A World Leading SFI Research Centre

Science Foundation Ireland sfi For what's next

IPIC

BRINGING PHOTONICS TO LIFE

IPIC for EQUITY Workshop

Prof. Paul Townsend, Director

HOST INSTITUTION

Tyndall National Institute Institiúid Náisiúnta

PARTNER INSTITUTIONS

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

DCU

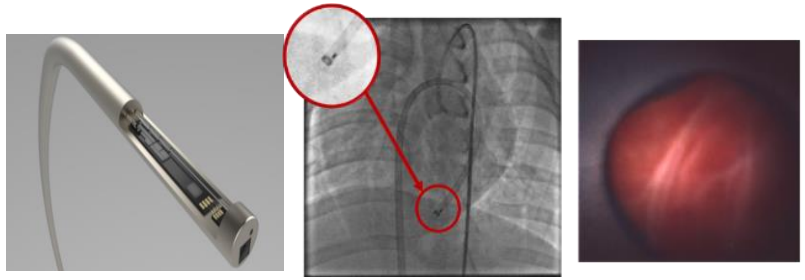
NUI Galway OÉ Gaillimh

Trinity College Dublin The University of Dublin

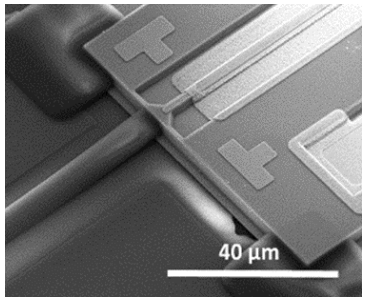
UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh

Integrated Photonics

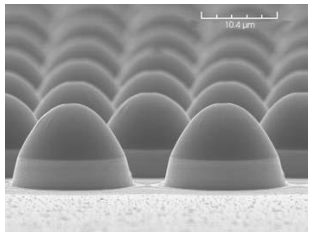
A €600 Billion industry helping to address major global challenges



IPIC: Diagnostic imaging and sensing systems for in-body surgical and wearable applications



IPIC Core technology: semiconductor photonic & electronic integrated circuits



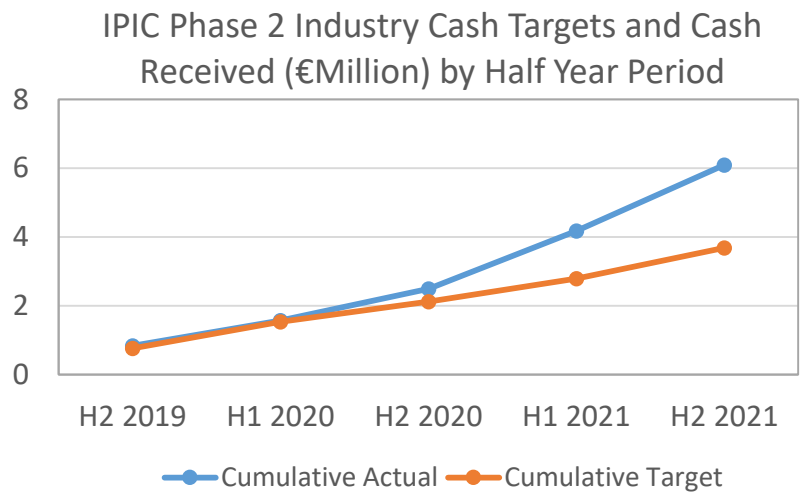
IPIC: MicroLEDs for AR/VR Micro-displays; next-generation optical communications

IPIC: Optical fibre sensing technologies to locate faults in offshore wind farm power cables and monitor environmental noise pollution

IPIC

Strong Track Record of Delivery to Industry

- 61 projects
- 33 Industry Partners
- From 13 countries
- 47% are SMEs or Start-Ups
- 25 Licenses
- Cash income €2.4M ahead of target

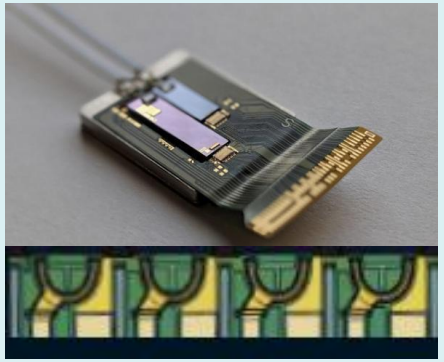


High speed optical interconnects for datacentres

KTI Knowledge Transfer Ireland Where Research & Business Connect

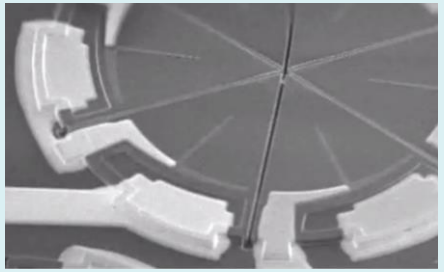
Impact Award 2021

Rockley PHOTONICS



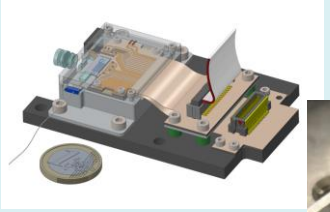
Photovoltaic cells for optically-powered in-body neuro-stimulators

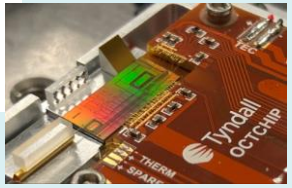
Synergia Medical



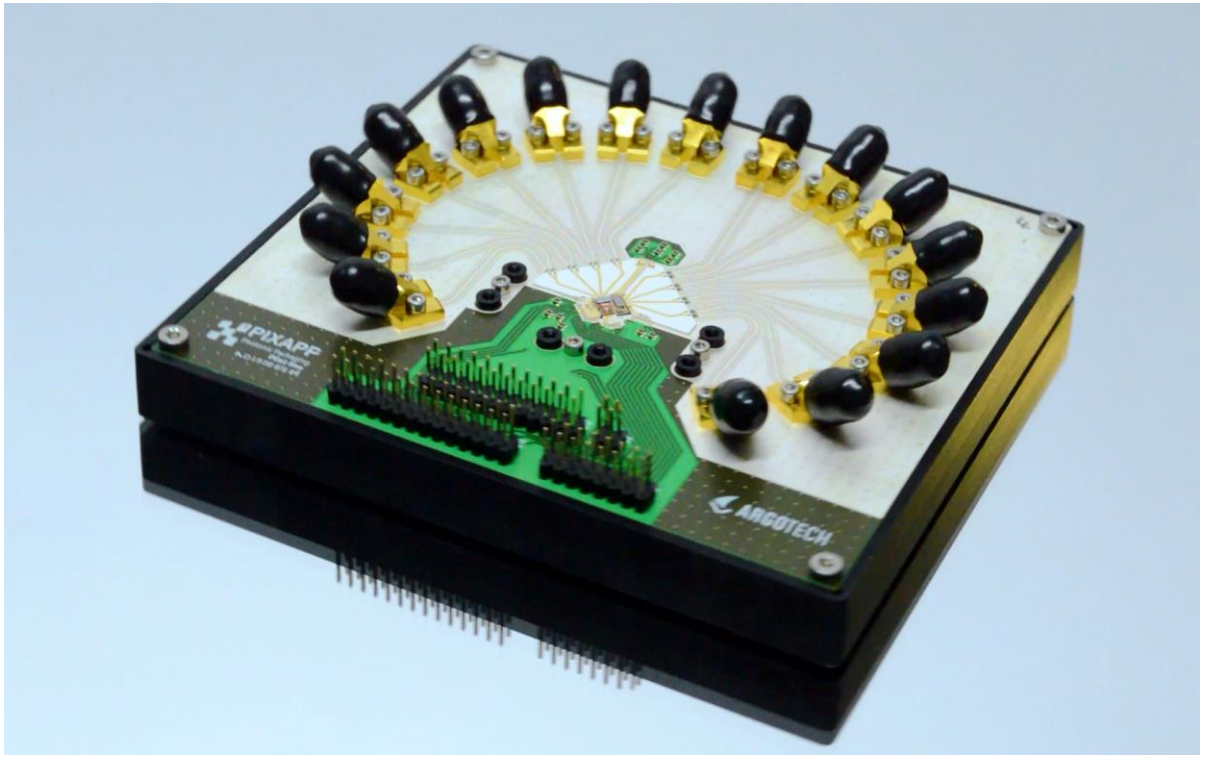
Optical Coherence Tomography System for retinal imaging

ZEISS

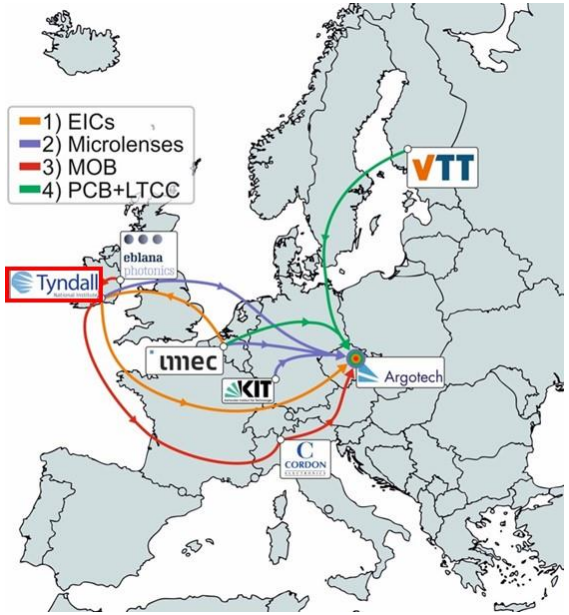


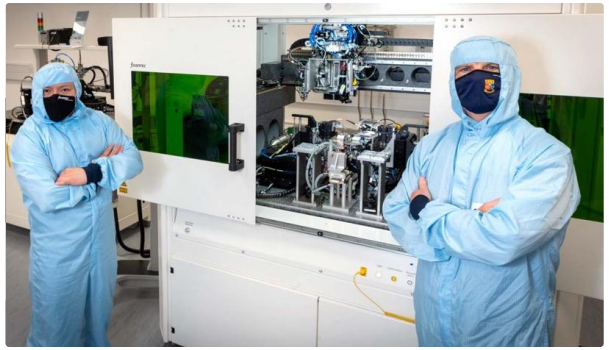


From Lab to Fab: Pilot Line Capability



PIXAPP
Photonic Packaging
Pilot Line





ficonTEC

XCeleprint

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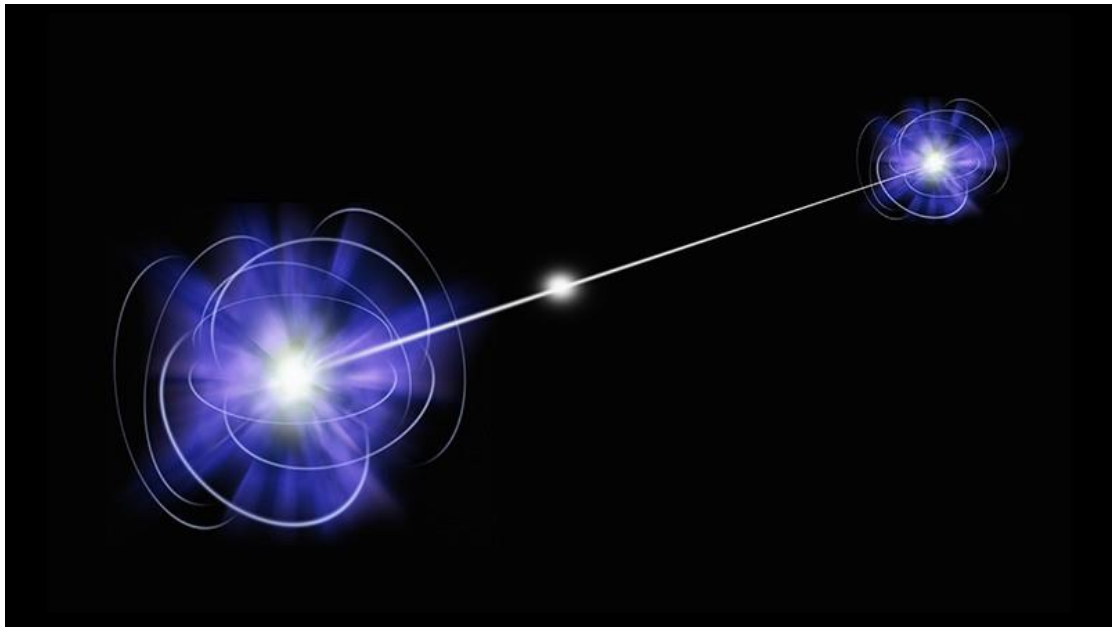
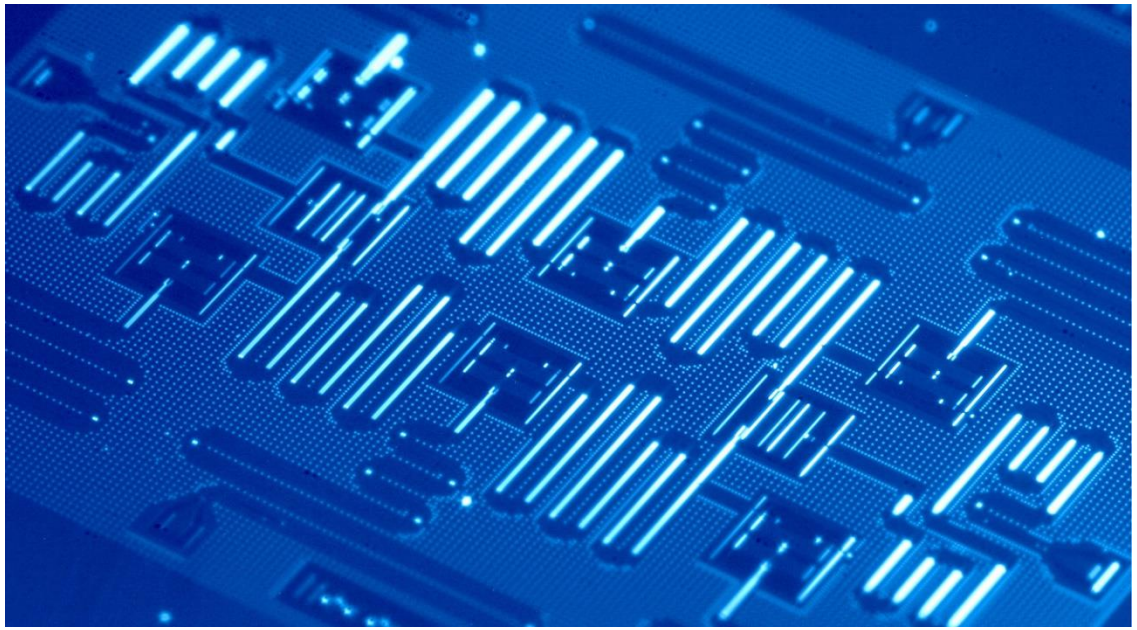
Core Research Themes

New in 2022: Quantum and Nanophotonics Catalyst Themes

- 200 researchers and support staff, including 60 PhD students

Quantum Catalyst Theme: Opportunity





Idea: exploit quantum entanglement as a new resource for computation and communication

Small-scale quantum computers realised, major companies e.g. IBM, Google, Microsoft investing, exciting new start-ups appearing e.g. PsiQuantum

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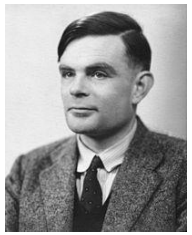
Quantum Information – Early Years

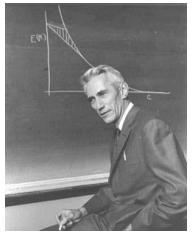
- Developed in early 1990s with goal of marrying the ideas of Turing & Shannon with quantum physics
- First steps towards practicality exploiting optical fibre technology

Digital Computation



Alan Turing

Digital Communication Theory



Claude Shannon

Optical Fibre Technology

Charles Kao

Rank Prize Fund Symposium on Quantum Communications and Computing, Broadway, Oxfordshire, UK (1993)

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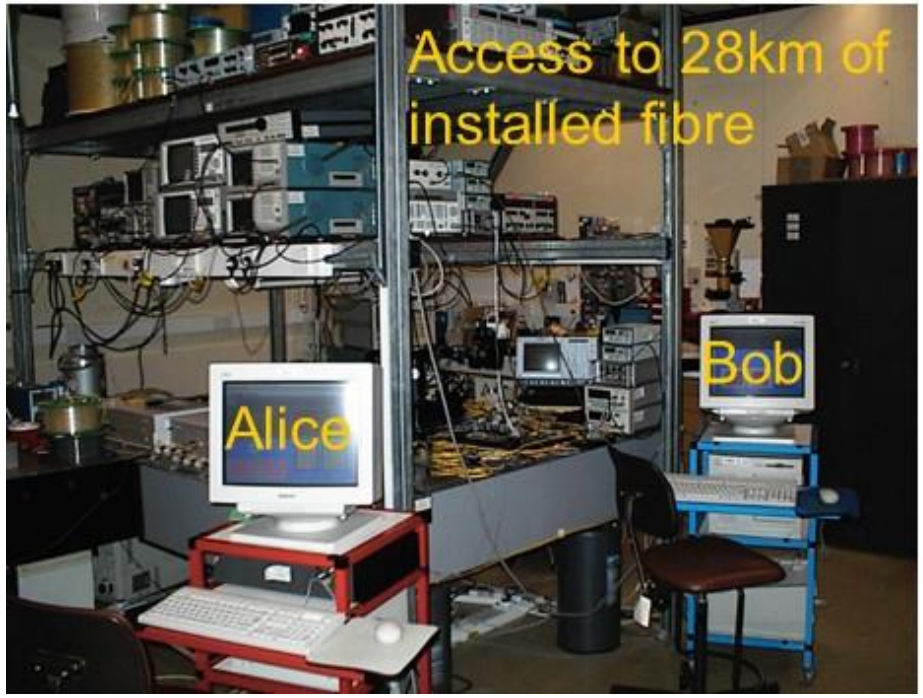
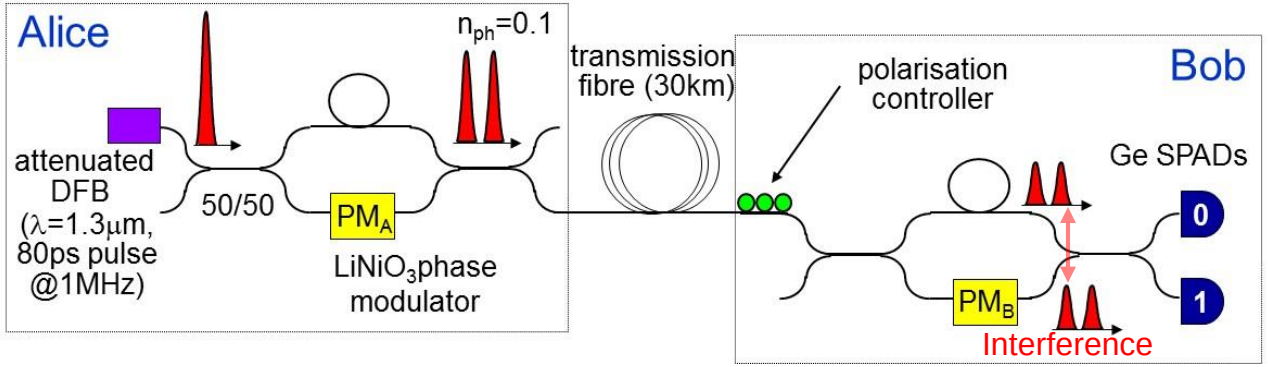
First Demonstrations of Secure Quantum Key Distribution (QKD) over Installed Optical Fibre





Research (1990s) – Phase Modulation-Based QKD

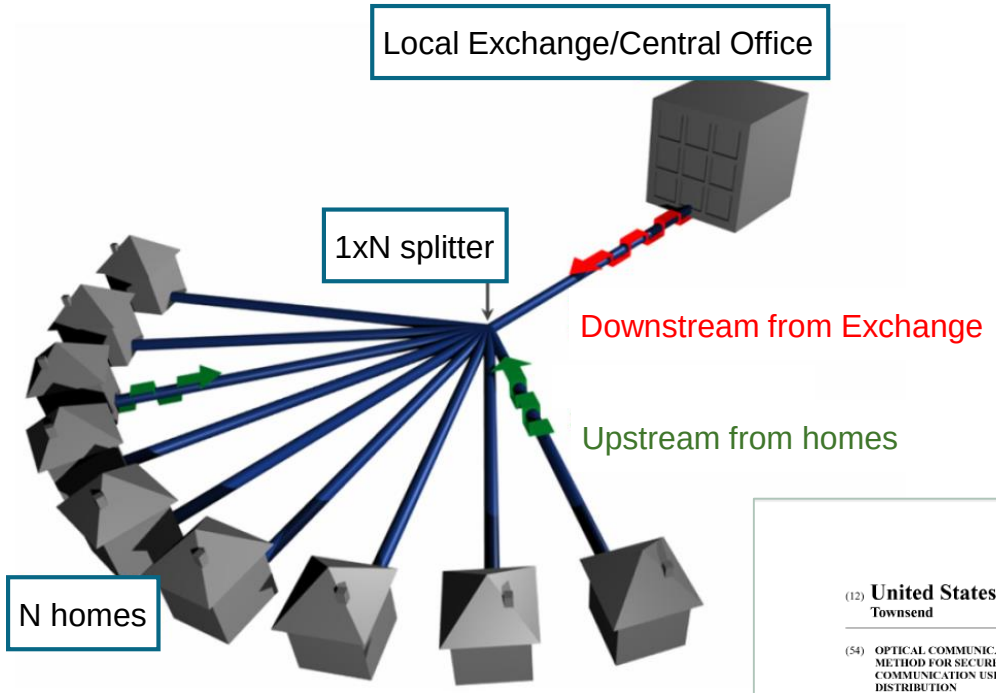
Products (2020s)

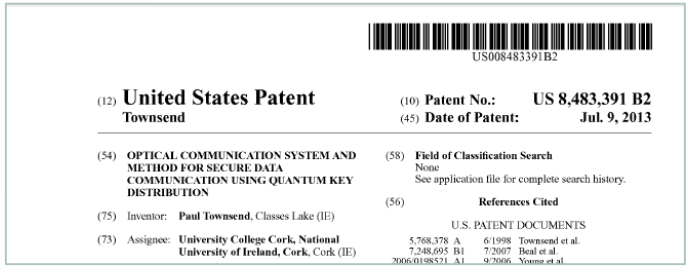
"Single photon interference in 10 km long optical fibre interferometer", P.D. Townsend, J.G. Rarity, P.R. Tapster - *Electronics Letters,* 29 (1993)

"Secure key distribution system based on quantum cryptography", P. D. Townsend, - *Electronics Letters,* 30 (1994)

"Quantum key distribution over distances as long as 30 km", C. Marand and P.D. Townsend - *Optics Letters*, 20 (1995)

First Proposal and Demonstration of QKD over Networks





US008483391B2

(12) **United States Patent**
Townsend

(10) **Patent No.: US 8,483,391 B2**
(45) **Date of Patent: Jul. 9, 2013**

(54) **OPTICAL COMMUNICATION SYSTEM AND METHOD FOR SECURE DATA COMMUNICATION USING QUANTUM KEY DISTRIBUTION**

(75) Inventor: **Paul Townsend**, Classes Lake (IE)

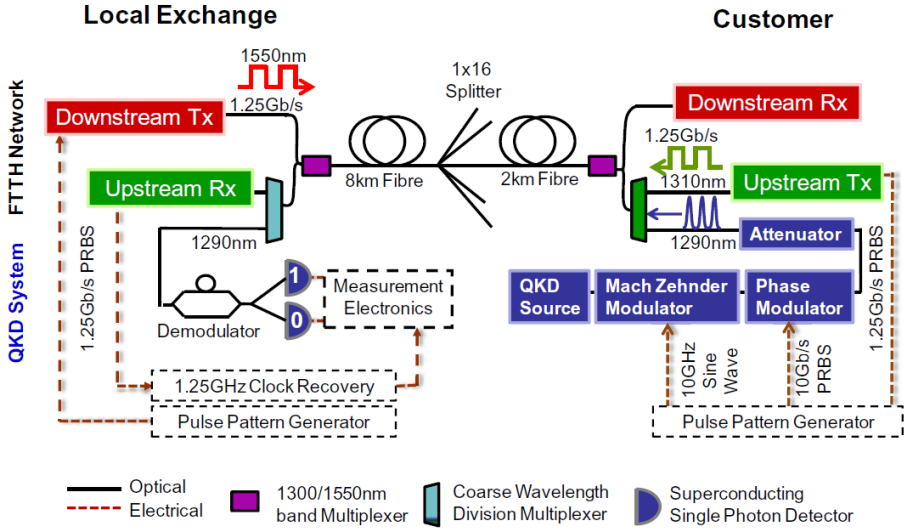
(73) Assignee: **University College Cork, National University of Ireland, Cork**, Cork (IE)

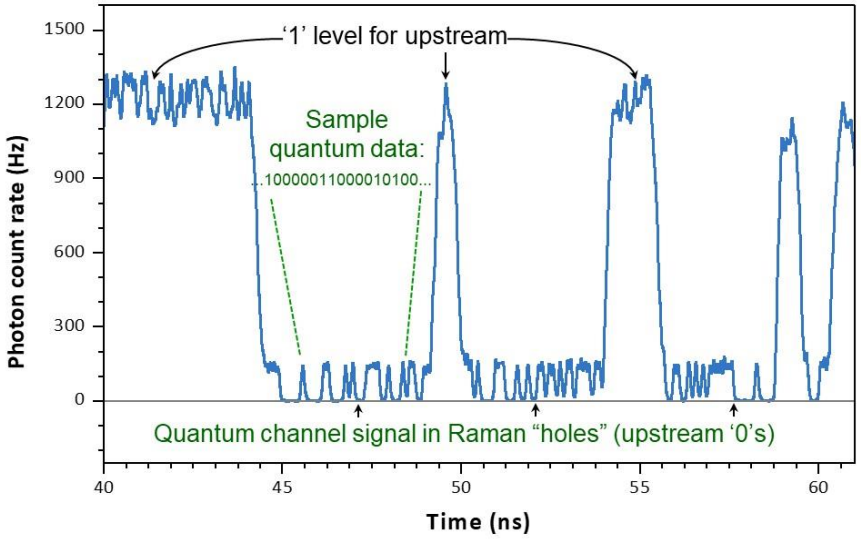
(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,768,378 A 6/1998 Townsend et al.
7,248,695 B1 7/2007 Beal et al.
2006/0198521 A1 9/2006 Young et al.





Core concepts

- 1xN splitter acts as random router for single photons
- Minimise Raman cross-talk from classical channels

"Quantum cryptography on Multi-User Networks", P. D. Townsend, *Nature* 385 (1997)

"Quantum Information to the Home", I. Choi, R. Young and P. D. Townsend, *New Journal of Physics* 13 (2011)

Global Race to Develop Quantum Secure Infrastructure

China

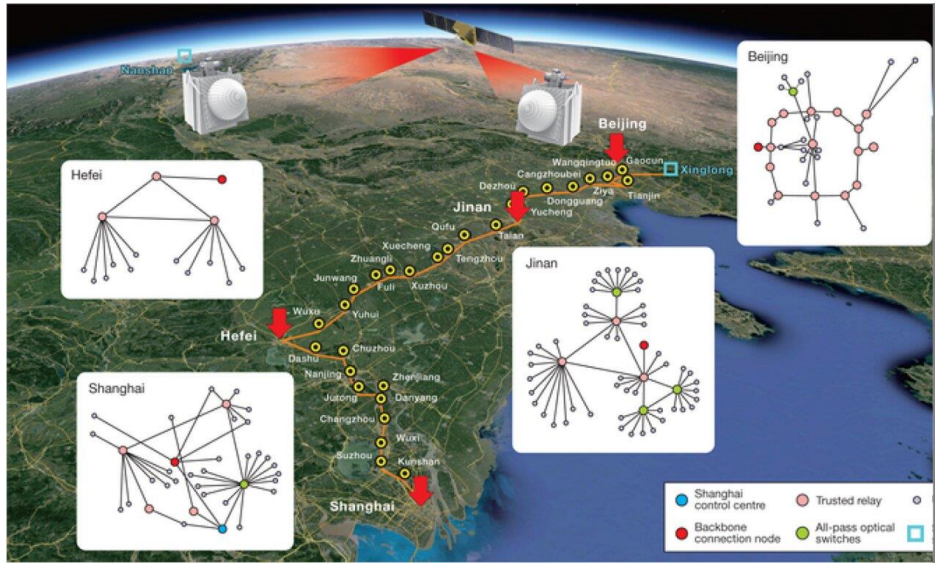
HOME | TECHNOLOGY NEWS

China Builds the World's First Integrated Quantum Communication Network

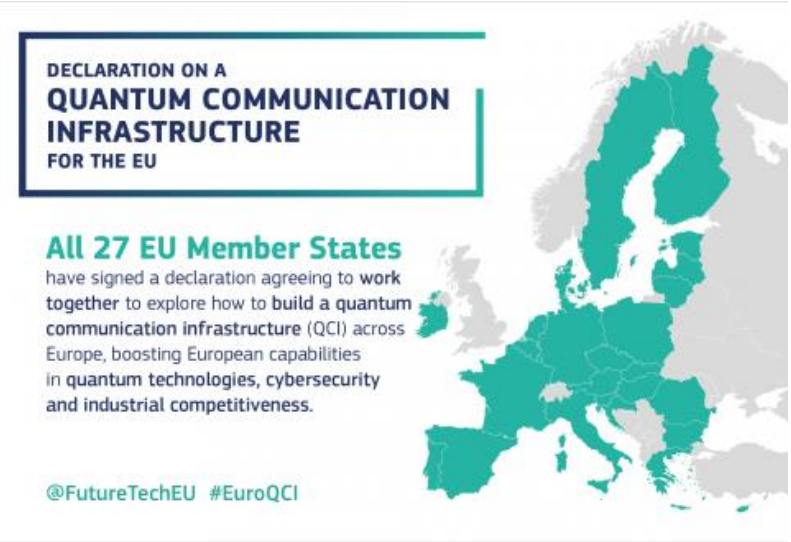
TOPICS: Popular Quantum Information Science Telecommunications

University Of Science And Technology Of China

By UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA JANUARY 6, 2021



EU



UK

Schematic representation of the UKQN/UKQNtel

05 OCTOBER 2021

BT and Toshiba to build world's first commercial quantum-secured metro network across London

Search...

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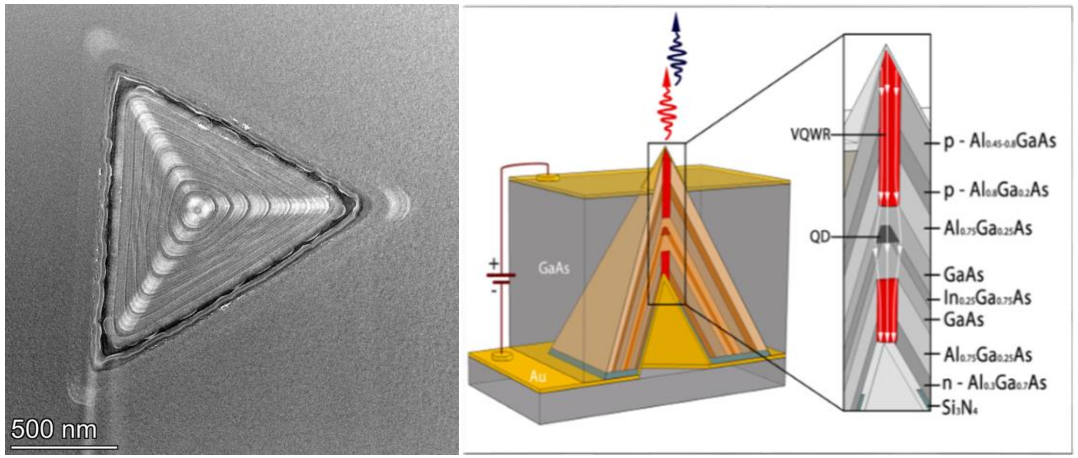
https://www.bt.com/media-enquiries

Address

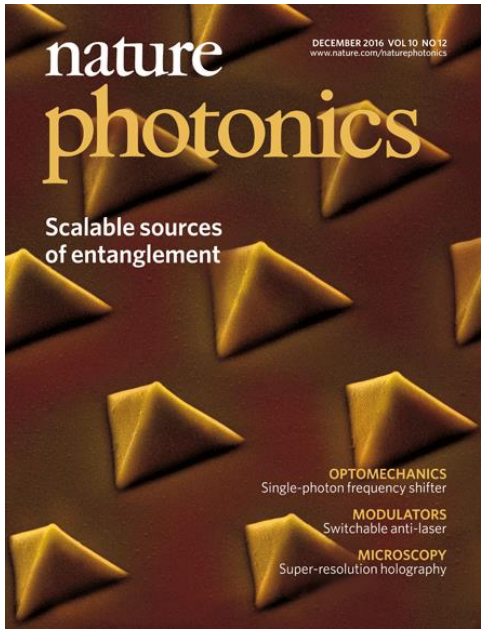
1 Braham Street
London E1 8EE

Entangled Photon Sources based on Pyramidal Quantum Dots

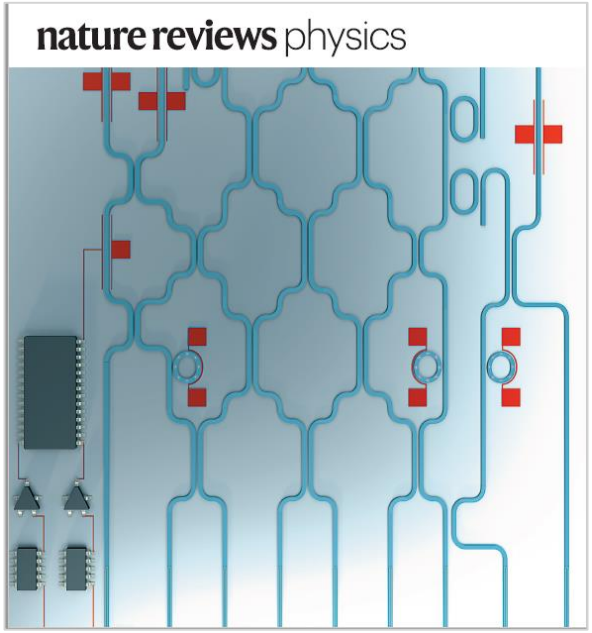
(TEM image, thanks to M. Arredondo QUB)



Site-Controlled Pyramidal Quantum Dots (PQDs)



T. H. Chung, et al. *Nature Photonics* 10 (2016): 782



E. Pelucchi et al., *Nature Reviews Physics* 4 (2022)

- World-leading work by Emanuele Pelucchi Group
- Unique self-assembly process enables QD “molecules” and – potentially – cluster states
- Next technological challenge: quantum photonic integration

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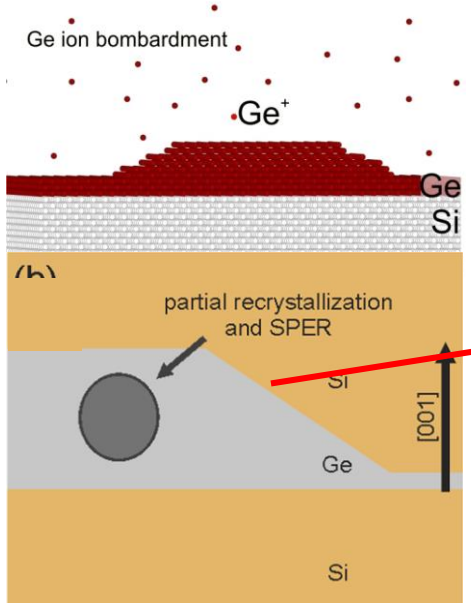
CMOS Compatible Quantum Dots

http://www.cuspidor-quantera.eu/

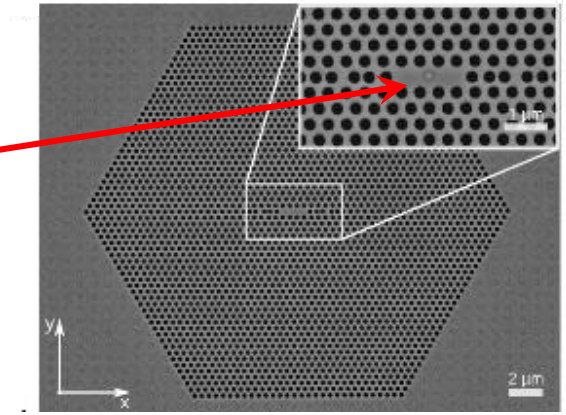
Germanium implant to create defects in the lattice to better confine the electron

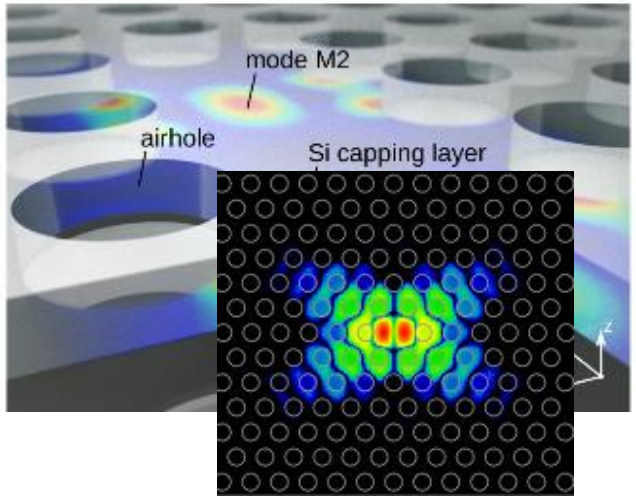
- Bandstructure Modelling (Phillip Murphy)
- Photonic Crystal to enhance light emission and p-n junction for electrical driving - design and fabrication (Liam O'Faolain)

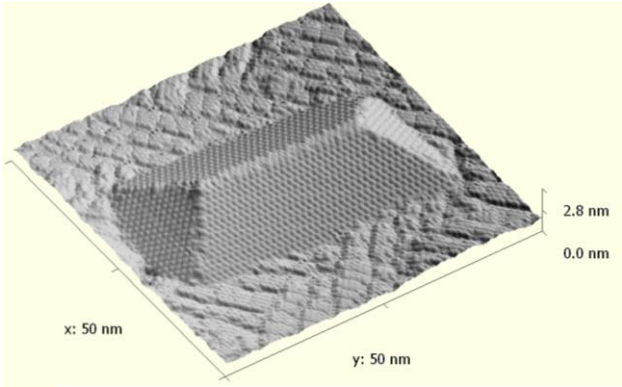
Defect engineering
Improve oscillator strength



Combination with photonic crystal
Enhance emission







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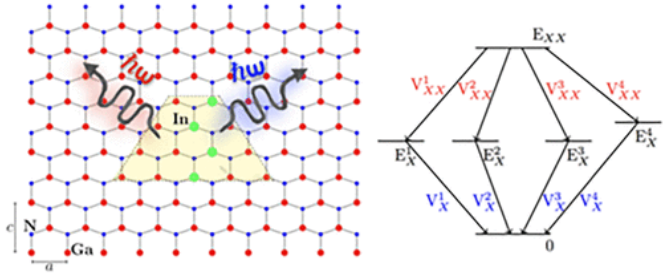
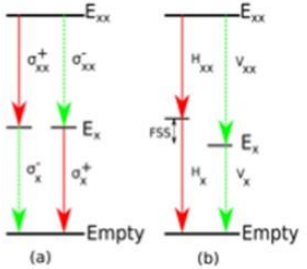
Theoretical Framework applied to Quantum Photonic Devices

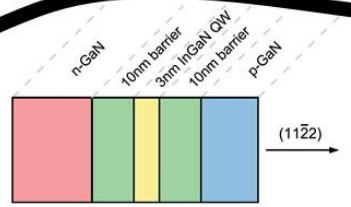
- Group of Eoin O'Reilly and Stefan Schultz
- Models of electronic & optical properties of site-controlled dots
- First theoretical atomistic analysis of novel twin- & entangled photon emission from (In,Ga)N dots



Many-body theory for quantum light emitters (entangled photon emission)



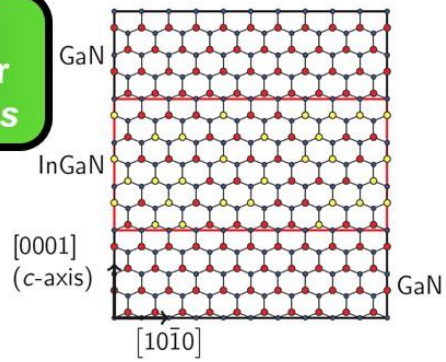
$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|\sigma^+_X X \sigma^-_X\rangle + |\sigma^-_X X \sigma^+_X\rangle\right)$$



Continuum-based models for *nanostructures & devices*
(macroscopic structures)

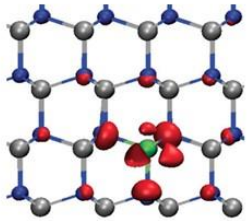
(hundred thousands of atoms up to few millions of atoms)

Empirical atomistic models for *alloys, nanostructures*



Empirical atomistic models for *bulk compounds*

First principles DFT for bulk compounds
(few hundred atoms)



Only very few groups in the world have these multi-scale simulation capabilities

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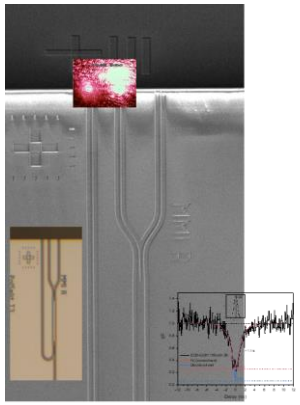
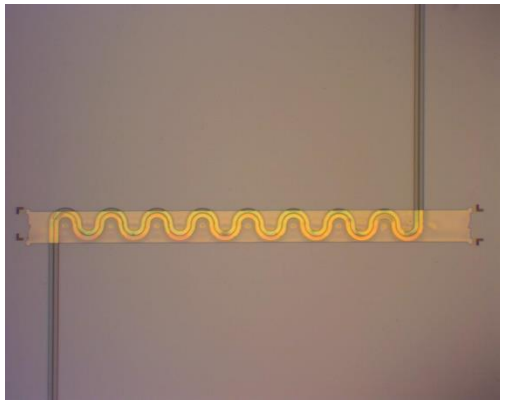
J. Phys.: Condens. Matter 26, 035303 (2014); Phys. Rev. B 94, 125308 (2016); Nano Lett. 20, 234 (2020); Mater. Quantum Technol. 1, 015001 (2021)

IPIC Catalyst Theme Goals: Quantum Photonic Integration Platform

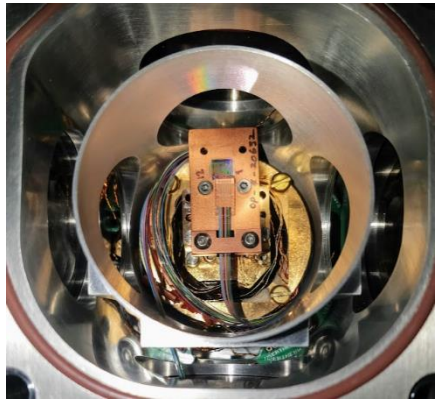
- Photonic integration key for scalability
- IPIC will play a leading role – 7 PIs active
- Challenge: unique integration platform needed
  - Hybrid integration of multiple device and material types
    - On chip III-V entangled photon sources and modulators
    - Silicon nitride or polymer waveguide interconnects
    - Hybrid integration of superconducting detectors…
  - Cryogenic operation
- Prospects for industry collaboration high e.g. DTIF project “Quantum Computing in Ireland (QCoIr)” and potential new projects currently under discussion



Integration of PQD photon sources with waveguides



Micro Transfer Printing for combining different materials/devices



Cryogenic packaging development (with Englund Group - MIT)

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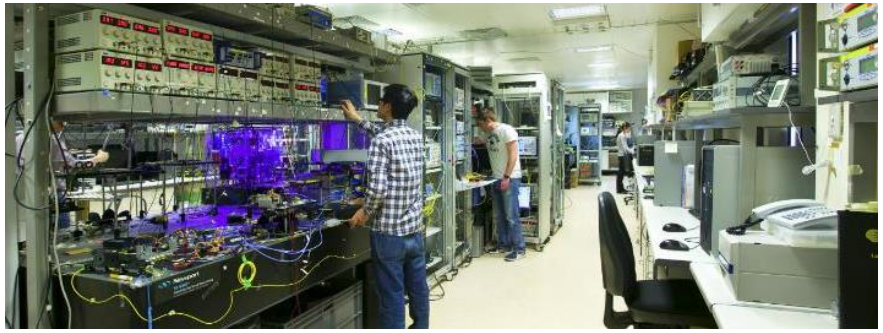
IPIC Catalyst Theme Goals: Quantum Networks

- Multi-Terabit capacity multi-carrier intensity modulation/direct detection and coherent testbeds
- Access to 1000km of field-installed fibre supplied by BT Ireland
- IPIC will use this capability to

  - Test new quantum integrated photonic devices and sub-systems in real-world scenarios

  - Develop interfacing and interworking schemes for integration with conventional (classical) communication systems

  - e.g. timing and control for entanglement transfer, switching and routing schemes etc.



Photonic Systems Lab at Tyndall with multiple fibre testbeds

50 GBaud complex modulation format coherent testbed (to be upgraded - SFI Infrastructure Award 2021)

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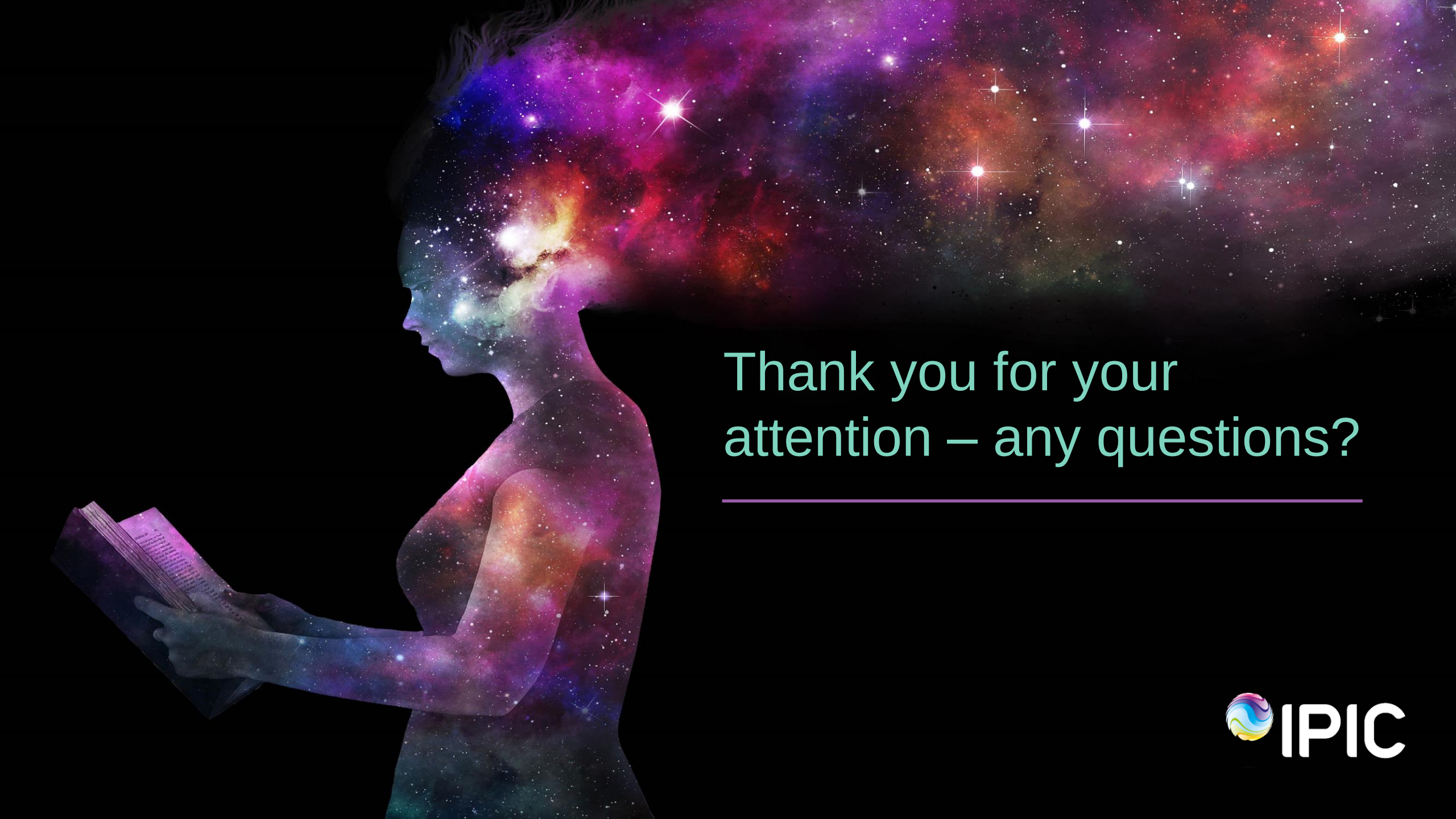

Thank you for your attention – any questions?

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