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What's Brilliant and BRIGHT at the Australian Synchrotron

Professor Michael James

VICTORIA State Government

Australian Synchrotron

Australia's Landmark Science Facilities

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OPAL Research Reactor

Lucas Heights, Sydney

Australian Synchrotron

Clayton, Melbourne

Australian Synchrotron

Just down the Hume Highway…

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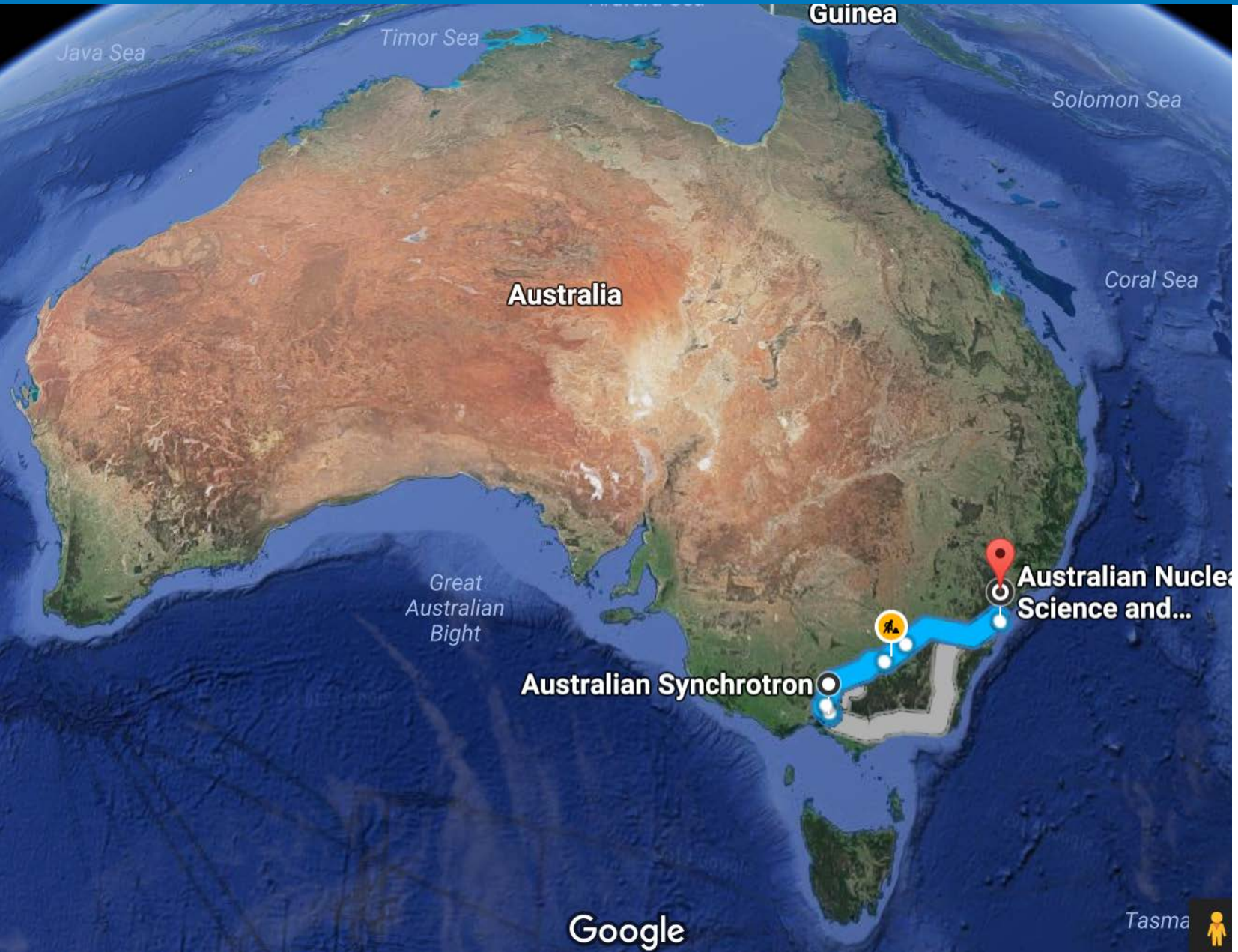

Lucas Heights

875 km

9 hrs drive

1½ fly

Clayton

The Australian Synchrotron

Australian Government

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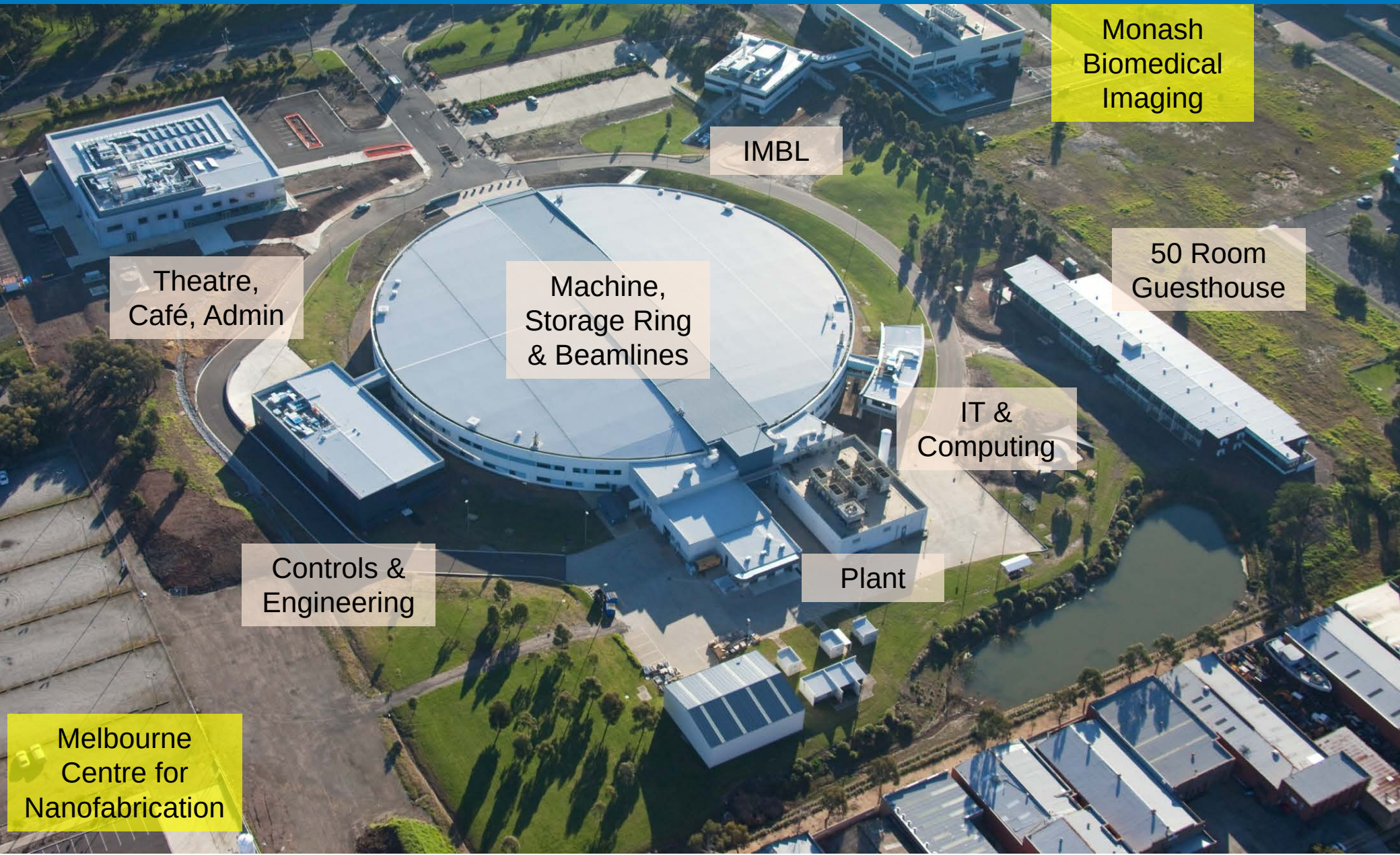

The Australian Synchrotron…

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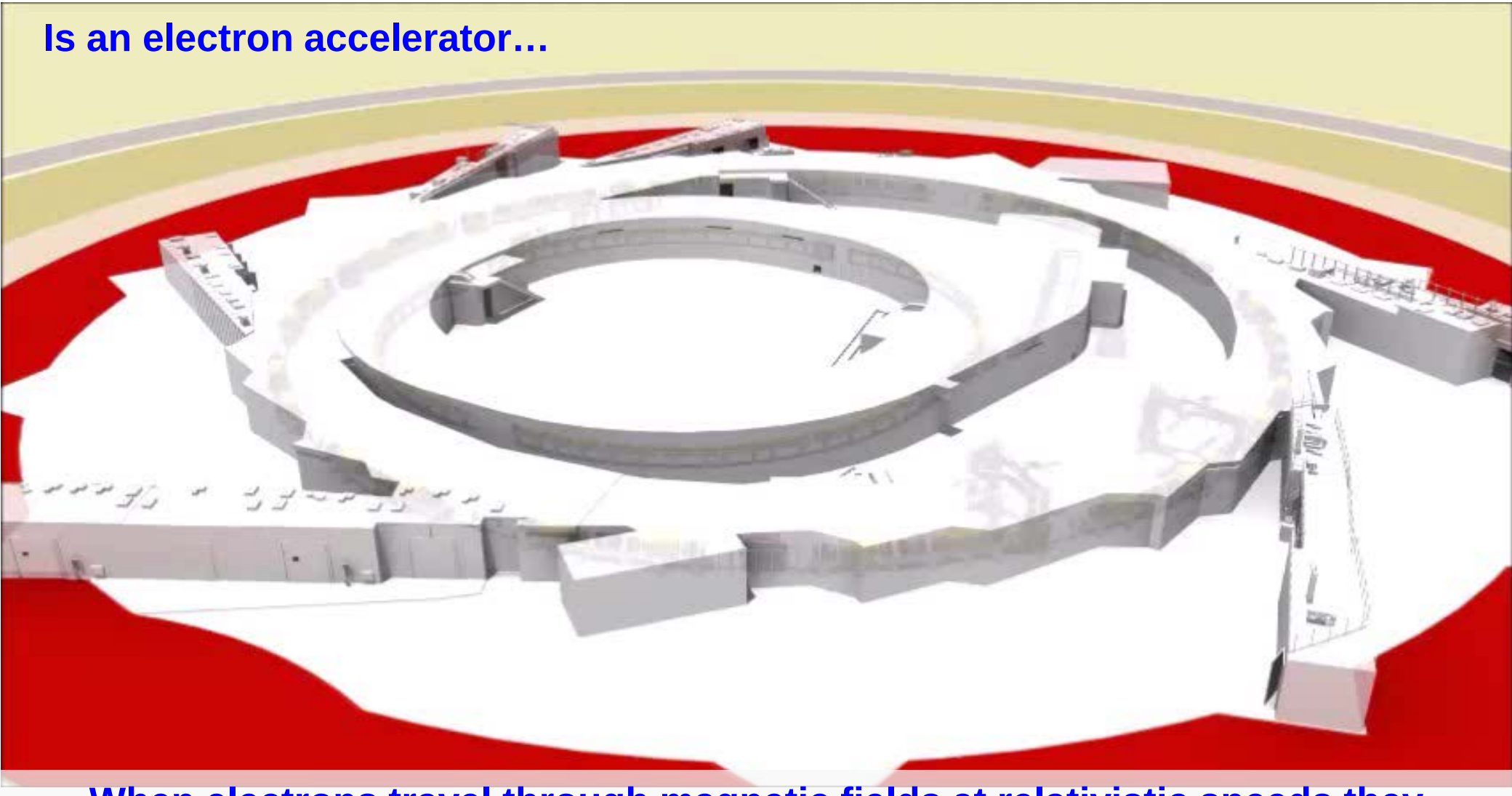
Is an electron accelerator…



When electrons travel through magnetic fields at relativistic speeds they generate intense beams of synchrotron light (Infrared, visible and X-rays)

The Australian Synchrotron…

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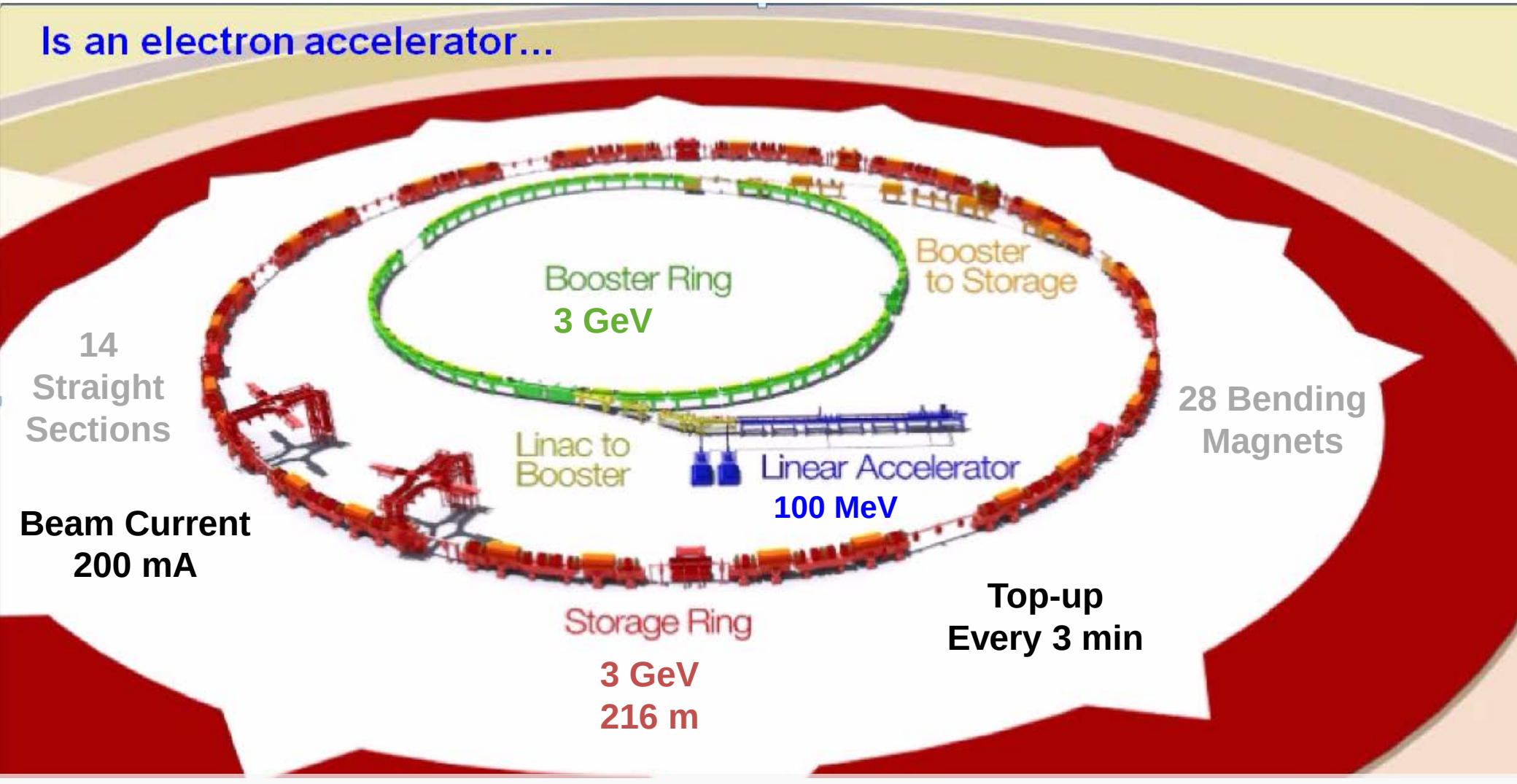

When electrons travel through magnetic fields at relativistic speeds they generate intense beams of synchrotron light (Infrared, visible and X-rays)

The Storage Ring…

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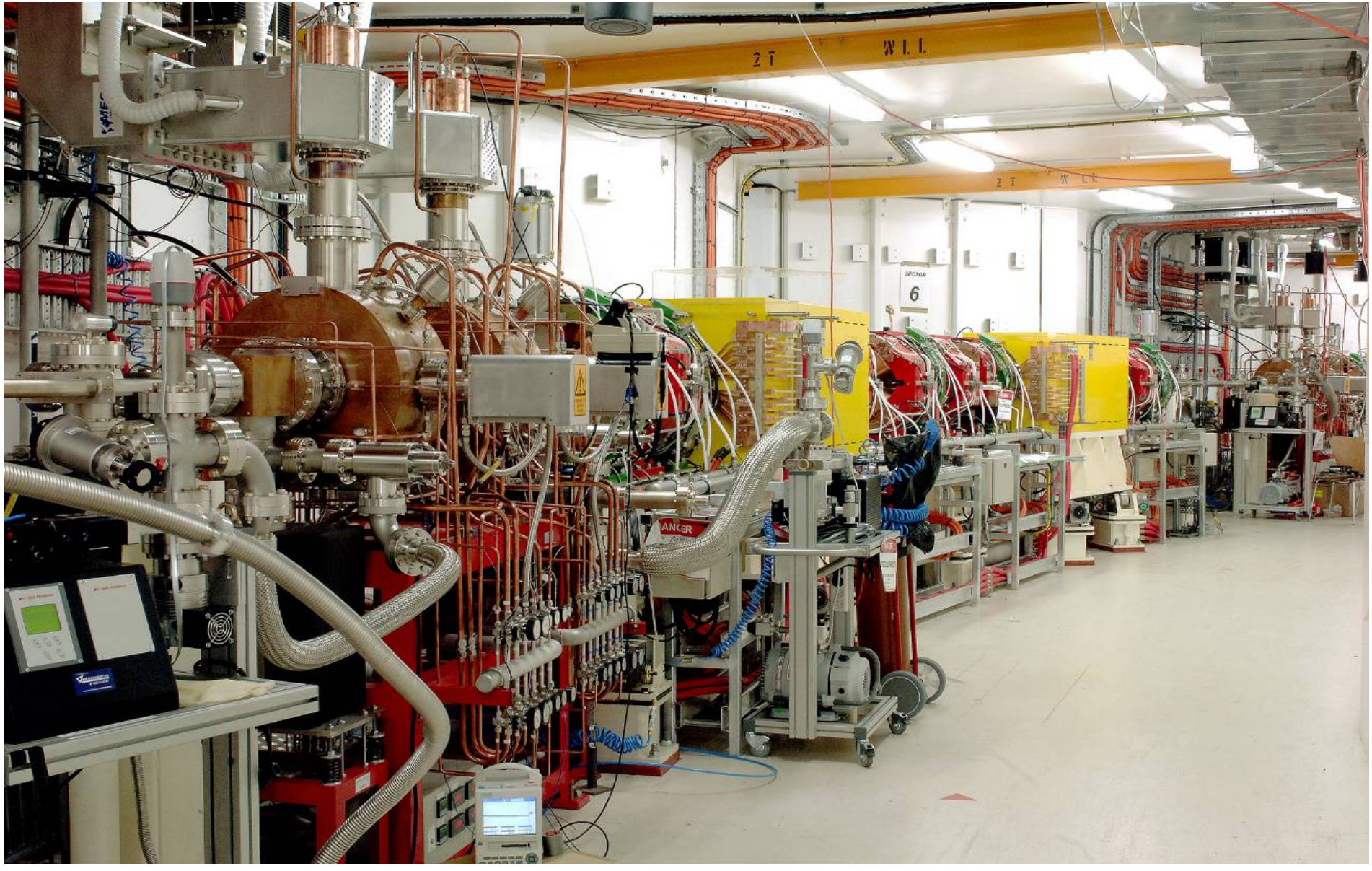

How is light produced in a Synchrotron?

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Source for:

IRM

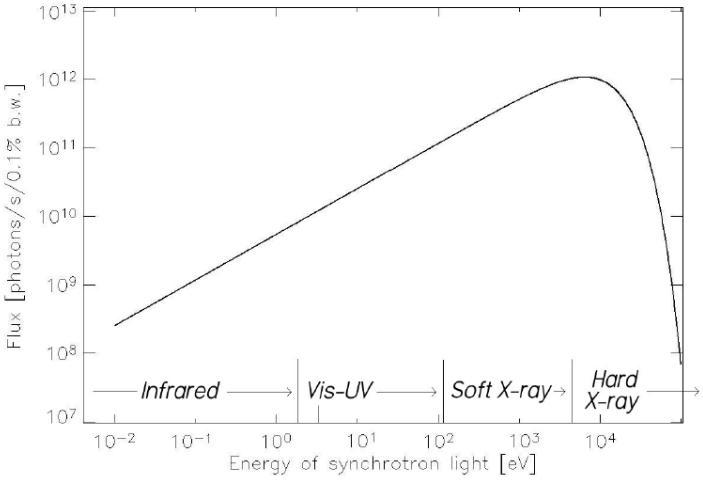
THz/ Far-IR

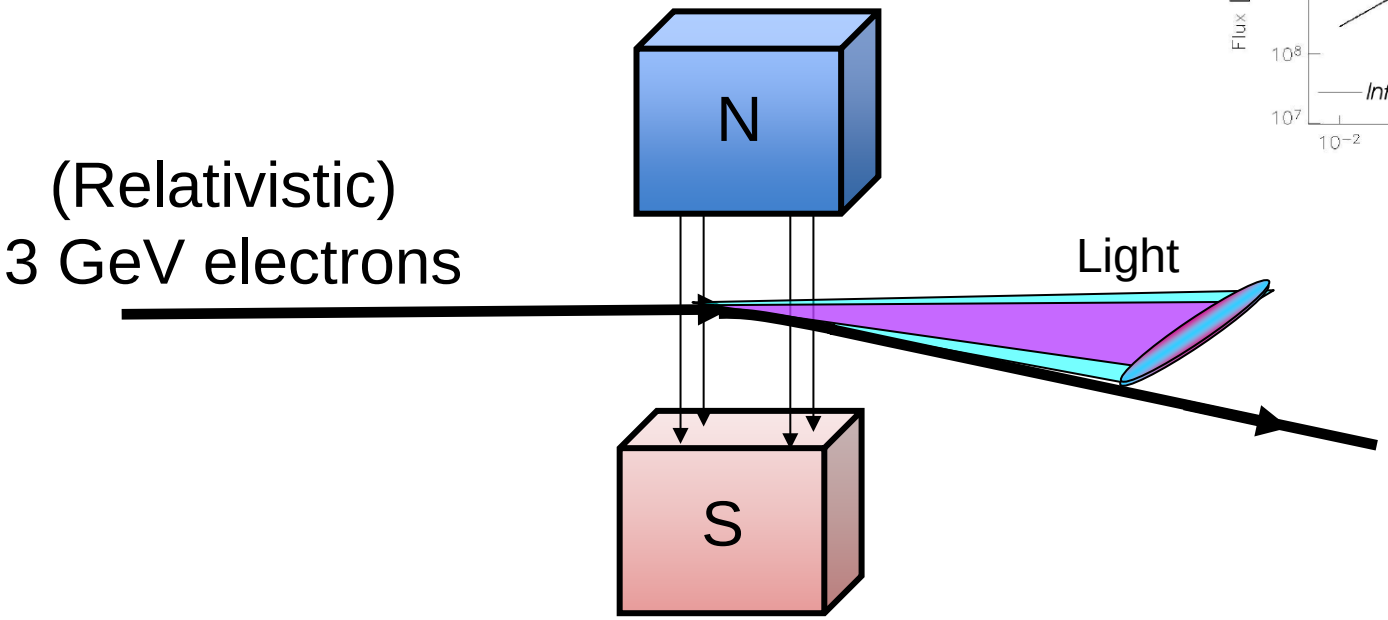
MX1

PD

Dipole Bending Magnet:

Broad spectrum emission





Synchrotron light produced by a bending magnet source is **collimated**, **tunable**, **polarized** and up to a ***million times*** brighter than the sun.

How is light produced by a Wiggler?

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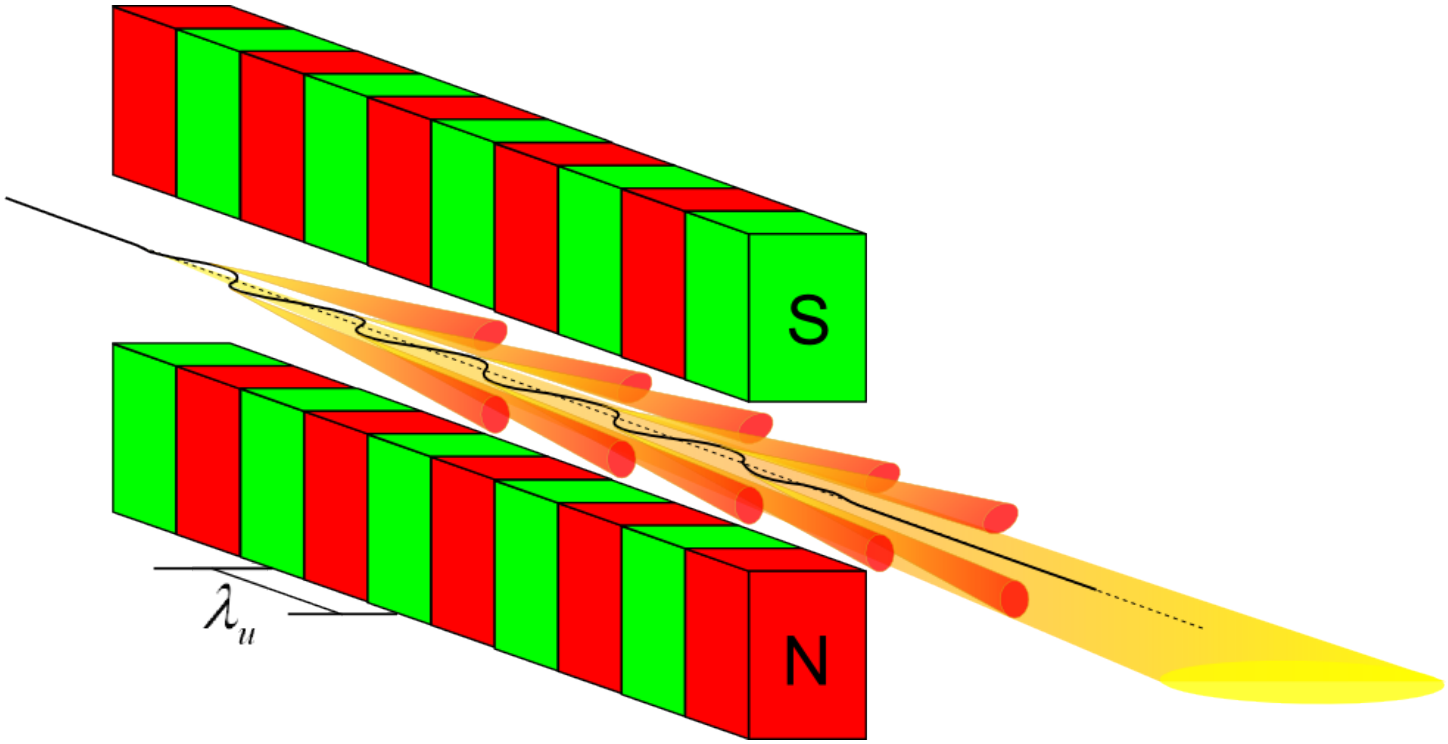
Wiggler:

Incoherent broad spectrum emission



Source for:

XAS

Higher energy and higher flux than a bending magnet

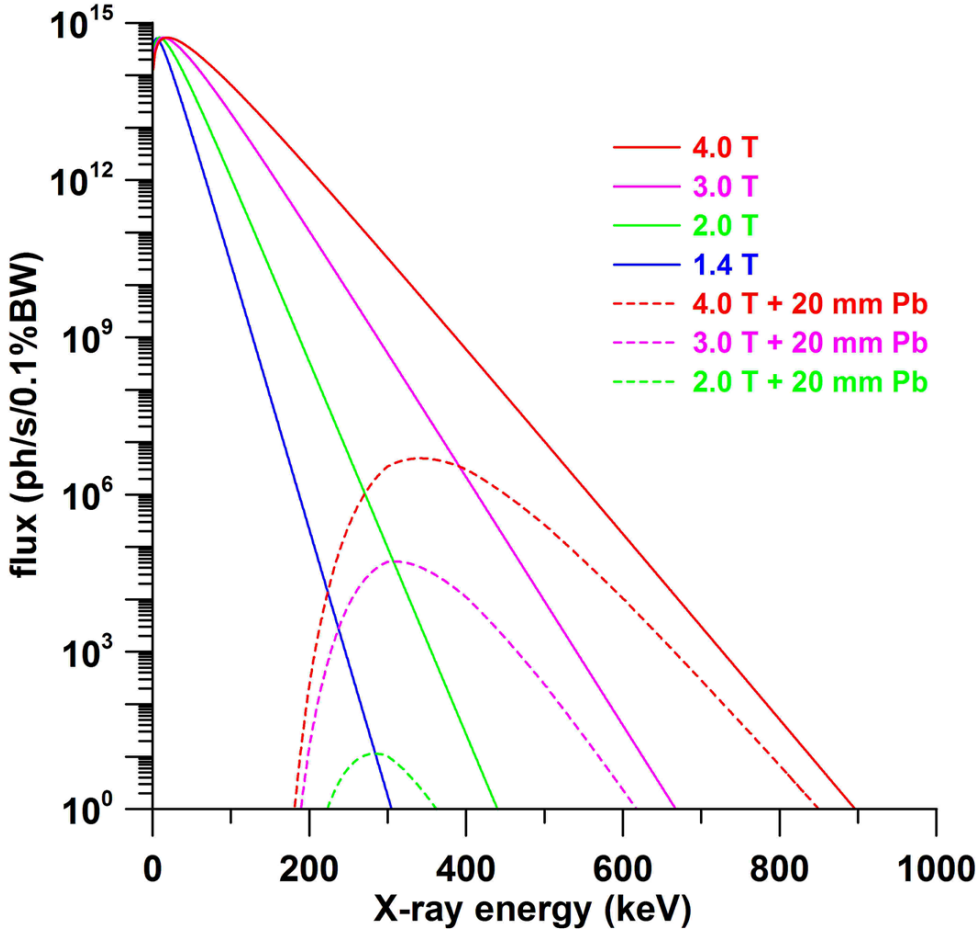
Superconducting Multipole Wiggler

Source for:
IMBL

Superconducting Multipole Wiggler

Operates at 4 K (Liquid He)

Generated fields up to 4 T



How is light produced by an Undulator?

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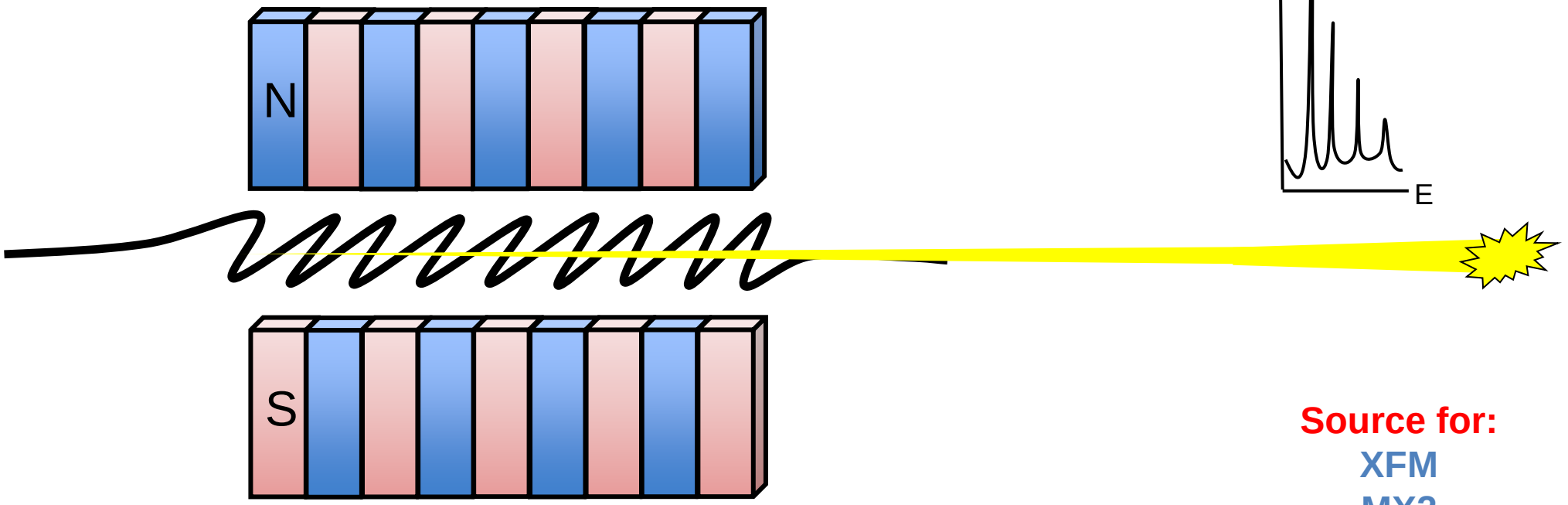
Undulator:

Coherent Interference

Narrow emission spectrum



Source for:

XFM

MX2

SXR

SAXS

Light produced by the Australian Synchrotron can be a ***billion times*** brighter than light from the sun.

Our Science

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Australian Synchrotron: Areas of Impact

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Research at the AS covers a broad range of fields:

Biosciences and Health; Earth and Environmental Science,

Advanced Materials; Engineering and Manufacturing;

Energy and Sustainability Science; Chemistry; Physics;

Agriculture and Food processing; Cultural Heritage and Archaeology;

Beamline and Technique Development; and Accelerator science.

The Australian Synchrotron at a Glance

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140 staff supports 5000 hours of User Operations

10 Beamlines

6,000 Registered Users

1000 User Experiments per year

5,600 User Visits per year

3,250 Journal Publications from Users or Staff
~ 500 Journal publications per annum.

450 Journal Publications with Impact Factor > 7

1,500 Protein Structures in Protein Data Bank

> 800 Graduate Theses

Australian Synchrotron

10 Operational Beamlines

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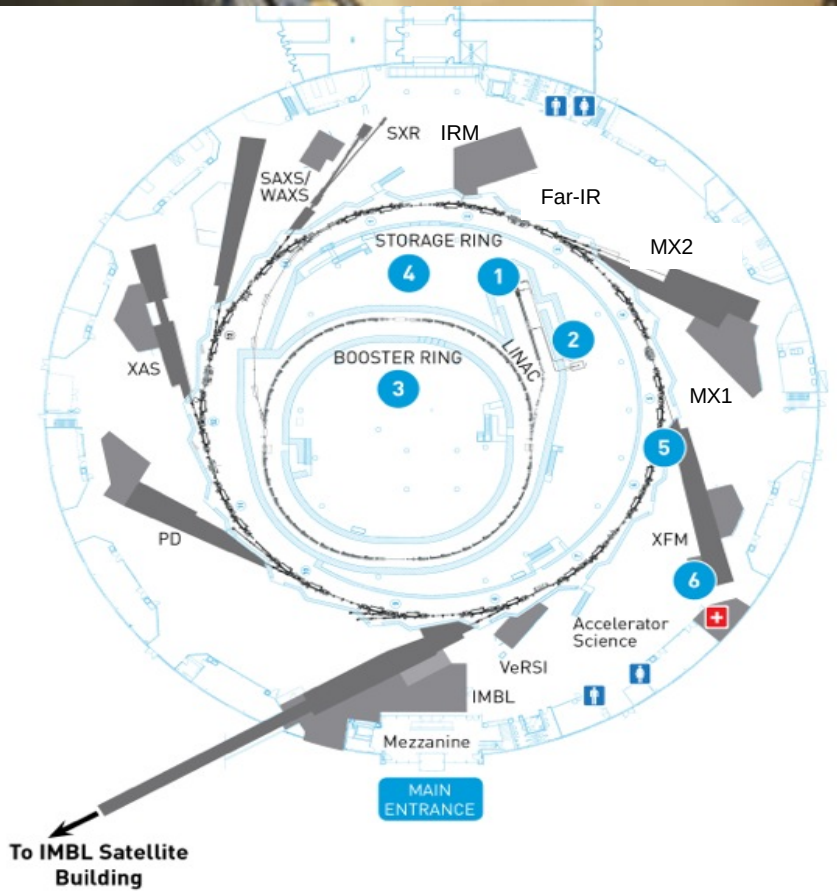

Infrared Microscope (IRM)

Terrahertz / Far-IR Spectroscopy (THz/Far-IR)

Soft X-ray Spectroscopy (SXR)

X-ray Absorption Spectroscopy (XAS)

Powder Diffraction (PD)

SAXS / WAXS

Macromolecular Crystallography (MX1)

Micro-focused Crystallography (MX2)

X-ray Fluorescence Microscopy (XFM)

Imaging and Medical Beamline (IMBL)

Structural Biology & Health: MX1 & MX2

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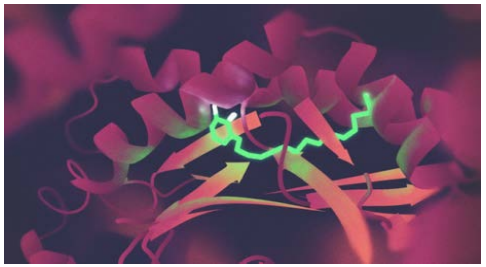
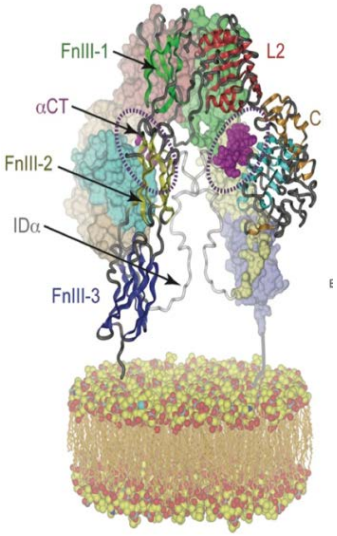
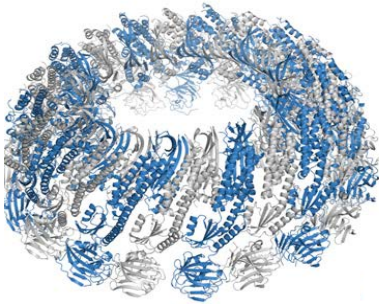


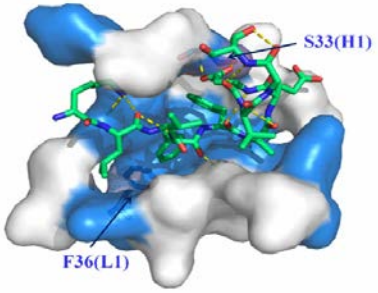
Immunology



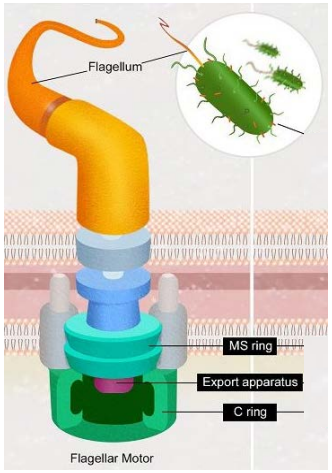
Diabetes



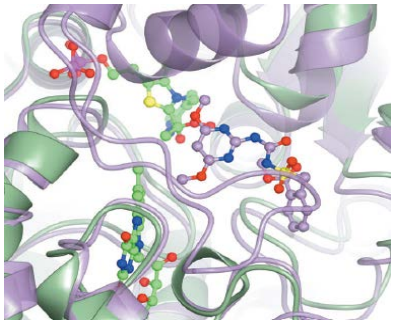
Toxins



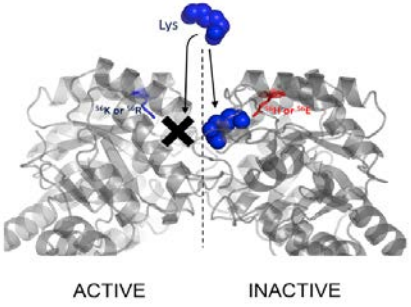
Alzheimer's disease



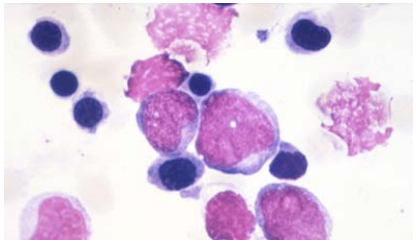
Bacterial Structure



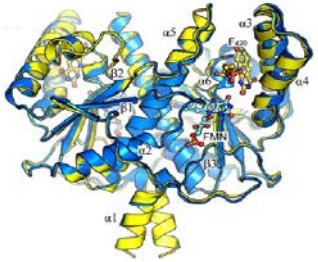
Herbicides



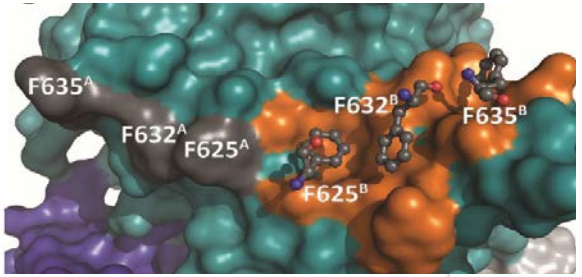
Antibiotics



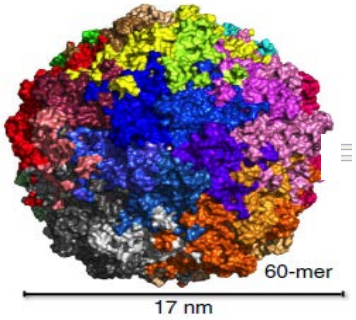
Cancer & Leukaemia



Tuberculosis



Malaria



Virology

Life-Changing Pharmaceutical Break-Throughs

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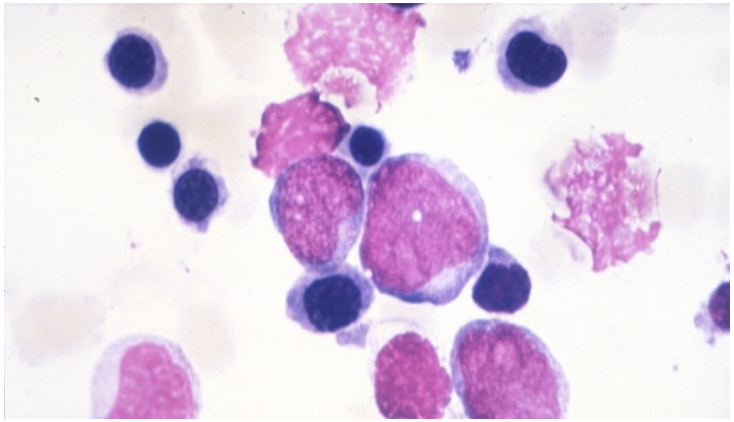
Venetoclax is now being used to treat *Chronic Lymphocytic Leukaemia*.



"There has not been a new effective treatment for Leukaemia for the past 50 years."

The US FDA recently granted approval for *Venetoclax*

Also approved in Australia, Europe and some Asian countries.

Chemical Crystallography for Advanced Materials

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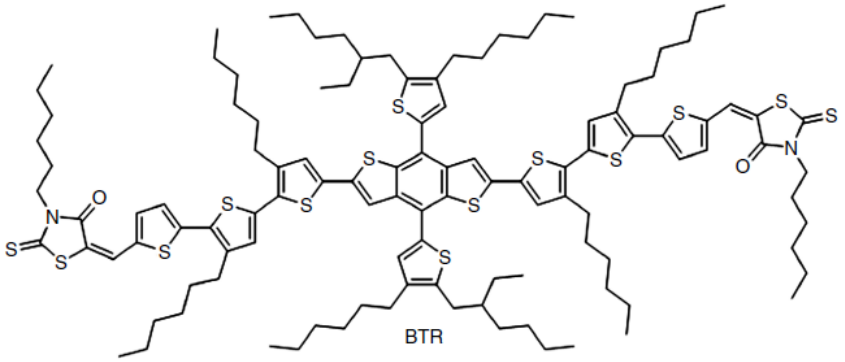
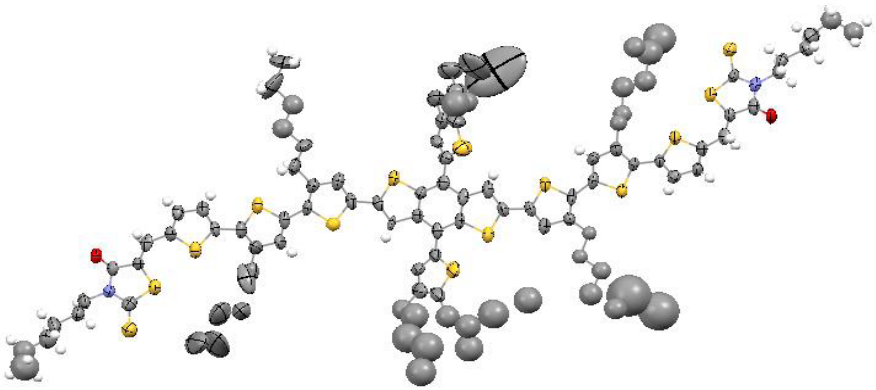
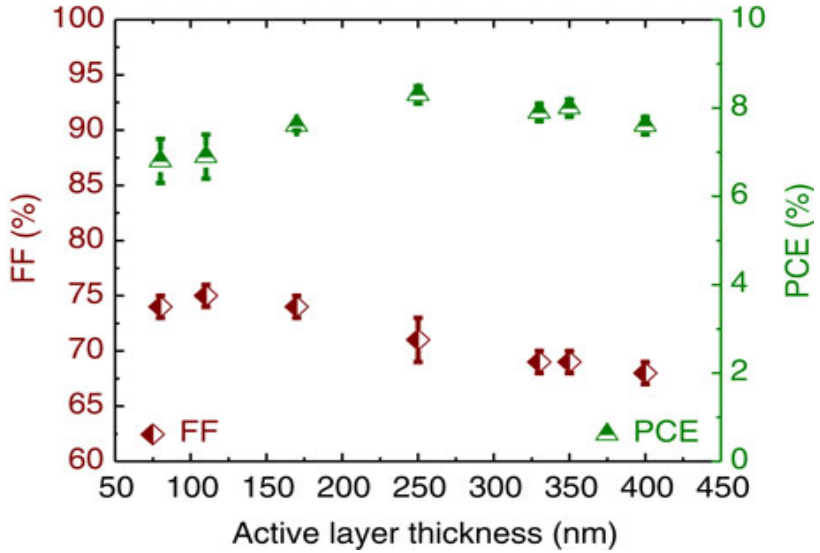
Kuan Sun, *et al.*, A molecular nematic liquid crystalline material for high-performance organic photovoltaics, *Nature Communications*, 6, 6013 (2015).





Crystal structure and molecular packing solved using MX2 beamline



OPV performance approaching 10% PCE in printable flexible films

Game-Changing Detector for Macromolecular Crystallography

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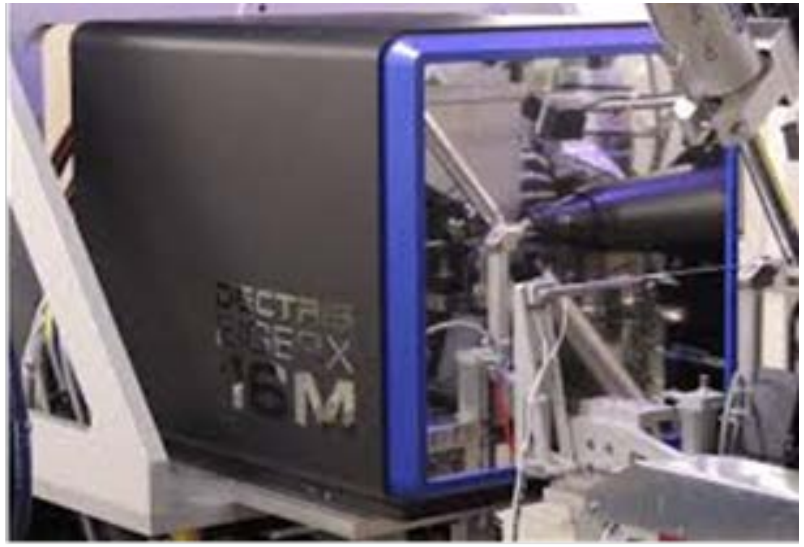


A state-of-the-art Eiger 16M detector is now operational on MX2.

The ACRF Eiger 16M can take data ~10x faster with quality that can lead to huge improvements in structural resolution.

$2M support from the

AUSTRALIAN CANCER RESEARCH FOUNDATION

Don't forget to upgrade your computing and data storage systems…

Infrared Microspectroscopy

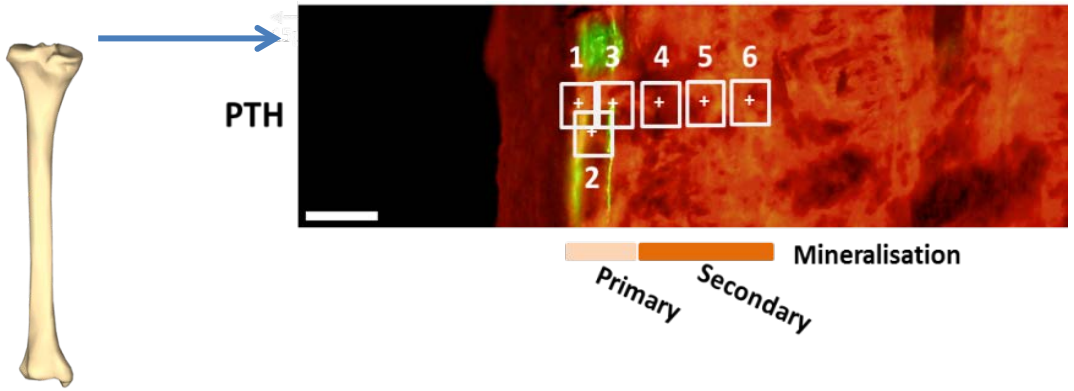
Bruker FT-IR spectrometer and
Hyperion 2000 IR Microscope

- Transmission
- Reflection
- Grazing Angle Objective
- Attenuated Total Reflection (ATR)
- Micro-compression Cell
- Linkam FTIR600 sample stage

  -196 °C to 600 °C
- Sample stages for the study of living biological cells

Motorised stage allows raster mapping
Spatially resolved “spectral maps”
(~3 -8 μm resolution)

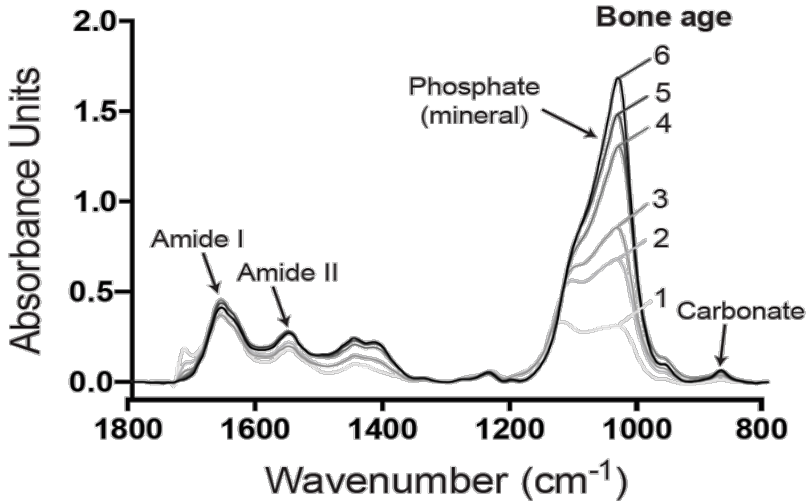
Studying Bone Quality After Drug Treatment



Fluorescence micrographs showing 6x15 µm regions from where Infrared spectra were taken.

Intermittent administration of parathyroid hormone (PTH) is used to stimulate bone formation in patients with osteoporosis.

Bone deposited during PTH treatment undergoes normal collagen maturation and normal mineral accrual.



C. Vrahnas, *et al*. *Bone*, **93**, 146, 2016

THz /Far-IR Spectroscopy

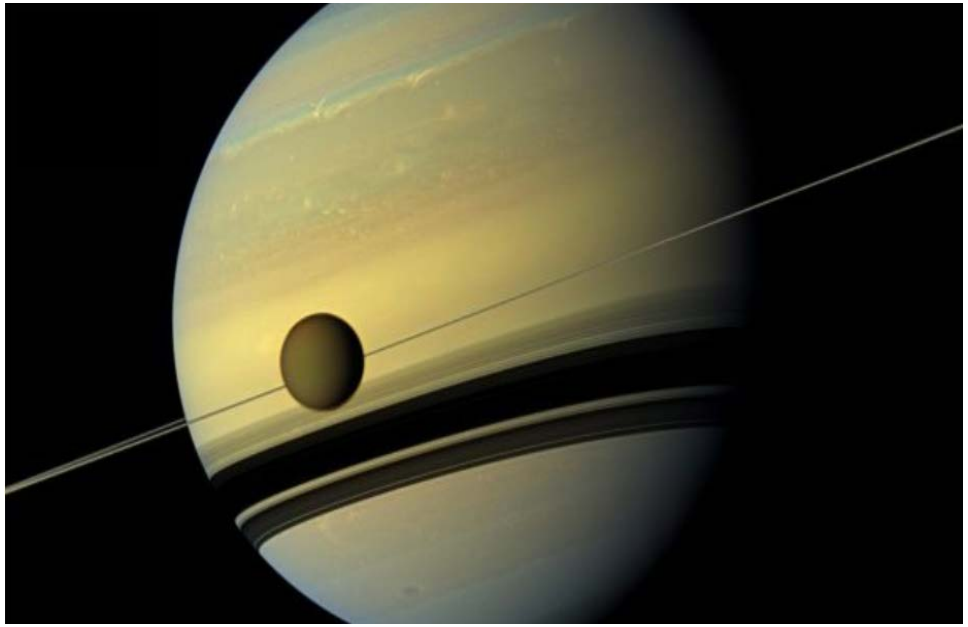
IFS 125 / HR Brüker spectrometer utilises a Michelson interferometer with an optical path length of 942 cm.

Continuous spectral coverage from the THz to the mid-IR region.

- Gases
- Surfaces
- Materials
- Cultural Heritage
- Forensic studies
- Protein & higher order structures

Can conduct studies of gaseous materials under a range of extreme environments

Astrochemistry Using THz Spectroscopy



Unlike Earth, where water drives the weather, on Titan water is frozen meaning it doesn't play a role in its atmosphere.

Weather on Titan is controlled by methane (5%) and nitrogen (95%).

The two chemicals react slowly with sunlight to form cyanide gas and other chemicals.

“Titan: 1.2 billion km away.

Cyanide rain falls from the skies and temperatures are around -180 °C.”

Far-IR spectra can be obtained using a collisional cooling cell and compared with data from the Cassini probe.

C. Ennis, *et al*.
Physical Chemistry Chemical Physics, **19**, 2915 (2017).

Imaging and Medical Beamline

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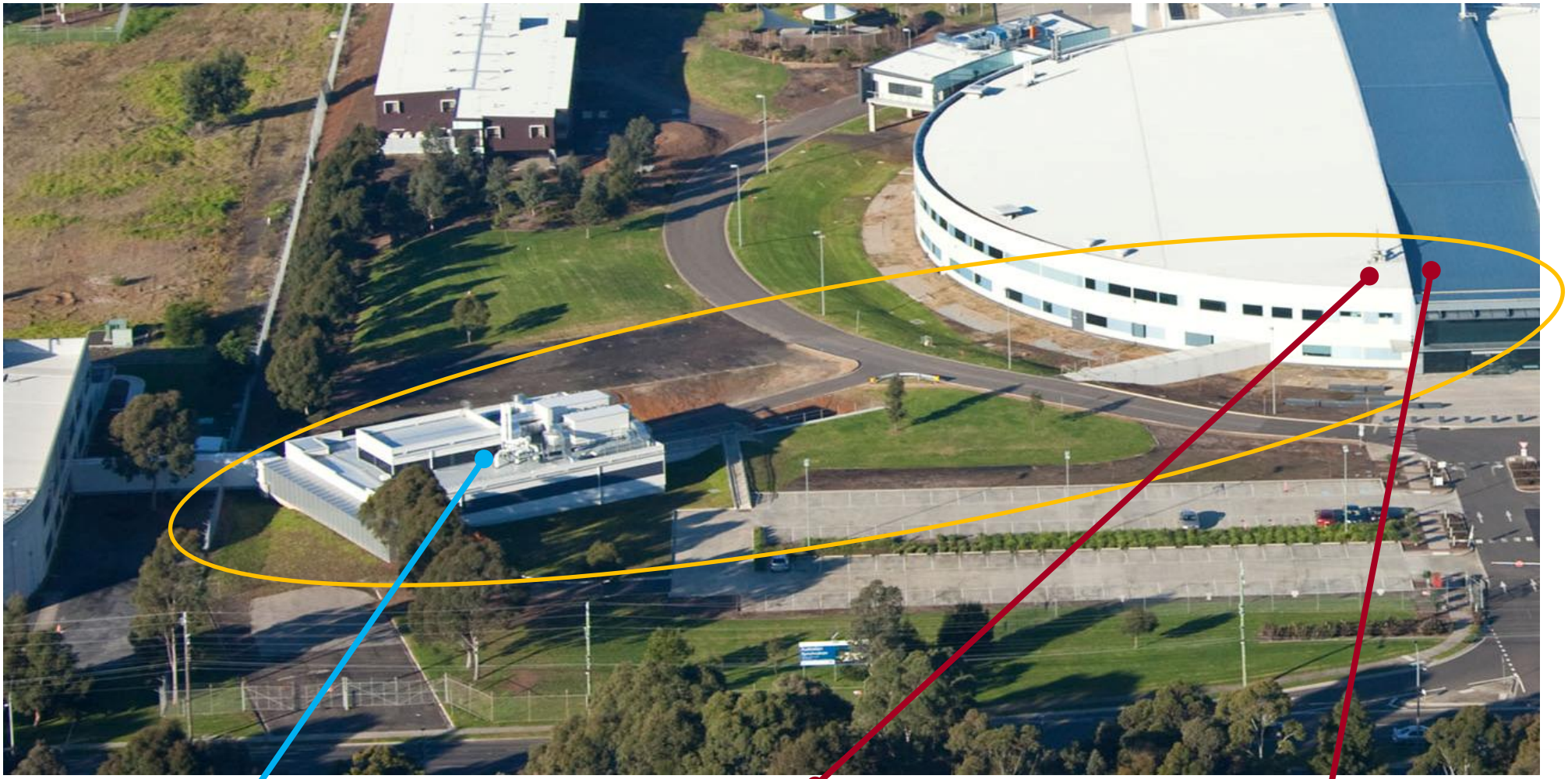

138m - High Resolution Phase Contrast Imaging

34m – Fast Imaging and Computed Tomography (CT)

22m - High Dose Irradiation, MRT

Conventional Imaging vs Phase Contrast using IMBL

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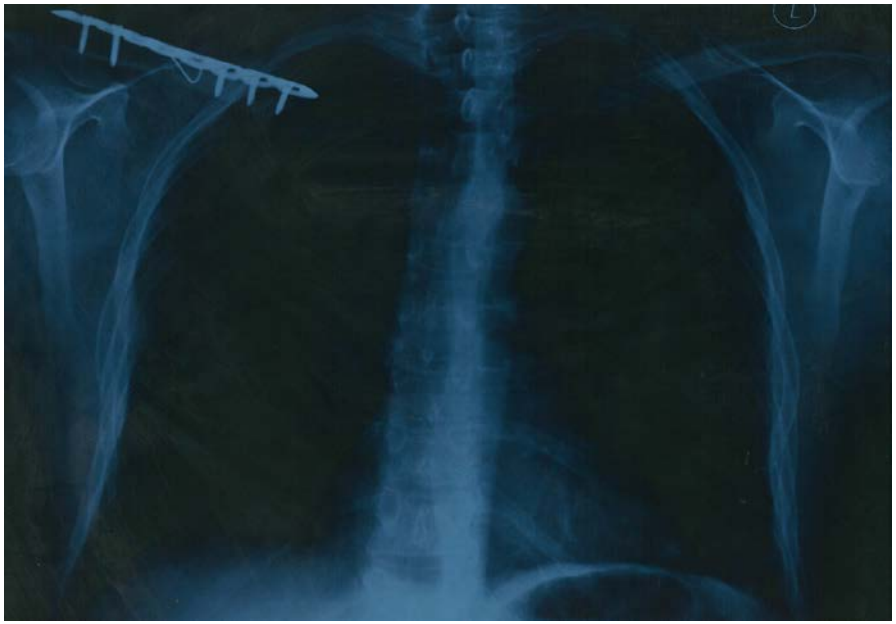
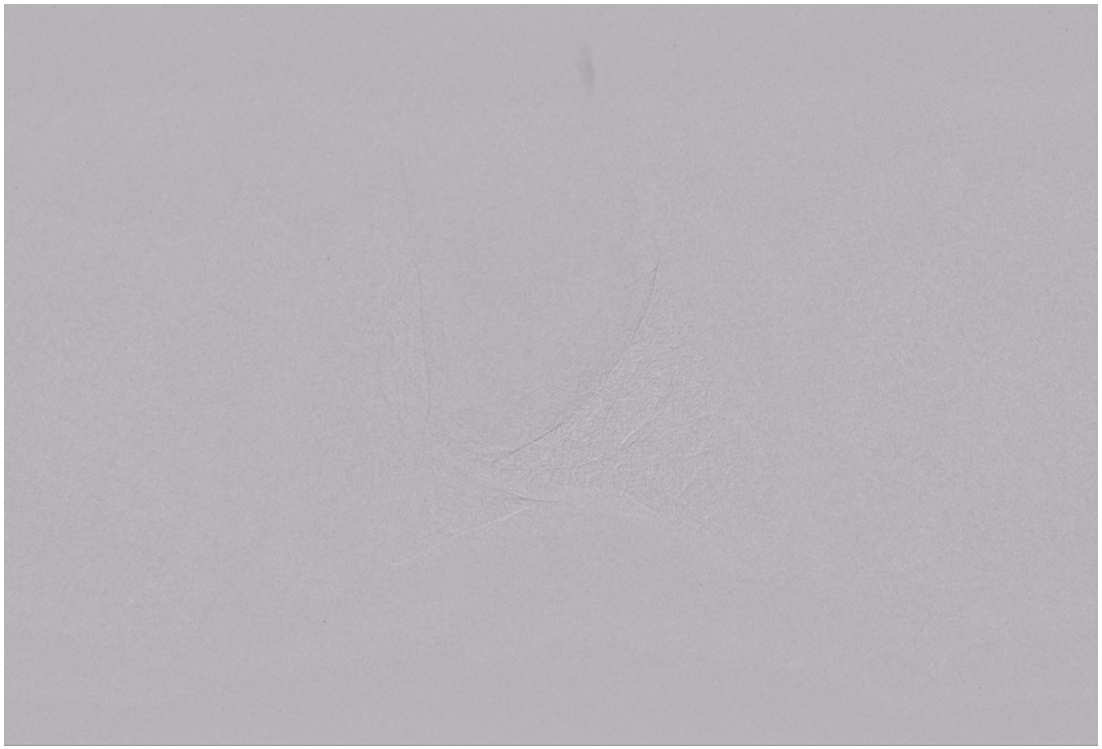


Conventional Radiograph



Phase contrast imaging provides exquisite structural detail at video speed.

CT on Large Objects – No Worries…

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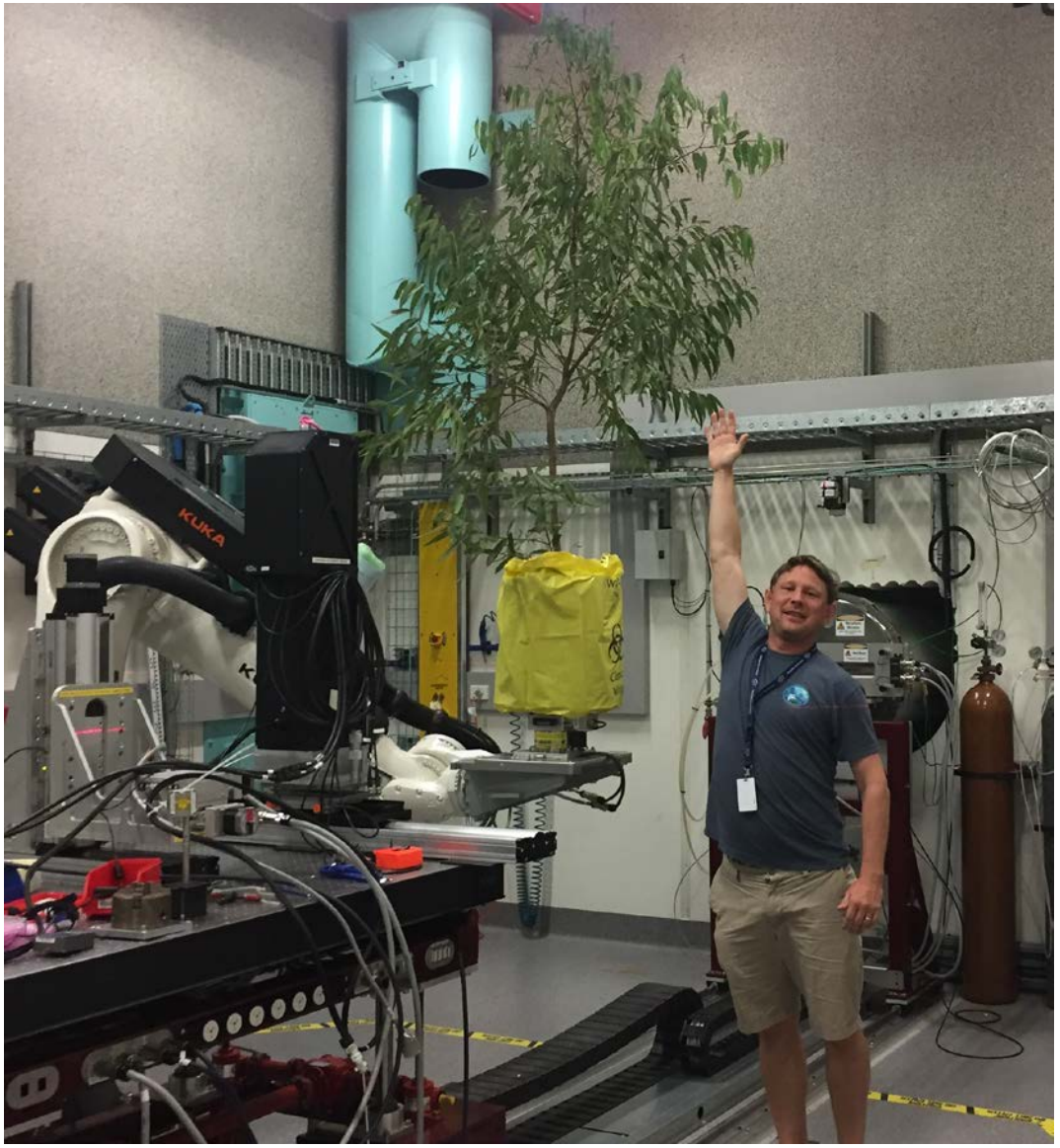


Upgraded Computed Tomography Stages

Enables *Phase Contrast* CT
of heavy (~80 kg) and
large (> 1m) objects

Photon Energy:
Up to 300 keV

Beam Dimensions:
300mm x 20mm

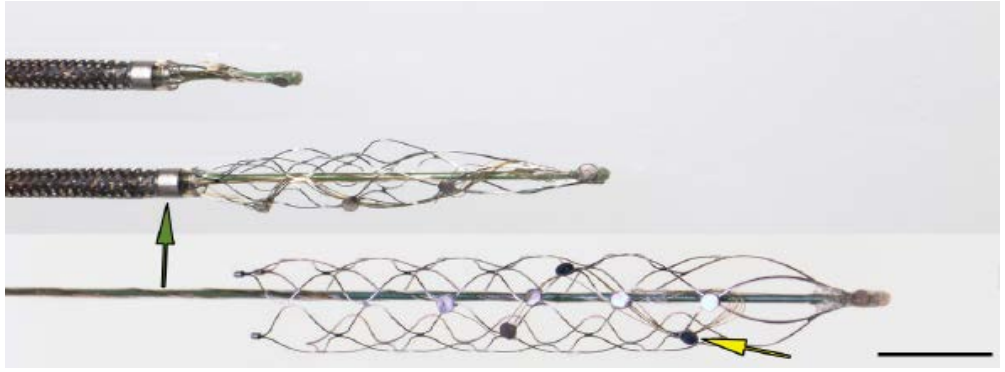
Resolution: 5-10 mm

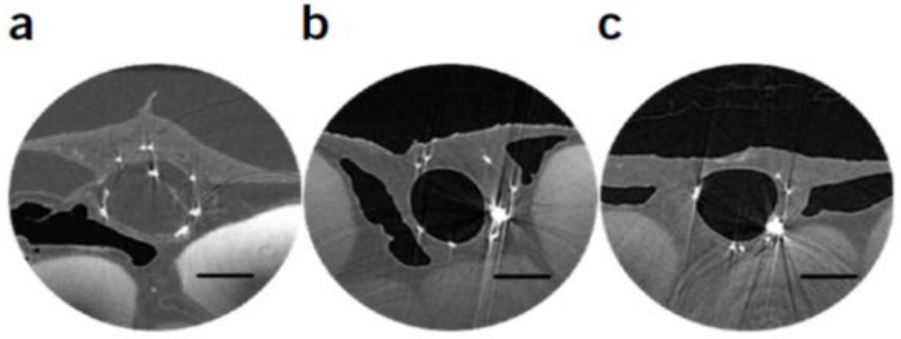
It’s Not Brain Surgery…

HOME » NEWS » WORLD NEWS » AUSTRALIA AND THE PACIFIC » AUSTRALIA

Australia scientists develop 'bionic spine' which could help paralysed patients walk

Device can be inserted in the brain – without brain surgery – and could allow paralysed patients to operate robotic limbs “using thought alone”





nature biotechnology

Thomas J. Oxley, *et al.*
Nature Biotech., **34**, 320 (2016).

Powder Diffraction Beamline

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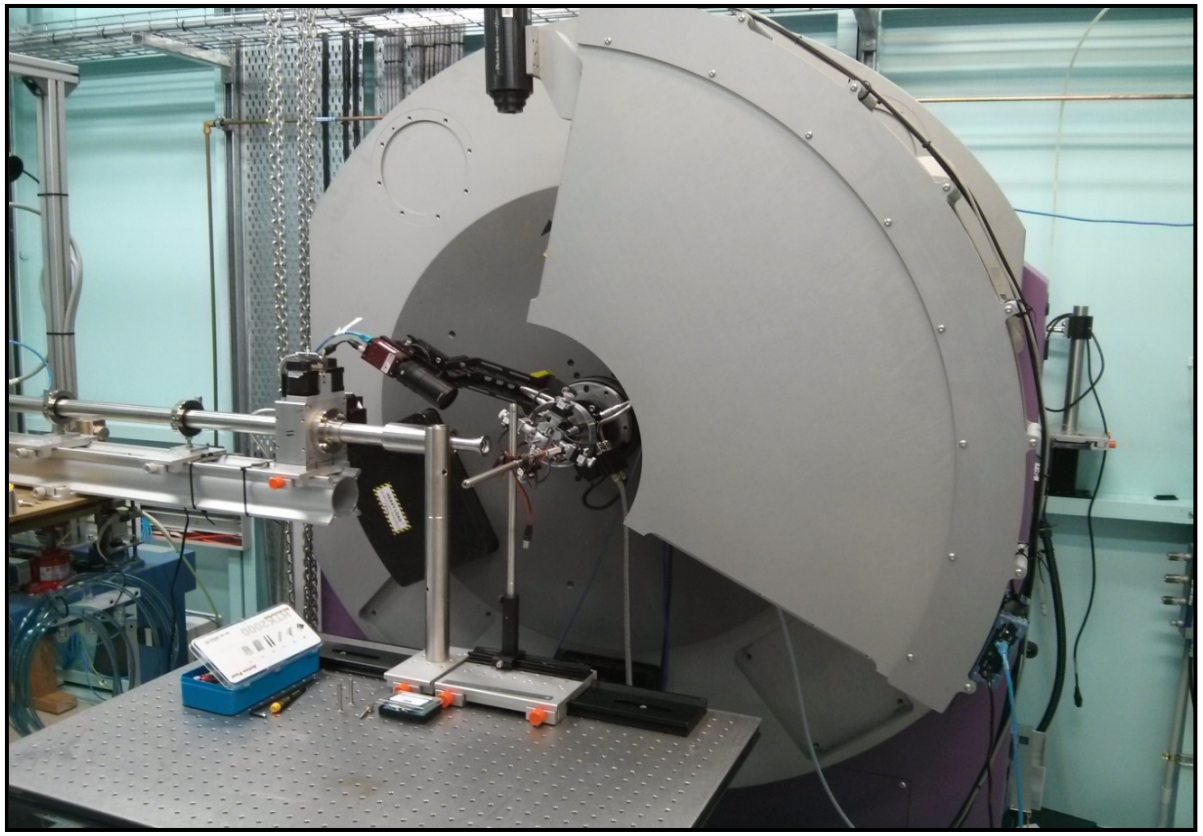
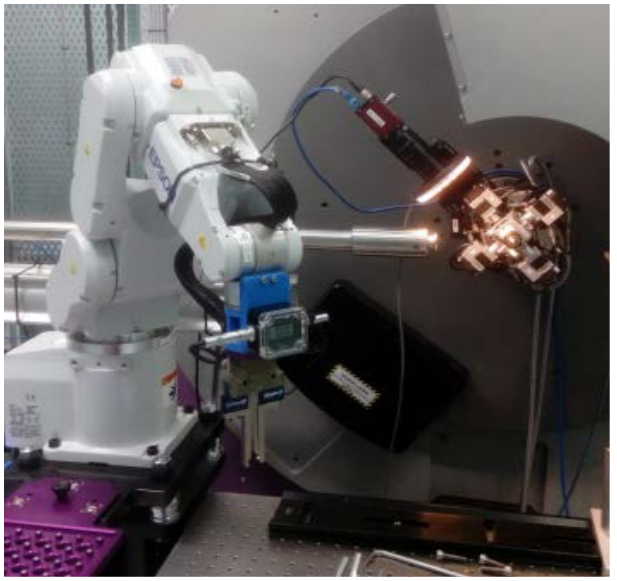




New Sample Robot

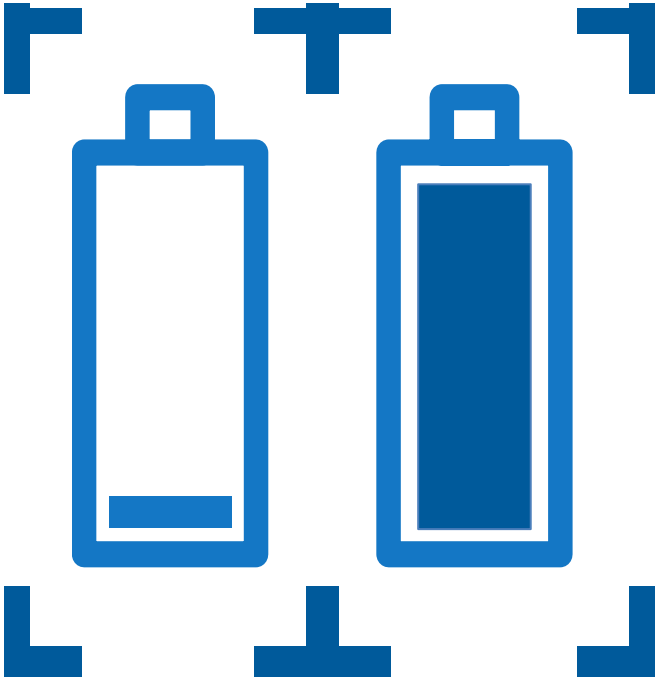
New robotic sample changer & auto-alignment system

Hot air blowers (1000 ° C), furnaces (2300 ° C), cryostream (80 K) and cryostats (10 K)

Gas & fluid flow cells, DAC (30 GPa), hydrothermal reactions

Batteries, electrochemical cells

Making Better Batteries



Li, Na and K ion batteries are key technologies for power storage

Charge / discharge → phase formation and stability at the cathode by

in situ Powder Diffraction and

X-ray Absorption Spectroscopy

High throughput battery measurement system now routine.

Studies of electrode and electrolyte chemistry.

Able to collect rapid data with realistic charge rates.

You Have More Chance of Being Hit by a Meteorite

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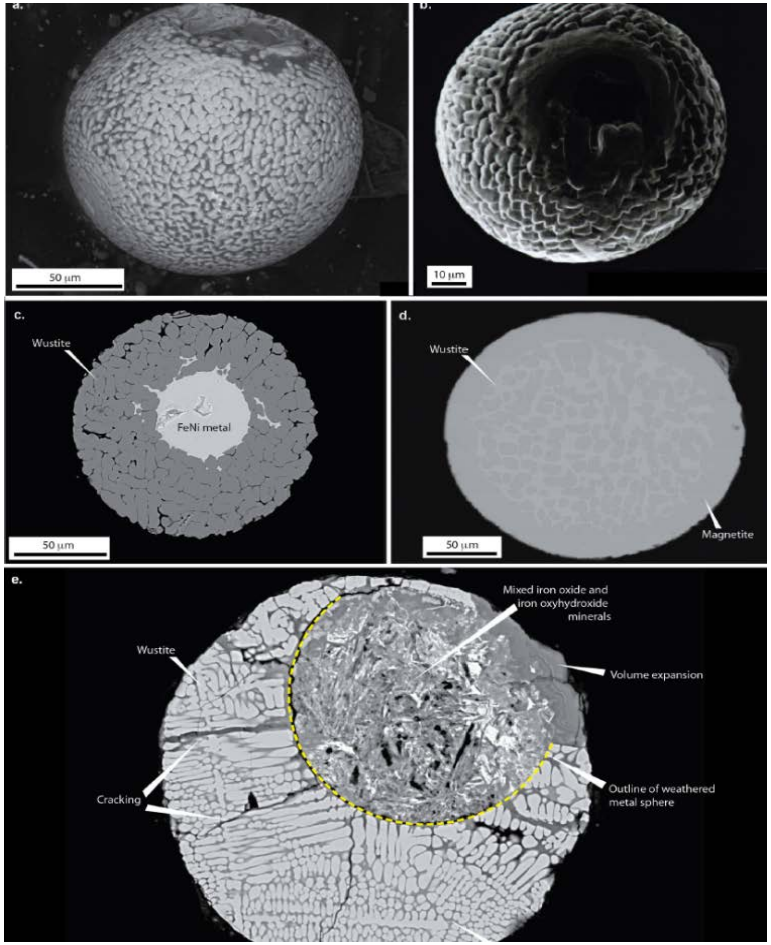
Ancient iron micrometeorites suggestive of an oxygen-rich Archaean upper atmosphere



Accepted theory on O_2 concentrations in early Earth's upper atmosphere

Oxidation of small micrometeorites passing through upper atmosphere

Separating the effects of geological oxidation

Powder Diffraction beamline used to characterise oxidised species from ~25 µm diameter samples

Andrew G. Tomkins, et al., *Nature*, **533**, 235 (2016).

Small Angle and Wide Angle X-ray Scattering

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SAXS/WAXS beamline generated > 100 publications in 2015 & 2016 and *more than 65 already in 2017*.

Polymers, Organic solar cells and electronics

Advanced drug delivery systems

Catalysis & Metal Organic Frameworks

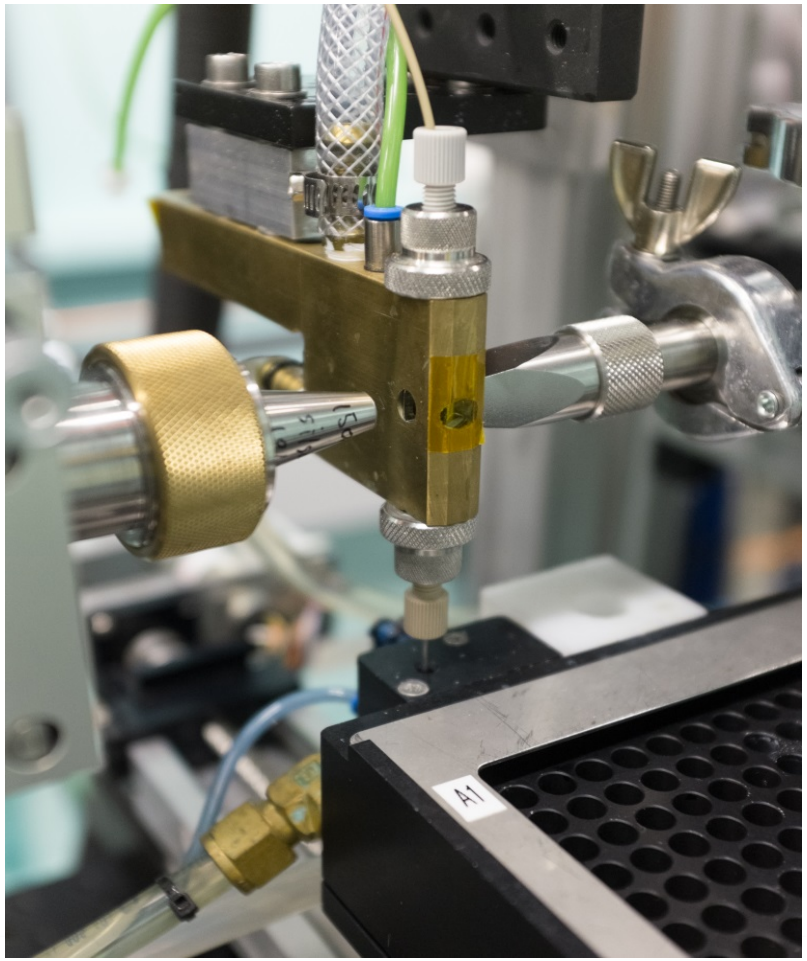
Surfactants, and Liquid Crystal systems

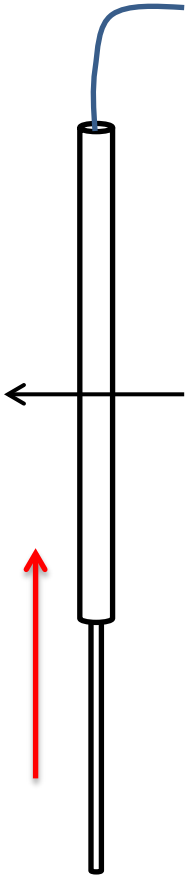
Food and Agricultural products

Nanomaterials

Protein structures and complexes

Old System for Solution Handling for Protein SAXS





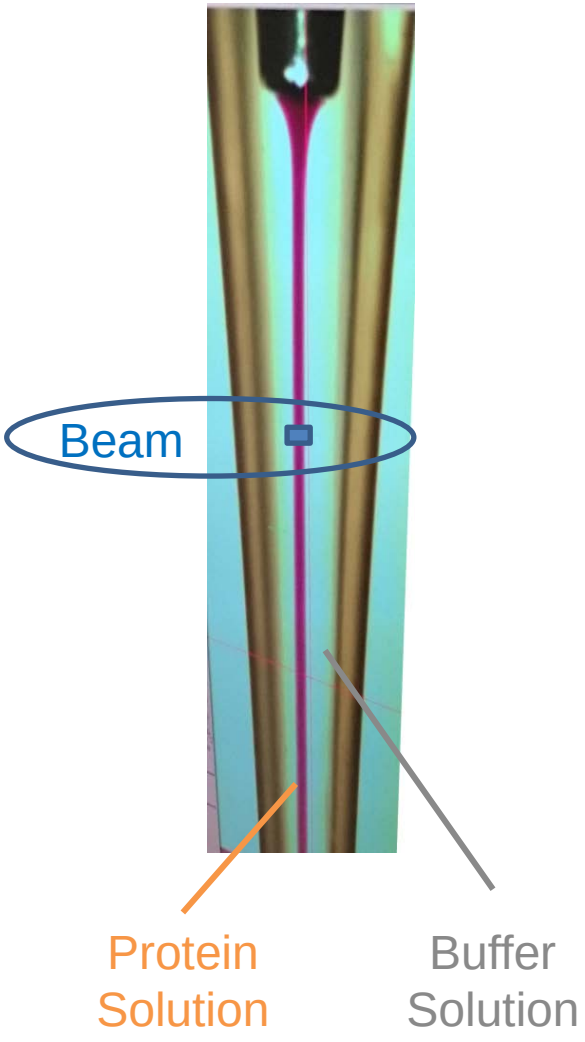
- Up to 96 samples automatically
- ~3.5 min/sample

Disadvantages:

- Requires ~50-100μL of sample

- Even under flow (~5 μL/s) still havs capillary fouling and radiation damage

Co-Flow is the Answer



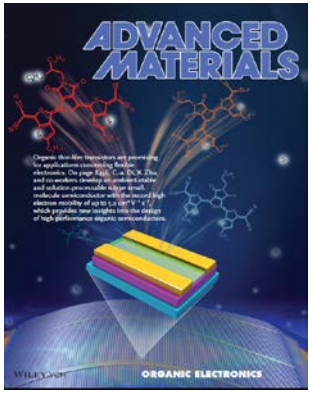
Flow sample only in centre of capillary

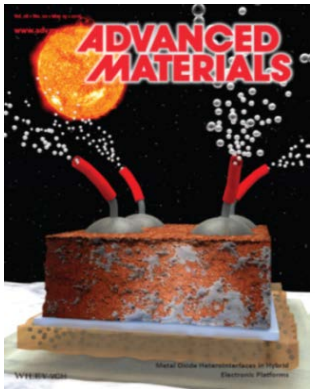
- Large improvement in dose efficiency (12-fold)
- Improved measurement statistics (2-fold)
- Reduced sample volume
  - 5-10 µL (routine) down from 50-100 µL
  - 2 µL (minimum) down from 30 µL
- Sample fouling gone
  - only very minor buffer contamination can occur
  - much more stable day to day User operations
- Throughput should be able to be increased ~3-4 fold for static samples &
  at-least 2-fold for *Size Exclusion Chromatography*.

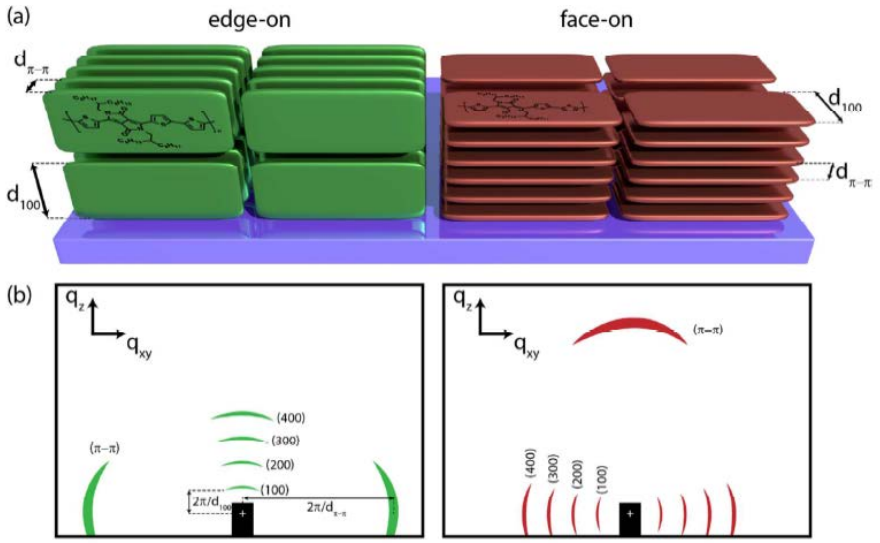
Nigel Kirby et al., *Acta Cryst. D*, **72**, 1254 (2016).

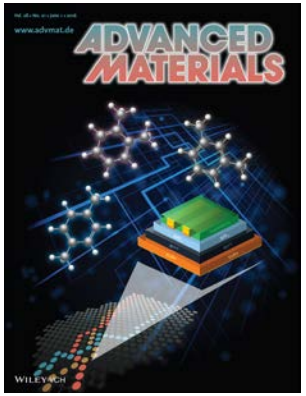
Polymer-Based Organic Photovoltaics & Electronics

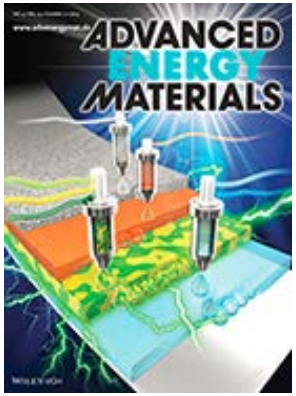
Researchers use the **Soft X-ray Spectroscopy beamline (NEXAFS)** to determine **molecular orientation**, and the **SAXS/WAXS beamline (GIWAXS)** to study **polymer crystallinity** in semiconducting polymer devices.











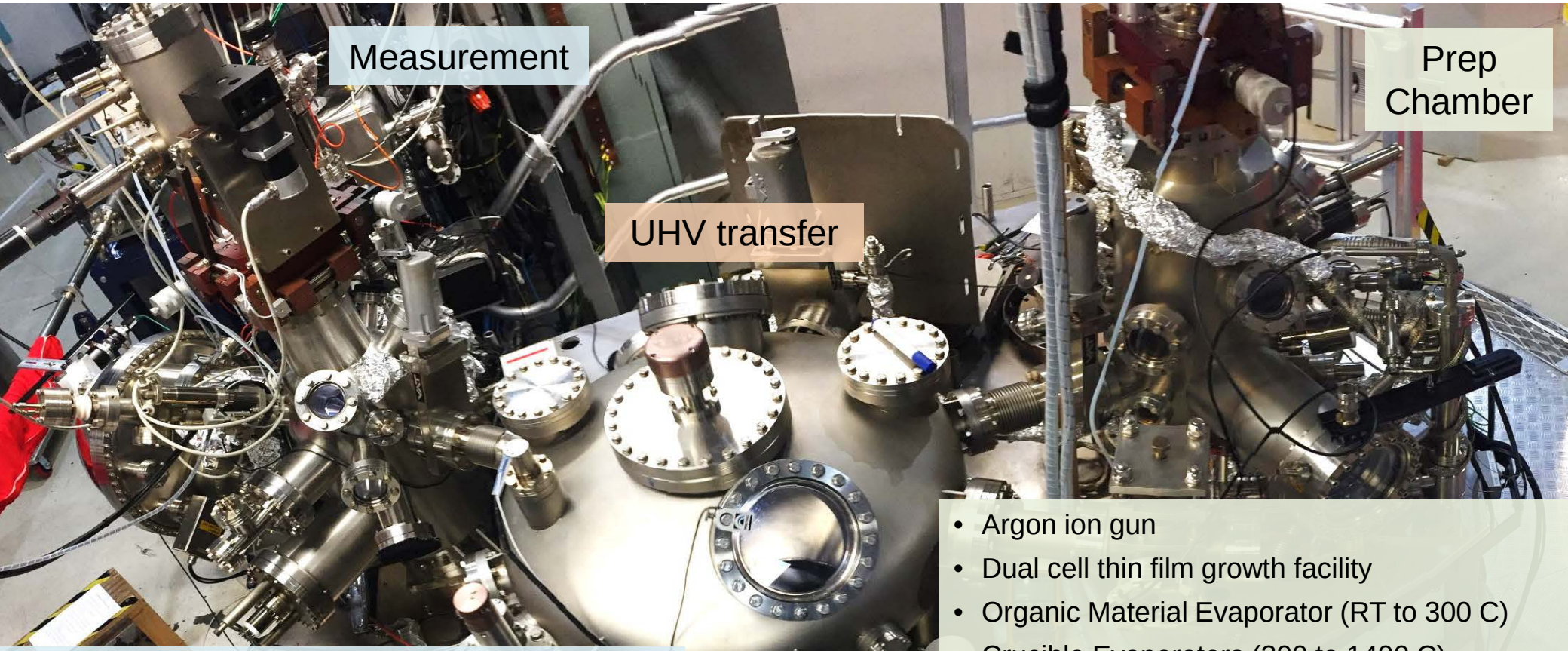
Plenty of great publications in:

Nature Communications, Applied Materials Interfaces, Advanced Materials, Advanced Energy Materials, Nano Energy, Chemistry of Materials,…

Soft X-ray Spectroscopy Endstation

Australian Government

Ansto



XPS

- SPECS Phoibos™ 150 energy analyser

NEXAFS

- Total electron yield (TEY)
- MCP – Total Fluorescence Yield (TFY)
- Channeltron – Partial Electron Yield (PEY)

- Argon ion gun
- Dual cell thin film growth facility
- Organic Material Evaporator (RT to 300 C)
- Crucible Evaporators (300 to 1400 C)
- Electron Beam (rod) evaporator (to 2500 C)
- Low Energy Electron Diffraction (LEED)
- Quartz Crystal Microbalance
- Heating/cooling of sample: -160 C to 1600 C
- Gas Dosing (to 10^{-5} mbar)
- Kelvin Probe, 4 point probe

Soft X-ray Spectroscopy Endstation

Australian Government

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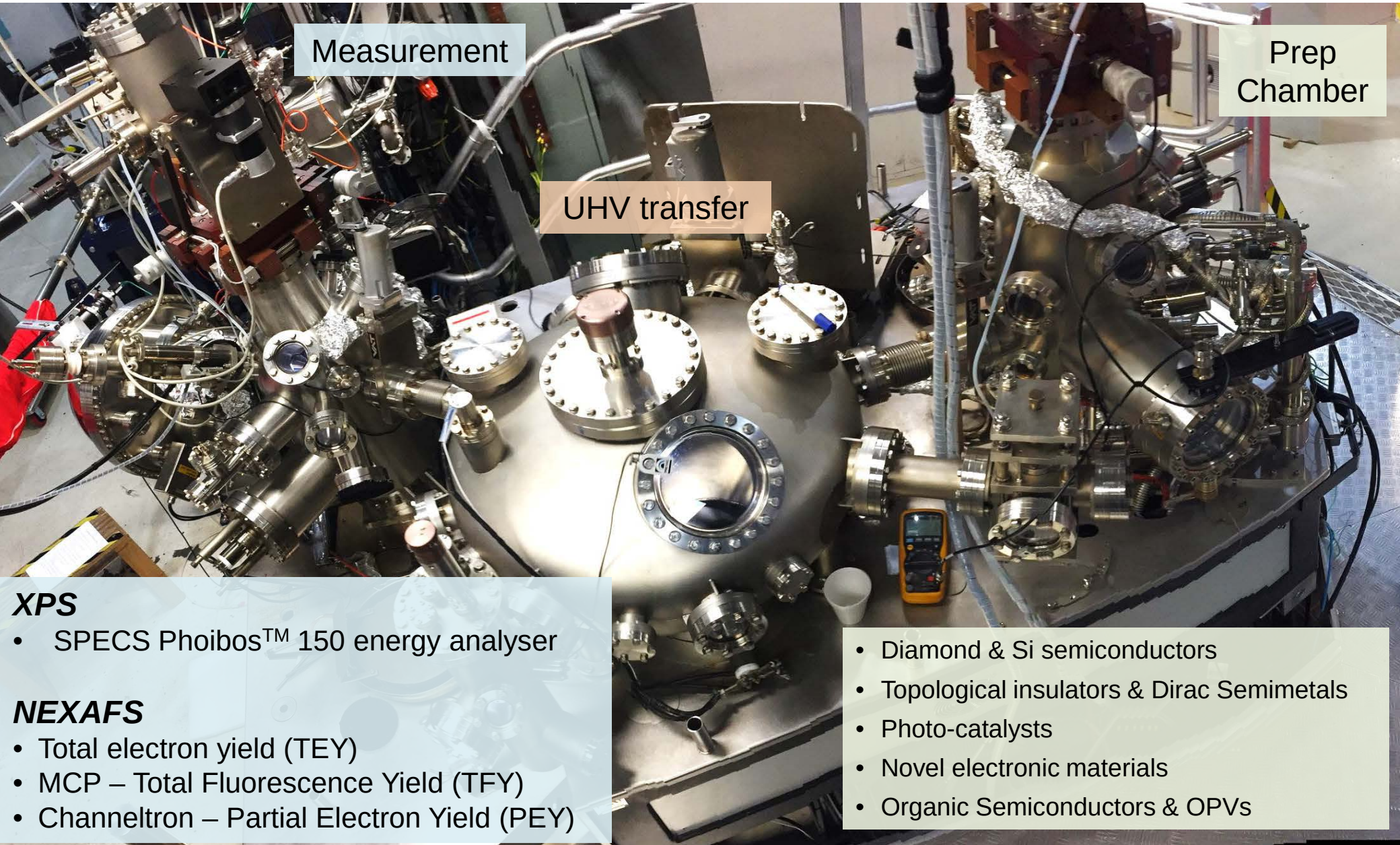


XPS

- SPECS Phoibos™ 150 energy analyser

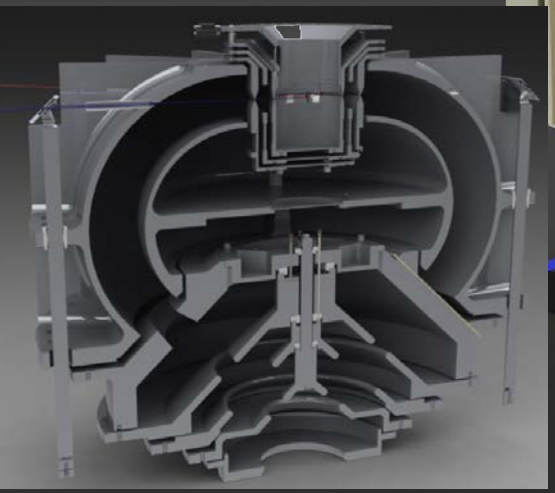
NEXAFS

- Total electron yield (TEY)
- MCP – Total Fluorescence Yield (TFY)
- Channeltron – Partial Electron Yield (PEY)

- Diamond & Si semiconductors
- Topological insulators & Dirac Semimetals
- Photo-catalysts
- Novel electronic materials
- Organic Semiconductors & OPVs

ARPES @ Australian Synchrotron
Toroidal analyser

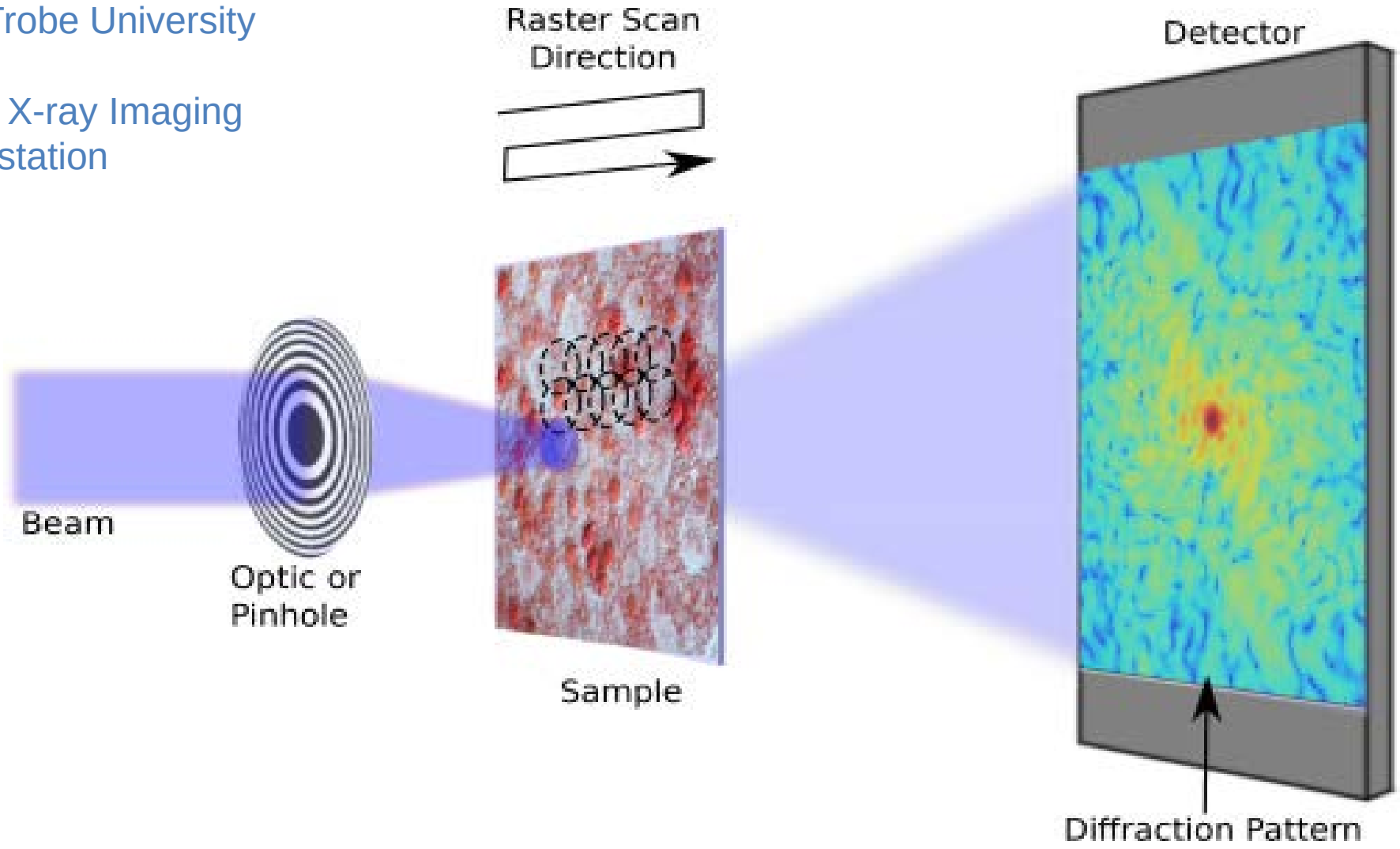
Offline (VUV lamp)
Online (SXR beamline)



“Super Resolution” Microscopy: Coherent Soft X-ray Ptychography

La Trobe University

Soft X-ray Imaging Endstation

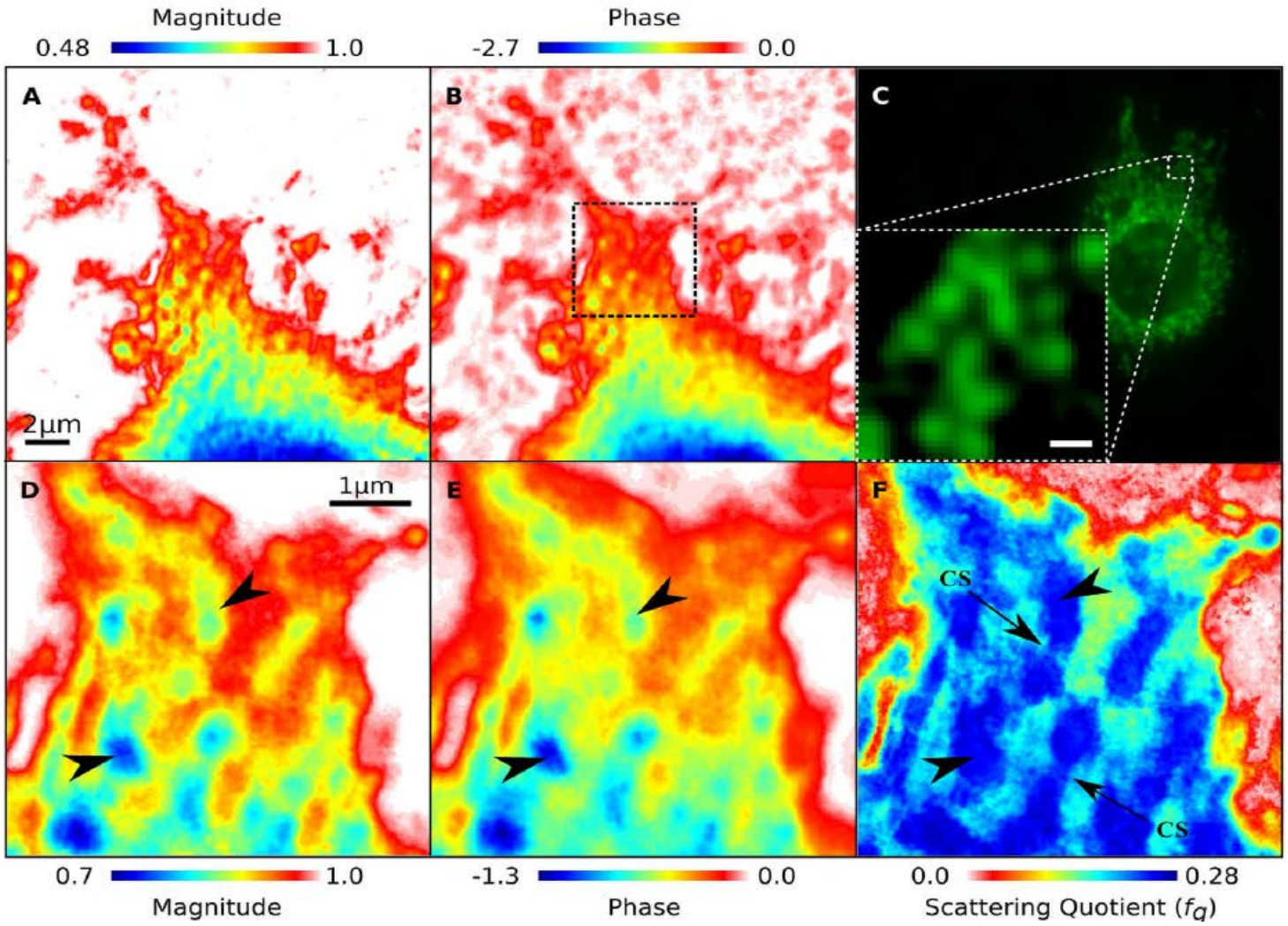


Michael Jones, et al., *Scientific Reports* **4**, 6796 (2014).

“Super Resolution” Microscopy: Coherent Soft X-ray Ptychography

Australian Government

ansto



Data taken using
La Trobe University

Soft X-ray
Imaging Endstation

Michael Jones, et al., *Scientific Reports* **4**, 6796 (2014).

X-ray Absorption Spectroscopy Beamline

Australian Government

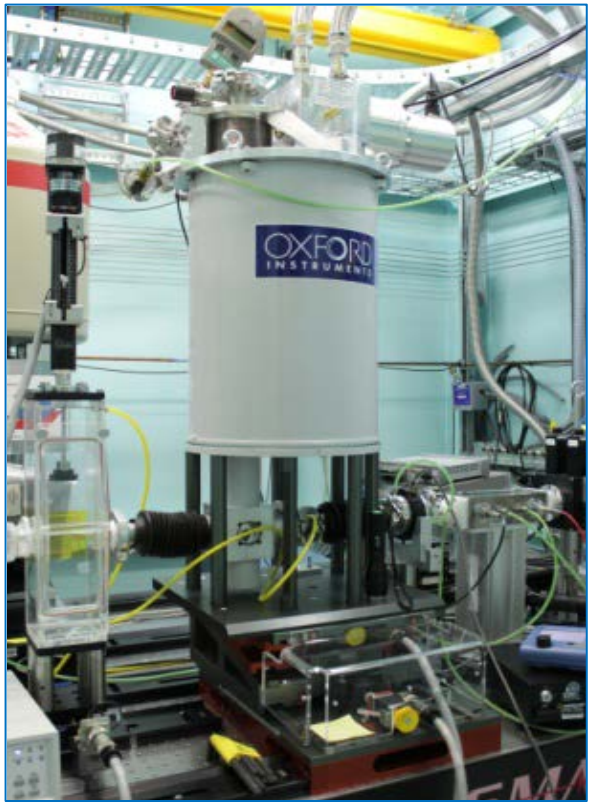
ansto

- High brilliance, micro-focused beam.
- Various sample types:

  liquids, solids, films, glasses, soft matter,

  biological tissues and cells,…
- Almost all metals and heavier elements (Ti to Pu)
- Large concentration range: ~100 ppb to ~10%
- p = 1...600 bar; T = 5...1500 K

(~$1M monochromator upgrade in progress)



Studies of metals in Environmental Science, Advanced Materials, Earth Science Minerals Formation & Processing,…

Multi-Anvil Press ("D-DIA") – XAS Hutch C

Australian Government

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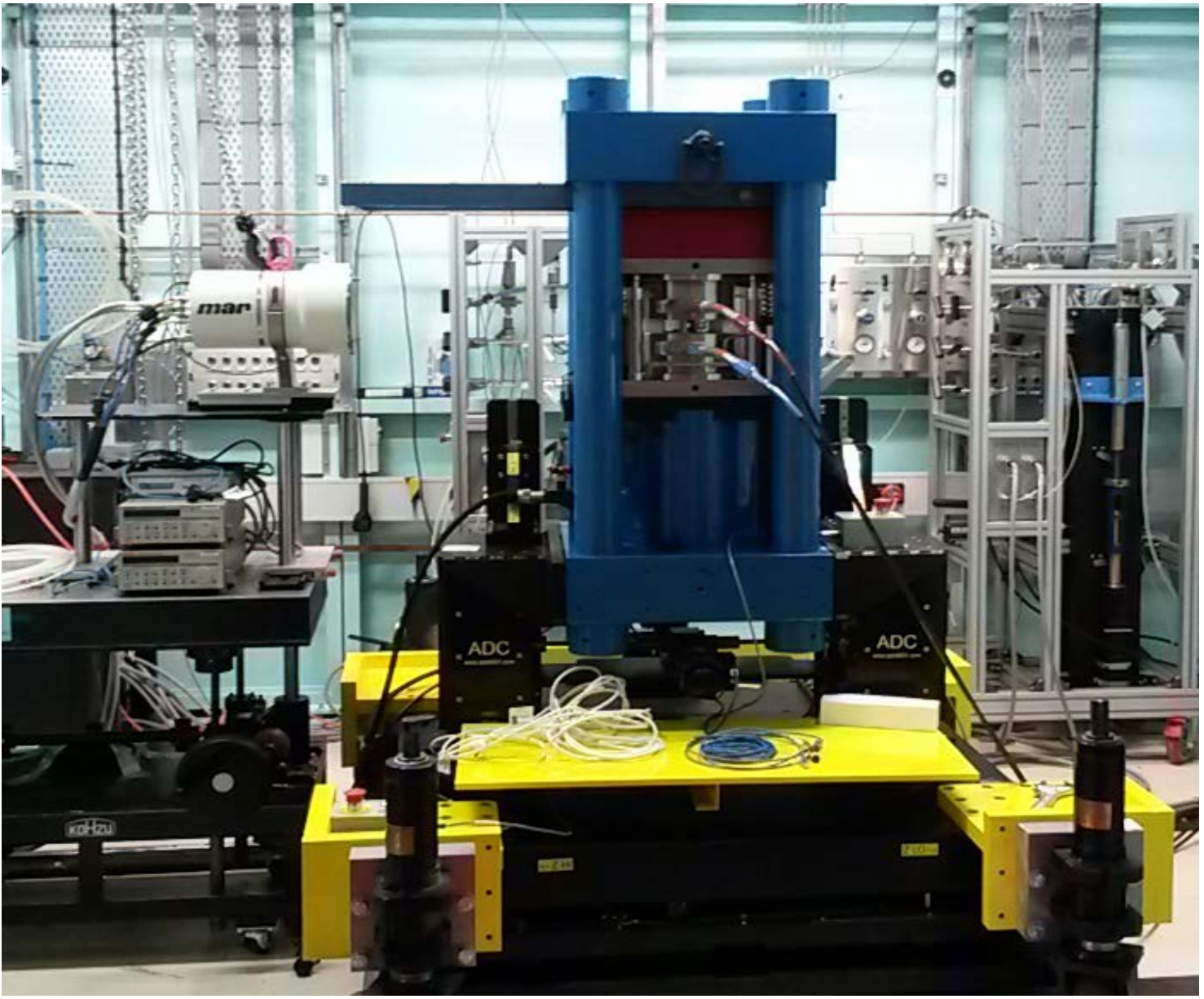


The D-DIA allows study of materials under extremes of temperature & pressure

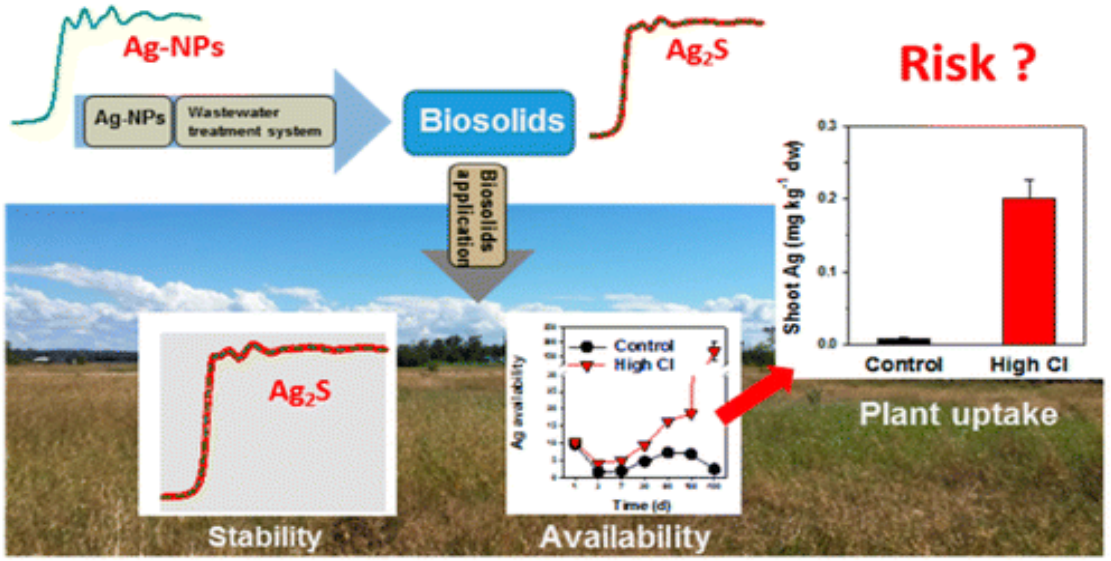
(~Upper Earth Mantle)

Australian Synchrotron

Nanoparticles and the Environment (XAS)

The widespread use of silver nanoparticles (Ag-NPs) results in their movement into wastewater treatment facilities and into agricultural soils.

Ag-NPs entering soils via wastewater pose a low risk to plants due to their conversion to Ag_2S in the wastewater treatment process.



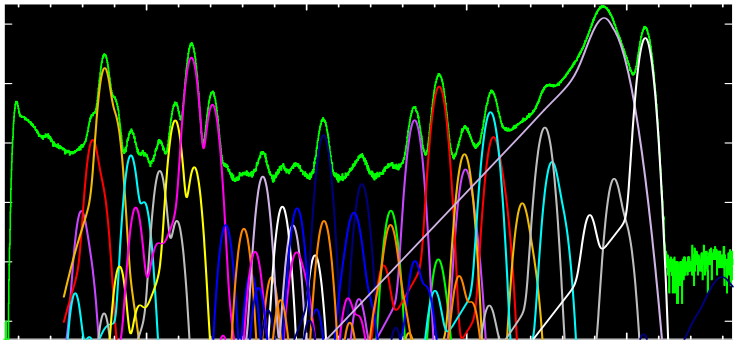
Peng Wang, *et al.*,
Environmental Science and Technology, **50**, 8274 (2016).
Environmental Science: Nano, **4**, 448 (2017).

XFM - For the Study of Metals in Biology, Environment, Earth Sciences,…

Australian Government | ansto

Simultaneous access to **10^{+} elements**
Z > 14 ~ Si

High sensitivity - sub-ppm; sub-mM; 1e-12 g/s



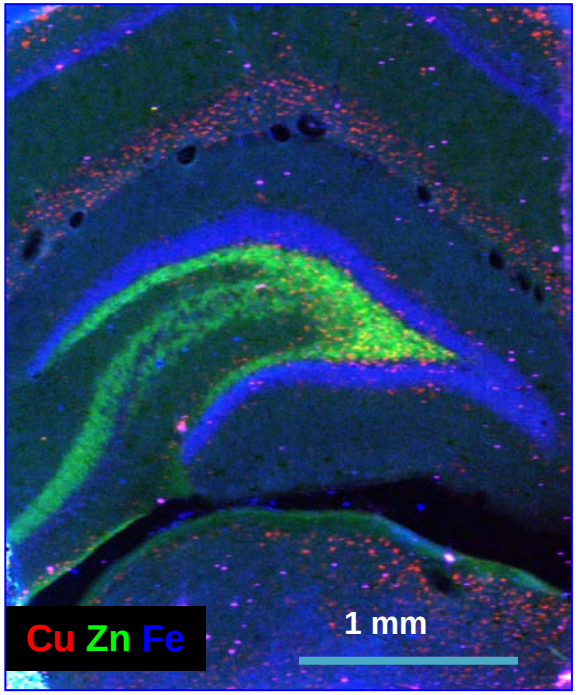
Native contrast - no dyes or contrast agents necessary

Quantitative

Non-destructive / minor damage

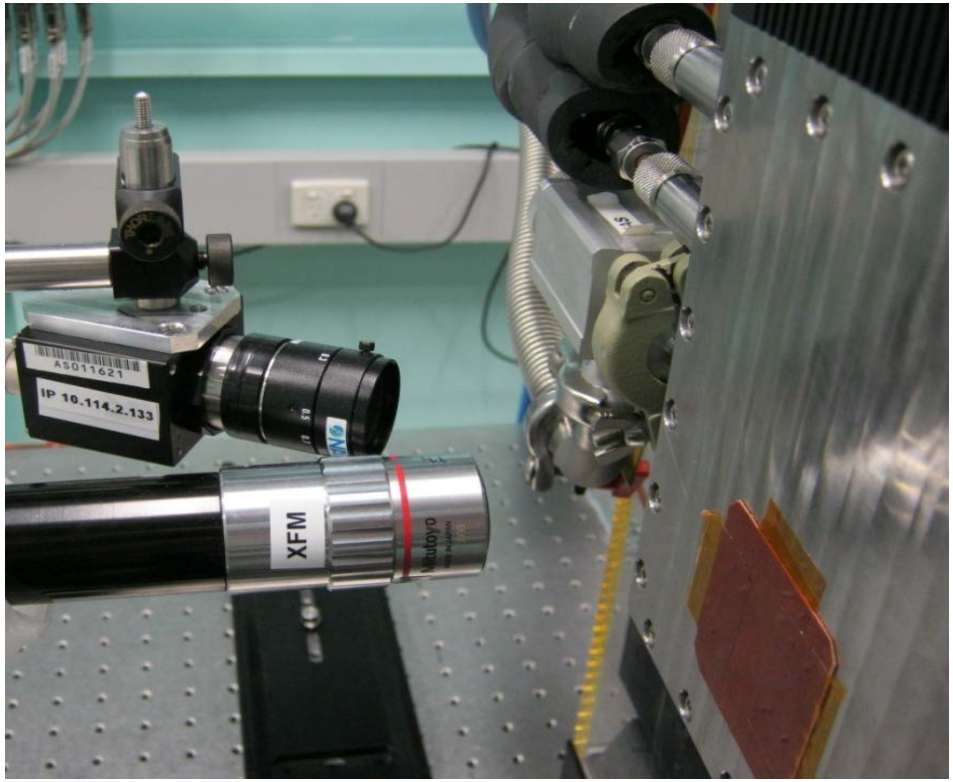
Extended penetration & Depth of Field
- study intact cells & sections

Sensitive to **chemical speciation** via XANES spectroscopy



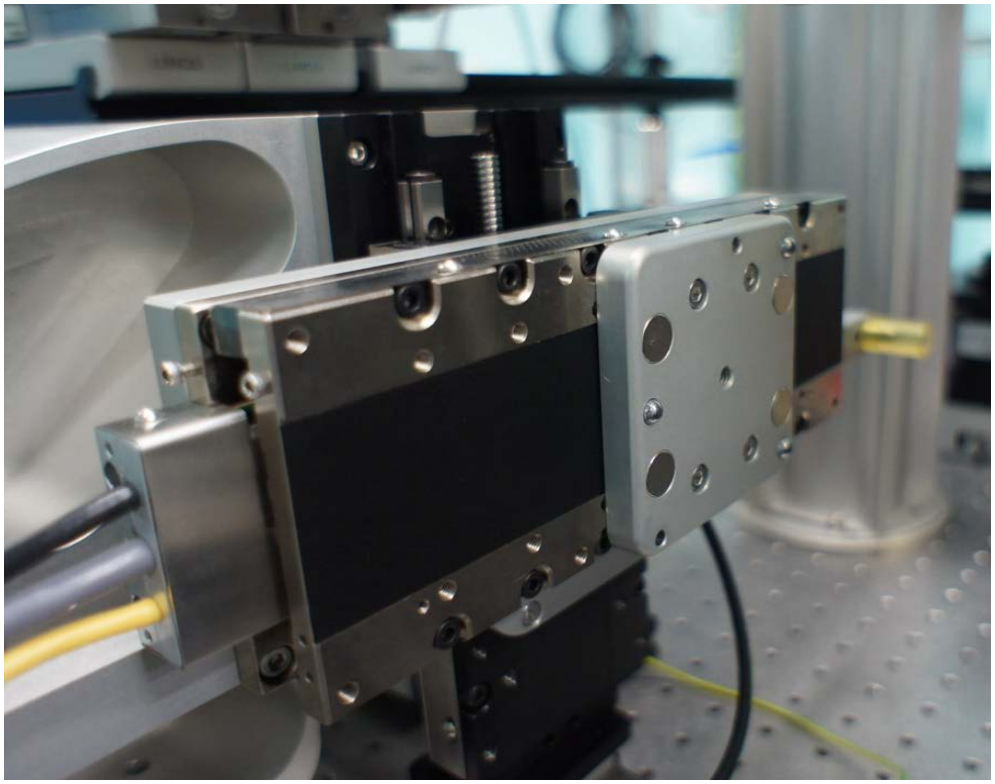
XFM Microprobe for Mapping Metals Now Approaching Megapixels/sec

Australian Government | Ansto



Maia Detector – Rev C

(Improved ΔE; Elements down to Si)



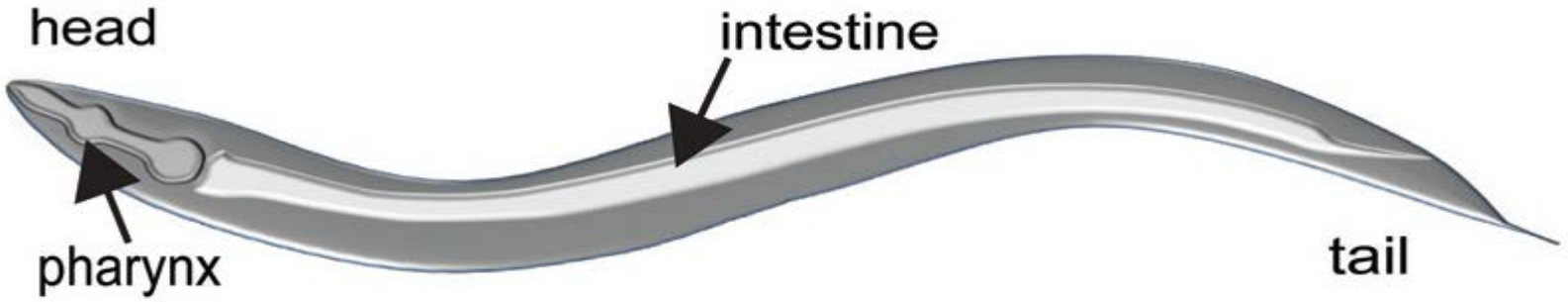
Fast Scanning Stages

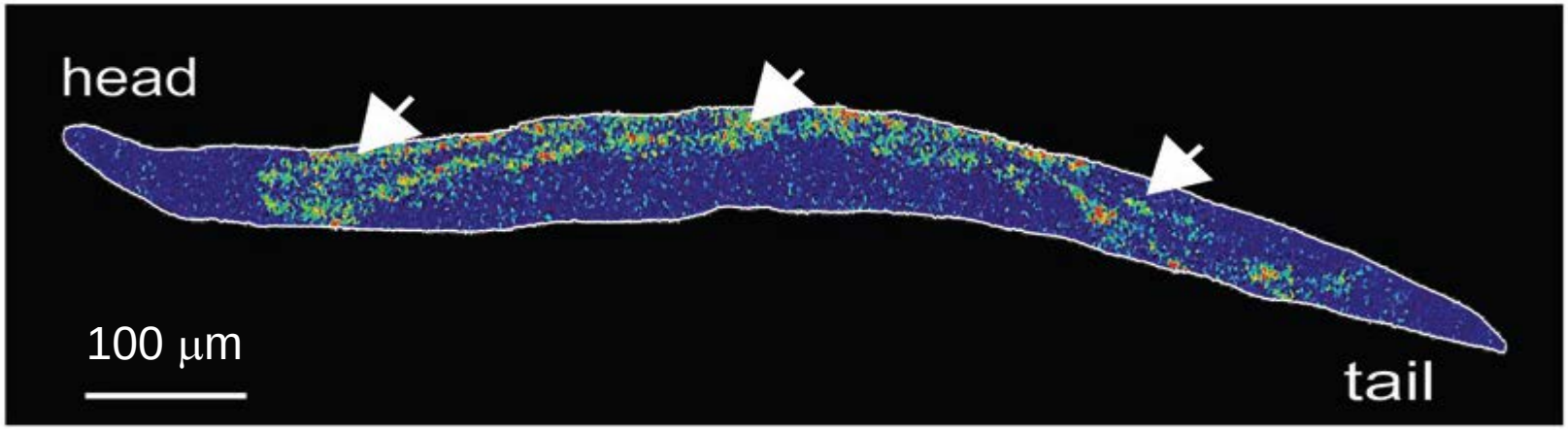
Up to 200 mm/sec

> 100,000 pixels/second

Australian Synchrotron

XFM: Scanning Metals in Biology





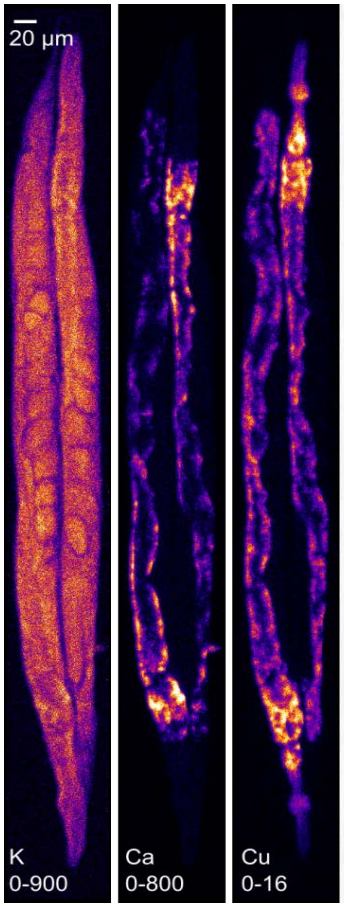
Katherine Ganio, et al. *Analyst*, **141**, 1434 (2016).

Multimodal Whole "Animal" Imaging With X-ray Fluorescence Microscopy

Australian Government

ansto

The X-ray Fluorescence Microprobe reveals elemental composition within *C. elegans* @ 2 μm resolution using a Maia Detector



Dr Gawain McColl
(unpublished)

synchrotron.org.au

Super-resolution
(~50 nm)
using
Coherent
X-ray
Ptychography

Phase
+
Fluorescence
(Cu)

Australian Synchrotron

Multimodal Whole “Animal” Imaging With X-ray Fluorescence Microscopy

Australian Government

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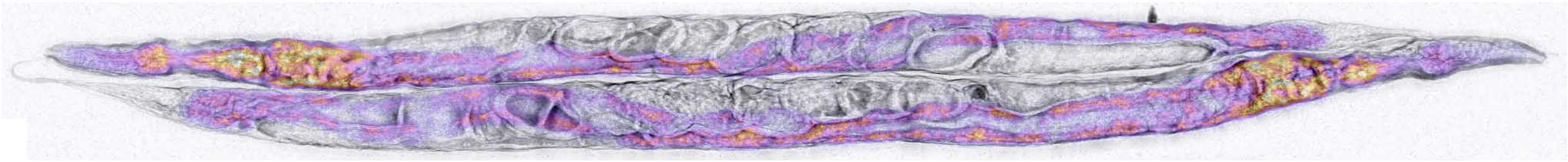
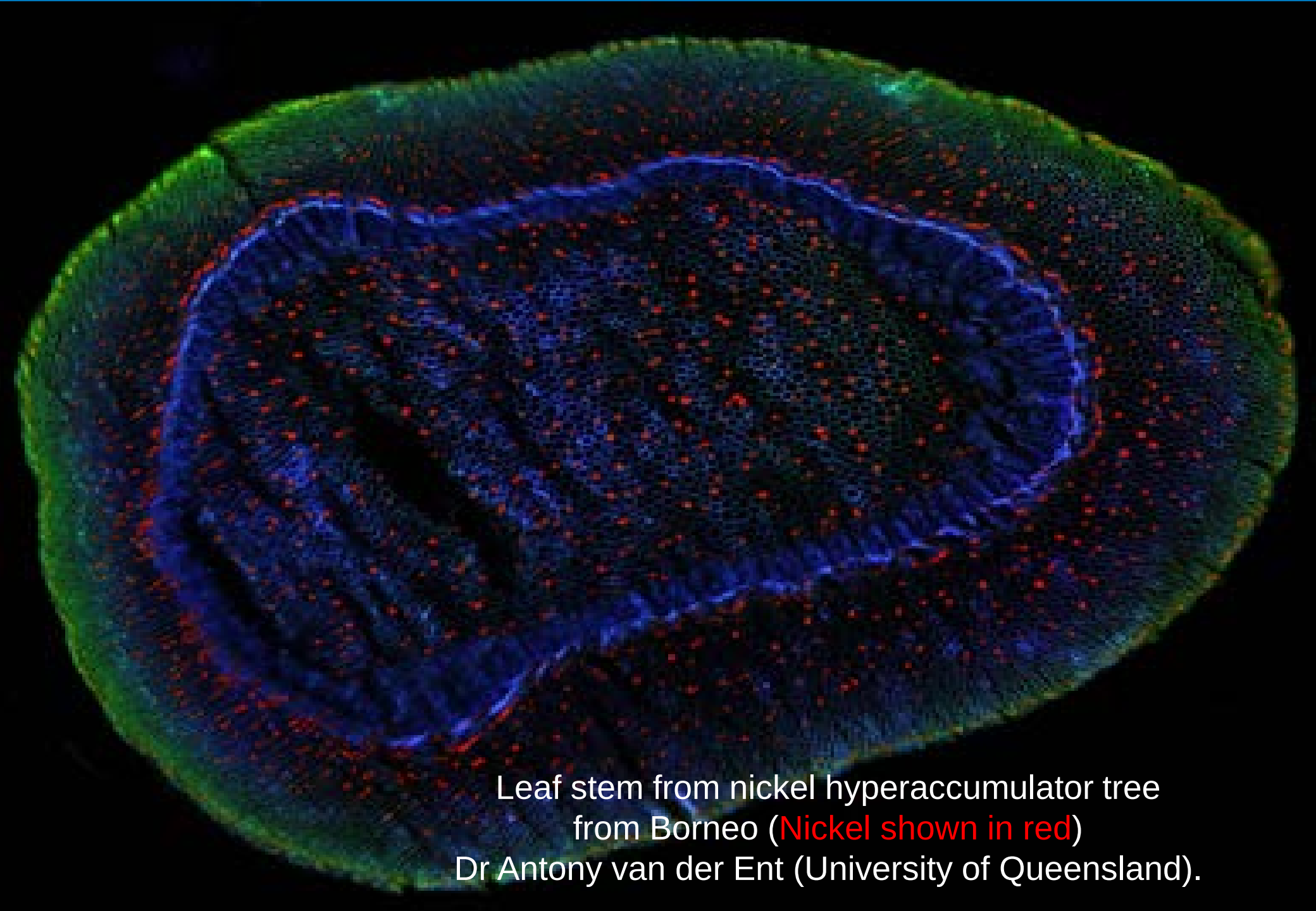


478,349 diffraction patterns in a single “fly scan” in 3 hours

(Previously, a similar “step scan” would take an additional ~26 hours)



Leaf stem from nickel hyperaccumulator tree
from Borneo (Nickel shown in red)
Dr Antony van der Ent (University of Queensland).

X-ray Fluorescence Microscopy Unlocks Hidden Treasures

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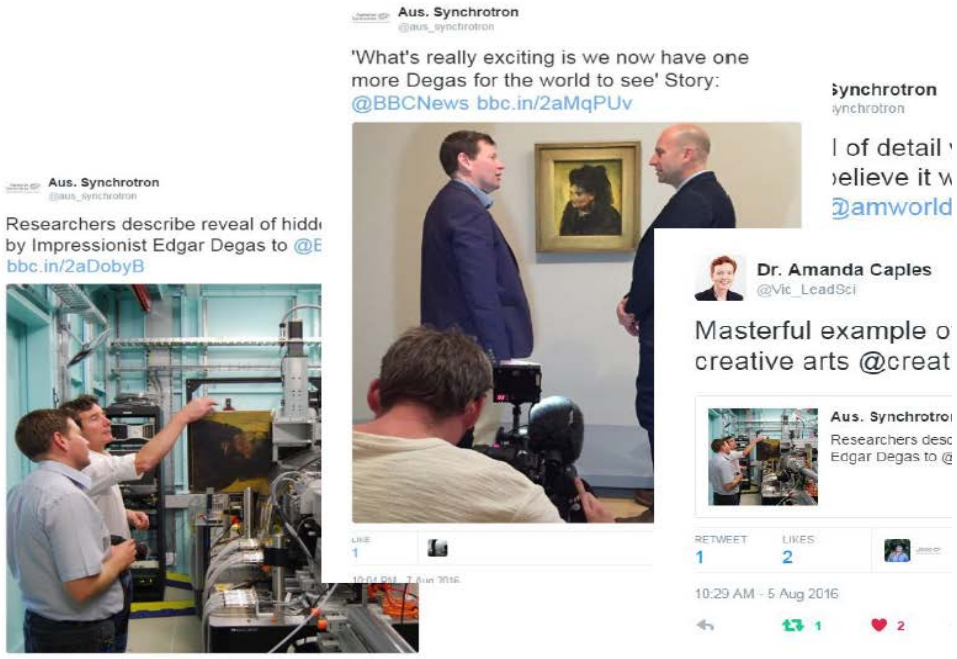
Paper in *Scientific Reports* describing analysis of Degas' "Portrait of a Woman".

Associated media release triggered *a massive* social and conventional media response.

Coincided with major Degas Exhibition at National Gallery of Victoria

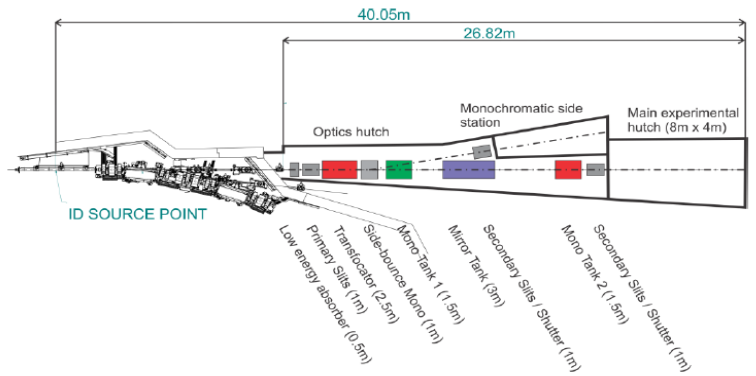


International Coverage
> 1400 Media Articles

TV – News, Catalyst
Radio
Newspapers
Web

Australian Synchrotron

BRIGHT: New Beamlines for the AS



$114 million program to design and construct the next 8 beamlines.

- Micro-Computed Tomography
- Medium Energy XAS
- Advanced Diffraction and Scattering
- Bio-SAXS
- High Performance Macromolecular Crystallography
- Micro Materials Characterisation
- Multi-Modal Nanoprobe

Program to Commence in July 2017

Any Questions?...

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