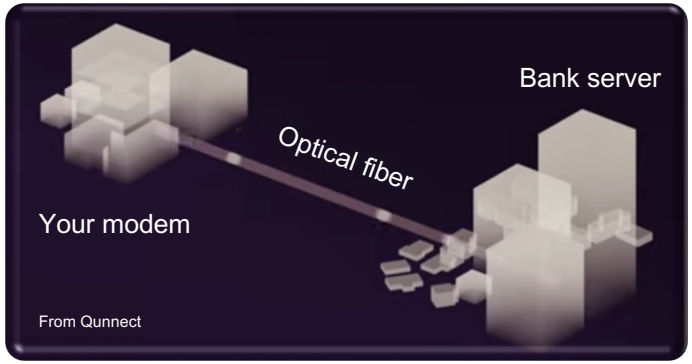
LE RÔLE DU SATELLITE POUR DES COMMUNICATIONS QUANTIQUES À GRANDE ÉCHELLE

10/11/2023

Thales Alenia Space Quantum Team

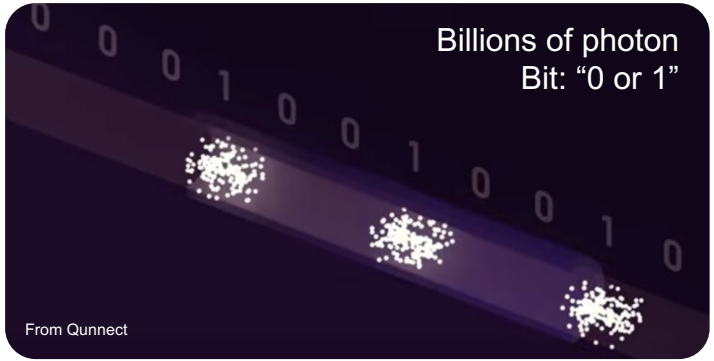
Laurent de Forges de Parny

PHOTONIC NETWORK : « LA FIBRE »

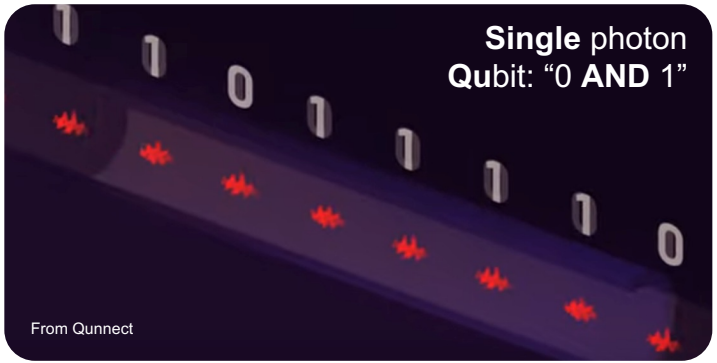


$$|\psi\rangle=\alpha|0\rangle+\beta|1\rangle$$

Classical Network



Quantum Network



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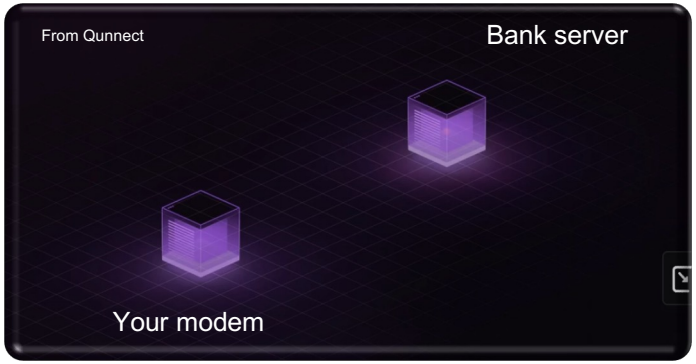
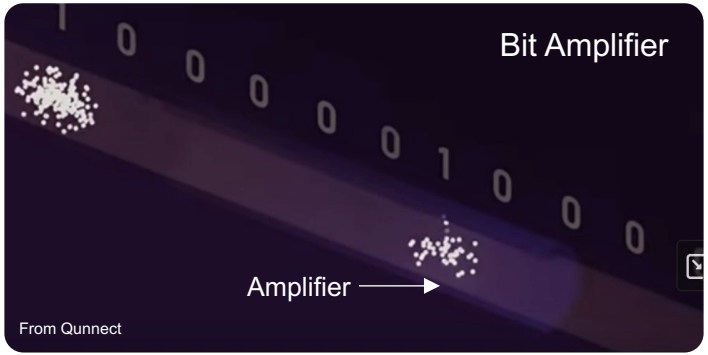
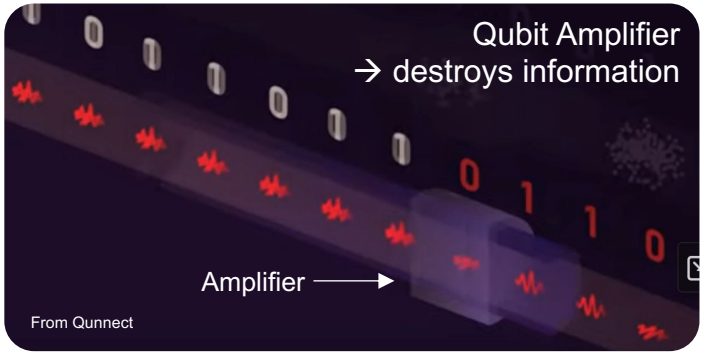
LOSS PROBLEM



Classical Network



Quantum Network



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LOSS PROBLEM

Classical Network

Amplifier is possible

Quantum Network

Amplifier is forbidden!

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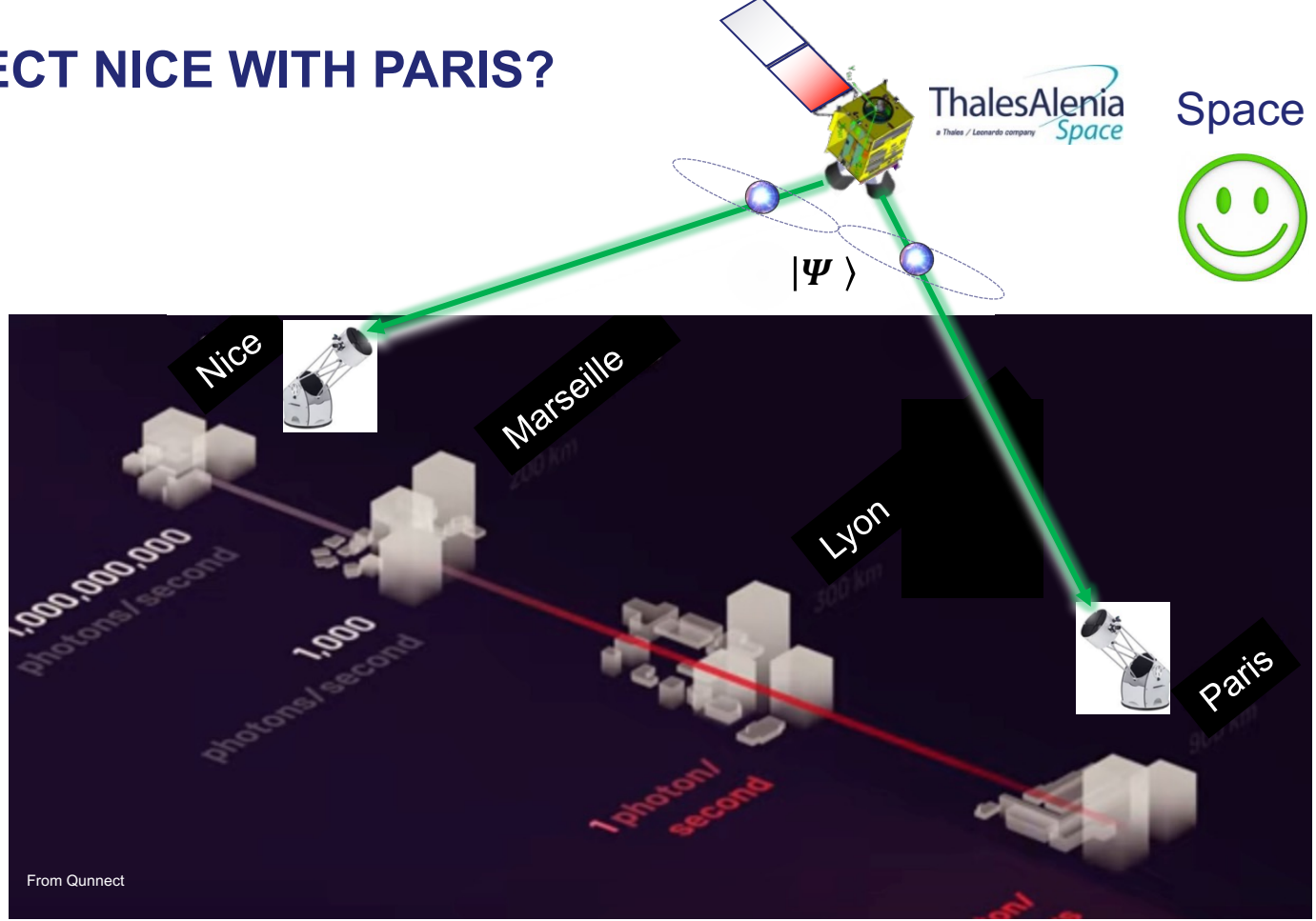
CONNECT NICE WITH PARIS?



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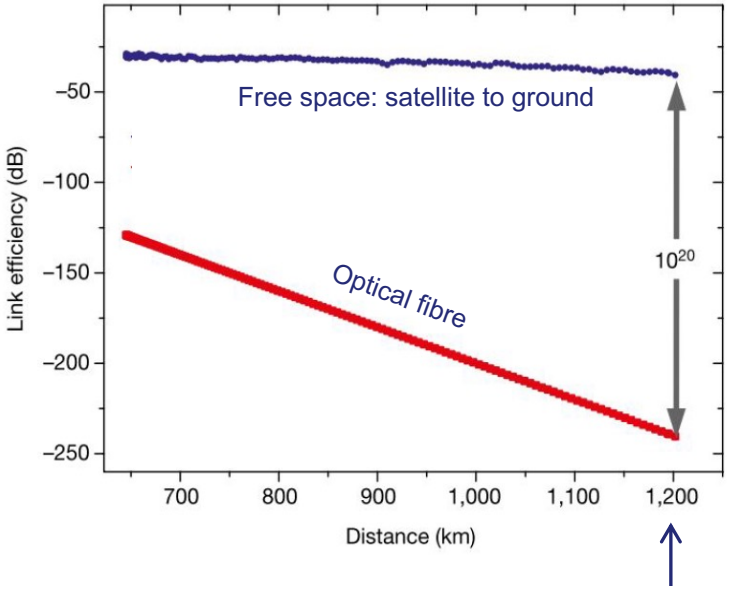
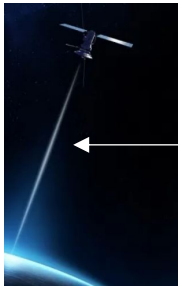
LOSS PROBLEM … IN NUMBER



… with a 1200 km fiber:
wait 380 billion years
(27 age of Univers) for 1 detection!

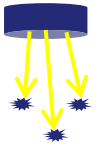
Satellite-to-ground quantum key distribution, Nature **549**, 43 (2017)
Satellite-Relayed Intercontinental Quantum Network, PRL **120**, 030501 (2018)

Free space

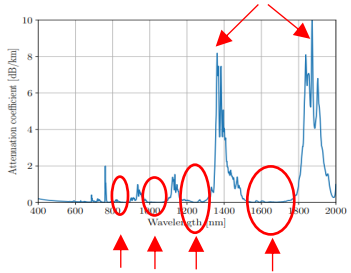


Single photon flow ~ nW

Absorption

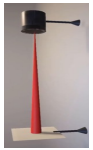


Absorption peak

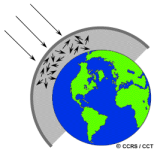


Transmission bands

Beam spreading



Scattering

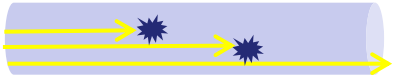


Clouds

Turbulence

Fibre

Optical fibre



Absorption

Optical fiber: 0.2 dB/km loss

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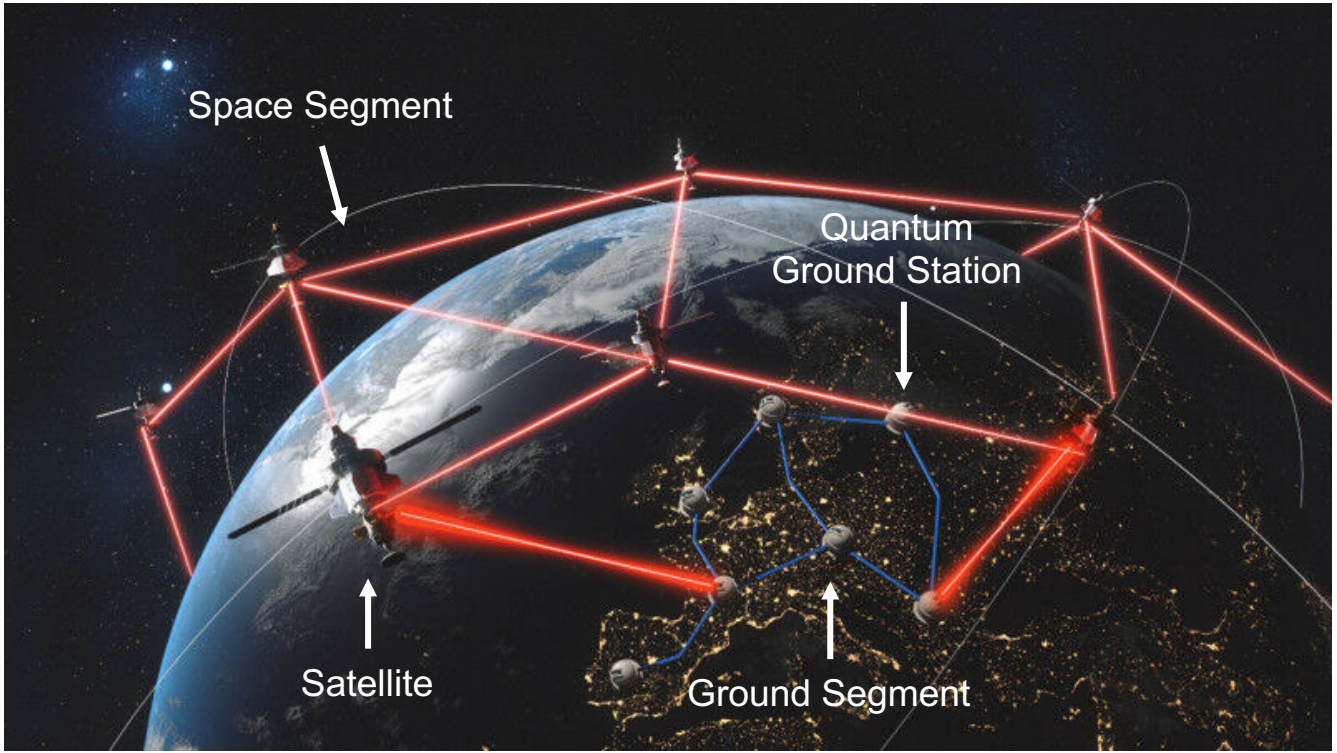
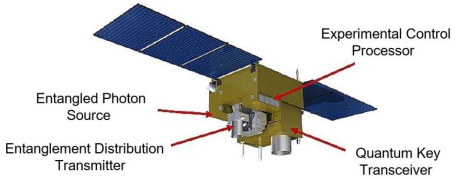
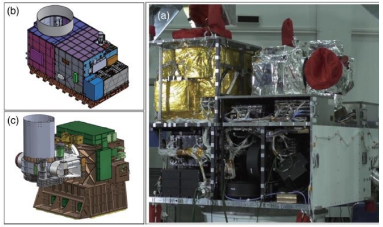
SATELLITE = SOLUTION FOR LARGE DISTANCES



Quantum Ground Station

Chinese Satellite (Micius)





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SATELLITE VS GROUND?

Quantum repeater ≠ amplifier

Ground **quantum repeaters** under development in research labs

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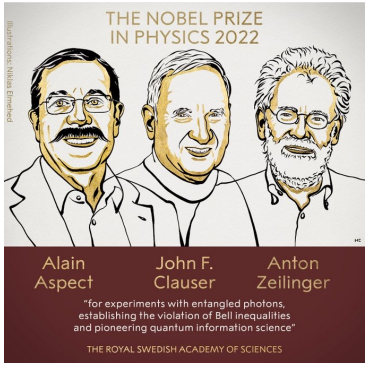
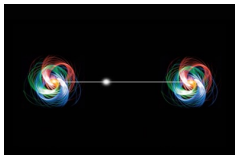
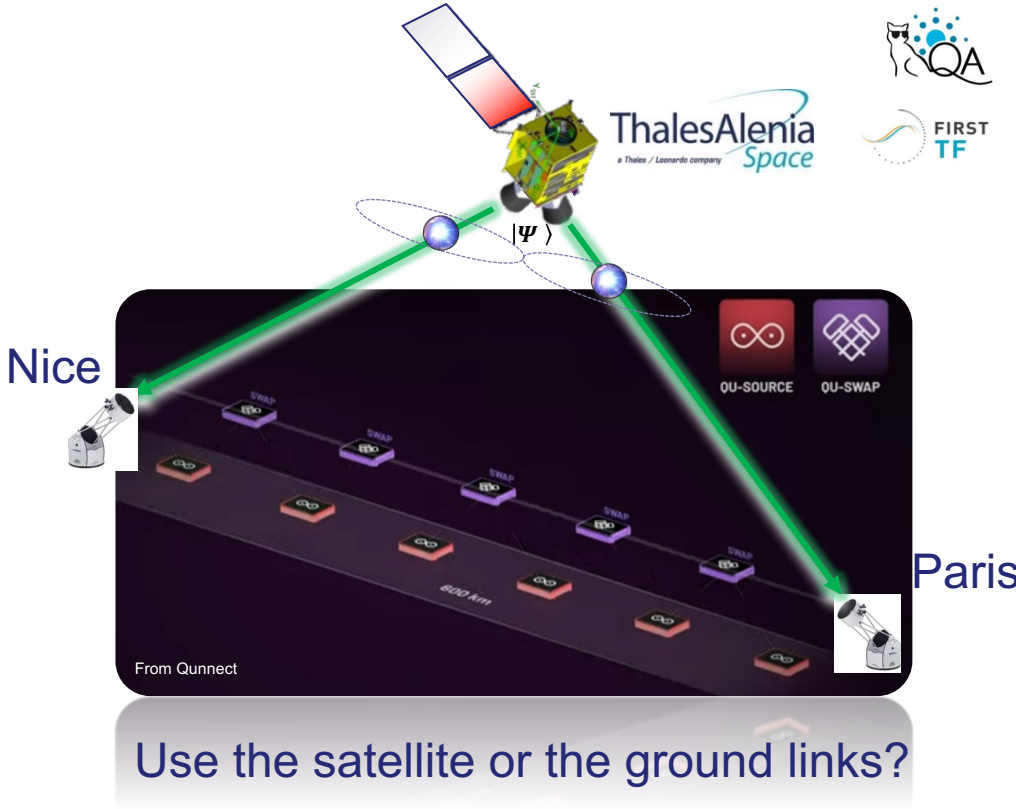
SATELLITE VS GROUND?



Quantum Entanglement
… is the key ressource!



$$|\psi_+\rangle=(|H\rangle_1|V\rangle_2+|V\rangle_1|H\rangle_2)/\sqrt{2}$$



Use the satellite or the ground links?

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CHINESE EXPERIMENTS SINCE 2017

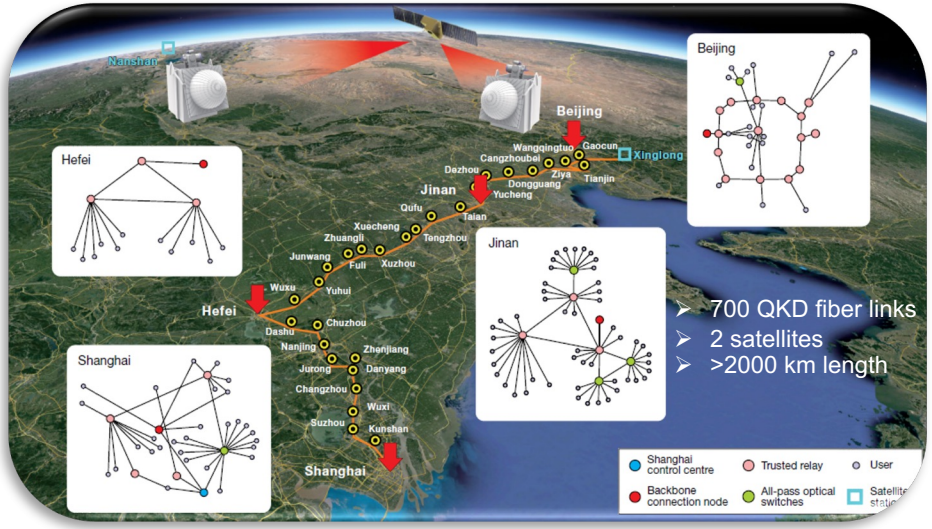
Entanglement distribution over 1200 km

Satellite-based entanglement distribution over 1200 km
Yin et al., Science 356, **1140** (2017)

Ground-to-satellite quantum teleportation over 1400 km
Ren et al., Nature **549**, 70 (2017)

… more publications

Chinese QKD network in 2021, *Nature* **589**, 214–219



Satellite-to-ground quantum key distribution up to 1200 km
Liao et al., Nature **549**, 43 (2017)

Satellite-Relayed Intercontinental Quantum Network
Austria-China 7600 km
Liao et al., Phys. Rev. Lett. **120**, 030501 (2018)

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For why? For whom?

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USE CASES?

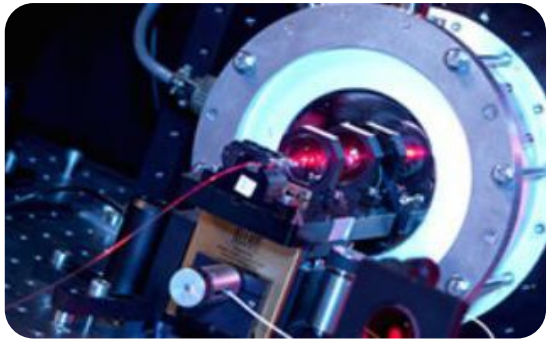
Quantum Computers

- Distributed Quantum Computing
- Blind Computing

- ➢ Simplify or solve hard problems
- ➢ Complex physical system modelling (pharma)
- ➢ Massive global parallel computing (global warming)
- ➢ Break asymmetric cryptography (RSA)

Quantum Sensors

- Distributed Quantum Sensing
- Pool of Quantum Sensors



- ➢ Quantum Clocks
- ➢ Precise time reference synchronization
- ➢ Magnetometers, accelerometers, gyrometers, gravimeters
- ➢ Pure random generation

Quantum Communications

- Quantum Cryptography
- Quantum Teleportation
- Entanglement Distribution

- ➢ Authentication of digital documents
- ➢ Secured communications with quantum cryptography: authentication, certificates
- ➢ Anonymous reliable voting
- ➢ Money → QuBitcoin
- ➢ Qubit Network: share entanglement

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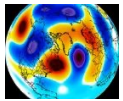
FOR WHOM? See our paper → Nature Comm Phys 6, 12 (2023)

- **Industry**: Materials computing capacities in pharma, secured communications, authentication

- **Critical infrastructures** energy, transport, telecom … extended sensors, security

- **Finance**: distributed/delegated computing, security, dating for cryptocurrencies, transactions, security

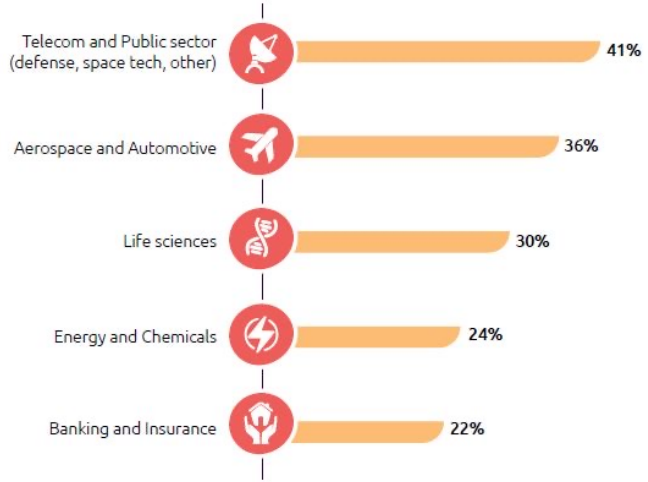
- **Administration**: dating, security: elections, document authentication, diplomatic communications



- **Operational science**: calculation, sensors: blind or distributed parallel computing, time transfer, positioning

- **Fundamental science**: sensors, distributed computing: astronomy, massive computing, interferometry, precise measurements

(% of organizations who are working or planning to work on the technology)



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THALES ALENIA SPACE – QUANTUM COMM PROJECTS

- ~10 projets en cours
- ~30 personnes (Toulouse+Cannes)
- Depuis 2020 :
  - 6 embauches (5 en CDI)
  - 9 étudiants formés
  - Effectif x10 !!!
- Aussi TAS Italie, Espagne, Suisse
- Groupe THALES: SIX, TRT

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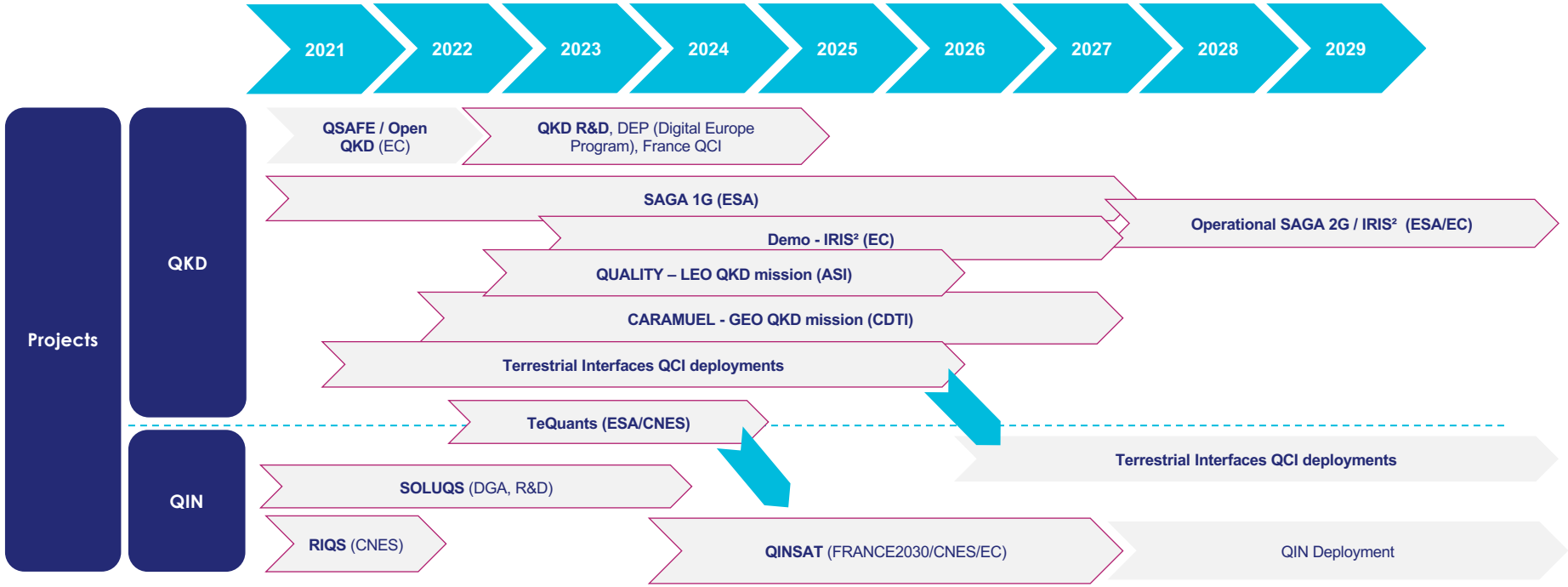
THALES ALENIA SPACE ROADMAP



Développement systèmes et sous systèmes (sources, détecteurs, télescopes, etc.)

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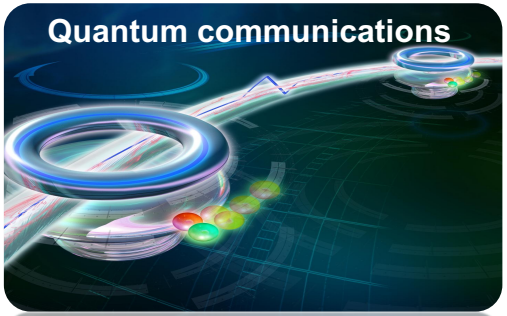
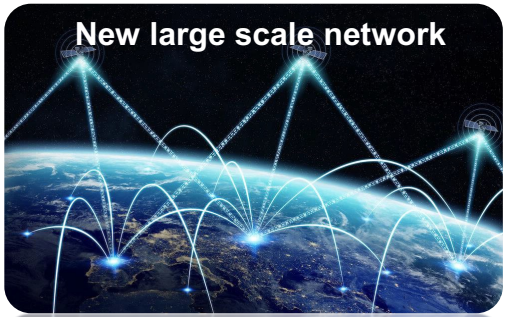
CONCLUSIONS

Quantum communication network under development



Satellite is ***mandatory*** for global connectivity



Industry needs Quantum Engineers

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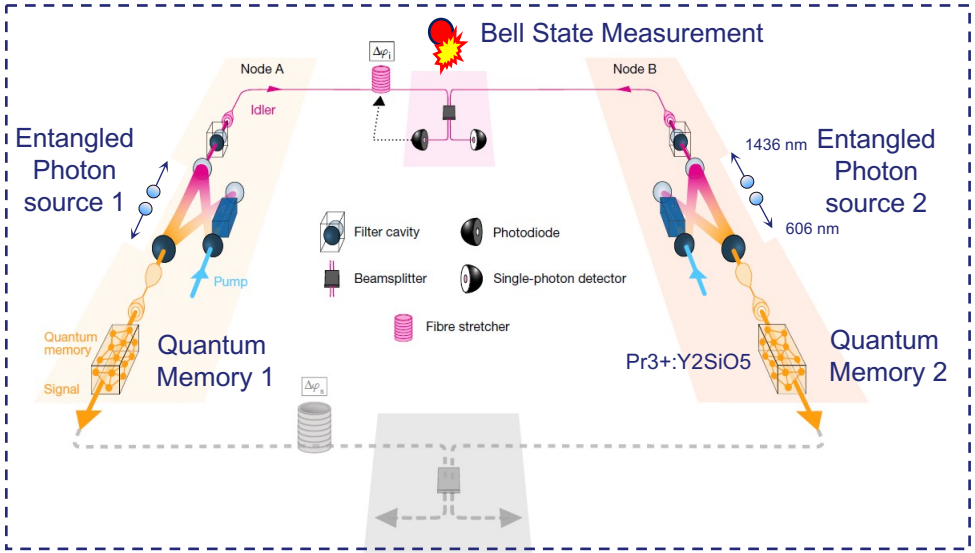
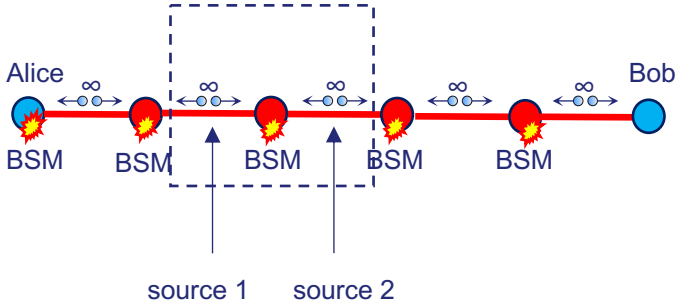
QUANTUM INTERNET BUILDING BLOCK IN A LAB



ICFO/ICREA Espagne, *Nature* **549**, 37 (2021)

Heralded quantum memory entanglement:

- 2 entangled photons sources
- 2 quantum memories (25 µs storage)
- 1 entangled telecom swapper (BSM)



Lago-Rivera, D., Grandi, S., Rakonjac, J.V. *et al.* Telecom-heralded entanglement between multimode solid-state quantum memories. *Nature* **594**, 37–40 (2021). https://doi.org/10.1038/s41586-021-03481-8

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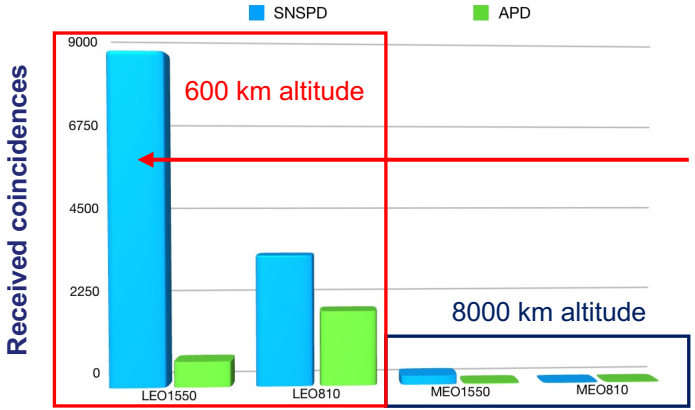
4. THE FUTURE OF SPACE-BASED QUANTUM COMMUNICATIONS

Thales Alenia Space Roadmap published in Nature Comm Phys 6, 12 (2023)

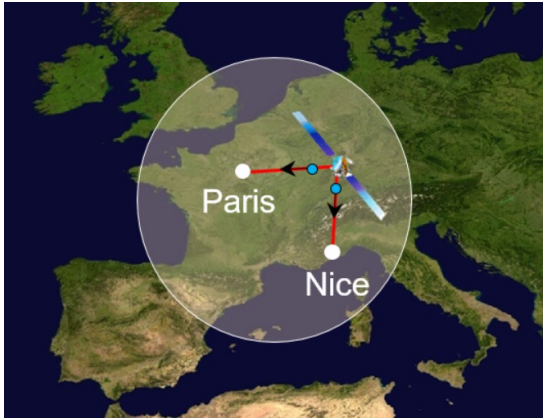
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
System	Feasibility		Design	development		Expe rimen tation	Feasibility	Design	Development		Expe rimen tation	Design	Development		Integration	Qualif ication	Maintenance
Payload equipment			Proto	Manuf	Integration		Expe rimen tation					Design	Development				
Ground equipement			Proto	Manuf				Feasibility	Design	Manuf		Design	Development				
Research & Techno	... Sources/protocols		Memories development				Higher performance					New protocols & use cases					
Stages	Resource stage						Network stage					Build stage					Service...

Prototype: 1 satellite & 2 ground stations in Nice & Paris



Our selection:

- Downlink configuration
- LEO orbit at 600 km
- Wavelength 1550 nm
- Detector SNSPD



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