OPTICA
Advancing Optics and Photonics Worldwide
Formerly OSA

Quantum Photonics Roadmap: Every photon counts

Tom Hausken, adapted by Christoph Harder
October 28, 2021

Other quantum roadmaps

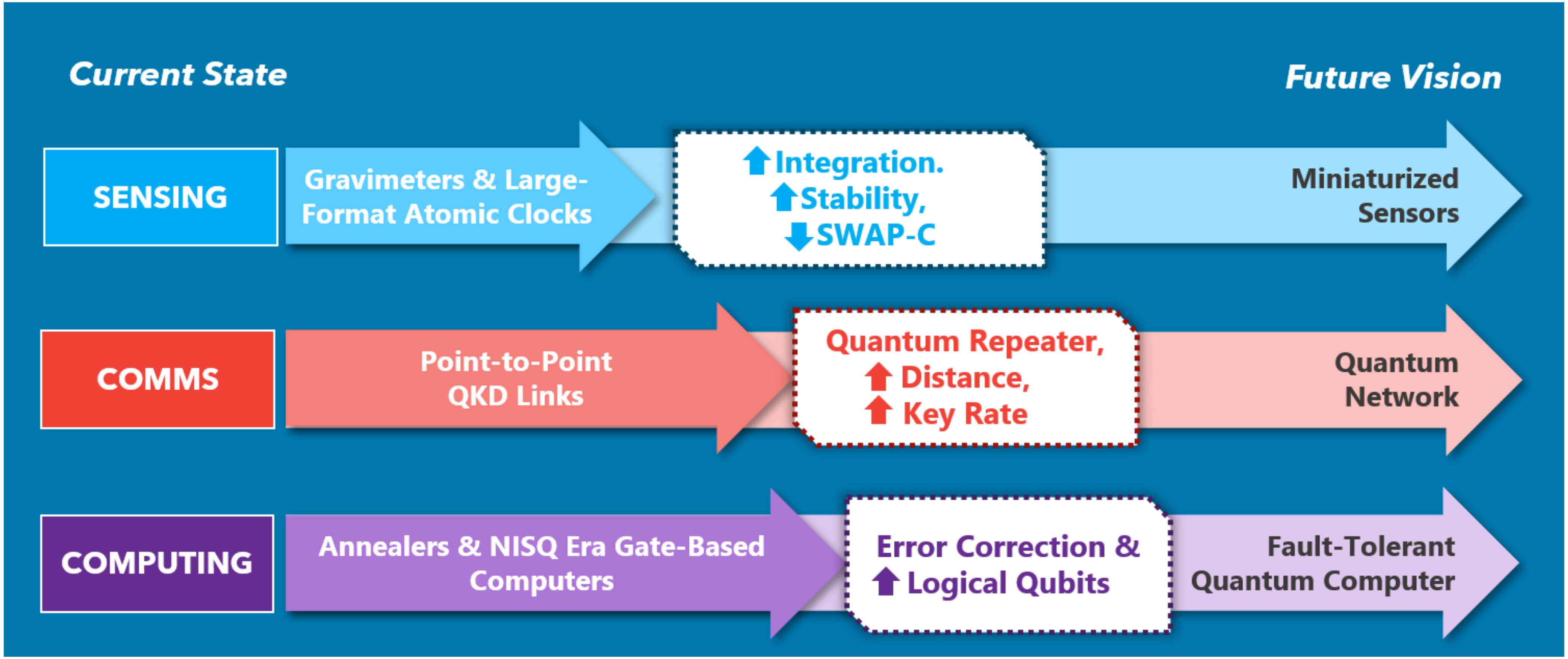
Created in collaboration with

CORNING

OPTICA

Milestones and metrics

-- Illustrative, Not Exhaustive --



Quantum applications

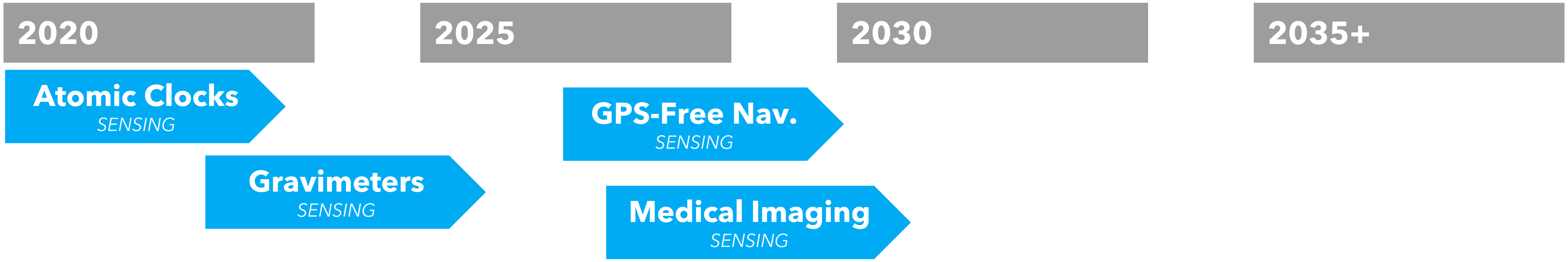
EXAMPLE APPLICATIONS FOR QUANTUM TECHNOLOGY

-- Not Exhaustive --

END MARKETS	SENSING & TIMING	COMMUNICATIONS	COMPUTING
Telecom	Clocks for synchronization	Cryptography	Network optimization
Medicine	Improved brain imaging	Protecting patient data long-term	Drug discovery
Oil & Gas	Through-ground imaging	Protecting critical infrastructure	Drilling location analysis; oil distribution logistics
Finance	Clocks for trade timestamping	Secure transactions	Portfolio management
Transportation	GPS-aided navigation; quantum LiDAR	Cryptography for connected vehicles	Battery material simulation; traffic optimization

Many quantum sensors are commercial or near-commercial

-- Illustrative, Not Exhaustive --



*Chevron placement represents anticipated start date of commercialization

Optical clock precision: Make excellent sensors

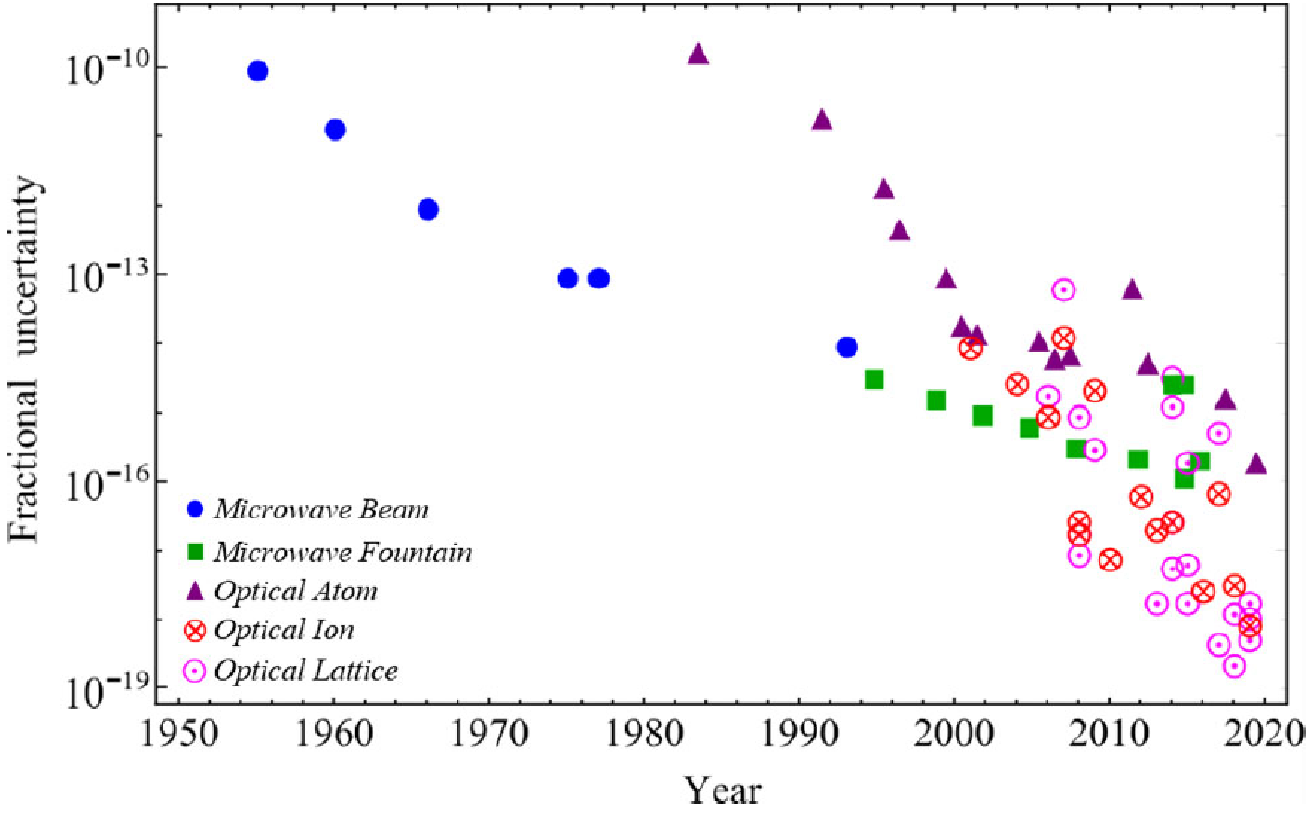


Fig. 1 Evolution of atomic clocks based on the improvement in fractional uncertainties in frequency

MĀPAN-Journal of Metrology Society of India (December 2020) 35(4):531–545
https://doi.org/10.1007/s12647-020-00397-y

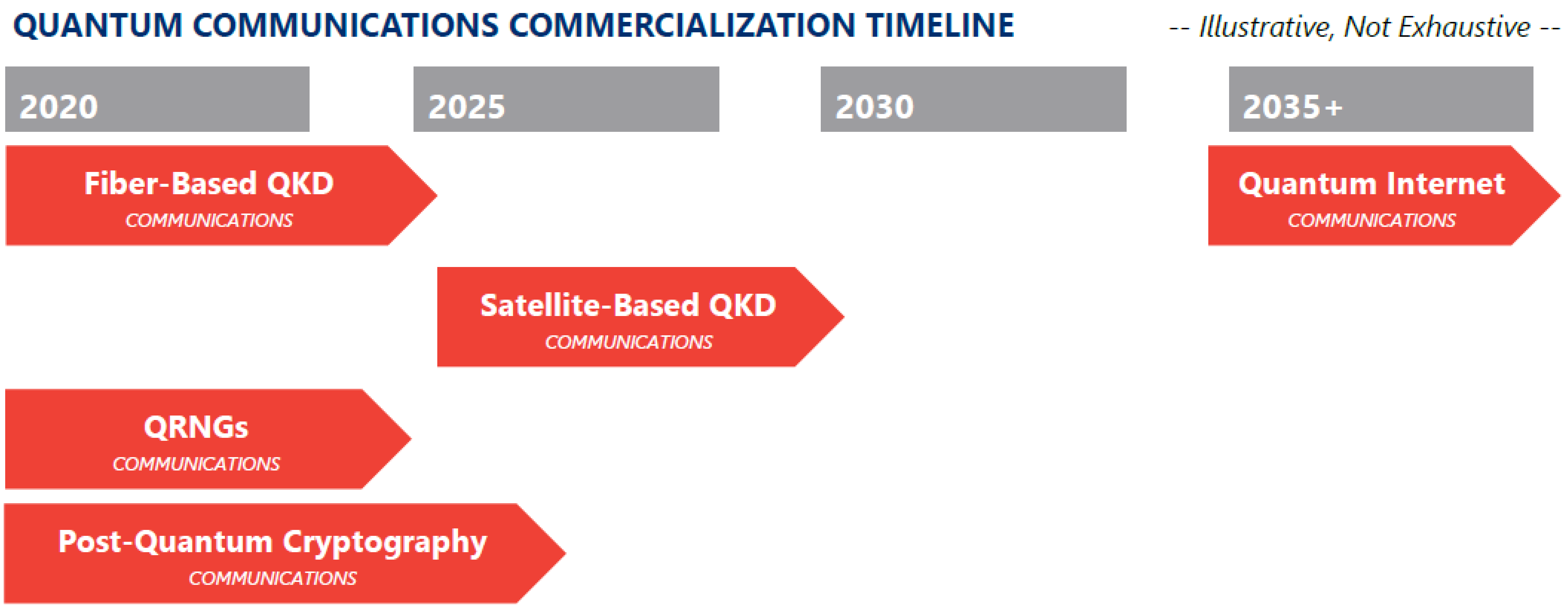
We control time:

PC: Clock cycle 3GHz (~10^-9)
- Light progagates 10cm in one clock cycle
- PC runs one clock cycle/second faster in space due to lack of gravitational slow down

Optical clocks
- Are 10 orders of magnitude more precise than PC clock cycle

Sensors
- Use «clocks» as sensors

Quantum key distribution is quasi-commercial



*Chevron placement represents anticipated start date of commercialization
Source: Expert interviews, Newry analysis

Quantum computing

Gate-based quantum computing approaches

	Superconducting	Spin	Topological	Ion Trap	Neutral Atom	Photonic
	Superpositions of currents flowing in opposite directions around a superconductor at the same time	Uses the spin state of electrons confined in quantum dots on silicon wafers	Maintain quantum states in large clouds of electrons rather than localized, individual electrons (Majorana particles)	Ions trapped in electric fields in vacuum chambers – uses lasers to manipulate quantum states	Atoms trapped in magnetic or optical fields in vacuum chambers – uses lasers to manipulate quantum states	Qubits encoded in the quantum states of photons traveling in waveguides / fiber
Example Players	IBM Rigetti Google Alibaba	Intel	Microsoft	IonQ Honeywell AQT	ColdQuanta Atom Computing	Psi Quantum Xanadu ORCA Computing

OPTICA

SUMMARY: OPTICS AND PHOTONICS COMPONENT REQUIREMENTS

Required   May Use

Category	Technology	Lasers	Single or Entangled Photon Sources	Single Photon Detectors	Heterodyne and Homodyne Photon Detectors	Fiber or Integrated Photonic Waveguides	Modulators	Transducers and Converters	Memories or Repeaters	Operating Wavelength
Sensing	Atomic Clocks							If networked		Non-Telecom
	Atom Interferometers							If networked		Non-Telecom
	NV Center Sensors							If networked		Non-Telecom
	Quantum LiDAR									Non-Telecom
Comms.	Continuous Variable QKD									Telecom
	Discrete Variable QKD									Telecom
	Entanglement-Based QKD									Telecom
Computing	Superconducting							If networked		--
	Ion Trap							If networked		Non-Telecom
	Neutral Atom							If networked		Non-Telecom
	Photonic - Discrete Variable							Memory-dependent		Telecom
	Photonic - Cont. Variable							Memory-dependent		Telecom
	NV Center							If networked		Non-Telecom
	Silicon Spin							If networked		--
	Topological							TBD	TBD	--

Source: Expert interviews, Newry analysis

OPTICA

Source: *OIDA Quantum Photonics Roadmap: Every Photon Counts* (2020)

Key Takeaways

- **Key end markets:**
  - Photonics is big part of quantum
  - Communications: Solutions available, waiting for commercial pick-up
  - Sensing/timing: Near term with big commercial impact expected
  - Computing: Most speculative (but huge market! (R&D money around))
- **What it means for photonics:**
  - Every photon counts (and noise, etc.)
  - Integrated photonics is a technology to watch
  - Photonics technology exists, but the engineering and ecosystem needs investment
  - The improvements can help classical applications too
  - Talent shortage in engineers, across disciplines
  - Diffent approaches in US/Europe and China
    - https://www.swissphotonics.net/libraries.files/Quantum_Photonics_Roadmap_2020_mo.pdf

Regional approaches

North America

Driven by commercial economy

The "Apple Economy": consumer products, 5G, autonomous vehicles, IoT, AI & cloud

Industry 4.0

Smart Cities

Quantum technologies

Europe post-Brexit

Europe and China

Top-down policy is prominent

Belt and Road Project

Made in China 2025

Quantum technologies

Thousand Talents Plan*

Source: OIDA (2020).

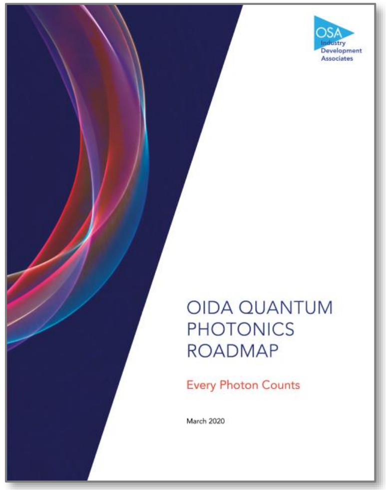
* Now named the "National High-end Foreign Experts Recruitment Program."

NAVIGATE THE FUTURE OF QUANTUM PHOTONICS

The New Optica Corporate Membership Quantum Photonics Roadmap

Download the report!
optica.org/industryreports (for corporate members)
optica.org/industryroadmap (for non-members)

Questions:
thausken@optica.org
industry@optica.org



Created in partnership with
CORNING