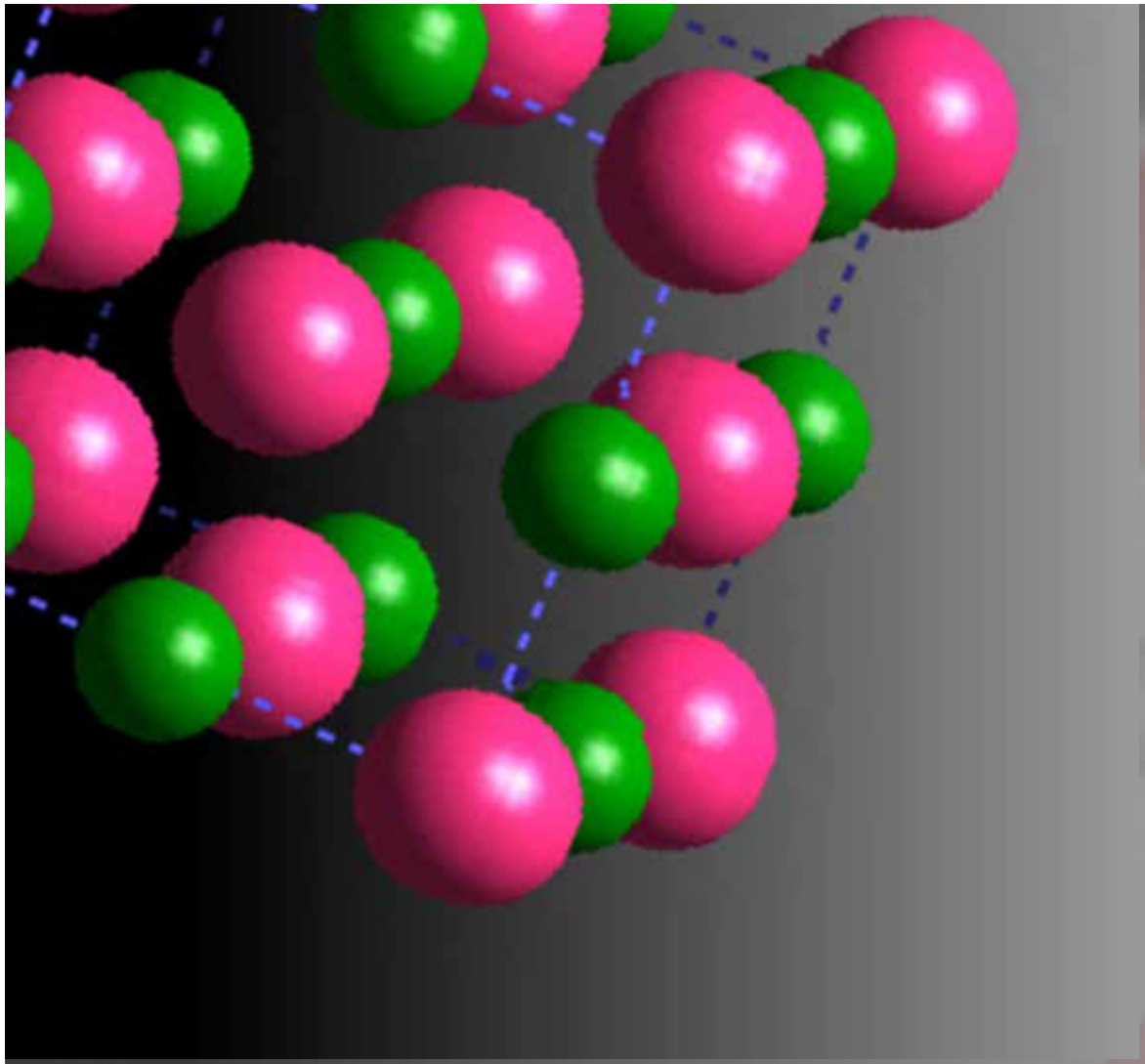
# Welcome to ISIS

Christopher Frost
ISIS Facility, Rutherford Appleton Laboratory, UK

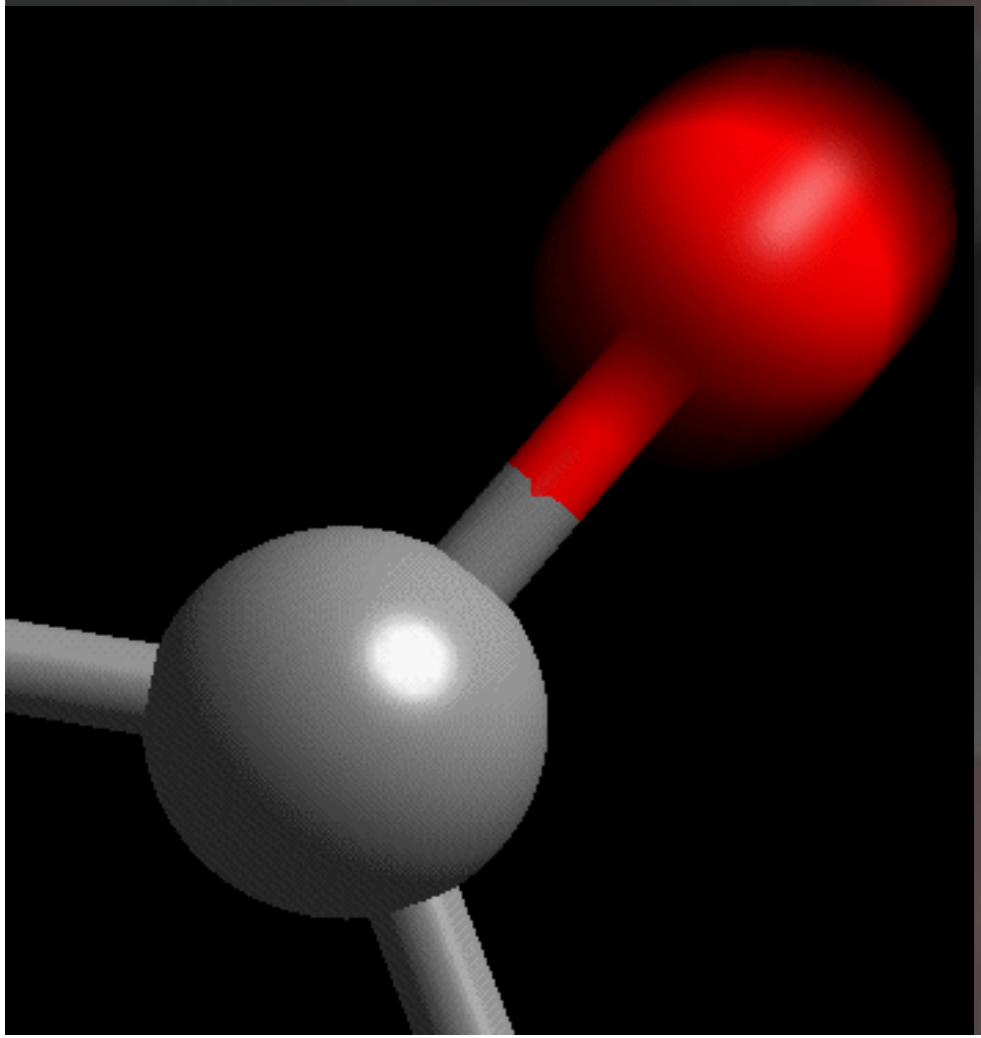

Welcome to ISIS



# Neutrons

Where atoms are...

# Neutrons



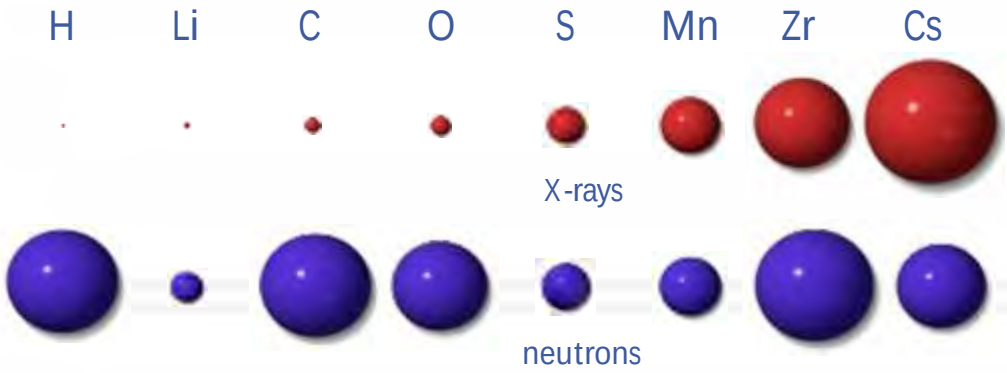
...and what they do


µm
4 µm


Health
Security
Curiosity Driven
Research
Energy
Digital
Economy
Environment

# Neutron

## Properties

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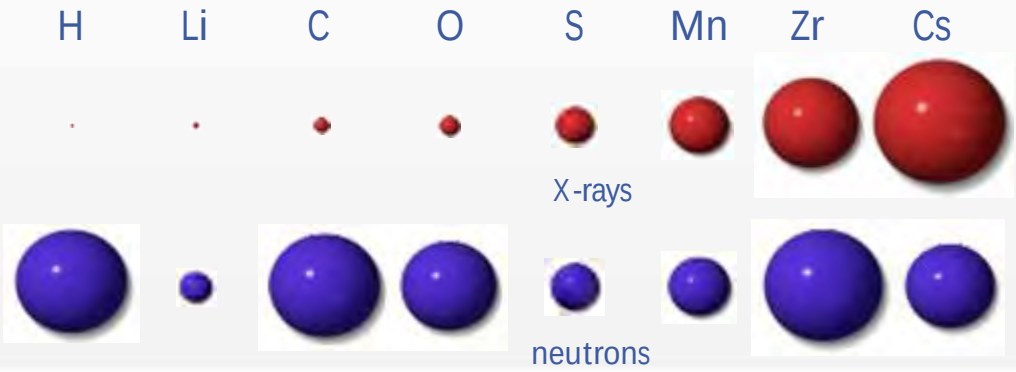
# Neutron

## Properties

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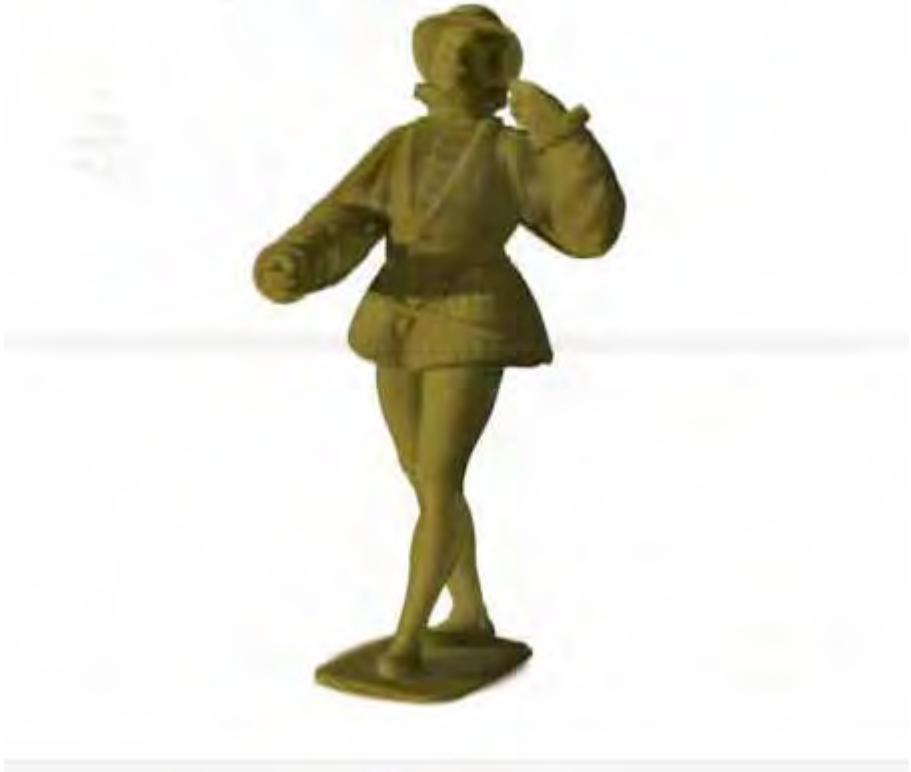
# Neutron

## Properties



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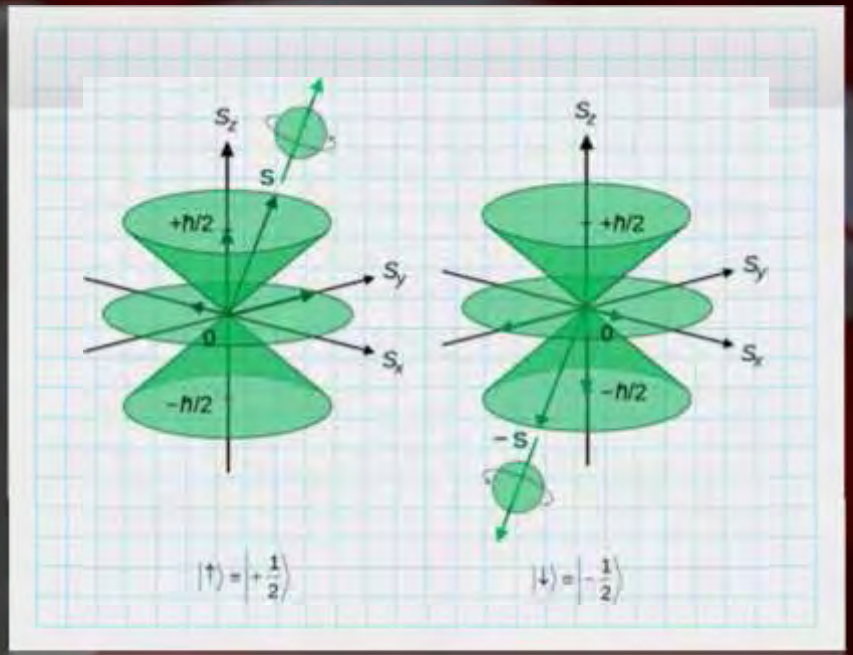
# Neutron
## Properties

Walter Gerlach
1889-1979

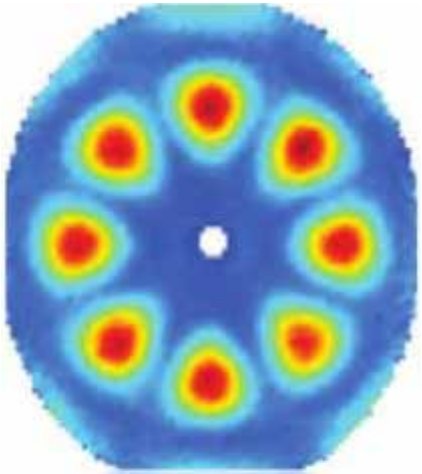
Otto Stern
1888-1969

Stern-Gerlach Experiment
1922

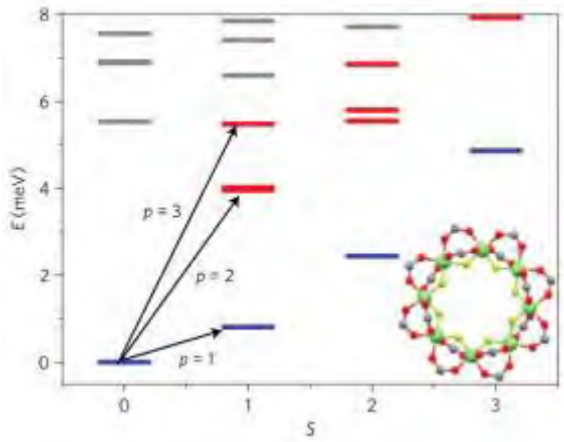


# Neutron

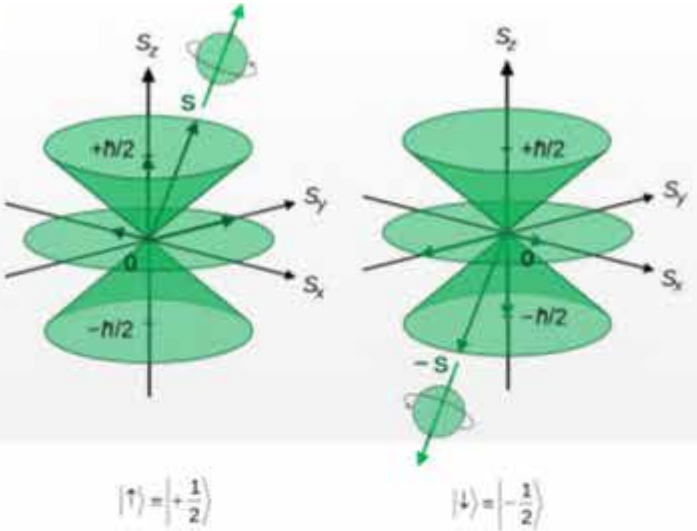
## Properties

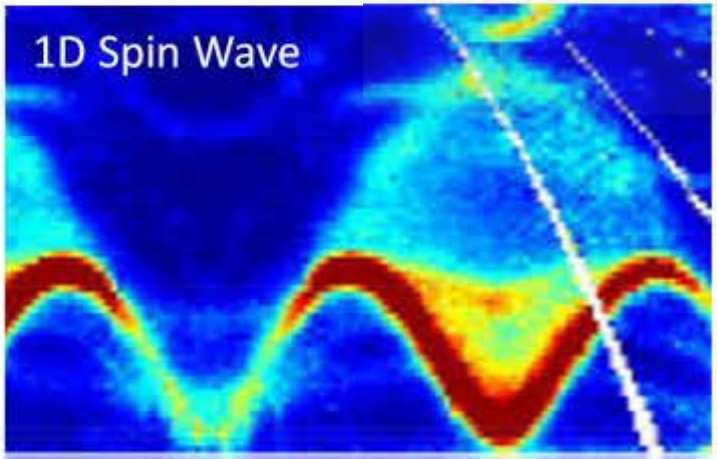


Molecular Magnets




## Probe for Quantum Magnetism

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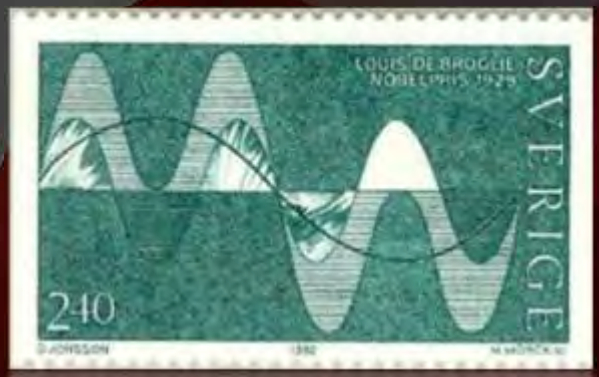
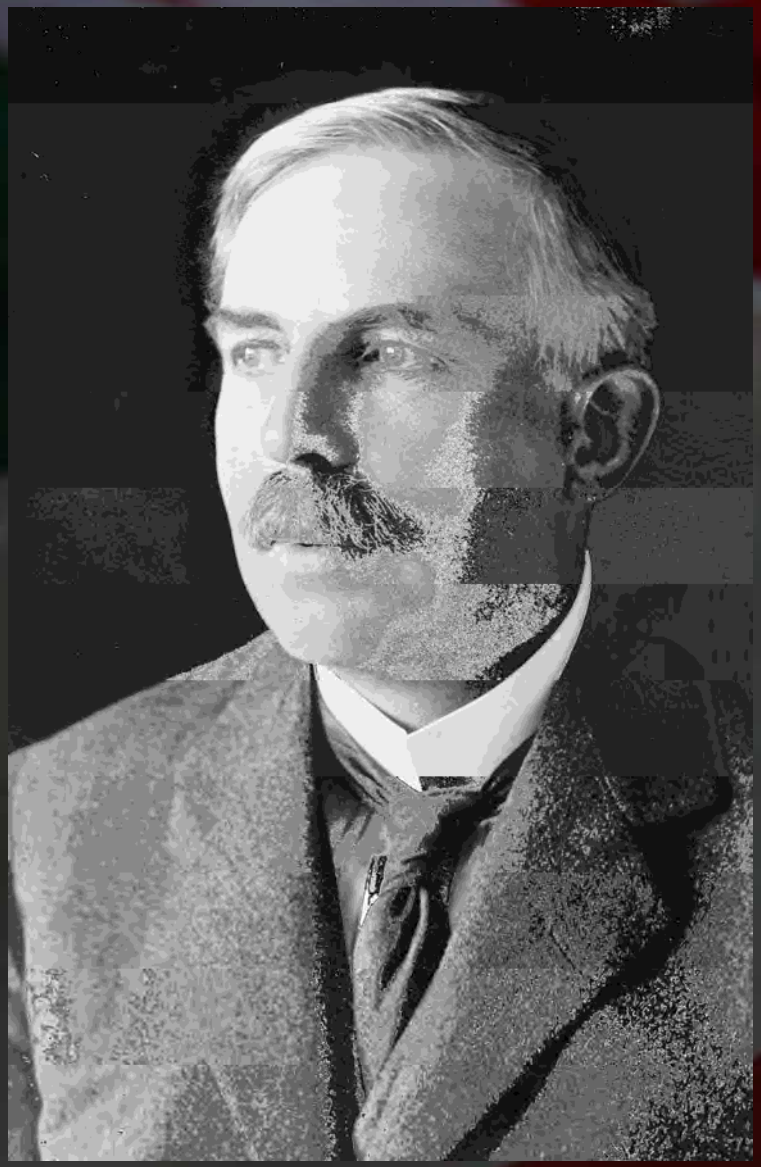
# Prince Louis Victor de Broglie

(1892-1987)

Doctoral Thesis 1924 at Paris University
*'Recherches sur la Théorie des Quanta'*







# Ernest Rutherford

(1871–1937)

"From the purely scientific point of view interest is mainly centred on the application of these high potentials to vacuum tubes in order to obtain a copious supply of high-speed electrons and high-speed atoms…

…of which the individual energy of motion is greater than that of the alpha particle… "

Rutherford's Challenge in a speech at the Royal Society AGM
30th November 1927

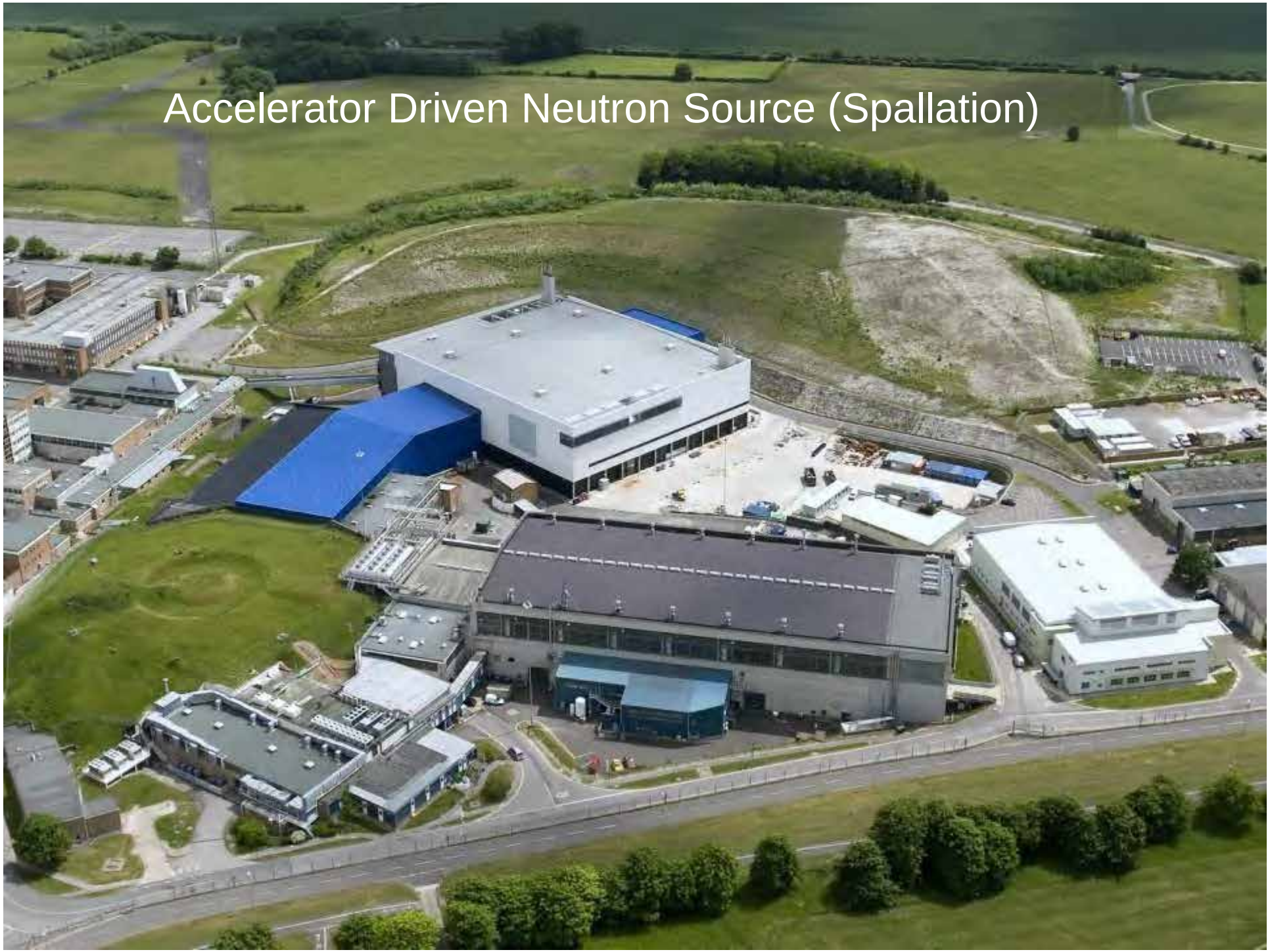
# The Harwell Neutron project

'the equipment — a pulsed source for neutron physics experiments — is intended to provide information about the detailed behaviour of neutrons of known velocities when they meet the materials used in the construction of reactors.'

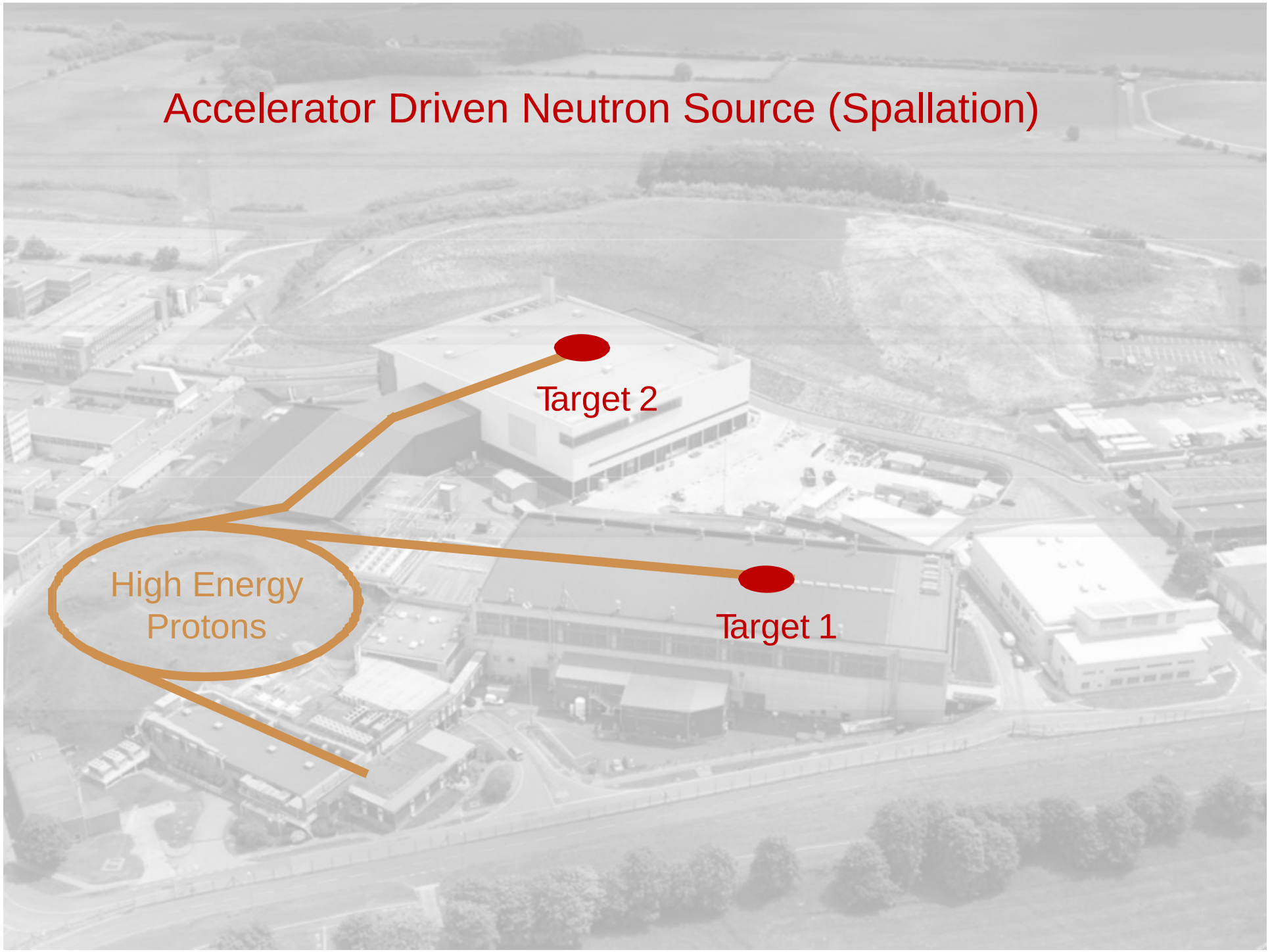
The Engineer 1959


ISIS – Neutrons and Muons
Rutherford Appleton Laboratory
Diamond
X-Rays
ISIS
Neutrons
Muons

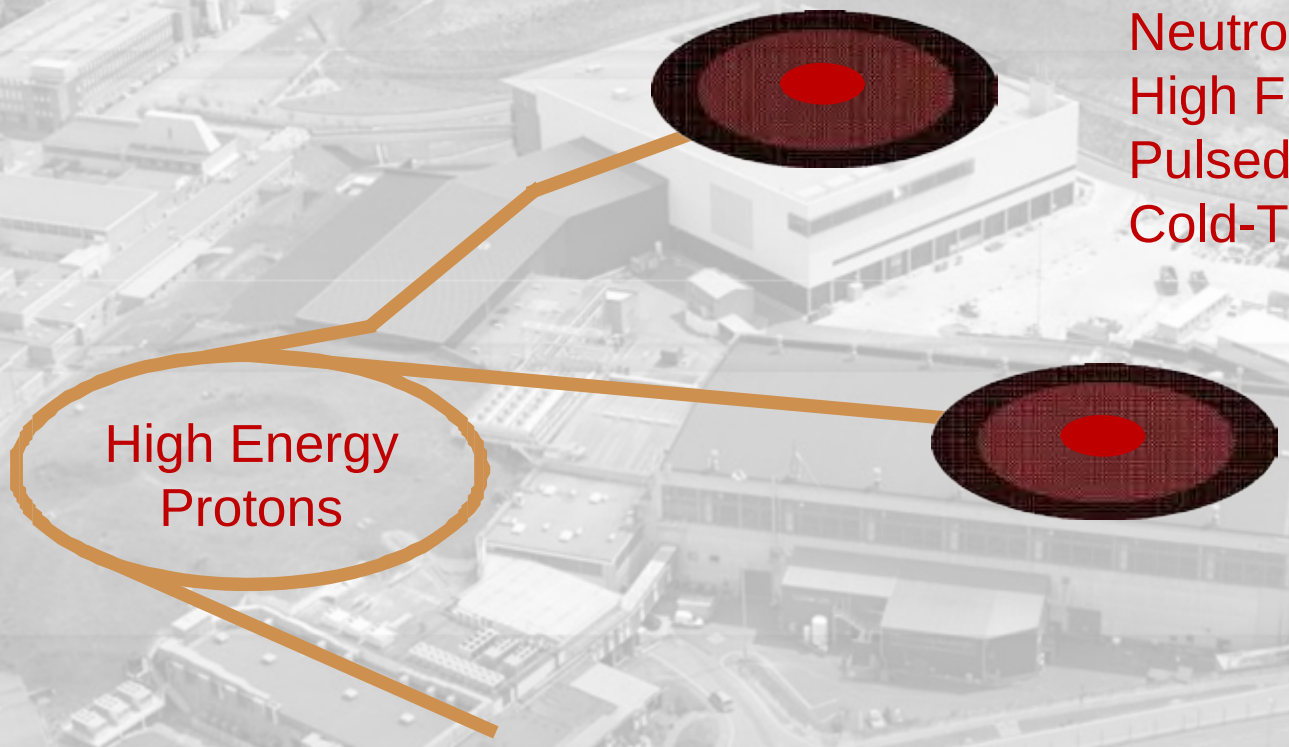
# Spallation Neutrons


Accelerator Driven Neutron Source (Spallation)

# Accelerator Driven Neutron Source (Spallation)

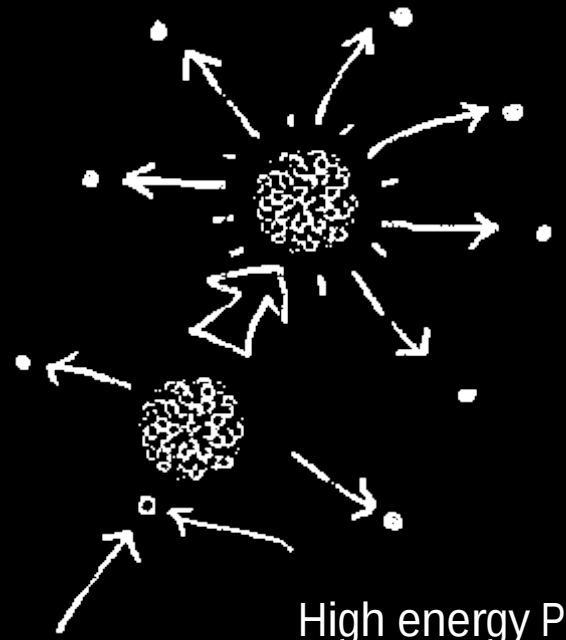


# Accelerator Driven Neutron Source (Spallation)




Neutron Radiation Field
High Flux
Pulsed
Cold-Thermal-Fast Regimes

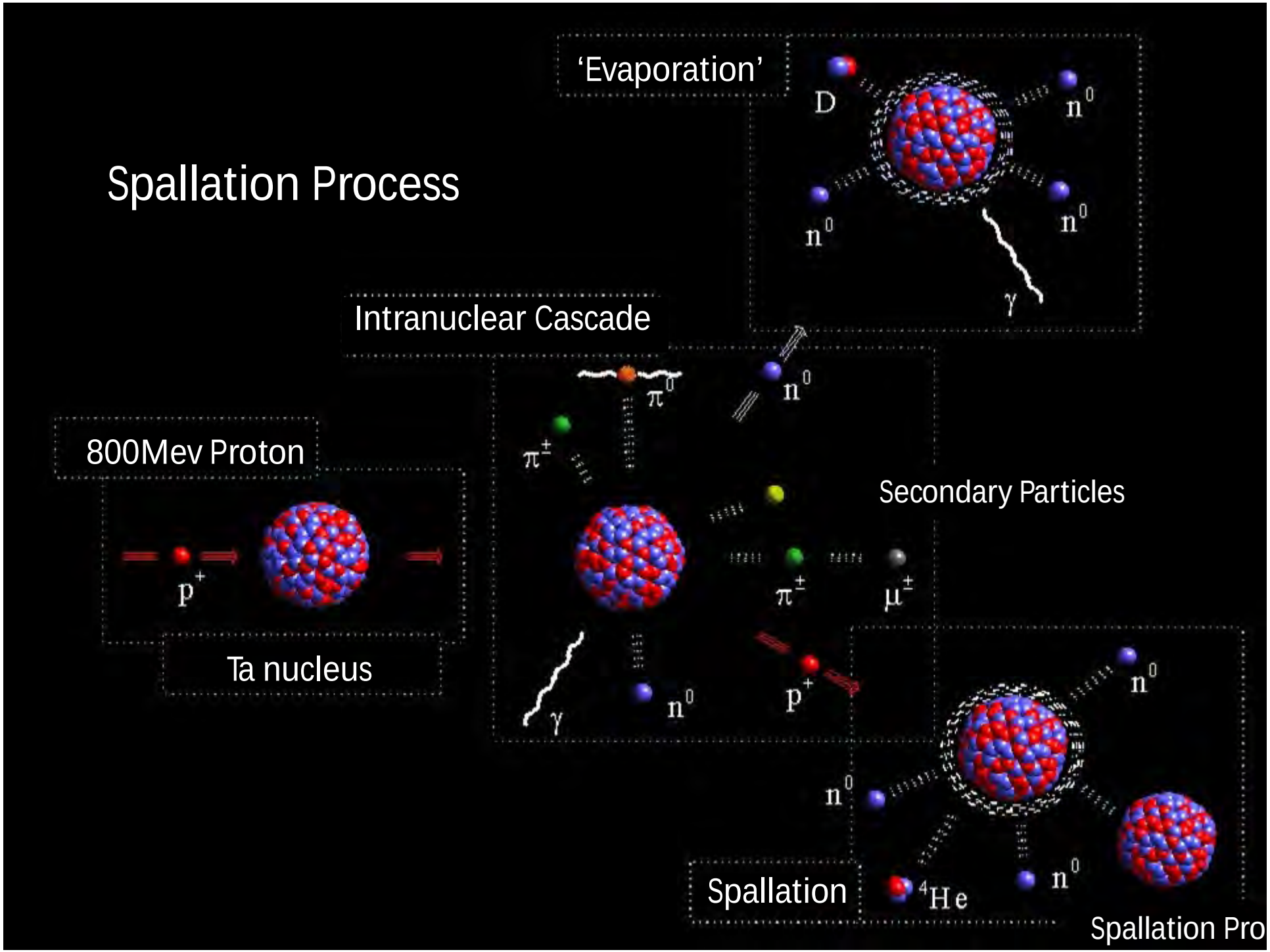
excited
nucleus

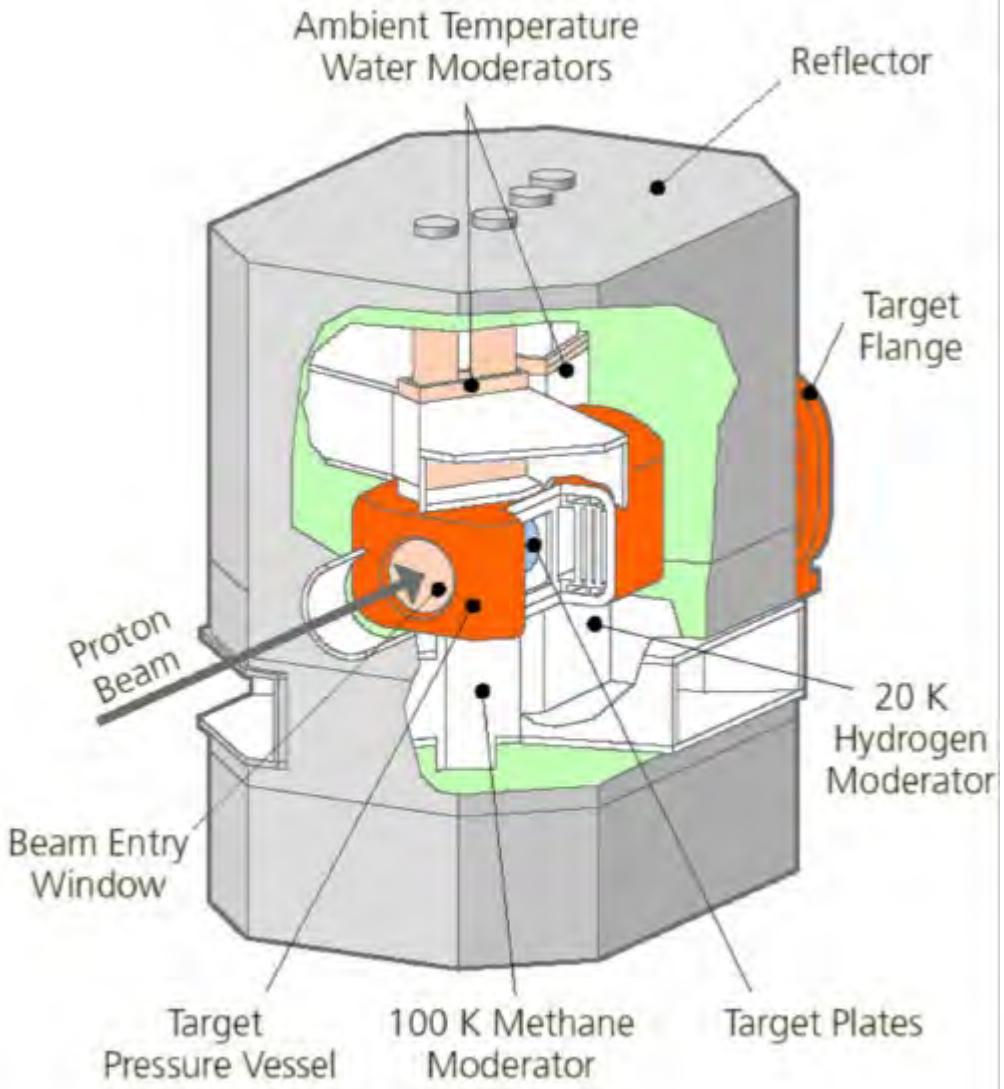


15-20 neutrons

High energy Proton

The collision of high energy protons with the tantalum nuclei releases neutrons

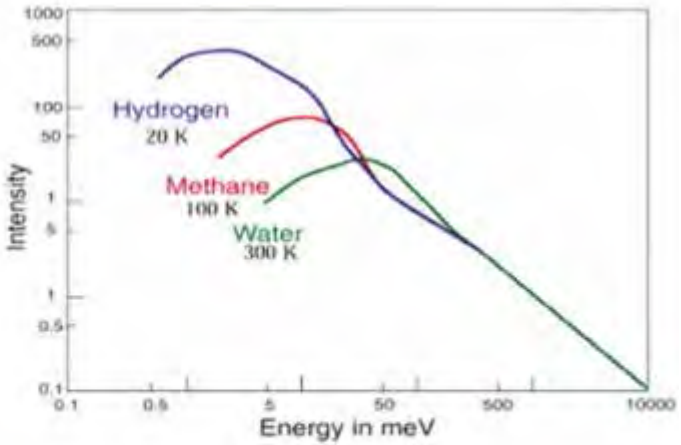

Spallation Process
'Evaporation'
D
n0
n0
n0
γ
Intranuclear Cascade
π0
n0
π±
800Mev Proton
Secondary Particles
p+
π±
μ±
Ta nucleus
γ
n0
p+
n0
n0
n0
Spallation
4He
Spallation Pro

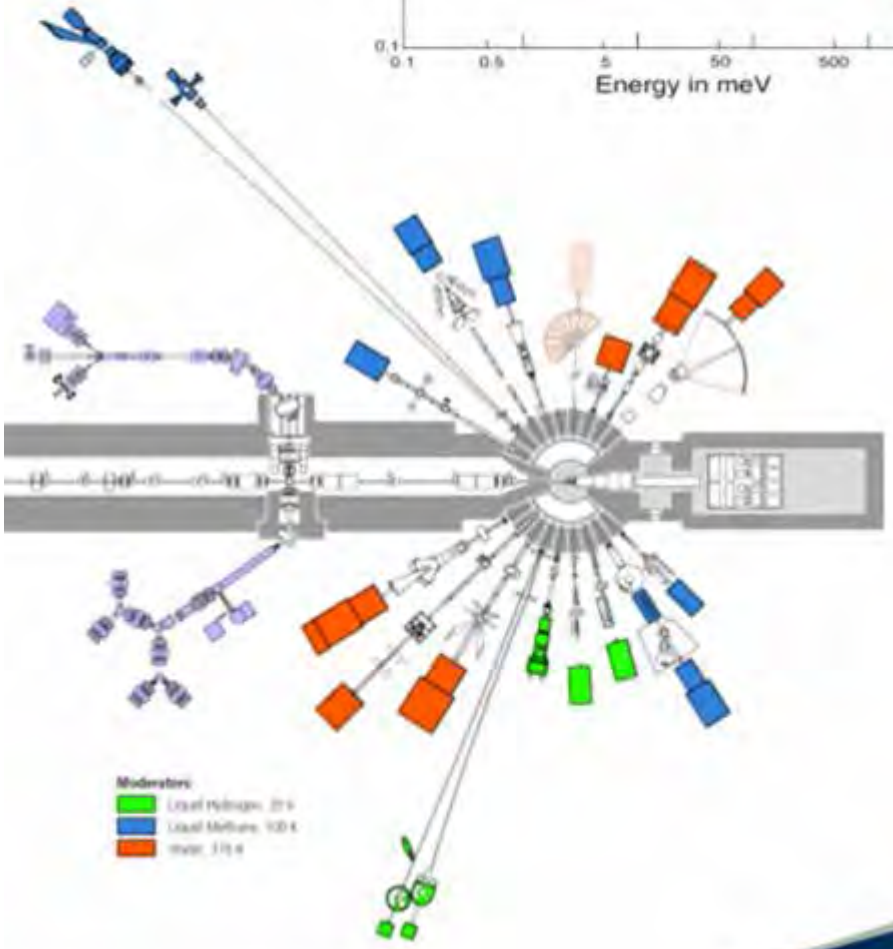



# Moderators

For experiments the neutrons energy is reduced from  MeV to meV

Hydrogen containing moderators produce required energies



# Moderators

Three moderators
- liquid hydrogen 20°K
- methane 100°K
- water 43°C

Neutron instruments view moderators and not target

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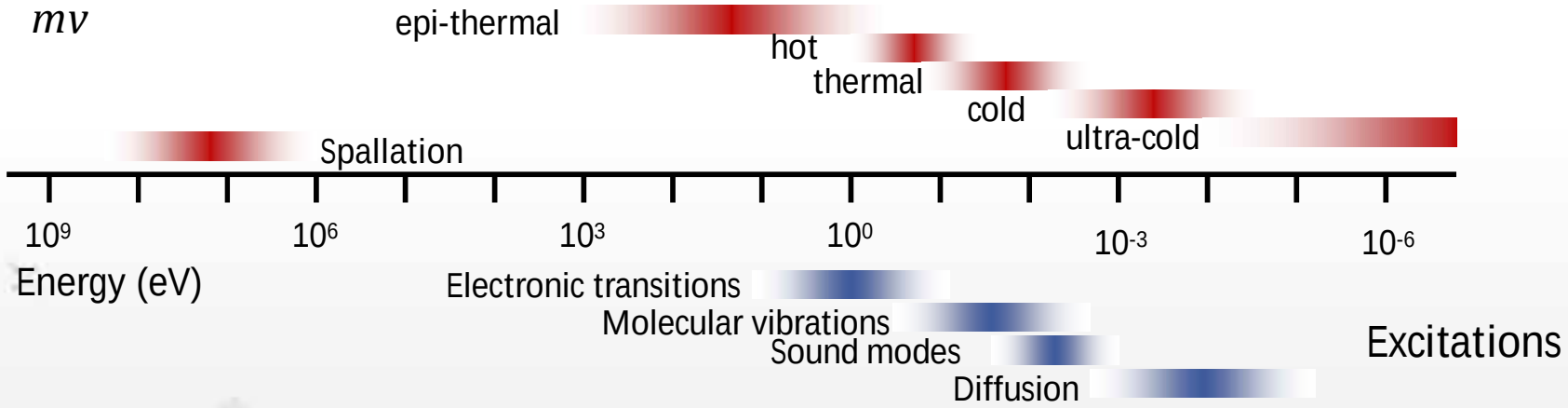
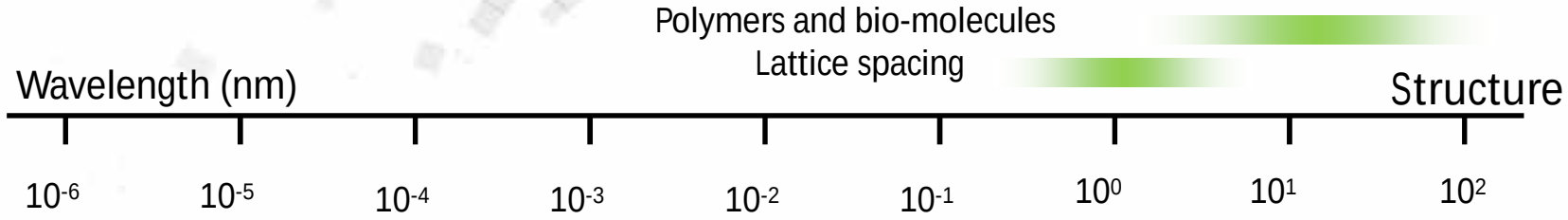
# Moderators

$$\lambda = \frac{h}{mv}$$




$T = 293K$ $\lambda = 1.798\ A$ $v = 2.20\ km/s$ $E = 25.3\ meV$

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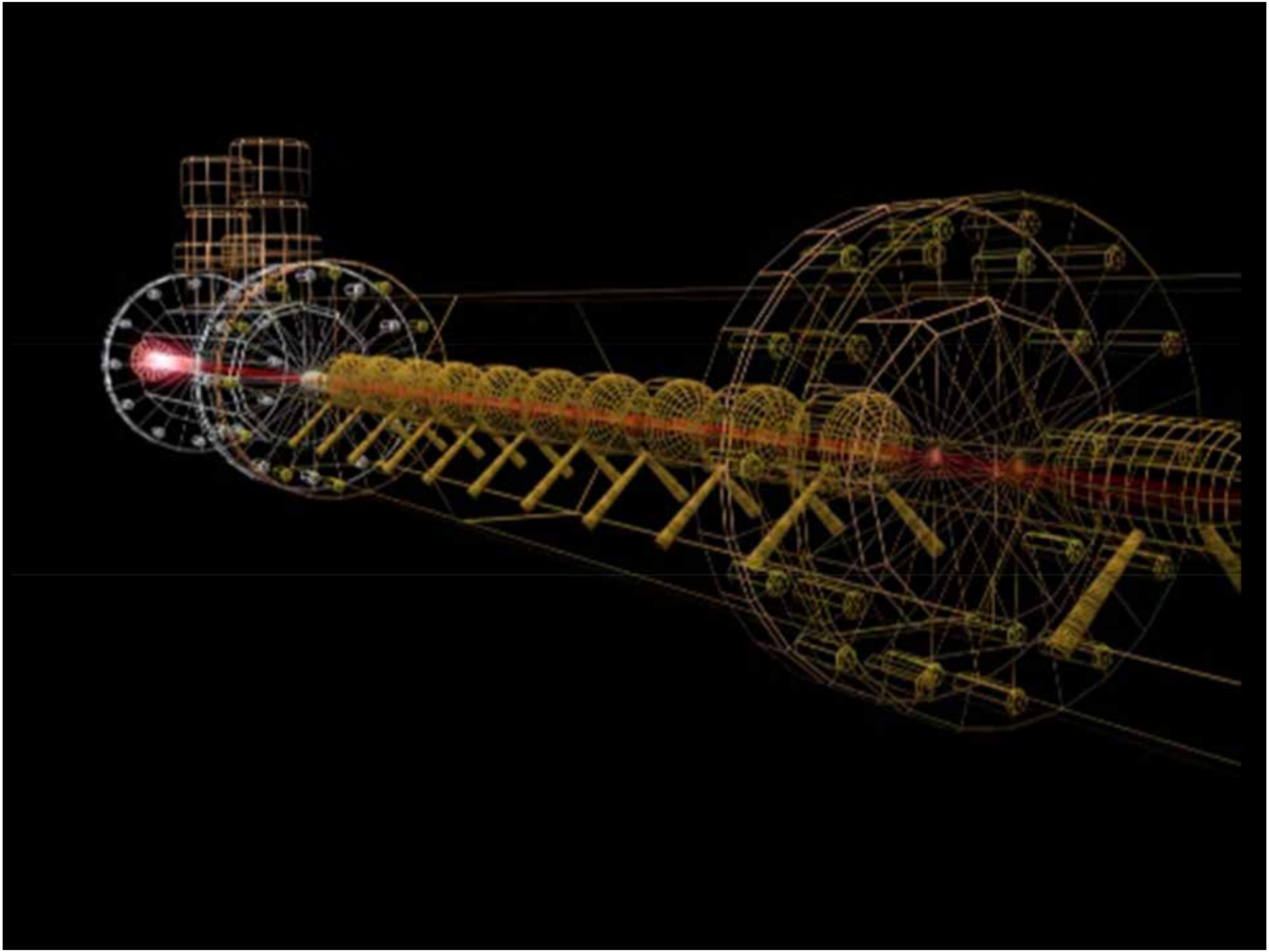

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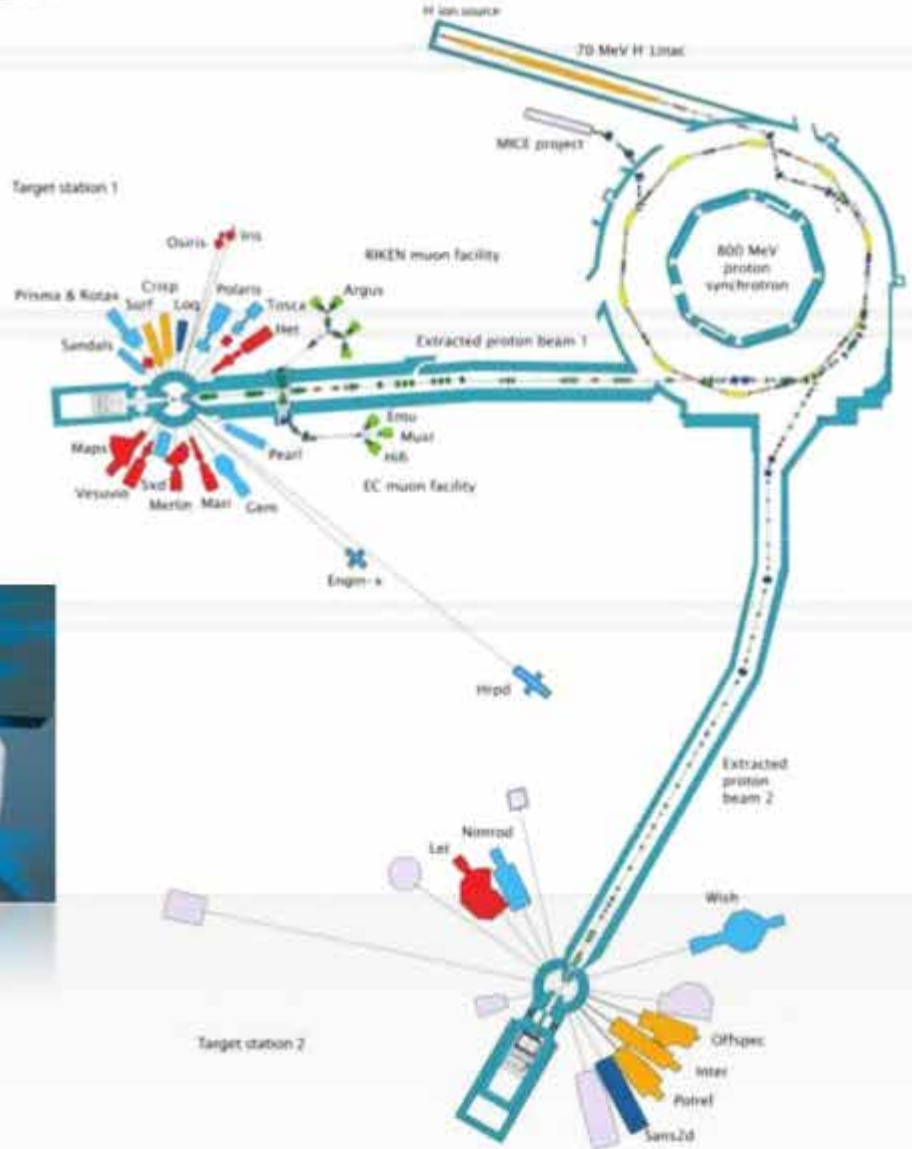
World leading expertise and instrumentation in the application of neutrons to condensed matter science

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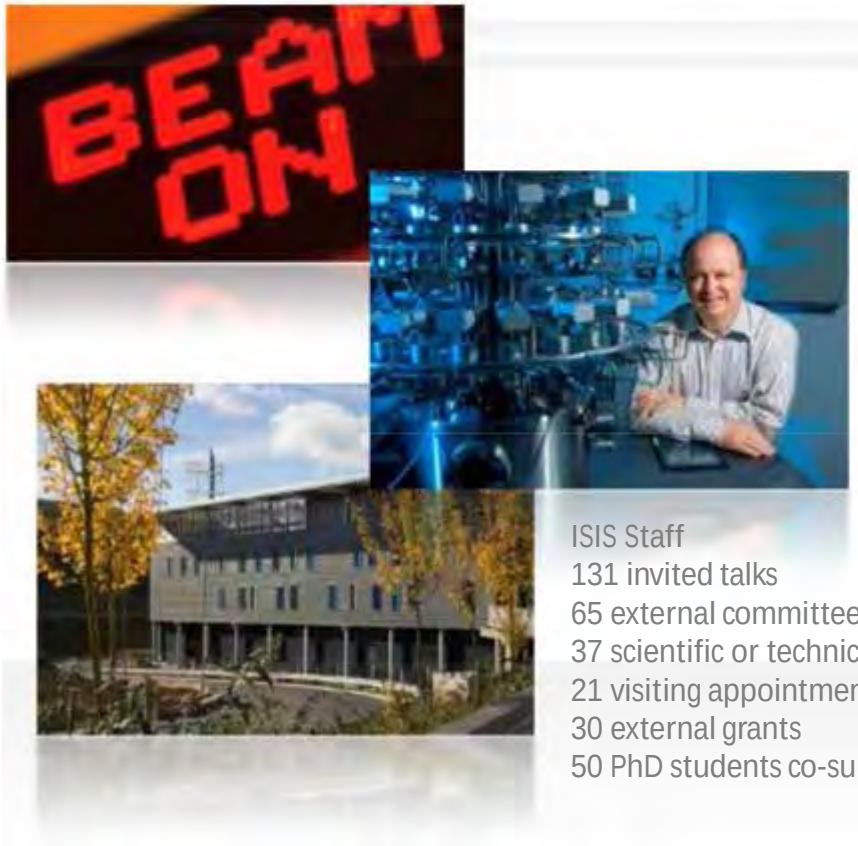


~ 2000 users/yr
~450 publications/yr
~ 800 experiments/yr
90% of UK Users 5/5* Departments

ISIS Staff
131 invited talks
65 external committee memberships
37 scientific or technical meetings organised
21 visiting appointments at universities
30 external grants
50 PhD students co-supervised

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## Molecular Spectroscopy
IRIS
OSIRIS
TOSCA
VESUVIO

## Large Scale Structures
SANS2D
OFFSPEC
POLREF
INTER
CRISP
SURF
LOQ

## Muons
EMU
MuSR
HIFI
ARGUS

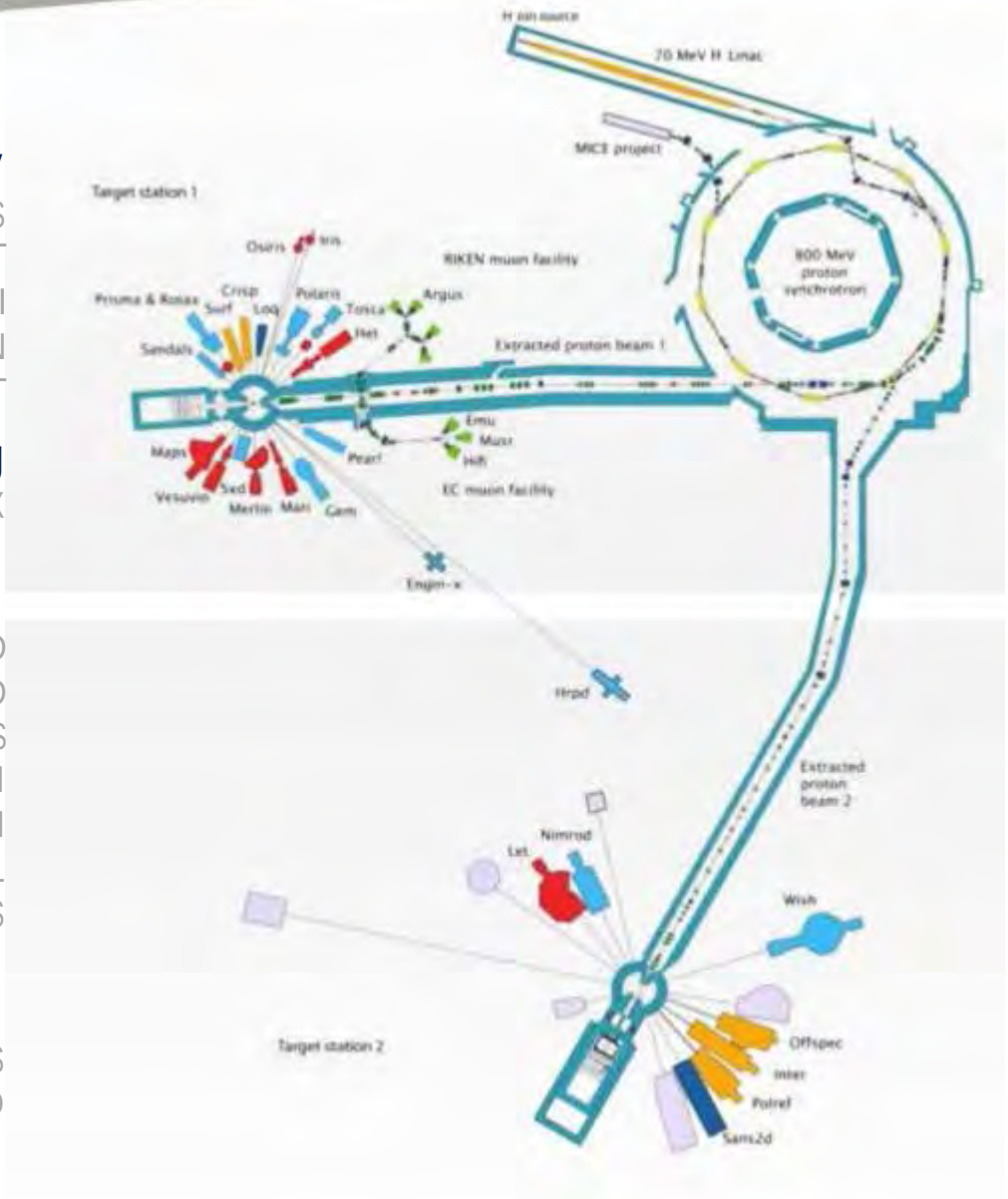
## Spectroscopy
MAPS
LET
MARI
MERLIN
HET

## Engineering
ENGIN-X

## Diffraction
HRPD
SXD
POLARIS
GEM
WISH
PEARL
INES

## Disordered Materials
SANDALS
NIMROD

**30**
Neutron and Muons Instruments



Science & Technology Facilities Council
ISIS

## Molecular Spectroscopy
IRIS
OSIRIS
TOSCA
VESUVIO

## Large Scale Structures
SANS2D
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POLREF
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SURF
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## Muons
EMU
MuSR
HIFI
ARGUS

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MAPS
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MARI
MERLIN
HET

## Engineering
ENGIN-X

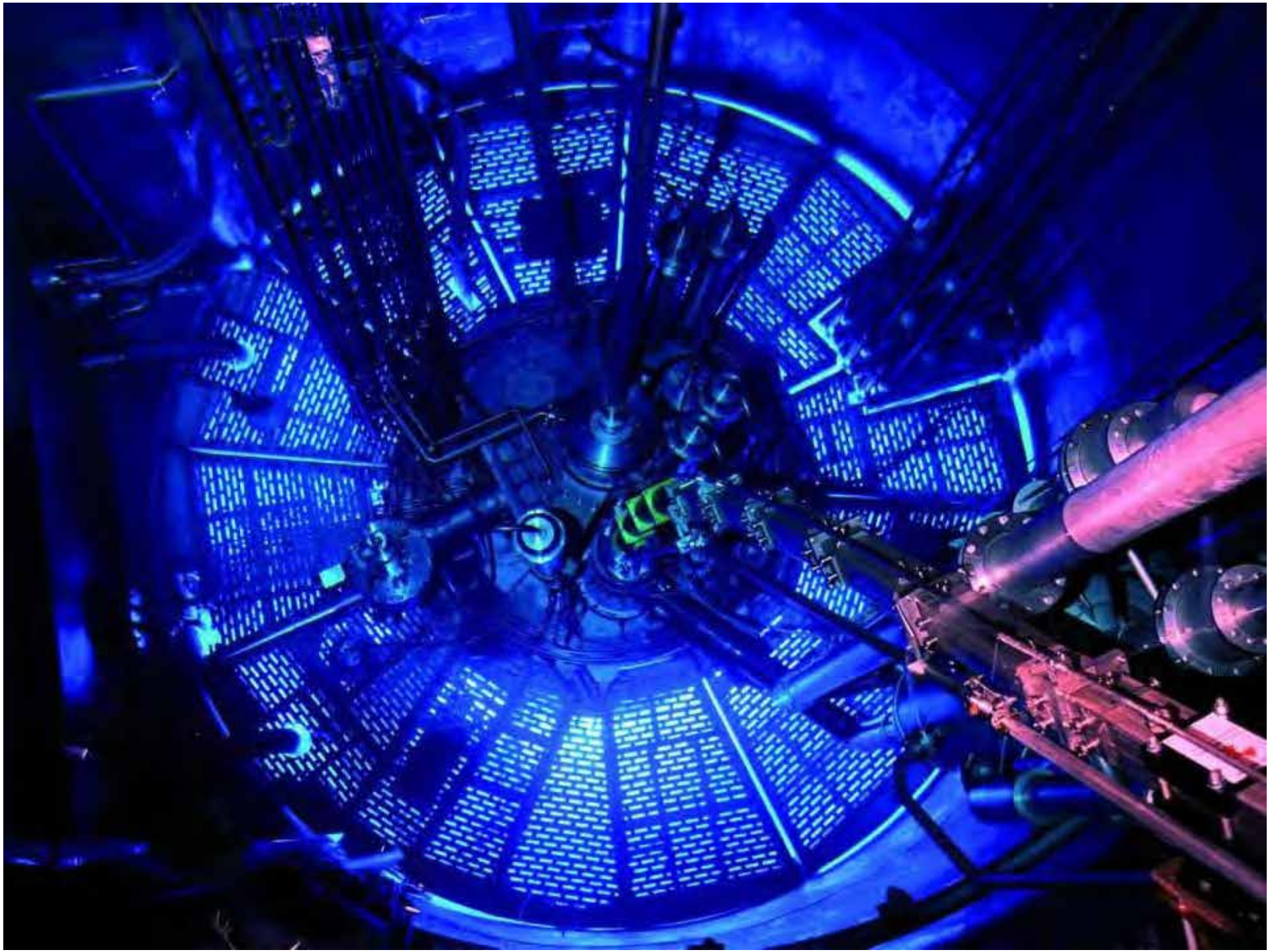
## Diffraction
HRPD
SXD
POLARIS
GEM
WISH
PEARL
INES

## Disordered Materials
SANDALS
NIMROD

**30**
Neutron and Muons Instruments

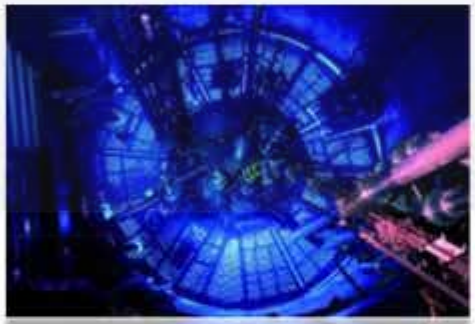
## Target Station 2 – Phase 2 Instruments
IMAT
ZOOM
LARMOR
CHIPIR

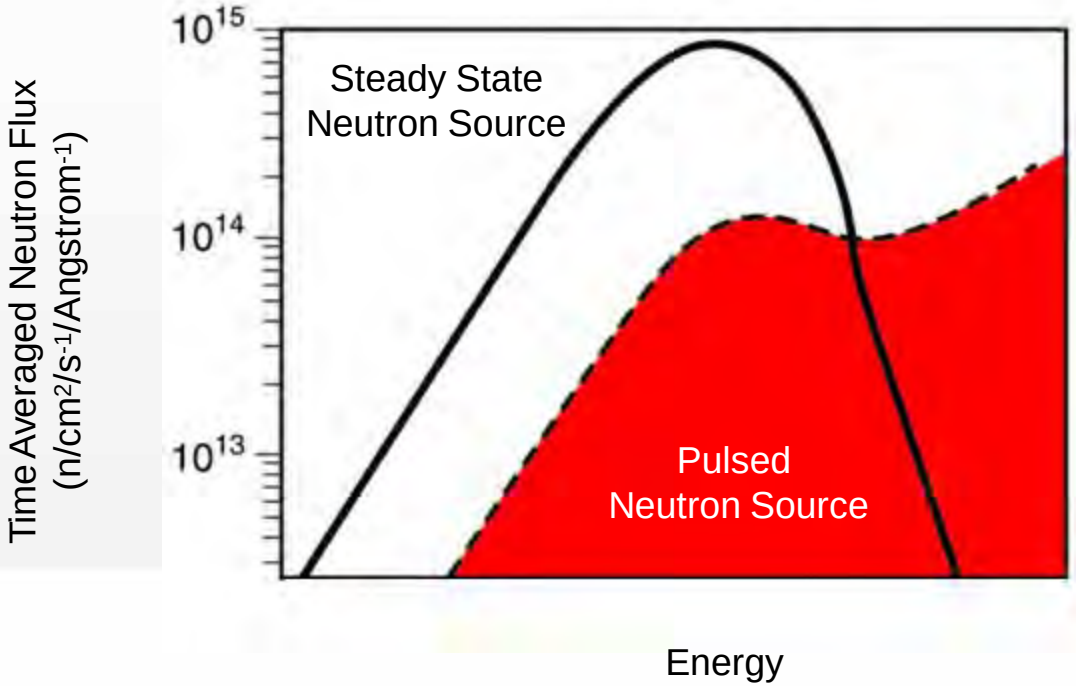
# Accelerators & Reactors



# European Photon & Neutron Science Campus

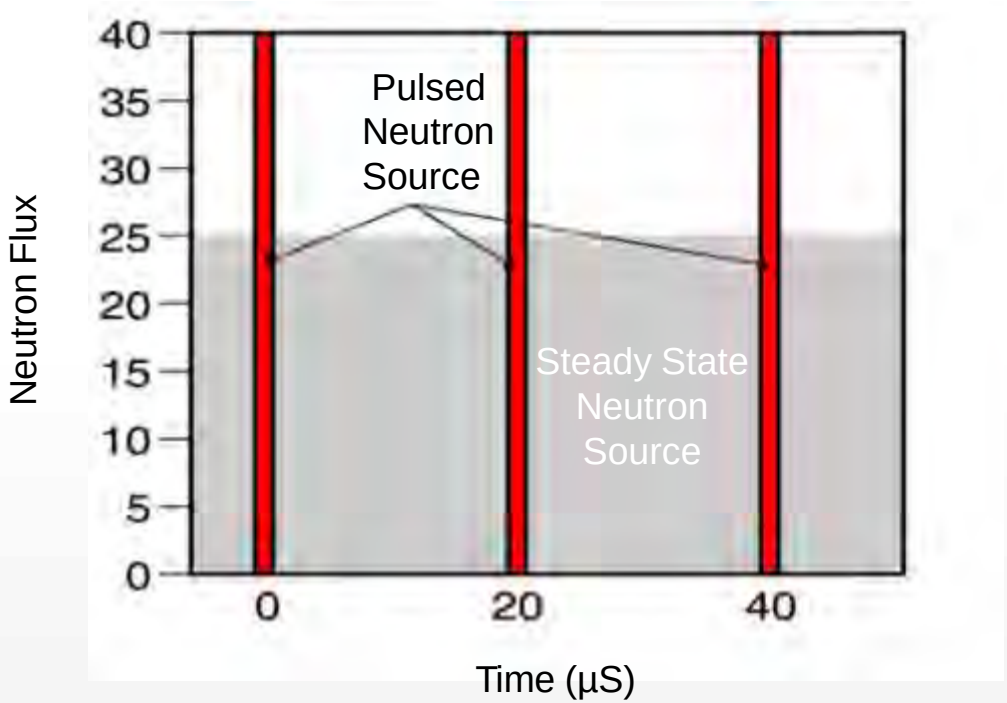

ISIS – Neutrons and Muons
Rutherford Appleton Laboratory
Diamond
X-Rays
ISIS
Neutrons
Muons






## Spallation Sources and Reactors

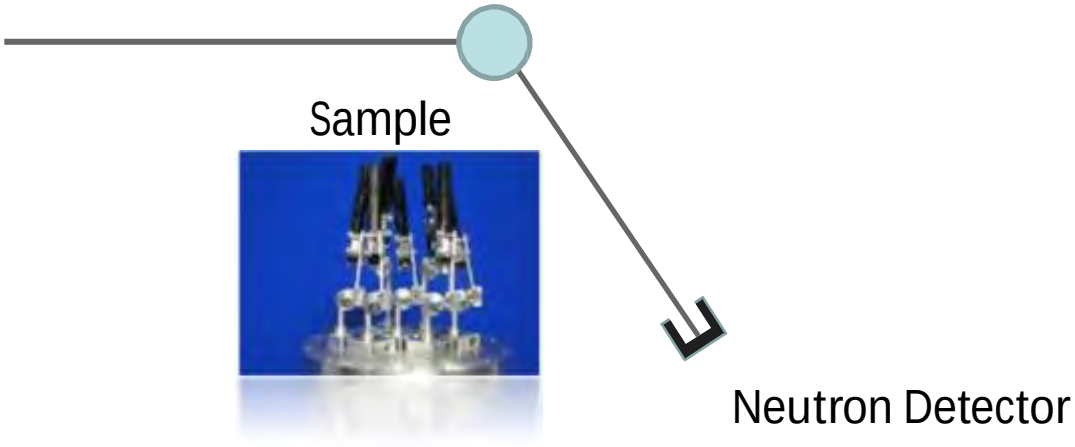
Different neutron spectrum




## Spallation Sources and Nuclear Reactors

Different neutron spectrum
Different time structure

Neutron Source

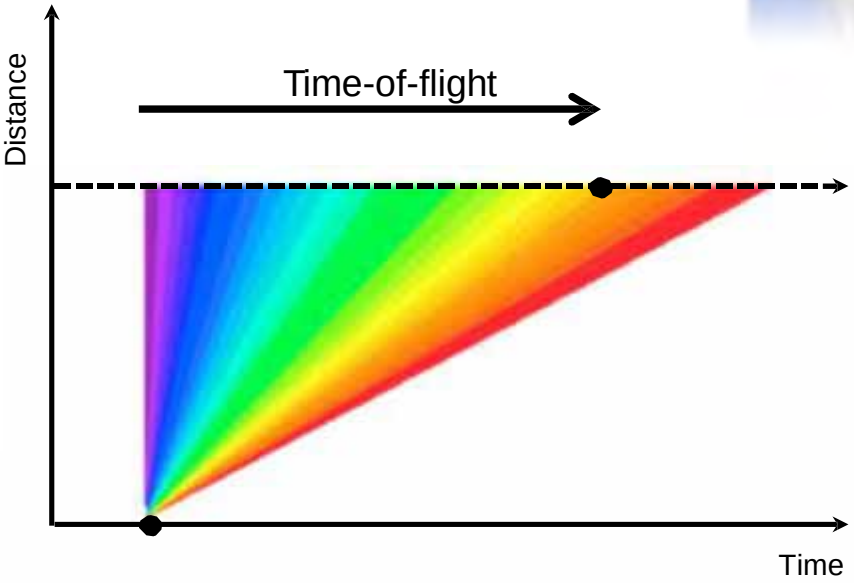



Neutron Detector

$$\frac{aa}{an} = \frac{number\ of\ neutrons\ scattered\ into\ an\ in\ the\ direction\ (),\ </}{incident\ flux\ .\ on}$$

Neutron Source

Sample




$$v = (L_1 + L_2)/t$$

$$E = \frac{1}{2}mv^2 \qquad \lambda = \frac{h}{mv}$$

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# Bragg's Law

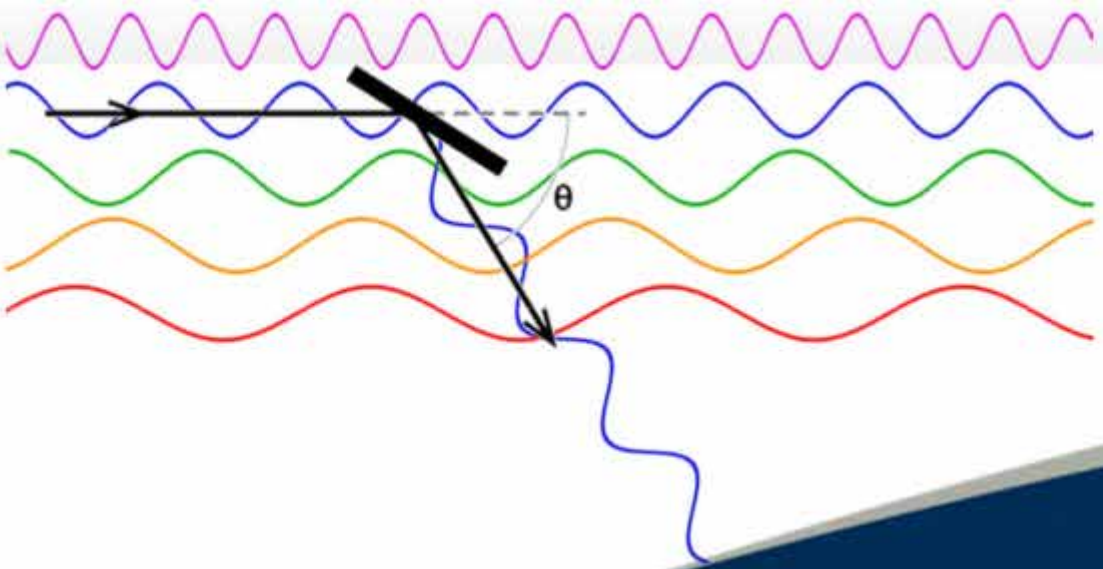
$$n \cdot \lambda = 2d \cdot \sin\theta$$

Foundation of crystallography and earned the1915 Nobel Prize for Physics

At 25 years old, Lawrence remains the youngest ever Nobel Laureate

Lawrence Bragg

(1890–1971)

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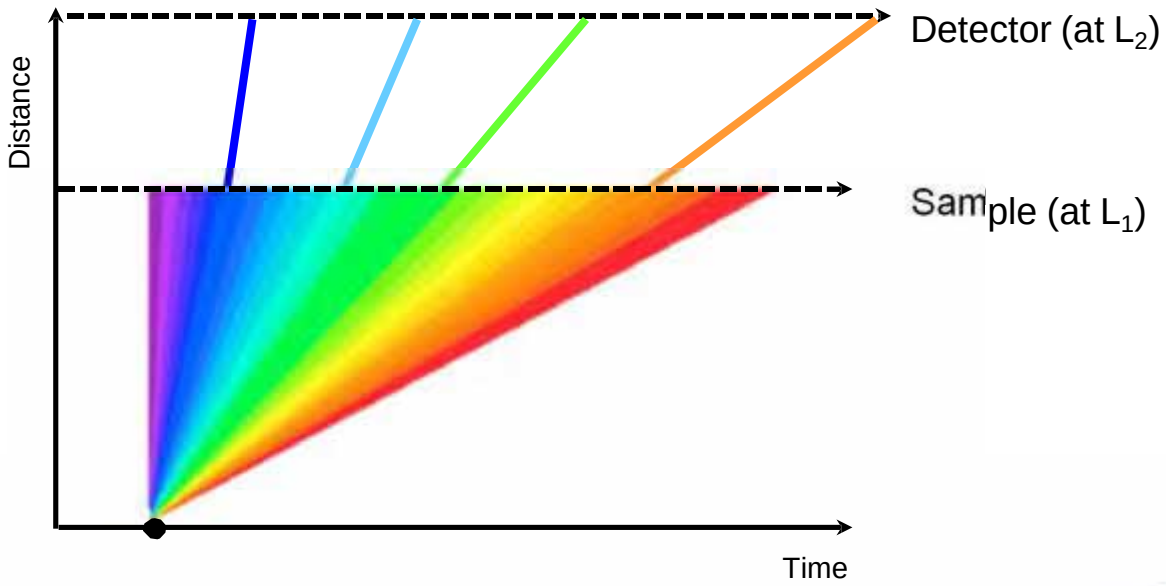
$$n \cdot \lambda = 2d \cdot \sin\theta$$




Lawrence Bragg

(1890–1971)

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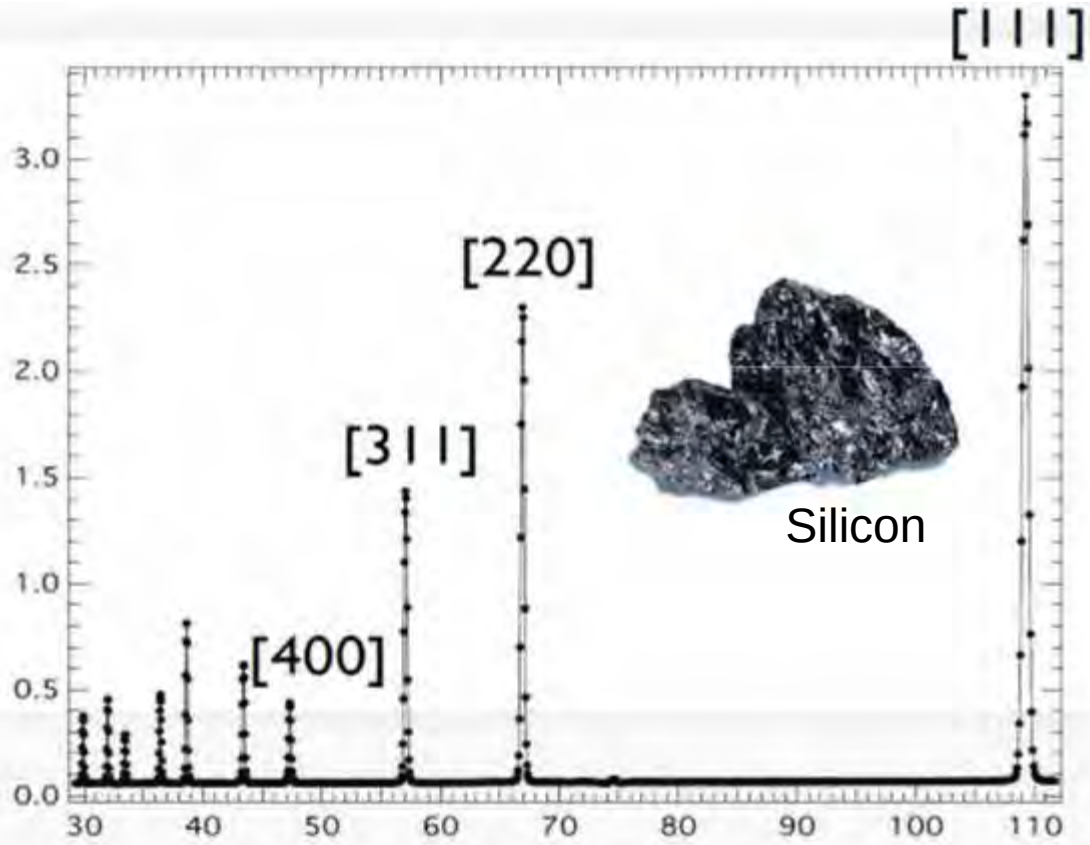
$$n \cdot \lambda = 2d \cdot \sin\theta$$






Silicon

Lawrence Bragg

(1890–1971)

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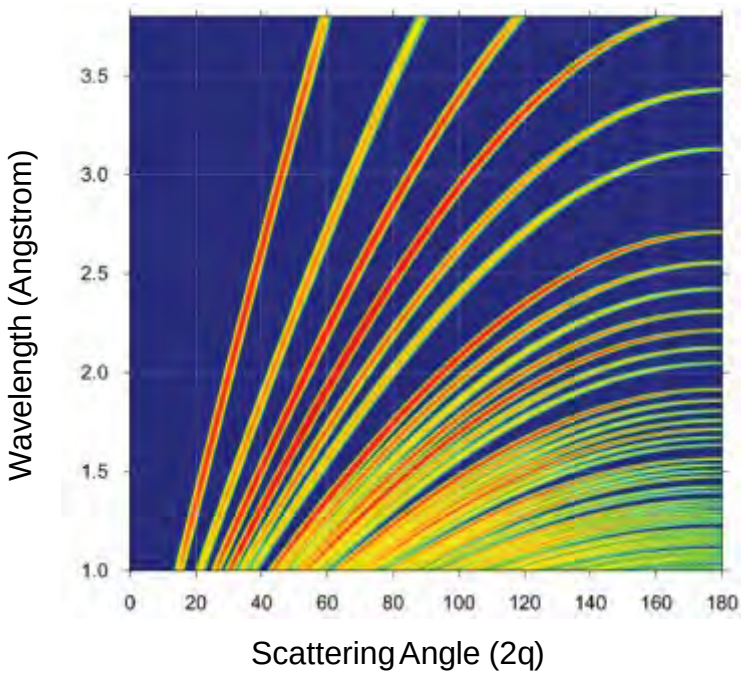
$$n \cdot \lambda = 2d \cdot \sin\theta$$




Lawrence Bragg

(1890–1971)

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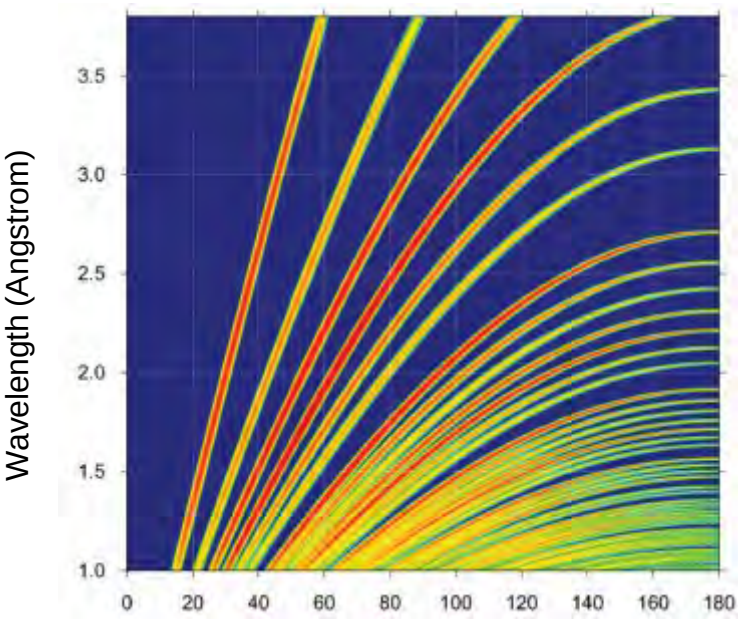


WISH diffractometer at ISIS

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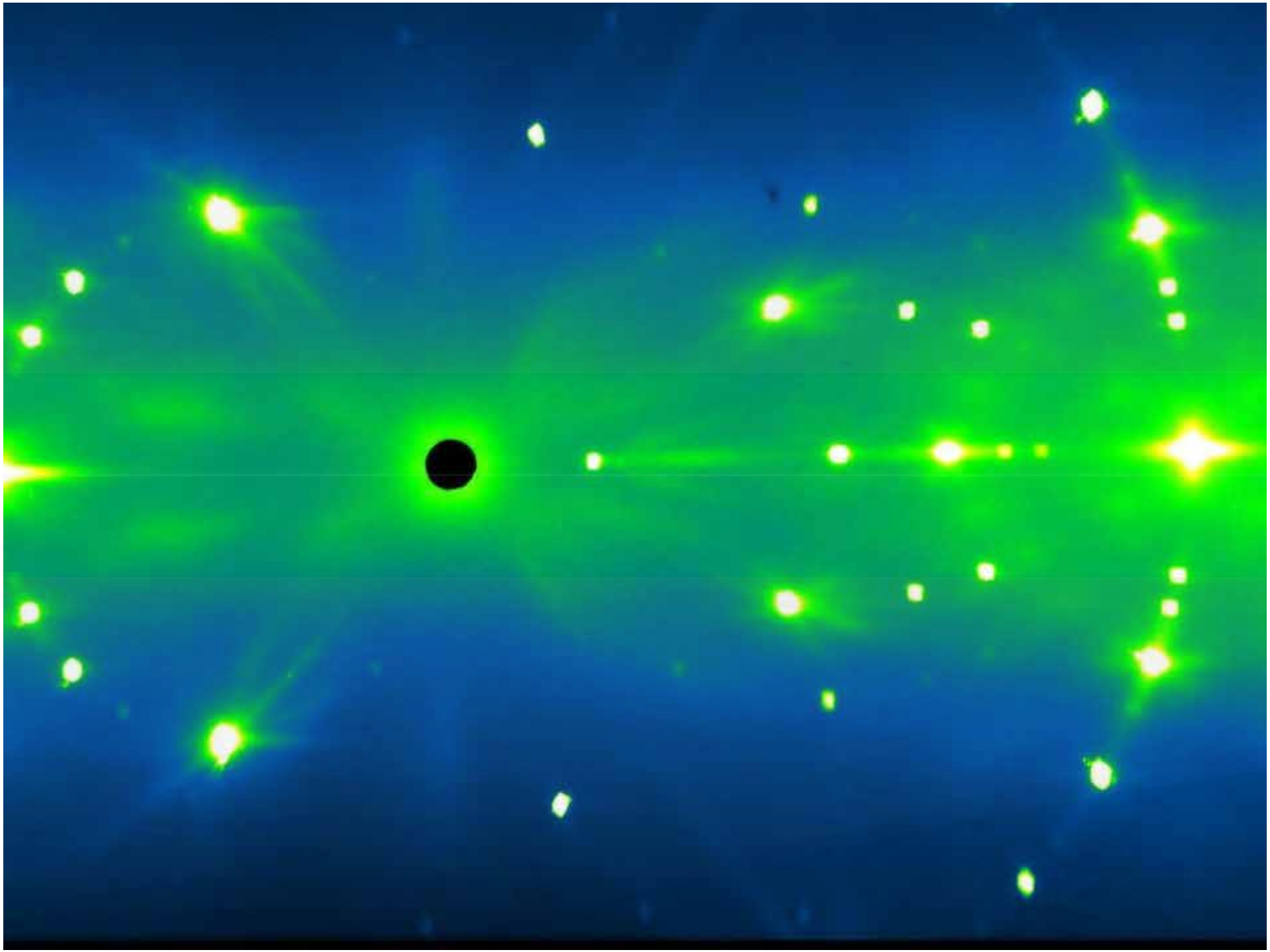
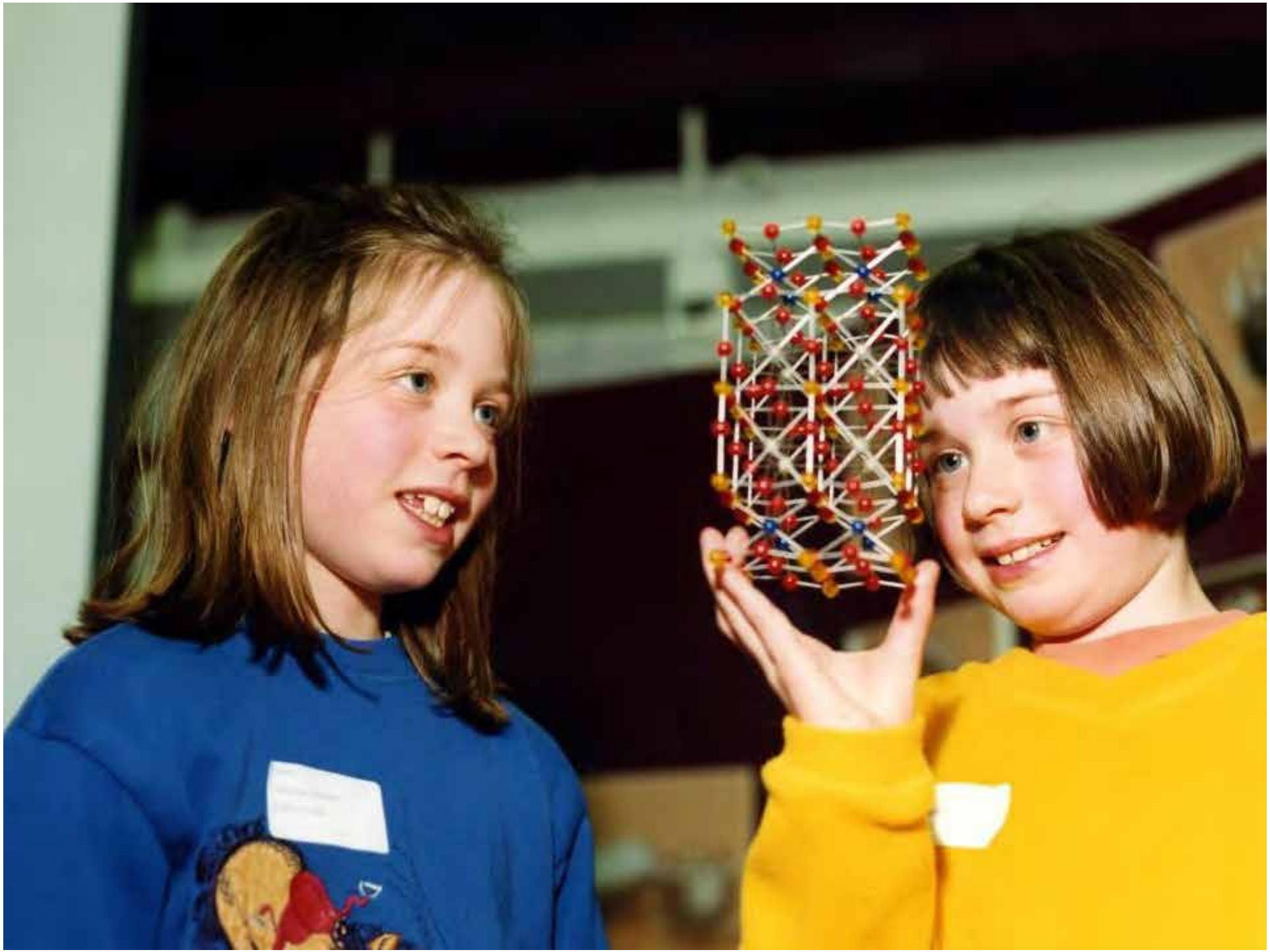
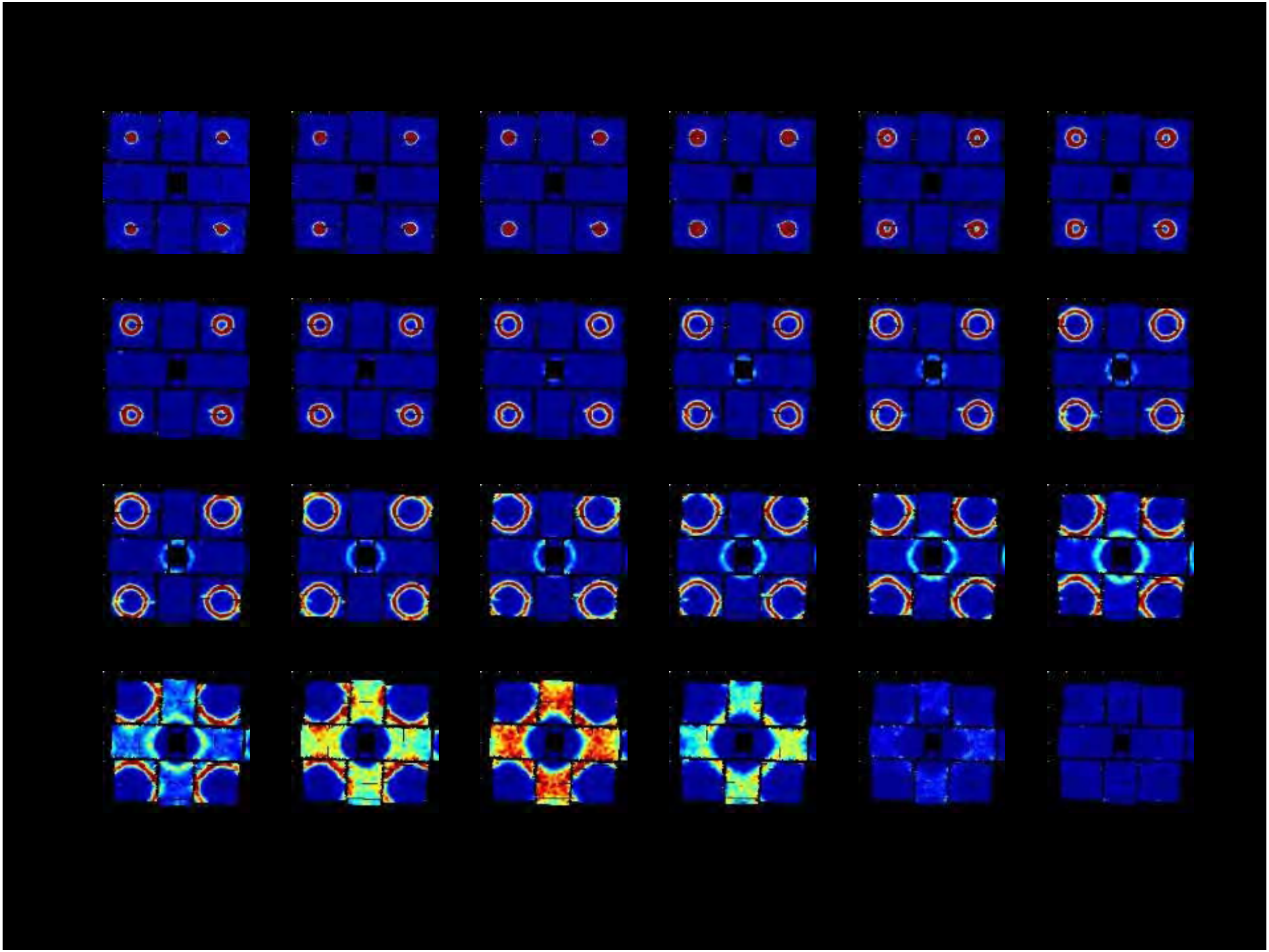
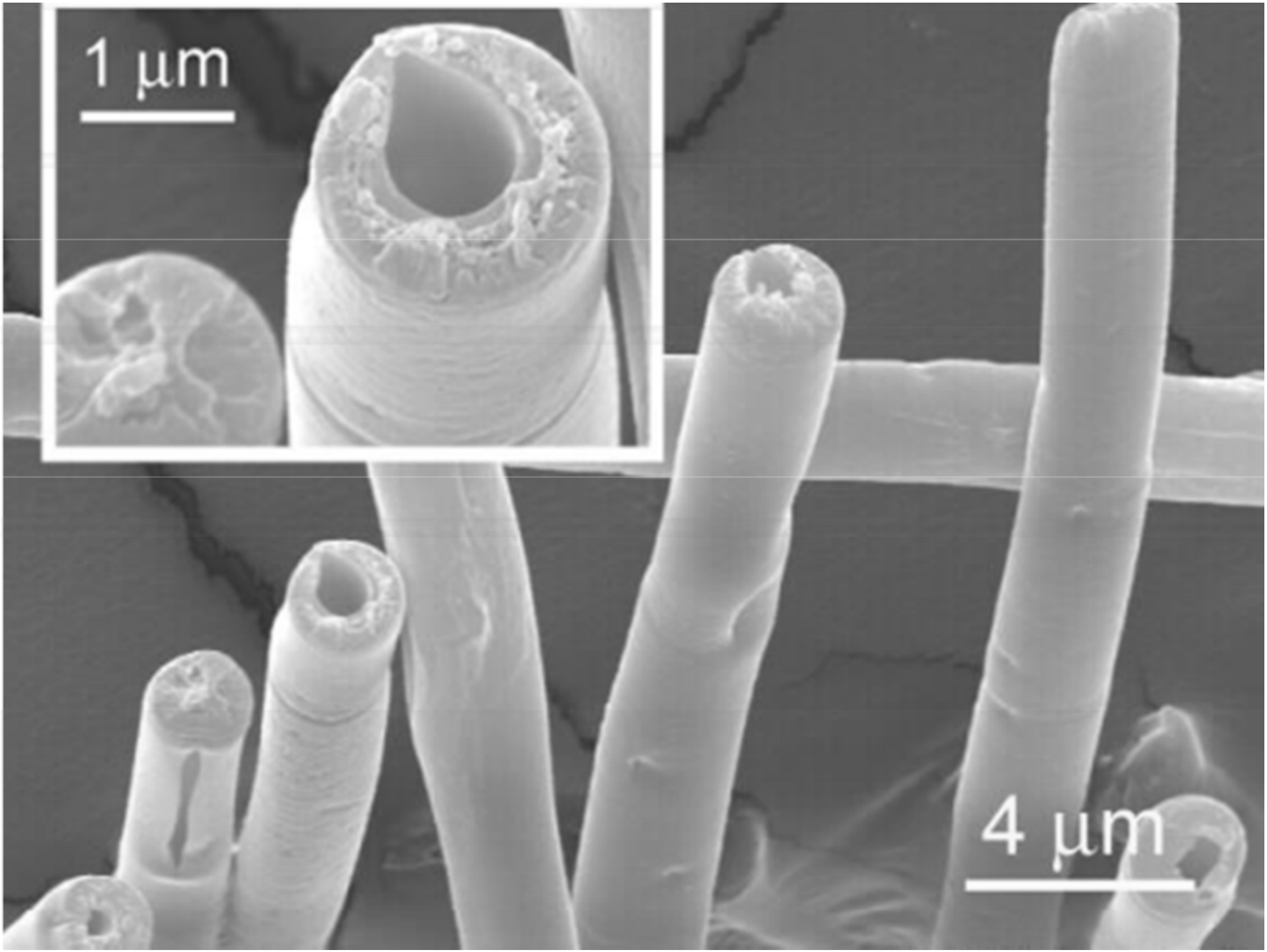
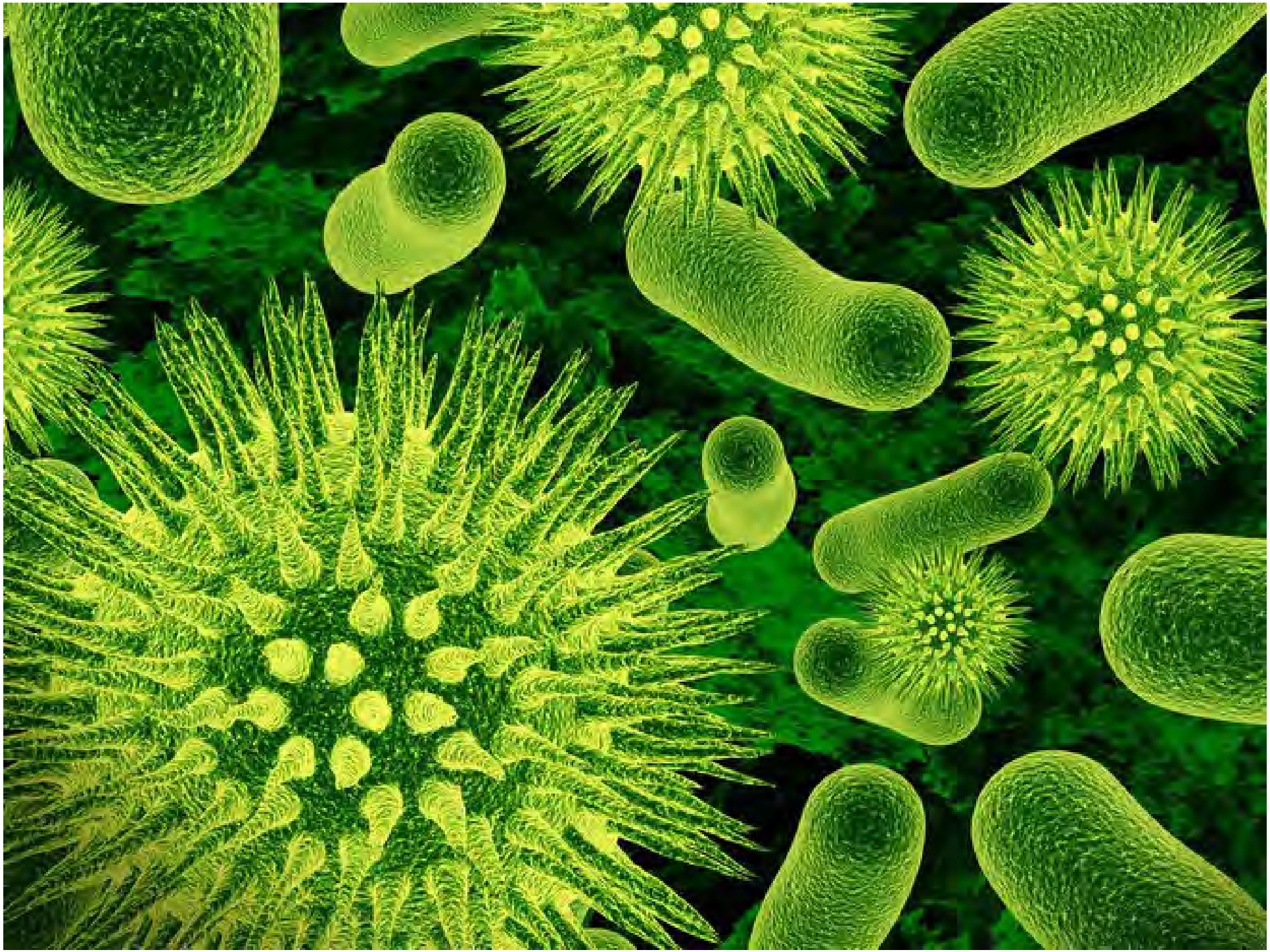
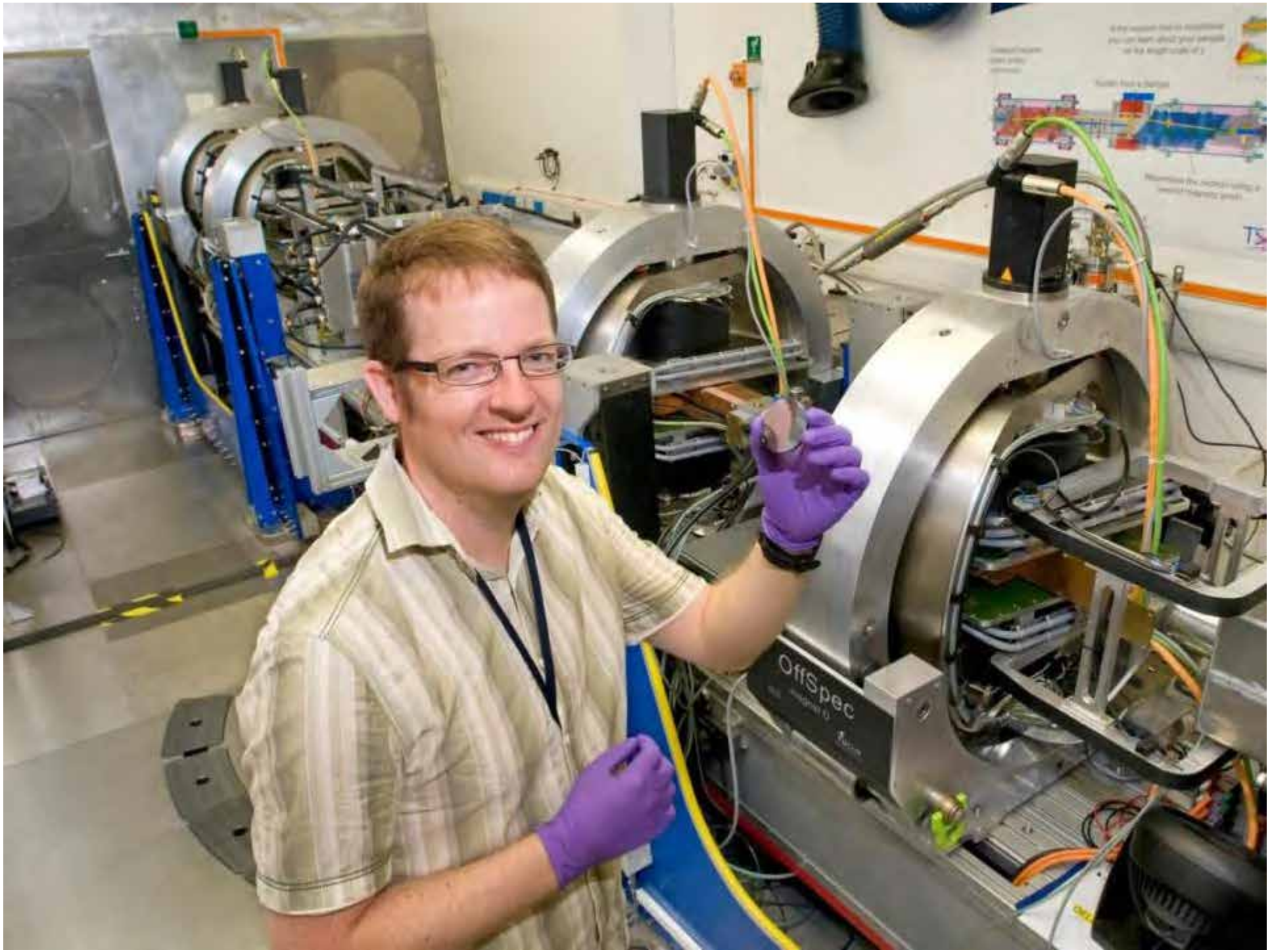







1 µm
4 µm

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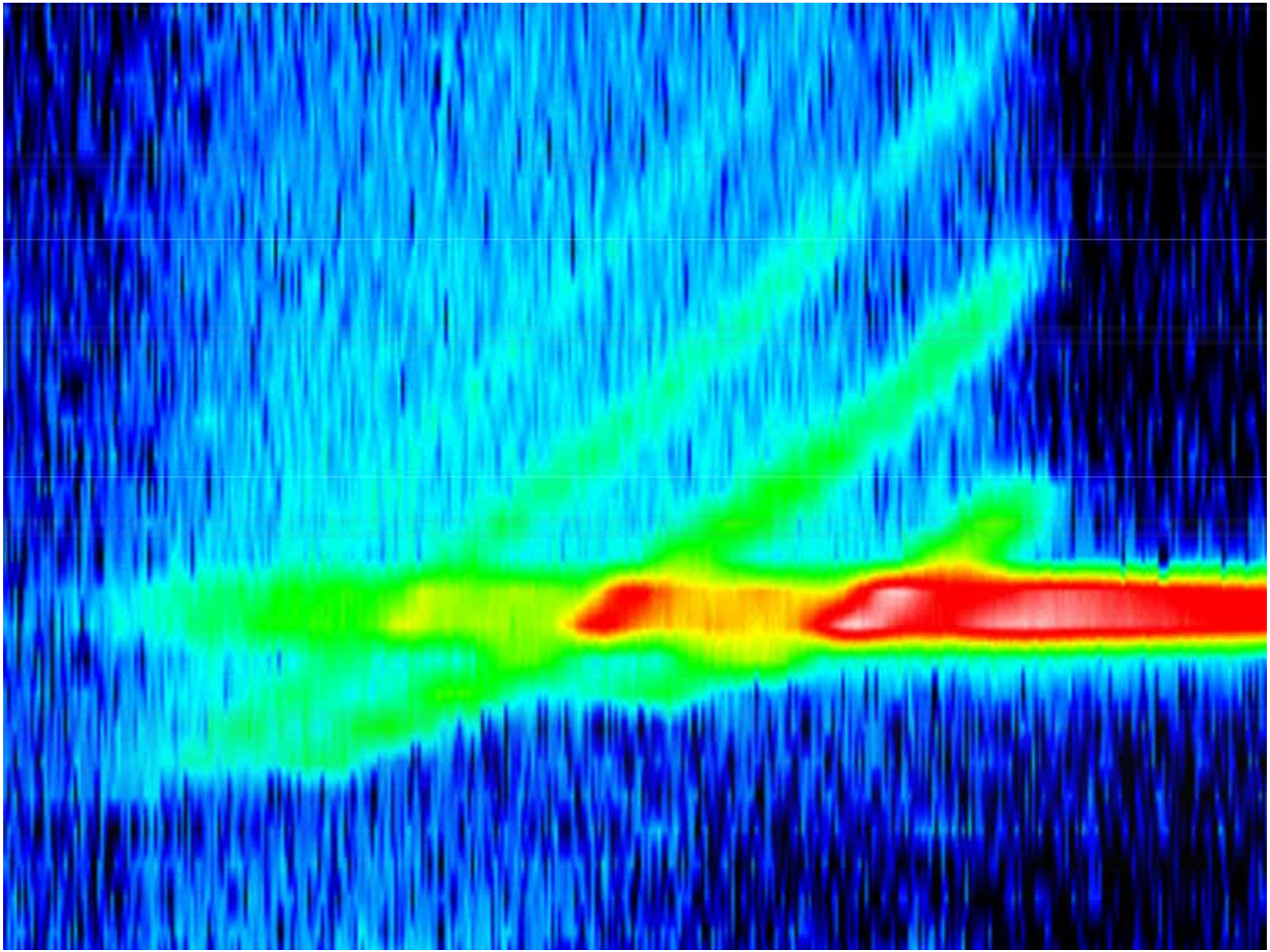
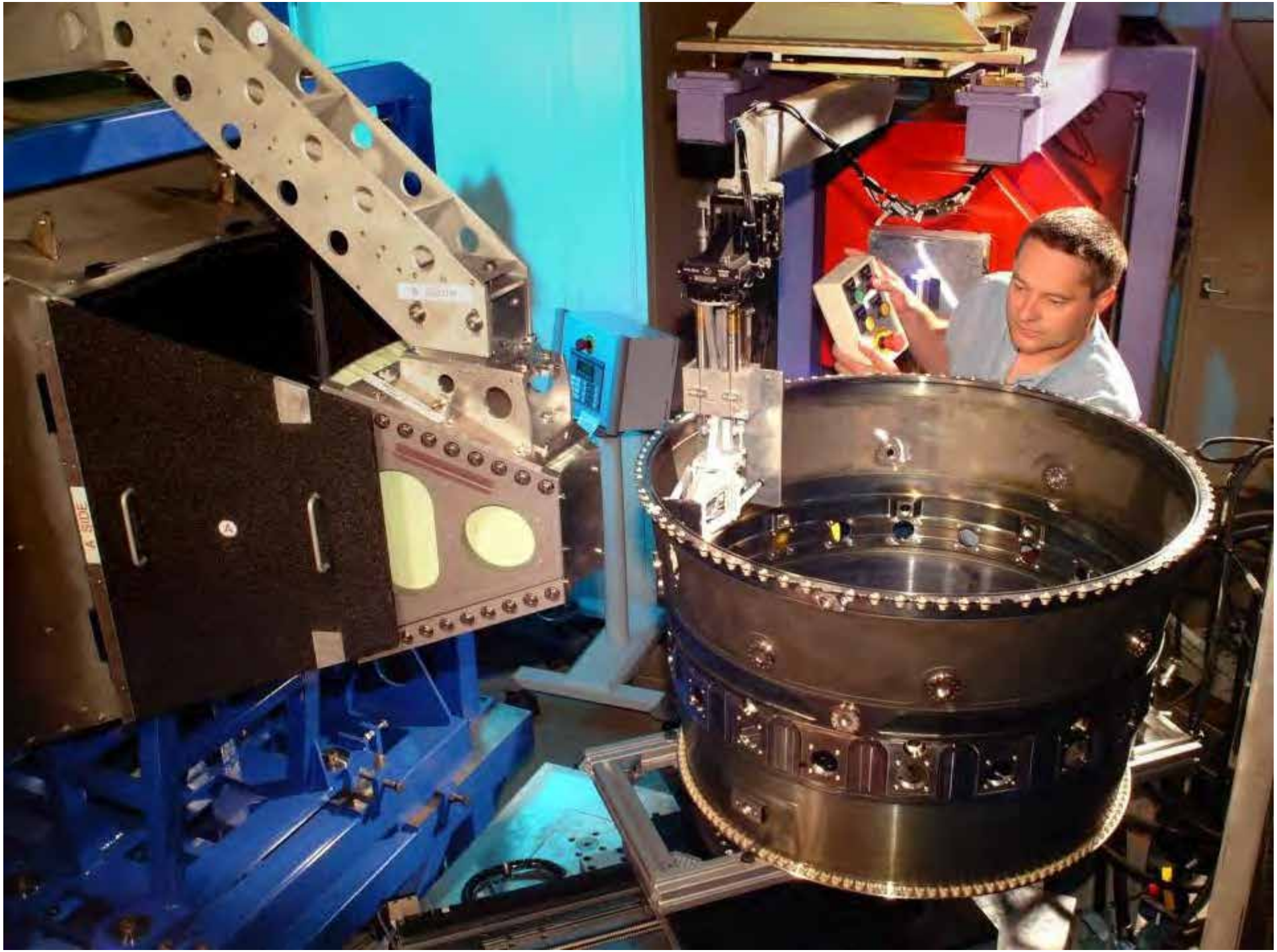
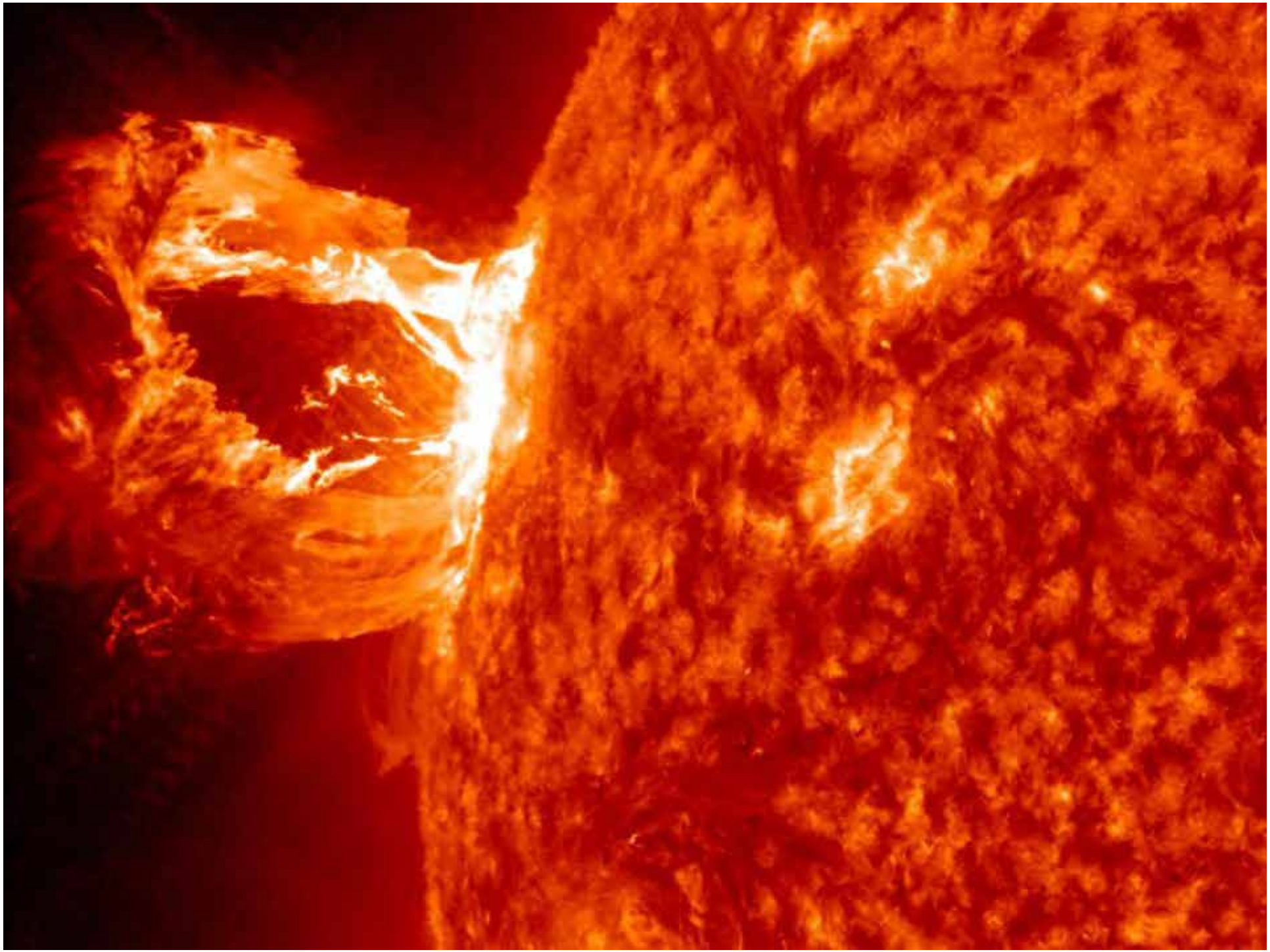
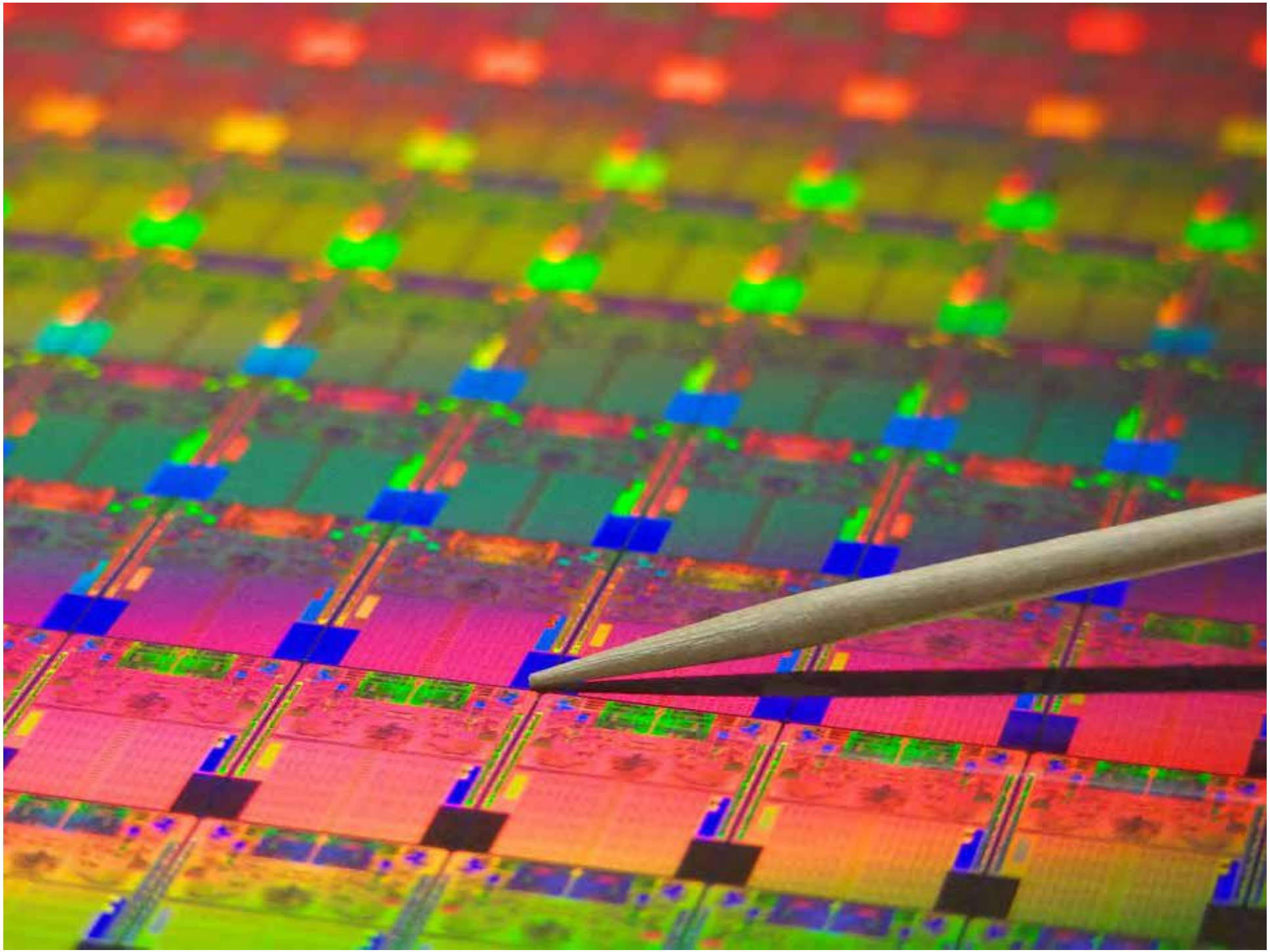
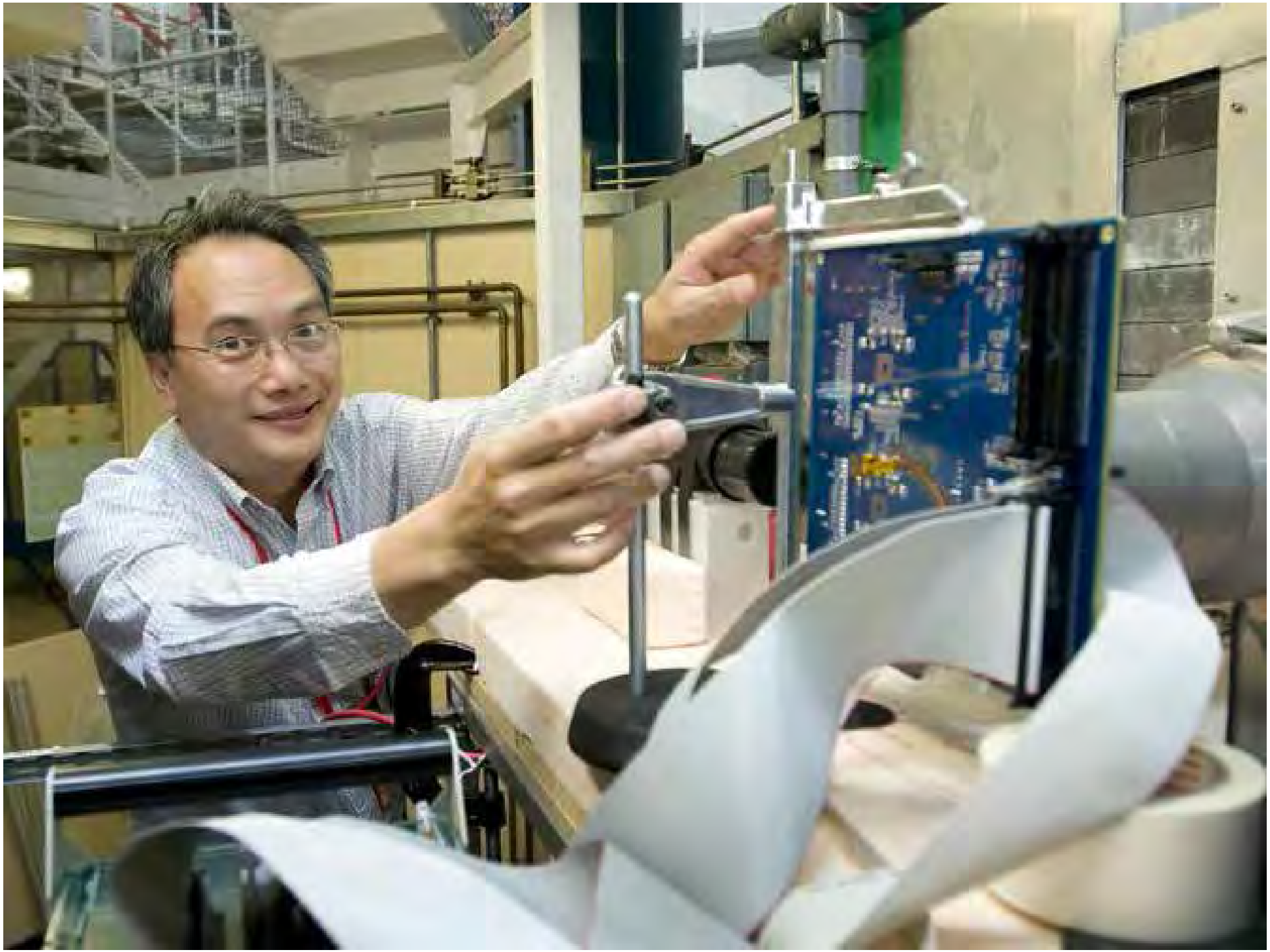



A SIDE


MSC HOME TERMINAL
Kalmar
SIEMENS
CLONLEE
CLONLEE








BEAM
ON

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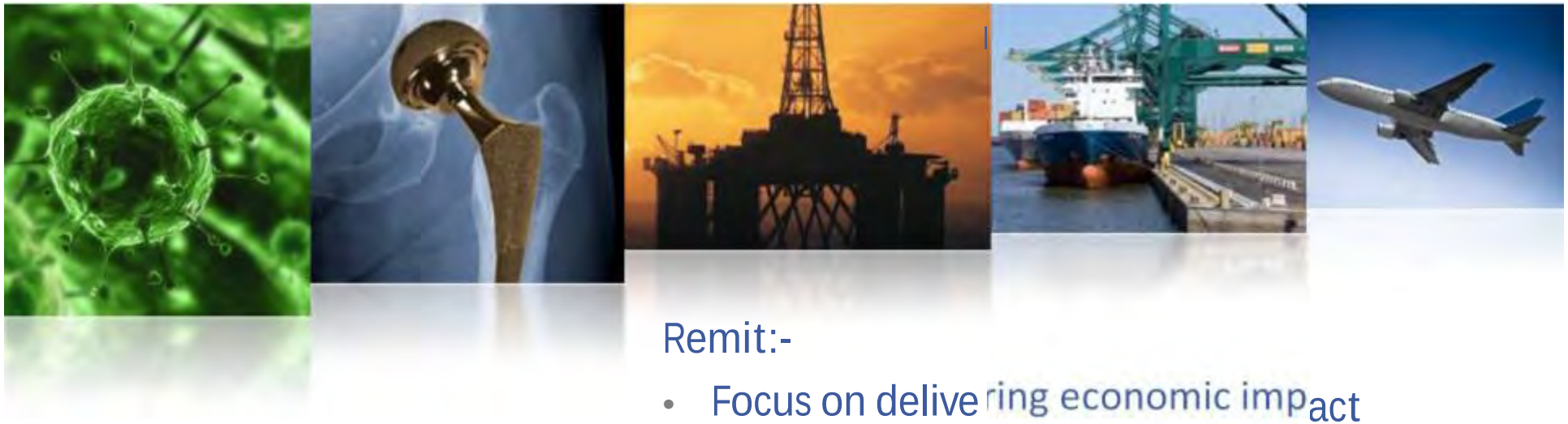
# ISIS Collaborative Research and Development Scheme



Remit:-

- Focus on delivering economic impact
- Build long-term partnerships with industry
- Engage with diverse industrial base
  - SMEs to Large Multinationals
  - Large Scale Engineering to Healthcare

# What is the value of ISIS to industry?

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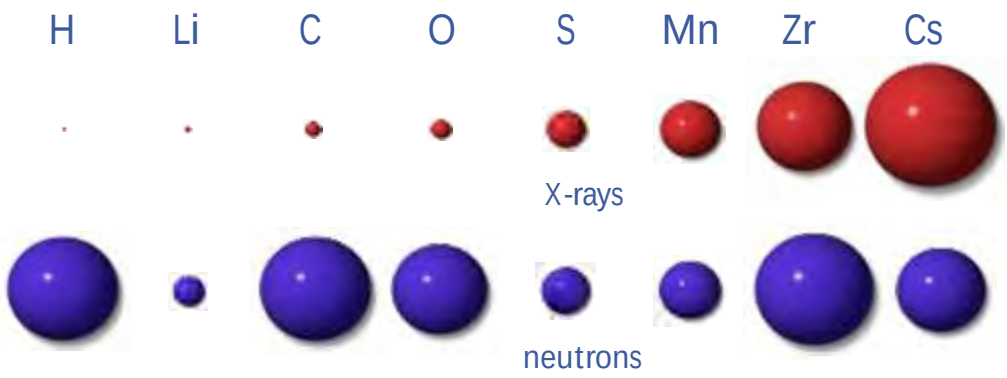
ISIS

# What is the value of ISIS to industry?


Neutrons can provide new or different information into material properties or behaviour

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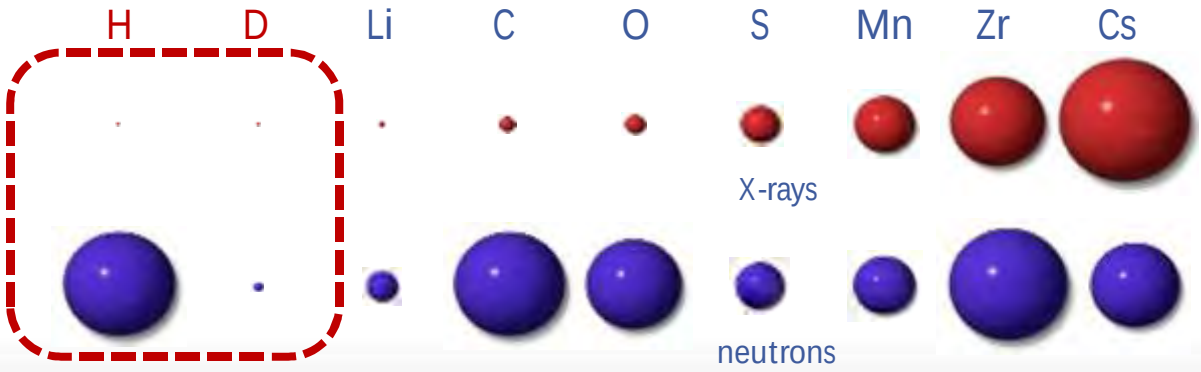
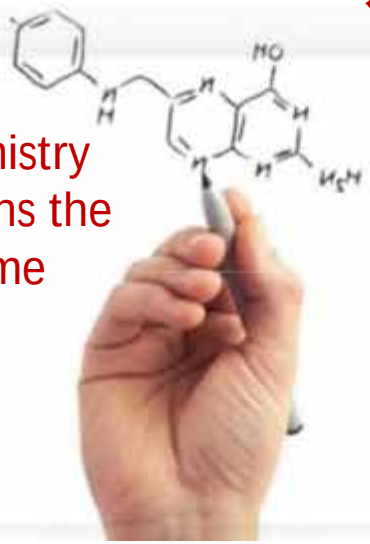
# What is the value of ISIS to industry?




Nuclear Interaction Changes



Chemistry Remains the Same

Neutrons can provide new or different information into material properties or behaviour

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ISIS has expertise and networks to help you interpret what the neutrons are telling you

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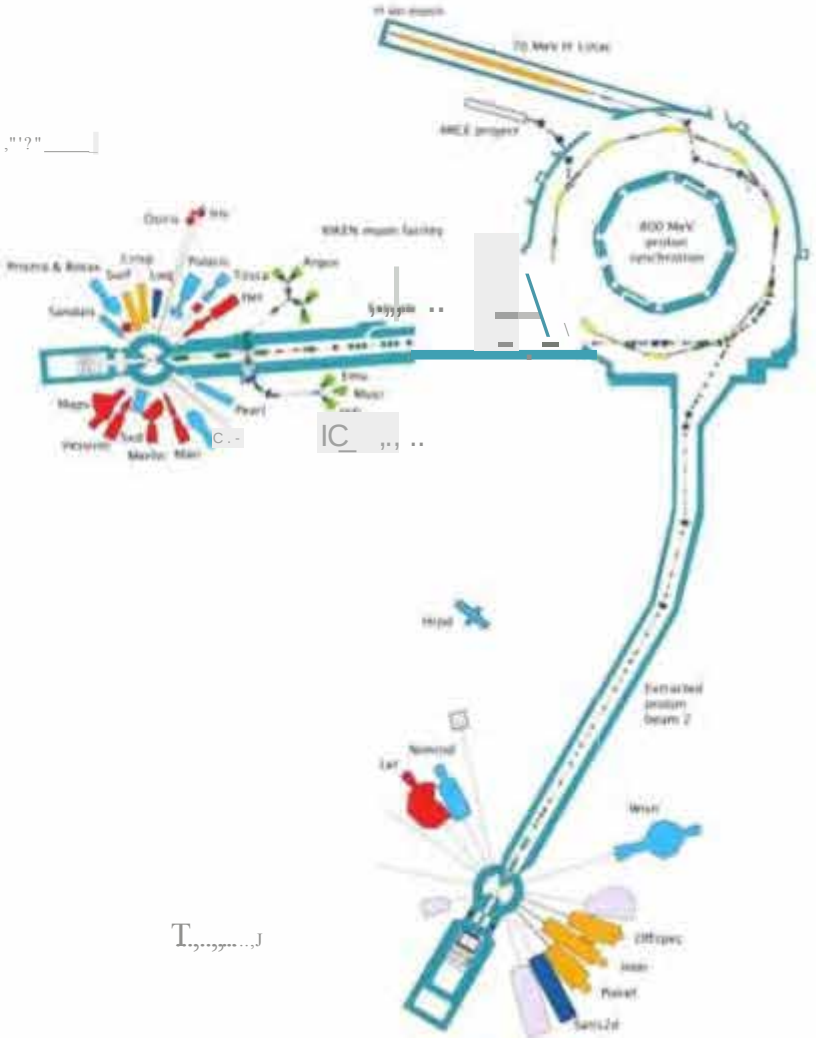

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## Molecular Spectroscopy
IRIS
OSIRIS
TOSCA
VESUVIO

## Large Scale Structures
SANS2D
OFFSPEC
POLREF
INTER
CRISP
SURF
LOQ

## Muons
EMU
MuSR
HIFI
ARGUS

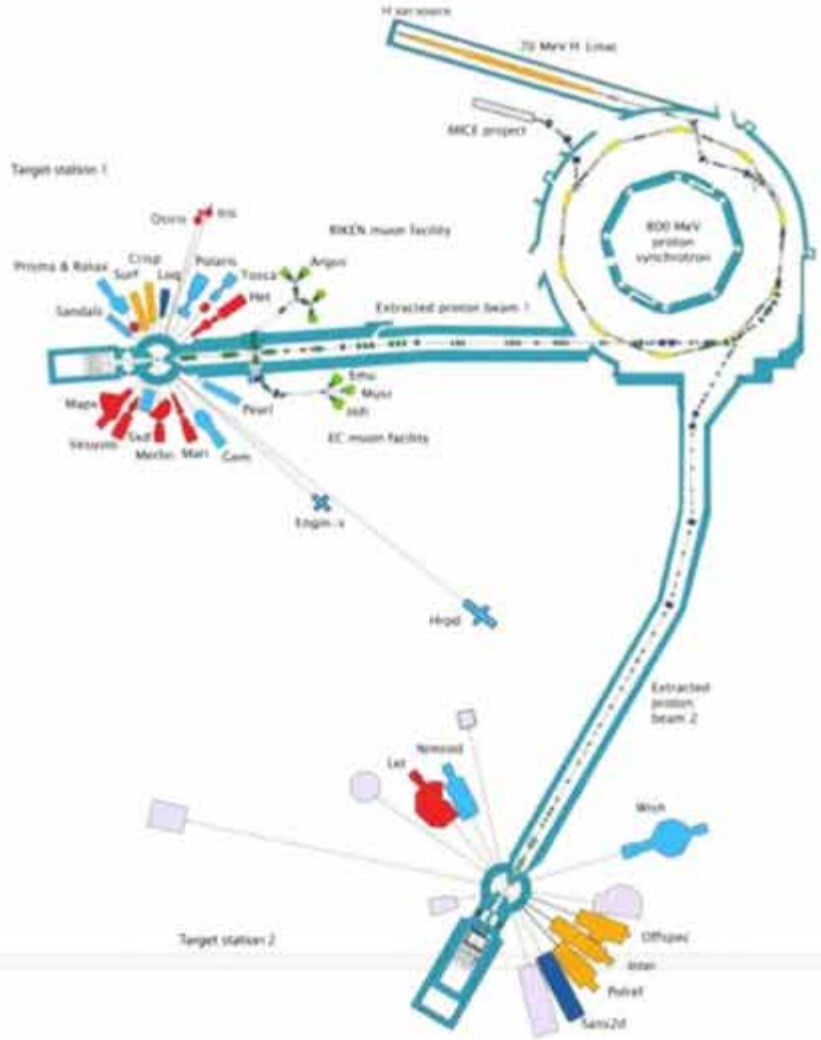
## Spectroscopy
MAPS
LET
MARI
MERLIN
HET

## Engineering
ENGIN-X

## Diffraction
HRPD
SXD
POLARIS
GEM
WISH
PEARL
INES

## Disordered Materials
SANDALS
NIMROD

# 30
Neutron and Muons Instruments



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## Spectroscopy

### Molecular Spectroscopy
IRIS
OSIRIS
TOSCA
VESUVIO

### Large Scale Structures
SANS2D
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SXD
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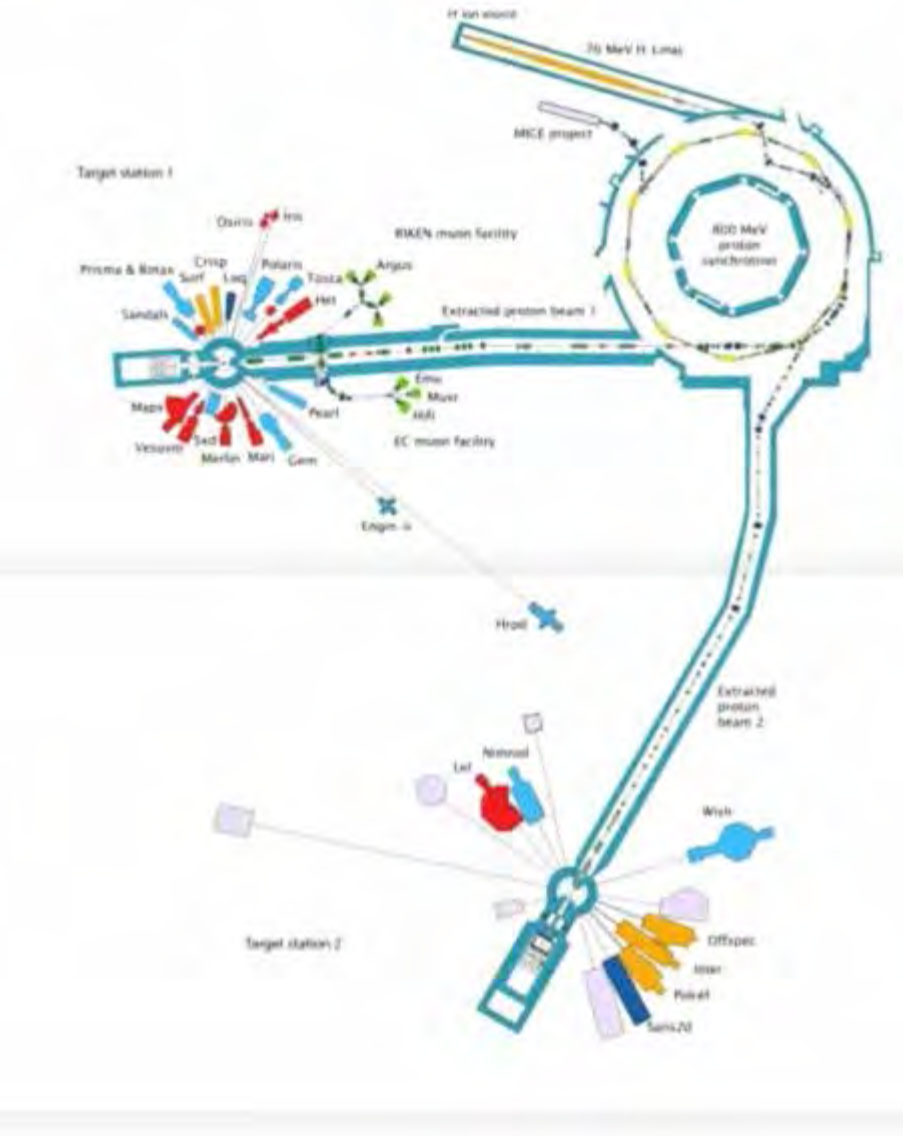
PEARL
INES

### Disordered Materials
SANDALS
NIMROD

# 15%

Peer-Review



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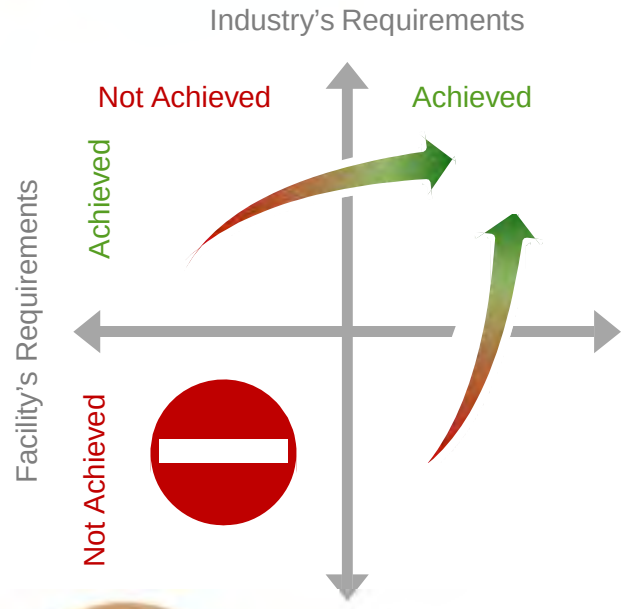


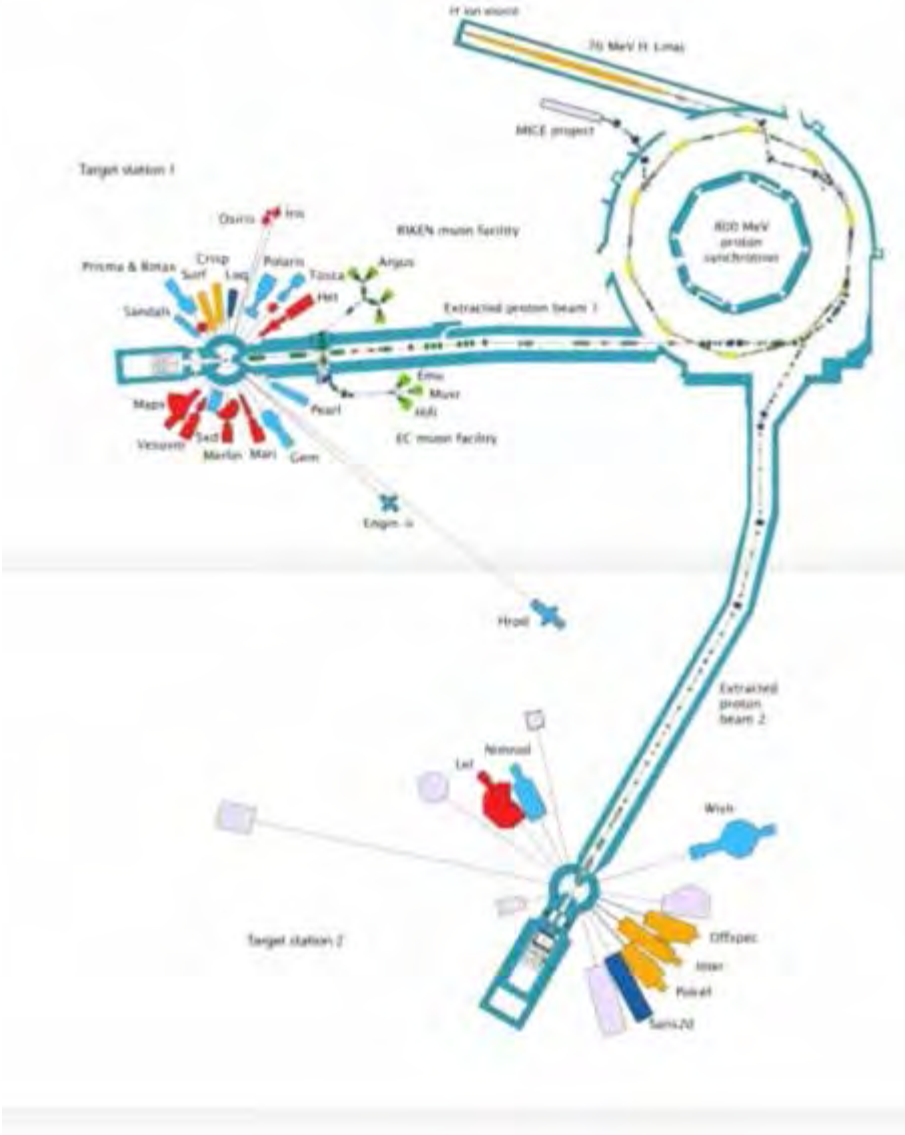

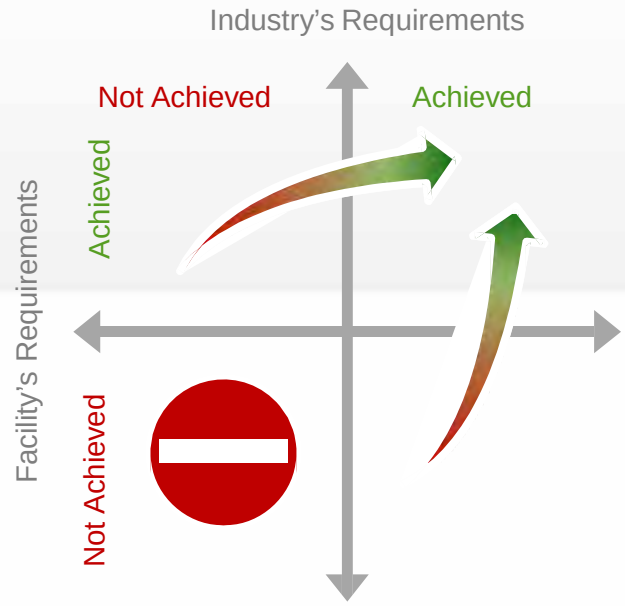


## New access mechanism's objectives:-

- Demonstrate the economic impact of neutrons to key stakeholders
- Widen and progress industrial use of ISIS

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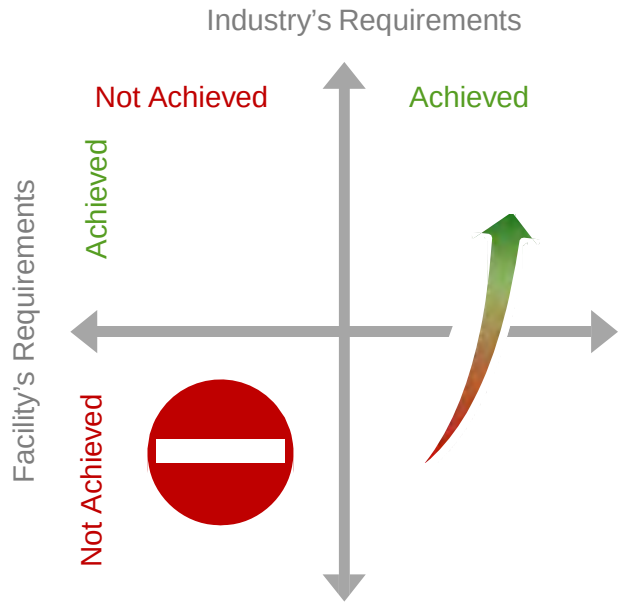


## New access mechanism should:-

- Allow industry to asses the value of neutrons for their business
- Use economic impact as an major assessment criteria
- Build-in impact reporting

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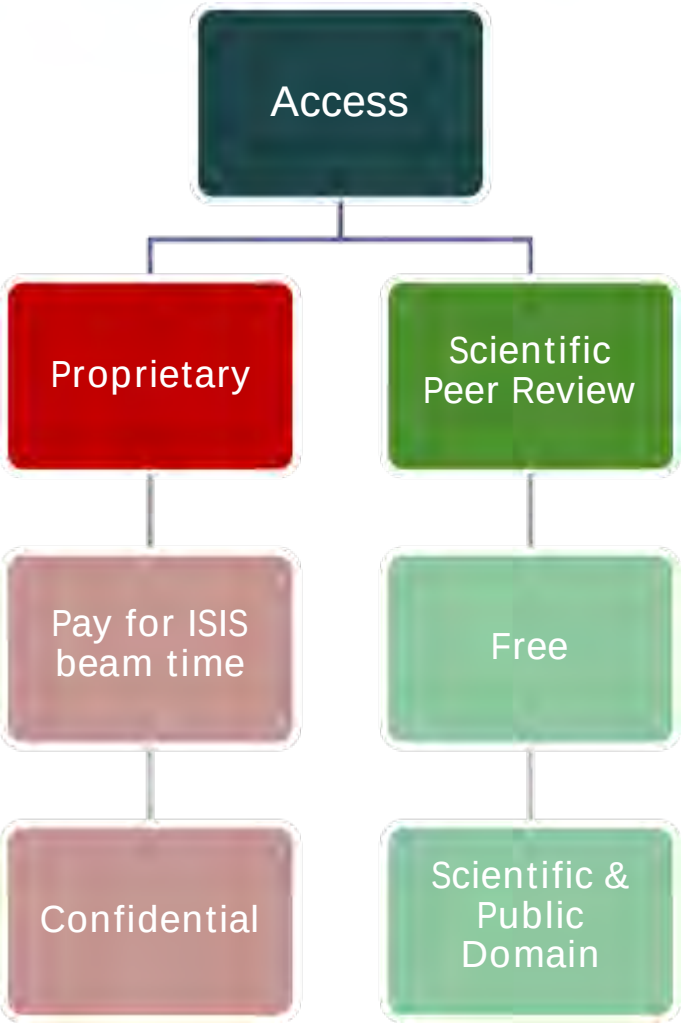


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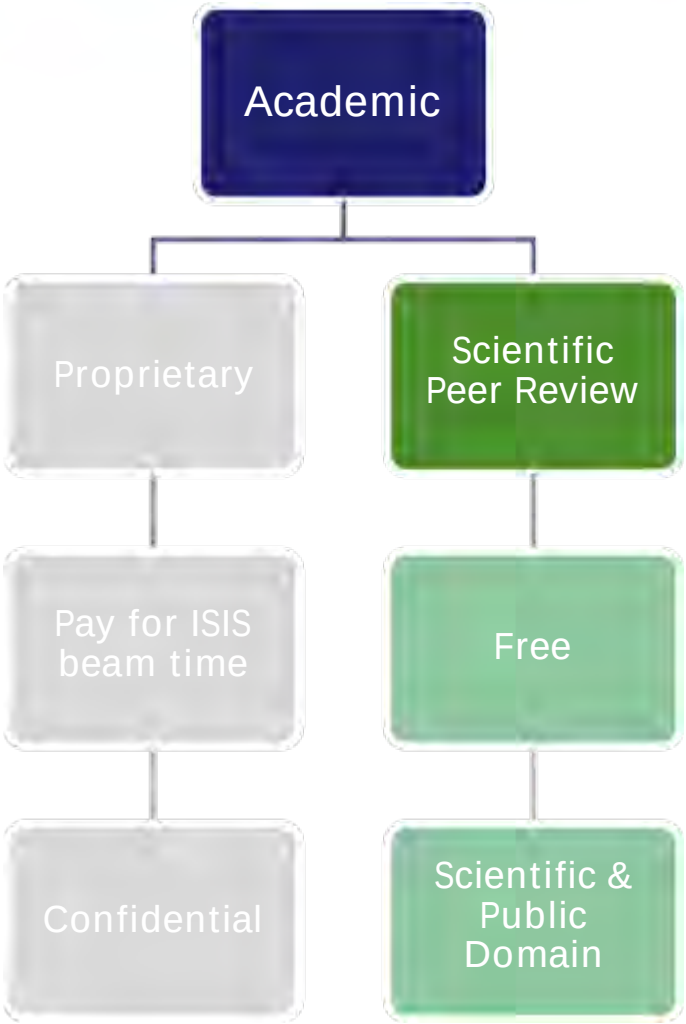


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UK Industrial

| Proprietary | Scientific Peer Review |
| --- | --- |
| Pay for ISIS beam time | Free |
| Confidential | Scientific & Public Domain |

Science & Technology Facilities Council
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UK Industrial

Proprietary

Scientific Peer Review

Pay for ISIS beam time

Free

Confidential

Scientific & Public Domain

Cost vs value…
Neutrons are expensive?

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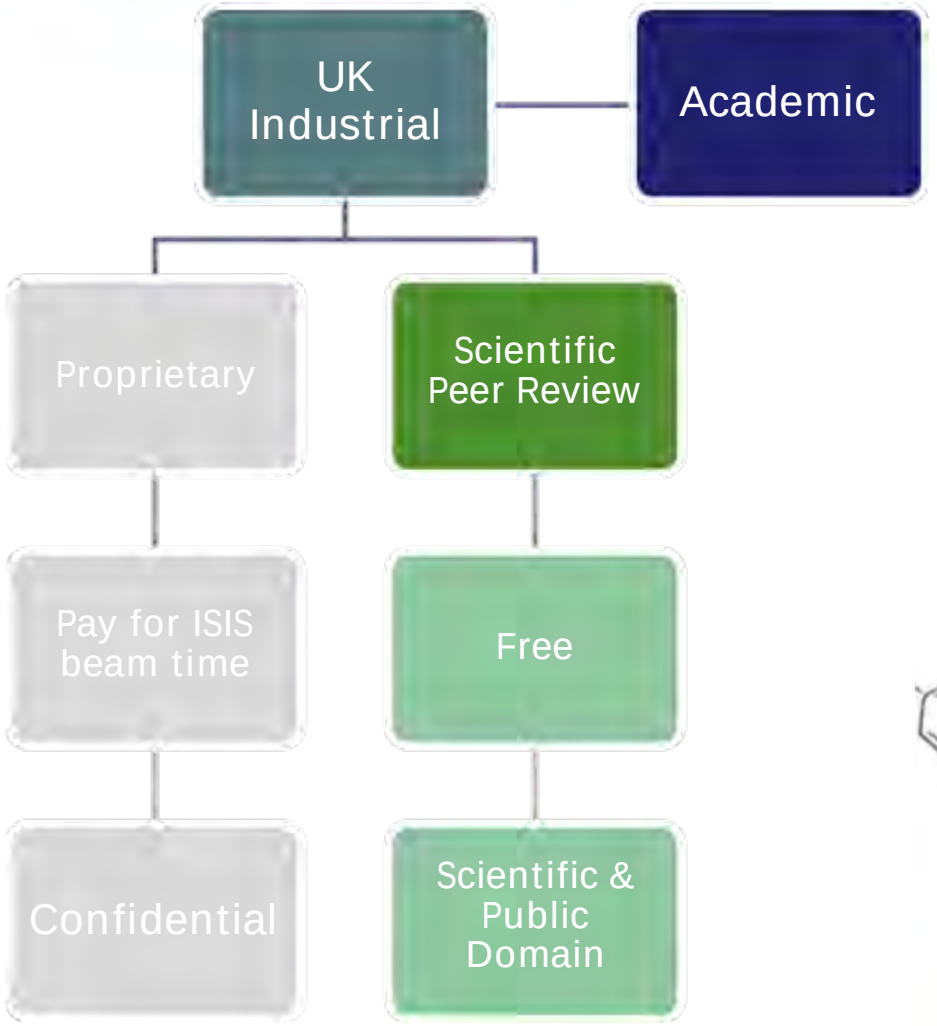


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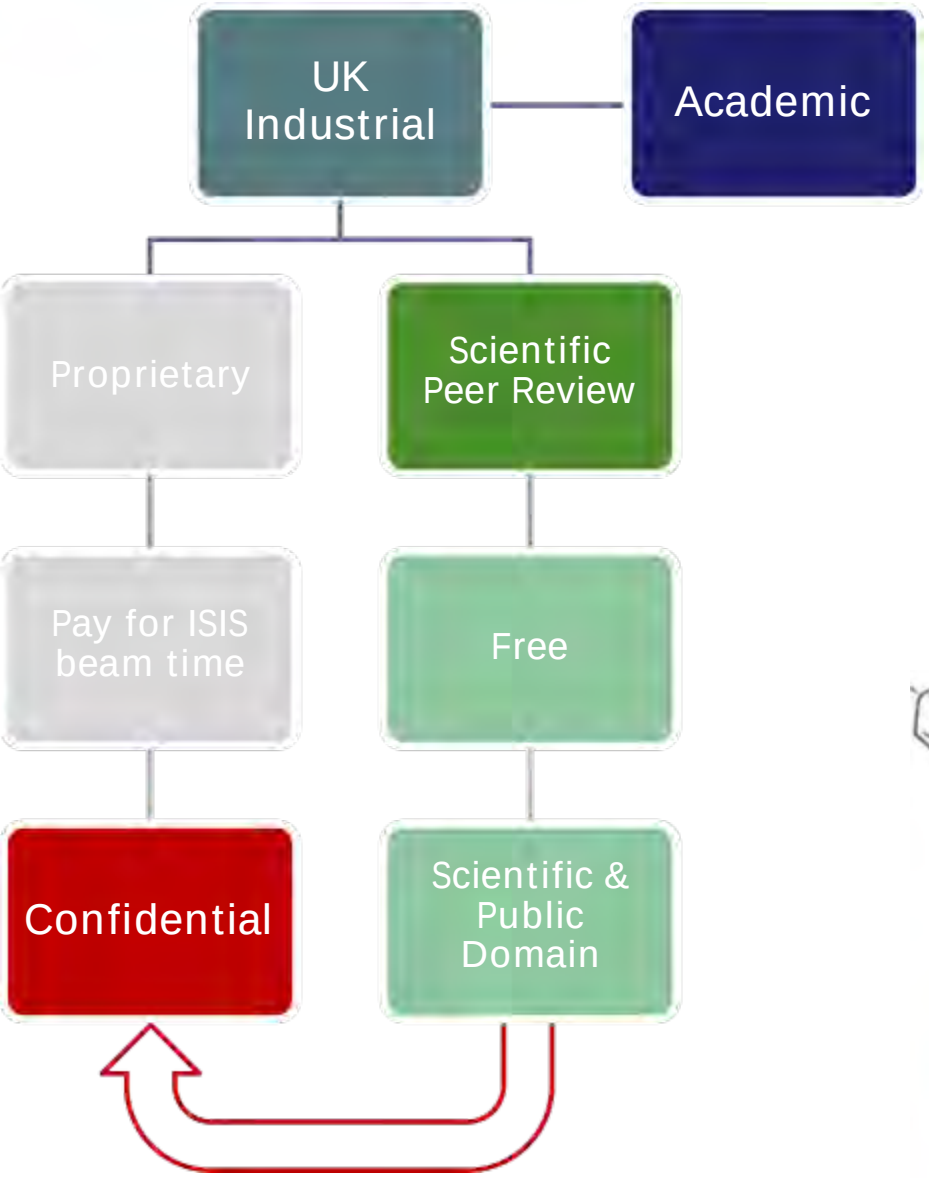


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UK Industrial

Academic

ICRD Programme

ICRD Route

Scientific Peer Review

Free

Scientific Public Domain

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UK Industrial

Academic

ICRD Programme

ICRD Route

CONFIDENTIAL

Scientific Peer Review

Free

Scientific Public Domain

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Academic

ICRD Programme

ICRD Route

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Economic & Public Domain

Scientific Peer Review

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Economic & Public Domain

Scientific Peer Review

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Scientific Public Domain

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Academic

ICRD Route

Scientific Peer Review

ICRD Programme

- Low risk for many industries
- Willing to explore or extend technique

Free

Scientific Public Domain

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UK manufacturing or research base

Scientific/Technical Feasibility Checked by ISIS

Small assessment panel

ISIS Senior Manager
ISIS Innovations Manager
External Expert (from ISIS Facility Access Panels)

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ISIS

# Economic Impact is the main assessment criteria

ICRD Programme

Science & Technology Facilities Council
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# Confidentiality intrinsic to process

ICRD Programme

# Beam-time is free at point of access through collaboration agreement

ICRD Programme

# Option to buy data confidentiality after the experiment

ICRD Programme

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# ISIS Collaborative Research and Development Scheme

## outcomes...

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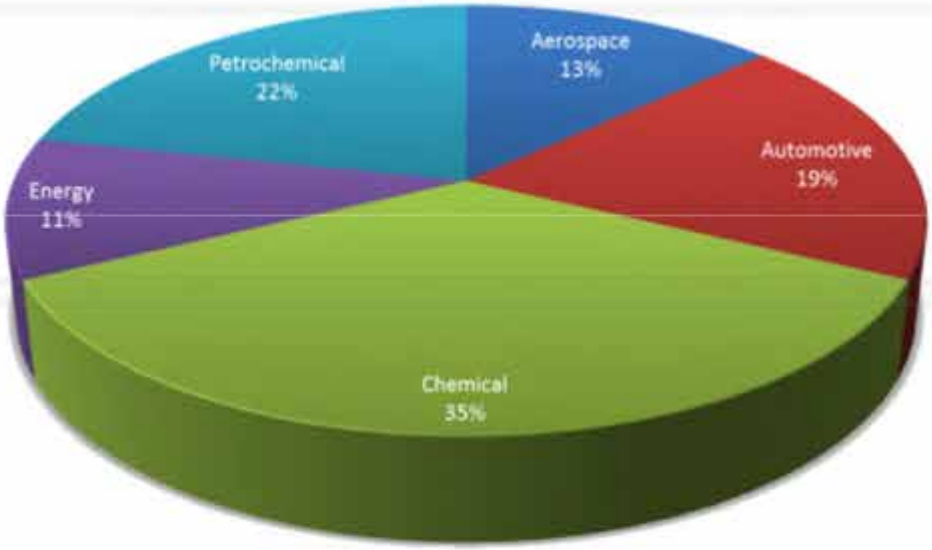
## 29 companies involved in the scheme...




## ...from across the industrial sector

In addition to the normal 15% through peer review

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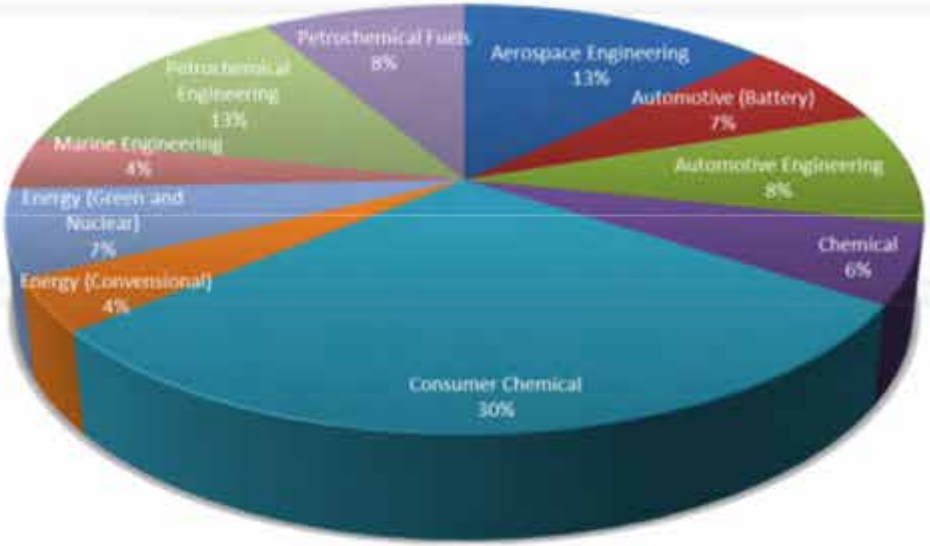
# 29 companies involved in the scheme...




# ...from across the industrial sector

In addition to the normal 15% through peer review

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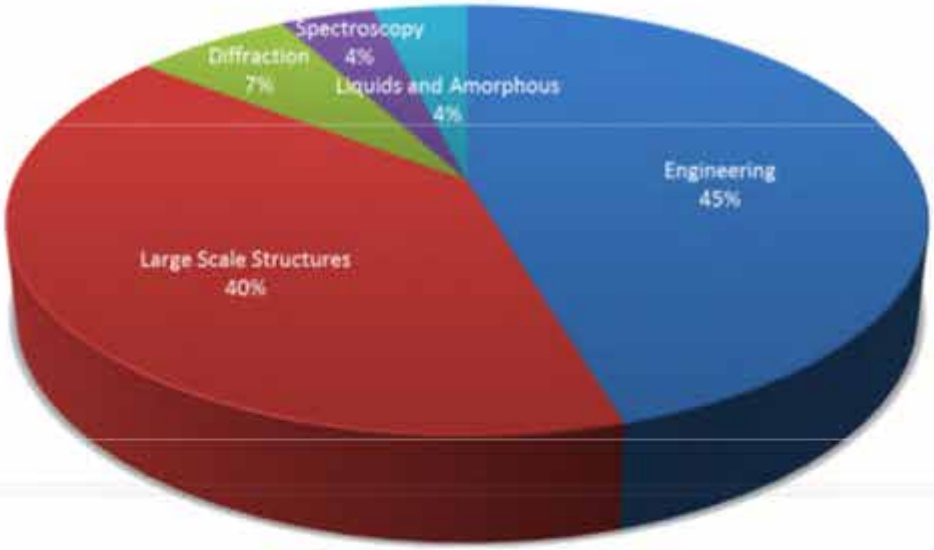
# Engineering and Large Scale Structures …




## … provide key ‘value’ to industry

- Non-destructive in-situ stress analysis
- High sensitivity to hydrogen/light atoms

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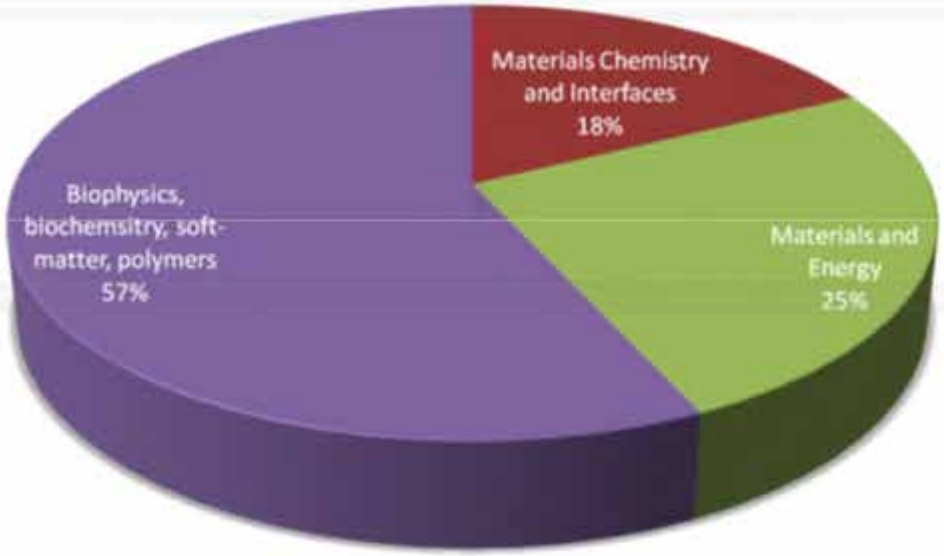
# New capability – Target Station Two




Industry is exploiting the new developments and capabilities for surfactant, polymer, and larger molecules available on Target Station 2

# Case Studies

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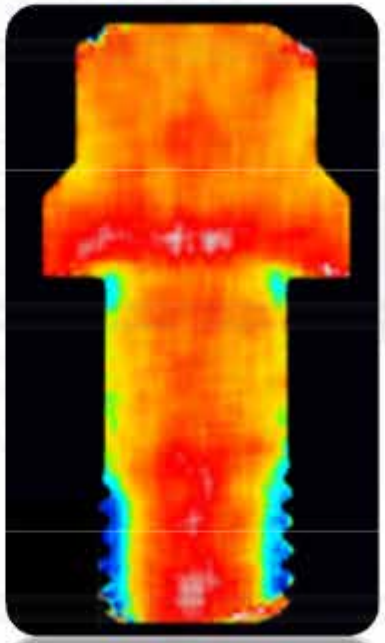
# Taking the Stress out of Engine Manufacture with Rolls-Royce



new bolts and the replacement of those that have worn out.

Rolls-Royce

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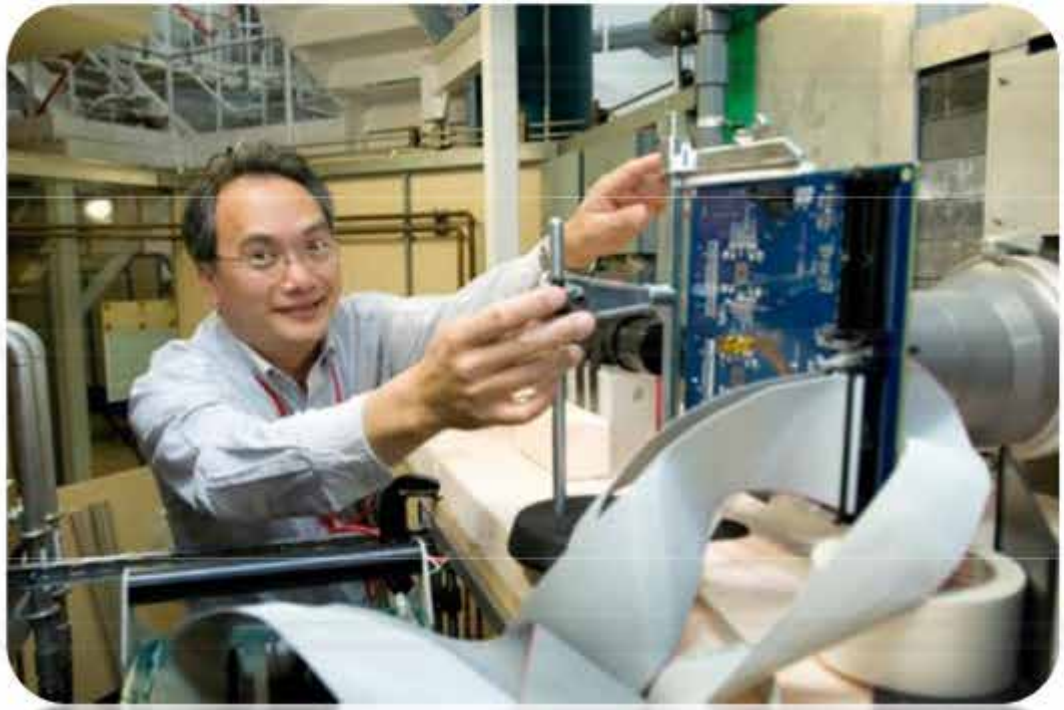
# Cosmic Ray muons and micro-electronics



Dr. Tam from Marvell Semiconductor

"The micro-electronics industry is on the verge of architectural shift as devices get to below 20 nm. It was predicted in 1979 that there will be a watershed moment when such devices become susceptible to muon ionisation, and we believe current technologies are approaching this threshold."

Source: Marvell

"Our experiments today are about understanding the probability of these events, which represents an important contribution to the semiconductor industry. This will inform future design decisions, enabling manufacturers to develop devices that are less susceptible to muon SEUs."

Prof. Bhuva, Vanderbilt University

MARVELL

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# Building safer ships with Lloyd's Register

*Ultrasonic peening is a technique for improving the fatigue performance of welded joints. Little research has been done on how UP-treated welds behave when they are subjected to real world conditions such as compressive overload or variable amplitude loading.*

*Lloyd's Register provides quality assurance to the marine industry, and they have been using ENGIN-X to investigate UP welded joints in these conditions.*

"For many years the advantages of adding a compressive stress in the area of the weld toe have been known but could not be practically applied to large ship structures....

...The ability to understand how residual stresses perform under realistic conditions has been a great help to the industry in pushing the process forward."

David Howarth, Lloyd's Register

Lloyd's Register

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# Optimising machining strategies for Boeing

Image Source: Boeing

*The Advanced Manufacturing Research Centre (AMRC), with Boeing, at the University of Sheffield have been using Engin-X at ISIS to study the evolution of residual stresses in AA7050 – an aluminium alloy commonly used in aerospace structures - as it is heated and then machined. This understanding will enable them to reduce non-conformance in the manufacturing process, and significantly reduce costs.*

Engin-X allowed the team to map residual stresses in three dimensions and build up residual stress profiles resulting from quenching and machining processes. This capability allowed the team to see the hidden residual stresses prior to releasing them during the machining process which is unachievable by other means.

BOEING

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# Testing new welding techniques for the nuclear industry

Image Source: EDF Energy

*AREVA has developed new welding procedures, but before deploying them, the very high levels of qualification and validation required by the nuclear industry and regulators must be met. Together with the Open University, AREVA has been using ENGIN-X to map residual stress in mock-ups of welded nuclear components for the purpose of validating models for over five years.*

AREVA has designed the new European Pressurised Reactor (EPR)

"This was a challenging experiment as we were working close to the operational limit of ENGIN-X. However the results were in good agreement with earlier measurements and validated the advanced weld prediction model developed by AREVA. We are confident that the knowledge we've gained will support implementation of this new welding process".

Professor John Bouchard, Open University

AREVA
forward-looking energy

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# Letting the train take the strain

*The University of Huddersfield and an industrial consortium of the Rail Safety and Standards Board, the Association of Train Operating Companies, Siemens and Lucchini, has been using Engin-X at ISIS understand how cracks begin and spread in train wheels.*

*Every five years or so, every wheel on every train in the UK has to be replaced. Maintenance and renewal of train wheels make up a significant proportion of the cost of our rolling stock.*

"We are always willing to support Universities in genuine new research such as this. We have extensive facilities in Italy but we don't have anything like ENGIN-X at ISIS. Collaboration between industry and academia can be beneficial and lead to improvements in safety and processes."

Sean Barson, Technical Services Manager at Lucchini UK

LUCCHINI ATOC RSSB SIEMENS

Science & Technology Facilities Council ISIS

industry."

Dr Elvin Eren, TWI

TWI

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# Helping make hydrogen cars a reality


Image Source: Toyota

*Toyota, who will release a hydrogen fuel cell vehicle in Japan in 2015, have been working with ISIS scientists to address a key challenge: hydrogen loss during cycling.*

*With the depletion of fossil fuels an alternative is needed, and hydrogen, provided it can be produced without using fossil fuels, is a promising option. But there are challenges in both producing and storing hydrogen that must be overcome before commercial hydrogen cars become reality.*

"Our work with ISIS has allowed us to develop in operando neutron powder diffraction techniques that has provided important insights into the nature and location of hydrogen in Ti-V-Cr-Mo alloy for hydrogen storage systems. This in turn provides new opportunities for the rational improvement of these materials for use as storage for future hydrogen cars."

Shin-ichi Towata, Toyota Central Research and Development Laboratories Inc

TOYOTA

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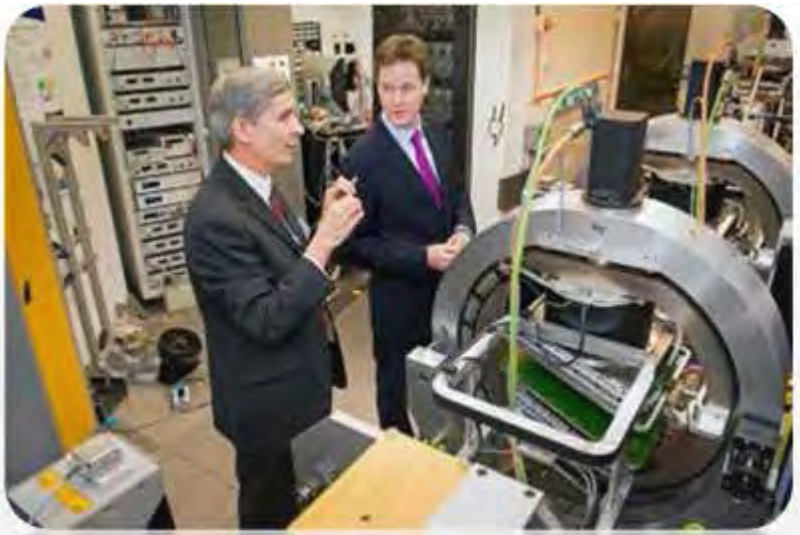
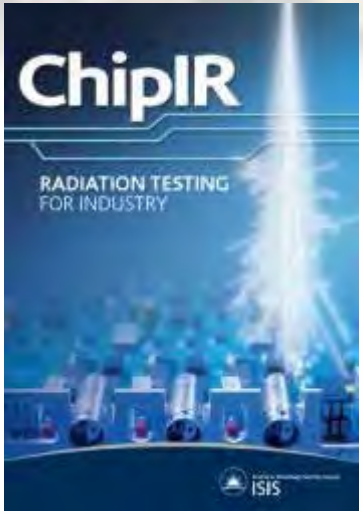
# Engaging Key Stakeholder






*"The Government understands how vital it is to innovate and tackle the challenges that face our electronics industry. This funding is helping to develop a facility capable of putting safety critical circuits through their paces, making planes safer and the electronics on which we all depend more reliable."*

*University, Science and Cities Minister, Greg Clark*

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# Science & Technology Facilities Council

# James Chadwick

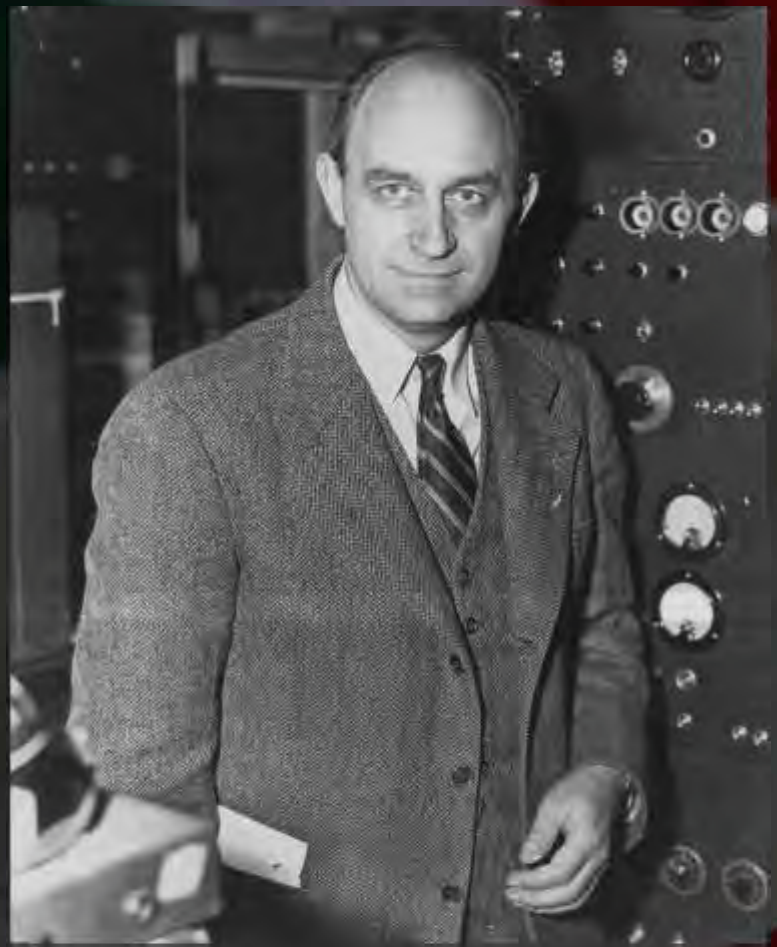
(1891–1974)

“Positive results in the search for 'neutrons' would add considerably to the existing knowledge on the subject of the construction of matter, and as such would be of the greatest interest to science, but, to humanity in general the ultimate success or otherwise of the experiments that were being carried out in this direction would make no difference."

From an interview with James Chadwick reported in The Times, Monday 29 February 1932

# Enrico Fermi

(1901-1954)



“History of science and technology has consistently taught us that scientific advances in basic understanding have sooner or later led to technical and industrial applications that have revolutionized our way of life. It seems to me improbable that this effort to get at the structure of matter should be an exception to this rule.”

Fermi, Enrico (2004). "The Future of Nuclear Physics". In Cronin, J.W. *Fermi Remembered*. Chicago: University of Chicago Press.

# The Harwell Neutron project

'the equipment — a pulsed source for neutron physics experiments — is intended to provide information about the detailed behaviour of neutrons of known velocities when they meet the materials used in the construction of reactors.'

The Engineer 1959

# Neutrons for Science, Neutrons for Society

Thank you…

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