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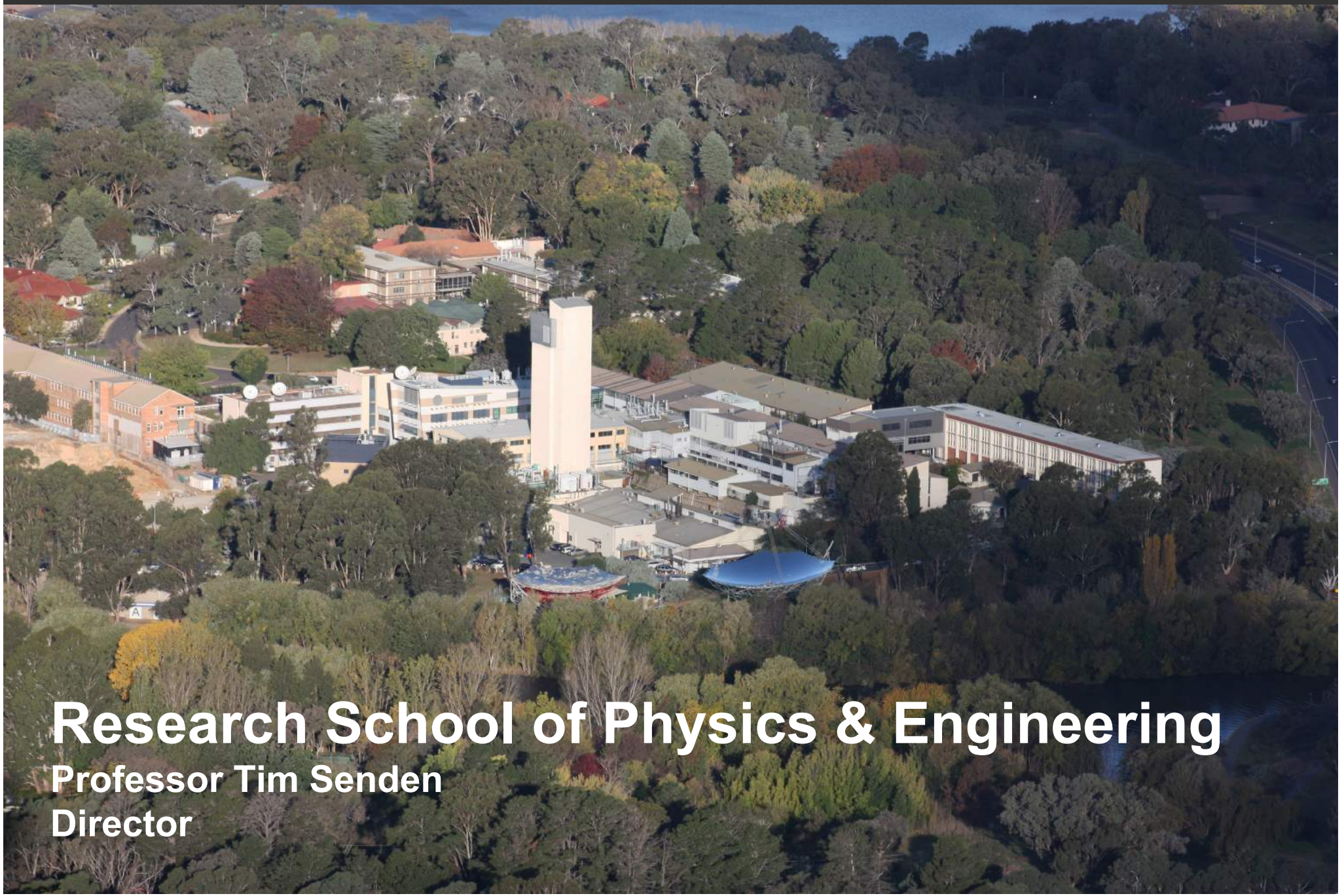
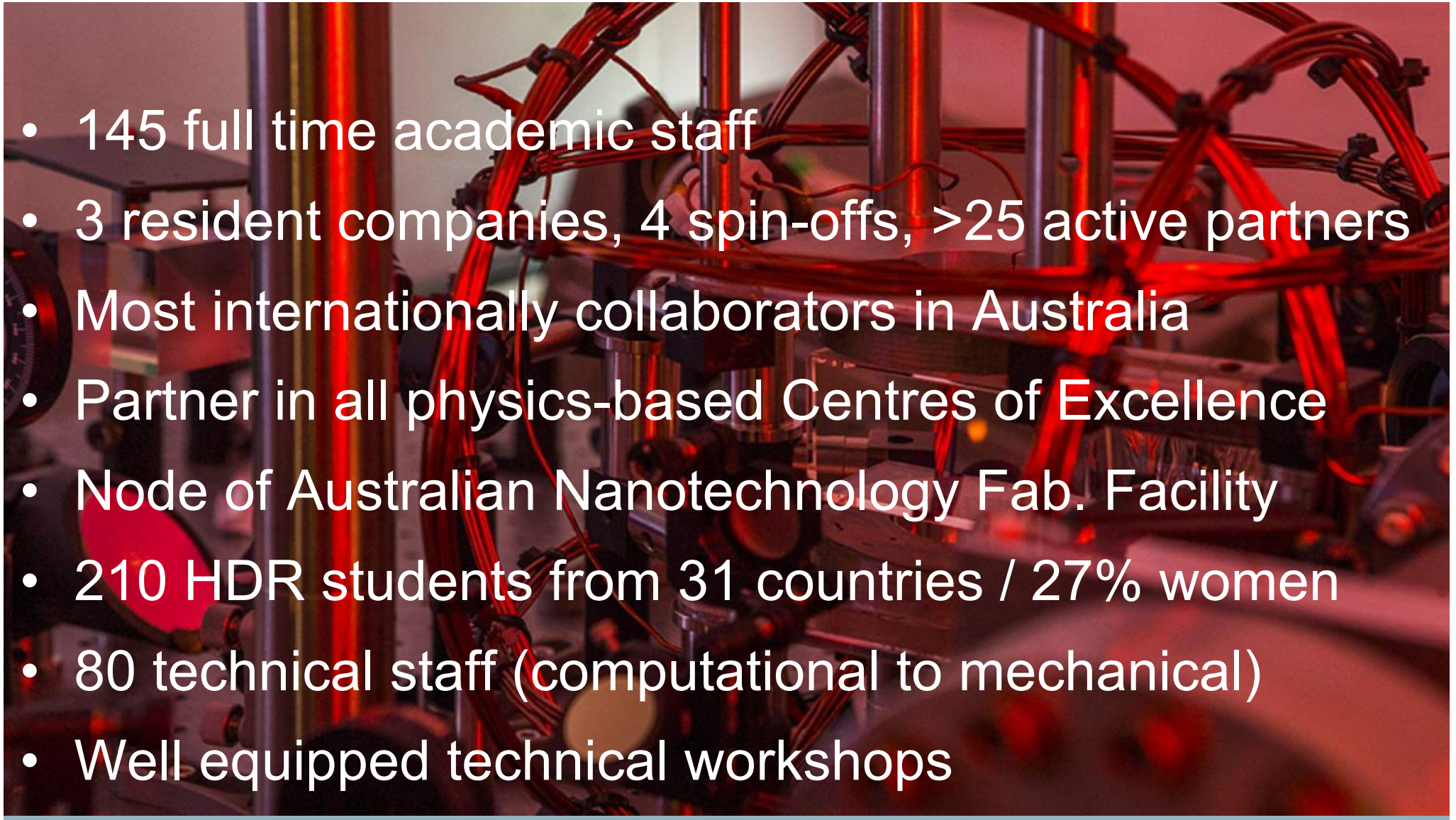


# Research School of Physics & Engineering

**Professor Tim Senden**
**Director**

Australian National University

# Largest university physics research activity in Australia



- 145 full time academic staff
- 3 resident companies, 4 spin-offs, >25 active partners
- Most internationally collaborators in Australia
- Partner in all physics-based Centres of Excellence
- Node of Australian Nanotechnology Fab. Facility
- 210 HDR students from 31 countries / 27% women
- 80 technical staff (computational to mechanical)
- Well equipped technical workshops

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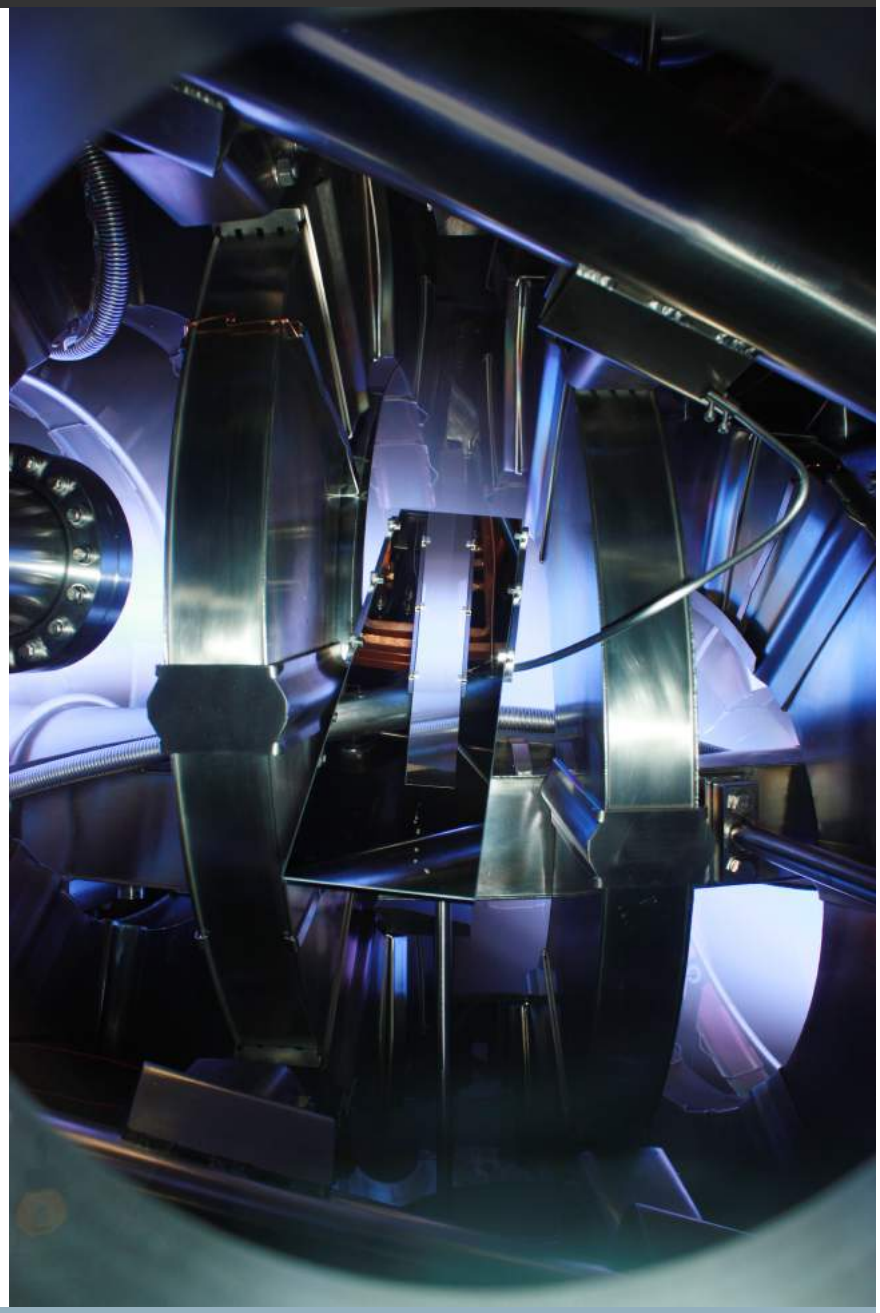
# Fundamental Research driven by National Capabilities

- Nanoscience
- Quantum & atom optics
- Non-linear physics
- Mathematical physics
- Atomic & molecular physics
- Antimatter-matter studies
- Nuclear science
- Materials & surface science
- Space science
- Plasmas/fluids
- Gravitational waves



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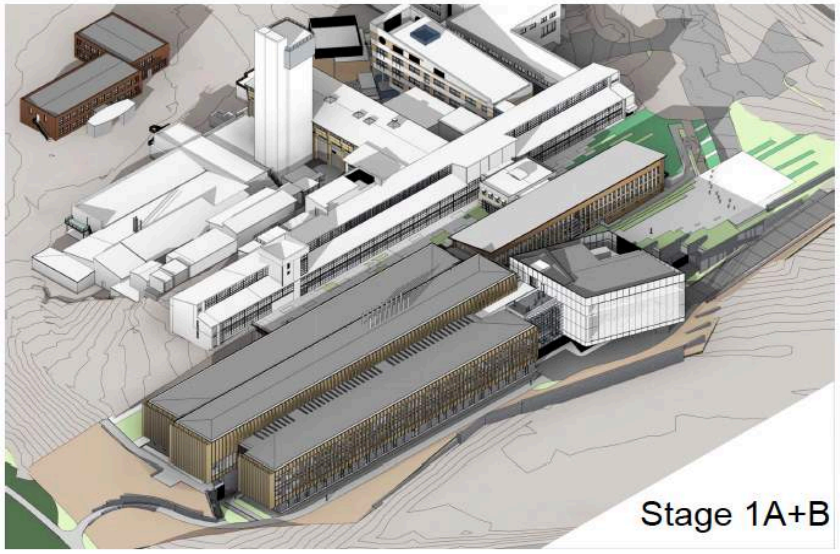
# New investment in infrastructure




## 26,000 $m^2$ in 4 Stages

- A clean ballroom and heterogeneous fab
- Ultra-stable laser and cryogenic labs
- Advanced materials facilities
- Accelerator facilities
- Technical workshops
- Integrated company/agency space
- Studio teaching and MakerSpace

# Nanowires Synthesis and Applications

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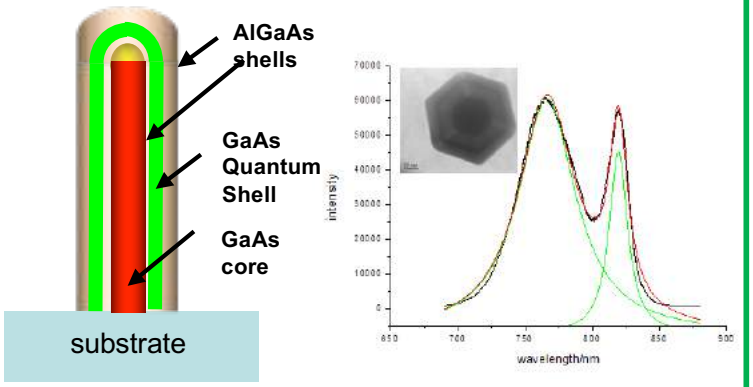
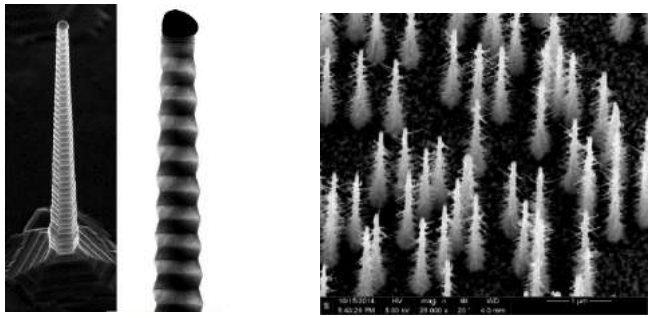
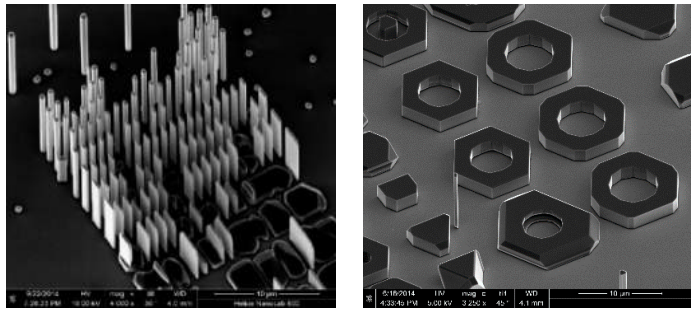
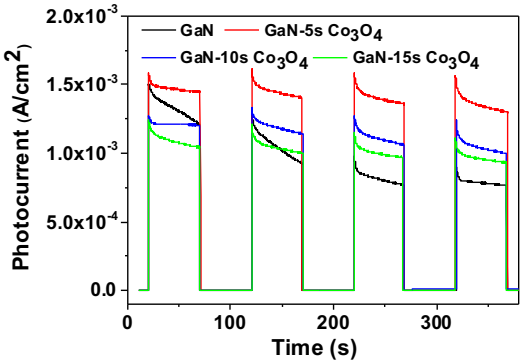
## Nanowires / Nanostructures

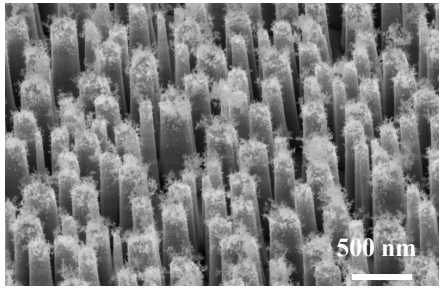


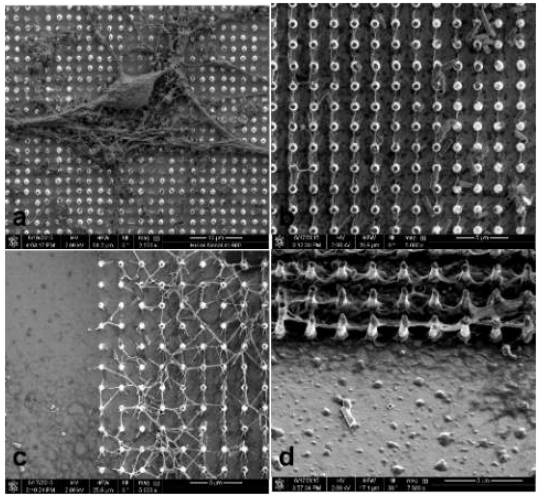


## Solar Water Splitting

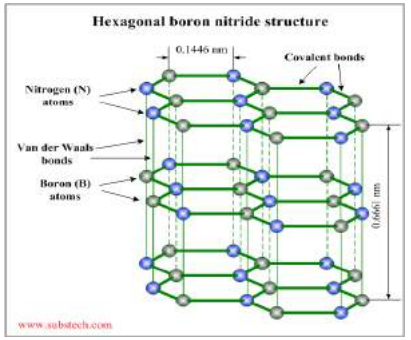



## Cell culture on NWs



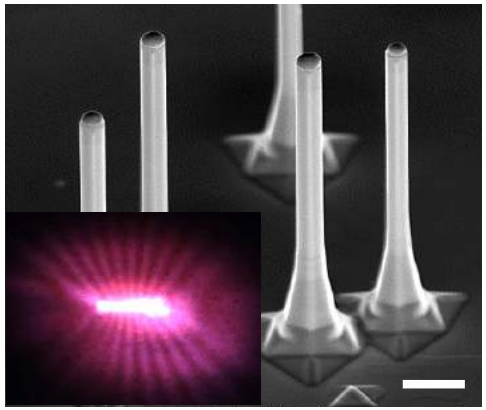

## DUV-LEDs (h-BN)

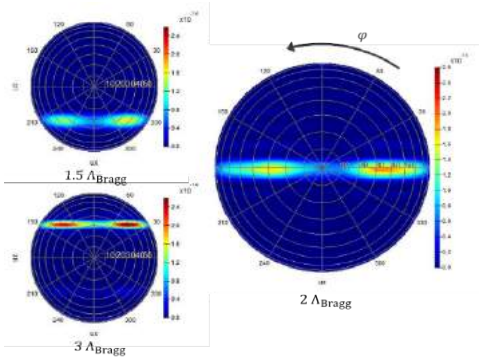


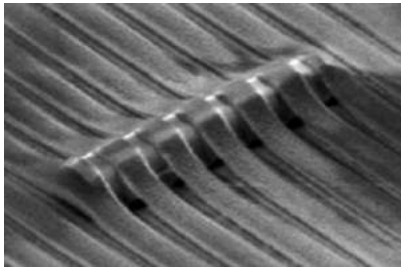

Contact: Prof. Hoe Tan – hoe.tan@anu.edu.au & Prof. Chennupati Jagadish – chennupati.jagadish@anu.edu.au

# Nanowire and 2-D Optoelectronics

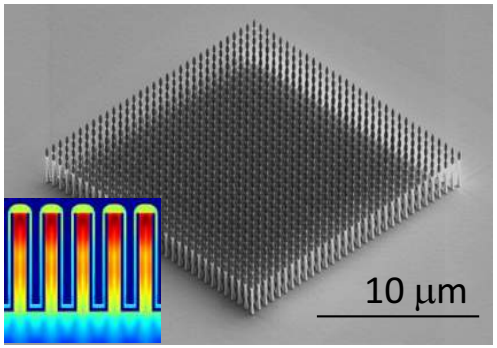
## Nanowire Lasers

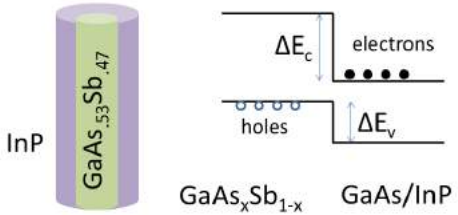




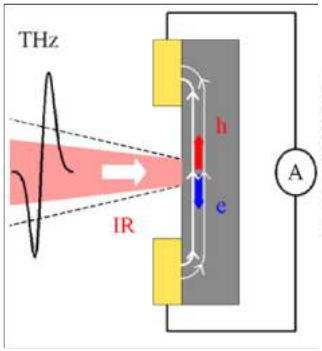



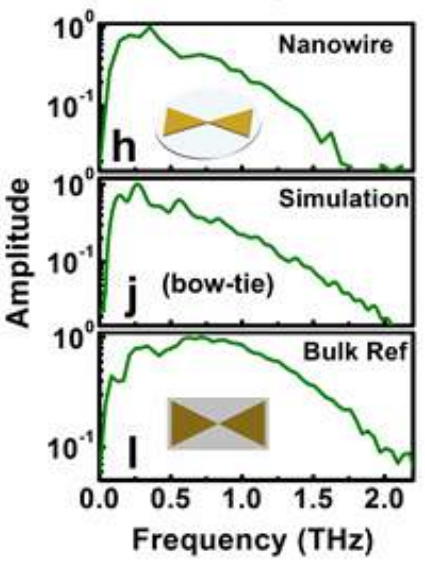
## Nanowire Solar Cells



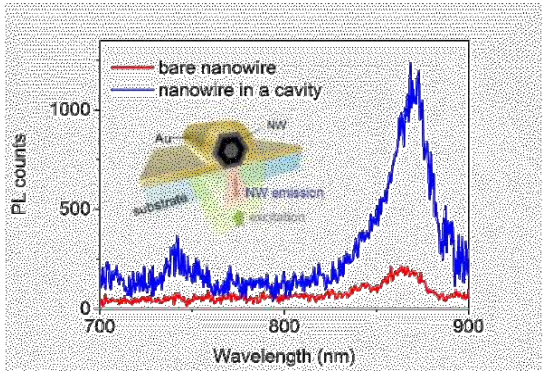




## Nanowire THz Detector

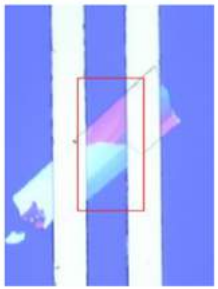


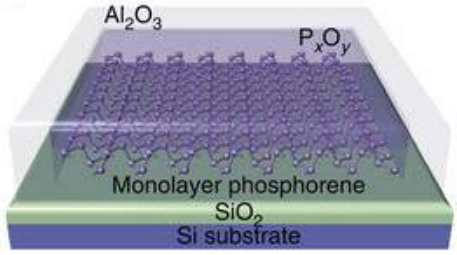




## Nanowire Plasmonics



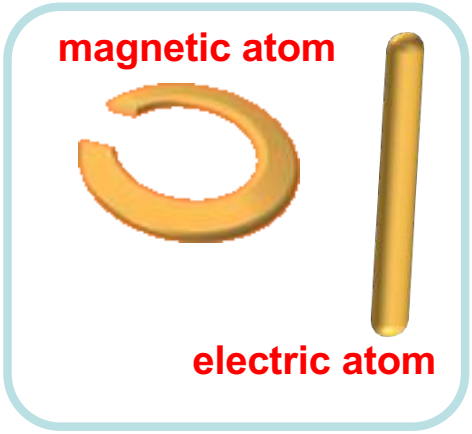

## 2-D Black Phosphorus Photodetector

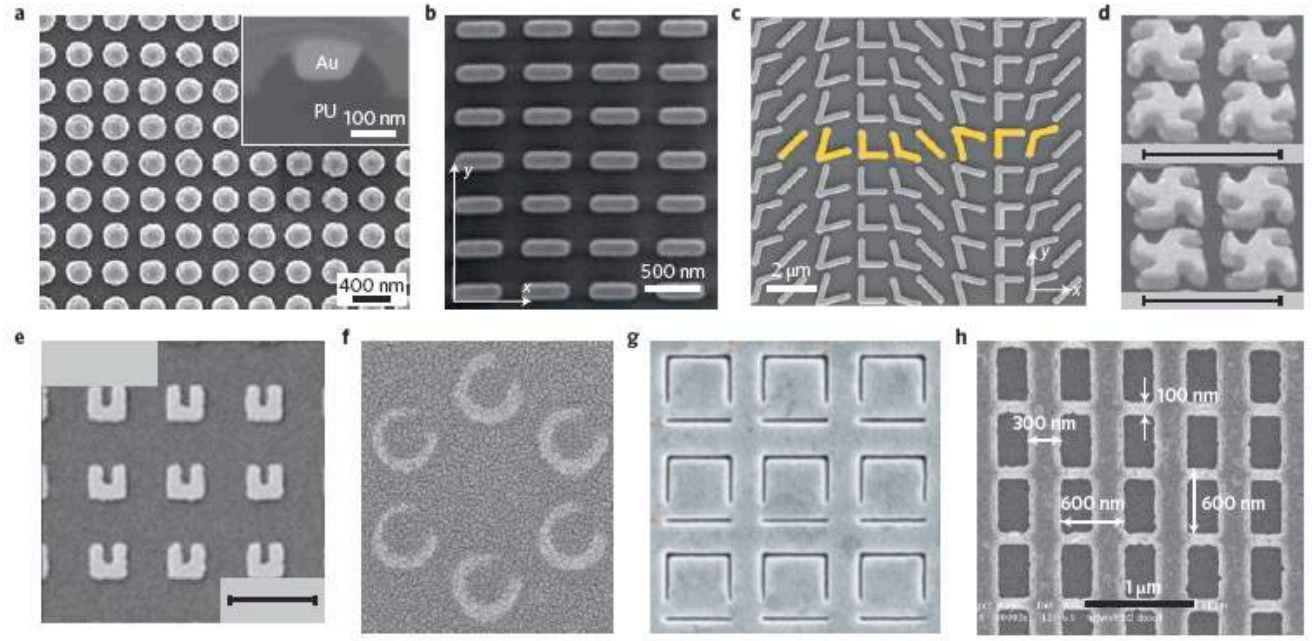





Contact: A/Prof. Lan Fu – lan.fu@anu.edu.au & Prof. Chennupati Jagadish – chennupati.jagadish@anu.edu.au

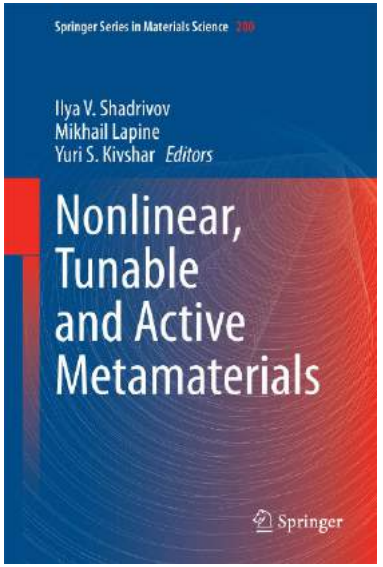
# Metamaterials: from microwaves to optics




## Potential applications of metamaterials

- Novel tunable flat antennas for RF to THz
- Improvement of Magnetic Resonance Imaging
- Subwavelength optical components for light manipulation, including flat lenses, beam deflectors and holograms
- Ultra-thin nonlinear light sources




Contact:Prof Yuri Kivshar - yuri.kivshar@anu.edu.au & Prof Ilya Shadrivov– ilya.shadrivov@anu.edu.au

# Quantum measurements with metasurfaces

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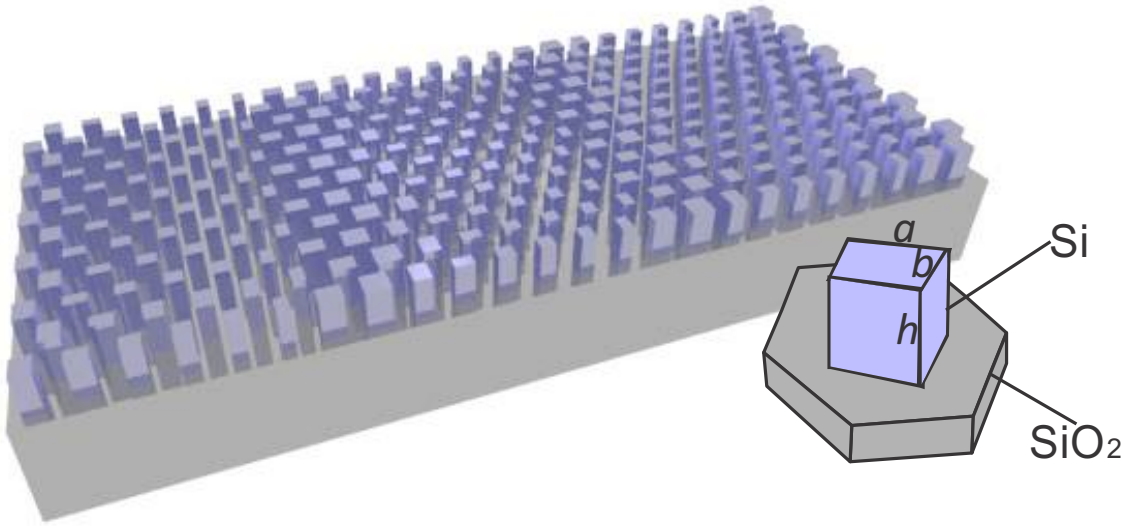
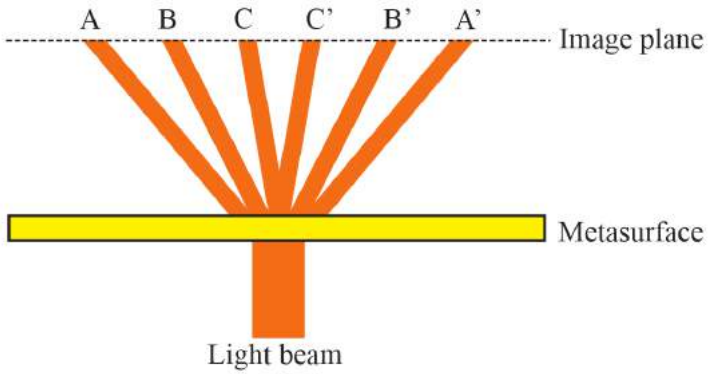
## Dielectric metasurface that automatically characterise the quantum state of light




Optimal design for measurement of optical signals

- Instantaneous detection of polarization of light
- High-efficiency and broadband
- Applicable to classical and quantum photon states
- Ultra-compact sub-μm thickness

Potential applications in
- Optical imaging
- Quantum communications
- Real-time spectroscopy

Contact: A/Prof. Andrey.Sukhorukov@anu.edu.au and Prof. Dragomir.Neshev@anu.edu.au

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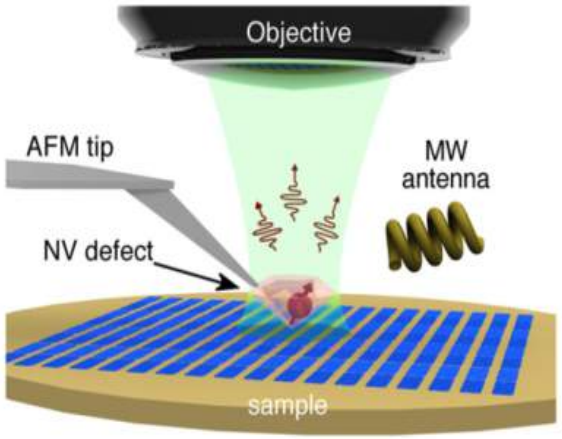
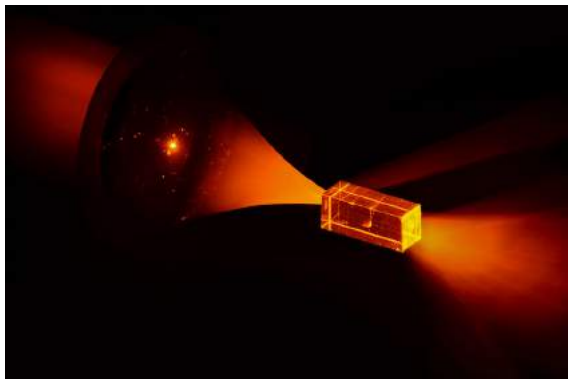
## Quantum sensing



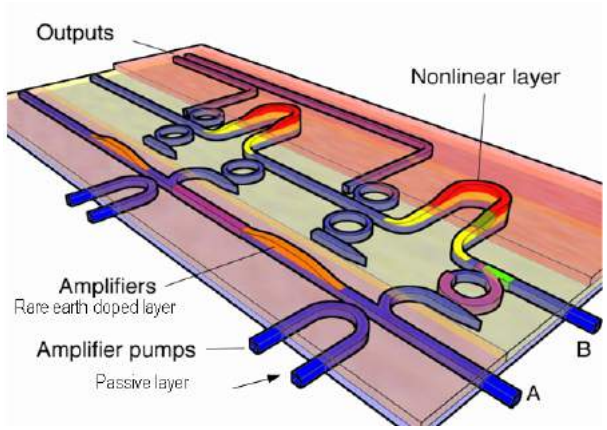

Scanning quantum microscope
Uses single N-V centres in a diamond tip to sense electric and magnetic fields on a nanoscale.

## Quantum information



Solid-state quantum memories for light, for long-range quantum communications and computing.

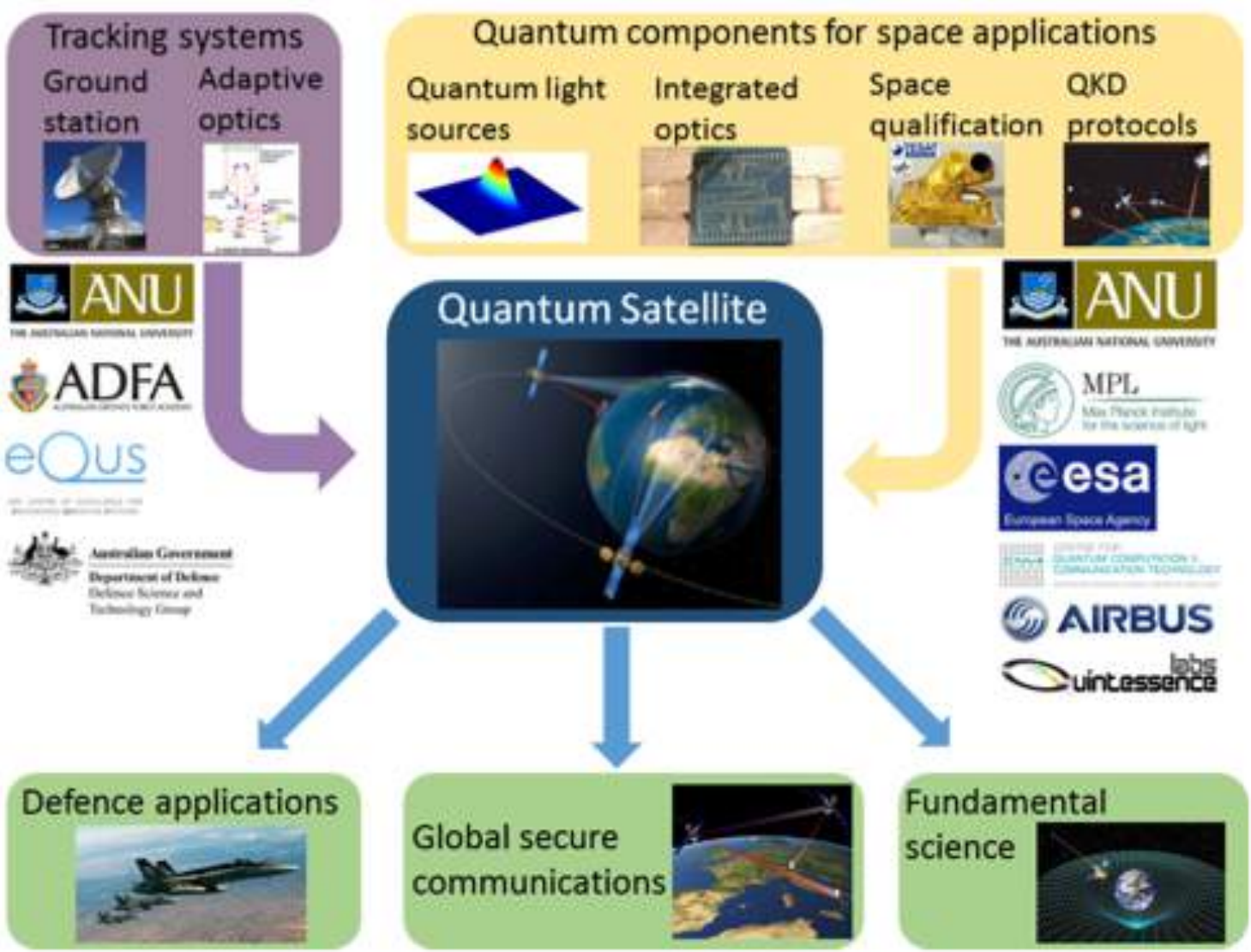
## Mid-infrared photonics




Integrated mid-infrared 2-8 μm photonics for sensing applications

Contact:A/Prof Matt Sellars matthew.sellars@anu.edu.au & A/Prof Steve Madden stephen.madden@anu.edu.au

# Australian National University Quantum Communication Satellite




Contact: Prof Ping Koy Lam – Ping.Lam@anu.edu.au

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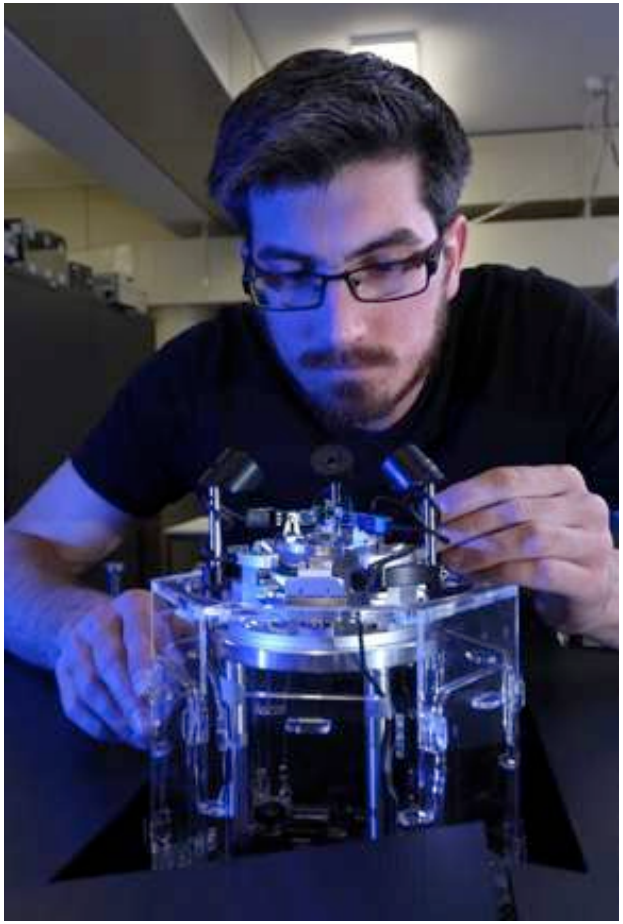
# Precision measurement with quantum sensors

Gravimetry

Gravitational wave detection



Squeezing

Atom optics

Light levitation

Contact: Prof John Close– john.close@anu.edu.au & Prof Ping Koy Lam – Ping.Lam@anu.edu.au

# Don’t worry about the fundamentals


- National and international physics networks are healthy
  - NCRIS & ARC (CoE)
- Two types of physics development
  - Device development
  - Instrumentation and measurement
- Product development capabilities are not well integrated

# Why *inhouse* spin-offs aren't the future

- **Quintesscence Labs**
  - quantum enhanced key management
- **Liquid Instruments**
  - Reconfigurable Test and Measurement equip
- **Lithicon**
  - Petrophysical simulation aided by tomography

*Future*: spend less time in university prototyping

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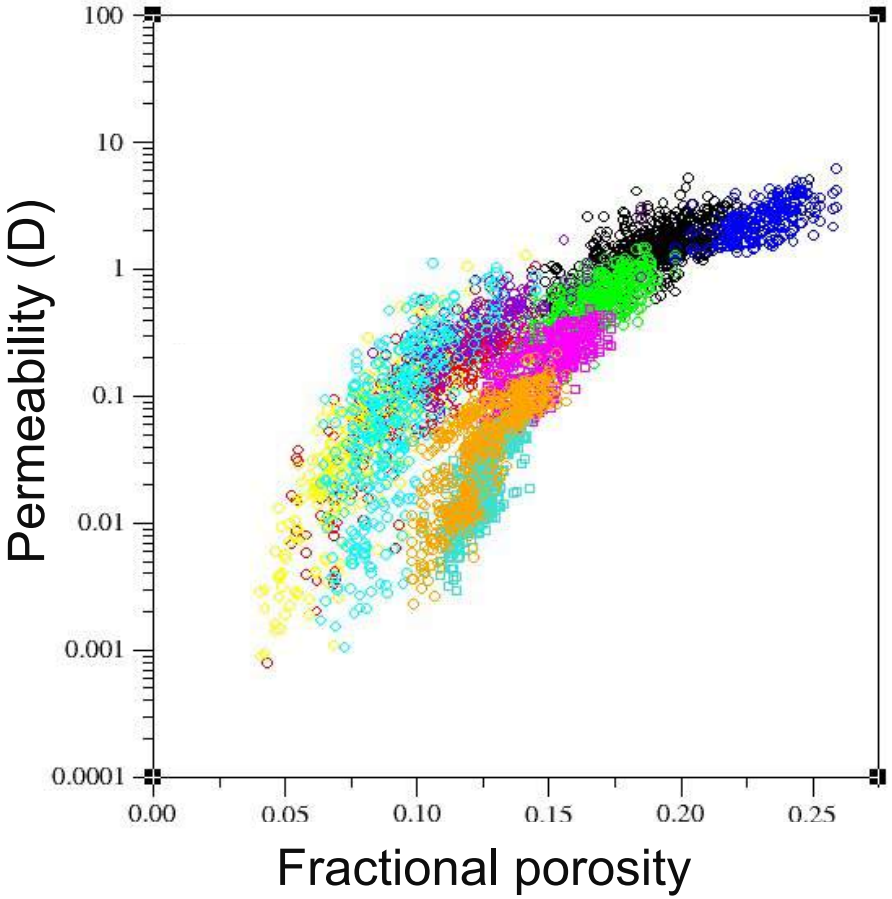
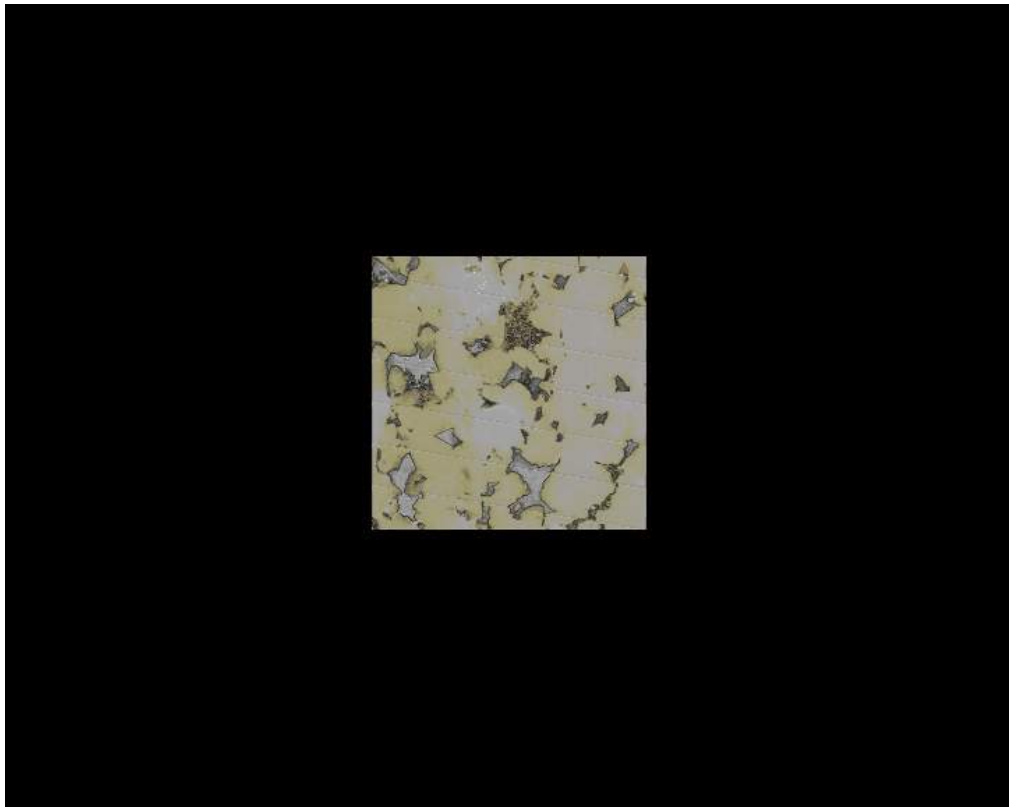
# Lithicon - tomography provides the framework for simulation



~ 1 mm$^3$ sandstone showing flow simulation

Many *bulk* physical properties can be readily simulated on a local scale

Contact: Prof Adrian Sheppard adrian.sheppard@anu.edu.au & Prof Mark Knackstedt

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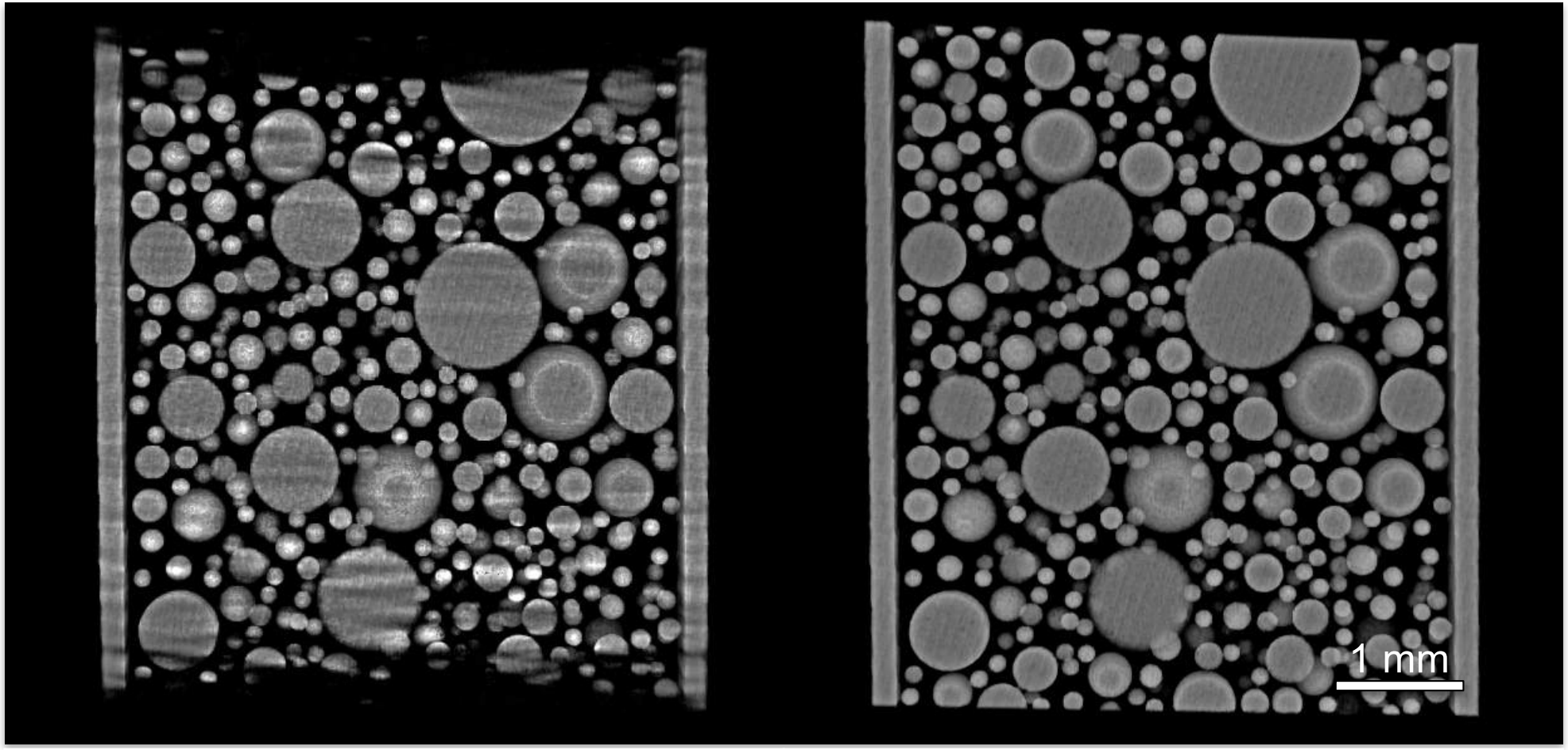
# Precise reconstruction and no geometric distortions




| Conventional circular scanning | Helical scanning |
| --- | --- |
| cone <10° | cone ~110° |

Contact: Prof Adrian Sheppard – adrian.sheppard@anu.edu.au & Tim.Senden@anu.edu.au

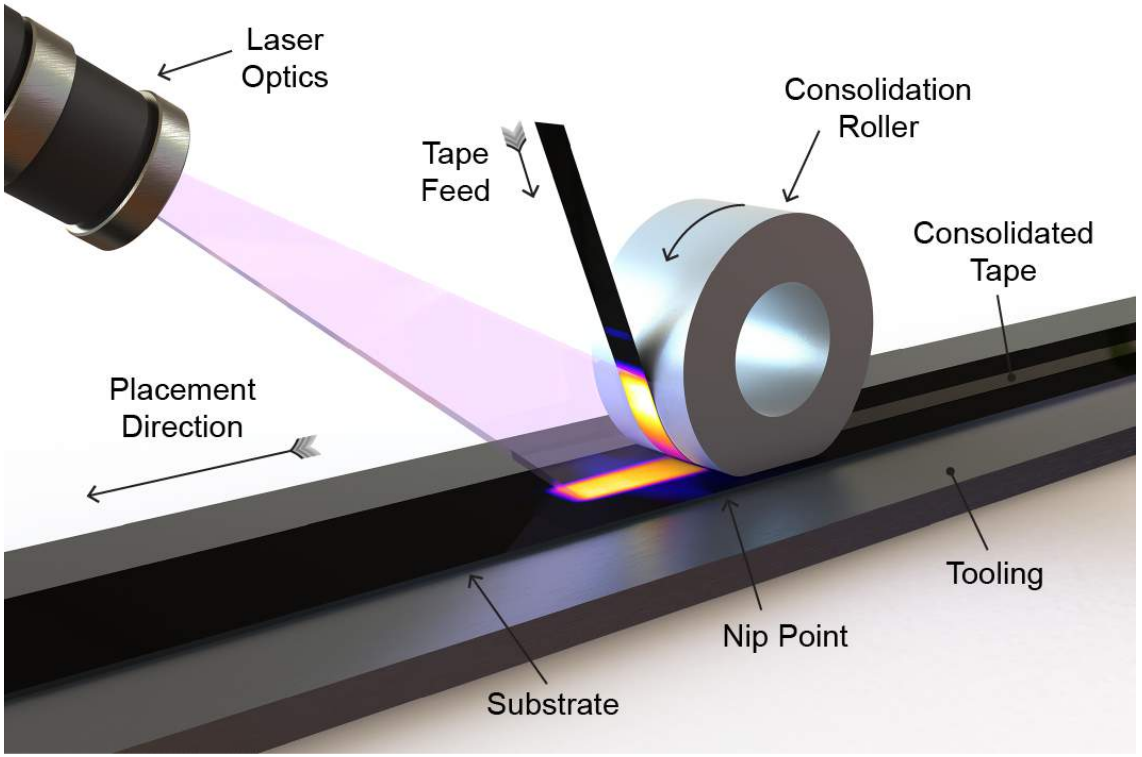
Australian National University

# Automated fibre placement (AFP)

## Problem

Slow, manual processes are limiting adoption of lightweight composites. ANU research aims to:

- rapidly manufacture carbon-thermoplastic composites *in situ*
- develop laser heating strategies to bond metal-composite hybrids




## Insight

- Through surface modification and optical modelling, laser absorption will be tailored for target bond line temperatures

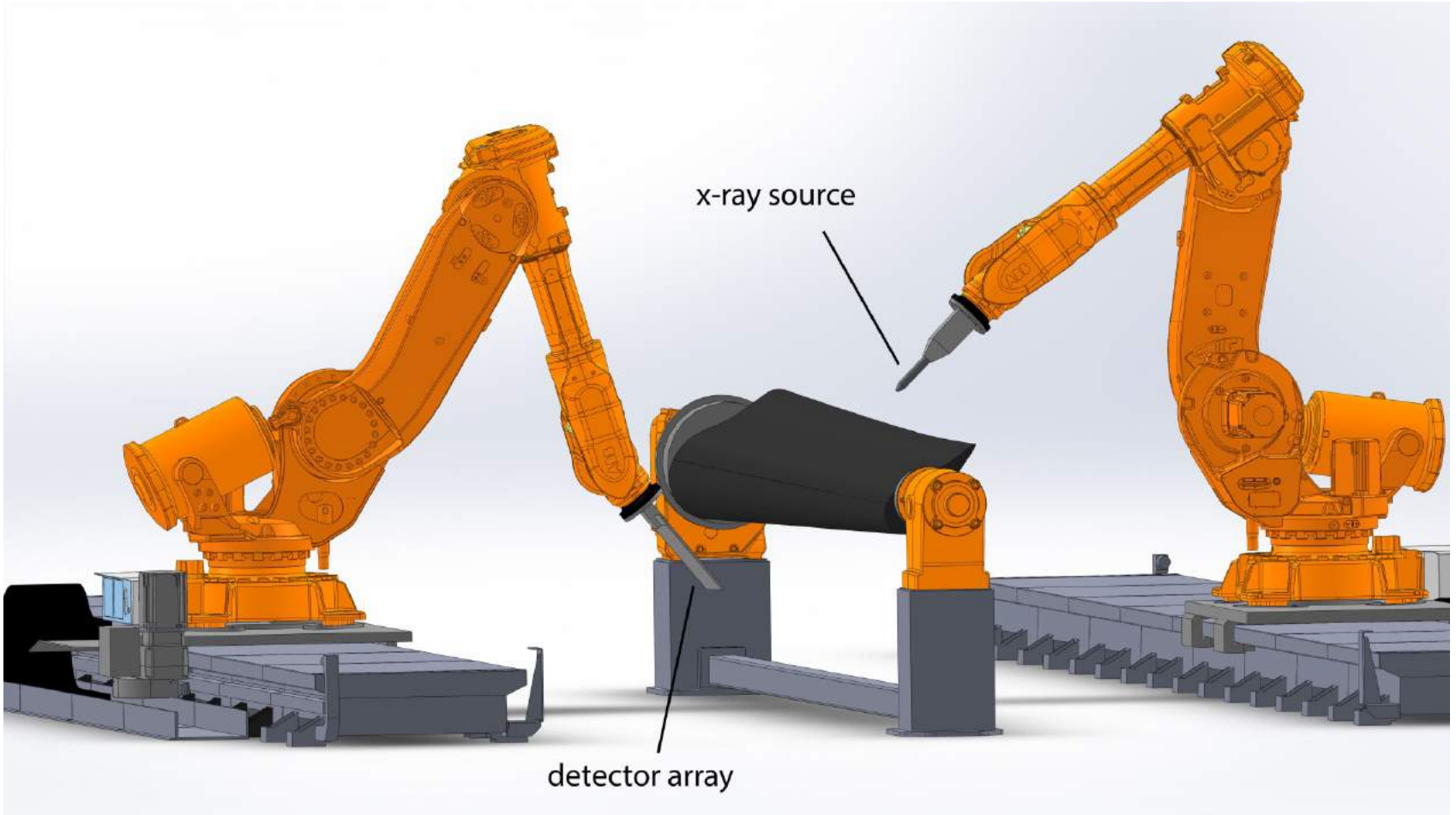
## Impact

- Automated manufacture of carbon composite manufacturing, optimized for speed and quality,
- High-volume manufacture of selectively reinforced metal-composite hybrids for automotive applications

Contact: Prof Paul Compston – paul.compston@anu.edu.au

# Future

*Prototype manufacture and diagnostic capability within a robotic workcell*



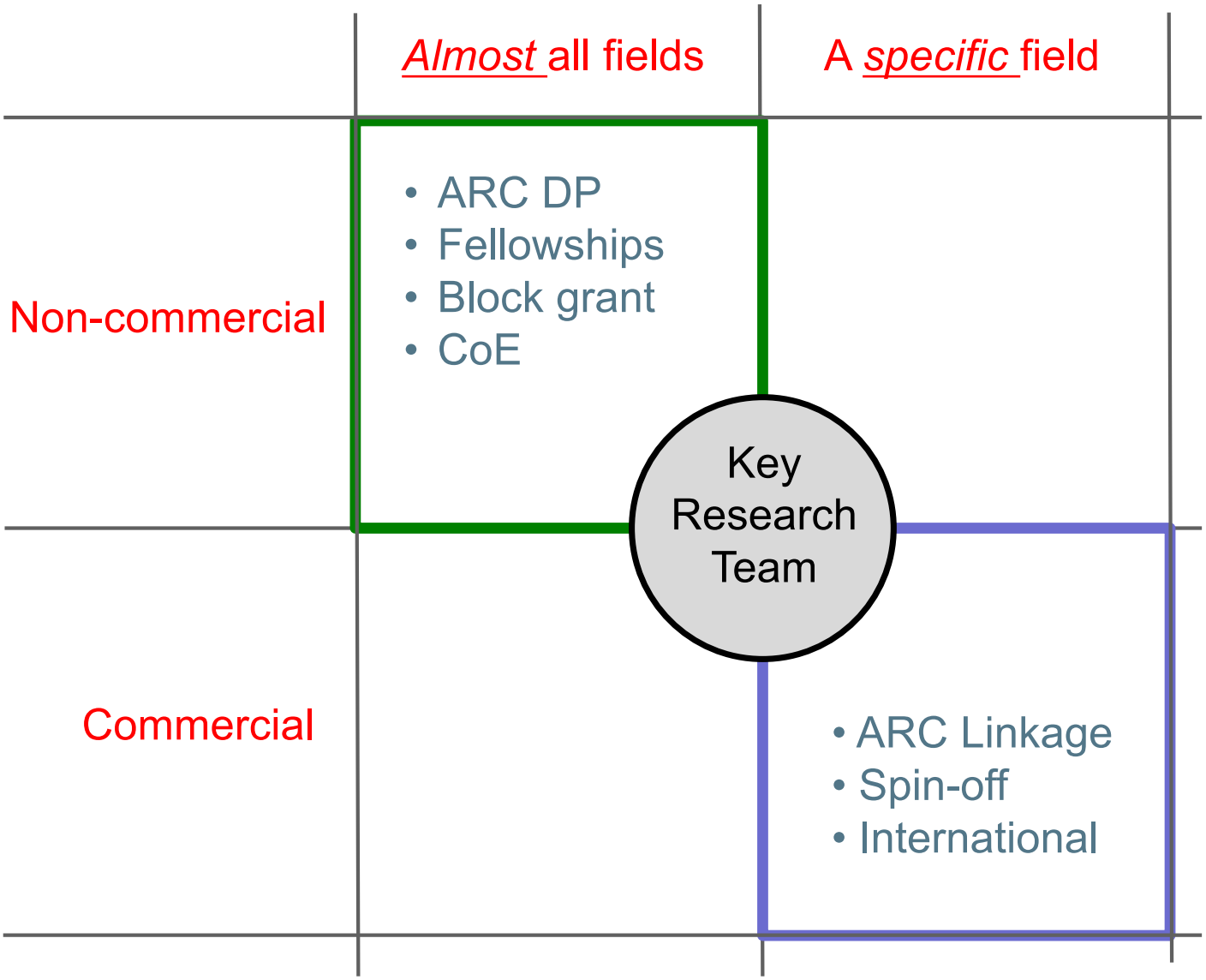

*Future*: is to integrate this capability with mesotype production

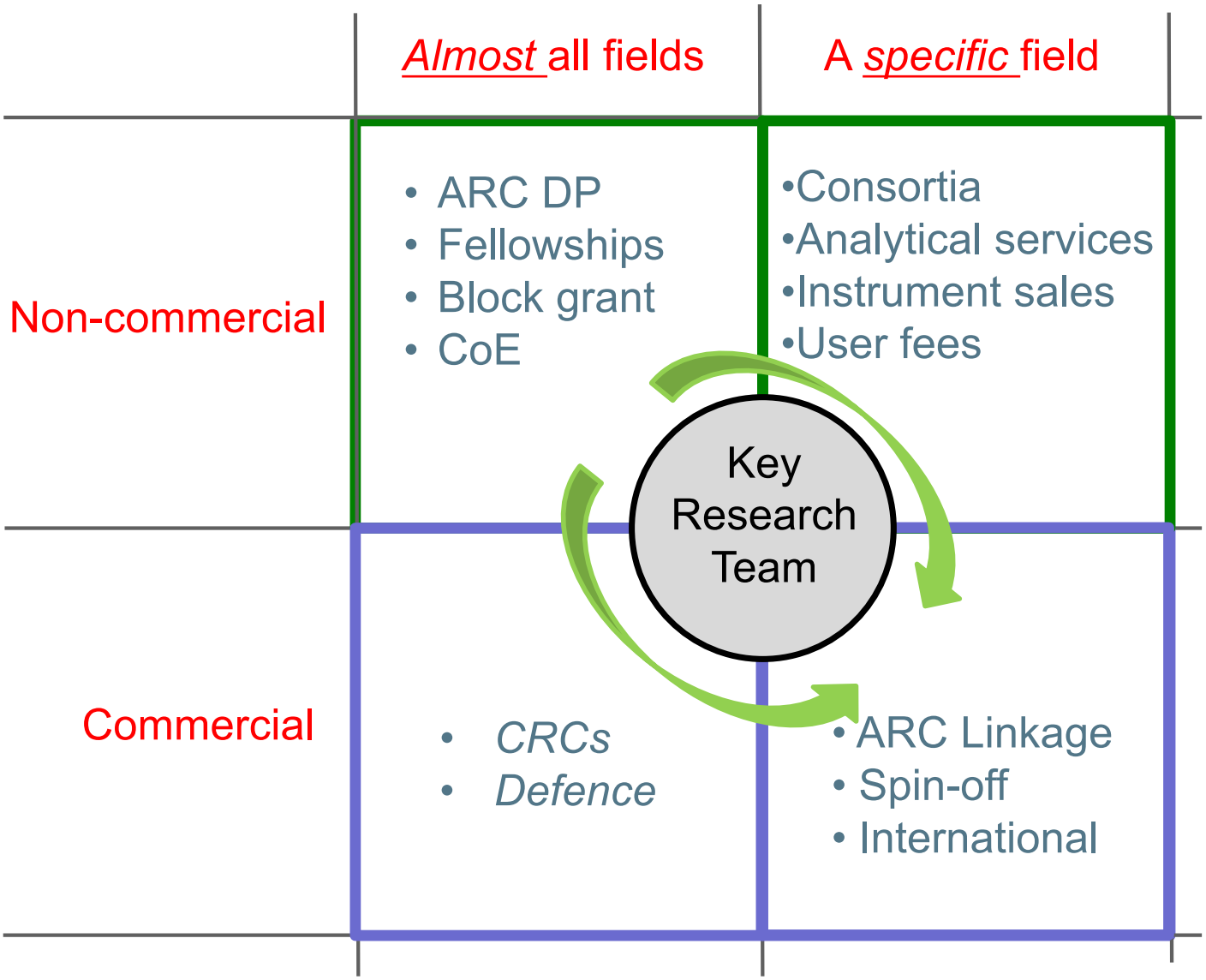
# Culture of mesotyping

- Heterogenous optical & short-run optics
- Device-level packaging
- Better integration of all digital fabrication
- CT-based rapid 3D metrology (online with AM)
- Whole of system simulators
  - EMI, FEA, DEA, LB, ICME….
- Training programs

# Culture of mesotyping

- Re-integrate VET and HE
- Universities are the right place to hold diverse technical skillsets
- Mesotyping means better staff transition to industry, and less time in prototyping
- Need Australian network for mesotyping


*Almost* all fields
A *specific* field
Non-commercial
Commercial
• ARC DP
• Fellowships
• Block grant
• CoE
Key Research Team
• ARC Linkage
• Spin-off
• International


*Almost* all fields
A *specific* field
Non-commercial
Commercial
• ARC DP
• Fellowships
• Block grant
• CoE
•Consortia
•Analytical services
•Instrument sales
•User fees
Key Research Team
• *CRCs*
• *Defence*
• ARC Linkage
• Spin-off
• International

# World Records and achievements

- The first demonstration of topological effects in exciton-polaritons
- World's largest optimisation-based tomographic image ~400 GB
- A new field of resonant all-dielectric nanophotonics and metasurfaces established
- The first demonstration of magnetic hyperbolic metamaterials

# World Records and achievements

- First ghost imaging with atoms
- Development of a quantum memory for the optical communication band
- First measurements of zeptosecond reaction time scales for superheavy element synthesis reactions.
- World first demonstration of self-stabilising stationary light.
- Mathematical derivation of the most symmetric periodic surfaces

# World Records and achievements

- The most efficient metamaterial hologram
- The highest nonlinear conversion efficiency from a nanoparticle
- First observation of the topological signatures of granular crystallisation
- Zinc doping of GaAs leading to one of the smallest lasers