Behind the technological challenges of QC, the end-user integration undertaking

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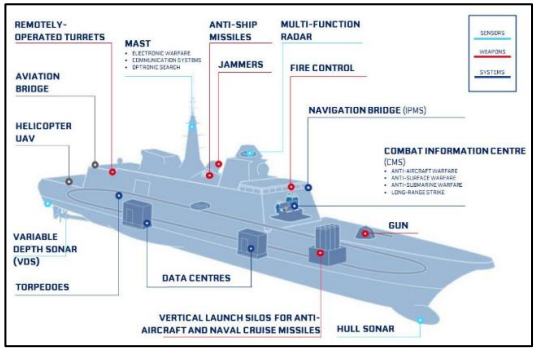
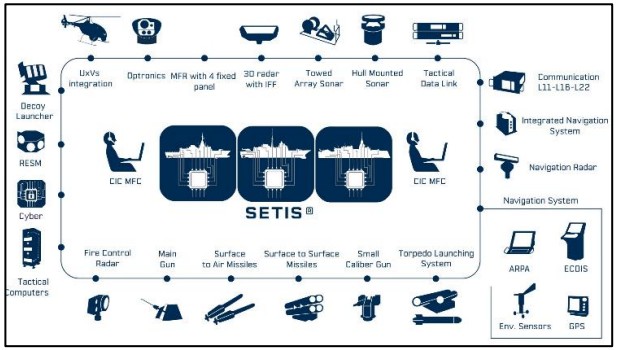
NAVAL GROUP CORE BUSINESS

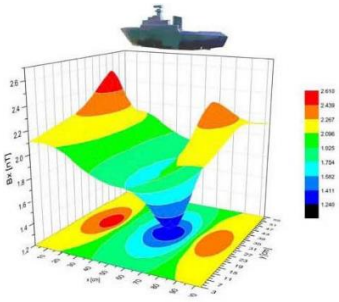
Shipbuilding of warships, submarines and naval weapons, **integration** of sensors and equipments, as well as **maintenance in operational conditions** services for clients fleet.

Designing the **combat system** (interconnection between weapons and sensors), the **navigation system** and the **machinery control system** (propulsion, ventilation).

Ensuring **military performances** : discretion, furtivity, speed, invulnerability, resilience…







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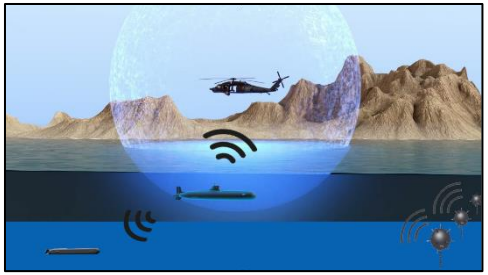
SOME USE CASES FOR NAVAL GROUP

CASE 1 : Communications through a QIN

- Securing encryption key exchanges between ships using optical links.
- Sharing quantum information with satellites under unbreakable protocols.
- Distributing computing jobs on quantum computers aboard and/or on shore.

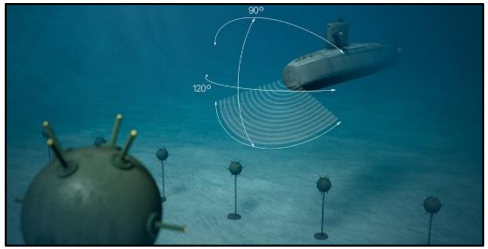
CASE 2 : Quantum sensing makes oceans transparent

- An increased threat coming from high-sensitivity magnetic anomaly detectors.
- Exploiting gravitational anomaly detection for maritime blockade operations.
- Enhancing the situational awareness with quantum sensors on UUV.



CASE 3 : Highly secure underwater navigation

- Extending the stability of inertial navigation using cold atoms IMU.
- Correlating differents sensors for a more acurate underwater positionning.
- Ensuring a safe area around submarines.



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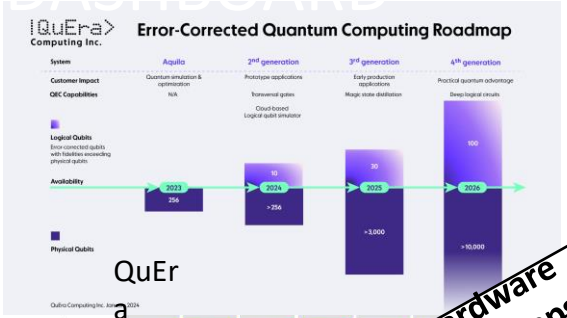
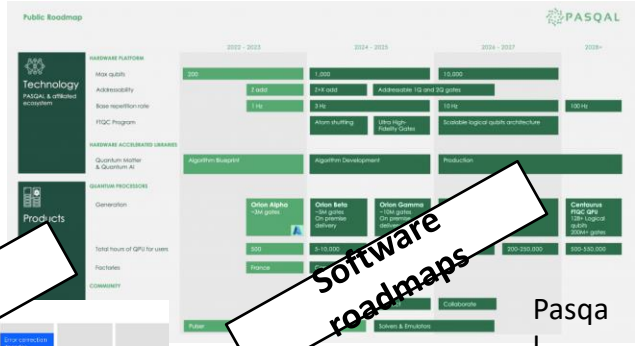
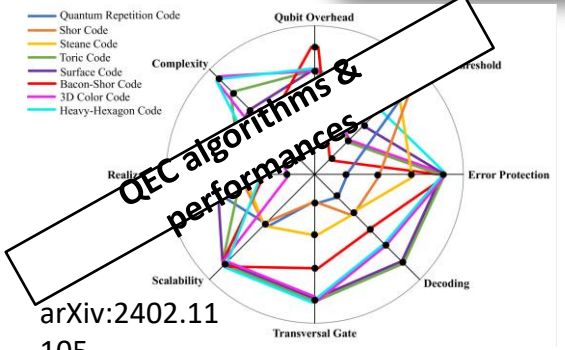
QUANTUM COMPUTING DEVELOPMENT



QuEra



Pasqal



arXiv:2402.11105

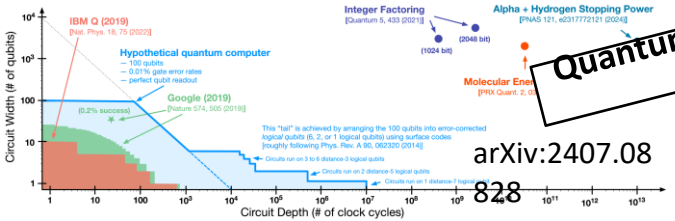
Hardware roadmaps

Software roadmaps

QEC algorithms & performances

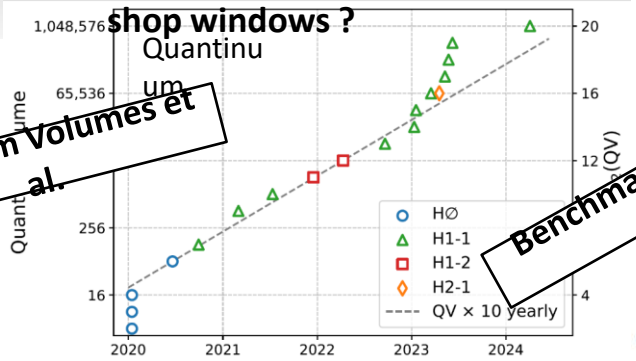
IBM

So many key figures and amazing results to follow … Are industrial future end-users doomed to be onlookers in front of the quantum shop windows ?

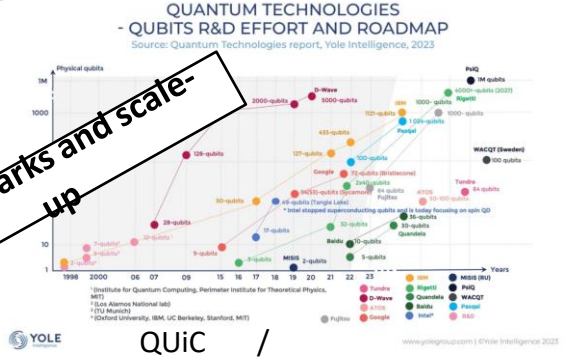


arXiv:2407.08828

Quantum Volumes et al.



Benchmarks and scale-up



QUiC / Yole

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INDUSTRIAL END-USERS POTENTIAL

- Identify **use cases** & prepare **future business**
- Interact with providers roadmaps & shareholders to **secure fundings**
- Team-up with industrial partners for **resources pooling** & reuse
- Cooperate with academics to **boost** & sponsor fondamental research and **codesign** algorithms
- **Benchmark** the prototypes, **experiment** PoCs and minimal examples

Systematic Paris Region Deep Tech Ecosystem
Inria
LIP6
aws Amazon Braket
GENCI Le calcul intensif au service de la connaissance
EDF
The University of Edinburgh
Région ileDeFrance
ALICE & BOB
Teratec
QSL Quantum Software Lab
JOURNEE PACK QUANTIQUE
PASQAL
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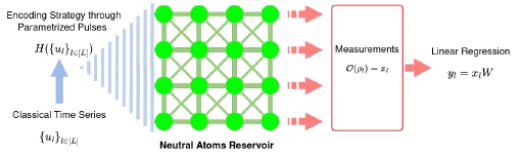

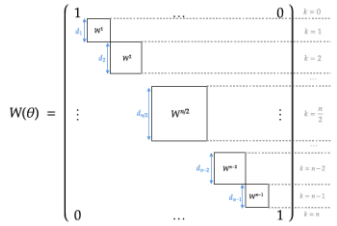

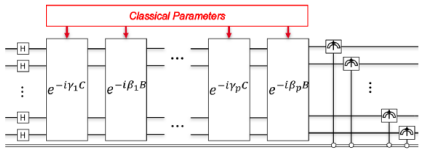

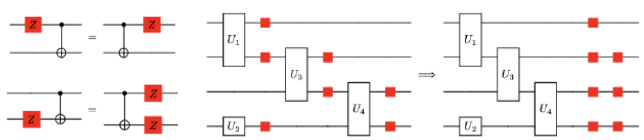

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INDUSTRIAL END-USERS POTENTIAL

We do **our share** towards pushing the **technology to scale-up** …
… but **nothing** has yet been done to prepare the **technology to be industry-compatible**.

Disclaimer : Not considering end-users who will have QC as a service, on cloud access or computing machines, in the same conditions as any HPC ressource (internally or externally).

But rather : companies that will buy QC as an equipment to install in a more complex product for a client *(for whom the QC unit cannot be desentangled from the product)*

This business segment might seem marginal, but is not adressed yet in the specification design fo the technology.

→ **Here comes the integration challenge**

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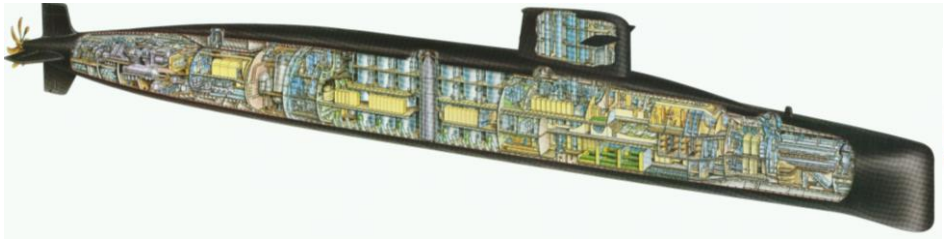
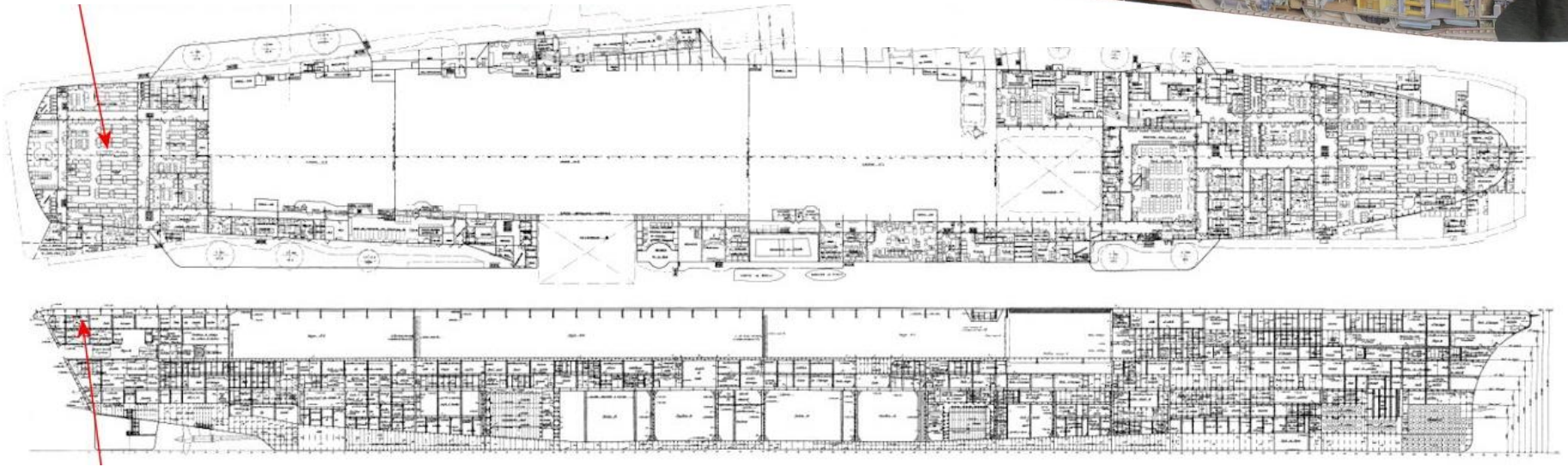
WHERE IS Q-WALDO ?





Pictures extracted from Association historique et amicale des anciens de DCNS (https://www.aadcns.fr) and Technology & Aéronautique (https://aviatechno.net/)

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DO WE REALLY NEED QC ONBOARD ?

If you have a definite answer to this question : please email emmanuel.macron@elysee.fr (put me in CC)

Finding the operational UC making QC mandatory is the **challenge** … as for everyone here, today ! But :

- The **typical timescale** of a major defence program is **20+ years** :

SSN Rubis 1976-1995 ; Barracuda 2007-2030 ; Attack (AUS) 2017-~~2040~~ ; Orka (NL) 2024-2038(?)

SSBN Le Redoutable 1960-1985 ; Le Triomphant 1981-2010 ; SNLE 3G 2021-2050(?)

Aircraft carriers Clémenceau/Foch 1949-1961/1963 ; Charles de Gaulle 1981-2001 ; PANG 2018-2038(?)

- Clients might **change their mind** during the program ; NO is generally not an acceptable answer.

→ **Naval Group cannot wait the confirmation that QC has operational advantages to anticipate that its clients ask for QC onboard *(for the same price and without any additional delays !)***

In parallel to the scale-up collective work, one needs to work backwards from the final product perspective

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WHY PUTTING QC ON A MILITARY SHIP IS SO HARD ?

A warship shall :

- Float ⟶ 1st architectural design phase is about **allocating volumes and masses** in the ship
- Have functions ⟶ 2nd phase is about **mapping all the cables** and **links** between equipments
- Interconnected ⟶ data exchange with redundancy and **critical systems protections**
- In military environments ⟶ movements, explosions, EM fields, humidity/grease/dust/electrical shocks, people running around, climbing on the equipment, power failures, maintained by **non specialists**.
- At sea for weeks ⟶ **no intervention**/debugging by expert subcontractors (even more for subs)

Applied to QC, in the first years of a program, one needs to have estimations of physical specifications (dimensions, weigth), energy consumption, resistance to shocks, vibrations and EM perturbations + the need for cryogenics, (cooling) water supply … one needs to anticipate technological obsolescences of other equipments that need to be upgraded or removed.

During the construction phase (5-10 years later) : the equipment must have not changed drastically, be available, its price must have not skyrocked. After the ship is delivered, the QC equipment will have to be maintained for 20 years ahead. **The technology provider has to survive on a (very) long timescale !**

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WILL QC BE AVAILABLE WHEN NEEDED ?


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Le service public de la diffusion du droit

10 février 2024 JOURNAL OFFICIEL DE LA RÉPUBLIQUE FRANÇAISE Texte 8 sur 110

Décrets, arrêtés, circulaires

TEXTES GÉNÉRAUX

MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA SOUVERAINETÉ INDUSTRIELLE ET NUMÉRIQUE

Arrêté du 2 février 2024 relatif aux exportations vers les pays tiers de biens et technologies associés à l'ordinateur quantique et à ses technologies habilitantes et d'équipements de conception, développement, production, test et inspection de composants électroniques avancés


Computers and related equipment, materials, software and technology

PL9014 The export or "transfer by electronic means" of the following goods, "software" or "technology", is prohibited to any destination:

a. Systems, equipment and components, as follows:

1. Quantum computers and related "electronic assemblies" and components therefor, as follows:

a. Quantum computers as follows:

1. Quantum computers supporting 34 or more, but fewer than 100, 'fully controlled', 'connected' and 'working' 'physical qubits', and having a 'C-NOT error' of less than or equal to 10 -4.

legislation.gov.uk

The UK Export Control (Amendment) Regulations 2024

Independantly of proven UC of any quantum advantage for Defence coming from QC, the technology and its auxiliary equipments (cryogenics, laser sources …) are now **dual-use**, meaning associated with **export control** and **end-user licences** issued by national administration for QC with at least 34 qubits (CNOT error < 10^{-4}). *« We shall not make QC a military thing »* (cf Eva Crck this morning) … but we regulate it as so.

Will QC become ITAR (International Traffic in Arms Regulations), a US legal lock for Defence applications ?

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WHICH QUESTIONS ARE STILL OPEN

Business related : which providers will (still) be here in 2035-40 ? At this time, who will develop the algorithms, who will install the hardware onboard. Who will put the **technical requirements** (the client / the software provider / Naval Group) and when will they do it ?

Supply chain related : how do we **secure** a **long term provider** ? When do we start booking products, based on which (future) performances ? Do we identify supply dependances on « gray countries » for critical subcomponents ?

How do we take precautionary measures in a **technology agnostic way** in the hypothesis that eventually one hardware will **have to be integrated** ?

Operational setups : standalone QC in submarines (no communications), shared networks on a surface fleet, with/out distributed jobs, with/out QIN connexion and/or access to cloud QC on site dedicated QPUs.

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TAKE AWAY MESSAGES

What seems to be bound to happen :

- Quantum sensors (with individual information carrier) will output quantum data that might give additionnal hidden correlations compared to a classical measurement of its state.
- Quantum communication will be needed to link these sensors for interferometry purposes
- Even if running complex algorithms onboard is not required, data encoding will be needed to be able to share quantum states with other ships. Thus, some minimal QC will be onboard.
- Cybersecurity requirements will concern the QC hardware : on its connexion with the ship network, on the data itself and on the way the QC will be monitored by the combat system.
- QIN sovereign communications with an ashore QC datacenter will be required.

What work needs to be done with technology providers :

- Robustness benchmarking towards shocks, EM fields, dirty and faulty environments
- Modularity and interconnectivity studies for reducing the space allocation constraints
- Technology hybridation (circuit knitting f.ex)
- Clients expertise support to guide them to consistent and realistic requirements.

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