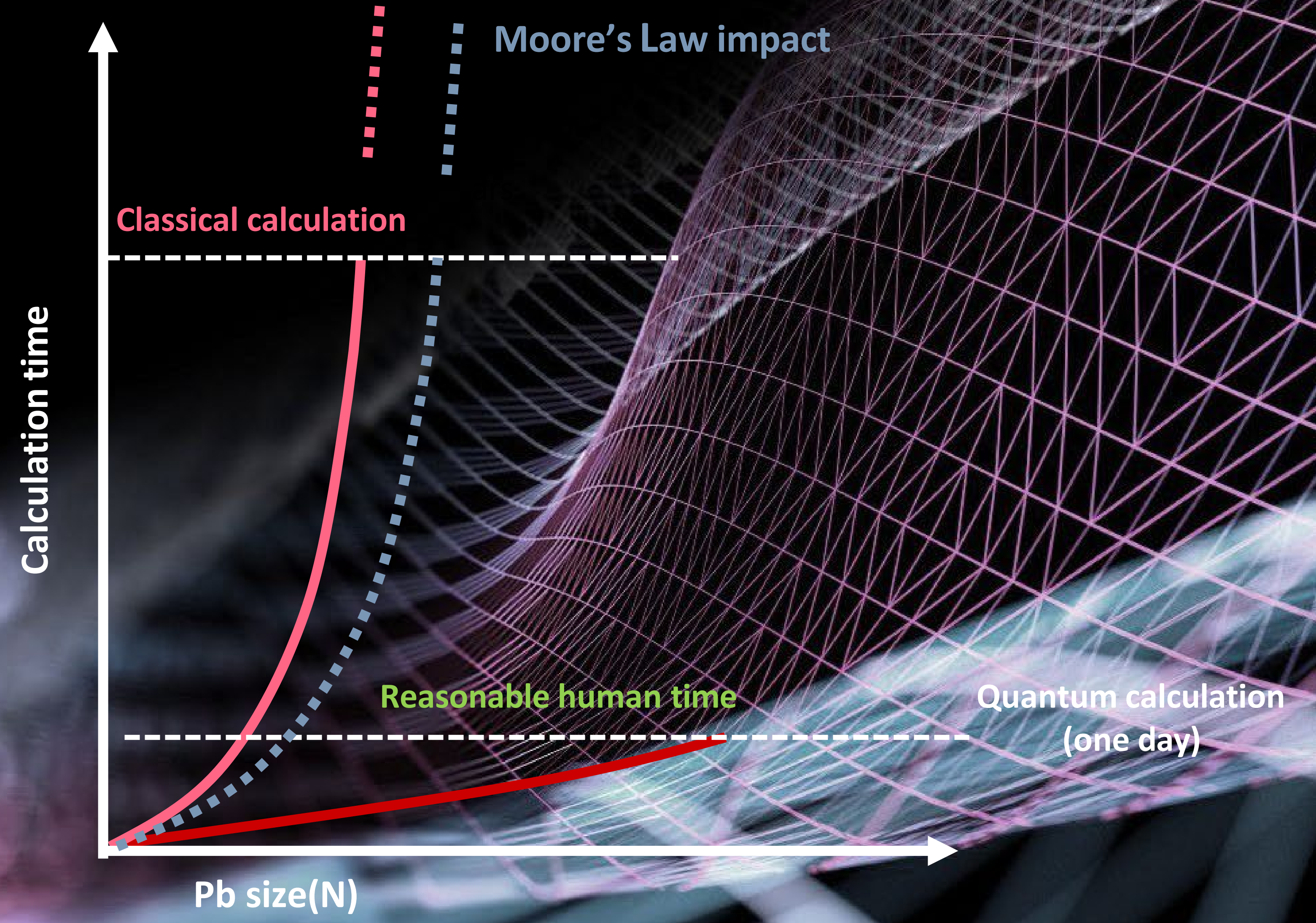
Tristan Meunier (CNRS)

S. Barraud[1], B. Bertrand[1], G. Billiot[1], B. Cardoso[1], M. Cassé[1], J. Charbonnier[1], J.-M. Hartmann[1], L. Hutin[1], H. Jacquinot[1], Y.-J. Kim[1], L. Le Guevel[1], V. Mazzocchi[1], G. Pillonnet[1], N. Rambal[1], C. Thomas[1], Y. Thonnart[1], A. Amisse[1,2], H. Bohuslavskyi[1,2], L. Bourdet[2], A. Crippa[2], E. Dumur[2], X. Jehl[2], R. Maurand[2], V. Michal[2], Y.-M. Niquet[2], M. Sanquer[2], B. Venitucci[2], A. Auffèves[3], G. Brès[3], E. Chanrion[3], E. Eyraud[3], C. Guttin[3], B. Jadot[3], B. Klemt[3], J. Minet[3], P.-A. Mortemousque[3], D.J. Niegemann[3], M. Nurrizo[3], C. Spence[3], V. Thiney[3], O. Tissot[3], R. East[3], D. Horsman[3], M. Urdampilleta[3], S. De Franceschi[2] , M. Vinet[1]

QSPINMOTION
QUCUBE

QUANTUM COMPUTING PROMISE

› Provides access to unchartered computation territories

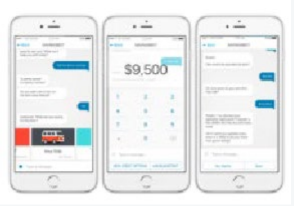


~ nb of qubits> 100

Transport & logistics
travel optimization
fleet management

Healthcare
molecular simulation
drug discovery

Energy & materials
battery design
renewables optimization
materials design

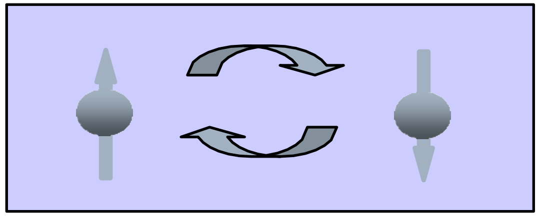


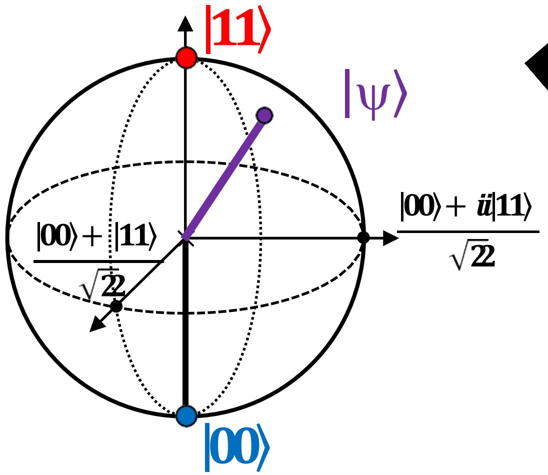
Finance
risk assessment
portfolio optimization

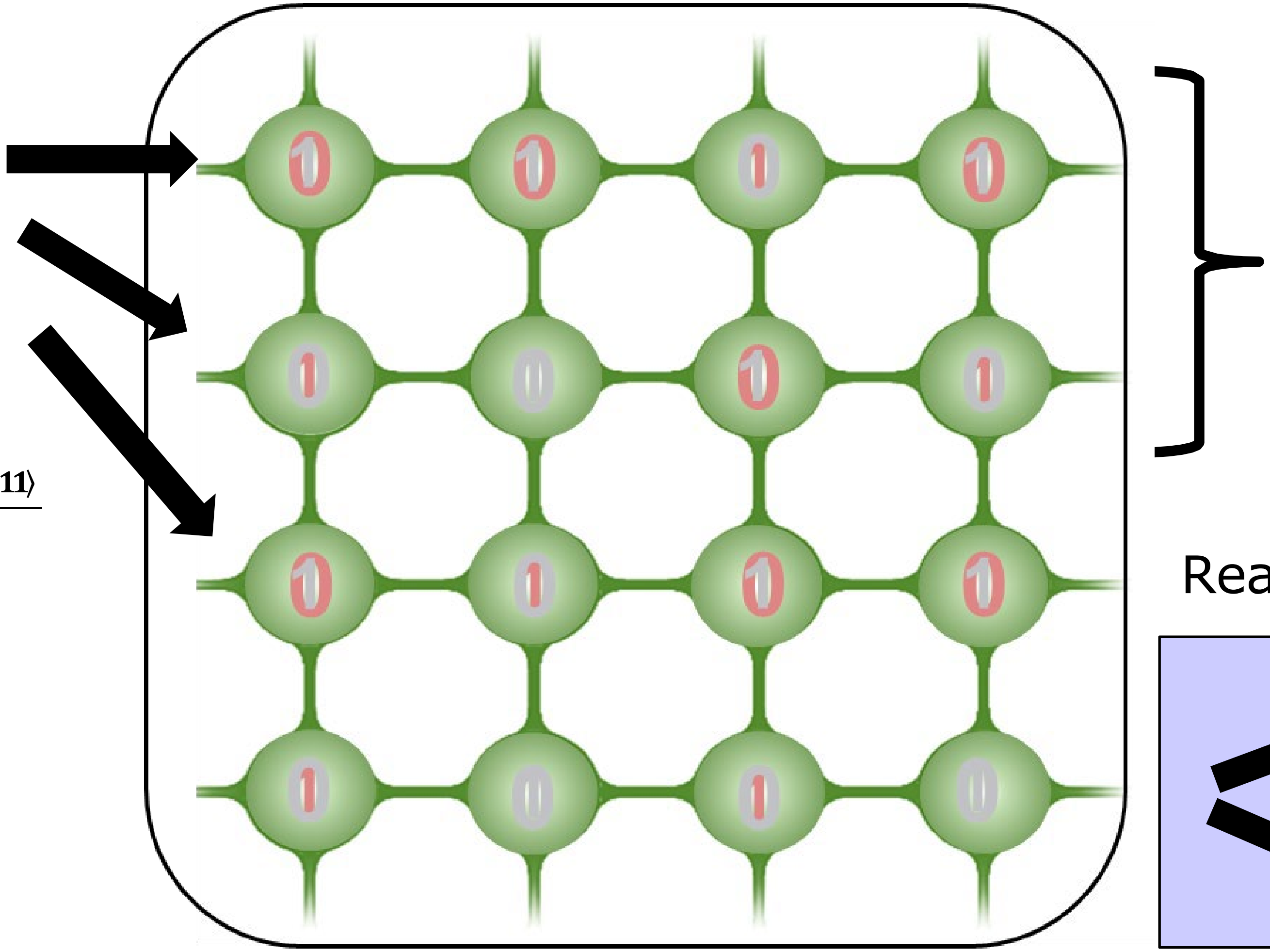
Defense & intelligence
cryptography
machine learning

Topology: 2D arrangement and 4 neighbors

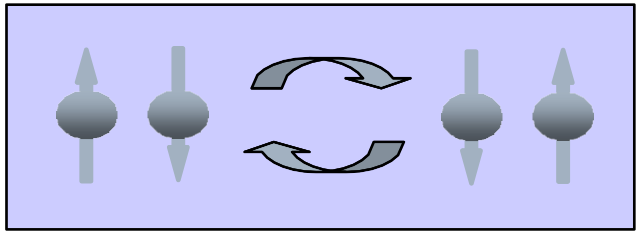
One-qubit gate



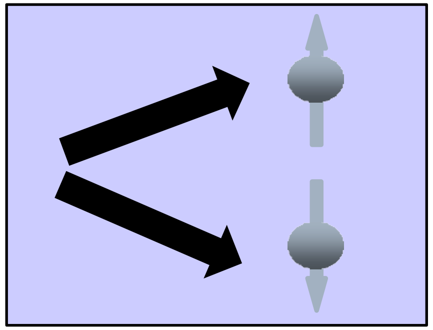




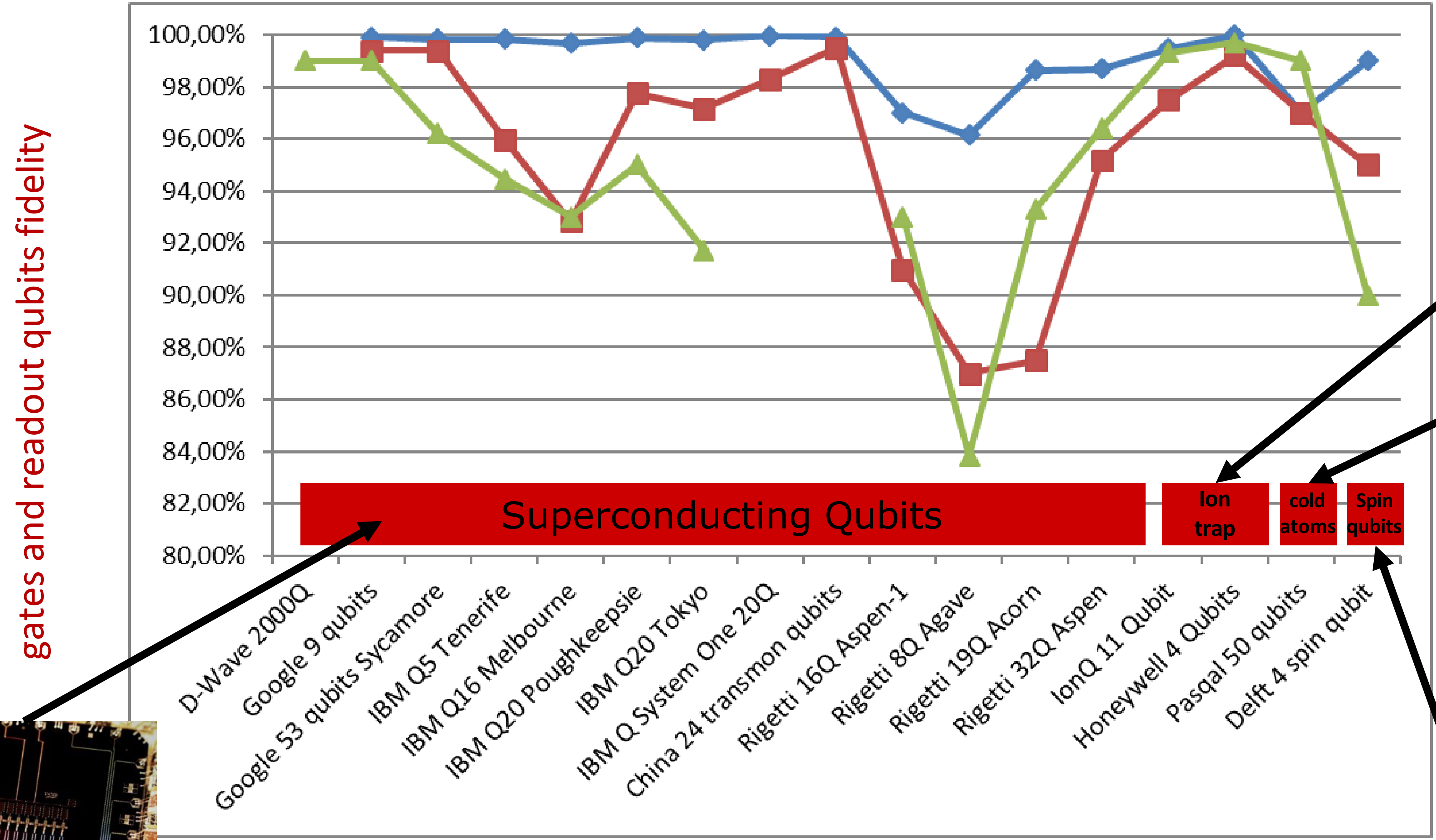
Two-qubit gate

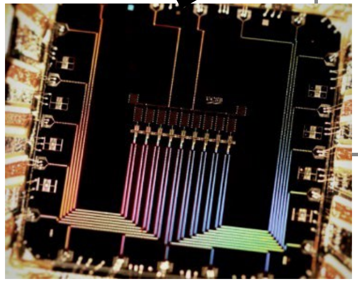


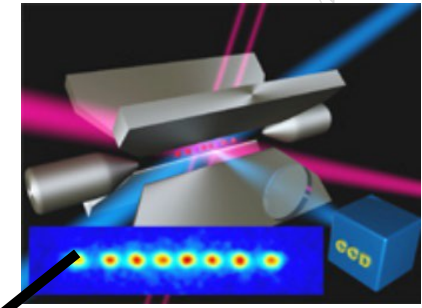
Read-out gate

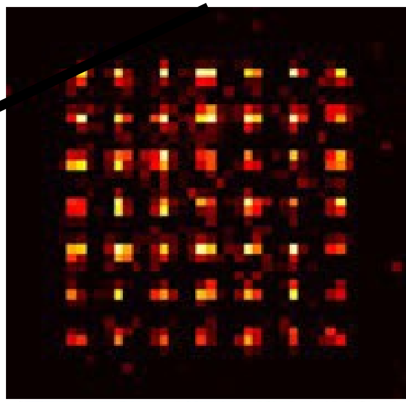


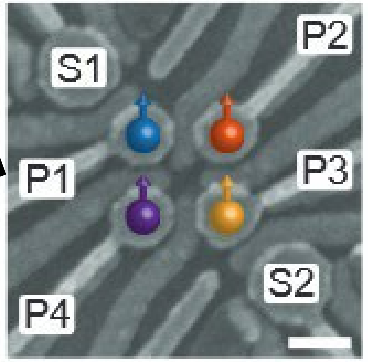
Error performance





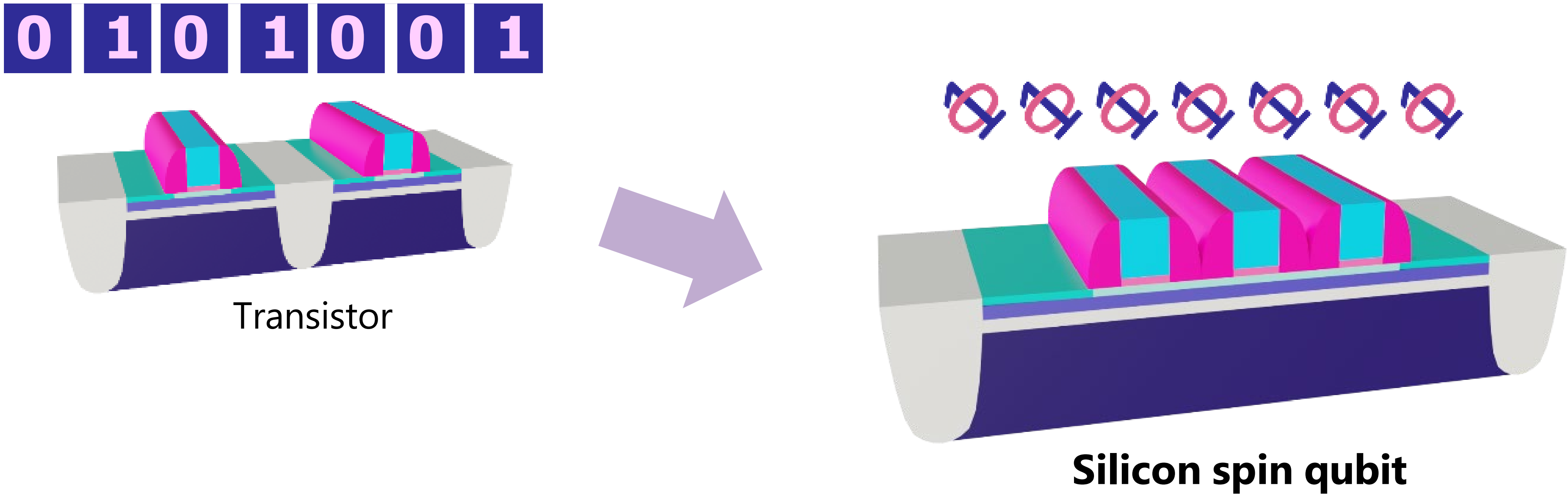






one and two qubit gates and readout fidelity in %, the higher being the better.
data source: https://quantumcomputingreport.com/scorecards/qubit-quality/ , Google, D-Wave and recent spin qubit experiments

From transistors to spin qubits



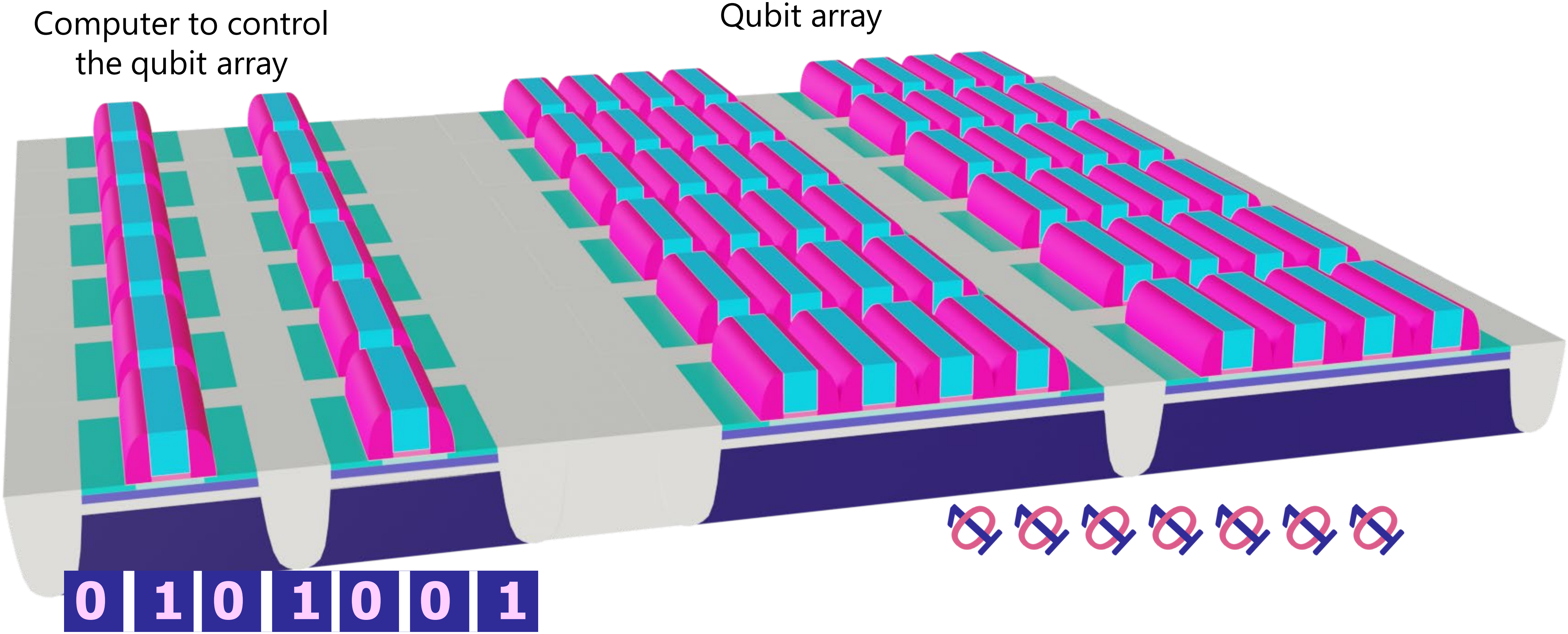
By transforming a transistor in a good qubit we levarage the ecosystem, know-how and methodologies of classical computing to build cost effective quantum computers

> 100 Millions in 1 cm²

Good quality qubits

- Coherence time msec
- Fidelity >99%
- Speed of operation usec

Controllable and programmable qubits

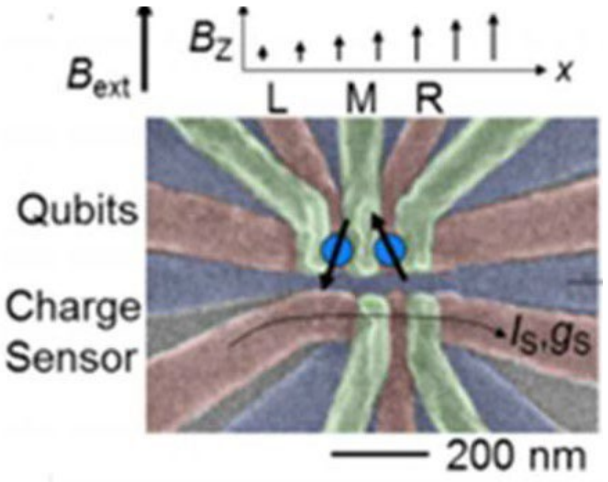


Know-how and methodologies of semiconductor industry

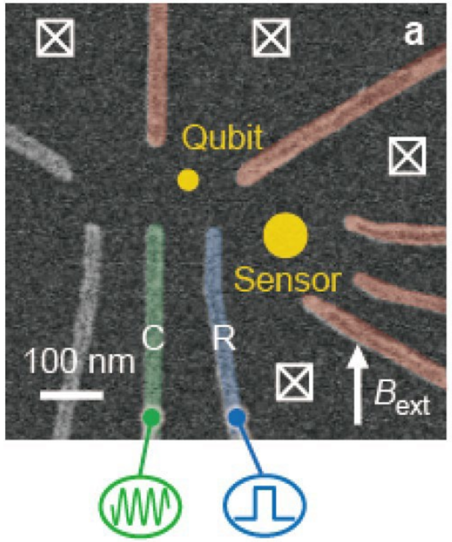
Reduced effort in Infrastructure

1K
1 quantum core
$1dm^3$

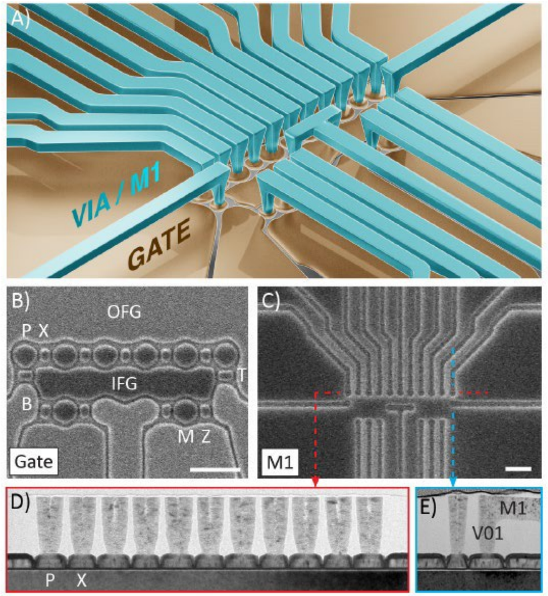
State of the art



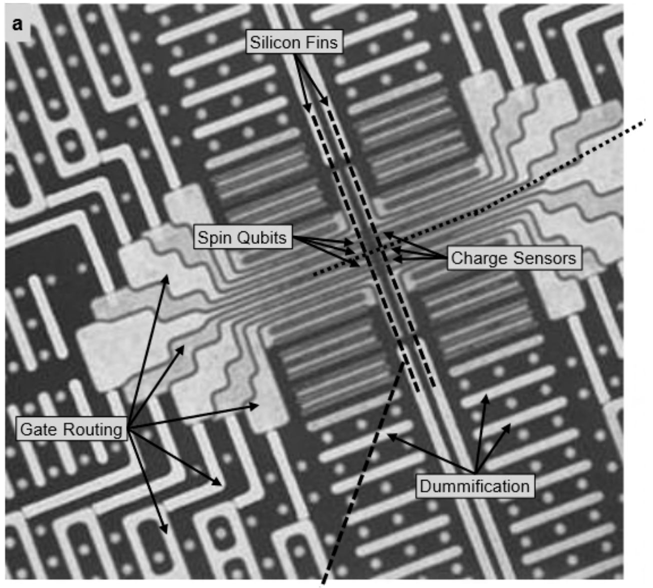
@Princetown



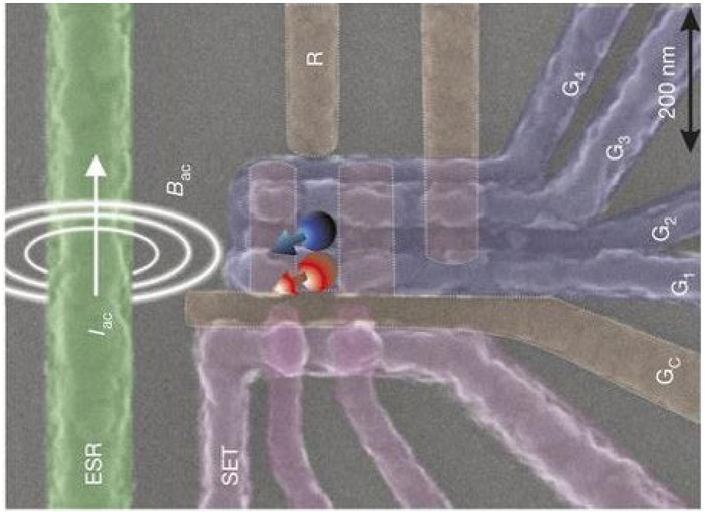
@RIKEN



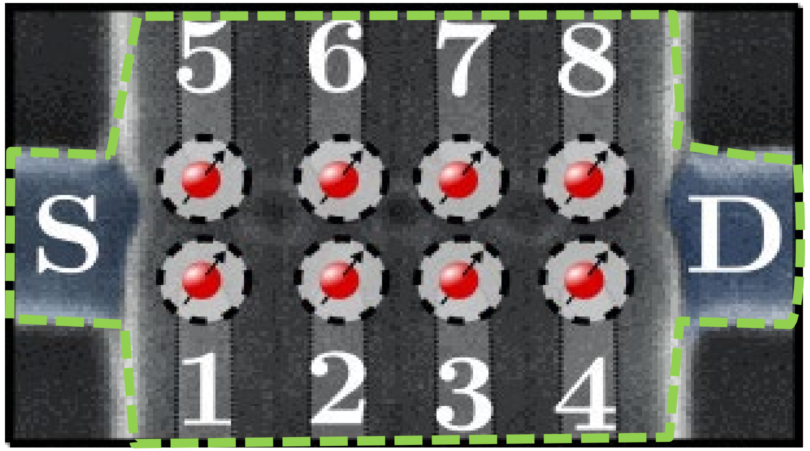
@HRL



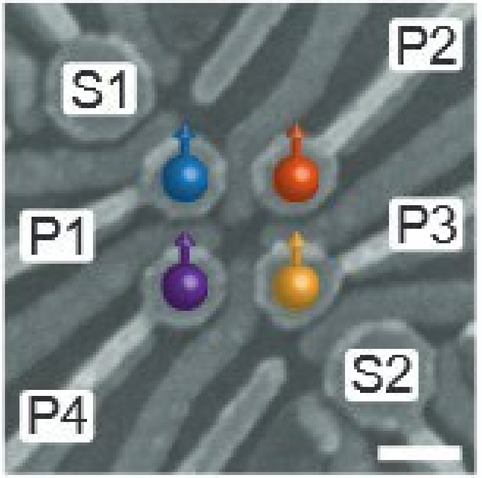
@Intel



@UNSW

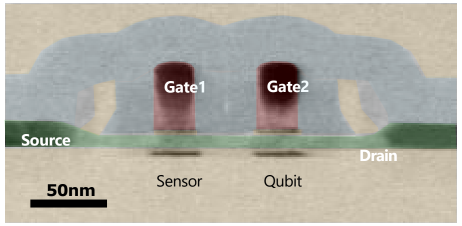


@Grenoble



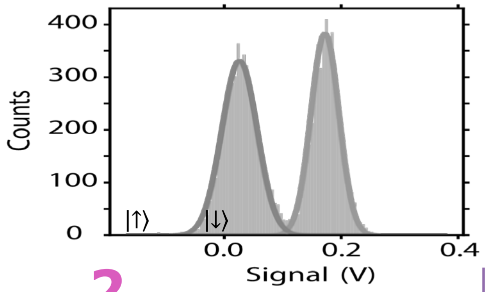
@Delft

Results before 2019: scientific world firsts



1

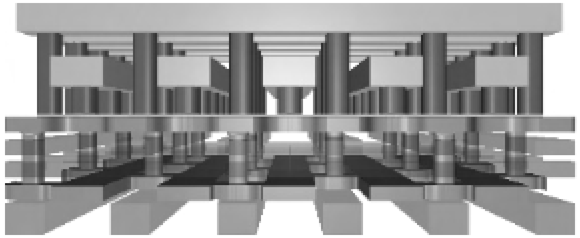
2016
First CMOS qubit



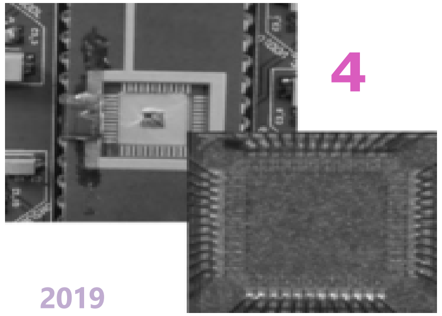
2

2019
Good quality qubits

2017
Large scale architecture



3

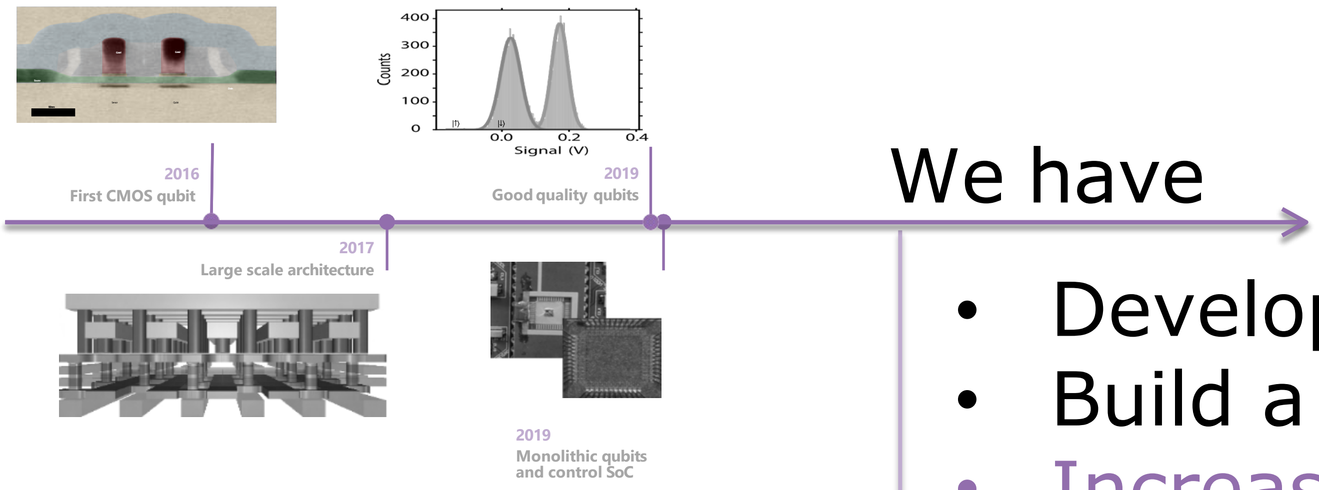


4

2019
Monolithic qubits and control SoC

1 Maurand et al, Nature comm, 2016 2 Urdampilleta, et al. Gate-based high fidelity spin readout in a CMOS device, (2019) Nature Nanotechnology
3 L Hutin, T Meunier, M Vinet, S De Franceschi US patent10607993B2, 4 Guevel, L.L., et al, A 110mK 295µW 28nm FDSOI CMOS Quantum Integrated Circuit with a 2.8GHz Excitation and nA Current Sensing of an On-Chip Double Quantum Dot, (2020) ISSCC

Since 2019: getting ready for industrialization



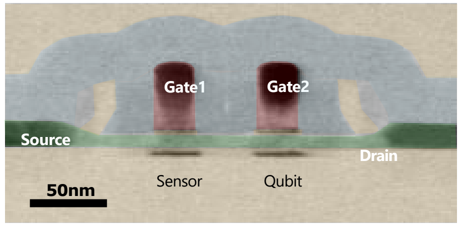
We have

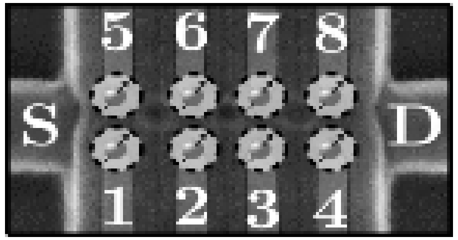
- Developed cloud interface
- Build a partner ecosystem
- Increased technology maturity*
- Secured supply chain*
- Sped up learning cycle*
- Developed system simulation*
- Developed control electronics
- Developed an assembly platform
- Grew up the team from 20 to 50 persons

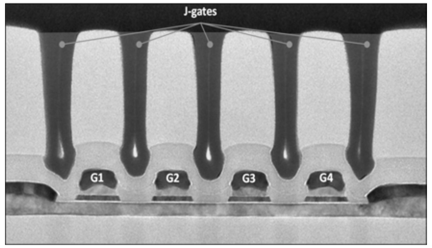
* Detailed in this presentation

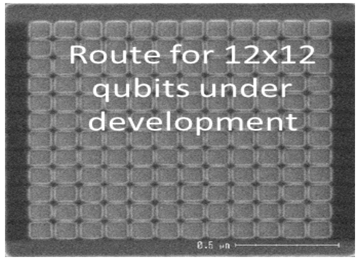
We have increased technology maturity

2016... | 2019 | 2020 | 2021 | 2022









1

Ebeam
Sdt FDSOI
1 working qubit
out of 100

2

Ebeam
Improved FDSOI
1 working qubit
out of 50

3

Ebeam
Improved FDSOI
Functional arrays
1 working qubit
out of 10

4

iDUV
Improved FDSOI
2 gate levels

5

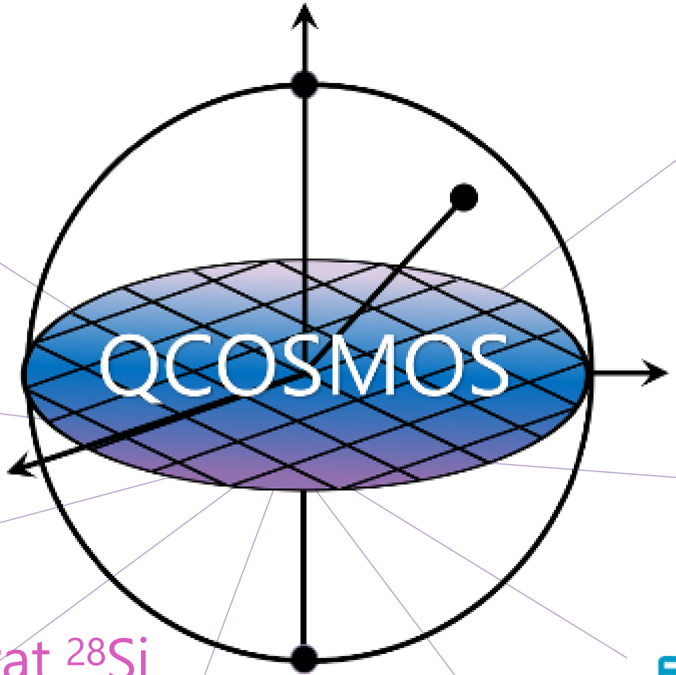
2D technology
Alliance with
foudnry

1 Maurand et al, Nature comm, 2016 2 Urdampilleta, et al. Gate-based high fidelity spin readout in a CMOS device, (2019) Nature Nanotechnology 3 Apra, et al Dispersive vs charge-sensing readout for linear quantum registers, (2020) Technical Digest - International Electron Devices Meeting, Chanrion, et al, Charge detection in an array of CMOS quantum dots, (2020) Physical Review Applied, Hutin, L., et al, Gate reflectometry for probing charge and spin states in linear Si MOS split-gate arrays (2019) Technical Digest - International Electron Devices Meeting 4 Bedecarrats et al, IEDM 2021, Cardosa Paz, ESSDERC 2022 5 R&D 2D mask set and technological route under development, first tape out with foundry planned by end 2022

We have secured supply chain

R&D collaboration[5]

cnrs cea



Electronics [1]

Radiall

SILENT WAVES

Semiconductor [4]

ST life.augmented

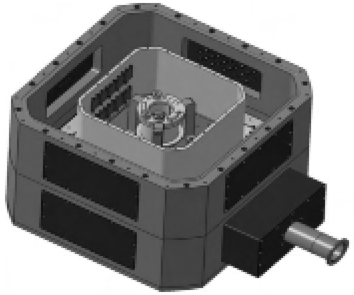
GlobalFoundries™

Substrat ^{28}Si

[3] soitec

orano

Air Liquide



ABSOLUT SYSTEM INNOVATIVE CRYOGENIC SOLUTIONS

Cryogeny [2]

CryoConcept

1 Qryolinq project on innovative cables and connectors, 2 P. Camus, high power cryogenic system for sub K electronic applicatoins, WOLTE 2021 3 Stable istope project, French National plan, V Mazzocchi et al, Journal of Crystal Growth, 2019, SOITEC QLSI H2020 project 4 First run with tape out planned in Nov 2022 5 Licencing and collaboration agreements under discussion

We have sped up learning cycle

2019

9 months — Design
3 months — Masques
18 months — Fabrication
1 sample per month — Test
1 sample every 2 or 3 months — Measurements

Modelling | Simulation | Design | Masques | … | Fabrication | Test | Measurements

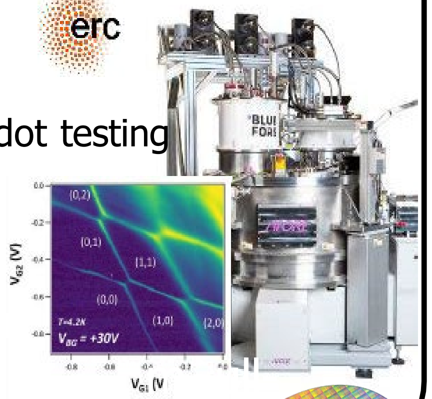
36 months

<2K

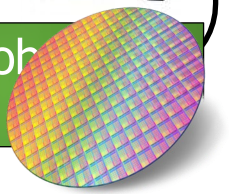
>2mn / device

erc

Qudot testing



wafer prob
Bluefors



1st focus: develop statitsical characterization from RT to LT

2019: 1 sample per months at low T°

2022: 600 samples/months at low T°

2022

6 months — Design
3 months — Masques
12 months [1] — Fabrication
6 months for a full extensive characterization [2] — Test & Measurements

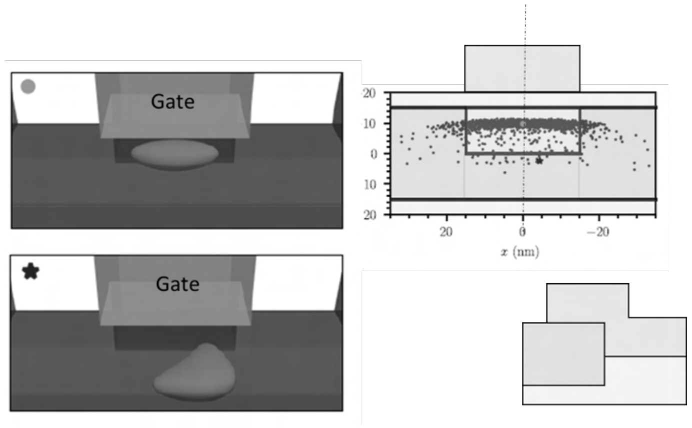
Modelling | Simulation | Design | Masques | … | Fabrication | Test & Measurements

27 months

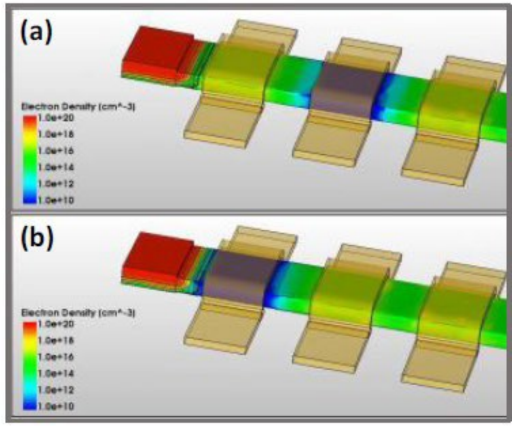
Next step 2023: decrease fabrication time

1 Niebojewski et al, VLSI 2022, 2 Contamin et al, IEDM 202

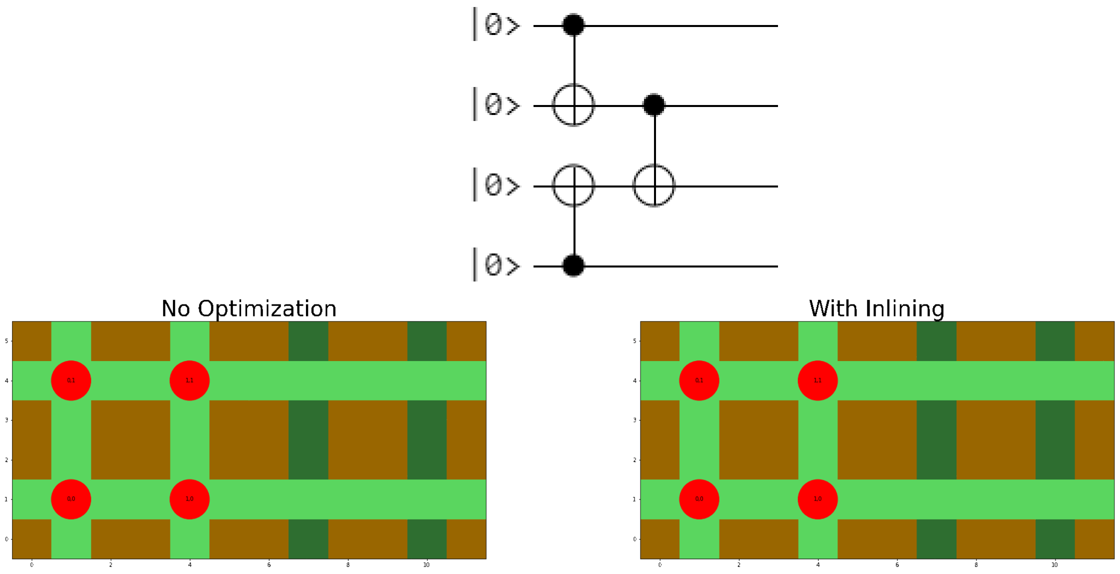
We have developed multiscale simulation



Tight binding qubit simulation
1



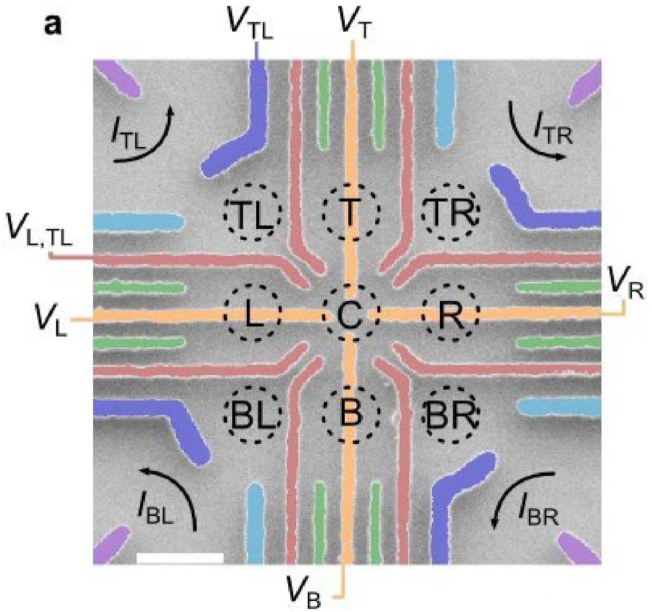
TCAD for qubits
2



Low level software primitives for QEC
3

1 Niquet, Y.M., Challenges and perspectives in the modeling of spin qubits (2020) Technical Digest - International Electron Devices Meeting, IEDM, 2 Niebojewski et al, VLSI 2021, 3 internal developments

Effort @Grenoble

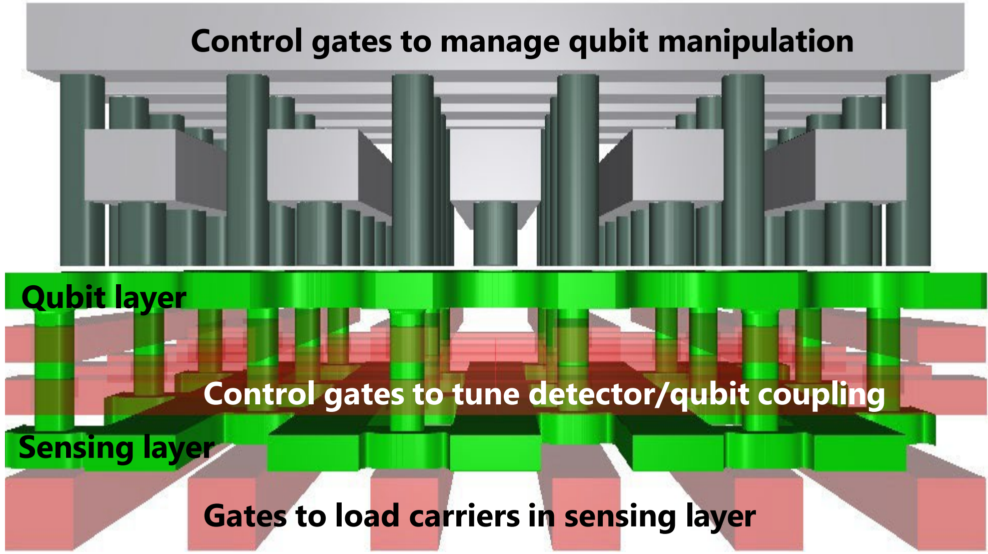


Multi-qubit hifi operations

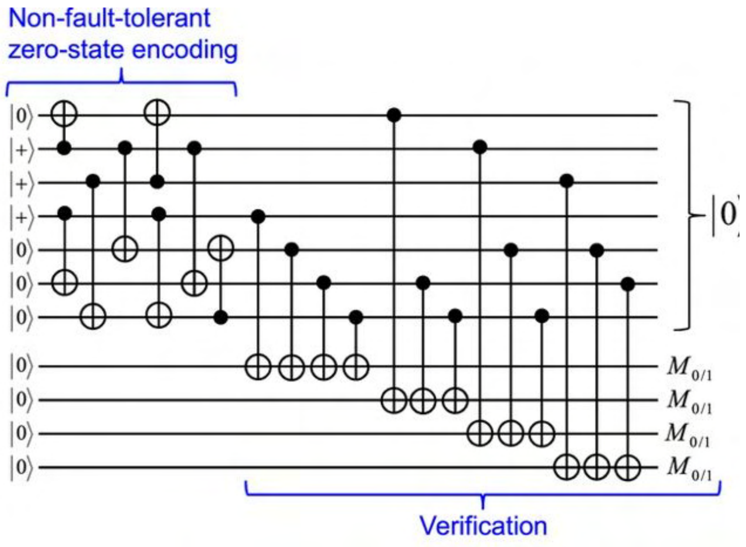
erc

Projet Qucube

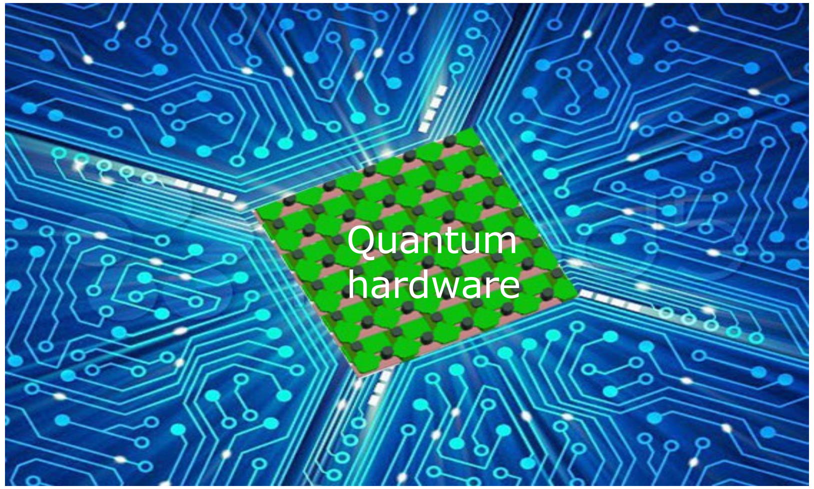
~ 50 engineers and researchers



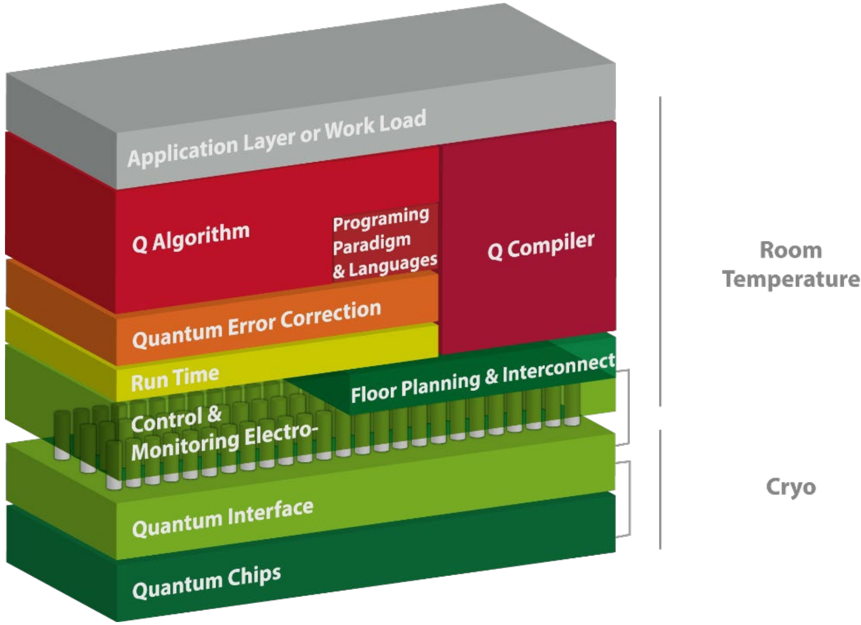
Integration of Silicon quantum nanostructure



Quantum software and algorithms



Classical control systems
@LowT°



Full stack

i-Lab
concours d'innovation

QCOSMOS

QuantumSilicon
Grenoble

European Commission
HORIZON 2020

erc
European Research Council
Established by the European Commission

Agence Nationale de la Recherche
ANR

leti
cea tech

irig
INTERDISCIPLINARY
RESEARCH INSTITUTE
OF GRENOBLE

NÉEL
institut

UNIVERSITÉ
Grenoble
Alpes

Quantum Engineering
Univ. Grenoble Alpes

Panorama des technologies quantiques

MINALOGIC
Auvergne-Rhône-Alpes

Les défis de l’informatique quantique dans un monde bruité

Alastair Abbott, Chargé de recherche / **INRIA**

The challenges of quantum information in a noisy world

Alastair Abbott
Inria Grenoble

Outline

- The problem of noise for (theoretical) quantum information
- A panorama of recent theoretical advances and challenges in the context of experimental progress

Noise: a pervasive problem

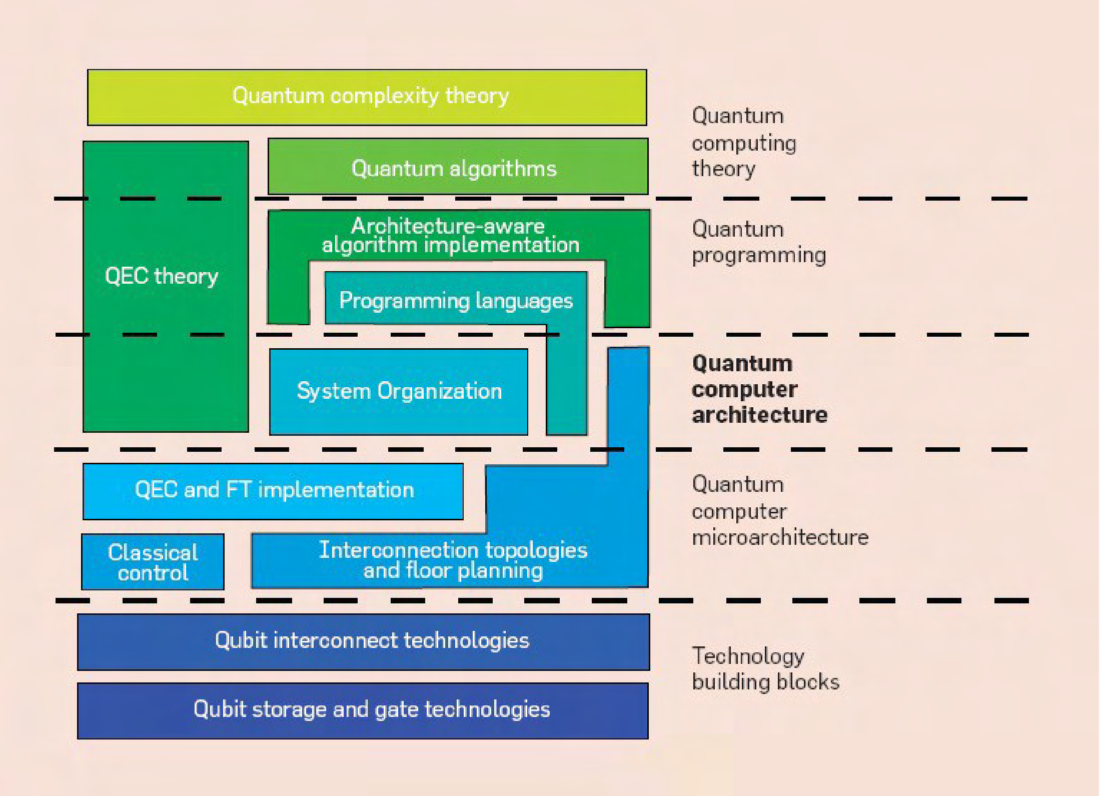
All quantum devices are subject to noise

Quantum computing

- How to use noisy quantum computers?
- How to certify/benchmark noisy devices?
- How to make quantum computers robust against noise?

Quantum communication

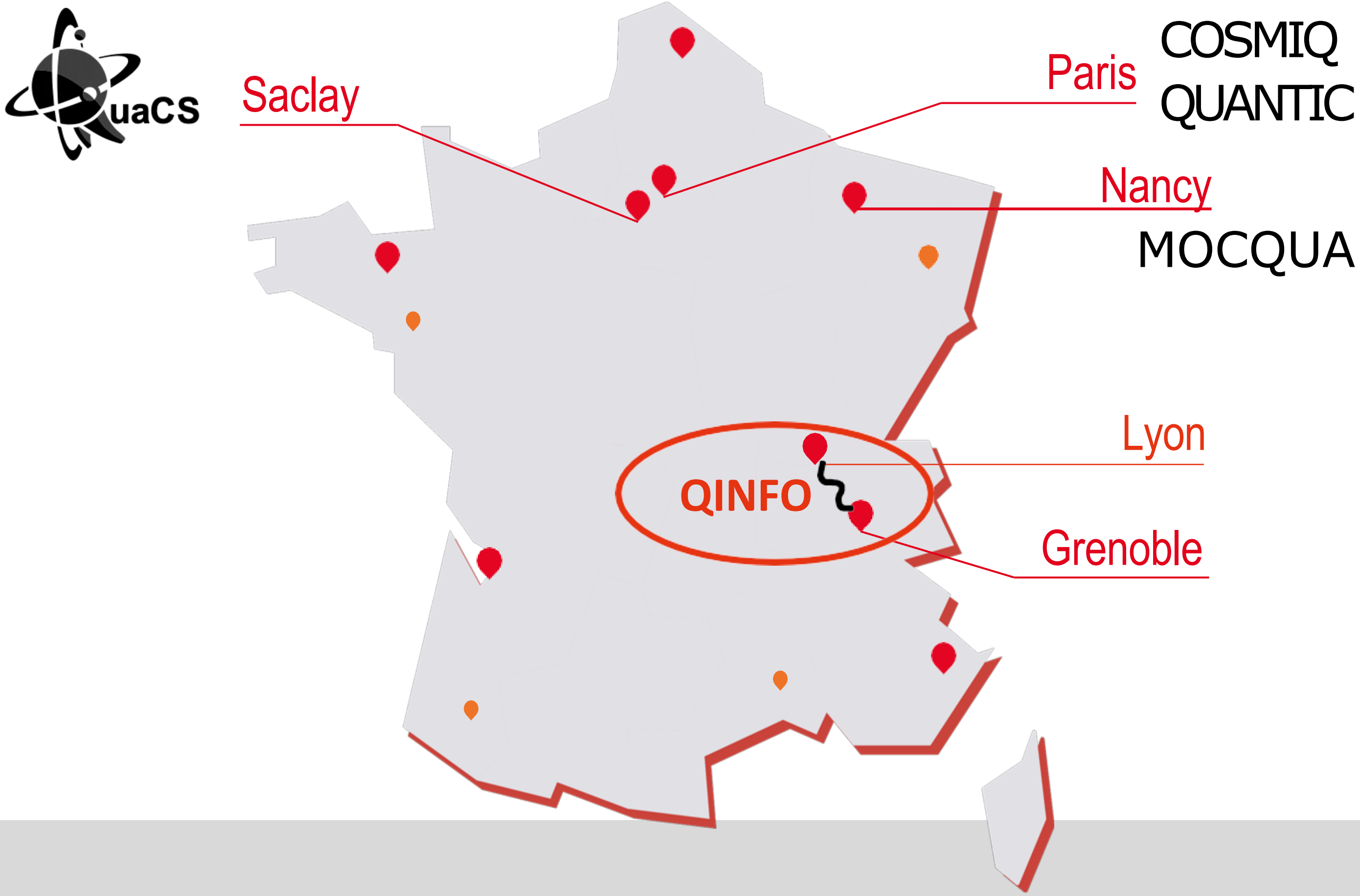
- How to send quantum information long distances over noisy networks?
- How to establish security despite noise?



[R. Van Meter, D. Horsman, *A blueprint for building a quantum computer,* Commun. ACM **56**, 84 (2013).]

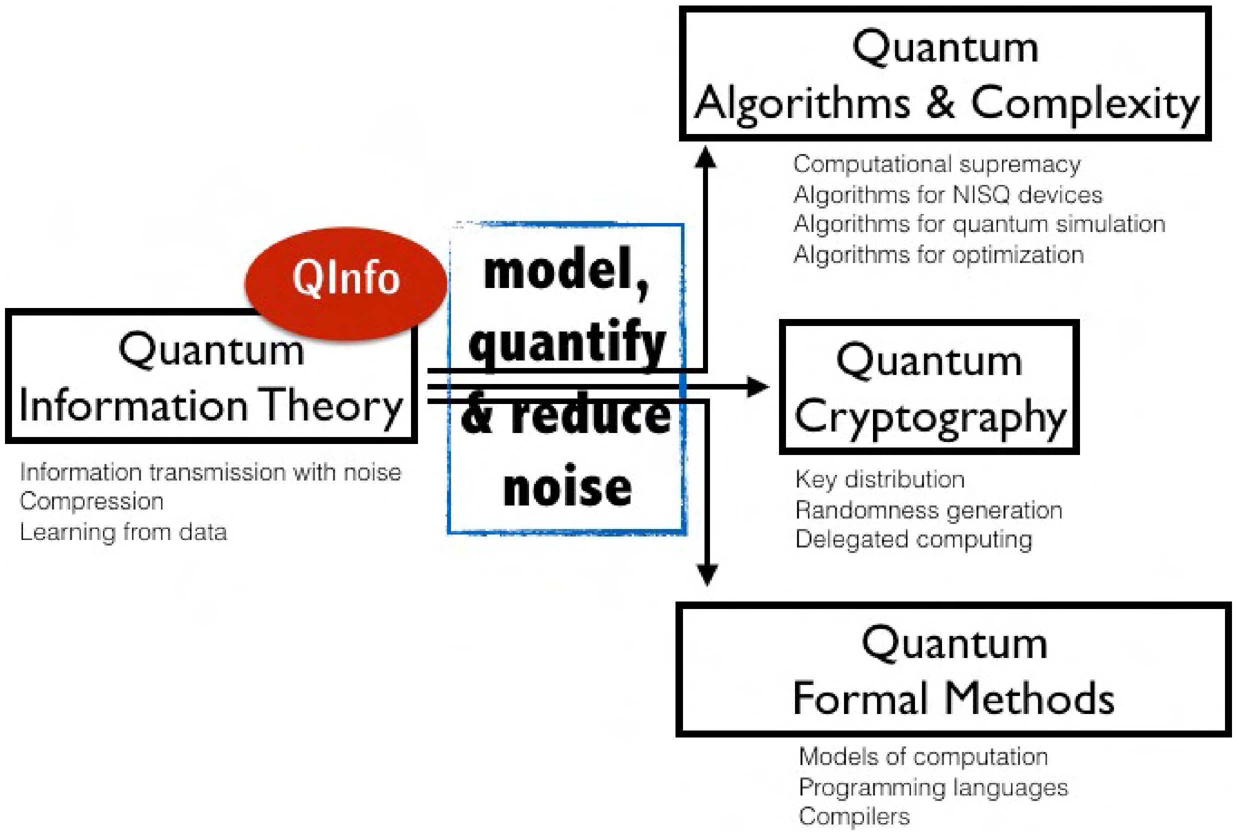
Context: the QINFO group

Optimal Information Processing with Quantum Devices



Context: the QINFO group

Optimal Information Processing with Quantum Devices



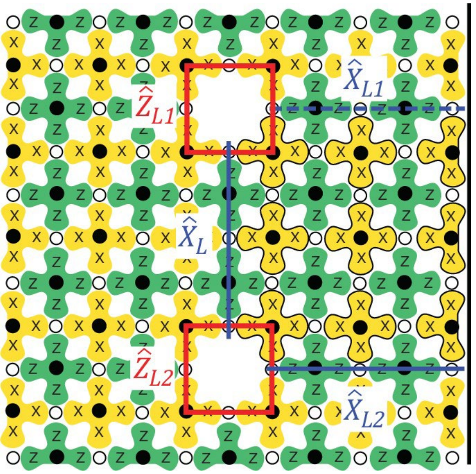
Outline

- The problem of noise for (theoretical) quantum information
- A panorama of recent theoretical advances and challenges in the context of experimental progress

Correcting noise-induced errors

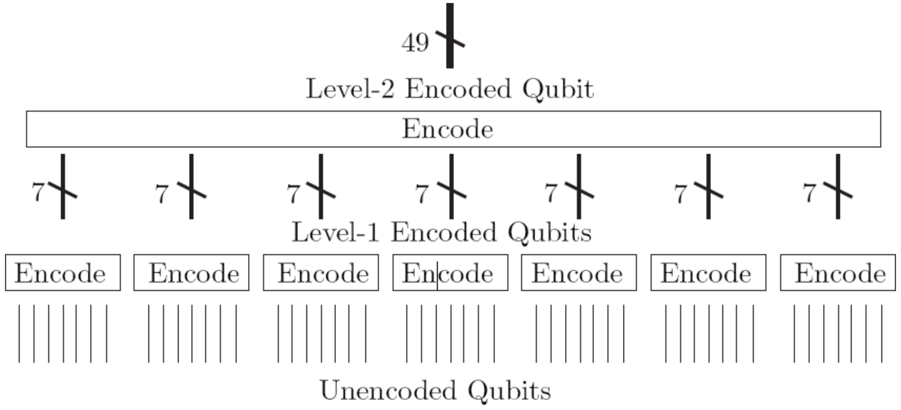
Quantum error correction

- General principle: encode k logical qubits in n physical qubits
- Syndrome measurements detect errors
- Decode syndrome and correct error



Fault tolerant quantum computing

- Uncorrected errors propagate out of control
- Solution: concatenate codes, fault tolerant gate implementations
- Threshold theorem
  > Errors suppressed if error rate below threshold
- Essential for large-scale quantum computing



Implementing error correction

Article | Published: 25 May 2022

Realizing repeated quantum error correction in a distance-three surface code

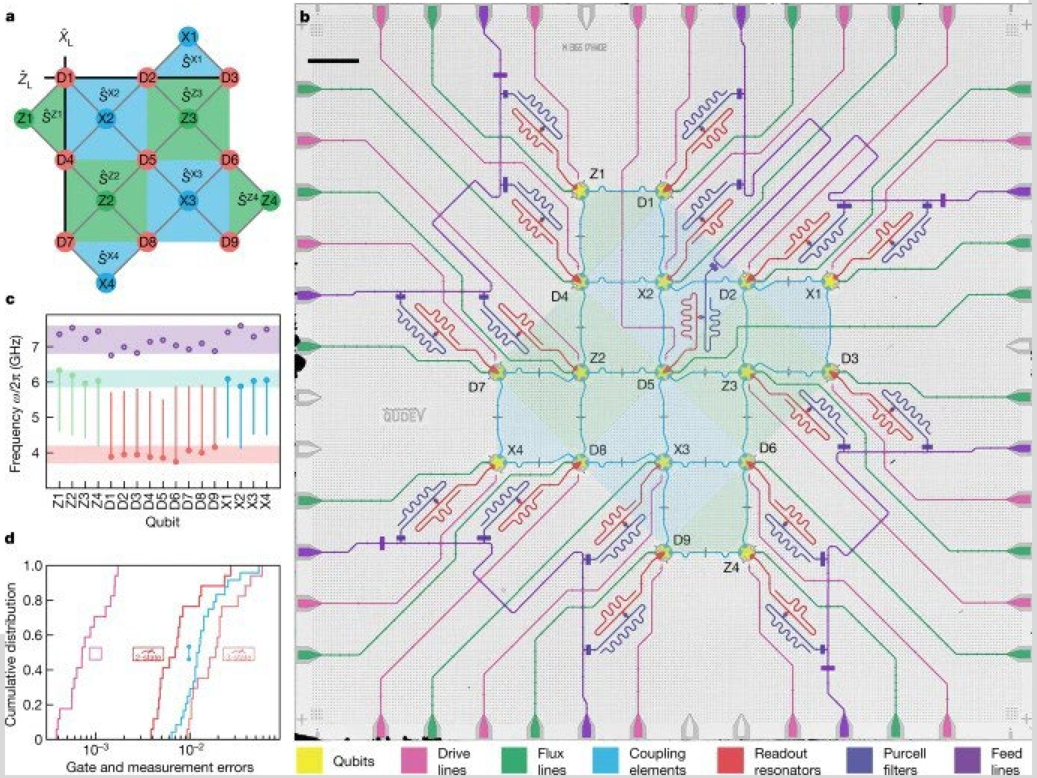
Sebastian Krinner, Nathan Lacroix, Ants Remm, Agustin Di Paolo, Elie Genois, Catherine Leroux, Christoph Hellings, Stefania Lazar, Francois Swiadek, Johannes Herrmann, Graham J. Norris, Christian Kraglund Andersen, Markus Müller, Alexandre Blais, Christopher Eichler & Andreas Wallraff

Nature **605**, 669–674 (2022) | Cite this article

Realization of an Error-Correcting Surface Code with Superconducting Qubits

Youwei Zhao *et al.*

Phys. Rev. Lett. **129**, 030501 – Published 11 July 2022



Surface code (and topological codes)

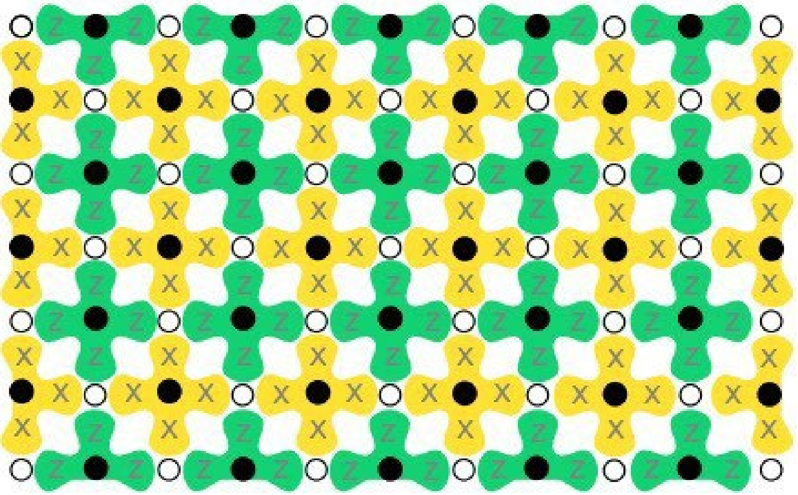
- Seen as prime candidates for practical error correction for quantum computers
- High tolerance to errors
- **But are they *good* codes?**

What is a good code?

- Relevant code parameters: $[n, k, d]$
  - > n: number of physical qubits
  - > k: number of logical qubits
  - > d: code distance (error correction capability)

  (rate: k/n)
- "Good" codes:
  - > Constant rate k/n
  - > Distance linear in n
  - > Easy to perform syndrome measurements
  - > Efficient decoding of error syndrome
  - > Low overheads for fault tolerance

Do we have better quantum codes?



- **Surface code:** $[n, k, d] = [n, 1, \sqrt{n}]$
  - > Good threshold for fault tolerance
  - > But not a very good code
  - > Large memory overhead

[A. G. Fowler, M. Mariantoni, J. M. Martinis, A. N. Cleland, PRA **86**, 032324 (2012).]

Quantum LDPC codes

Quantum LDPC Codes (Low-Density Parity Check)

- Syndrome checks are sparse
- Surface code is a special case
- Do “good” quantum LDPC codes exist?
  - > Constant rate quantum LDPC codes: $[n, \Theta(n), \Theta(\sqrt{n})]$ (Tillich-Zémor 2009)

- What about linear distance, or at least better than $\Theta(\sqrt{n})$?
  - > Yes! Breakthrough $[n, \Theta(n), \Theta(n)]$ construction in November 2021 (Panteleev-Kalachev)
  - > Efficiently decodable
  - > Constant (asymptotic) overhead for fault tolerance (Gottesman 2013; improved by Fawzi, Grospellier, Leverrier 2018)

Making it practical

Asymptotic “practicality”

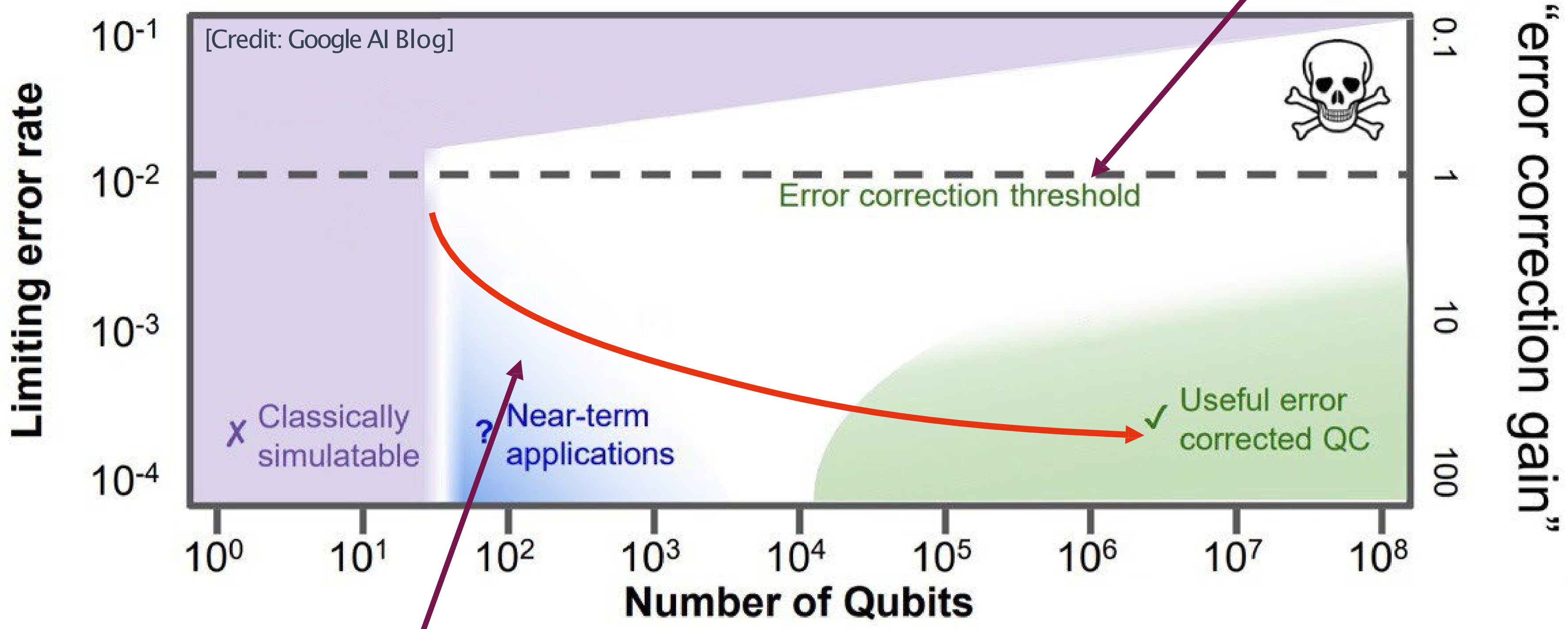
- New codes may have constant rate and linear distance, but the devil is in the constants
- Much improvement needed before really practical
  - > Efficient decoders in practice?
  - > How to implement experimentally?

Bringing theory and experiment closer?

- What overheads, threshold, with more general noise models? (Fawzi, Müller-Hermes, Shayegi 2022)
- Threshold analysis with realistic parameters

The NISQ reality

Improve threshold & overheads

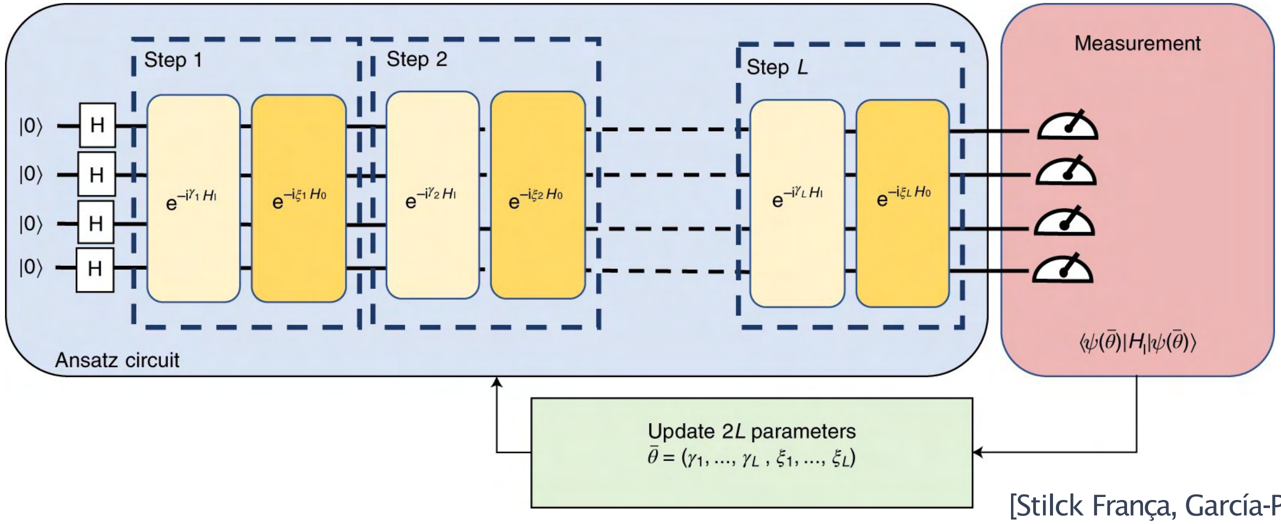


How to use and certify NISQ devices?

NISQ algorithms

Quantum Approximate Optimization Algorithm (QAOA)

[Farhi, Goldstone, Gutman, arXiv:1411.4028 (2014).]



[Stilck França, García-Patrón, Nature Phys. (2021)]

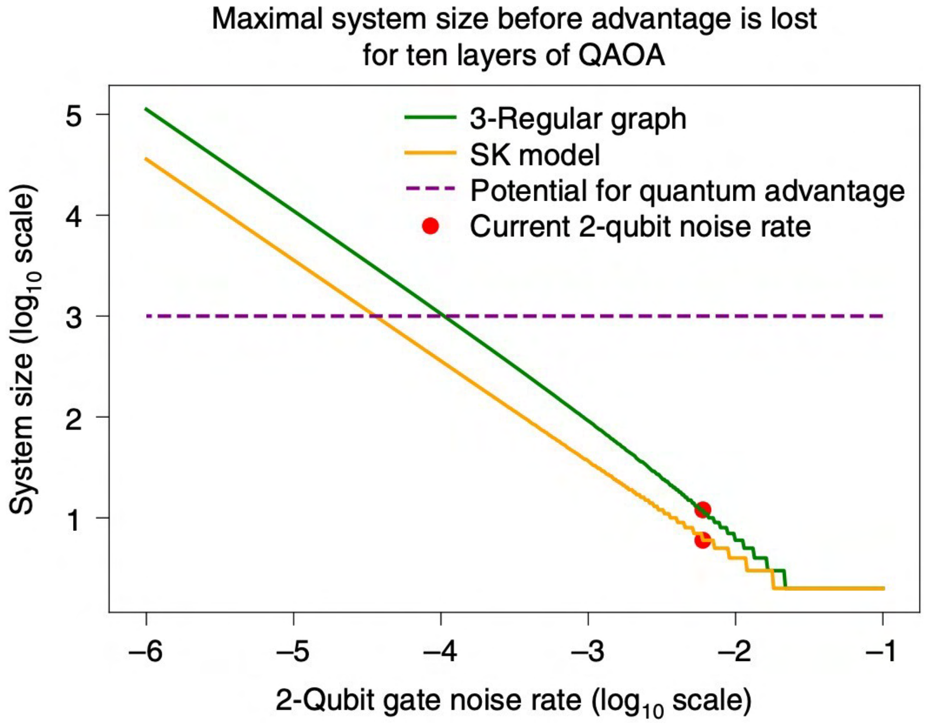
- Potentially good candidate for quantum advantages on NISQ devices
- Wide interest in recent years, can run on current hardware
- **Theoretical status of any quantum speedup still an open question!**

What effect does noise have?

- How much could noise hide any potential quantum advantage?
- Partial response: It's a rather big limitation!

  [Stilck França, García-Patrón, Nature Phys. (2021)]

  > Idea: noise washes out output distribution to one that is easy to approximate classically
  > Sufficient criterion for classical simulability for given number of qubits, circuit depth, noise model…
- Unless topology of problem matches device, noise currently several orders of magnitude too high for any speedup
- **Need a better theoretical understanding of potential speedups or advantages for NISQ devices**



[Stilck França, García-Patrón, Nature Phys. (2021)]

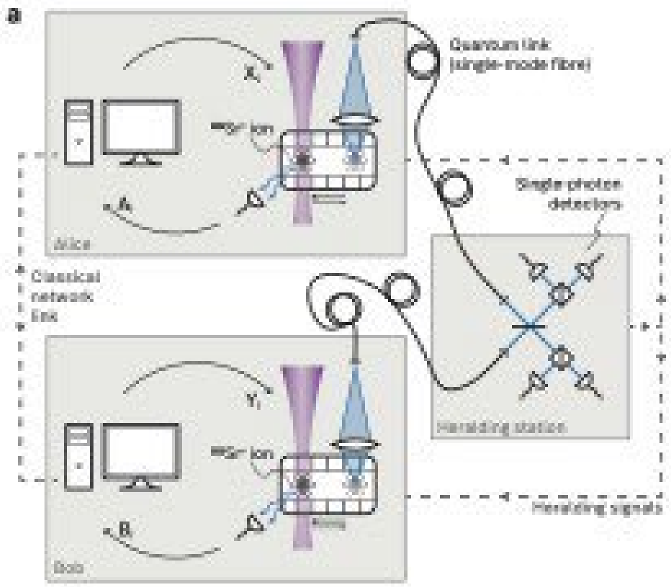
Quantum Cryptography

Device Dependent

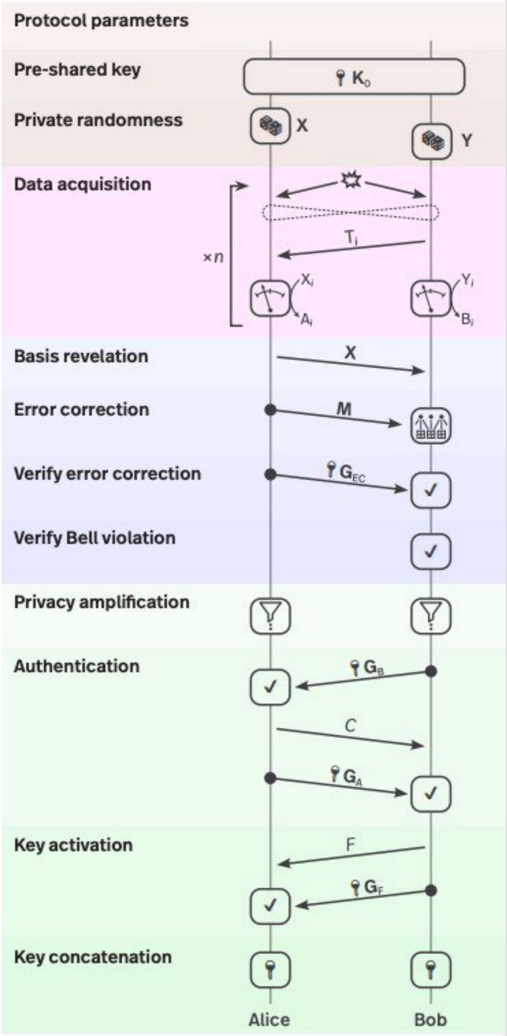
- Current generation QKD
- Trust quantum devices behave as claimed
- Vulnerable to quantum hacks, malicious suppliers

Device Independent

- Next generation QKD?
- Minimal trust assumptions
- Extremely demanding experimentally
  > Less robust to noise



[D. P. Nadlinger *et al.*, Nature 2022]
[Wei Zhang *et al.*, Nature 2022]
[Wen-Zhao Li *at al.*, PRL 2022]

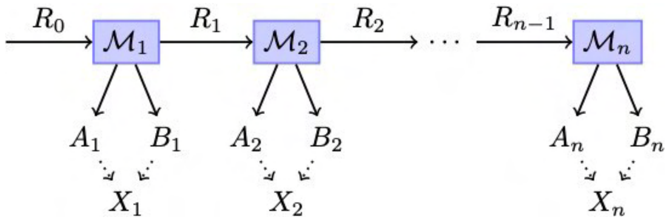


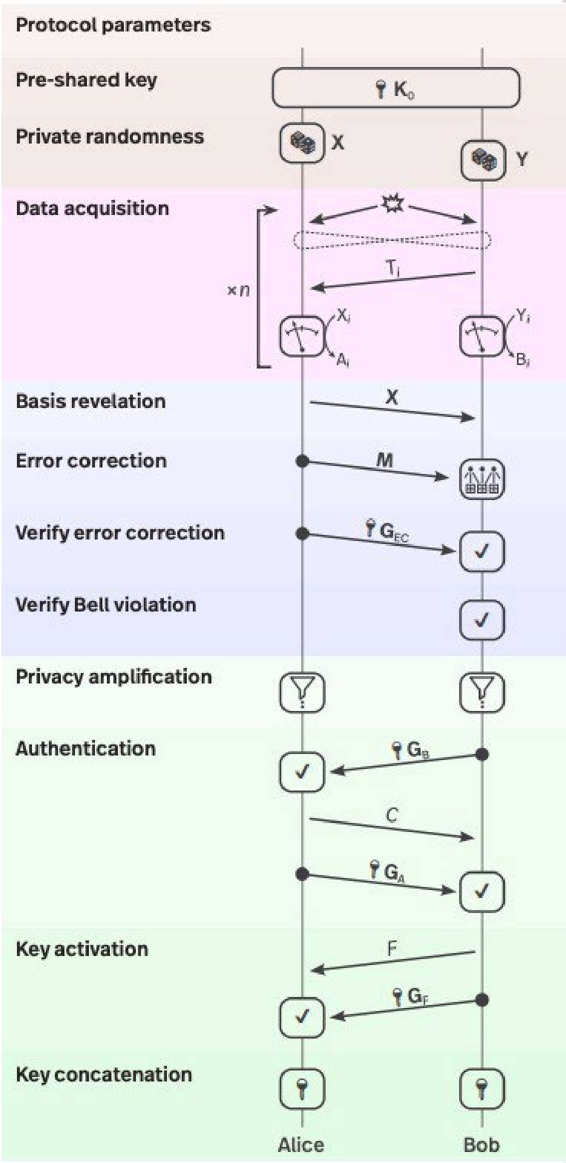
The hidden ingredient

- How to obtain good bounds on how much key is obtained?
  > Finite statistics, no i.i.d. assumption, …

Quantum Information Theory

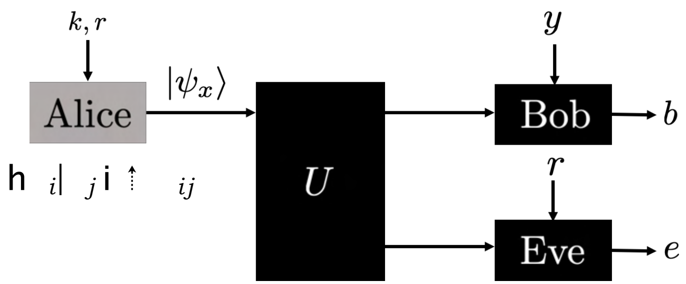
- Study of quantum entropy provides good bounds
- Entropy Accumulation Theory (Dupuis, Fawzi, Renner 2016; Metger, Fawzi, Sutter, Renner 2022)
  > Shows how random key accumulates over repeated rounds





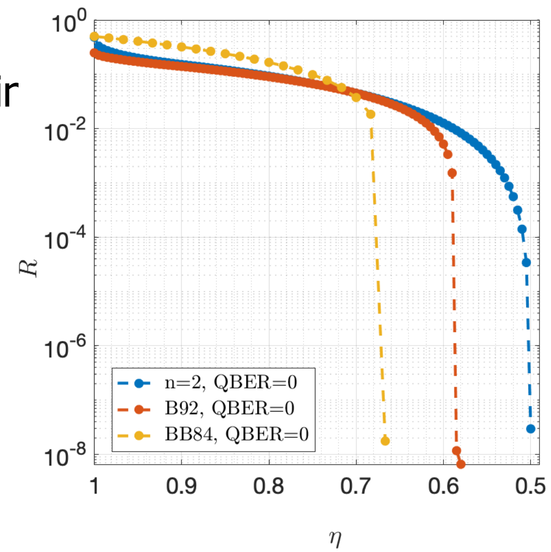
Inria

A practical middle ground?



Semi-device-independent quantum cryptography

- Relax some of the trust assumptions
- Goal: obtain more practical protocols while maintaining core of security gair
  - > Example: Untrusted measurements, weak assumption on states



- What assumptions to obtain a good protocol?
- How to apply entropy accumulation?

[M. Ioannou, M. A. Pereira, **A. Abbott**, *et al.*, NJP 2022]
[M. Ioannou, P. Sekatski, **A. Abbott**, *et al.*, Quantum (2022)]

Panorama des technologies quantiques

MINALOGIC
Auvergne-Rhône-Alpes

Les opportunités de financement nationales

Neil Abroug, Coordinateur national pour la stratégie quantique / **SGPI**

PREMIER MINISTRE

Liberté
Égalité
Fraternité

Secrétariat général pour l'investissement

FRANCE 2030

France National Quantum Strategy

An overview

Oct 4, 2022

Technological development priorities

I. Develop technologies and applications of NISQ era accelerators ;

II. Develop large scale fault taulerant quantum computing technologies ;

III. Develop technologies and applications of quantum sensors ;

IV. Develop and deploy technologies of post quantum cryptography ;

V. Develop applications of quantum communications ;

VI. Develop enabling technologies.

Ecosystem development priorities

I. Develop competences and workforce ;

II. Enforce research, fab and testing infrastructures ;

III. Encourage entrepreneurship and technology transfer ;

IV. Encourage interdisciplinarities ;

V. Enforce patenting and standardization activities

Deployment

INVESTIR L'AVENIR

Sept. 2021	Basic Science Reserch and Infrastructure Program: Solid State Qubits, Cold Atoms, Algorithms, Qcomm and Beyond
Oct. 2021	Standardization Program
Jan. 2022	Hybrid HPC Quantum Facility Initiative Program: Two of three quantum hardwares, close intregration to HPC
Feb. 2022	Education Program Undergrad, graduate and doctoral programs
Feb. 2022	Entrepreneurship and technology transfer Program
Feb. 2022	PQC Call for proposals
May 2022	Cryogenics Program
2022	Large Scale Fault tolerant quantum computing program

Panorama des technologies quantiques

MINALOGIC
Auvergne-Rhône-Alpes

Quantum Programming: A programming shift

Olivier Hess, Atos Quantum Computing Leader / **ATOS**

JT Quantique Minalogic

Quantum Computing:
The programming Shift

Olivier Hess
Atos Quantum Computing Lead - France
olivier.hess@atos.net

Atos

Quantum Computing : Where we are

***1981*: First basic model** of a quantum computer
R. Feynman

2016*: *IBM Q Network

***2017*:** Atos introduced **Quantum Learning Machine**

mid-term 2023/2026
NISQ devices : Quantum accelerator industrialization

Discovery phase — **NISQ Era** *(Noisy Intermediate-Scale Quantum)* — FTQC era

***1994*: Quantum algorithm development** to factorize large numbers. *P. Shor*

Today

- **NISQ HW prototypes**
  (IBM, Google, Intel, DWave, Rigetti, Honeywell…
  Pasqal Quandela, IQM, AQT …
- **Emulators / Learning Systems**
  (Atos QLM, NVIDIA …)

2035+: Logical qubits

- *FTQC (Fault Tolerant Quantum Computers)*

New Potential and new Computing Paradigm

Quantum Computing in theory :

- An unprecedented exponential computing power
- 2^N faster than a classical computer
- Exascale beaten with only 60 (perfect) qubits !

But

- There is no « application portability » from Classical to Quantum Computing
- Classical software will never benefit of the quantum technology
- New algorithms have to be invented

Why Quantum hardware is not enough ☺

- Good qubits necessary but not sufficient

- **Beyond Hardware**
  - Quantum Algorithmics
    - Very few known Algorithms
    - How to program and validate new ideas

  - NISQ Era
    - How to compile a program for a targeted hardware ?
    - Can we design noise resilient algorithm ?
    - Analog vs digital approaches ?

  - Quantum Applications
    - Quantum-classical interface (Variationnal methods, error, mitigation, pre and post treatment, parallelism

➔ Need for (classical) programming / simulation / optimization tools

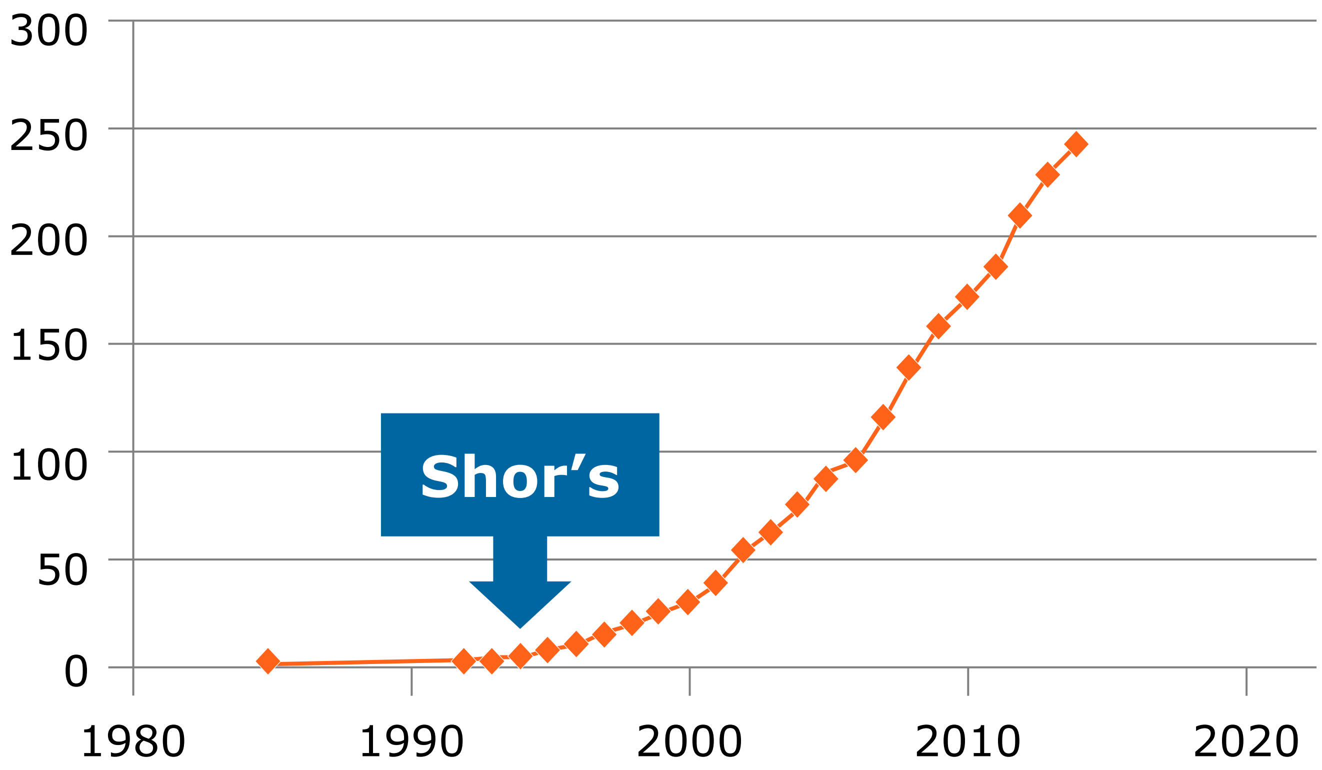
A Huge Paradigm Shift

Classic	Quantum
deterministic	probabilistic
create, overwrite, delete data	reversible computing: information can't be destroyed
move and copy data	information can't be cloned
massive readouts	as few readouts as possible
control flow + boolean operations	superposition + entanglement

- No classical algorithm can be implemented « as is » on a quantum computer with a quantum speedup ! …. and only quantum algorithms can run on quantum computers with a (possible) speedup
- There will (never ?) exist an automatic converter (magic tool ☺) classical to quantum !
- But also : Classical and Quantum will co-exist – Hybrid mode

Known Quantum Algorithms with a Speedup

Progress in QC Algorithms



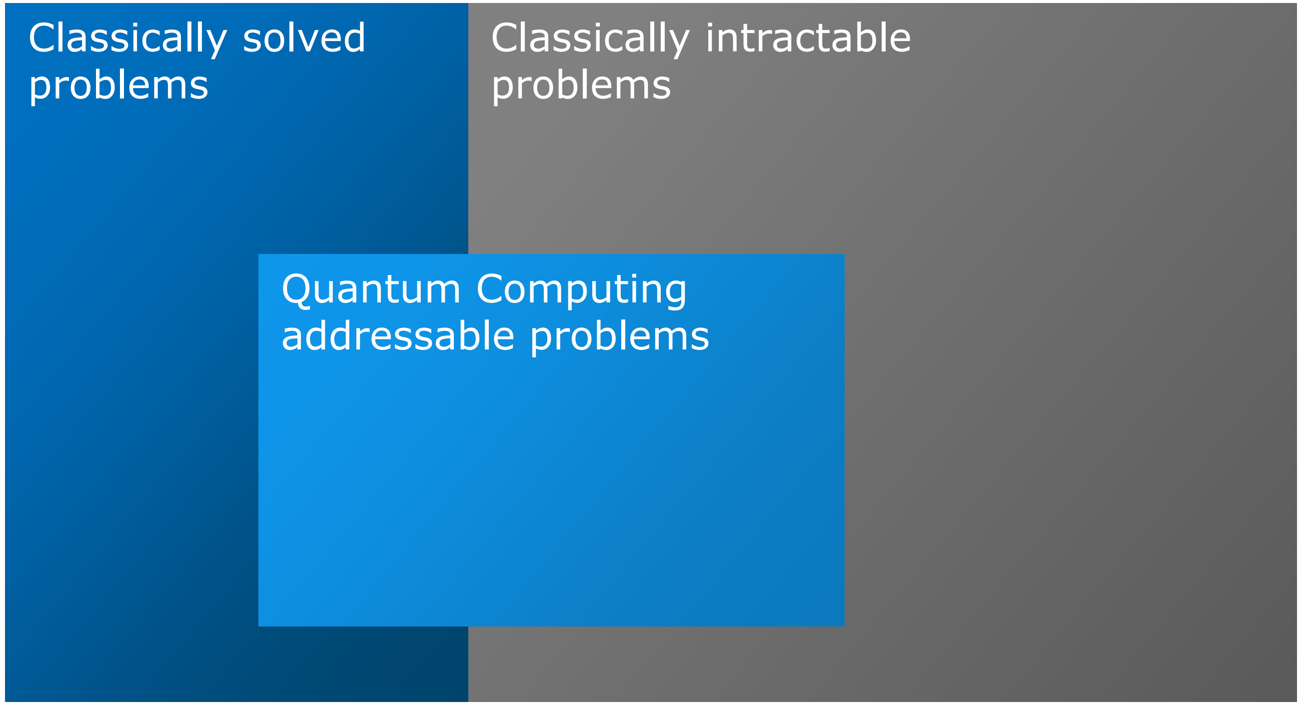
http://quantumalgorithmzoo.org/

What Applications?

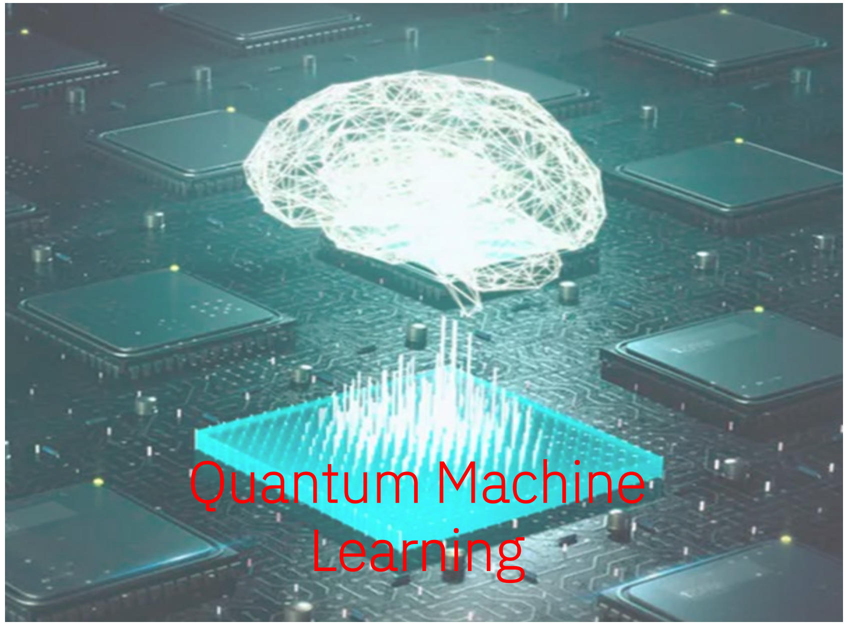
- New algorithmics, no counterpart in the classical world

- Researchers found **computation speedups** for
  - Some hard optimization problems (Travelling salesman-like problems)
  - Some numerical computations (matrix inversion, PDE, …)
  - Some physics/chemistry problems

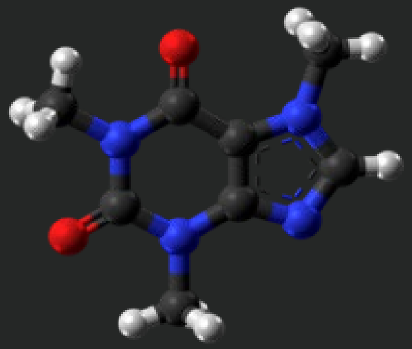
- With strong impacts in applications:
  - AI & ML
  - Optimization (smart grids, logistics ..)
  - Drug discovery
  - New materials….



Quantum Circuits for Applications



Quantum Simulations

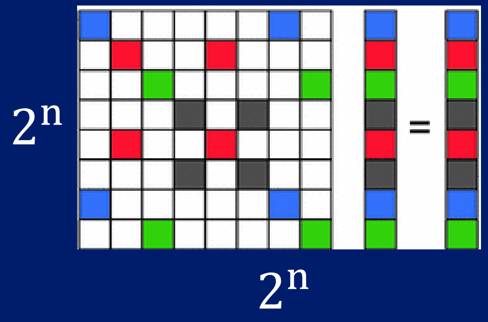


Physics

Chemistry

Materials discovery

Linear Systems ($\mathbf{Ax} = \mathbf{b}$)



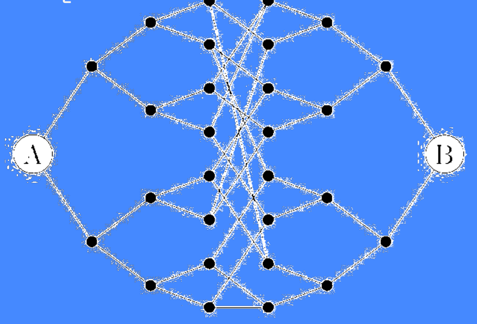
Network analysis

Differential equations

Option pricing, heat transfer

Classification (Machine Learning)

Quantum Walks



Graph properties (network flows, electrical resistance)

Search

Collision finding

Quantum Computing applications

Numerous cross-industry impacts

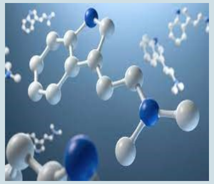
Manufacturing

- Autonomous vehicle
- Logistics
- Supply chain
- Software validation
- Batteries
- Polymers

Public Sector & Defense

- Neural networks
- Process optimization
- Cryptanalysis
- Material science
- Nanotechnologies

Chemistry & material Science



- Materials science
- NanoTech.
- Batteries
- Polymers
- Catalysts, enzyme design
- Molecular modeling
- Protein folding
- Drug discovery

Financial Services & Insurance

- Fraud detection
- Trading strategies
- Market simulation
- Portfolio optimization
- Risk assessment
- Cryptocurrency

Telecom, Media & Technology

- Personalized content
- 5G antenna location
- Chip layout optimization
- Post-quantum cryptography

Resources & Services

- Smart grids
- Flight scheduling
- Oil well optimization
- Yield management
- Cybersecurity
- Carbon dioxide capture

Health & Life Sciences

- Genomics
- Virtual screening
- Protein folding
- Drug discovery
- Personalized medicine

Atos QLM

- Natively hardware agnostic
- Connectable to any QPU
- High performance emulation of real physical qubits
- Advanced compilers and circuit optimizers
- Support of all 3 major paradigms

- Free desktop version: https://github.com/myQLM

- **Soon available on OVHcloud** !

What is the Atos Quantum Learning Machine?

A complete programming environment and a quantum processor emulator

PROGRAMMING

AQASM
Assembly language to build quantum circuits

pyAQASM
Python extension to AQASM

CIRC
Binary format of quantum circuits

QLIB
AQASM & pyAQASM libraries

CO problems class
Describe any Combinatorial Optimization problem

INTEROP.
Connectors with other frameworks

ProjectQ

OPTIMIZATION

PBO
Pattern based optimizer

NNIZER
Topology constraint solver

Circuit Optimizer
Generic circuit optimizer

SIMULATION

SIMULATORS
Digital QC Simulators
Quantum-Inspired Simulators

PHYSICS
Physical Noise models

Atos Quantum Computing - at a glace

1 Atos Quantum Learning Machine

On-Premise solution

- Advanced simulation
  - Noise modelling
  - Optimization
  - Quantum annealing
- Multi-tenancy
- Performance
  - Optional GPU acceleration

2 myQLM

Universal programming environment

Desktop solution

- Freeware
- Entry-level simulation
- Open-source plugins

Universal front-end for quantum technologies

Any Quantum Computing hardware

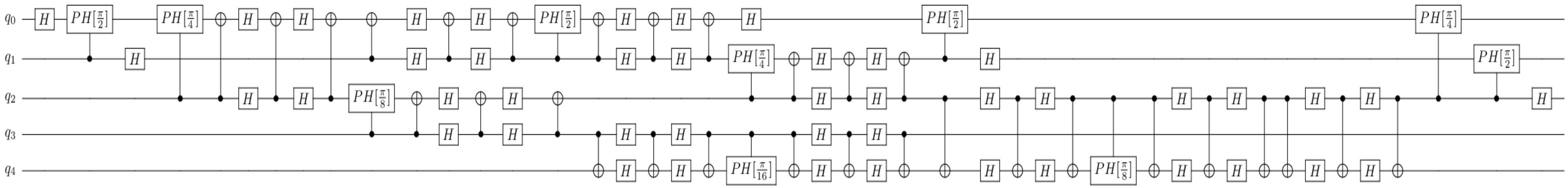
- Superconducting
- Trapped ions
- Rydberg atoms
- …

Atos strategy in the Quantum hardware

- Objective : Empower HPC with Quantum Computing
  - Accelerator for HPC, same logic as GPU
- Milestone: To demonstarte a first accelerator by 2023
- How we see an accelerator : QLM + QPU
  - QLM middleware and compilation assets (QLM is an HPC Building block)
  - Source QPU at pure players
- No exclusive technology for the QPU
  - Different QPU technologies may be good at different uses cases
  - Address all paradigms: digital, annealing, analog
  - Offer the most to our users to experiment

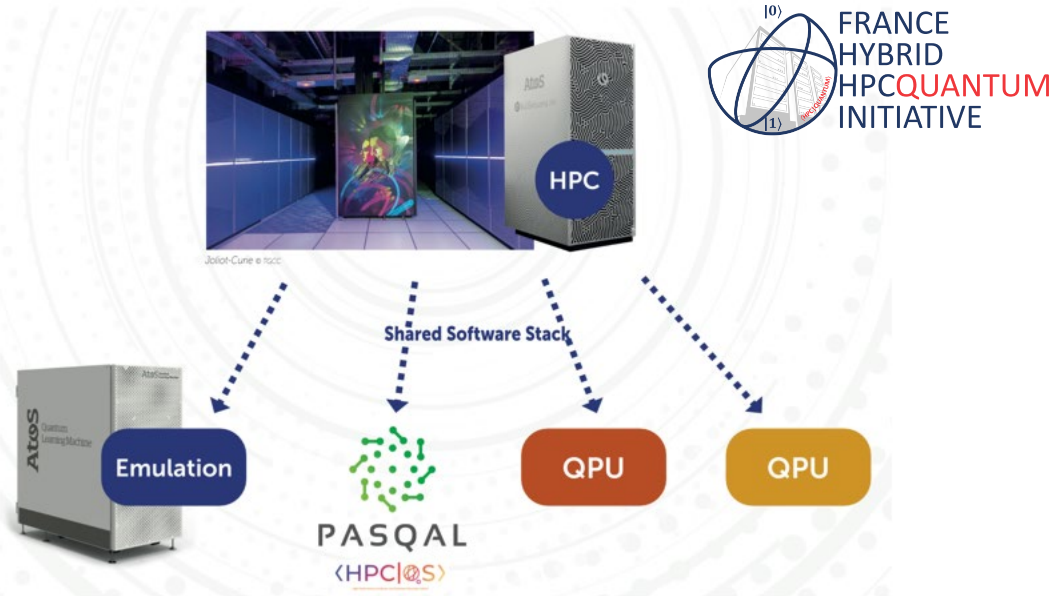
HPC to HPC-Quantum Hybrid

From this :



To :

C or C++ or Fortran instructions
C or C++ or Fortran instructions
If HPC then
Call FFT
else if
Call Q_FFT (qubits_type, nb_qubits, ..)
end if
C or C++ or Fortran instructions
C or C++ or Fortran instructions

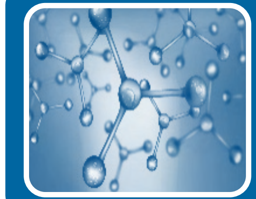


Toward real life applications –European initiative NEASQC

- YouTube channel :

https://www.youtube.com/channel/UCP2ypPsf8FD3r_HQC_izUmQ

- Website : www.neasqc.eu

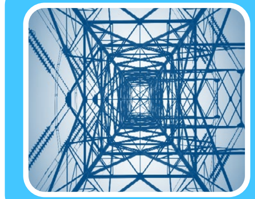


Chemistry

- CO_2 recapture
- Drug discovery

Machine Learning & Optimisation

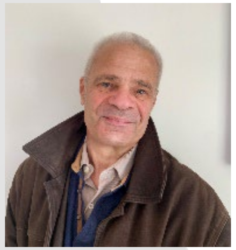
- Reinforcement learning for stock management
- Hard optimization problems for energy management
- Financial applications
- HPC mesh segmentation



Symbolic AI and graph algorithmics

- Quantum natural language processing (QNLP)
- Quantum probabilistic safety assessment (QPSA)
- Quantum rule-based systems (QRBS) for breast cancer detection

Many Thanks …



Olivier HESS
Atos Quantum Computing Lead - France
Tel: 06 76 75 79 02
olivier.hess@atos.net

L’initiative HQI - France Hybrid HPC Quantum Initiative

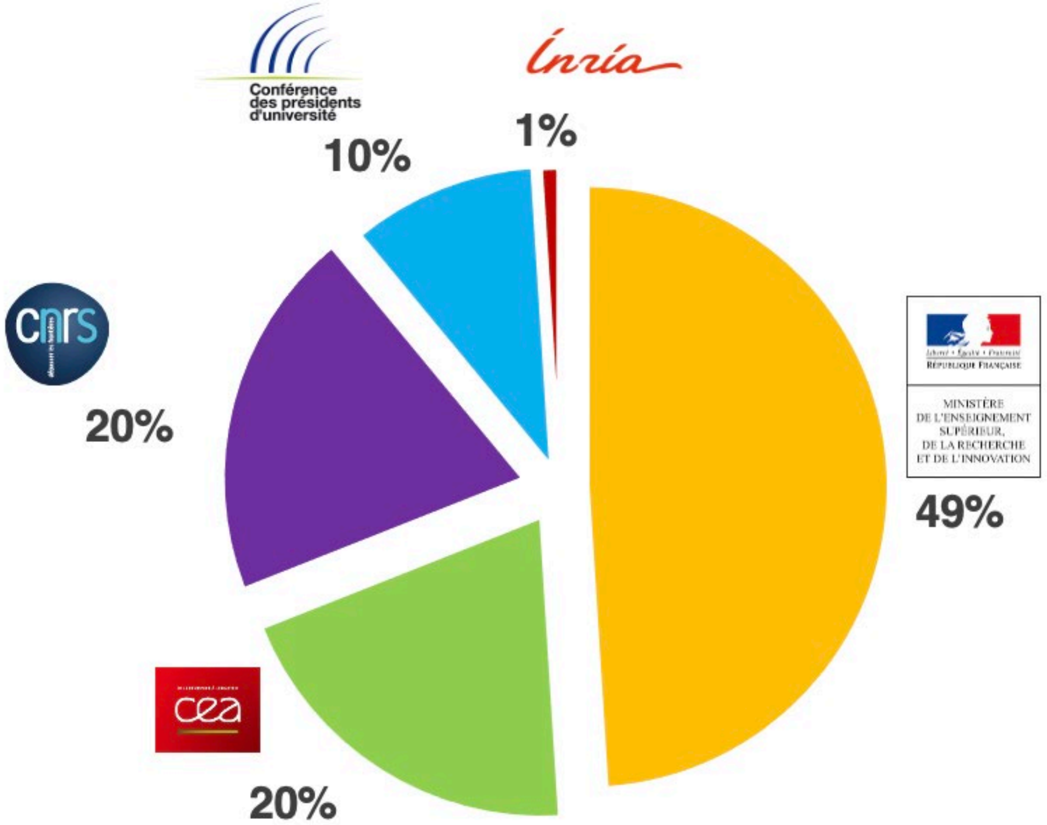
Sabine Mehr, Responsable Calcul Quantique **/ Genci**

FRANCE HYBRID HPCQUANTUM INITIATIVE

FRANCE HYBRID HPCQUANTUM INITIATIVE

GENCI

Grand Equipement National de Calcul Intensif



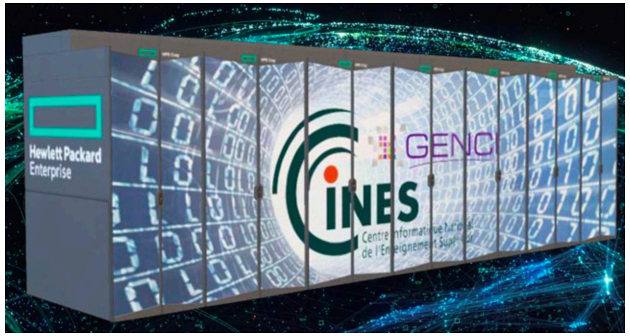
Our Missions

- **Implement** HPC, HPC/IA and QC National Strategies
- Support Academic and Industrial **open Research** Community
- **National procurement** for HPC, IA, massive storage capabilities for data processing, Quantum simulator and computer
- **Distribute computing hours** to scientific community
- **Support** Regional, National and European (PRACE – EuroHPC) presence to promote HPC, AI and Quantum ecosystem
- Coordinate National **Technology Watch** Group

FRANCE HYBRID HPCQUANTUM INITIATIVE

GENCI

National supercomputing centers



TGCC/CEA

- **National and European node with Joliot Curie**
- Candidate hosting site for **Exascale (EuroHPC)**
- Hosting site for the **French and European hybrid HPC+Quantum infrastructure** (already announced a first 100 qubits system from Pasqal)

IDRIS/CNRS

- **1st converged system (HPC+IA) in France** in response to *AI for Humanity*
- Provide **sovereign** facilities for AI research in France (>3000 GPUs)
- **More than 400 AI projects / year**

Update: Introducing The World's Largest Open Multilingual Language Model - BLOOM 🌸

CINES/FU

- **Adastra (>70 PF)**
- **Next gen AMD CPU and GPUs**
- Last step before Exascale

FRANCE HYBRID HPCQUANTUM INITIATIVE

A HYBRID HPC-QC APPROACH

Coupling supercomputers with QPUs

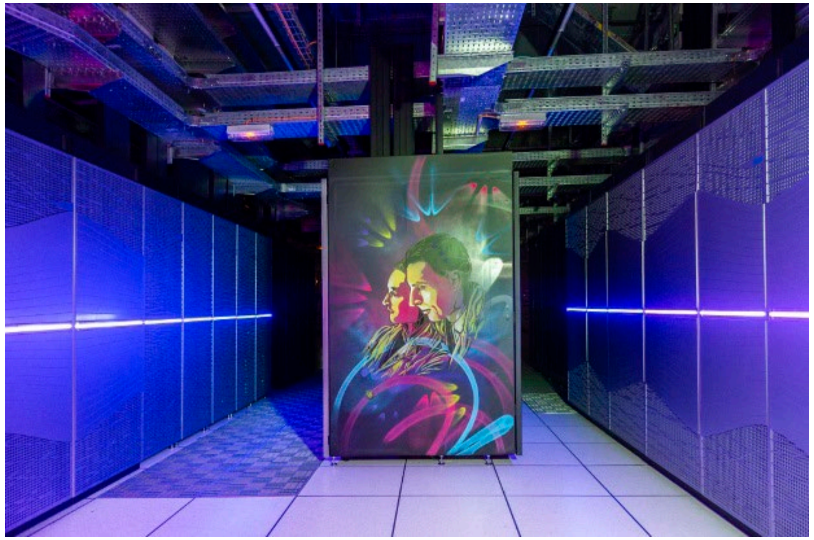
- Quantum computing is **an accelerator** pour for targeted **HPC/AI** applications and algorithms that will be **offloaded to the QPU**

- A **workload evalution** that must be adapted on existing middleware environments

- **A well-known access procedure**

- A central platform to build programming environments, develop and provide access to scalable and interconnected quantum computers as well as applications.

*QPU = Quantum Processing Unit



GENCI's Joliot-Curie supercomputer operated at TGCC/CEA

FRANCE HYBRID HPCQUANTUM INITIATIVE

QUANTUM COMPUTING: HQI INITIATIVE

Scope

An academic and industrial research program that relies on a physical national hybrid HPC-QC platform

- Overall budget **€72.3M** (PIA4) - this amount will be matched and completed by European, regional and industrial co-funding
- 5 years

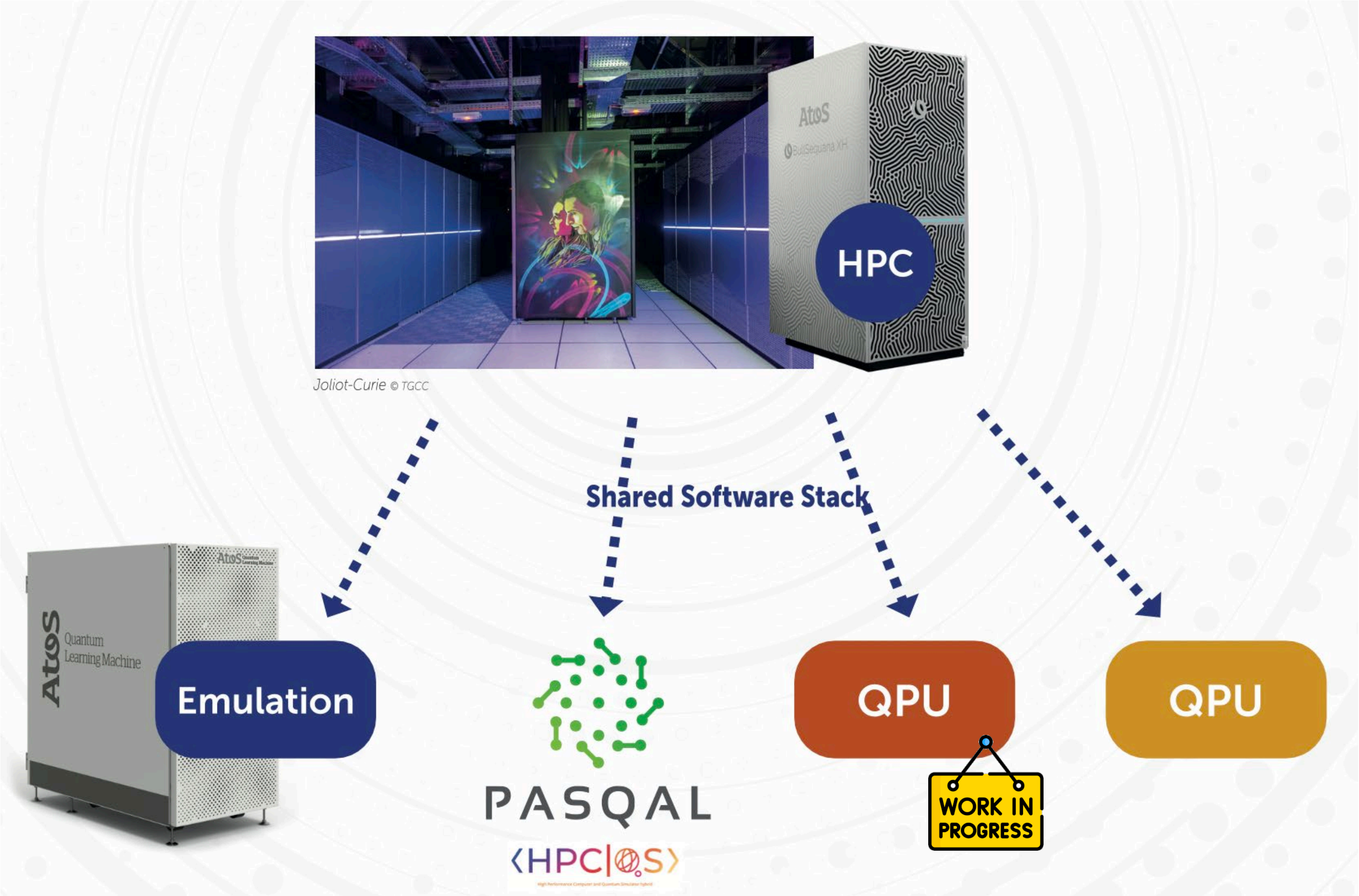
TGCC
Très Grand Centre de calcul du CEA

2 segments, 4 work packages

Segment	Work package	Title	Responsability	Main Partners
1 (€36.3M)	0	**Procurement and deployment of QC platforms**	GENCI	cea, GENCI
2 (€36.0M)	1	**Academic research**	cea	Atos, cea, cnrs, GENCI, Inria
	2	**Industrial research**		
	3	**Dissemination and end-user community support**		

HQI: WORK PACKAGE 0

Procurement and deployment of QC platforms



From experimentation to production-class systems…

…2025:
Value Proposition for the French Exascale application

Production-class
Quantum Computing partition
for targeted communities

FRANCE HYBRID HPCQUANTUM INITIATIVE

HQI: WORK PACKAGE 0 PHASE 1

HPCQS, HQI's 1st building block !

4 years

2021-2025

€12M

€6M from Europe – €6M from member states

6 countries

15 partners

A scalable platform, open to a variety of QPU technologies

EuroHPC

⟨HPC|QS⟩

The first Pan European hybrid HPC-QC cloud infrastructure

2x100 qubits Q4 2022

GENCI

Le calcul intensif au service de la connaissance

cea

Atos

PASQAL

.....

JÜLICH Forschungszentrum

FRANCE HYBRID HPCQUANTUM INITIATIVE

HQI: WORK PACKAGES 1 & 2

Academic and industrial research

Results will be implemented on the platform

Pilot design and implementation

- Integration of QPU and hybrid architecture (QLM, Cloud, HPC)
- Environnement logiciel (outils de développement, runtime)

Applications

- Optimisation and Machine Learning
- Simulation of physical systems

Exploration

- Noise characterization and mitigation
- Quantum links for computing

FRANCE HYBRID HPCQUANTUM INITIATIVE

HQI: WORK PACKAGE 3

Dissemination and end-user community support

Choice of a sovereign Cloud Services Provider to provide access to the platform

Community platforms - websites, wiki, Slack forum

Organization of dissemination **events**

Development of **International relationships**

Hands-on training for end-users

Setting up an HQI platform end-user **high-level support team**

Development of **use cases** through national and international extensions of the Quantum Pack initiative

Creation of a network of excellence centers: **Houses of Quantum**

HQI: WORK PACKAGE 3

The Ile-de-France region Quantum Pack

FRANCE HYBRID HPCQUANTUM INITIATIVE

Région îledeFrance — le lab quantique — Teratec

Started in **2020**

24-month projects

45% of the project costs covered for the start up

The start up must be **located in Ile-de-France**

AQUAPS

QUantum **A**dvantage to solution **P**lanning and **S**cheduling issues

PASQAL — THALES

OCH2Q

Optimization of **H**ydrogen **C**onversion through **Q**uantum Computing

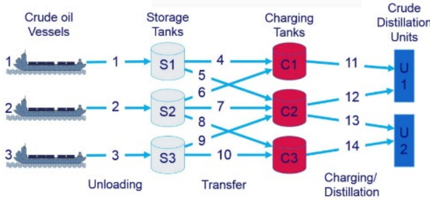
Air Liquide — C12

AQCMED

Quantum **A**dvantage for **D**rug **D**esign

Qubit pharmaceuticals — PASQAL

TotalEnergies — QC WARE



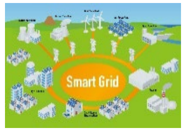
AQMuSE

Quantum **A**dvantage for **Mu**lti-**S**ourcing **E**nergy

AQUARE

QUAntum **A**dvantage to solve complexe problems for smart grid **E**nergy

PASQAL



EDF

3 new Proofs of Concept just received fundings, in the **Aeronautics, Spatial and Defense (ASD)** industry:

MBDA MISSILE SYSTEMS — ONERA THE FRENCH AEROSPACE LAB — QUANDELA — AQCMA

AIRBUS — AQUAEDP — PASQAL

NAVAL GROUP — Inria — QMLCAT — ALICE & BOB

FRANCE HYBRID HPCQUANTUM INITIATIVE

HQI: WORK PACKAGE 3

Dissemination and end-user community support

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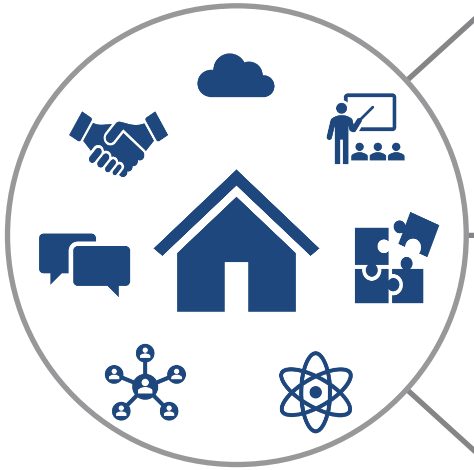
HQI: WORK PACKAGE 3

Building a ”Houses of Quantum” network

FRANCE HYBRID HPCQUANTUM INITIATIVE

Quantum Technology – 04 octobre 2022 – Mercure Grenoble Centre Président



Academic Research

- Expertise
- Support

leti ceatech – UGA Université Grenoble Alpes

Industrial Research

- **Pack Quantique** = Use-case-oriented Quantum Computing program to support industries

ARKEMA – MICHELIN – Schneider Electric – soitec

Communication, Dissemination and Promotion

- Communication
- Dissemination
- Promotion

MINALOGIC – le lab quantique – QuantAlps

- ✓ **Identify** and **select** at least 5 centers of excellence with complementary
  - ✓ Localizations
  - ✓ Vertical expertises

  ➔ **House of Quantum** label
- ✓ **Support** industrial, academic and institutional end-users in their adoption of quantum computing
- ✓ **Attract** international talents and start-ups to enrich the existing ecosystem

Setting up a **national “Houses of Quantum” network** spread across the country (Grand Est, AURA, Occitanie, Nouvelle Aquitaine, etc) and export of the concept to Europe, with **a first French-German initiative** (HPCQS)

FRANCE HYBRID HPCQUANTUM INITIATIVE

HQI France

@HQI_France

THANK YOU

For more information on the HQI initiative, please contact:

Sabine MEHR
Responsable Calcul Quantique @ GENCI
sabine.mehr@genci.fr
+33 (6) 79 81 21 15

Panorama des technologies quantiques

MINALOGIC
Auvergne-Rhône-Alpes

IDQ’s technologies for mobile phones security and optical quantum simulation

Gaëtan Gras, R&D Scientist **/ ID Quantic**

IDQ's technologies for mobile phones security and optical quantum simulation

Journée thématique Minalogic 2022
Panorama des technologies quantiques

Gaëtan Gras, R&D Scientist

04/10/22

20 YEARS QUANTUM INNOVATION

The value of Quantum Technologies

Quantum technologies are set to revolutionize the world we live in.

Quantum technologies

- Quantum Sensing
- Quantum Computing
- Quantum Communications

Energy/transportation

Machine learning

High Tech

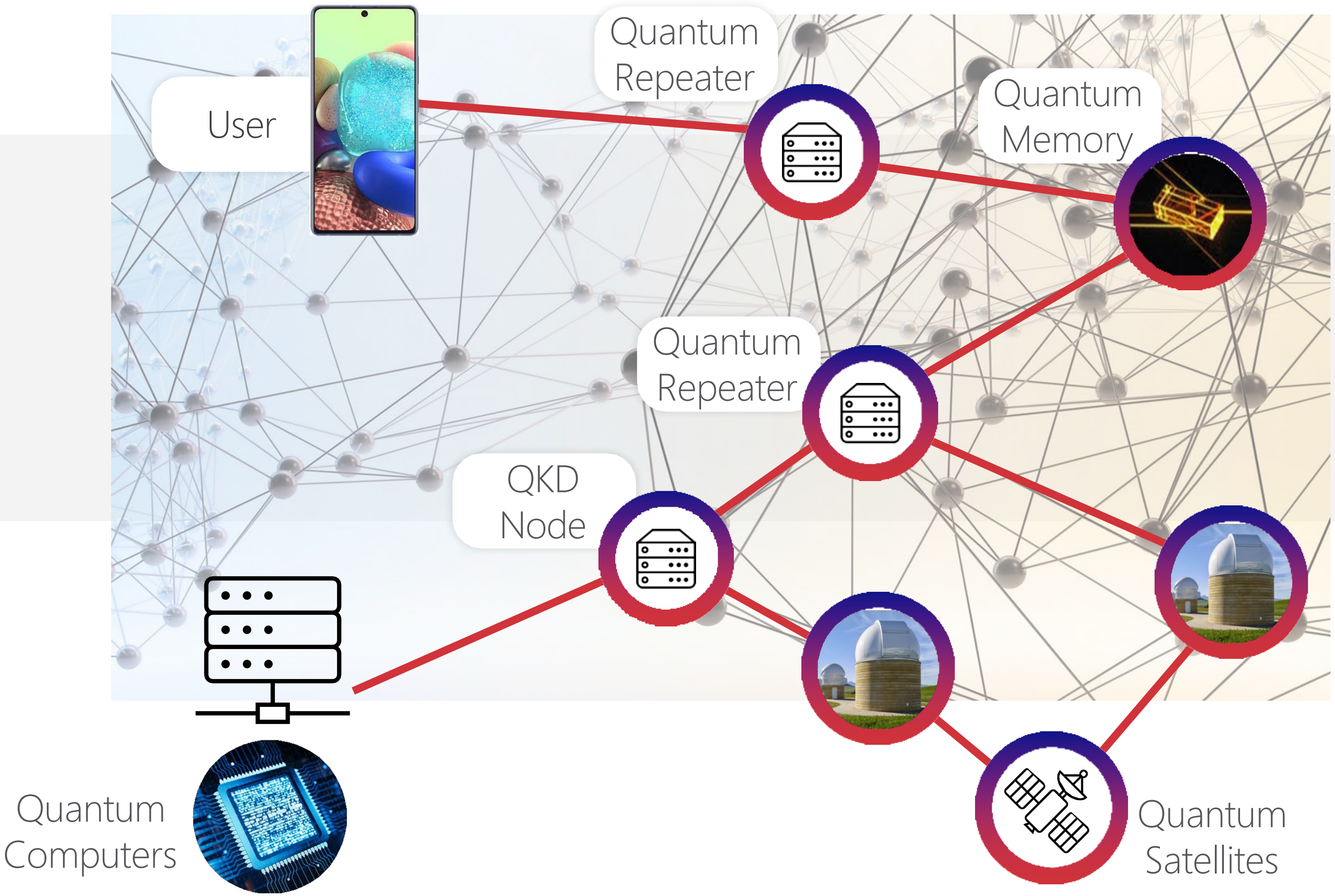
Chemistry & Pharma

Finance

Public Safety

But will also break keys!

Towards the Quantum Internet



ID Quantique

Founded in 2001

By 4 quantum physicists from the University of Geneva

Geneva, Switzerland
Seoul, South Korea
Boston, USA

100+ employees, including 50 engineers/scientists

Investments in 2018 by SK Telecom & Deutsche Telekom

Develops technologies and products based on quantum physics within 2 business units:

- Quantum-Safe Security
- Quantum Sensing

Performs R&D, production, professional services, integration, support

Clients: Governments / Banks / Gaming Industry / Universities / IT Security

Quantum safe security at IDQ

Building a trusted future using quantum technologies

Feed your security systems with quantum randomness

1011011100
01011000110
011010010

True random numbers
Foundation

Strong keys
Tool

Secure crypto-system
Result

QRNG is the only solution offering provable entropy thanks to the laws of quantum physics

The security of any cryptographic system is determined by the security of its keys...

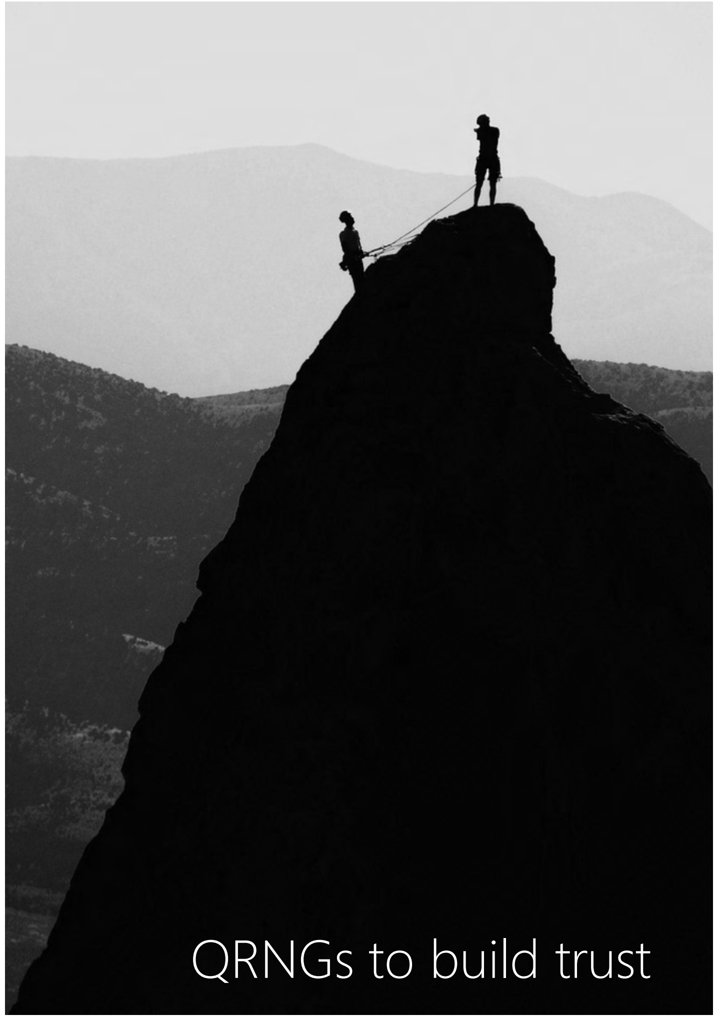
Which rely on random numbers.

Getting the foundation right is crucial.

The solution?

Quantum Random Number Generation (QRNG)

Quantum random number generation on a chip



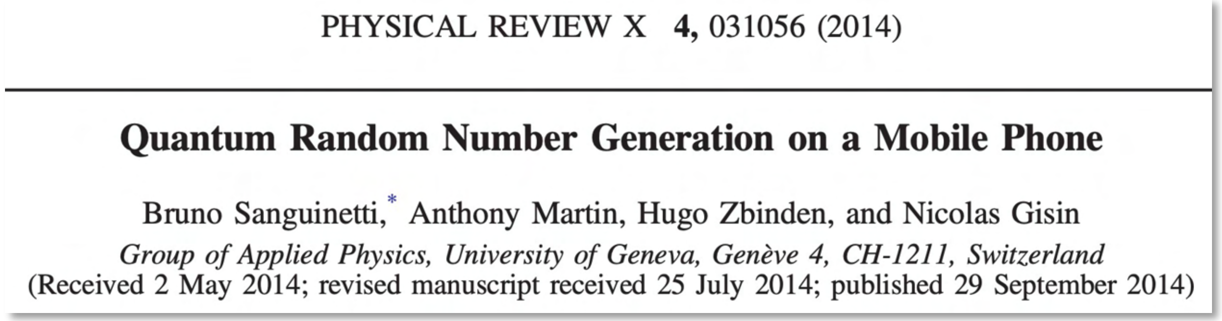
Why do QRNGs help?

They provide a clear and robust entropy generation mechanism with a physical security proof

What is needed to make ubiquitous?

- Low production costs for mass market
  - CMOS IC compatible
- Small footprint
- Low-power consumption
- Compliant with security standards (FIPS/NIST, CC/AIS-31)

The original idea behind IDQ's QRNG chip (2014)


PHYSICAL REVIEW X 4, 031056 (2014)

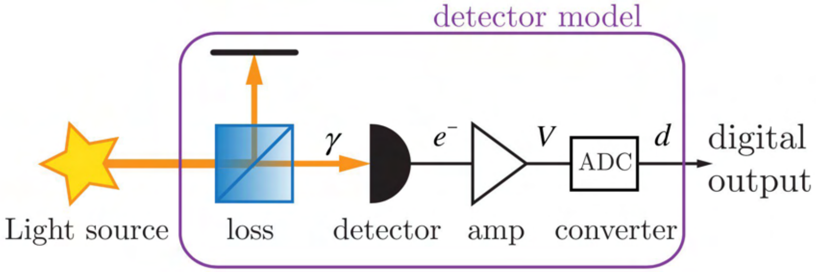
Quantum Random Number Generation on a Mobile Phone

Bruno Sanguinetti,* Anthony Martin, Hugo Zbinden, and Nicolas Gisin

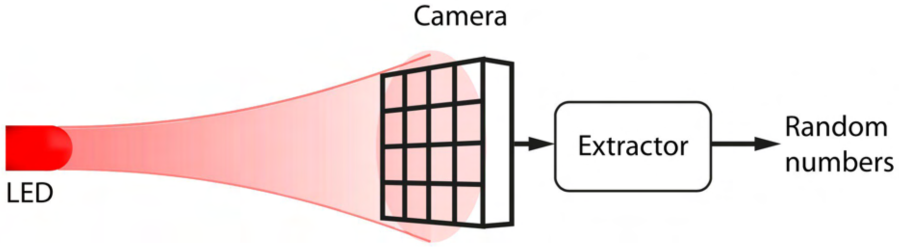
Group of Applied Physics, University of Geneva, Genève 4, CH-1211, Switzerland

(Received 2 May 2014; revised manuscript received 25 July 2014; published 29 September 2014)

Single pixel model



System-level view with array of pixels



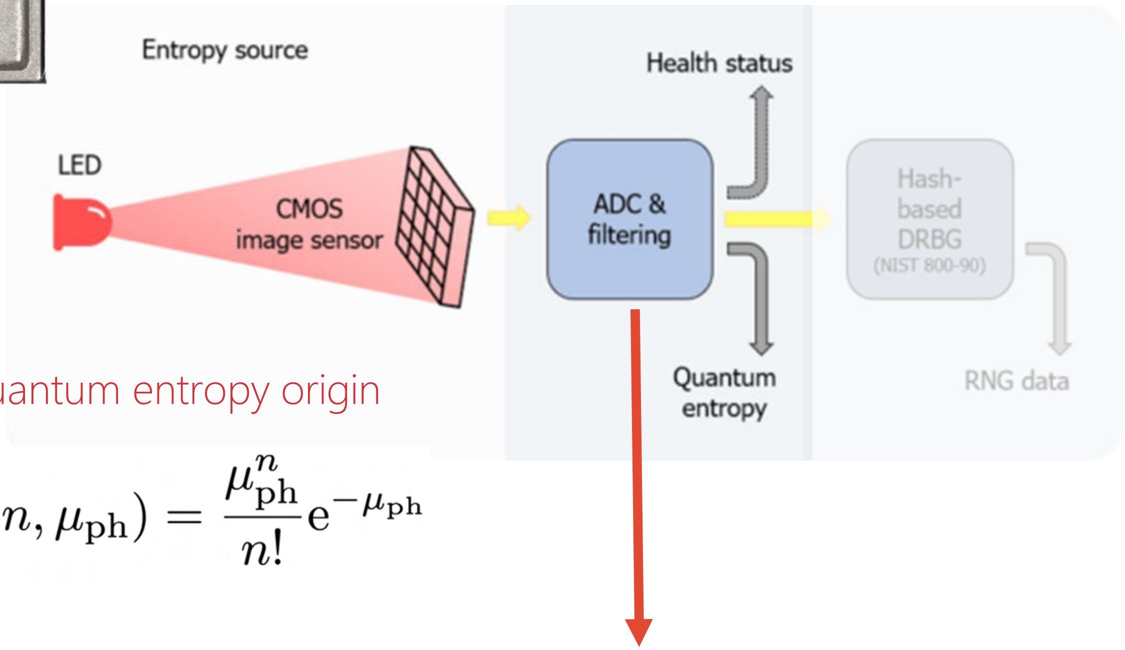
CMOS Image sensor: each pixel = photodiode + amp provides a random voltage

(low-noise + high QE)

Arrays can provide large rates of raw entropy

(industry-compatible elements are there)

IDQ's QRNG chip architecture



Quantum entropy origin

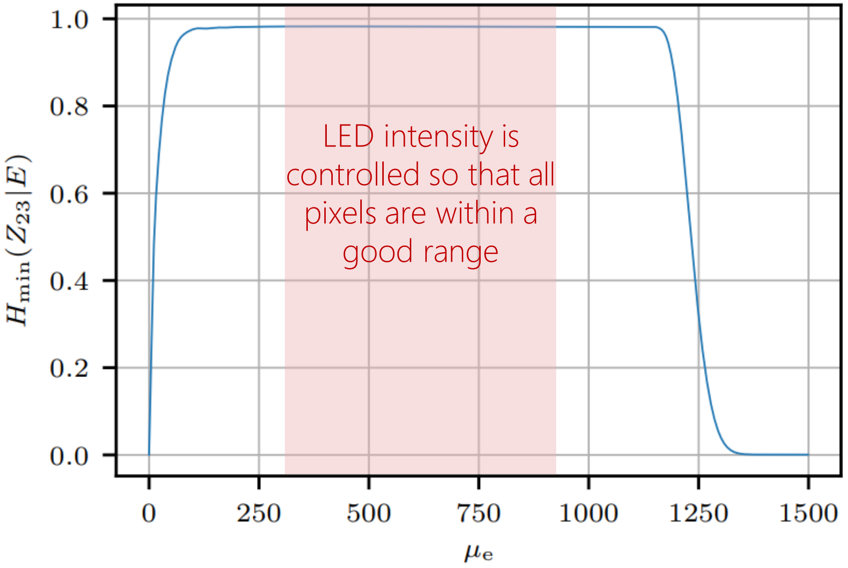
$$p(n, \mu_{\text{ph}}) = \frac{\mu_{\text{ph}}^{n}}{n!} e^{-\mu_{\text{ph}}}$$

MSB	9	8	7	6	5	4	**3**	**2**	1	0	LSB

Only LSB 2 and 3 are kept

Almost optimal min-entropy per bit

$HH_{min} \geq 0.98$



G. Gras, A. Martin, J. W. Choi and F. Bussières, "Quantum entropy model of an integrated Quantum-Random-Number-Generator chip", *Phys. Rev. Appl.*, vol. 15, **054048**, 2021

Statistical tests of entropy and randomness quality

Entropy tests

Optimal results on NIST 800-90-B IID and non-IID test suite (in varying environmental conditions)

Randomness tests

Passes NIST SP 800-22 and DieHarder tests with expected rate (in varying environmental conditions)

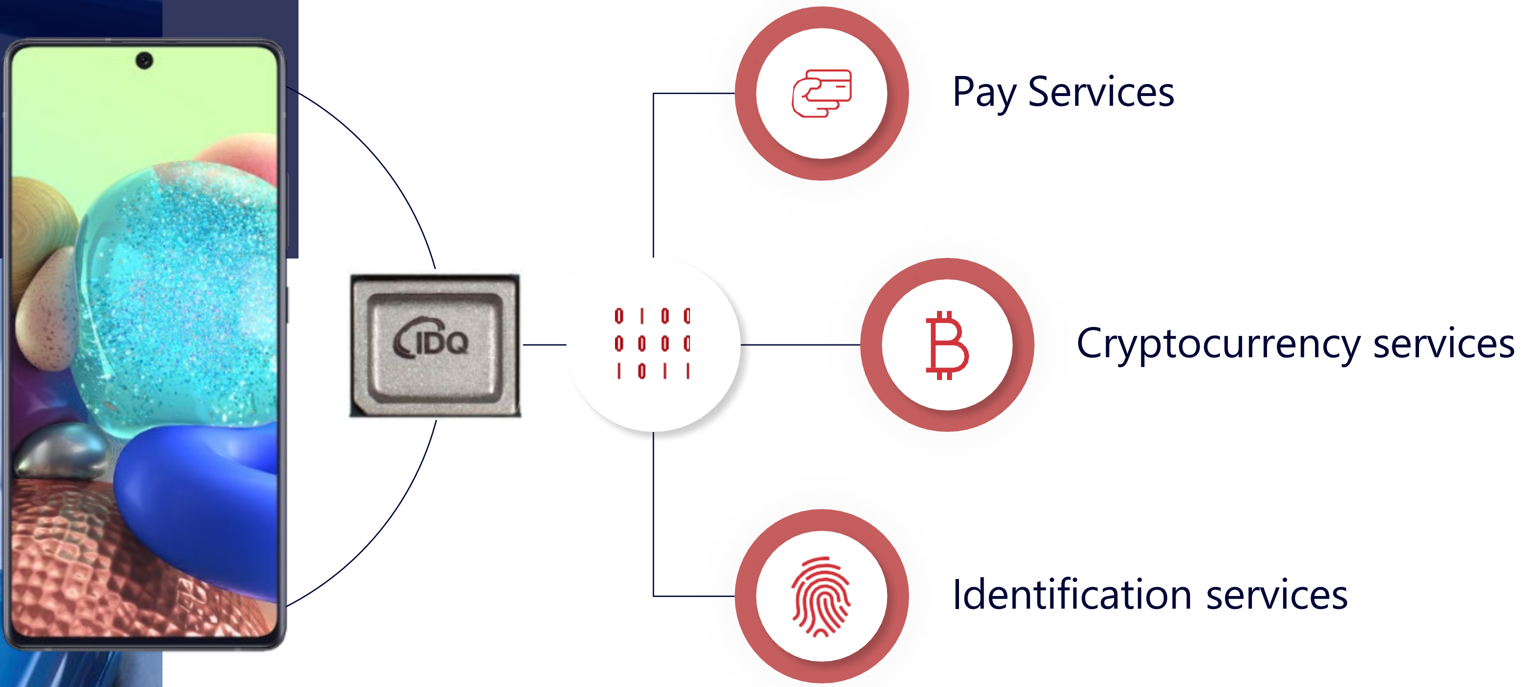
Automotive certification

AEC-Q100 certification for the IDQ6MC1 chip (guarantees functionality in harsh environment)

Applications

- Mobile
- Home Appliances & Home Security
- Telco and Cloud Service Provider
- Automotive
- IoT
- Blockchain
- Critical Infrastructure
- Financial services and Banks

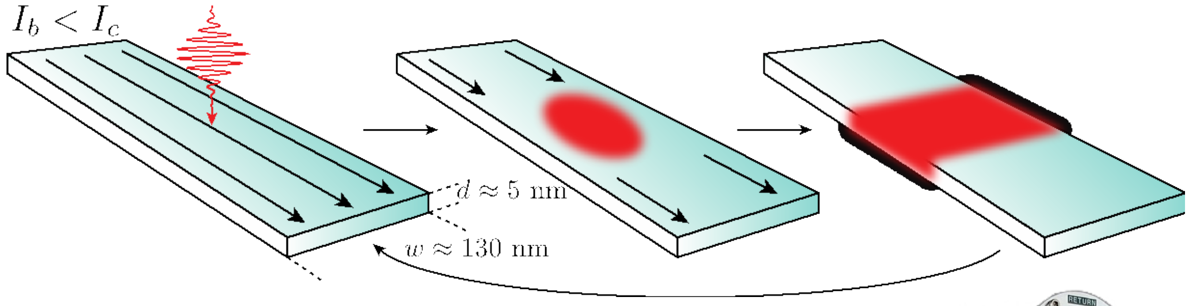

SKT 5GX
QUANTUM
Secured by Swiss Quantum


IDQ
0 1 0 0
0 0 0 0
1 0 1 1
Pay Services
Cryptocurrency services
Identification services

Quantum sensing at IDQ

Empowering researchers and industries in advancing the frontiers of single-photon science and applications

Superconducting nano(wire/strip) single-photon detectors



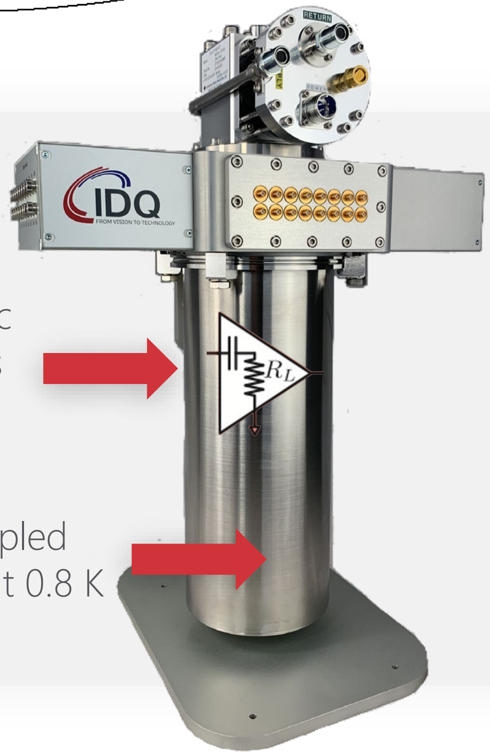
SNSPDs offer

Free-running operation: no need for synchronization
High efficiency: up to 95%
Low noise (dark counts): <1 to <100 cps
Low jitter: few tens of ps
Short recovery time: detection rates in the tens of MHz

Started in collaboration with

UNIVERSITÉ DE GENÈVE

ID281 system



Cryogenic amplifiers at 40 K

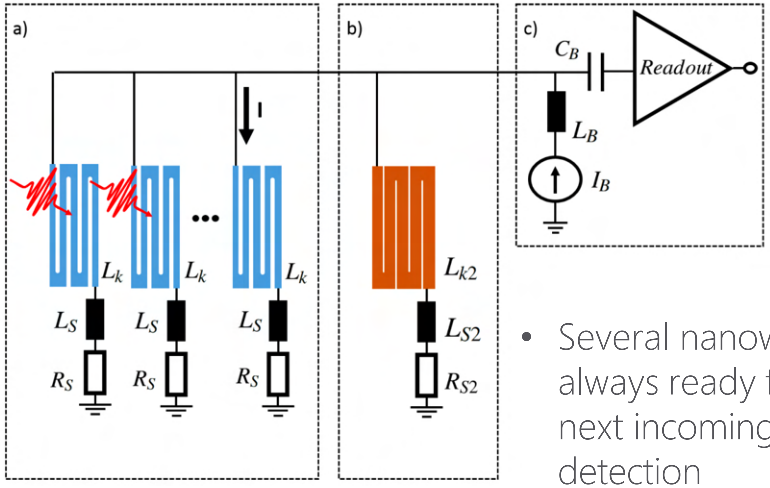
Fibre-coupled SNSPDs at 0.8 K

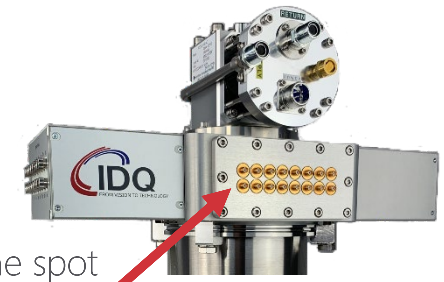
Enable a new applications

Going beyond the limits of one

Enabling faster detection rates and photon-number resolution

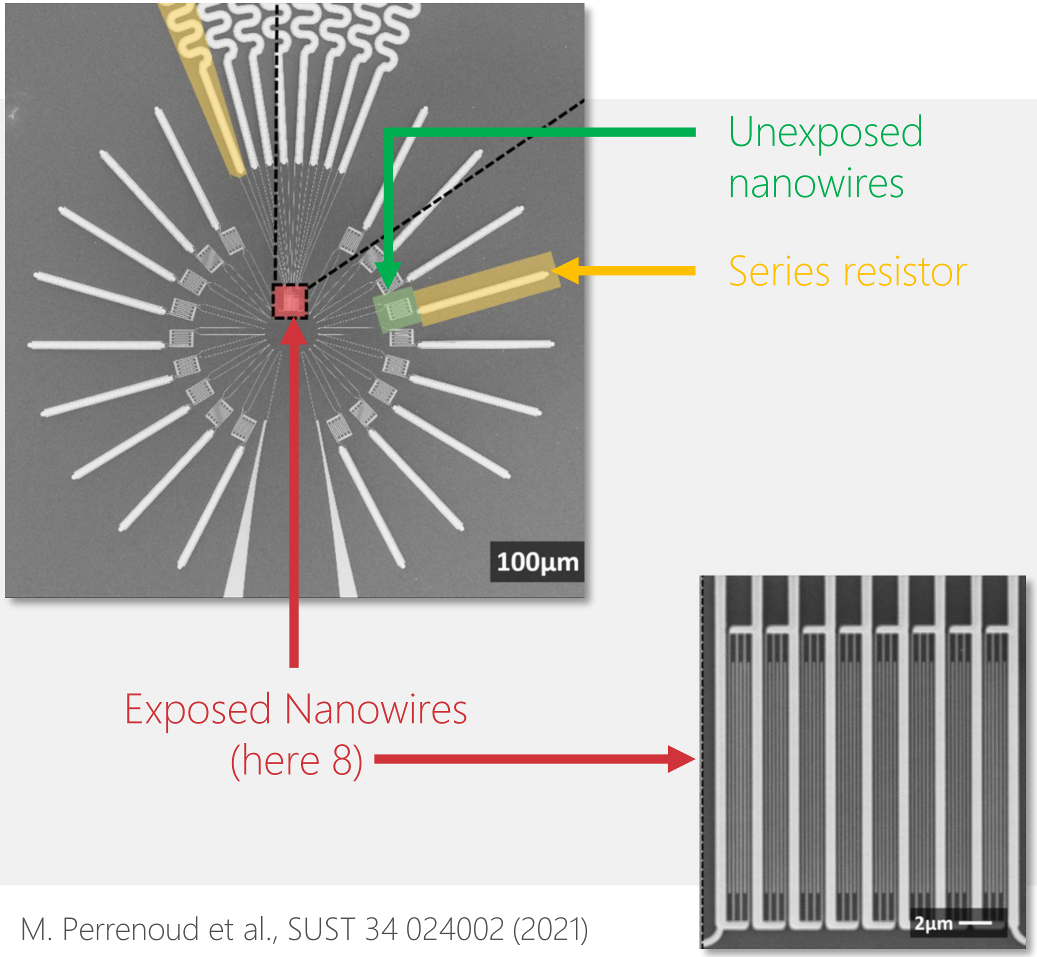
Connecting several nanowires in parallel for speed and PNR

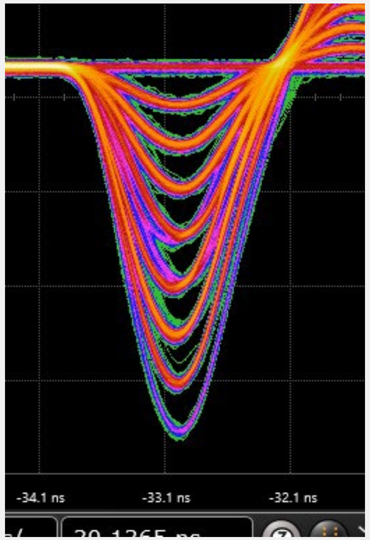




One spot in cryo

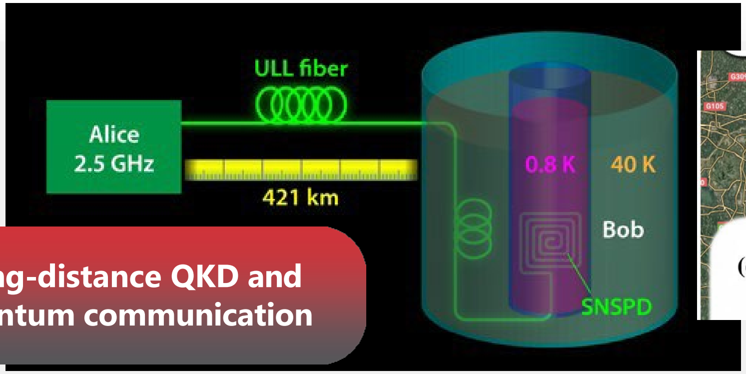
- Several nanowires always ready for next incoming detection
- Signals of each pixel add for photon-number resolution
- Patented





M. Perrenoud et al., SUST 34 024002 (2021)

SNSPDs entering new landscapes in research & applications



Long-distance QKD and quantum communication

Optical quantum computing and simulations

Quantum internet

OTDR

Range finding (e.g. in sea fog)

Broadband/MIR spectroscopy

Bioimaging

Single-photon emitters characterisation

More!

Advances in Quantum Advantages

NEWS | 23 October 2019

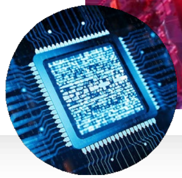
Hello quantum world! Google publishes landmark quantum supremacy claim

The company says that its quantum computer is the first to perform a calculation that would be practically impossible for a classical machine.

Quantum computational advantage using photons

HAN-SEN ZHONG, HUI WANG, YU-HAO DENG, MING-CHENG CHEN, LI-CHAO PENG, YI-HAN LUO, JIAN QIN, DIAN WU, XING DING, [...] JIAN-WEI PAN +15 authors Authors Info & Affiliations

SCIENCE • 18 Dec 2020 • Vol 370, Issue 6523 • pp. 1460-1463 • DOI: 10.1126/science.abe8770

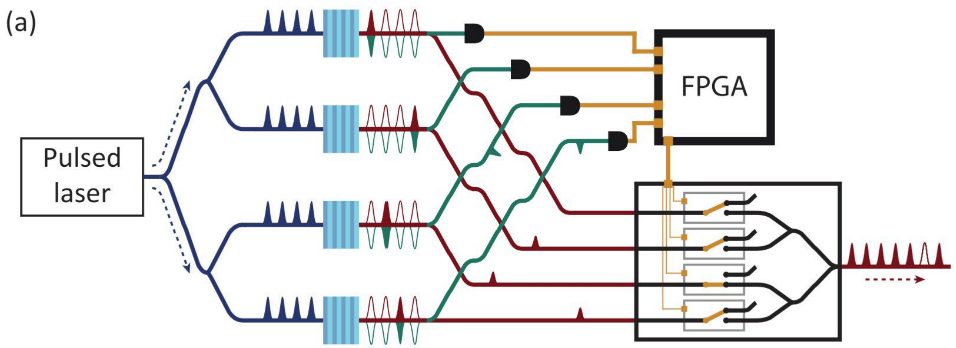


Relied on 100 SNSPDs

Quantum simulations and computing with photons

Growing need for excellent PNR detectors

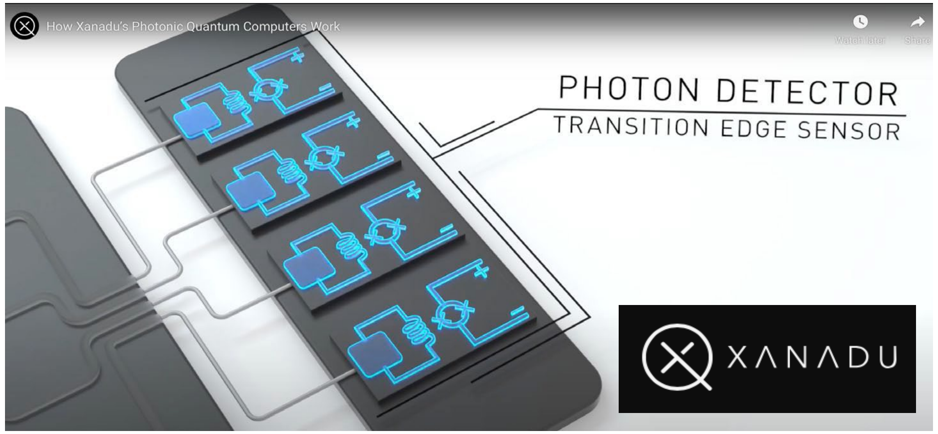
High-rate sources of single photons



Photonic quantum information processing: A concise review

Cite as: Appl. Phys. Rev. 6, 041303 (2019); https://doi.org/10.1063/1.5115814
Submitted: 20 June 2019 . Accepted: 16 September 2019 . Published Online: 14 October 2019

Squeezed states with PNRs



Quantum circuits with many photons on a programmable nanophotonic chip

J. M. Arrazola, V. Bergholm, [...]Y. Zhang

Nature **591**, 54–60 (2021) | Cite this article

The Quantum decade has begun

Thank you for your attention!

See our webinars on IDQ's website

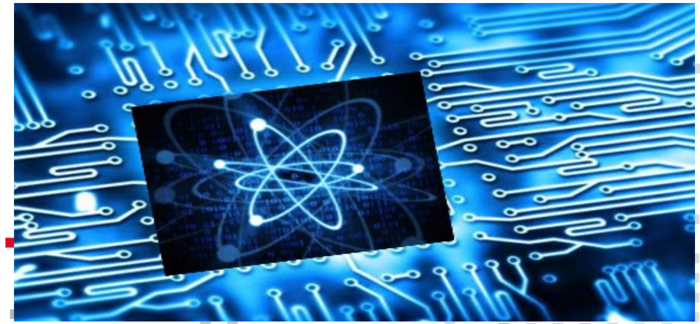
info@idquantique.com | www.idquantique.com

Panorama des technologies quantiques

MINALOGIC
Auvergne-Rhône-Alpes

Composants et circuits intégrés photoniques pour les communications et le calcul quantique

Ségolène Olivier, Integrated Quantum Photonics Program Manager / **CEA-LETI**
Jean-Michel Gérard, Directeur de recherche / **CEA-IRIG**



INTEGRATED COMPONENTS AND CIRCUITS ON SILICON FOR QUANTUM COMMUNICATIONS AND COMPUTING

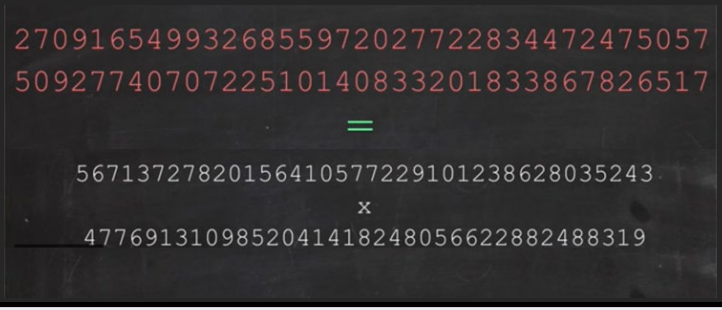
Ségolène Olivier and Jean-Michel Gérard

SECURE COMMUNICATIONS : A MAJOR CONCERN

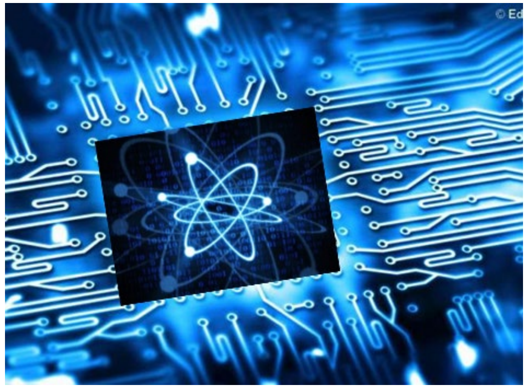
> 75 zettabytes data generated in 2021
(1 ZB=10^{21}, thousand billions of gigabytes)

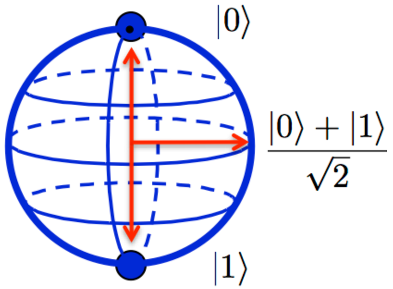
Current data encryption with RSA algorithms

Based on the difficulty to factorize very large numbers into a product of their prime factors



The threat of quantum computers





State superposition

Quantum advantage :
Very fast resolution (**intrinsically parallel**) of complex problems

→ Shor algorithm for the factorization of very large numbers (1997)

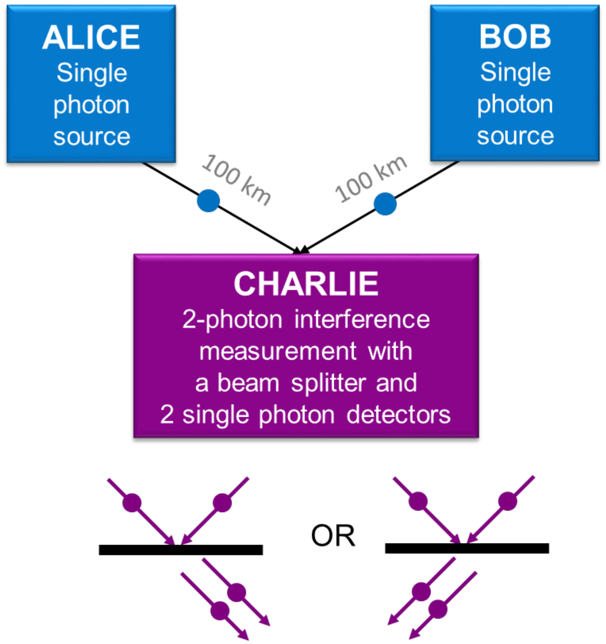
→ A threat for the security of worldwide communications

QUANTUM CRYPTOGRAPHY PROTOCOLS

› Based on single photon sources and detectors

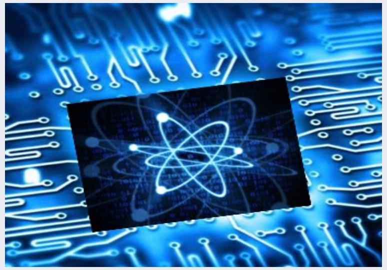
- › Use of **<u>single photons</u>** or **<u>squeezed modes</u>** for each qubit of the secret key (BB84 protocol)
- › Untrusted transmission channel
- › but Alice and Bob are trusted nodes
- › Experimental demonstrations over typically ~ 100 km
- › Commercial systems already available (banks, governments)

- › Advanced protocols immune to side channel attacks : Measurement Device Independant (MDI-QKD)
  - › Requires a 3rd untrusted party Charlie



- › Towards DI-QKD : Stronger requirements
  - › Photon entanglement
  - › Ultra-low optical losses

QUANTUM COMPUTING WITH PHOTONS ?



STRENGTHS

- No decoherence
- Multiple degrees of freedom (polarization, path, time, frequency…)
- Good connectivity
- Room temperature processing (in modular approach)
- Scalable technology
- Natural connection between distributed quantum processors

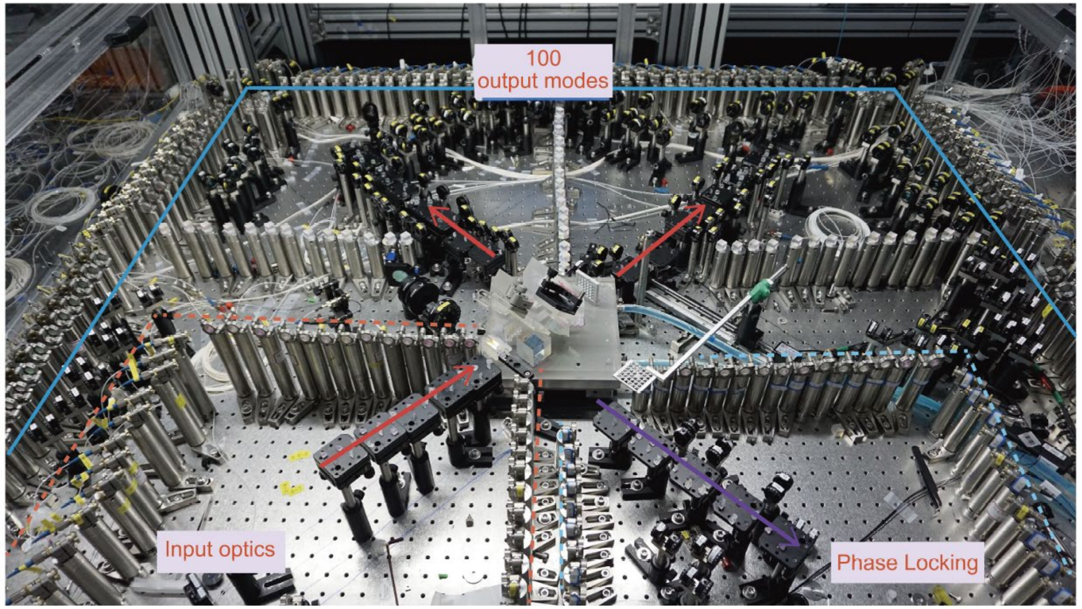
CHALLENGES

- Non-deterministic 2-qubit gate → measurement-based quantum computing schemes exploiting cluser states of indistinguishable photons (2001)
- Sources of single photons with high purity, high brightness, high indistinguishability
- Detectors of single photons with high efficiency and low dark counts

QUANTUM COMPUTING ADVANTAGE WITH PHOTONS

› **1st demonstration in 2020 (China)**

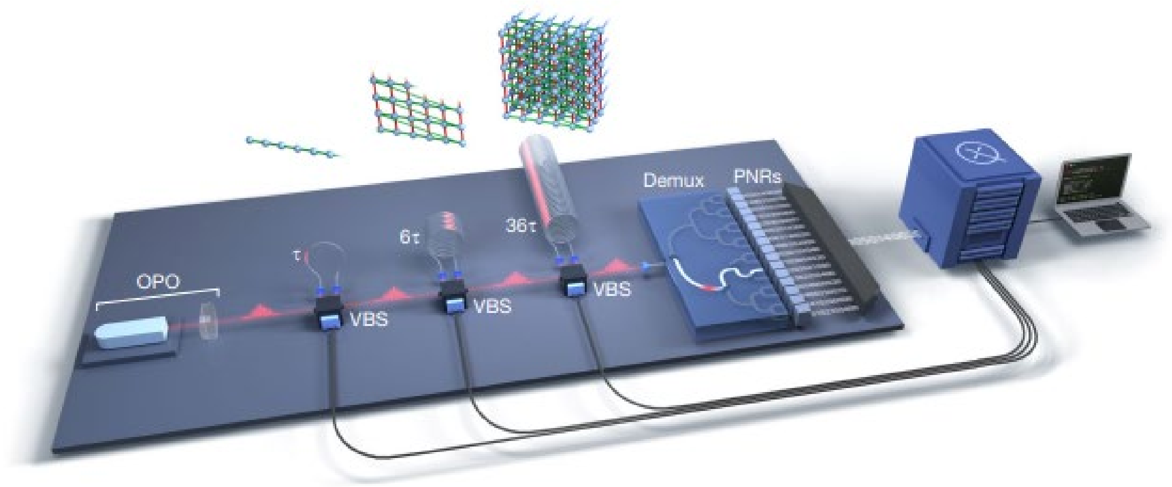
› Heroic experimental demo with 50 photonic squeezed-state qubits (not programmable)



Univ. of Science and Technology of China, 2020

› **2nd demonstration in 2022 (Xanadu, Canada)**

› Programmable processor with 216 squeezed-state qubits using fiber-based optics



www.doi.org/10.1038/s41586-022-04725-x

We need quantum integrated circuits for the future !

CMOS-COMPATIBLE INTEGRATION TECHNOLOGIES

› For future large-scale deployment

Miniaturization & Scalability
High density of components

High volume
& low cost

CMOS compatible
3D co-integration with driving /
readout electronics

Si PHOTONICS PLATFORM @ CEA-LETI

State-of-the-art 200/ 300 mm platform

- Design, Process integration, Test
- Optical & electrical packaging

Record low optical losses

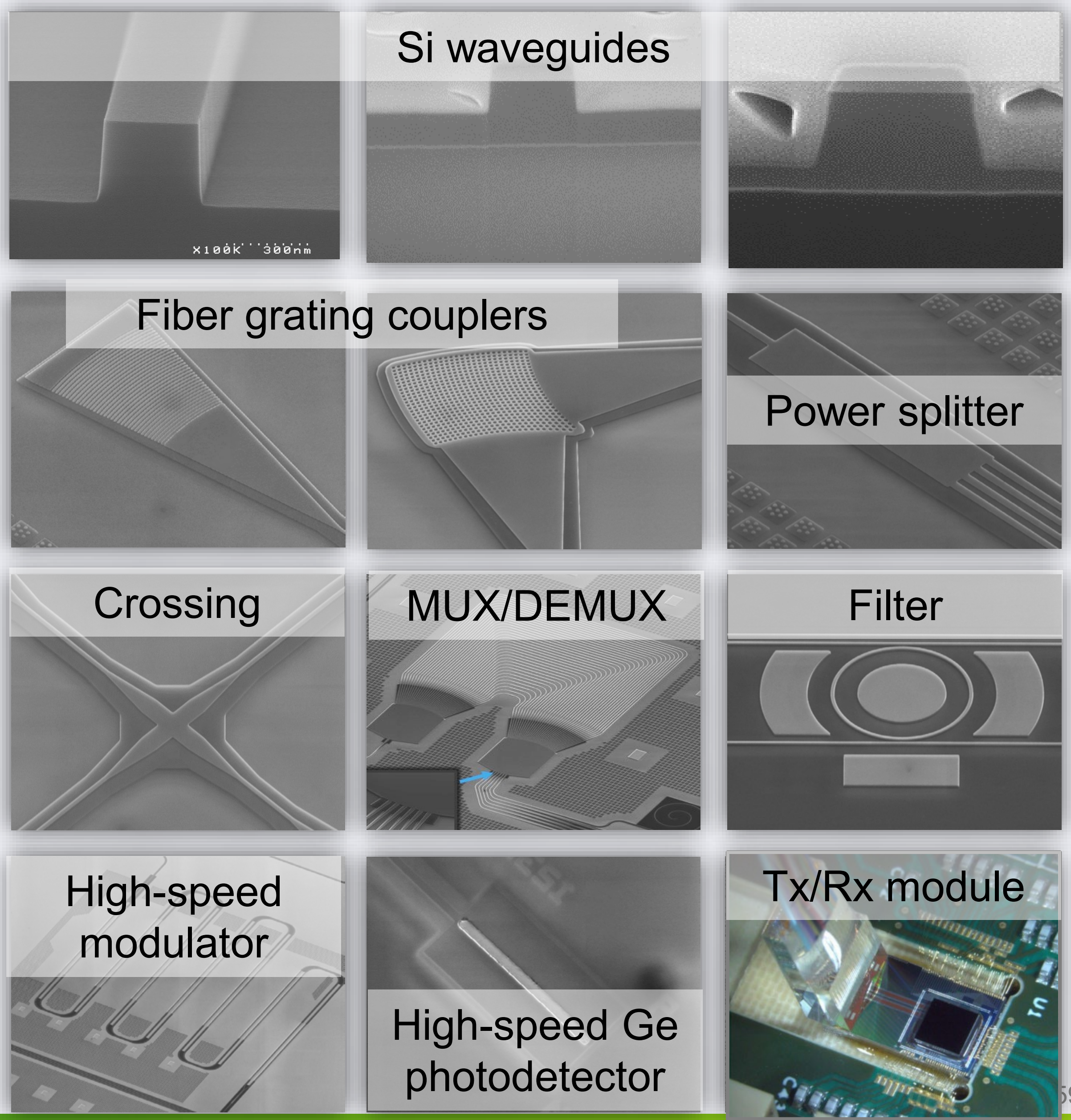
- Si waveguides: 0.2-1.1 dB/cm

Input/Output coupling

- Si fiber grating couplers : 1.5-2 dB

Versatile

- Comprehensive library of mature components
- @ 1310 and 1550 nm
- Integration of new materials (direct bonding)



Wilmart et al., Appl. Sciences 9 (2019)
Wilmart et al., J. of Lightwave technol. 39 (2021)
Bernabe et al., Sol. State Electron. 179 (2021)

SiN PLATFORM @ CEA-LETI

State-of-the-art 200 mm platform

- **High quality LPCVD Si_3N_4**
- Design, Process integration, Test
- Optical & electrical packaging

Record low optical losses

- **SiN waveguides: 0.03-0.15 dB/cm**

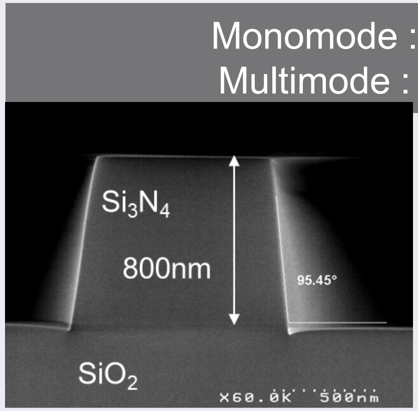
Input/Output coupling

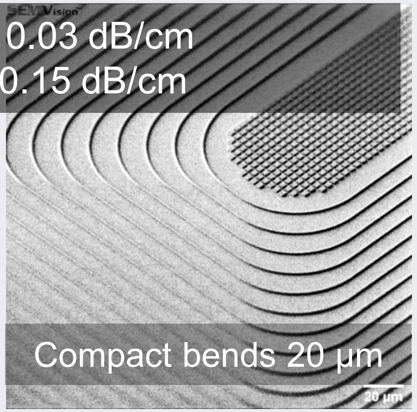
- SiN edge couplers (on-going) : 4 µm mode field diameter

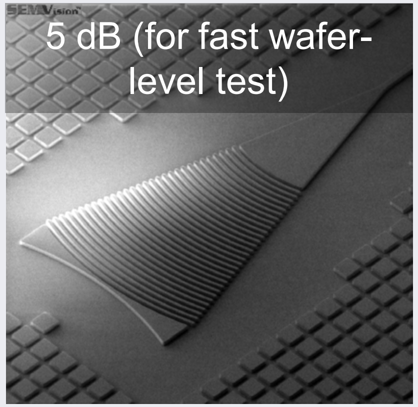
Versatile

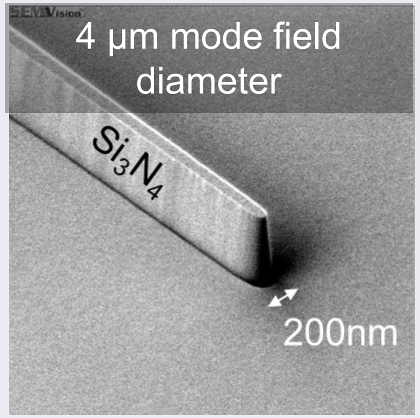
- Comprehensive library of passive components @ 1550 nm
- Integration of new materials (direct bonding)
- Other wavelengths possible

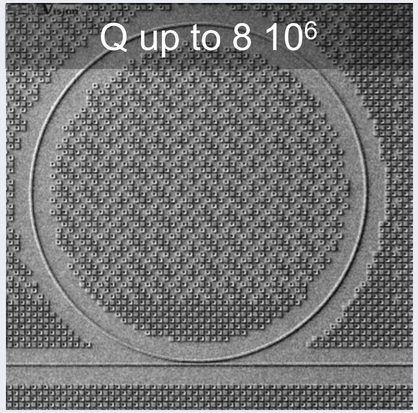
H. El Dirani et al., Ultralow-loss tightly confining Si3N4 waveguides and high-Q microresonators, Opt. Exp. 2019

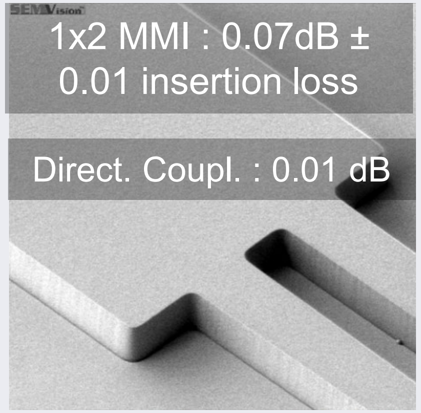






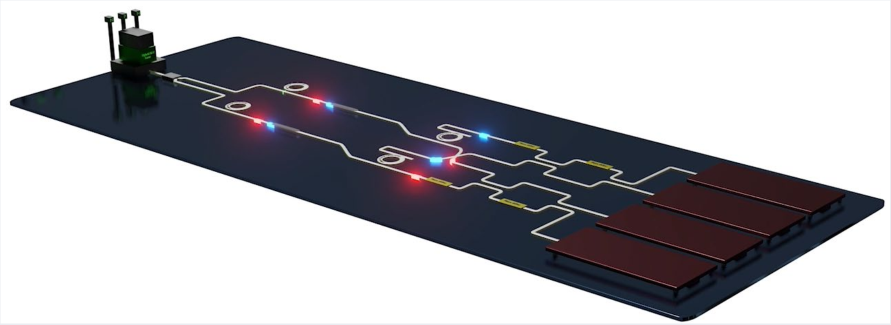






QUANTUM-GRADE INTEGRATED COMPONENTS & CIRCUITS

Objective : Leverage CEA-Leti's mature silicon photonics platform to build :



› Quantum-grade integrated components

for generation, fast encoding, programmable processing & detection of photonic qubits

Design, fabrication process, development of quantum characterization setups

› Quantum photonic integrated circuits

Transmitters & receivers for quantum key distribution (QKD) →

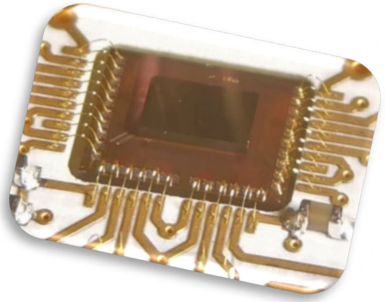
Processors for quantum computing

EU project HYPERSPACE (2022-2025)

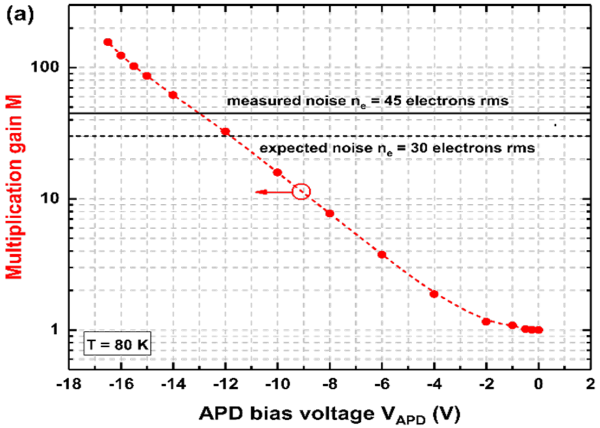
DETECTION OF PHOTONIC QUBITS

› Towards hybrid integration of II-VI APDs for high detection rate

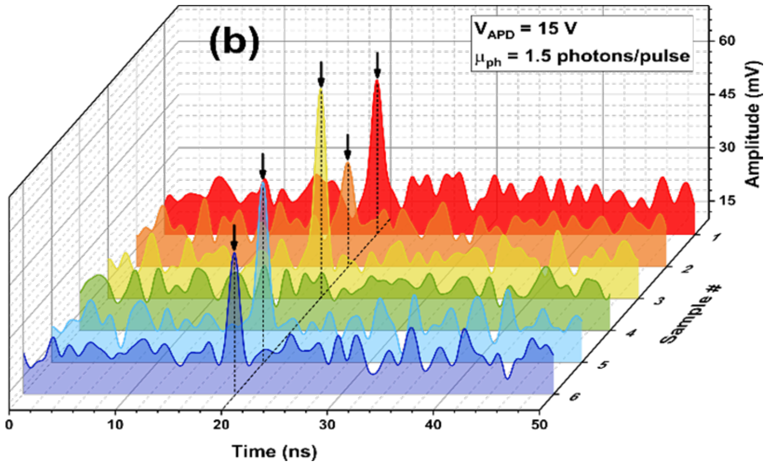
Mature stand-alone APD technology previously developed for IR imaging



Linear counting regime



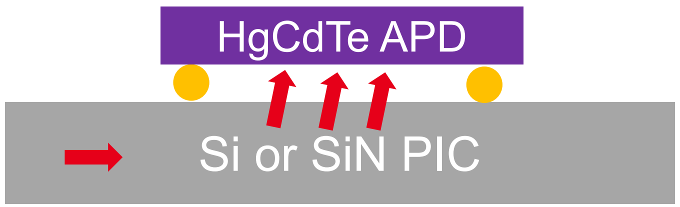
Record high detection rate (GHz) down to single-photon level @ 77K



Rothman et al., J. of electron. Materials
https://doi.org/10.1007/s11664-020-08461-8 (2020)

Perspectives and applications

- Hybridation on Si PICs

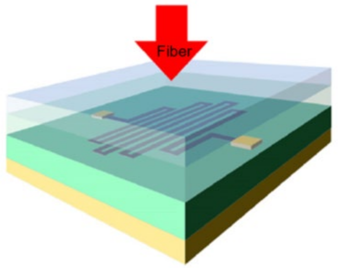


- For quantum communication networks, incl. free-space ground-satellite quantum links

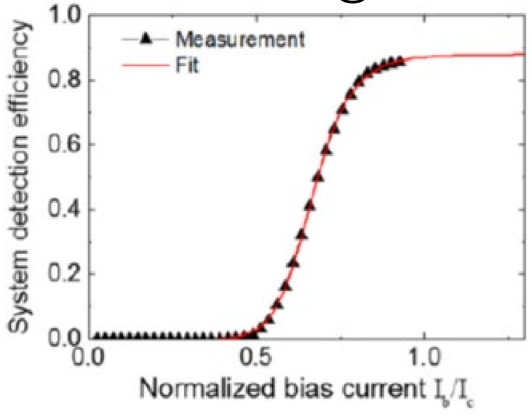
DETECTION OF PHOTONIC QUBITS

› From stand-alone to waveguide-integrated SNSPDs for ultra-high efficiency and low dark counts

Previous work @ CEA-IRIG : Stand-alone SNSPDs at normal incidence

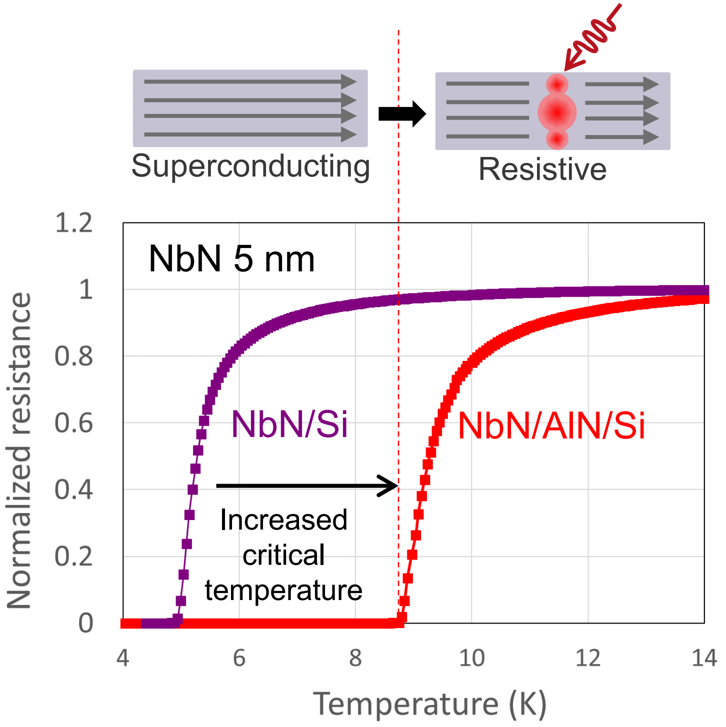


85 % detection efficiency at 1310 nm @ 2.5K



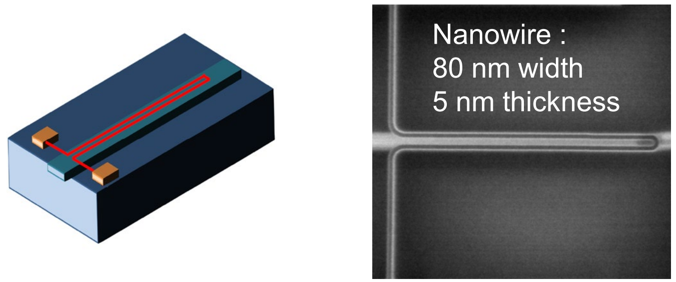
L. Redaelli et al., Supercond. Sci. Technol. 29, 065016 (2016)

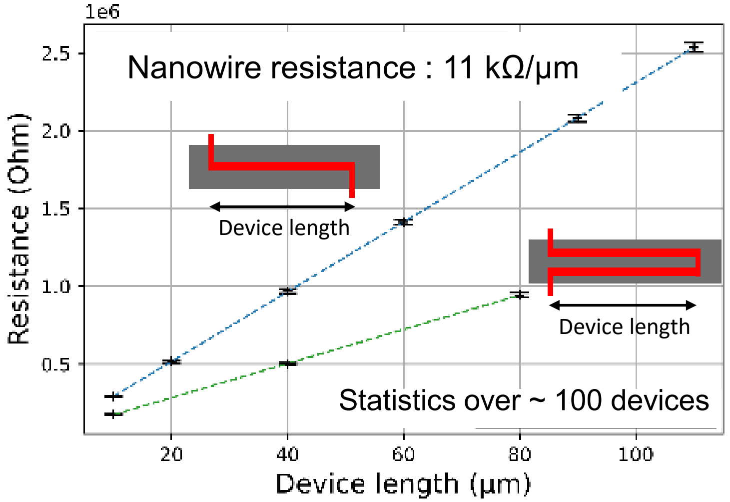
Optimized NbN with AlN buffer layer on 200 mm SOI wafers



R. Rhazi, S. Olivier et al., Superconductor Science and Technologies 34, 045002 (2021)

Excellent electrical uniformity across 200 mm SOI wafers



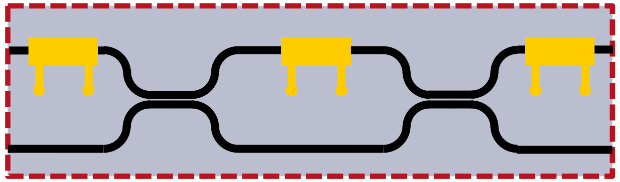


Promising for cryogenic characterization after packaging

PROGRAMMABLE PROCESSING / FAST ENCODING OF PHOTONIC QUBITS

Thermo-optical modulators

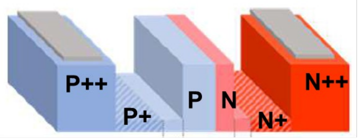
Preparation, manipulation and analysis of arbitrary quantum states

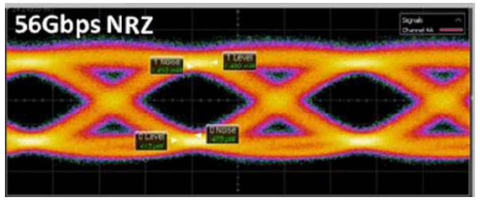


- No insertion loss
- But slow speed : ~10-100 kHz
- And high dissipation

For programmable quantum processing at room temperature

Plasma-dispersion phase modulators





- High bandwidth > 35 GHz
- But intrinsic insertion losses due to doping ~ 10 dB/cm

For quantum communications

Towards low-loss, high-speed, cryo-compatible modulators

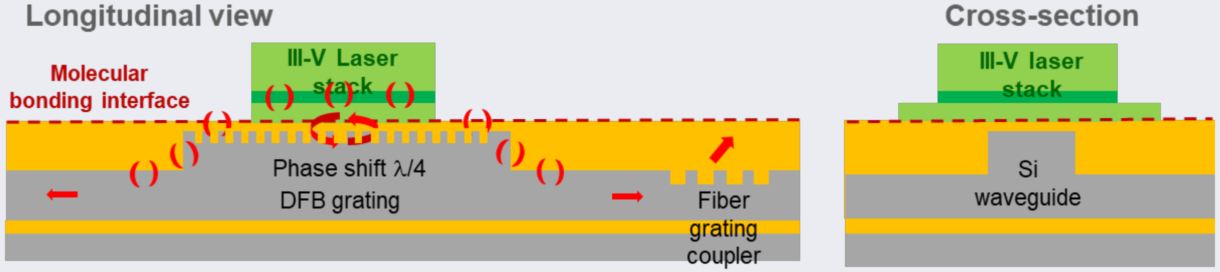
- Hybrid $LiNbO_3$/Si(N) modulators using direct bonding technology
- Expected performances
  - High-speed > GHz
  - low-losses < 0.5 dB/cm
  - Low dissipation

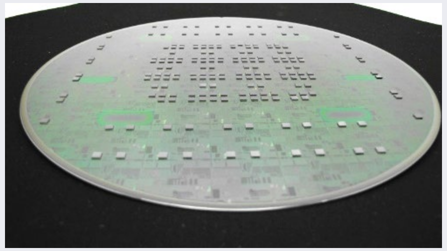
For advanced QKD protocols for quantum communications

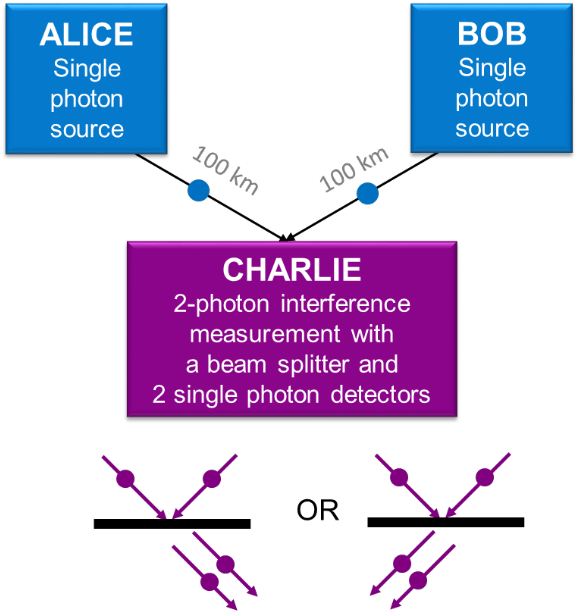
& for Quantum computing

GENERATION OF PHOTONIC QUBITS

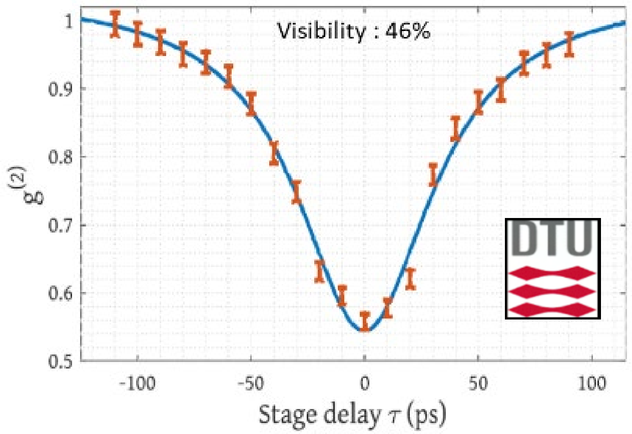
› Attenuated hybrid III-V/Si lasers to deliver weak coherent pulses







HOM interference with 46 % visibility between WCPs generated by two independent III–VV/Si lasers



C. Agnesi et al., Opt. Lett. 44, 271 (2019)

Features

- Good approximate of single photon sources
- Easy to implement experimentally
- GHz operation

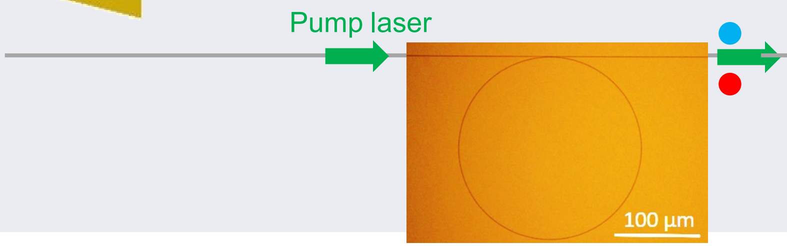
Perspectives and applications

- Integrated transmitters for Alice & Bob
- QKD protocols based on quantum superposition (from BB84 up to MDI-QKD immune to side-channel attacks)

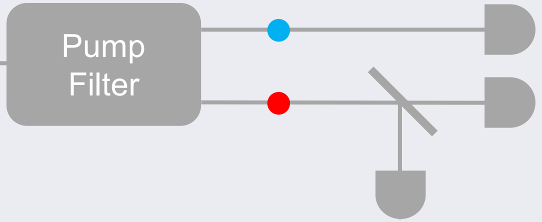
GENERATION OF PHOTONIC QUBITS

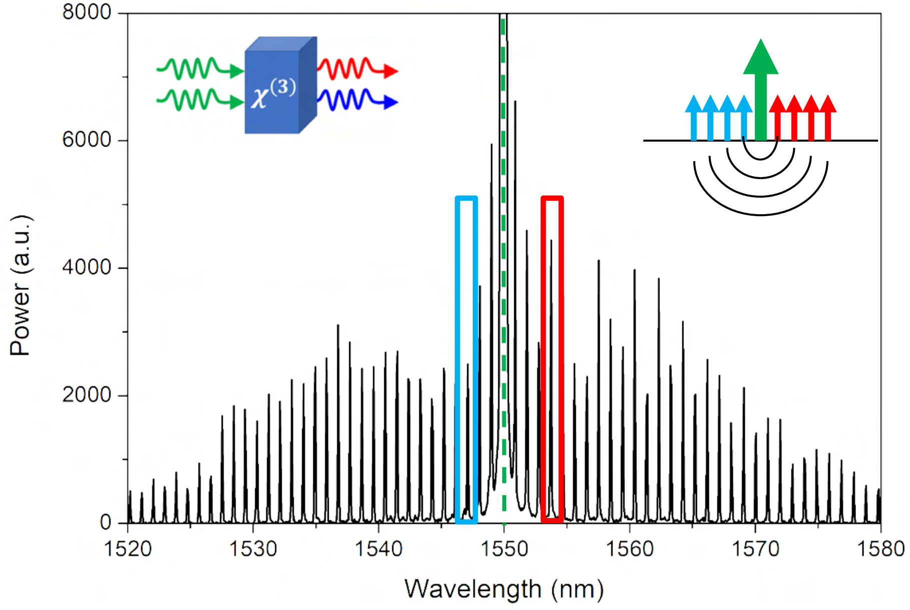
› Heralded single photon source in Si

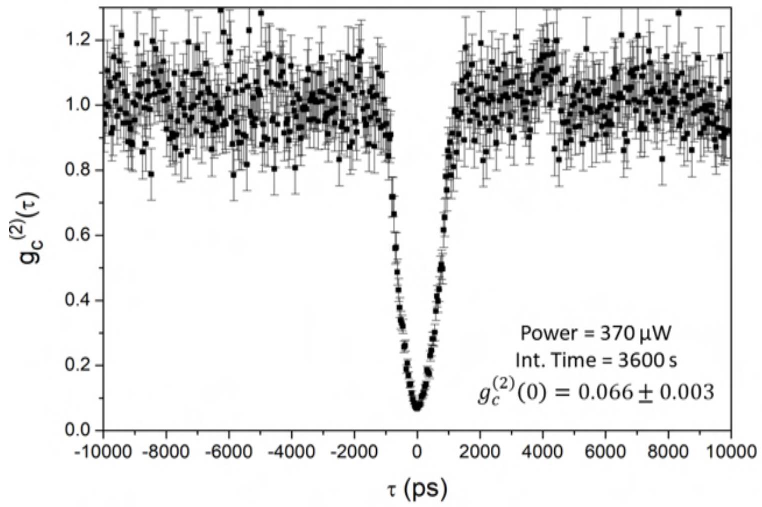
Non-linear four-wave mixing in a high-Q ring resonator



Heralded single photon generation @ MHz rate







H. El Dirani et al., Group IV Photonics Conference (2019)

Features

- True single photon source
- MHz generation rate
- Potentially excellent indistinguishability using fine thermo-optical tuning
- Non-deterministic in time

Perspectives

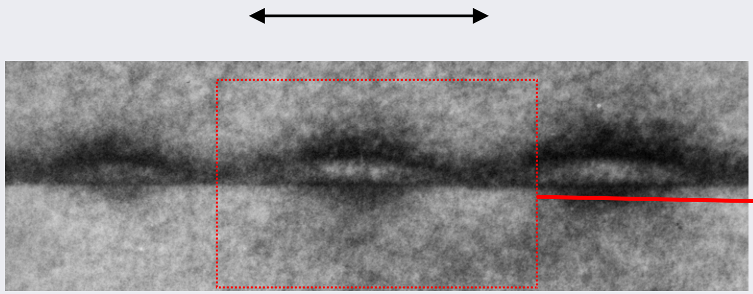
- Towards GHz rate
- Integration of high-rejection pump filter and demultiplexer

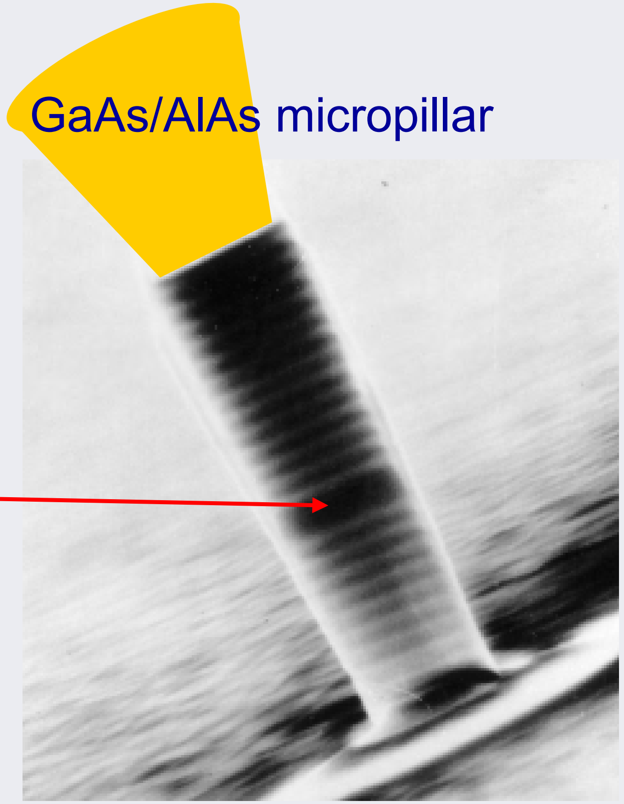
Applications

- Advanced protocols based on photon entanglement, e.g. with quantum relays
- Quantum computing

2001 : THE FIRST EFFICIENT, SINGLE-MODE SINGLE PHOTON SOURCE

Isolated InAs QD as « artificial atom »





=> Single-photon emission

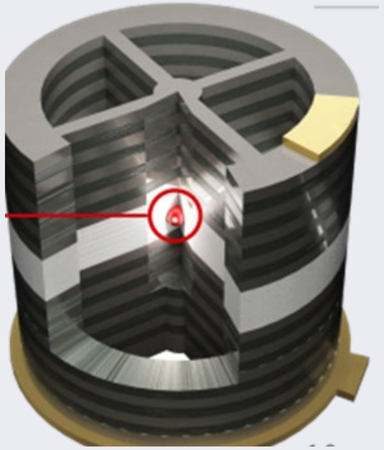
Purcell effect ⇨ bright source + single-mode behaviour

first demonstrations : E. Moreau, JM Gérard et al (CNRS/LPN), APL 2001

M Pelton et al (Stanford), PRL 2002

QUANDELA

CNRS/LPN technology
Founded in 2017 by V.Giesz, N. Somaschi, P. Senellart

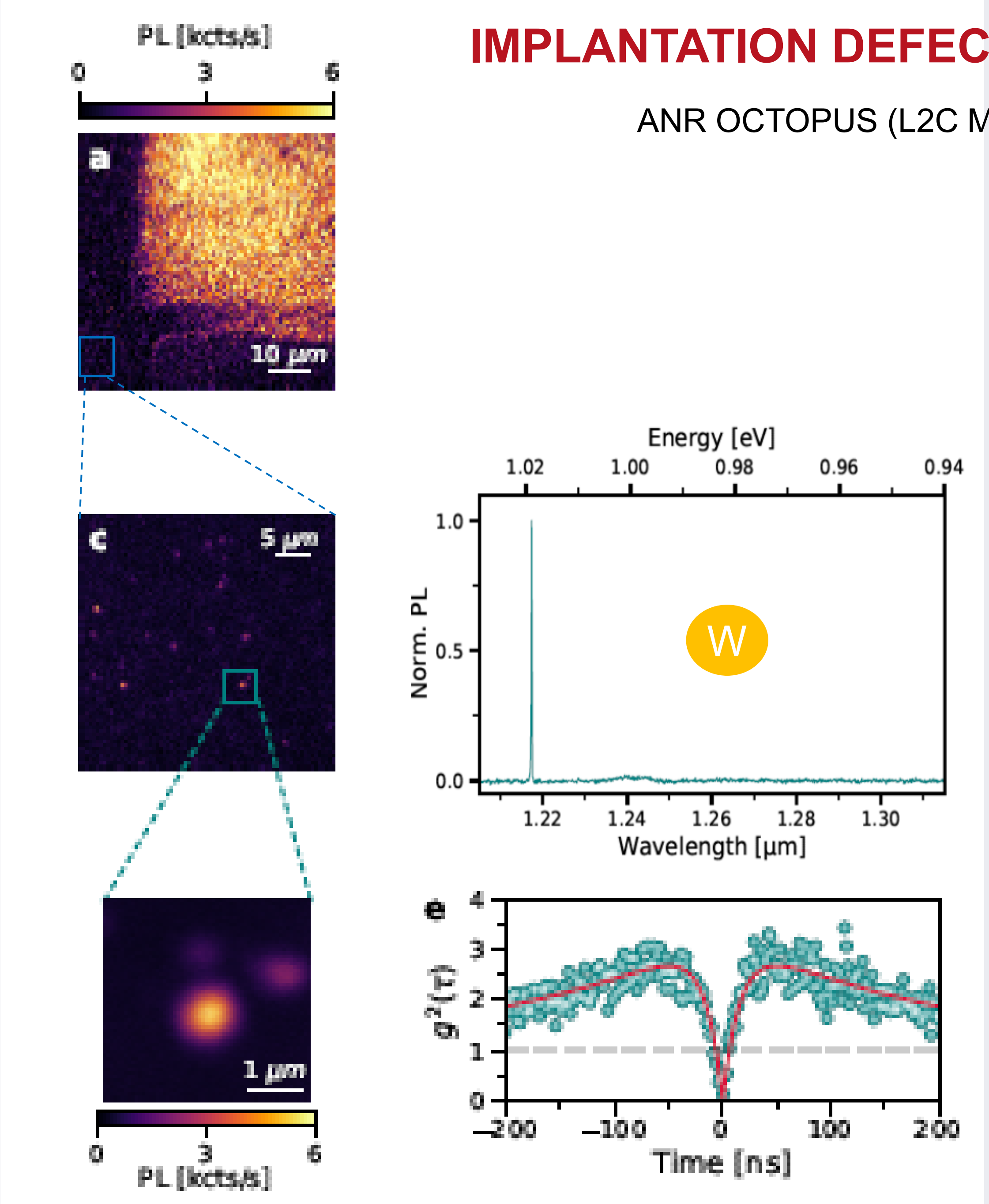


The most mature single-photon source on the market

(But still room for improvement)

IMPLANTATION DEFECTS AS SINGLE PHOTON SOURCES IN SOI

ANR OCTOPUS (L2C Montpellier, IM2NP Marseille, U Leipzig, IRIG)



2020 : implantation defects in silicon are studied at the single defect level

C-related defects, including the« G-center »

Redjem et al, Nature Electron. 2020

Durand et al, Phys. Rev. Lett. 2021

W-center, cluster of 3 auto-interstitials

Baron et al ACS Nano 2022

Photon antibunching observed in correlation experiments

Isolated color centers act as « artificial atoms », able to emit photons one by one in SOI

IMPLANTATION DEFECTS AS SINGLE PHOTON SOURCES IN SOI

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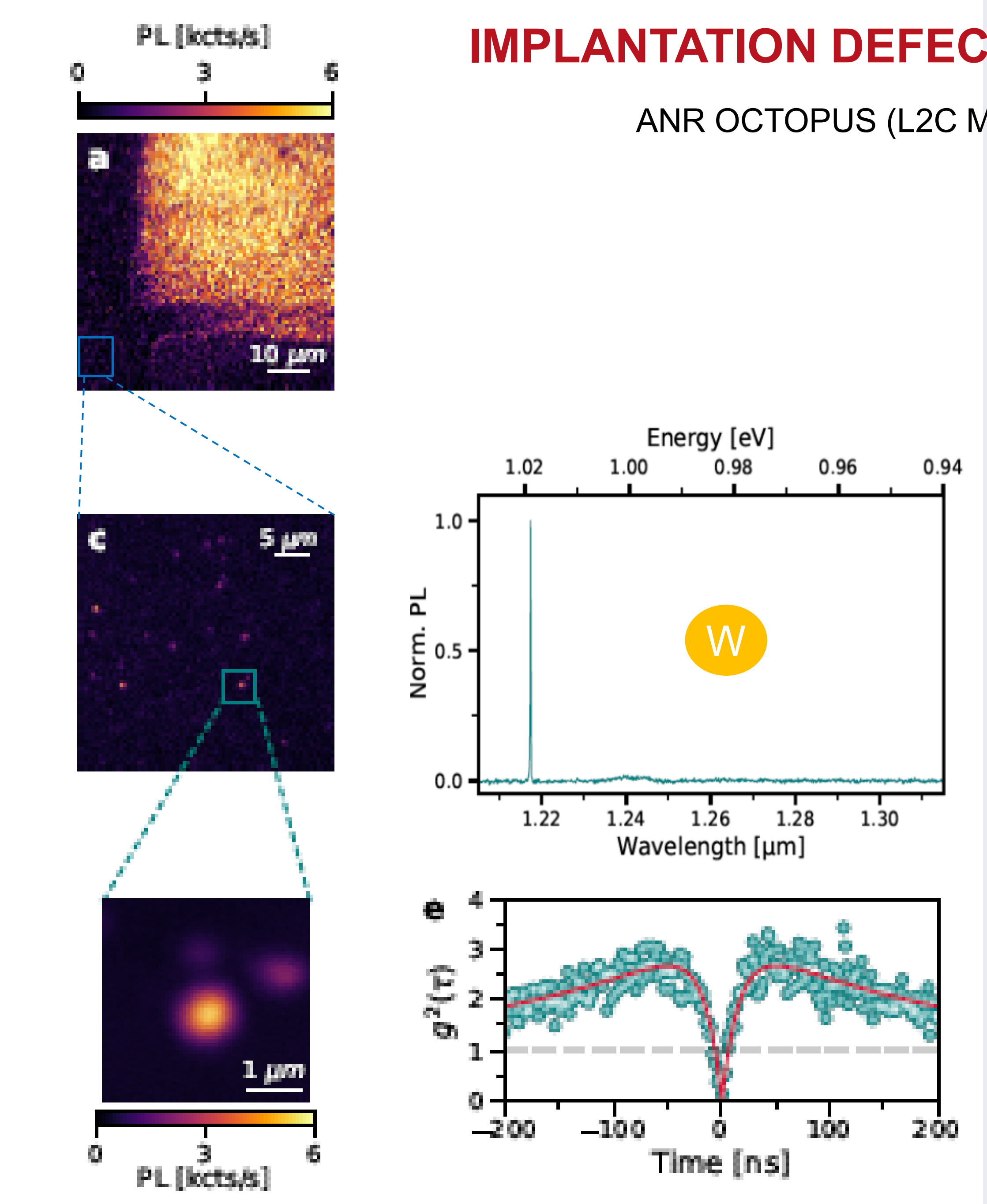

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Photon antibunching observed in correlation experiments

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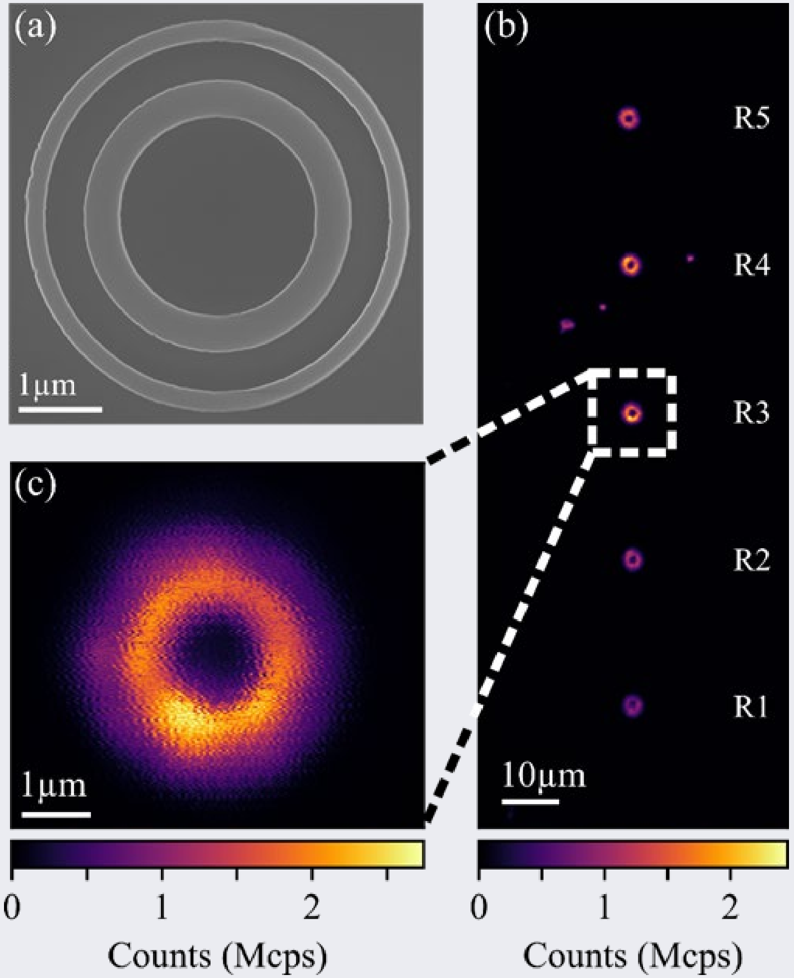
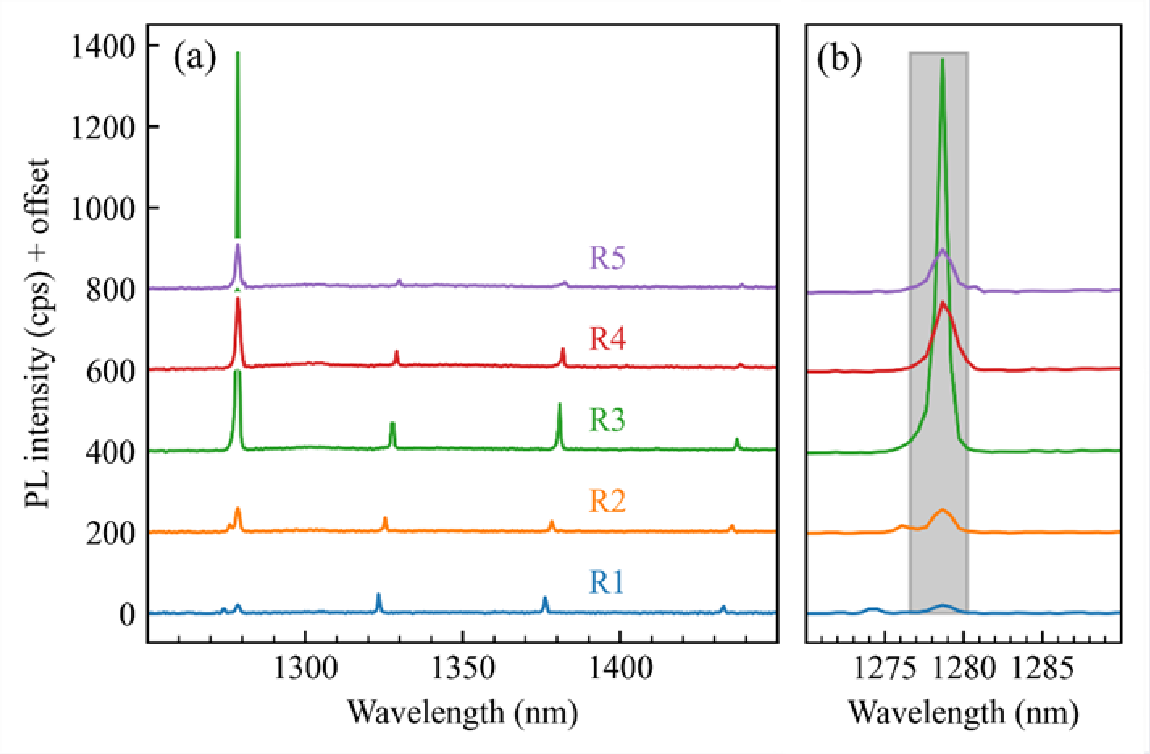
G- CENTERS IN SOI MICRORING CAVITIES

B Lefaucher (PhD), JB Jager, V Calvo, coll. L2C Montpellier





G centers are not destroyed by nanofabrication steps

x5 PL enhancement when zero-phonon line in resonance with one of the modes

Next step : Deterministic integration of a single defect in a SOI cavity

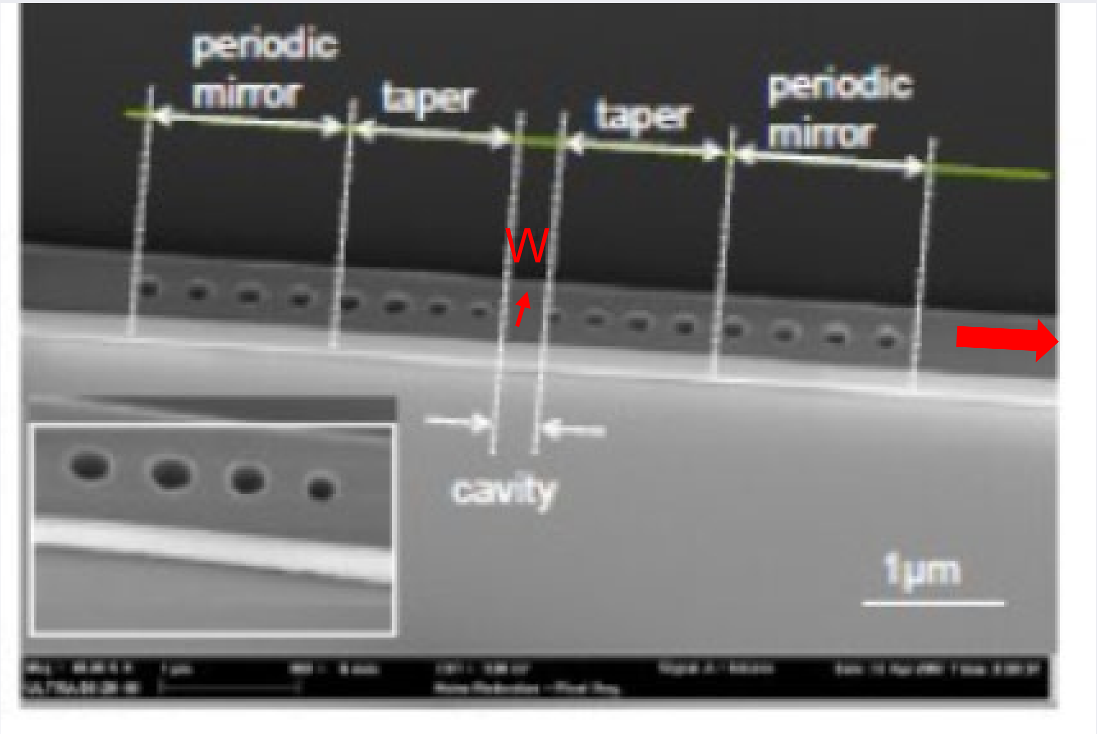
THE NEXT STEP…

Deterministic integration of a single color center

in SOI photonic structures

- On demand source of indistinguishable single photons (IRIG)
- Optically addressable single spin quantum memory

(L2C Montpellier + IRIG)

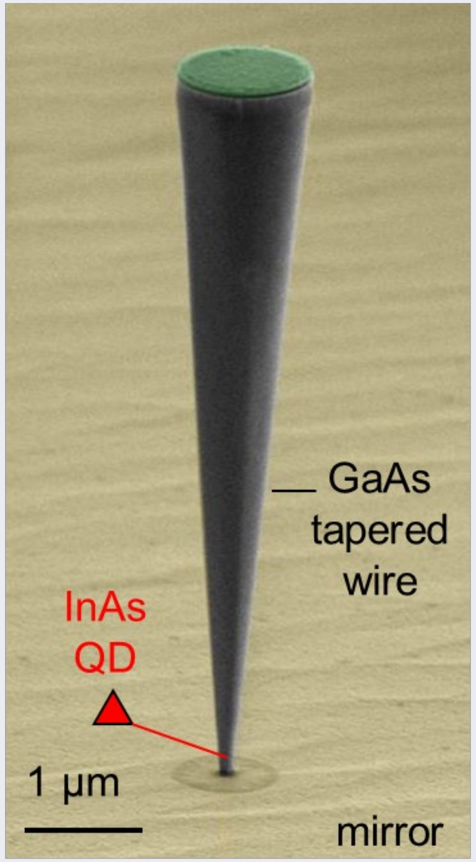


« Nanobeam » photonic crystal cavity
IRIG/SiNaPS et al, Opt. Exp 2007

NOVEL GEOMETRIES FOR QD SINGLE PHOTON SOURCES

ANR IPOD, J Claudon et al, IRIG, coll JP Poizat, CNRS/Néel

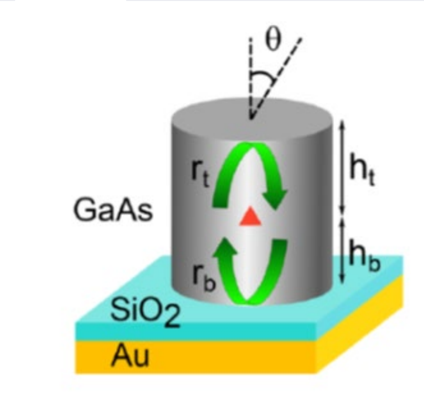
Photonic nanowires : excellent collection of QD spontaneous emission into a single mode, without any cavity

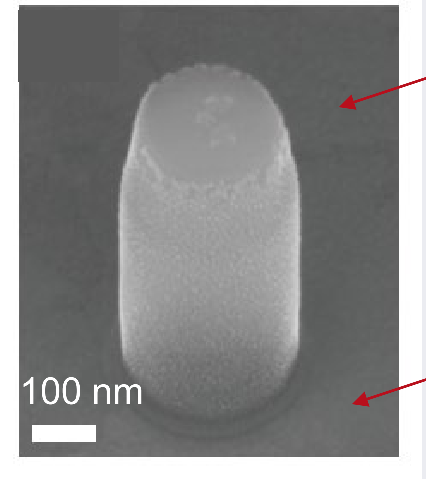


M Munsch et al, PRL 2013

- Very high efficiency (75% measured, >92% reachable)
- Broadband spontaneous emission control
  widely tunable single photon sources (>2nm), bright sources of photon pairs
- Limited indistinguishability due to coupling to wire vibrations

Photonic wire nanocavities : combining the best of both worlds?





A. Artioli et al, PRL 2021; S. Kotal et al, APL 2021

Contact :

jean-michel.gerard@cea.fr
segolene.olivier@cea.fr

Panorama des technologies quantiques

MINALOGIC Auvergne-Rhône-Alpes

L’apport des technologies quantiques pour les capteurs de Thales

Cédric Demeure, VP Research and Technology / **Thales**

THALES

MINALOGIC
Auvergne-Rhône-Alpes

L'apport des technologies quantiques pour les capteurs de Thales

C. Demeure

Journée Panorama des technologies quantiques
Minalogic
4 Octobre 2022

Thales's Mission

Sensing & data gathering

Data transmission & storage

Data processing & decision making

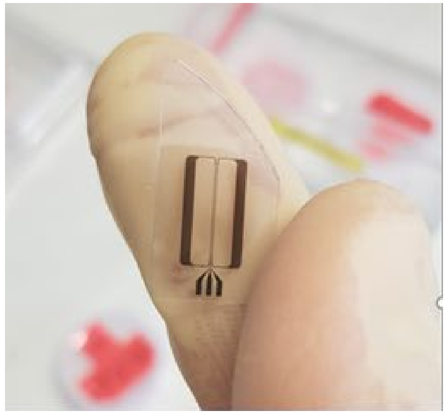
- Digital Identity and Security
- Defence and Security
- Aerospace
- Space

We help customers master decisive moments by providing the right information at the right moment

Capteurs quantiques

Magnétomètre

- Filtre Interférentiel Quantique en Supraconducteur (SQIF)

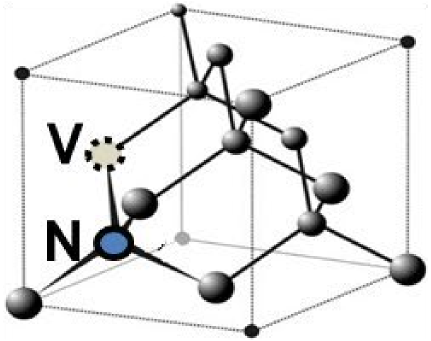


Antenne RF
- Structure non résonnante
- De kHz à x 10GHz
- 80 K

Réduction de taille jusqu'à 10^6

Centres NV diamant

- Crystal de diamant avec des impuretés
- Azote + lacune : qubit artificiel

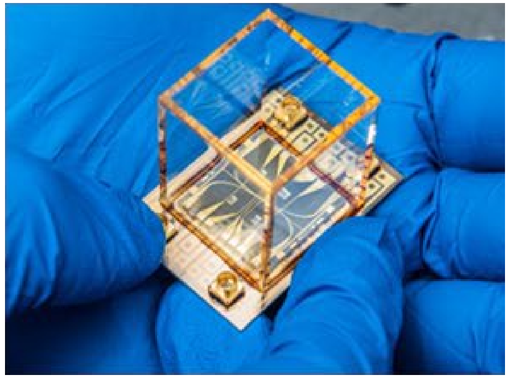


Capteurs de
- Champs magnétique
- Champ électrique
- Température
- Pression

Température ambiante

Atomes froids

- Dualité onde particule
- Refroidissement laser

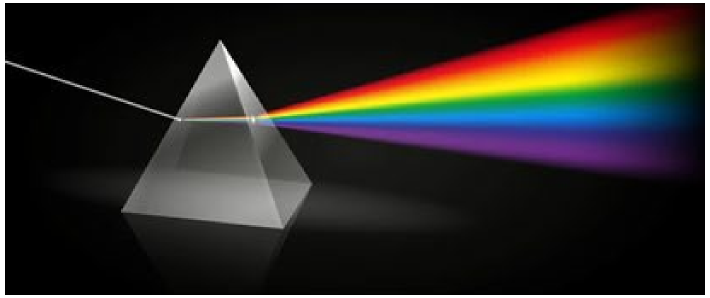


Centrale inertielle
- Plus précise que les gyrolasers
- Volume identique

Une précision ~ GPS sans satellite

THALES

Avantages des capteurs quantiques



Compacité

Des ordres de grandeurs par rapport aux solutions classiques

Sensibilité

Un outil adapté pour scruter la matière et le vivant au niveau moléculaire

Parallélisme

Permet d'entrevoir d'autres modes de fonctionnement et utilisations

Besoin de technologies habilitantes pour miniaturiser et baisser les coûts

Les applications des capteurs quantiques

Antennes

Mag

Systèmes inertiels Ima

micr

H

Capteurs ch

Défense

- Ecoute et renseignement (ELIN, COMINT), Observation / détection, Navigation sans GPS

Santé

- Imagerie IRM, imagerie cérébrale,…

Environnement

- Monitoring de la terre (gravité, magnétisme), détection de gaz polluants,..

Géo prospection

- Relevés géologique, structures du sol, forage,…

Mobilité - transport

- Navigation et positionnement précis en condition sans GPS, systèmes autonomes,..

Métrologie & instrumentations

- Horloges atomiques ultra précise, instrumentation scientifique (ondes gravitationnelles)

Thales TRT Quantum activities

Quantum sensing

- Compact **CPT clocks**
- Accelerometers, gravimeters (**cold atoms**)
- Spectrum analyser (**SHB**, NV centers)
- Magnetometers (**NV centers**)
- RF electromagnetic sensors (**SQIFs**, Rydberg atoms)
- Fiber based sensors & Lidars

Quantum communications

- Secure communications (QKD) for space applications
- Quantum processors, quantum networks (SHB)

Quantum algorithms

- Optimisation

Enabling technologies : cryocoolers, lasers, PICs …

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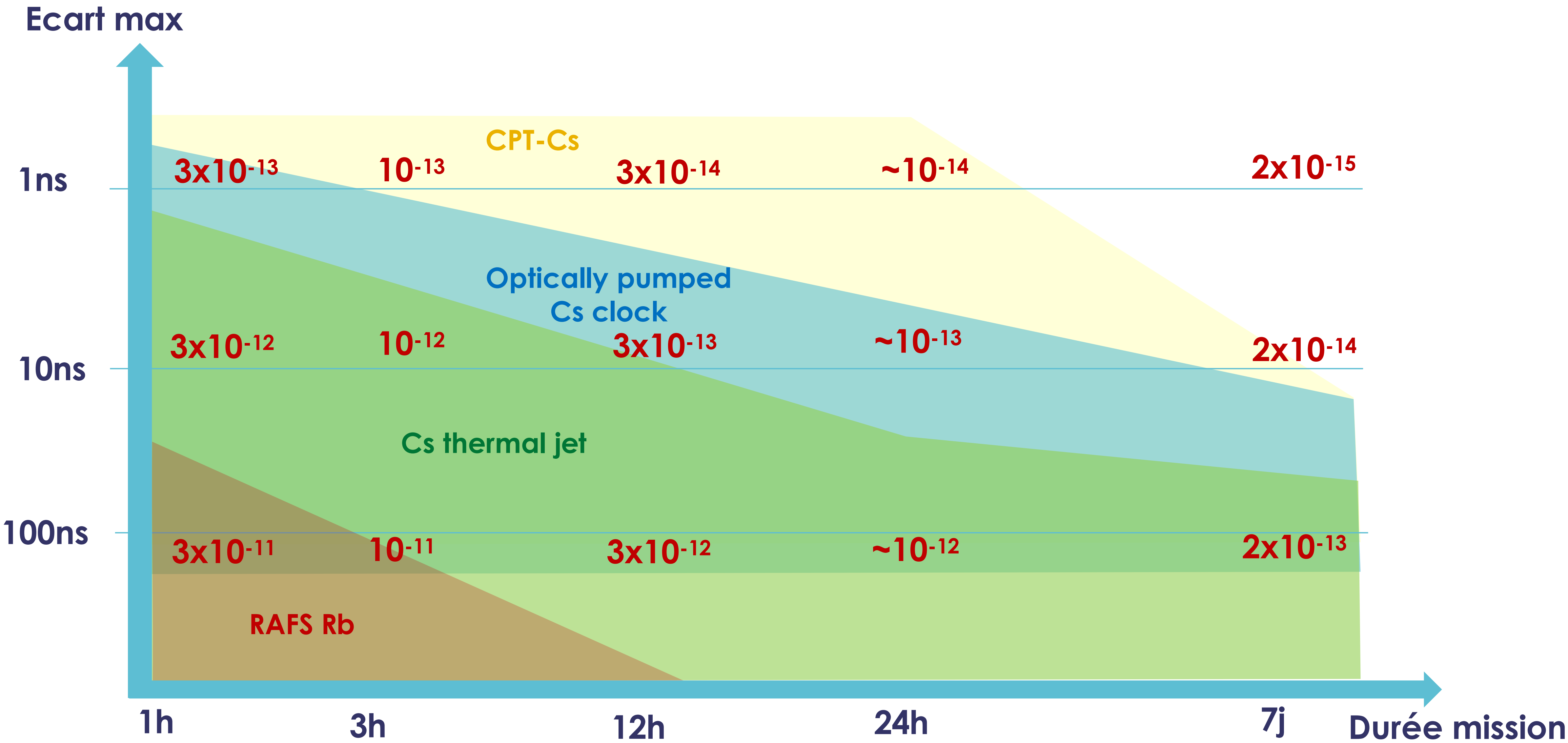
Atomic clocks: performance classes



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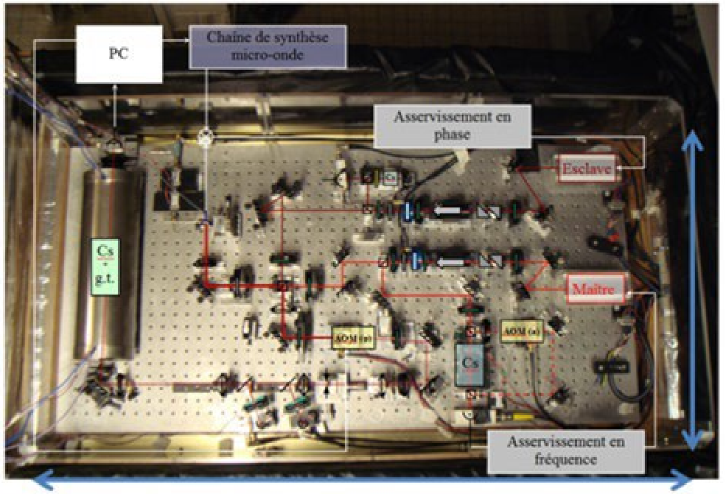
CPT Cs clock based on the use of a dual frequency laser

CPT Cs clock : Coherent Population Trapping Cesium clock

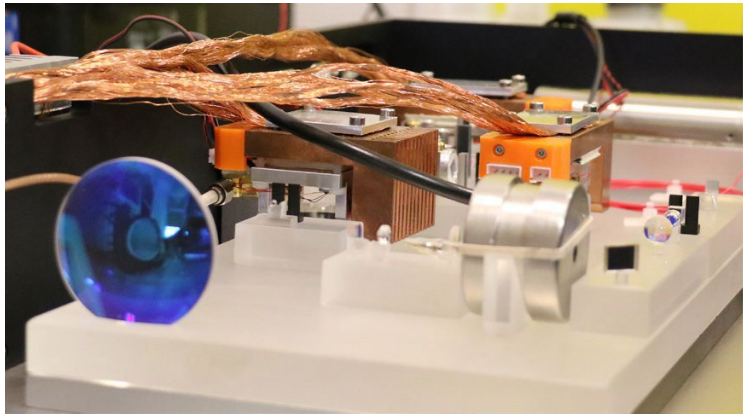
Demonstration at SYRTE



> 1000 mm

> 1500 mm

Compact Cs CPT clock at TRT



10 litres

Applications

- Navigation, GNSS
- Communication networks synchronization
- Radar and E.W multistatic systems

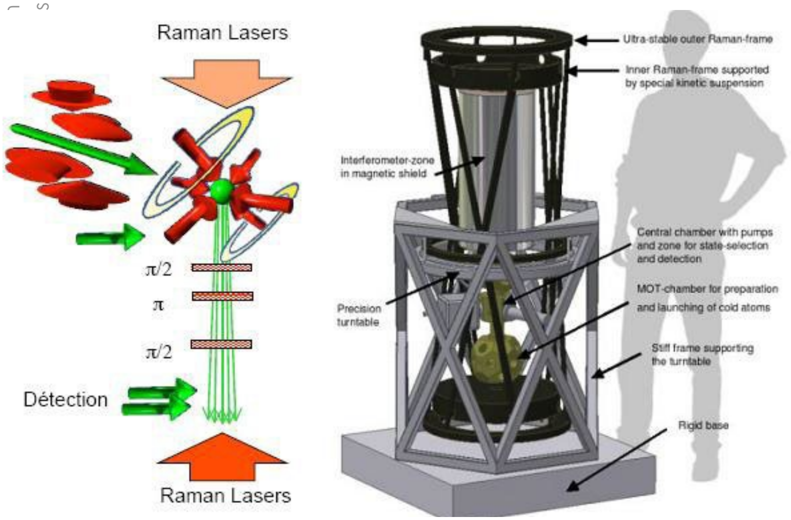
Differentiators

- **24h stability x 10**
- **Volume ÷ 10**

Compared to Cs optically pumped atomic clocks in current development

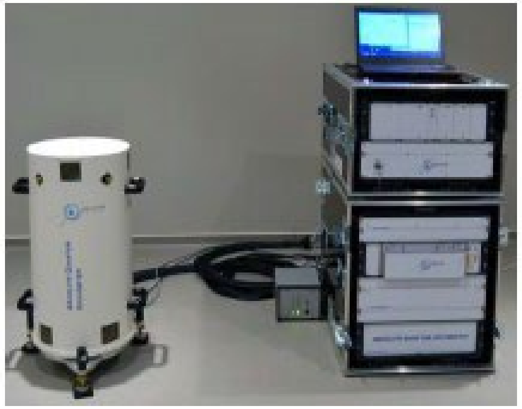
THALES

Cold Atoms

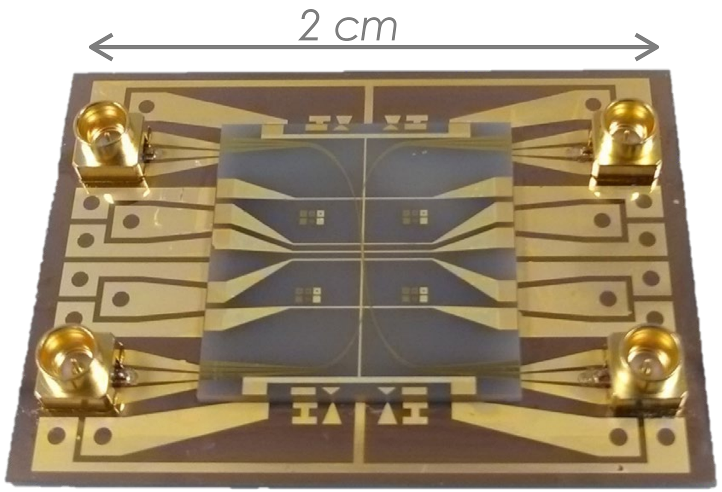


First generation atomic gravimeter
Atoms are free falling

Source : SYRTE (left) & Berlin University (right)



Muquans



Atom Chip (TRT / III-V Lab)

On-chip atomic accelerometer
Atoms are trapped in the vicinity of a chip

Proof of concept academic demonstrator

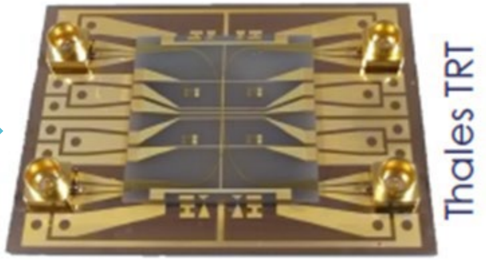
Industrial product

1st step toward an integrated demonstrator

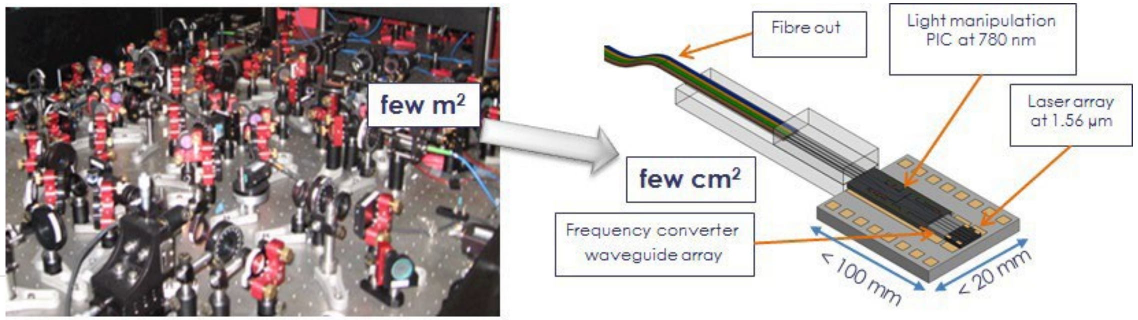
THALES

Cold atoms for inertial measurement units

Gyrolaser



1-3 liters targeted



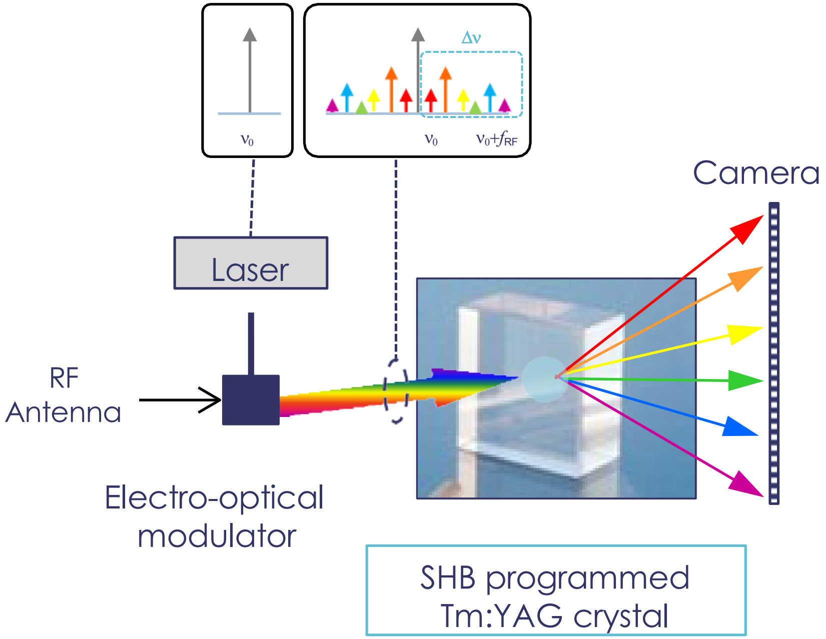
Applications

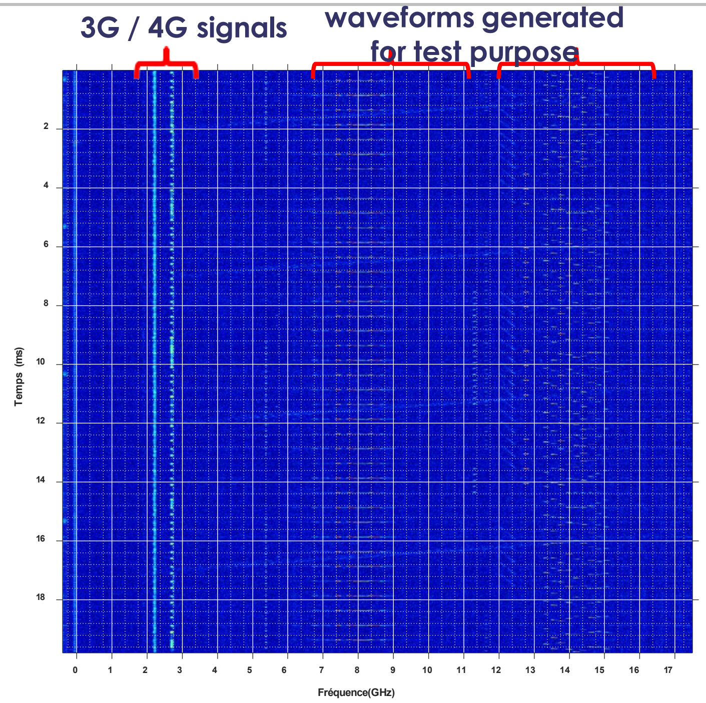
- Atomic clock (navigation, GNSS reference, telecom networks synchronization)
- Gyroscopes, accelerometers : ***towards an ultra-compact multifunction inertial measurement unit***

Differentiators

- low-energy and high precision device
- compact
- integration of advanced function on the same chip + sensors multiplexing

SHB : Spectral Hole Burning





Applications

- Electronic warfare

Differentiators

- Instantaneous bandwidth > 40 GHz
- 100% probability of intercept
- 50 dB dynamic range
- Sensitivity < -90dBm
- down to 3 μs temporal resolution

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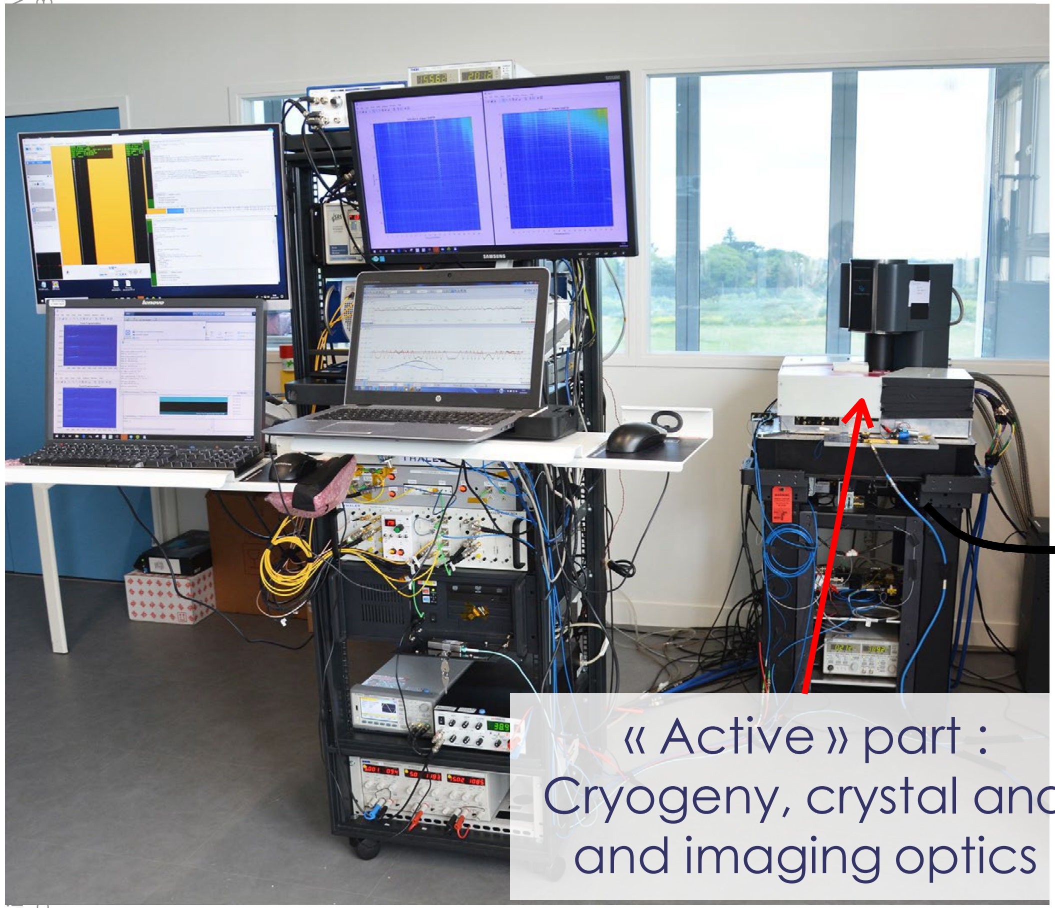
SHB Field tests in Brest, France

« Rainbow » demonstrator



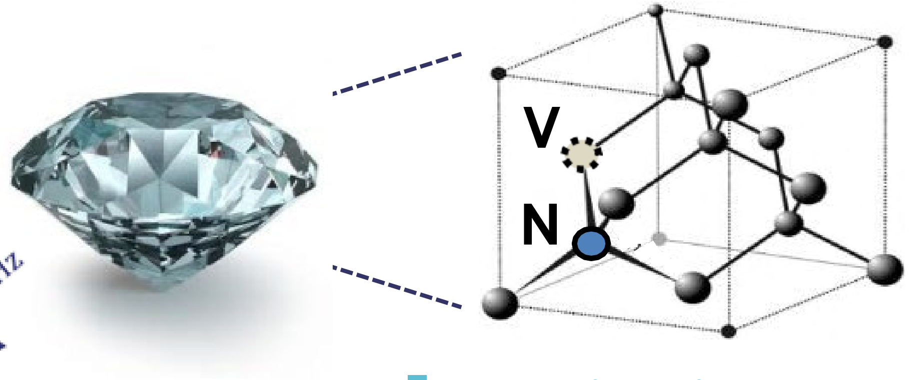
« Active » part :
Cryogeny, crystal and
and imaging optics

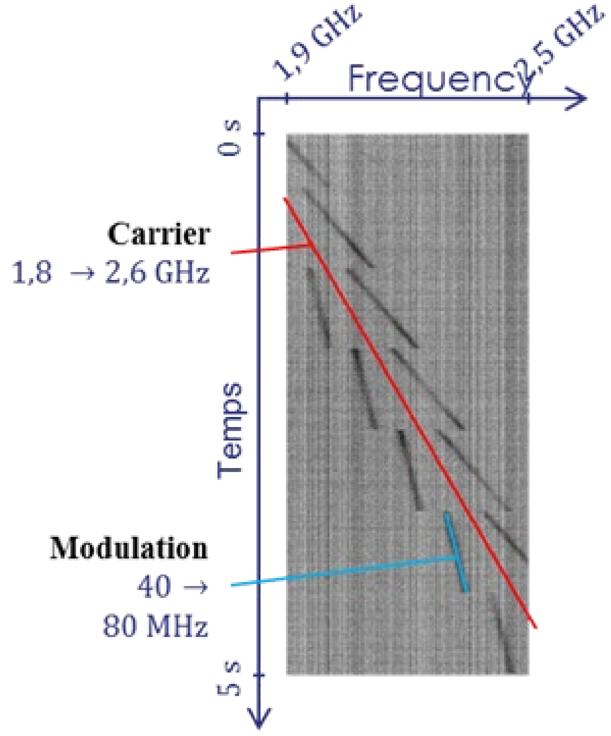
RF antenna and
transposition onto
the optical carrier

40 m
optical fiber
RF-analog link

NV centers in diamond : Magnetometry and Spectrum Analysis

NV center as an artificial atom hosted in the diamond matrix





Applications

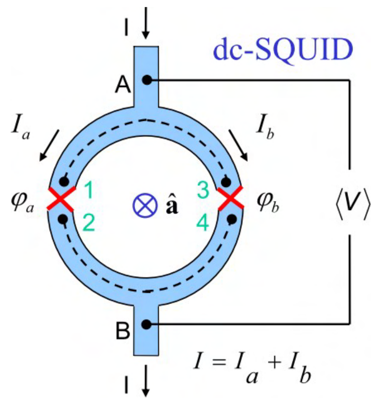
- Magnetic Anomaly Detection (MAD)
- Spectrum surveillance

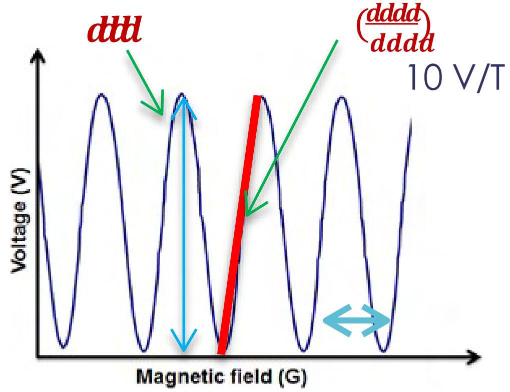
Differentiators

- **Small size (Solid-state device)**
- **Room temperature operation**
- 5 GHz typ. analyzed BW with <1 MHz resolution

THALES

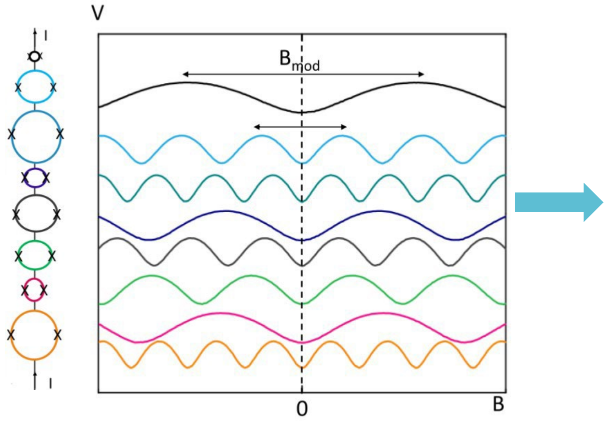
SQUID/SQIF based electromagnetic sensors

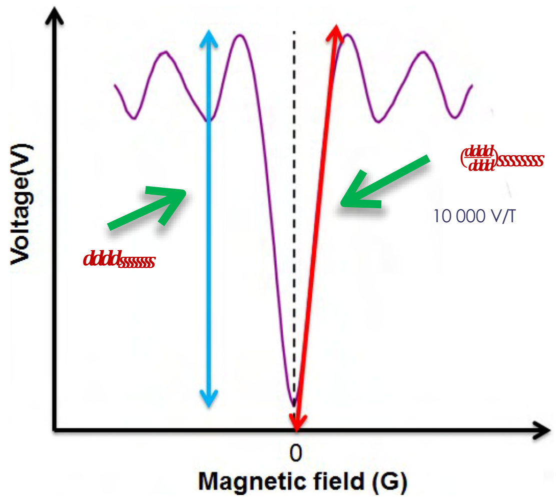


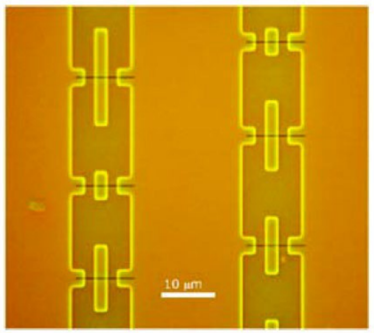


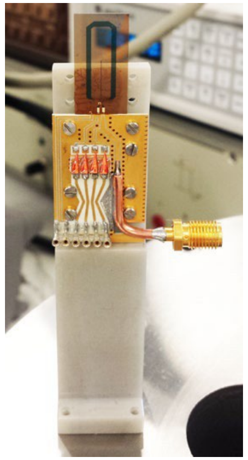
SQIF

SQUID = array of SQIFs









Periodic in field → period proportional to its surface

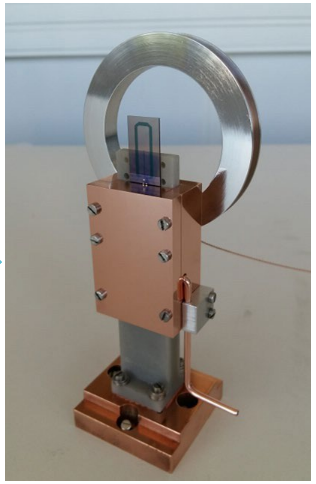
Josephson Junctions in high Tc superconductors

THALES

SQIFs based electromagnetic sensors

Extremely sensitive / large bandwidth electromagnetic sensing *(from VLF to millimeter waves)*

SQIF : Superconducting Quantum Interference Filter
SQUID = Superconducting Quantum Interference Device



Cryocoolers

Applications

- Antennas VLF, LF, HF
- Airborne HF detection and direction finding
- Radio-communications
- Magnetic Anomaly Detection (MAD)

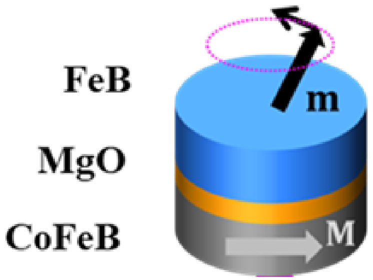
Differentiators

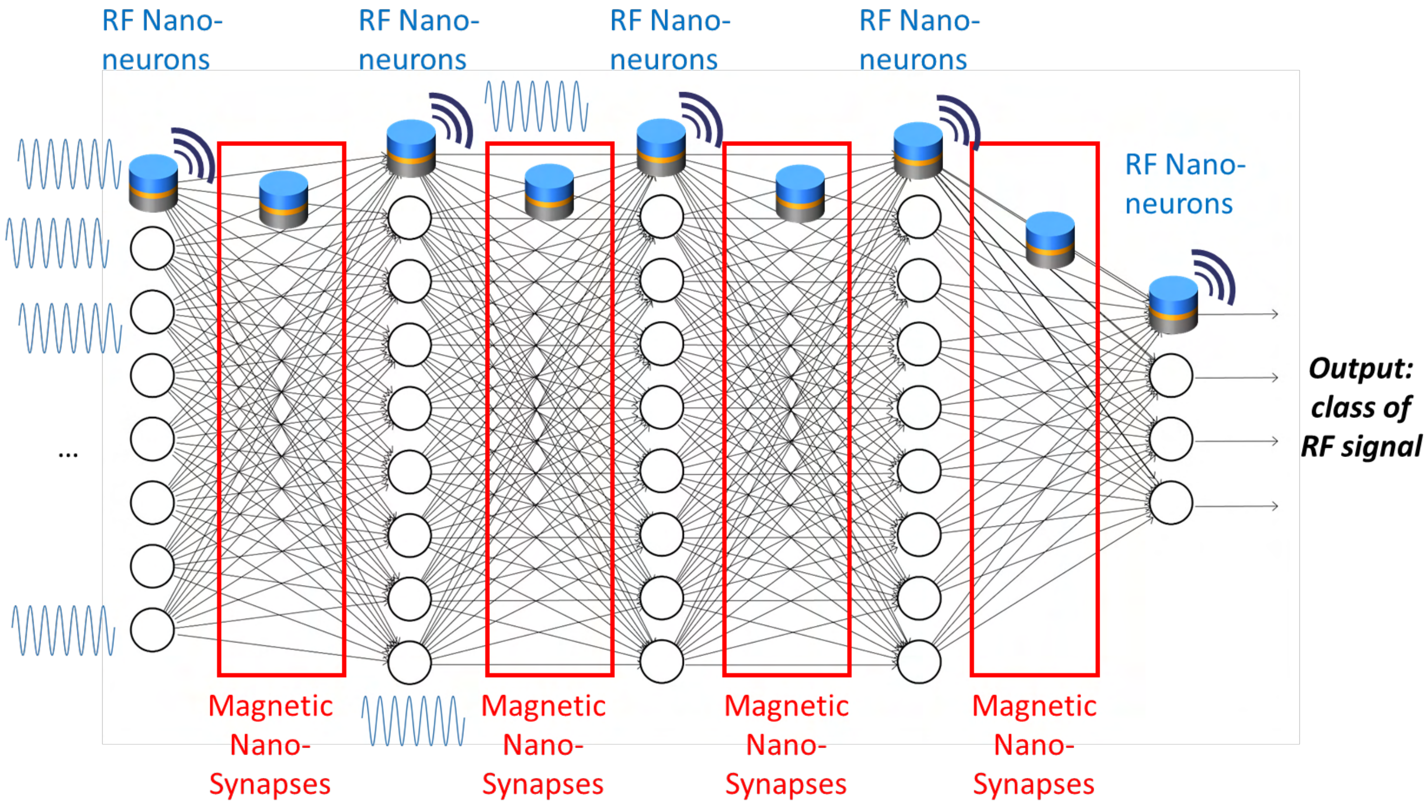
- **Large reduction of antennas size**
- Stealth

THALES

Neuromorphic computing

Magnetic tunnel junctions





Applications

- Direction of arrival with antenna network
- Object recognition with SAR
- Motion recognition with micro-Doppler effect

Differentiators

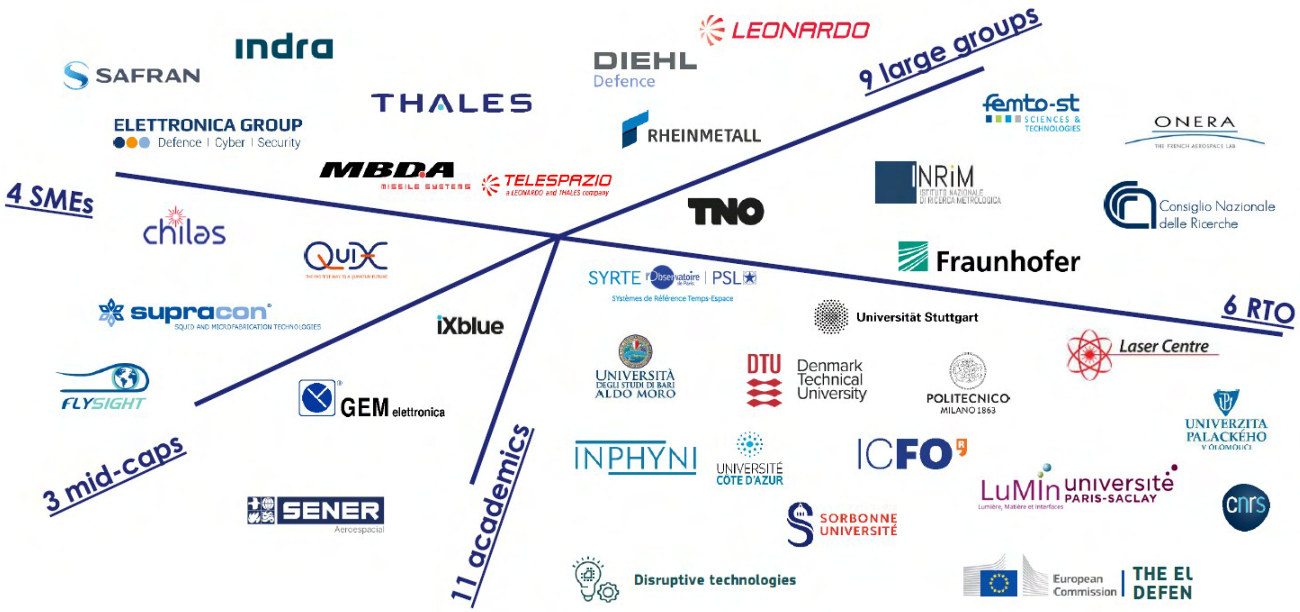
- Strong reduction of chip's size, power consumption and price
- More robust to noise and equipment imperfections

THALES

European Defense Fund ADEQUADE project

Advanced, **D**isruptive and **E**merging **QUA**tum technologies for **De**fence

- Positionning, navigation and timing
- Quantum radio frequency sensing
- Quantum optronics sensing



33 members
T0 Jan 2023
4 years
27 M€

Table Ronde

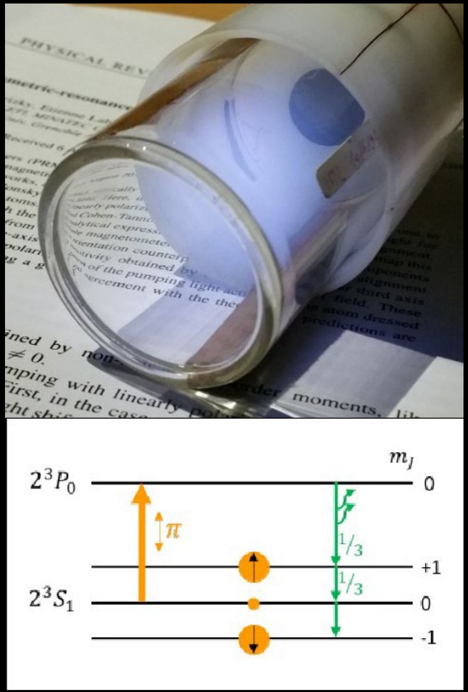
Les capteurs quantiques

Modérateur : **Audrey Bienfait**, CNRS Researcher at ENS de Lyon

Participants

- **Agustin Palacios-Laloy**, PhD, CTO / **Mag4Health**
- **Dimitri Labat**, Co-founder & CTO / **Chipiron**
- **Gauthier Chicot**, Founder and CEO, **Diamfab**
- **Cédric Demeure** / VP Research and Technology / **Thales**

MAG4Health



Un capteur basé
sur la physique atomique

Mûri dans l'exploration
spatiale

Pour **démocratiser**
l'imagerie fonctionnelle
du cerveau

Marchés

- Recherche neurosciences
- Chirurgie de l'épilepsie
- Diagnostic précoce Alzheimer
- Évaluer commotion cérébrale
- Applications émergentes

Valeur

- Rendre l'imagerie fonctionnelle accessible
  - Diviser le prix par 3
  - Pas de consommable
  - Data processing as a service

Statut

- Lauréats iLab 2020 &
  AMI Santé Numérique 2021
- 8 salariés
- Collaboration avec 7 équipes cliniques
- Exploite 12 brevets
- 1er produit : 2023

Dimitri Labat, CTO
dimitri@chipiron.co

chipiron

Portable medical MRI machine powered by ultrasensitive quantum detection

DIAMFAB
DIAMOND ENHANCED TECHNOLOGIES

Diamond Synthesis and Doping for Quantum Applications and Power Electronics

gauthier.chicot@diamfab.com

www.diamfab.com

Thales Research & Technology

- 1 des 5 centres de recherche du groupe Thales
- 250 chercheurs permanents, 40+ thésards
- 4000m² de salles blanches
- 35 brevets/an, 50+ publications scientifiques
- UMR Physique : 1 Nobel, 6 ERC, médaille argent CNRS…
- GIE III-V lab avec Nokia et le CEA-Leti
- Labo communs avec ENS-Paris-Saclay, X, CEA-List, Chaire ENS-Paris, …

Cédric Demeure

- VP R&T France
- Directeur de TRT
- Fellow expert Thales

OPEN

THALES

Conclusion

Le quantique à Grenoble

Thierry Chanelière, Scientific Researcher CNRS, Institut Néel
Anna Minguzzi, Directrice de recherche au CNRS

Andrea Busch, Head of inward Investment, Invest in Grenoble Alpes

QuantAlps

Fédération grenobloise pour les sciences et les technologies quantiques

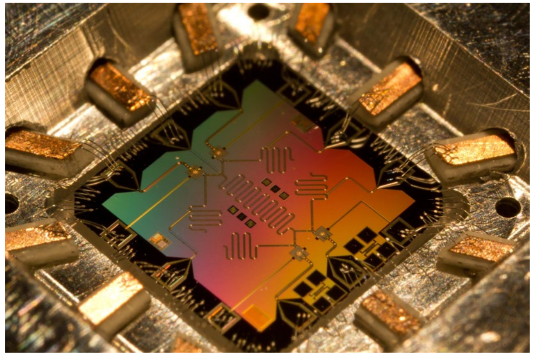
Contexte des technologies quantiques

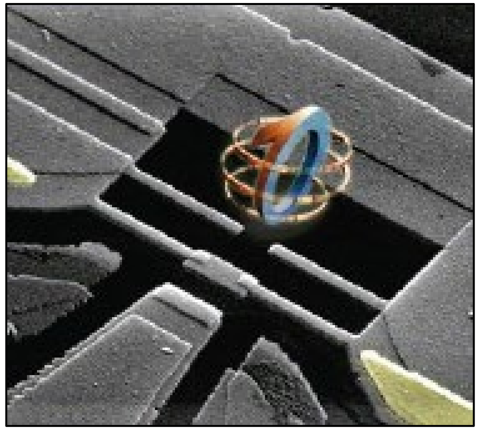
Exploitation des aspects les plus contre intuitifs de la mécanique quantique (intrication, cohérence) pour

- communiquer avec plus de sécurité
- calculer plus rapidement
- mesurer plus précisément

Couplage fort recherche fondamentale et développements technologiques
Enjeu d'interdisciplinarité et d'intersectoralité
Cercles d'innovation

- Enjeu de souveraineté nationale et industriel majeur
- Stratégies quantiques nationales
- Forts investissements du secteur privé



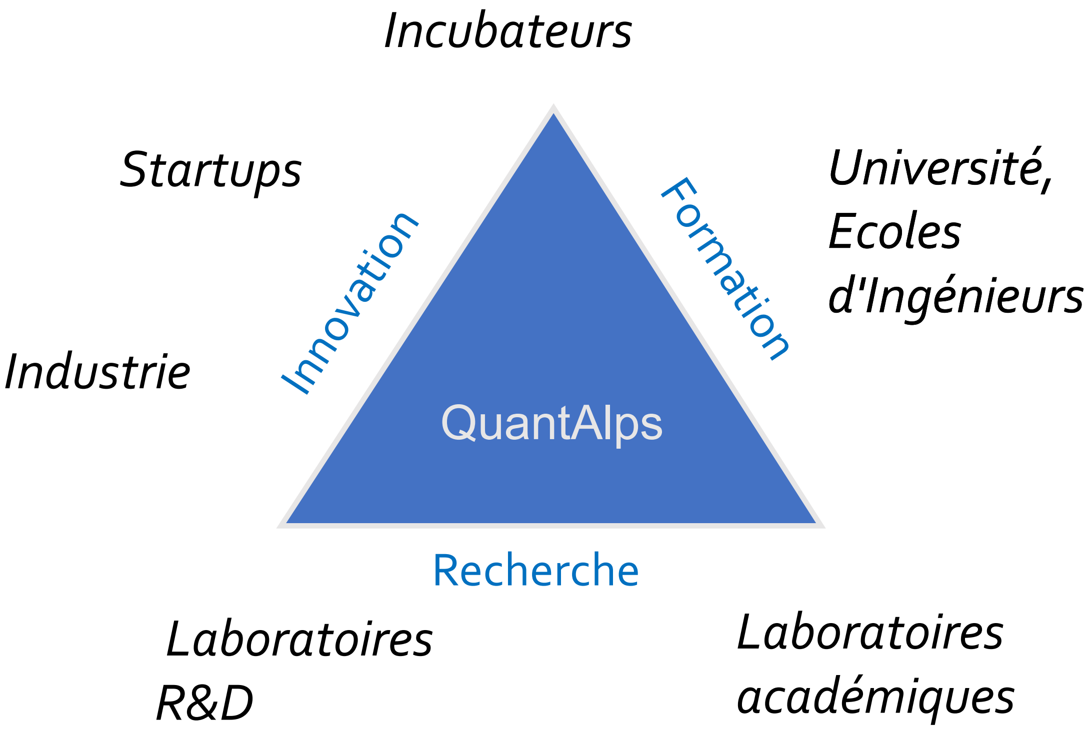


Grenoble site pilote pour le quantique

- 2007 : Fondation Nanosciences
- 2011 : Labex LANEF (équipement, fonctionnement, bourses de thèse)
- 2016 : Première initiative autour du qubit silicium “Quantum Silicon Grenoble”, ERC Synergy QuCube 2018, équipe mixte UGA-CNRS-CEA QuantECA 2019
- 2017 : projet fédérateur IdEx QuEnG + MSCA COFUND GreQUE
- 2019 : Labex LANEF renouvelé
- 2021 : Programme thématique QUANTUM, Graduate School UGA
- 2022 Federation de recherche QuantAlps
- 2022 Programme QuanTEdu France
- 2022 COFUND MSCA ‘Quantum Grenoble’

QuantAlps :

Fédération grenobloise pour les sciences et les technologies quantiques



Périmètre scientifique - axes Thématiques

Humanités pour le quantique (10) [Philosophie, Sociologie]
Éthique, Sociologie des usages, Ontologie

Information quantique & software (30) [Mathématique, Informatique, Physique]
Nouvelles techniques pour la manipulation, le traitement et le transfert de l'information quantique

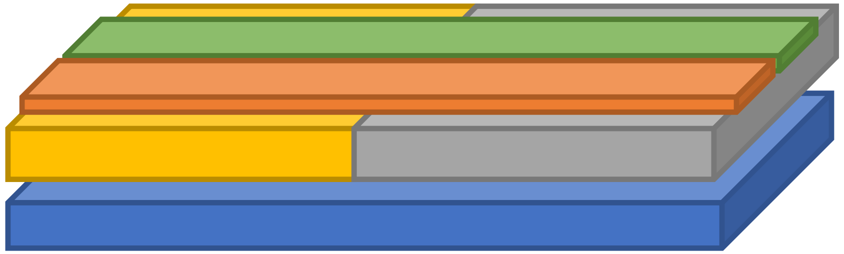
Ingénierie quantique & Hardware (100) [Physique]
Manipulation et intrication contrôlée de systèmes quantiques individuels

Matière quantique (90) [Physique]
Effets quantiques collectifs et nouveaux états de la matière

Technologies habilitantes (90) [Microélectronique, Physique]
Elaboration, Cryogénie, CryoCMOS, Spintronique

QuantAlps

230 chercheur.e.s et enseignant.e.s-chercheur.e.s sur 5 axes thématiques



Soutien à la recherche pour les technologies quantiques

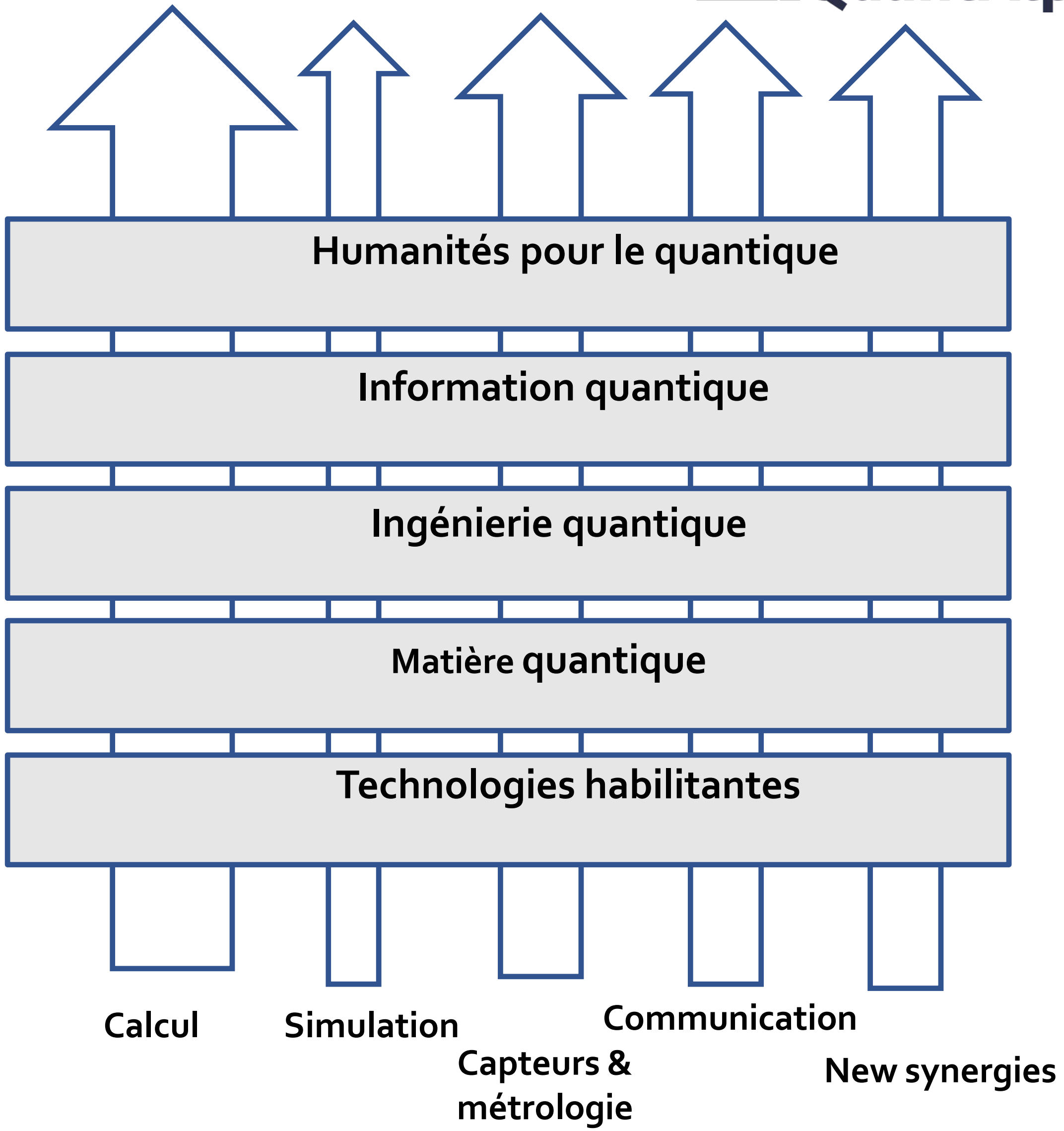
Promouvoir l'**innovation** scientifique et technologique = Connexions inter-axes, interdisciplinaires, intersectorielles pour les technologies quantiques ; exploration des nouvelles voies pour les technologies quantiques post stratégie quantique

Moyens:

- Animation des projets fédérateurs, workshops thématiques et QuantAlps Days
- Chercheur.e.s invité.e.s (séjours de 1 semaine à 1 mois)
- Personnel non-permanent (bourses de thèse)

Financement: Tutelles, AMI Formation de la Stratégie nationale, cofund MCSA (Europe)

QuantAlps



➢ **Pilotage par le CoDir + CoPil de QuantAlps**

Formation pour le quantique

QuantAlps

Motivation nationale: Création de 16 000 emplois directs et indirects à l'horizon 2030 dans les nouveaux métiers du quantique

Diagnostic : besoin en formation aux technologies quantiques : techniciens, ingénieurs, docteurs

Actions

- Programme **QuanTEdu France** (porteur Grenoble) de la stratégie nationale : 50 bourses de thèse
- Programme **QuanG** (MCSA COFUND) : 36 bourses de thèse cofinancées par l'Europe
- Soutien à la **formation initiale** et **continue**

Objectifs: réponse aux besoins en formation dans le domaine du quantique

➢ **Pilotage par le Comité Formation QuantAlps**

Quantique, Environnement, Société

Motivation : Comprendre le coût en ressources (eau, matières premières, énergie) des technologies quantiques ; analyser leur impact à la société ; explorer comment les concepts quantiques changent notre perception de la réalité

Forces: lien unique en France quantique-SHS : philosophie, éthique, usages et impacts; ligne transverse sur l’énergétique du calcul classique et quantique; expertise matériaux

Actions : analyse des scenarios predictifs, ontologie quantique, sustainable quantum

Financement: CDTools TIQUA (Idex UGA)

QuantAlps

- **Pilotage par le Comité CDTools de QuantAlps**

QuantAlps connecté

QuantAlps

Objectifs:

- ✓ Se coordonner avec les centres quantiques français en tirant parti des structures nationales (GDRs IQFA, Méso, AF) et de la Stratégie Quantique Nationale
- ✓ Dévélopper une stratégie à l'international en accord avec les instances nationales (Stratégie Nationale, ONR, MESRI, DGA...) et locales (UGA, LabEx...)
- ✓ Soutenir et faciliter les échanges d'étudiant.e.s (Master & Doctorat) et de chercheur.e.s vers les centres quantiques partenaires

Forces: Liens déjà établis avec les principaux centres quantiques nationaux et internationaux

Financement: Tutelles, Cofund

➢ **Pilotage par le Comité Relations Internationales de QuantAlps**

QuantAlps Innovation

QuantAlps

Transfert:

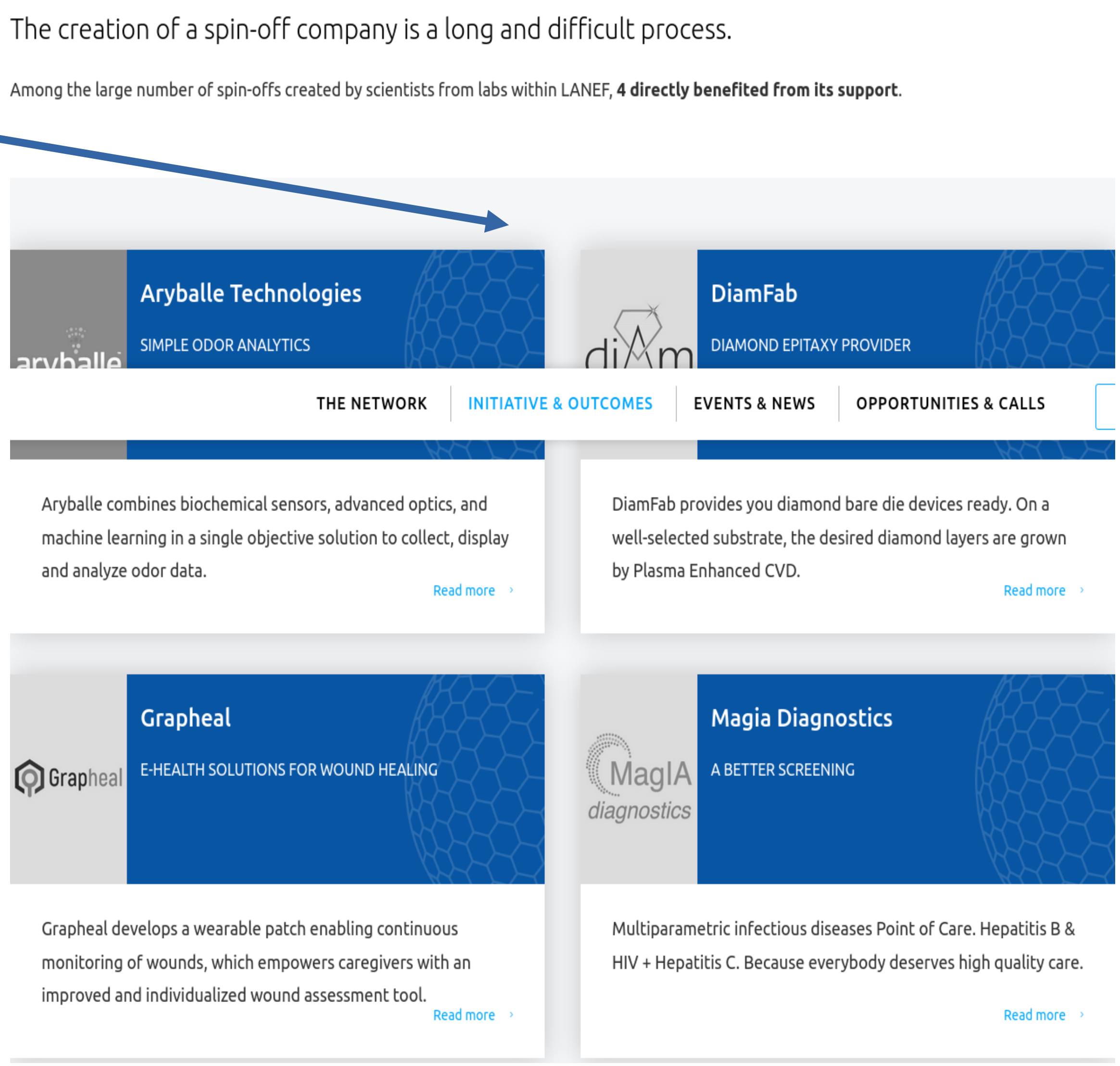
- ✓ Labex LANEF 2011
- ✓ (Pré-)**Maturation** – programmes institutionnels augmentés : CNRS – CEA – INRIA - UGA
- ✓ SATT Linksium

Collaborations:

- ✓Projets collaboratifs
- ✓**Thèses** CIFRE

Communication:

- ✓Faire comprendre le millefeuille académique et ses **compétences**
- ✓Briser la glace … **visites de labo bientôt**



Merci beaucoup pour votre attention

QuantAlps

WELCOME TO GRENOBLE ALPES
A LEADER IN INNOVATION & INDUSTRY

Invest in
Grenoble
Alpes

A DYNAMIC REGIONAL ECONOMY

70 000 Km²
(THE SIZE OF IRELAND)

8 MILLION INHABITANTS
SAME POPULATION AS SWITZERLAND OR ISRAEL

#2 FRENCH REGION
12% OF FRANCE'S POPULATION

3.2 MILLION JOBS
(12% OF FRENCH JOBS)

#2 FRENCH REGION FOR GDP
€250 BILLION (GDP OF CZECH REPUBLIC OR PORTUGAL)

60 MILLION CONSUMERS
WITHIN A 500 KM RADIUS

200 MILLION CONSUMERS
WITHIN A 1,000 KM RADIUS

GRENOBLE ALPES
AN EXCEPTIONAL QUALITY OF LIFE!

Invest in Grenoble Alpes

Invest in Grenoble Alpes

GRENOBLE ALPES AT A GLANCE

805,600
INHABITANTS

2nd LARGEST
ENGLISH-SPEAKING
POPULATION IN FRANCE

84% OF
LOCAL DRINKING WATER
IS NATURAL (UNTREATED)

30% OF WASTE RECYCLED
87% VALORIZED

20 MILLION CONSUMERS
WITHIN A 200 KM RADIUS

25 SKI RESORTS
AROUND GRENOBLE

35% OF INHABITANTS UNDER 30 Y/O

#1 CITY
FOR BIKE COMMUTERS
425 KM OF BIKE PATHS

1H ⇨ LYON
3H ⇨ PARIS
(BY HIGH-SPEED TRAIN)
3H ⇨ TURIN
3H ⇨ MARSEILLE

EASY ACCESS TO
LYON & GENEVA
INTERNATIONAL AIRPORTS

2,020 HOURS
OF SUN EACH YEAR

Invest in Grenoble Alpes

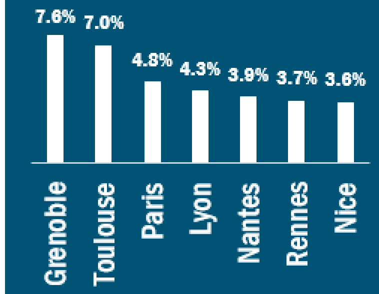
GRENOBLE ALPES UNIQUE INNOVATION ECOSYSTEM

#2 FRENCH RESEARCH HUB

#1 SCIENTIFIC CITY IN FRANCE (OUTSIDE PARIS)

#75 WORLDWIDE

-NATURE INDEX 2020



#1 IN R&D IN FRANCE

R&D STAFF AS A % OF TOTAL JOBS

25,000 PUBLIC & PRIVATE JOBS IN R&D

1 of 4 FRENCH INSTITUTES FOR ARTIFICIAL INTELLIGENCE

MIAI Grenoble Alpes

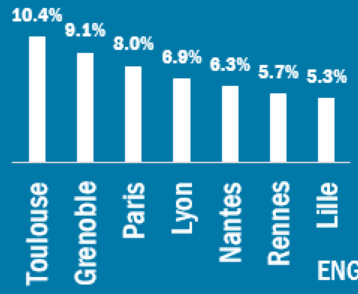
cea

#3 MOST INNOVATIVE PUBLIC RESEARCH INSTITUTE IN THE WORLD (REUTERS 2019)

14 DOCTORAL SCHOOLS IN FRANCE FOR **PHD** CANDIDATES

5 MAJOR EUROPEAN RESEARCH FACILITIES

- ESRF – SYNCHROTRON RESEARCH CENTER
- ILL – NEUTRON RESEARCH CENTER
- IRAM – RADIO ASTRONOMY INSTITUTE
- EMBL – MOLECULAR BIOLOGY LAB
- EMFL – MAGNETIC FIELD LAB



#2 IN FRANCE FOR ENGINEERS

ENGINEERS AS A % OF TOTAL JOBS

7.1 PATENTS PER 10,000 INHABITANTS

MAJOR COMPETITIVE CLUSTERS

axelera – ENSEMBLE, CATALYSONS LES RÉUSSITES
Cluster montagne – Mountain Development France
OSV
LYONBIOPOLE Auvergne-Rhône-Alpes
tenerrdis Energy Cluster Auvergne-Rhône-Alpes
MINALOGIC Auvergne-Rhône-Alpes

Invest in Grenoble Alpes

GRENOBLE ALPES HIGHER ED KEY FACTS & FIGURES

65,000 STUDENTS

3,100 PHD CANDIDATES

14 DOCTORAL SCHOOLS

GRENOBLE INP UGA — NETWORK OF 6 COMPETITIVE **ENGINEERING SCHOOLS**

GRENOBLE ECOLE DE MANAGEMENT TECHNOLOGY & INNOVATION — EXPERTISE IN MANAGEMENT OF **TECHNOLOGY & INNOVATION**

UGA Université Grenoble Alpes — RANKED AMONG **TOP 100** UNIVERSITIES WORLDWIDE

#1 IN FRANCE FOR

- NANOSCIENCE & NANOTECHNOLOGY
- METALLURGICAL ENGINEERING
- HOSPITALITY & TOURISM MANAGEMENT
- WATER RESOURCES
- GEOGRAPHY

2021 SHANGHAI RANKING

ENSIMAG APPLIED TECHNOLOGY & MATH

PAGORA BIOMASS & BIOSOURCED MATERIALS

ENSE3 ENERGY, WATER & ENVIRONMENT

5,100 TEACHERS & RESEARCHERS

SCIENCE-ORIENTED 42% IN A SCIENTIFIC FIELD

ESISAR ADVANCED SYSTEMS & NETWORKS

10,000 FOREIGN STUDENTS

+160 NATIONALITIES

PHELMA PHYSICS, ELECTRONICS & ENERGY MATERIALS

GENIE INDUSTRIEL SUSTAINABLE PRODUCT DESIGN

+350 STUDENT ASSOCIATIONS

Invest in Grenoble Alpes

GRENOBLE ALPES A MAJOR HUB FOR INDUSTRY

+7,000 EMPLOYEES
ST – life.augmented

+4,000 EMPLOYEES
Schneider Electric

+2,000 EMPLOYEES
EDF, BD

+1,500 EMPLOYEES
CATERPILLAR, orange

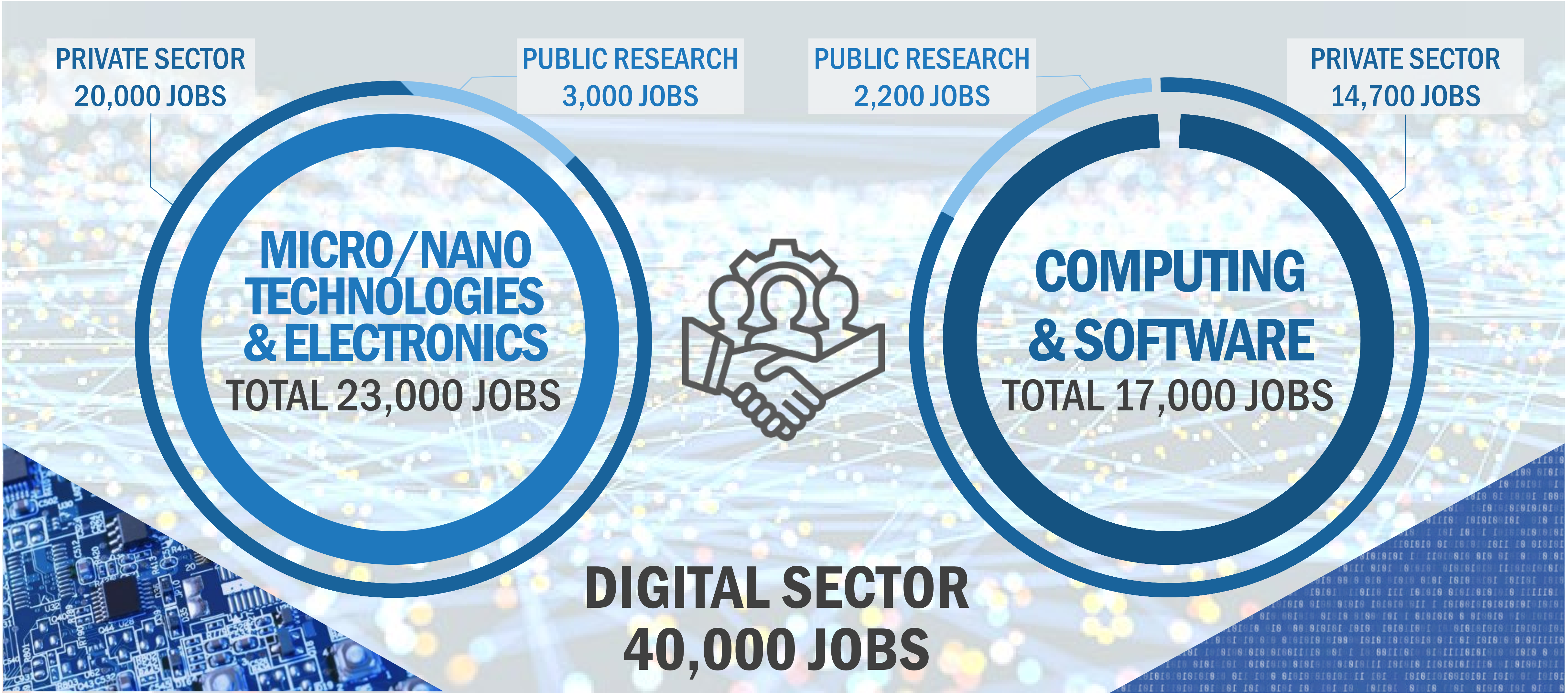
+1,000 EMPLOYEES
soitec, Air Liquide, ARaymond (MORE THAN FASTENING), Capgemini, LYNRED (BY SOFRADIR & ULIS), Atos

500 - 1,000 EMPLOYEES
Hewlett Packard Enterprise, Roche, HARDIS GROUP, GE, GE Renewable Energy, TRIXELL

DIGITAL SECTOR
WHERE HARDWARE MEETS SOFTWARE

Invest in Grenoble Alpes

A UNIQUE DIGITAL COMMUNITY UNITING HARD & SOFTWARE



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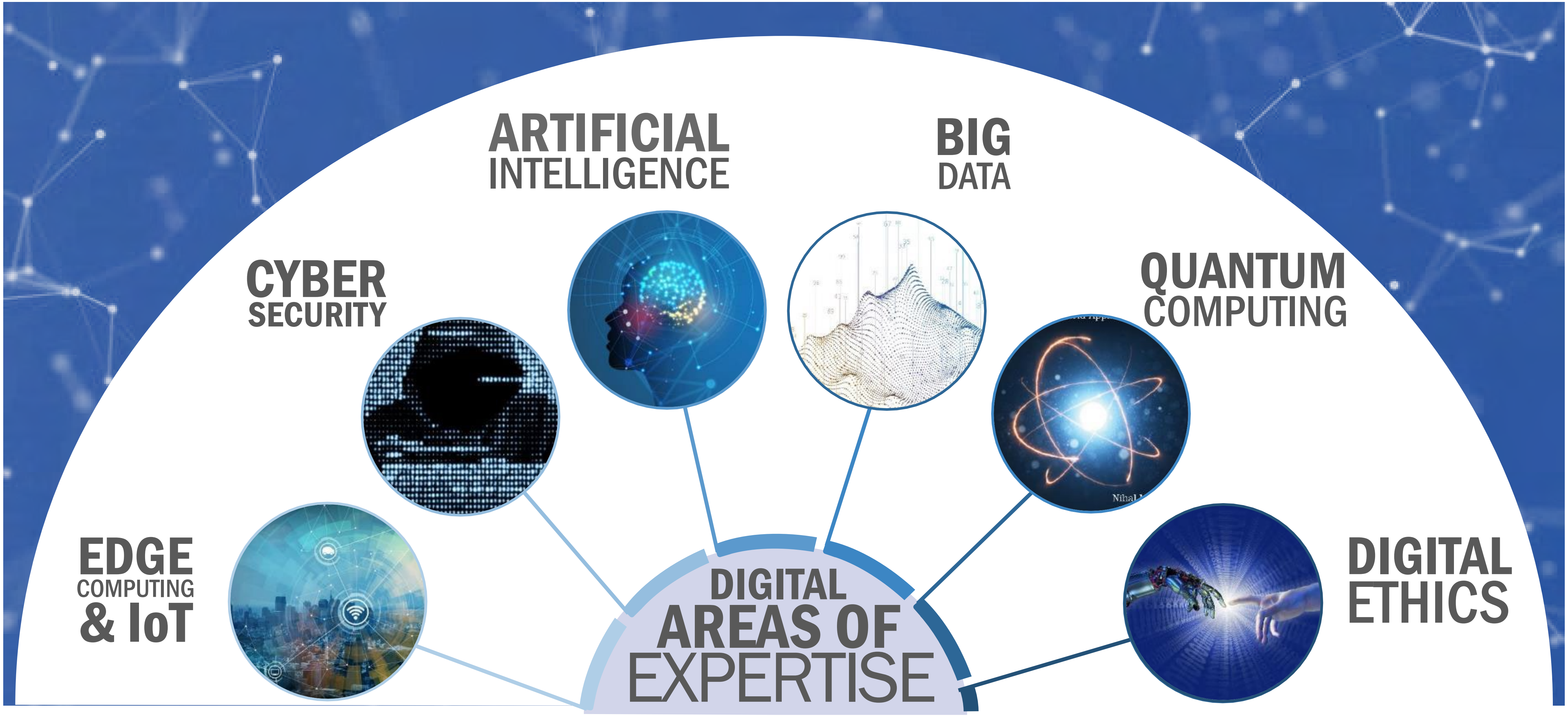
DIGITAL SECTOR AREAS OF EXPERTISE



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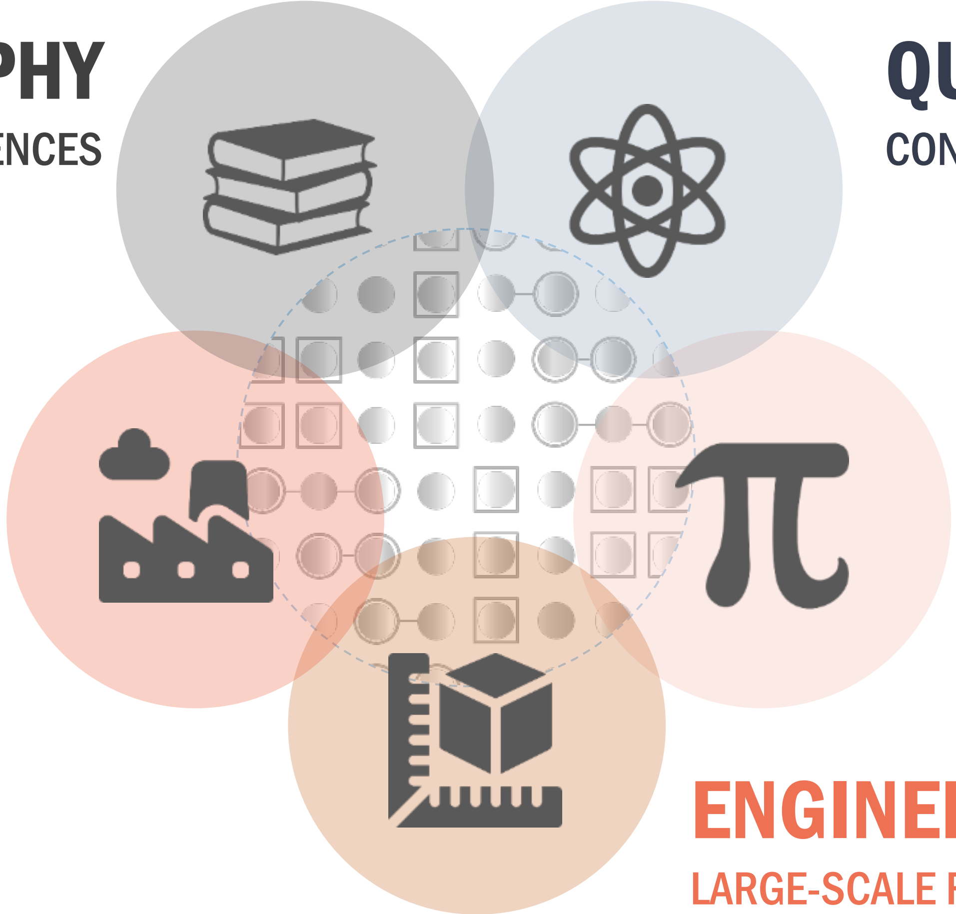
QUANTUM TECHNOLOGIES DEMANDS A UNIQUE ECOSYSTEM

PHILOSOPHY
& SOCIAL SCIENCES

QUANTUM PHYSICS
CONDENSED MATTER, NANOSCIENCE



INDUSTRY
& ENTREPRENEURSHIP

MATH
& COMPUTER SCIENCE

ENGINEERING
LARGE-SCALE FACILITIES, NANOTECHNOLOGIES

Invest in Grenoble Alpes

GRENOBLE ALPES ORGANIZED AROUND QUANTUM INNOVATION

QuantAlps

LPMMC laboratoire de physique et de modélisation des milieux condensés

NÉEL institut

SBT

Pheliqs Quantum Physics & Engineering

INSTITUT FOURIER

Pacte Laboratoire de sciences sociales

IPhiG Université Grenoble Alpes

leti ceatech

IMA CNRS · Grenoble INP · UGA

MEM MODÉLISATION, EXPLORATION DES MATÉRIAUX

LIG

gipsa-lab

spintec SPIN IN ELECTRONICS

LNCMI

Inria INVENTEURS DU MONDE NUMÉRIQUE

list ceatech

Verimag

OUR STARTUPS OVER €2B RAISED SINCE 2000

+€100M

- McPhy – 264M€
- Aledia – 200M€
- WAGA ENERGY – 122M€
- ecential robotics – 115M€
- VERKOR – 110M€
- CROCUS TECHNOLOGY – 113M€

€40M-€100M

spartoo, isorg, diabeloop, KALRAY, PDC*line pharma, advicenne, HRS

€20M - €40M

UroMems implantable solutions, Kayentis Dedicated to eCOA & Patient Engagement, Bonitasoft, VOLUBILL, adeunis

€10M-€20M

GREENWAVES TECHNOLOGIES, movea, Remedee, Xenocs, CYTOO, aryballe, WIZBII, MULTIX Xray Spectrometric Imaging, OpsiTech, iskn, STREAMDATA, nh TherAguix, QAPA, APIX, ELICHENS, antaios

€5M - €10M

ALPINOV X, iROC TECH, Primo1D The E-Thread Company, THIVE TECH FEATURING THE INVISIBLE, TERA environnement, Weebitnano The Future Memory, ENDOCONTROL, LANCEY energy storage, EXAGAN, ICALPS, ENERBEE, SQUADRONE SYSTEM, Hexo+

Merci à tous


QUANTUM
TECHNOLOGY
04
OCTOBRE
2022
MINALOGIC
Auvergne-Rhône-Alpes