UCL

Quantum Photonic Integrated Circuits in Europe

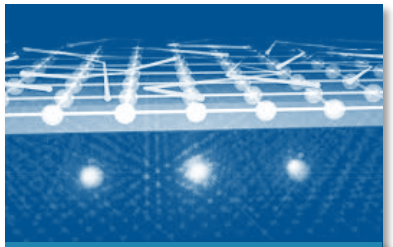
Prof. Michael Wale

Joint Symposium on Quantum Photonic Integrated Circuits, 2nd November 2021

The Second Quantum Revolution

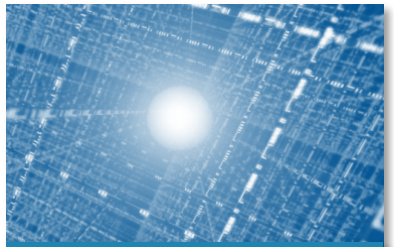
Quantum Imaging

Imaging around obstacles, ultra-high sensitivity



Quantum Sensing

Magnetometry, gravity anomaly detection, for surveying, medical diagnostics, environmental research, industrial controls



Quantum Computing

Computing power many orders of magnitude beyond present day computers, for drug design, cryptanalysis, logistics, …

Quantum Communication

Secure key distribution, secure communication over fibre networks, in buildings and in space

is built on photonics

Photonics is a key enabler for quantum systems, providing both core quantum functionality and the means by which quantum effects can be achieved, expressed, combined and utilized

PHOTONICS21

QUANTUM FLAGSHIP

The Challenge – and the Opportunity

From room-sized experiments

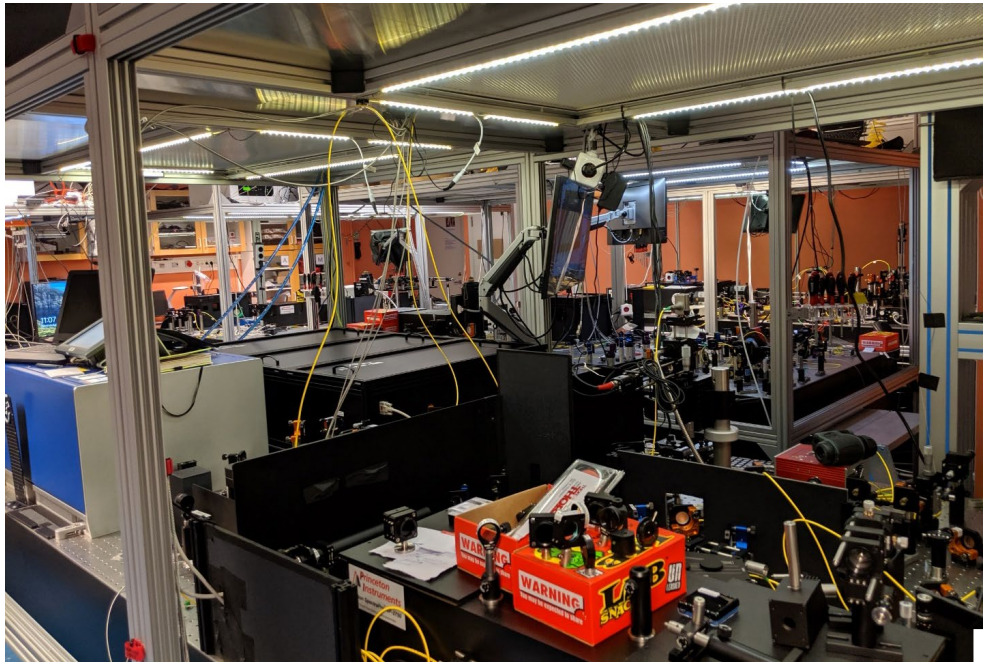
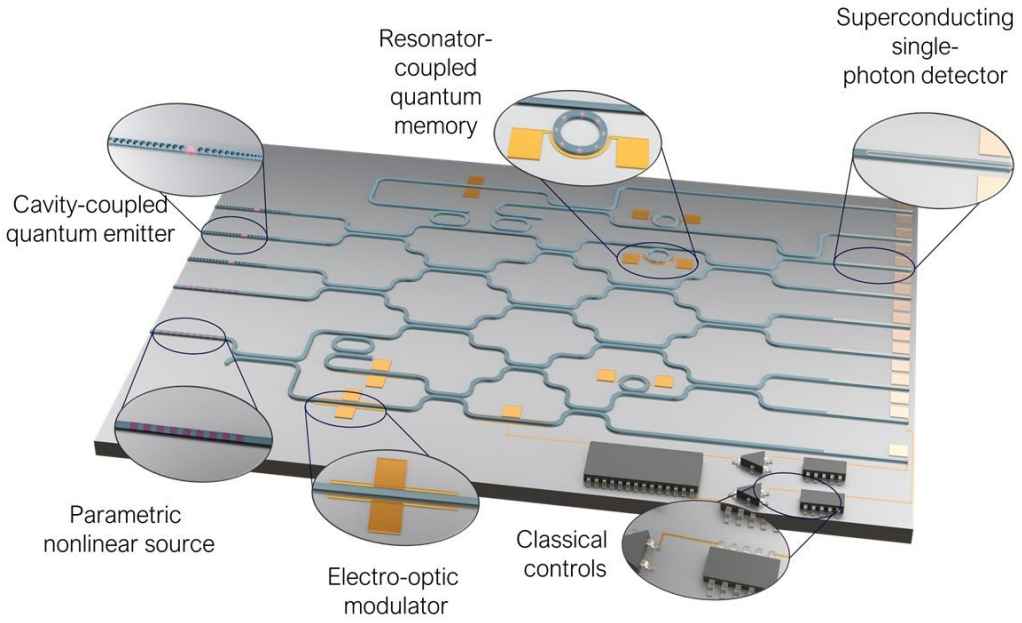


Photo: Katharina Zeuner, KTH Stockholm

To integrated circuits of a few mm^2



All functions in integrated form, merging classical and quantum, to form basis of practical Quantum Tech products

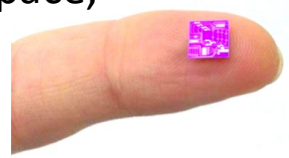
Figure: E. Pelucchi et al., accepted for publication in Nature Review Physics

QUANTUM FLAGSHIP

PHOTONICS21

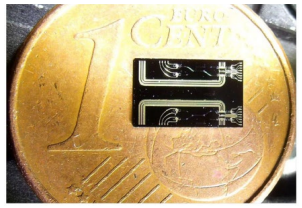
PIC technology is a European strength

- Major investment by industry and by EC over more than 3 decades
- 30 projects supported by Photonics Unit in Horizon 2020
- Pilot lines for InP PICs (JePPIX/InPulse), silicon nitride (PIX4LIFE), packaging (PIXAPP)
- Generic platforms established for major technologies (JePPIX for InP and silicon nitride, ePIXfab for silicon photonics and silicon nitride)
- World-leading expertise in technology development and exploitation in diverse domains (communications, aerospace, sensing, …)



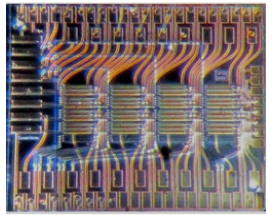
PHOTONICS21

A few examples fabricated on the JePPIX platform (InP)



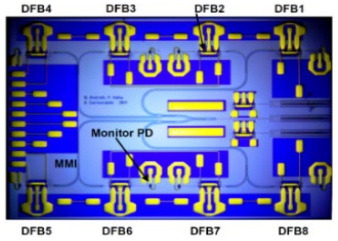
Quantum Random Number Generator

[Abellan et al.,OPTICA 3(9), 2016]



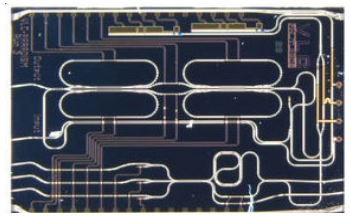
Optical Switch Matrix

[Stabile et al., ECIO, 2016]



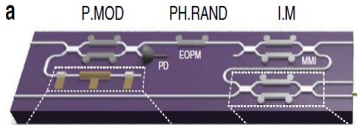
Multi-Wavelength Transmitter

[Andriolli et al., IEEE JSTQE 24(1), 2018]



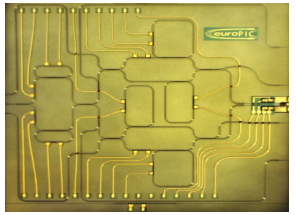
MWP Filter

[Fandiño et al., Nature Phot. 11(2), 2017]



Quantum Key Distribution

[Sibson et al., Nature Communications 8, 2017]



Optical Frequency Discriminator

[Fandiño et al., OE 21(3), 2013]

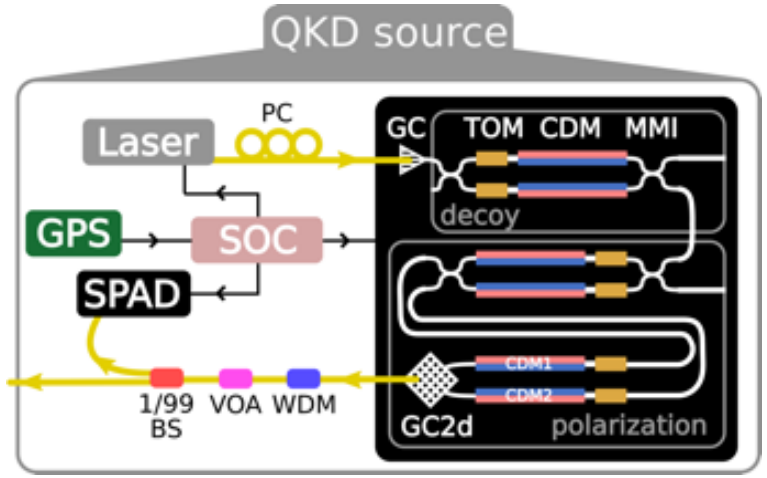
JePPIX
Joint European Platform for Photonic Integration of Components and Circuits

Quantum Photonic Integrated Circuits: some examples, things are moving fast

Full daylight quantum-key-distribution at 1550 nm enabled by integrated silicon photonics

M. Avesani, L. Calderaro, M. Schiavon, A. Stanco, C. Agnesi, A. Santamato, M. Zahidy, A. Scriminich, G. Foletto, G. Contestabile, M. Chiesa, D. Rotta, M. Artiglia, A. Montanaro, M. Romagnoli, V. Sorianello, F. Vedovato, G. Vallone, P. Villoresi

npj Quantum Inf **7,** 93 (2021)



Università di Padova, Scuola Superiore Sant'Anna, InPhoTec, Italy

c/o K. Jöns, University of Paderborn

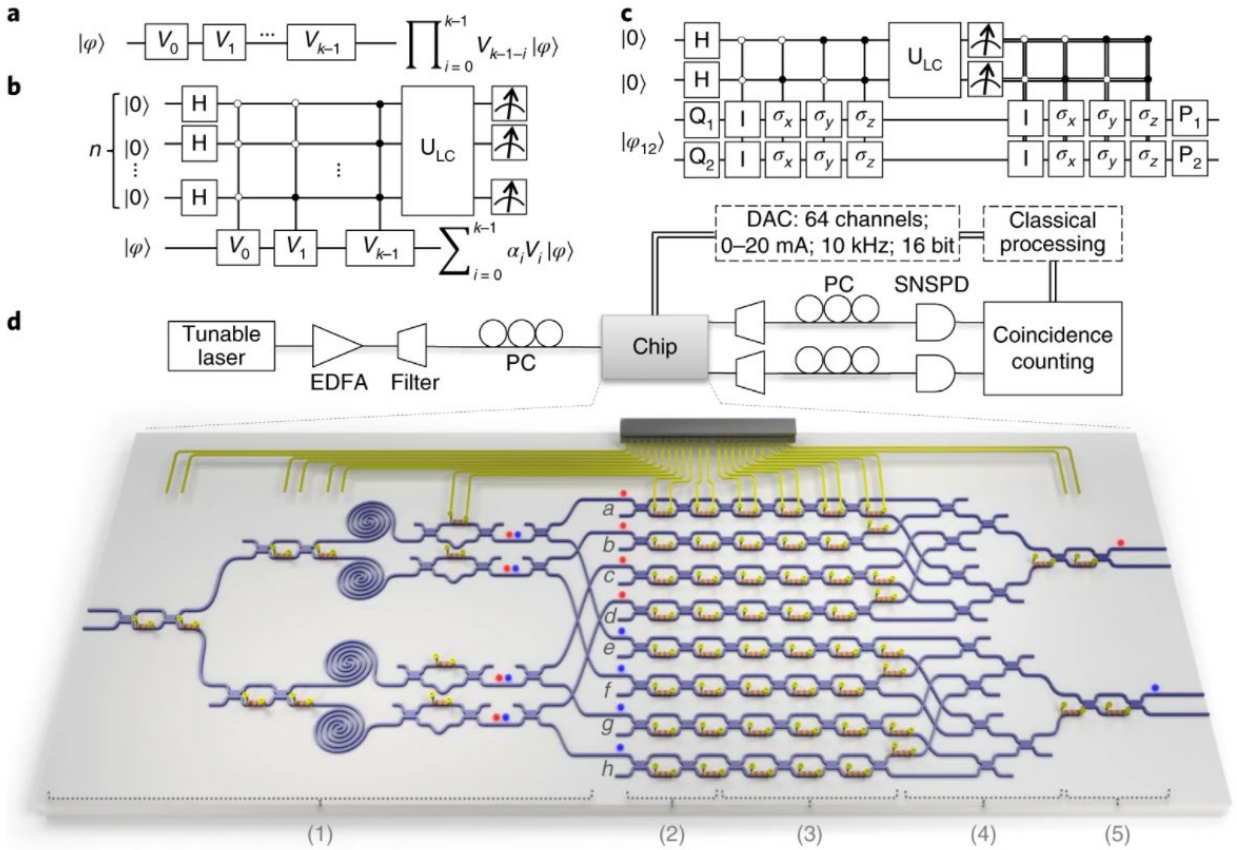
Quantum Photonic Integrated Circuits: some examples, things are moving fast

Large-scale silicon quantum photonics implementing arbitrary two-qubit processing

Xiaogang Qiang, Xiaoqi Zhou, Jianwei Wang, Callum M. Wilkes, Thomas Loke, Sean O'Gara, Laurent Kling, Graham D. Marshall, Raffaele Santagati, Timothy C. Ralph, Jingbo B. Wang, Jeremy L. O'Brien, Mark G. Thompson & Jonathan C. F. Matthews

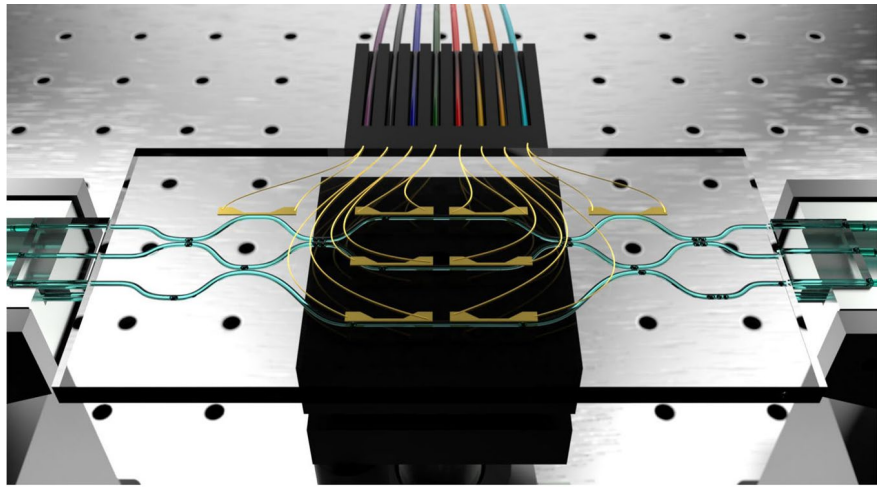
Nature Photonics **12**, 534–539(2018) | Cite this article

Team led by University of Bristol, UK



c/o K. Jöns, University of Paderborn

Quantum Photonic Integrated Circuits: some examples, things are moving fast

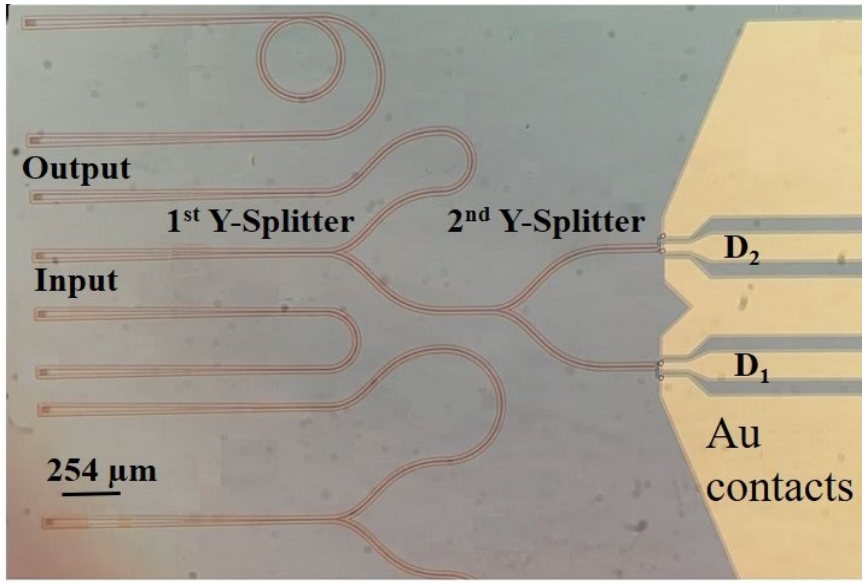


Experimental adaptive Bayesian estimation of multiple phases with limited data

Mauro Valeri, Emanuele Polino, Davide Poderini, Ilaria Gianani, Giacomo Corrielli, Andrea Crespi, Roberto Osellame, Nicolò Spagnolo & Fabio Sciarrino

npj Quantum Information **6**, Article number: 92 (2020) | Cite this article

Sapienza Università di Roma et al., Italy



Amplitude-multiplexed readout of single photon detectors based on superconducting nanowires

Alessandro Gaggero,[1,†,*] Francesco Martini,[1,2,†] Francesco Mattioli,[1] Fabio Chiarello,[1] Robert Cernansky,[2] Alberto Politi,[2] and Roberto Leoni[1]

[1]Istituto di Fotonica e Nanotecnologie—CNR, Via Cineto Romano 42, 00156 Roma, Italy
[2]Department of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, UK
*Corresponding author: alessandro.gaggero@ifn.cnr.it

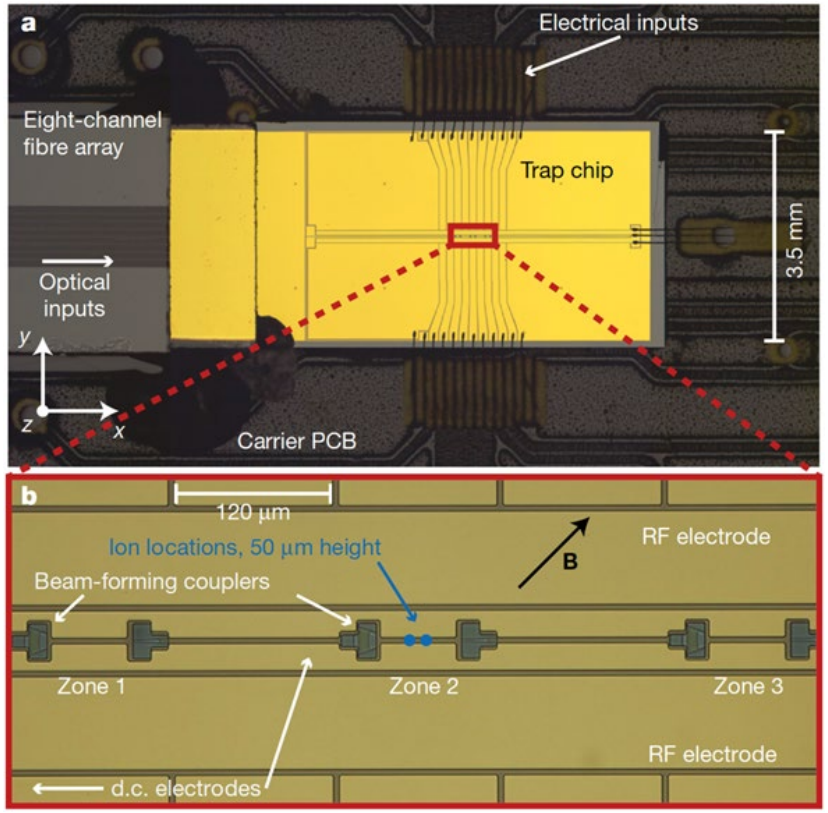
Received 21 December 2018; revised 14 May 2019; accepted 15 May 2019 (Doc. ID 356104); published 20 June 2019

CNR, Italy, and University of Southampton, UK

PHOTONICS21

QUANTUM FLAGSHIP

Quantum Photonic Integrated Circuits: some examples, things are moving fast



Optical micrograph of an assembled ion trap device with an eight-channel fibre array attached

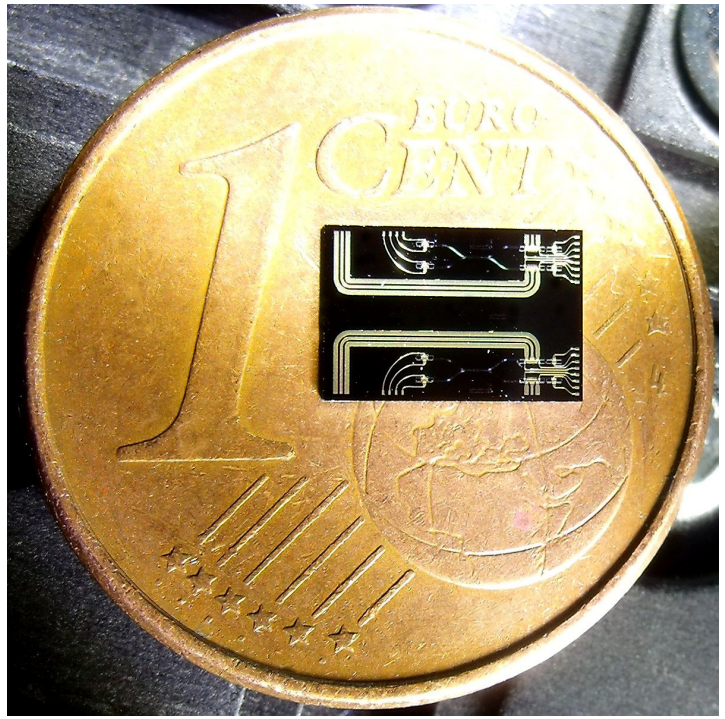
K.K. Mehta et al., Integrated optical multi-ion quantum logic, Nature (2020)
https://doi.org/10.1038/s41586-020-2823-6

ETH Zürich, Switzerland

PHOTONICS21

QUANTUM FLAGSHIP

Quantum random number generator



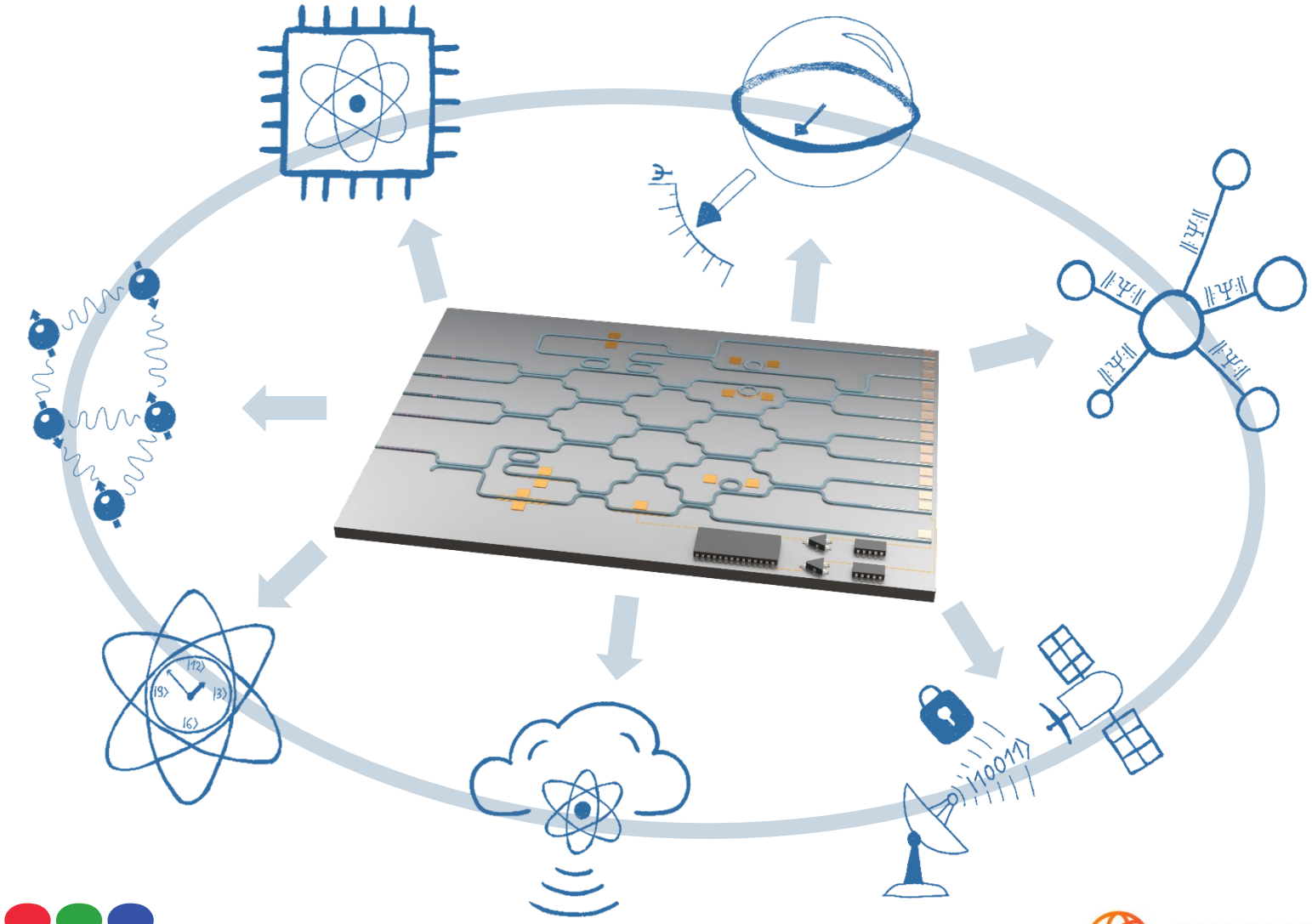
- Quantum entropy source
- InP chip fabricated at Fraunhofer HHI
- Two-DFB lasers interference
- Heterodyne detection

VLC PHOTONICS

Fraunhofer Heinrich Hertz Institute

C. Abellan et al. (ICFO, Barcelona), Optica, vol. 3, p. 989 (2016)

Quantum Photonic Integrated Circuits



E. Pelucchi et al., accepted for Nature Review Physics, 2021

Some key challenges for QPICs:

Performance

Ultra-low loss, ultra-low laser linewidth, ultra-high extinction ratio, very high sensitivity, high device count/complexity

Functionality

Single photon sources, entangled pair generation

Environment

Cryogenic temperatures

Multi-technology integration

Atomic/ion traps, superconducting devices, MEMS, electronics, fibre interconnects, packaging

Quantum PICS Focus Group:
Experts from Photonics and Quantum communities join forces

PHOTONICS 21

QUANTUM FLAGSHIP

TU/e Technische Universiteit Eindhoven University of Technology
Where innovation starts

CNR IFN Istituto di Fotonica e Nanotecnologie

UPMC SORBONNE UNIVERSITÉS

ICFO

POLITECNICO MILANO 1863

UNIVERSITÄT PADERBORN

MAX PLANCK INSTITUTE FOR THE SCIENCE OF LIGHT

cea

FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE

Fraunhofer HHI

Tyndall National Institute
Institiúid Náisiúnta

cnit consorzio nazionale interuniversitario per le telecomunicazioni

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

UNIVERSITÀ DEGLI STUDI DI PADOVA

PHOTONICS 21

Anchored In

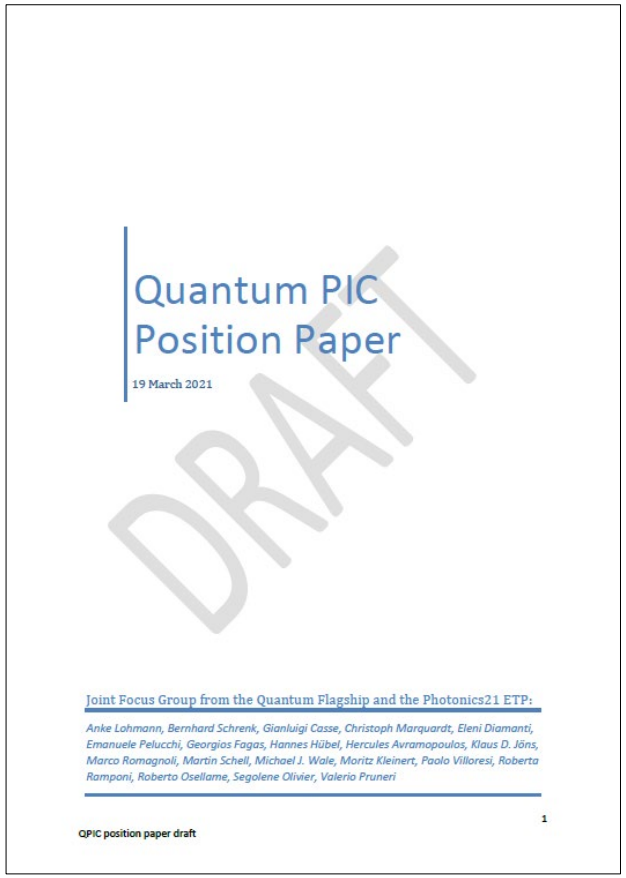
QUANTUM FLAGSHIP

Objectives

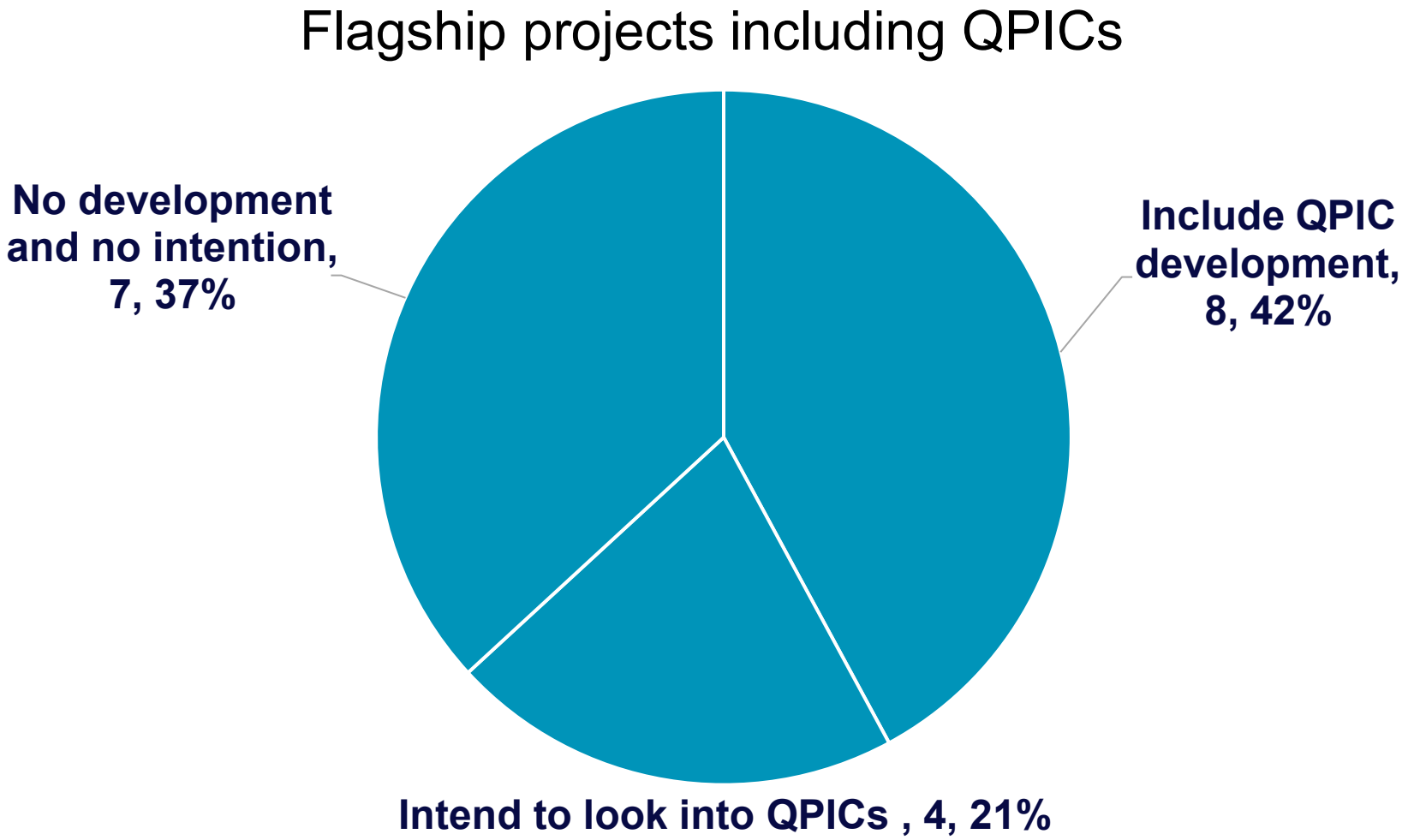
- Make QPICs a European priority as a disruptive enabling quantum platform
- Strongly support the development of materials, devices and components associated with quantum photonic integration with tailored programmes
- Promote infrastructure for monolithic, hybrid, heterogeneous, and composite integration challenges of QPICs
- Invest in a significant education effort to train next-generation quantum photonic engineers

Collaboration on Quantum Photonic Integrated Circuits

- Joint focus group of Photonics21 and Quantum Flagship formed in June 2020
- Initiative of Photonics21 and Quantum Flagship to coordinate activities in Quantum PICs and maximise collaborative efforts in this important field
- Numerous working meetings
- Position paper drafted, containing technical survey, analysis and recommendations
- Successful workshop held on 1st March 2021, with 285 attendees from 30 countries
- Second workshop held online, 6th October 2021
- 3rd workshop will be held at European Quantum Technology Conference (EQTC), 1st December 2021
- Programme recommendations will be approved by Photonics21 and Quantum Flagship Boards



QPIC Landscape in Quantum Flagship



Next steps

- Final version of position paper will be available shortly
  - Currently in final editing following feedback from community
  - Requirements, analysis, recommendations (~23 pages)
- Workshop at European Quantum Technology Conference, https://www.eqtc.org/ (Workshop 3.1, online, 1 December 2021), https://www.photonics21.org/events-workshops/2021/11/2021-11_QPICS-workshop.php
  - Maximizing dialogue with PIC community
- Discussions on formal collaboration and joint programmes
- Provide input to Horizon Europe WP 2023/4 by end of 2021

Thank you

With special thanks to Focus Group co-chairs Roberta Ramponi, Eleni Diamanti and Klaus Jöns, all members of the Focus Group and members of the wider community who are helping to build QPIC capabilities in Europe

M.Wale@ucl.ac.uk

M.J.Wale@tue.nl

qpicworkshop@photonics21.org

PHOTONICS 21

QUANTUM FLAGSHIP