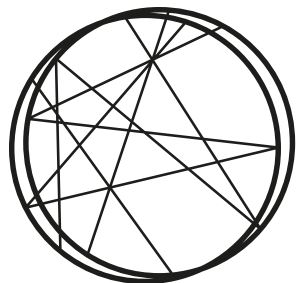




Image by Basics (www.basics.land)



**LUND INSTITUTE OF ADVANCED
NEUTRON AND X-RAY SCIENCE**

LINXS

Visit us at: www.linxs.se

MAX IV and ESS are the biggest investments in science infrastructure in the history of Sweden



MAX IV

SVS

ESS

MAX IV and ESS are the biggest investments in science infrastructure in the history of Sweden

Annual visits at full operations
2000-3000

Average visit length
2-4 days

How do we ensure a dynamic national and international user base?

How do we ensure that users are active in shaping the future of the facilities?

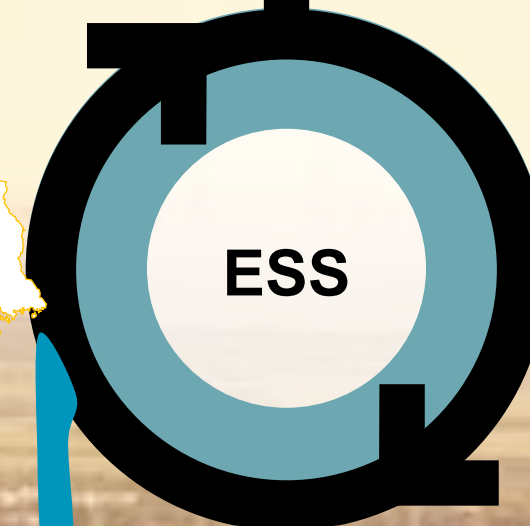


New user groups

LINXS

50-90
Researchers on any given day at full operations

World-class researchers



Annual visits at full operations
2000-3000

Average visit length
3-5 days

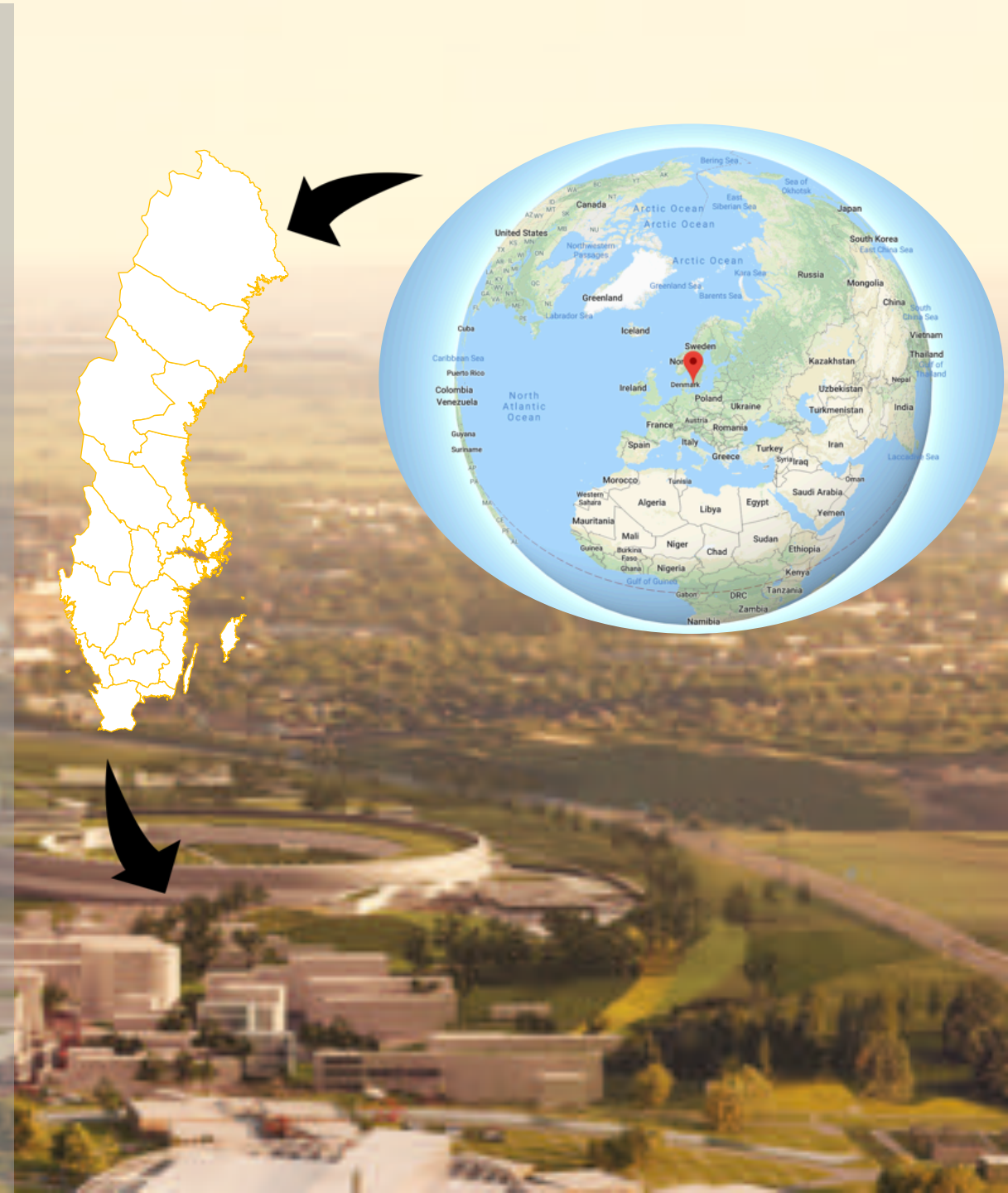
SETTING THE STAGE FOR OPTIMUM USE OF MAX IV AND ESS:

LINXS is an advanced study institute dedicated to becoming the nucleus for national and international scientific activities in Science Village Scandinavia situated between MAX IV and ESS.

LINXS will be an international competence centre, research networking hub and think tank for science with neutrons and x-rays.

LINXS is built on a stream of highly motivated world-leading scientists invited for short-term focused topical research visits.

More info: www.linxs.se/about



CURRENT THEMES & Working Groups

IMAGING

IMAGING WITH X-RAYS AND NEUTRONS, FROM ACQUISITION THROUGH PROCESSING TO APPLICATION

- **GeoArCH**: Geology, Archaeology and Cultural Heritage
- **Quantim** – 3D/4D image analysis
- **New imaging** possibilities with x-rays and neutrons
- X-ray and neutron imaging applications in **soil sciences**
- **TBT**: Tomography of Biological Tissues

DYNAMICS

UNDERSTANDING DYNAMIC PROCESSES THROUGH THE USE OF NEUTRONS AND X-RAYS

- Dynamics and structure of **biological macromolecules**
- **XPCS**: Characterizing soft matter with x-ray photon correlation spectroscopy
- Dynamics and structure of **membranes** and their constituents

INTEGRATIVE STRUCTURAL BIOLOGY

PUSHING THE LIMITS IN INTEGRATIVE STRUCTURAL BIOLOGY WITH NEUTRONS, X-RAYS AND COMPLEMENTARY TECHNIQUES

- **Biocompute**
- **Time resolved ISB**
- **Membrane proteins**
- **AMYLOID**: an integrative approach

SCIENTIFIC ACTIVITIES

Previously

The image displays a series of overlapping posters for scientific events. The posters are arranged in two main groups. The left group contains 11 posters, and the right group contains 8 posters. Each poster includes a date, a title, and a brief description of the event.

Left Group (from top to bottom):

- LINXS Kickoff** (SEP 27)
- Imaging thematic symposium** (DEC 18, 2017, 12:00 – Tue, Dec 19, 2017, 15:00)
- X-ray Fluorescence imaging - how to plan and execute the perfect** (SEP 15)
- Workshop - Dynamics of biological macromolecules** (JUN 4)
- Satellite Meeting - The Future of Chemistry with MAX IV and ESS** (JUN 20)
- Workshop - Dynamics of membranes and their constituents** (SEP 12)
- First symposium - Integrative Structural Biology** (NOV 19, 2018, 12:00 – Wed, Nov 21, 2018, 12:00)
- The Quantim Hackathon at LINXS!** (NOV 26)
- Workshop - Scattering and Dynamics of Flowing Soft** (DEC 10)
- LINXS Event: Geology, Archaeology and Culture Heritage studies in a new light** (JAN 15, 2019, 16:00 – Thu, Jan 17, 2019, 14:00)

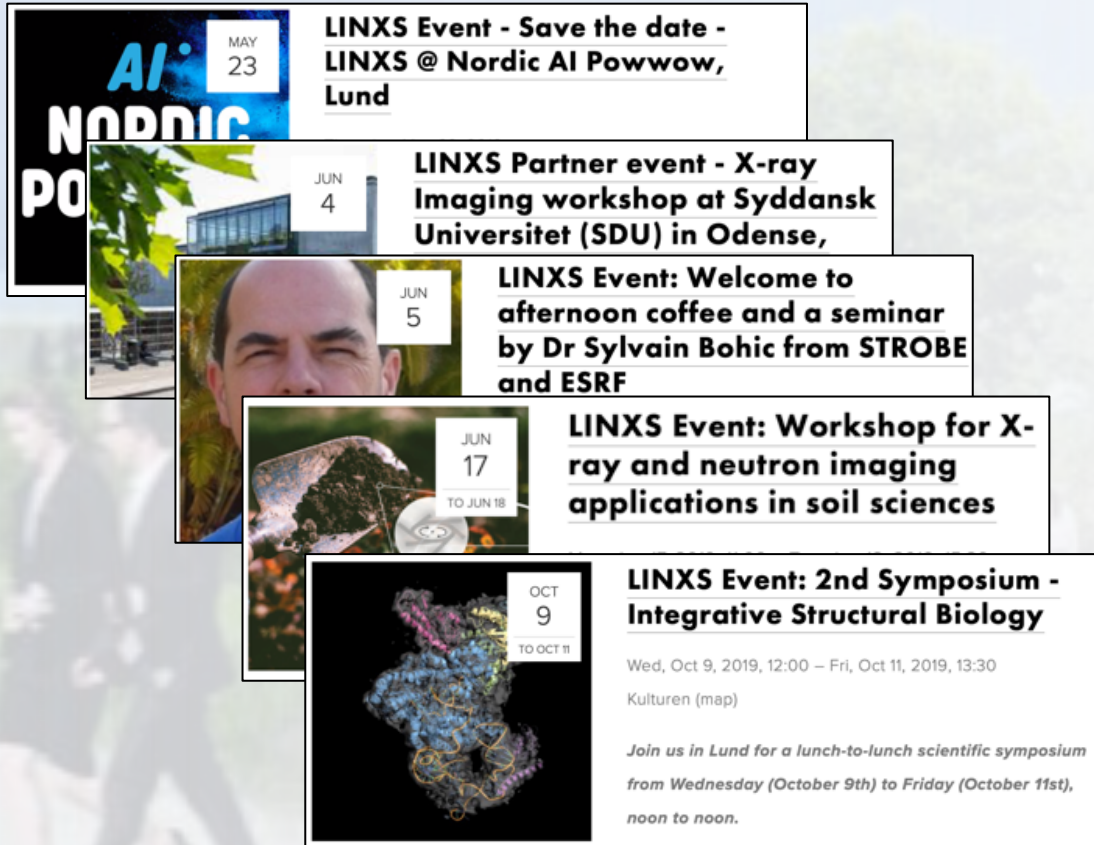
Right Group (from top to bottom):

- Partner Event: Magnetism, Correlated Systems and X-** (MAR 14)
- Partner Event: Symposium -** (MAR)
- 2nd QUANTIM Hackathon - Cellular materials in 3D and 4D** (MAR)
- LINXS Event: Workshop - Tomography of Biological** (MAR 25)
- Partner Event: Northern Lights on Food** (MAR 26)
- LINXS Event: Inverse problems in X-ray phase retrieval and** (APR)
- Partner Event: BigScience@LU - addressing the need of** (APR 24)
- LINXS related event - lecture with Prof. Marco Stampanoni from the** (MAY 7)
- Partner Event: French and Swedish School on Energy Materials** (MAY 13 TO MAY 17, 2019, 08:30 – Fri, May 17, 2019, 12:30)

The bottom-most poster in the right group features the **Fasem** logo and the text: "Joint French-Swedish school on X-rays and Neutrons tech the study of functional materials for energy".

Statistics Aug 2017 – Dec 2018:
Total number of participants: 773
(42% national/international)

SCIENTIFIC ACTIVITIES – recent/upcoming events



MAY 23
LINXS Event - Save the date - LINXS @ Nordic AI Powwow, Lund

JUN 4
LINXS Partner event - X-ray Imaging workshop at Syddansk Universitet (SDU) in Odense,

JUN 5
LINXS Event: Welcome to afternoon coffee and a seminar by Dr Sylvain Bohic from STROBE and ESRF

JUN 17 TO JUN 18
LINXS Event: Workshop for X-ray and neutron imaging applications in soil sciences

OCT 9 TO OCT 11
LINXS Event: 2nd Symposium - Integrative Structural Biology
Wed, Oct 9, 2019, 12:00 – Fri, Oct 11, 2019, 13:30
Kulturen (map)
Join us in Lund for a lunch-to-lunch scientific symposium from Wednesday (October 9th) to Friday (October 11st), noon to noon.

- Modelling of scattering data (autumn 2019)
- Coherent Diffractive Imaging (autumn 2019)
- 2nd Fluorescence imaging workshop (autumn 2019)
- IDP workshop (autumn 2019)
- XPCS workshop (autumn 2019)
- STXM imaging workshop (early 2020)

<http://www.linxs.se>

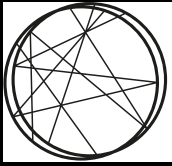
Get Involved!

- Join an event
- Join an activity or working group
- Co-organise a workshop in your area
- Become an organisational member



www.linxs.se

We welcome Swedish and International organisations to become partners/members to work together to forge a world-class, open institute for the whole x-ray and neutron science community



LUND INSTITUTE OF ADVANCED
NEUTRON AND X-RAY SCIENCE

LINXS

IMAGING WITH X-RAYS AND NEUTRONS

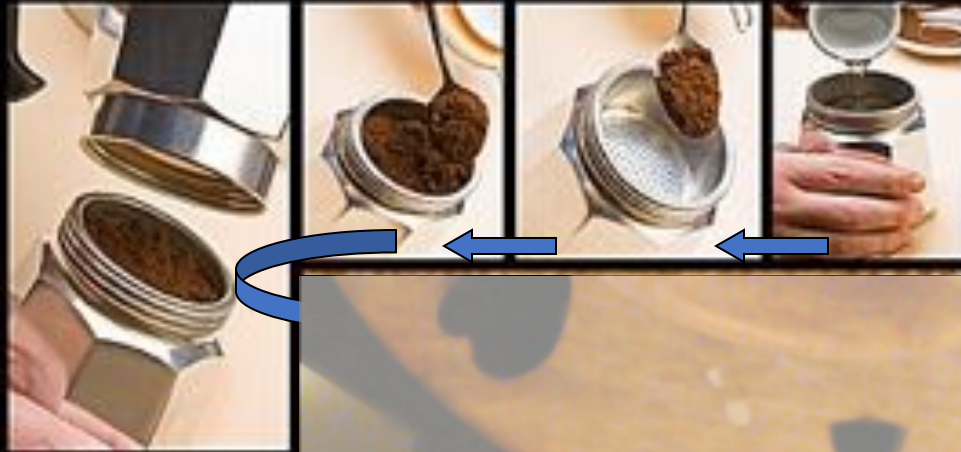
Stephen Hall^{1,2,3}

¹Lund Institute of advanced Neutron and X-ray Science

²Division of Solid Mechanics, Lund University

³4D Imaging Lab @ LTH

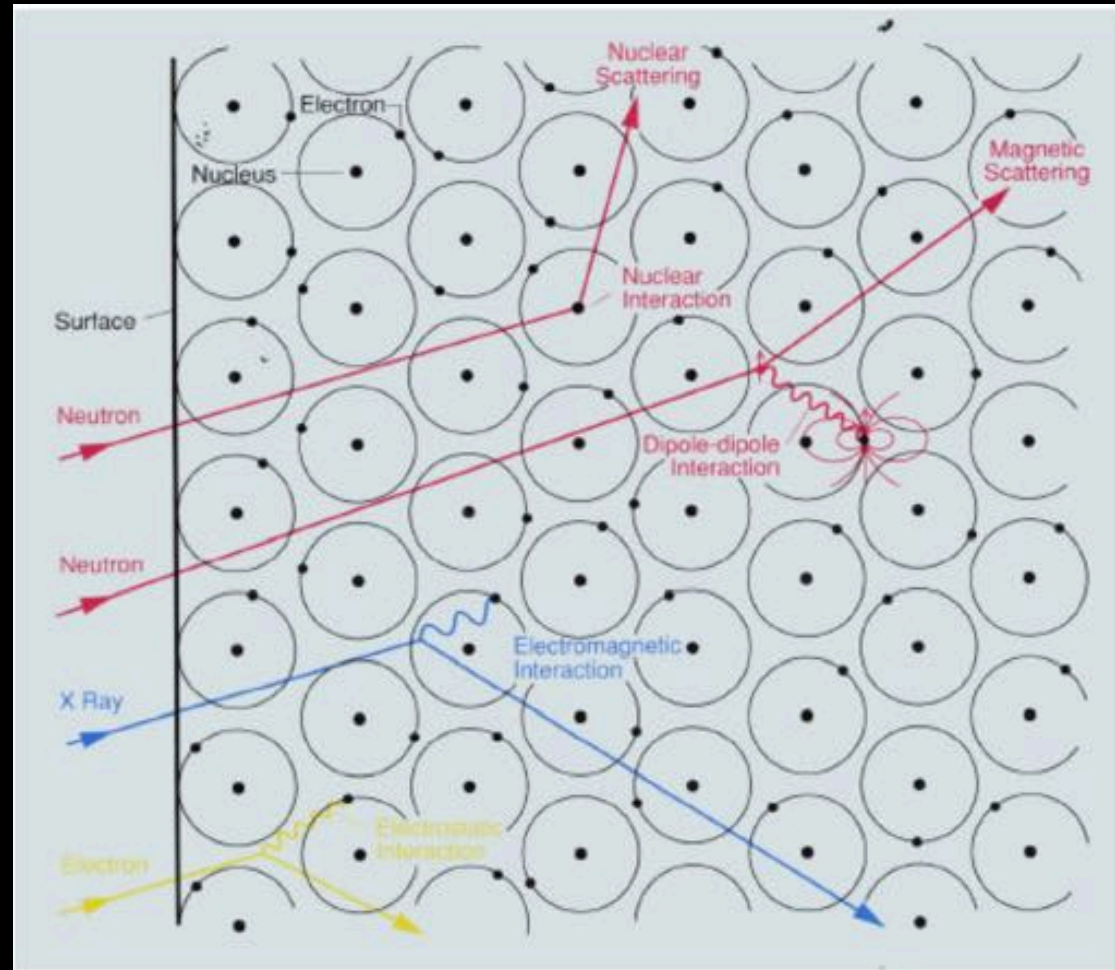
A quick experiment to start....



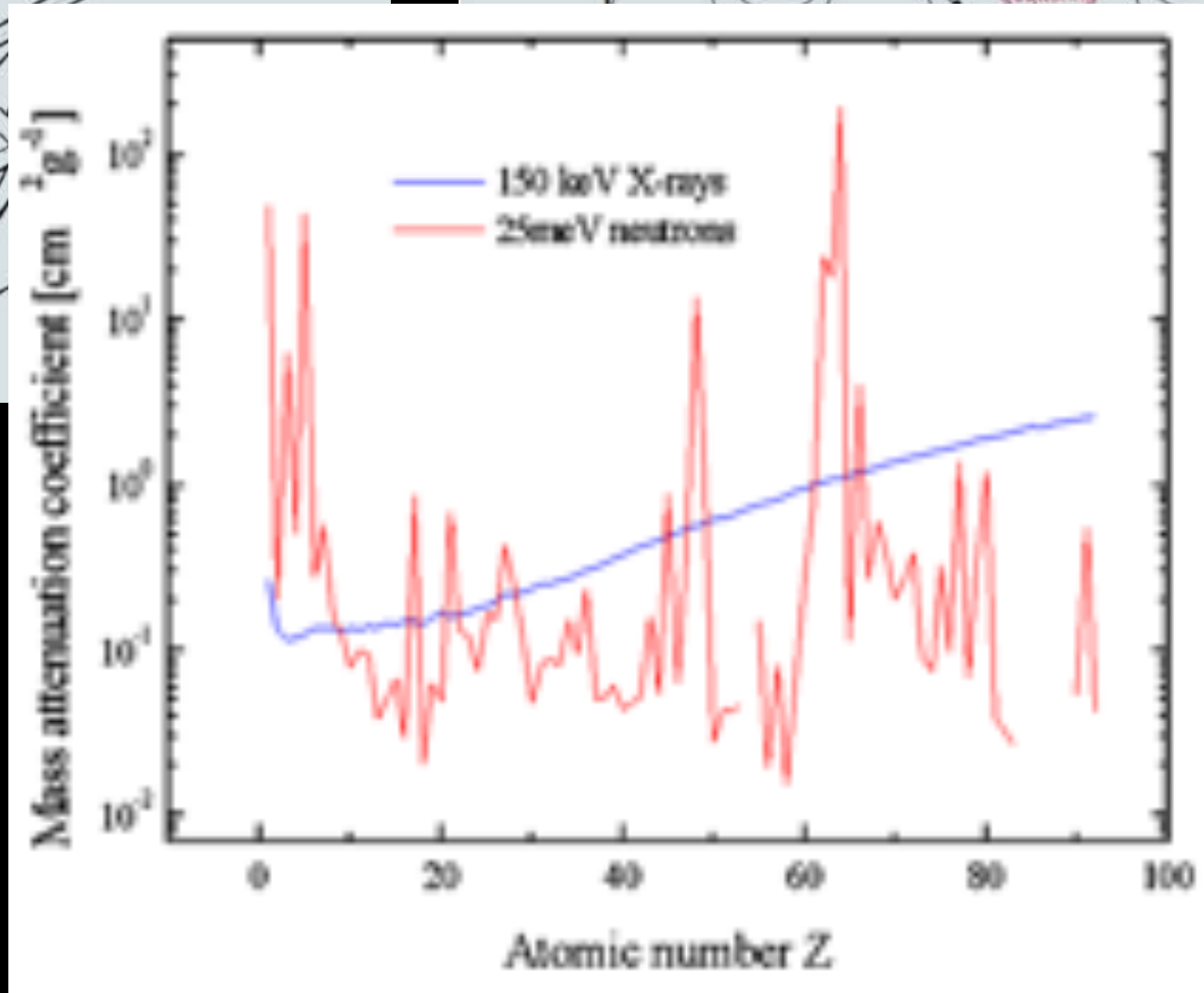
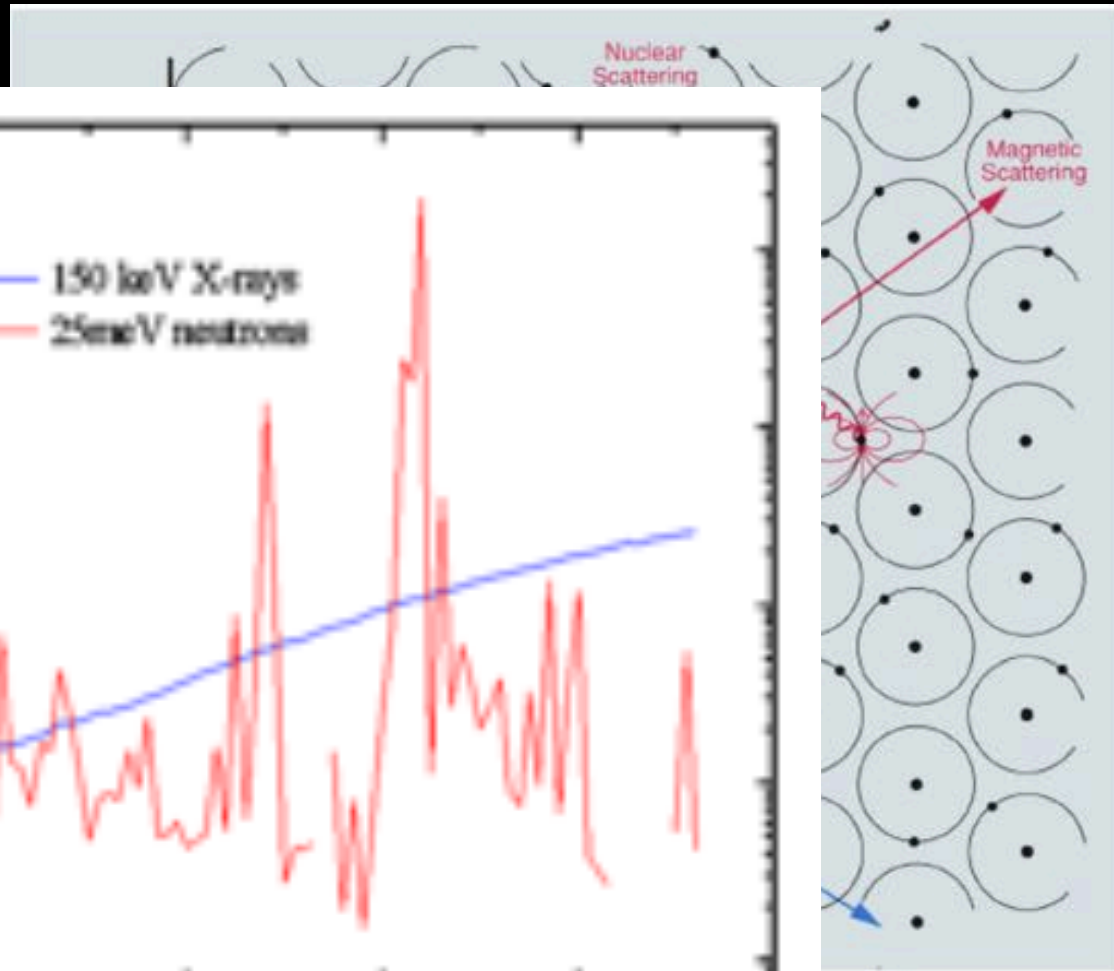
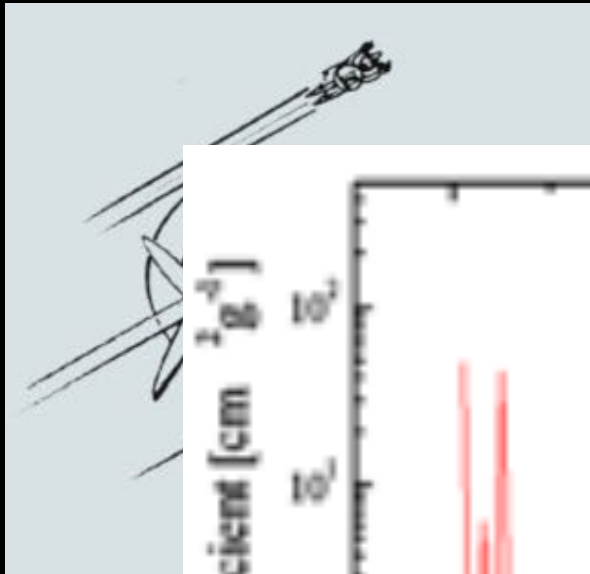
Time-resolved neutron radiography of coffee being made



Neutron, x-ray and electron interaction mechanisms

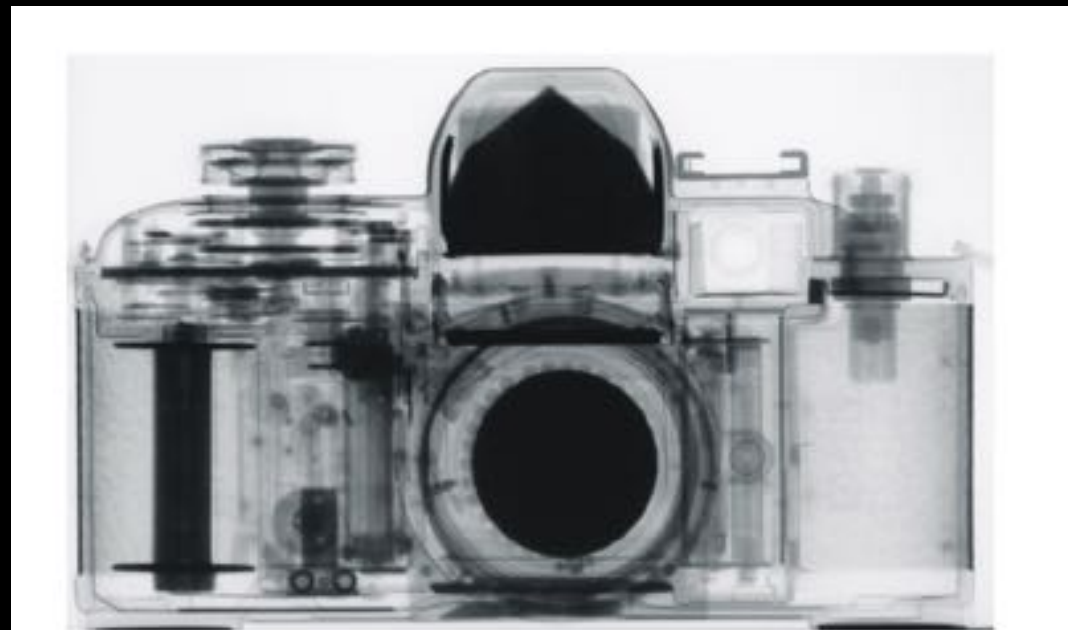
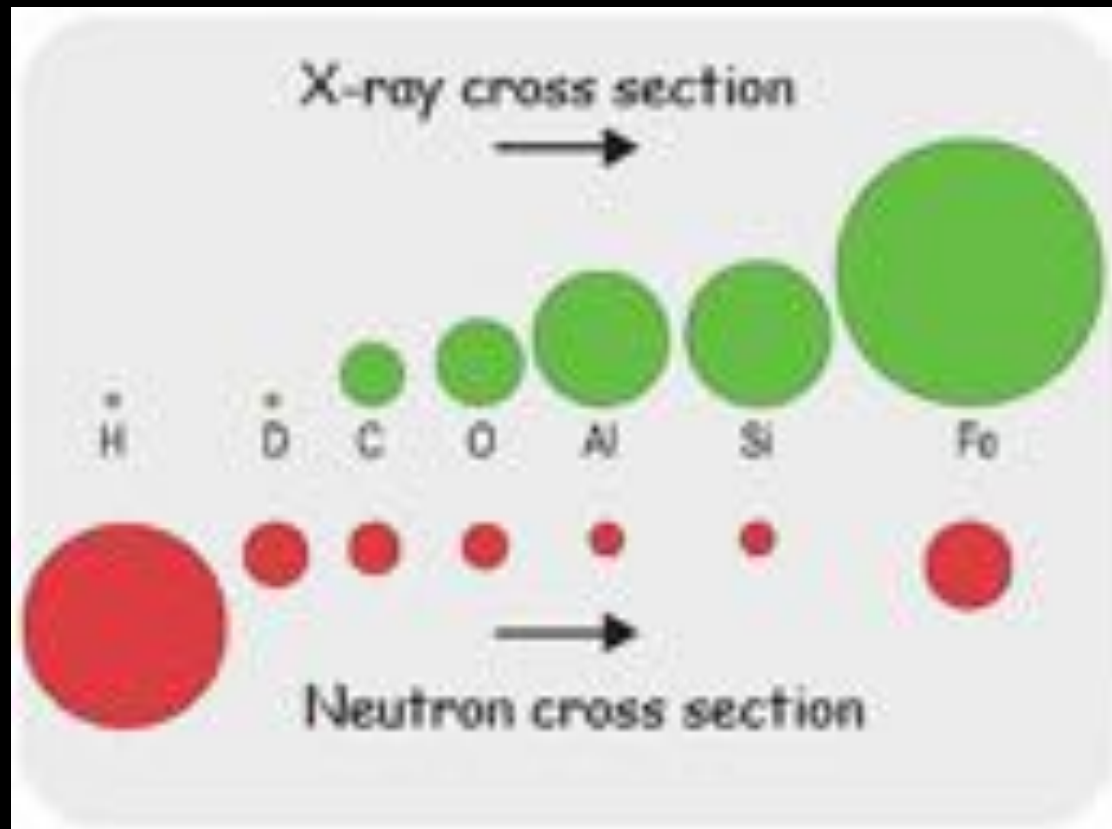


Neutron, x-ray and electron interaction mechanisms



Neutrons ~~versus~~ x-rays

Neutrons complement x-rays (and vice versa)



X-ray Imaging History

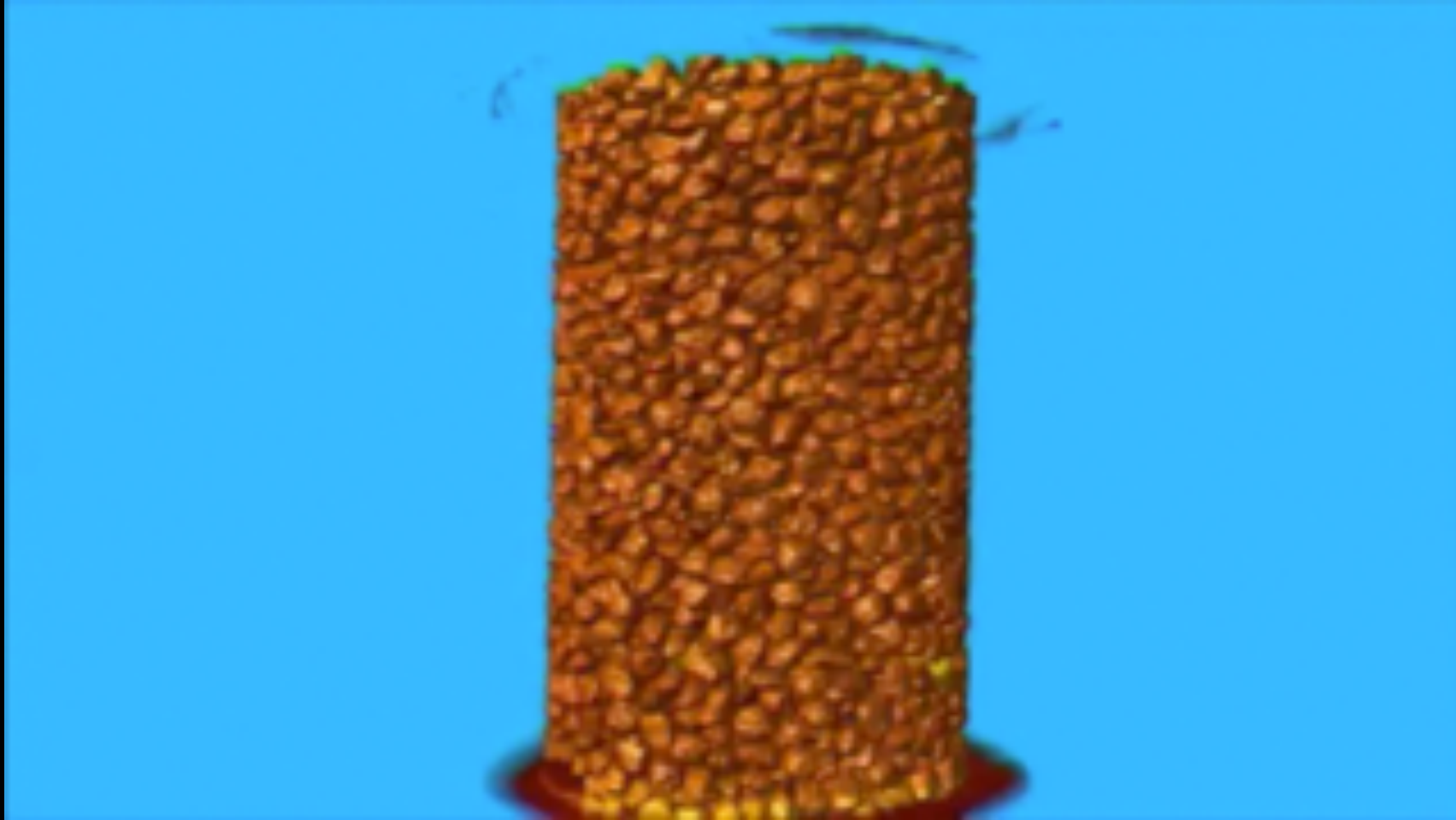
- Discovery of X-rays by Wilhelm Röntgen
- First radiographies in 1895
- First Nobel prize in Physics in 1901



Hand mit Ringen (Hand with Rings): print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Professor Ludwig Zehnder of the Physik Institut, University of Freiburg, on 1 January 1896

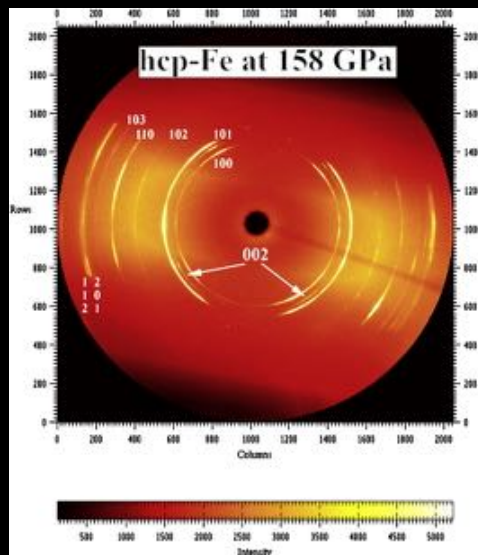
(<http://en.wikipedia.org/wiki/X-ray>)

Structural imaging in by tomography



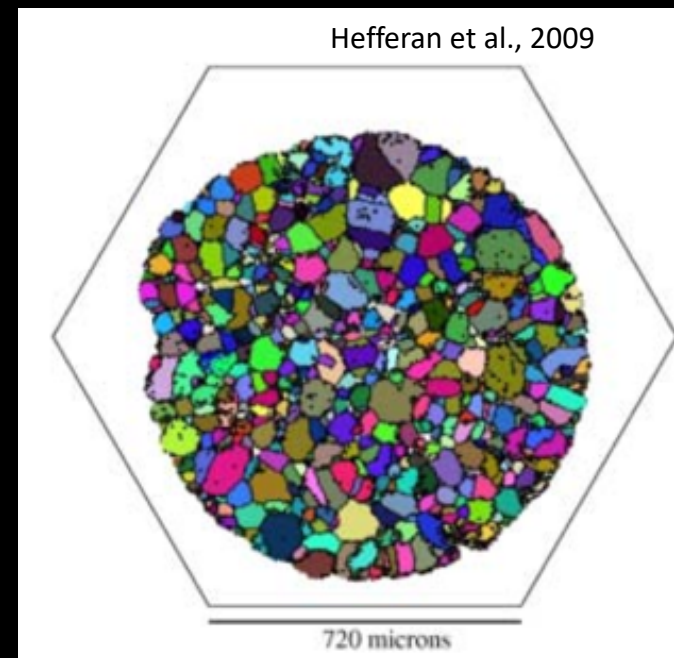
Structural mapping and texture by scattering

Atomic structure, Orientation...



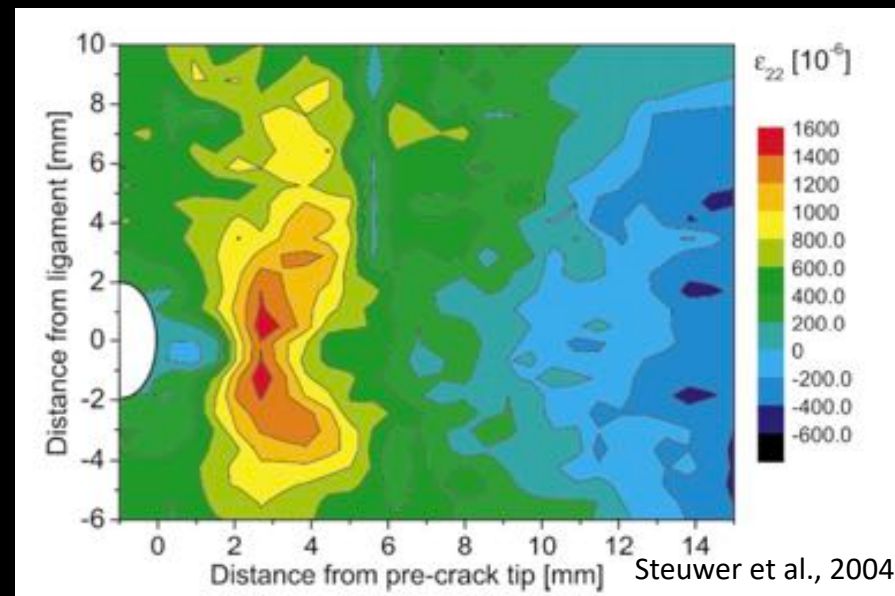
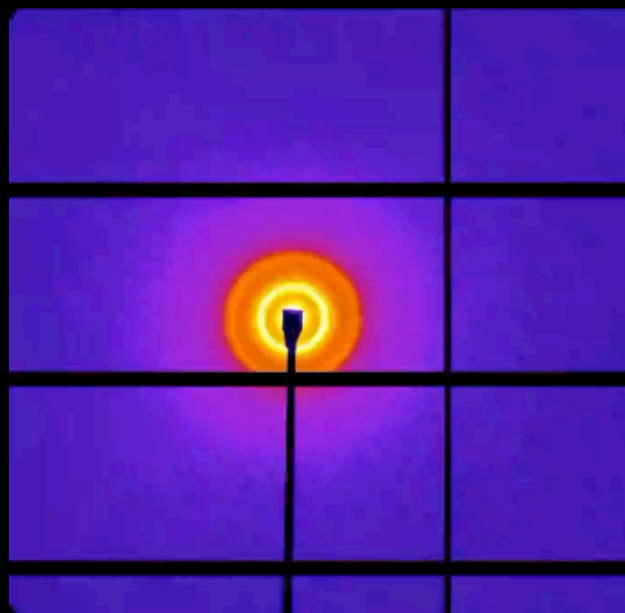
Lin et al. (2010)

3D diffraction
- grain structure and orientations in polycrystalline materials



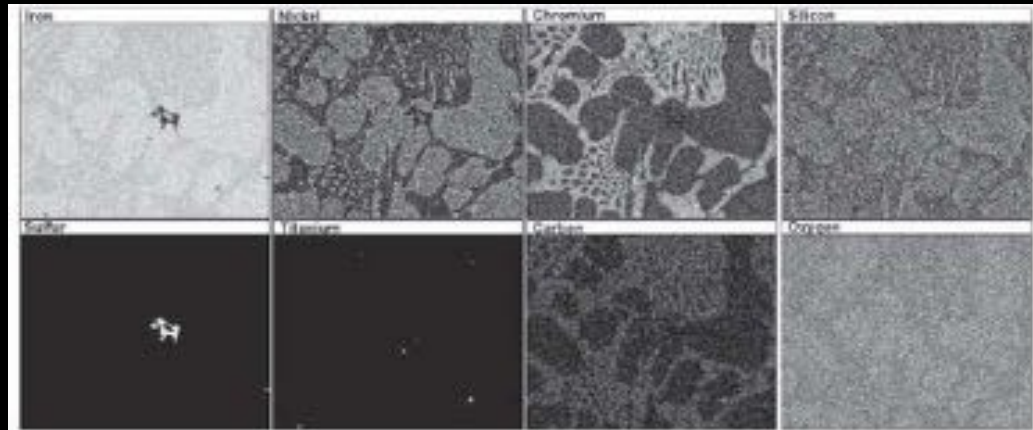
Diffraction scanning , e.g., for strain

Molecular structures from
small angle scattering
Small angle scattering from SEBS polymer
during tensile load-unload cycle



Chemical mapping

Energy dispersive imaging

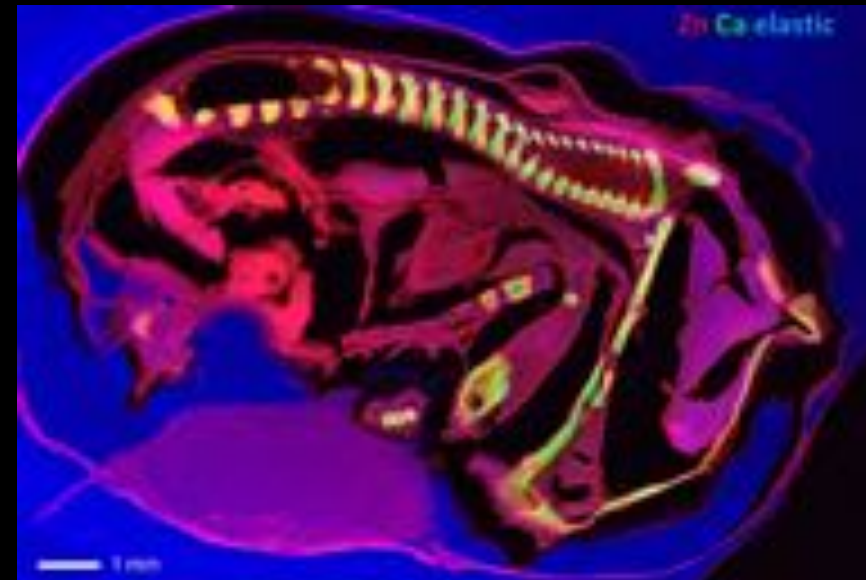


Elemental Map for the Microstructure of a White Iron Casting

Energy dispersive x-ray spectroscopy

<http://mee-inc.com/eds.html>

X-ray Fluorescence

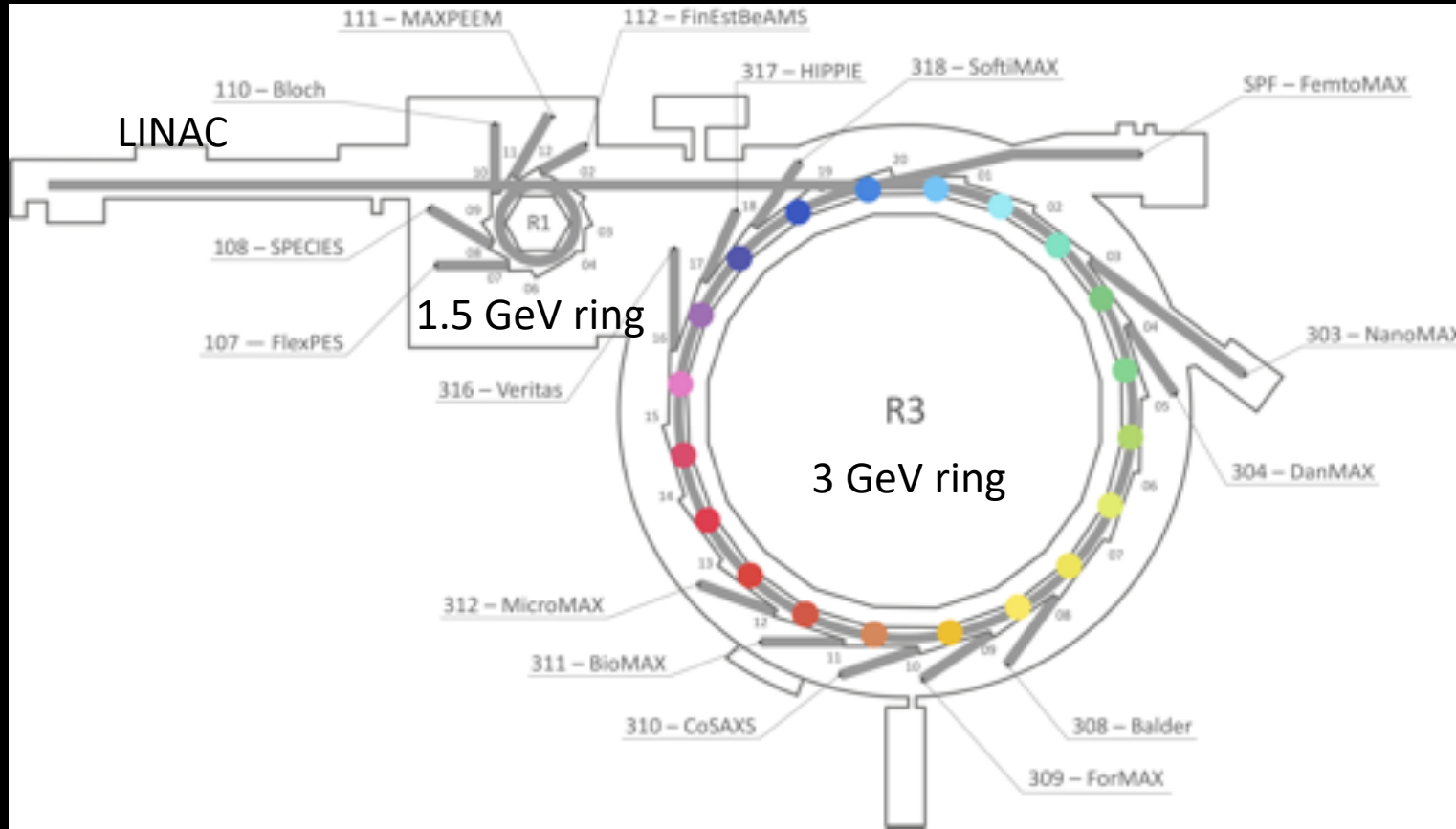


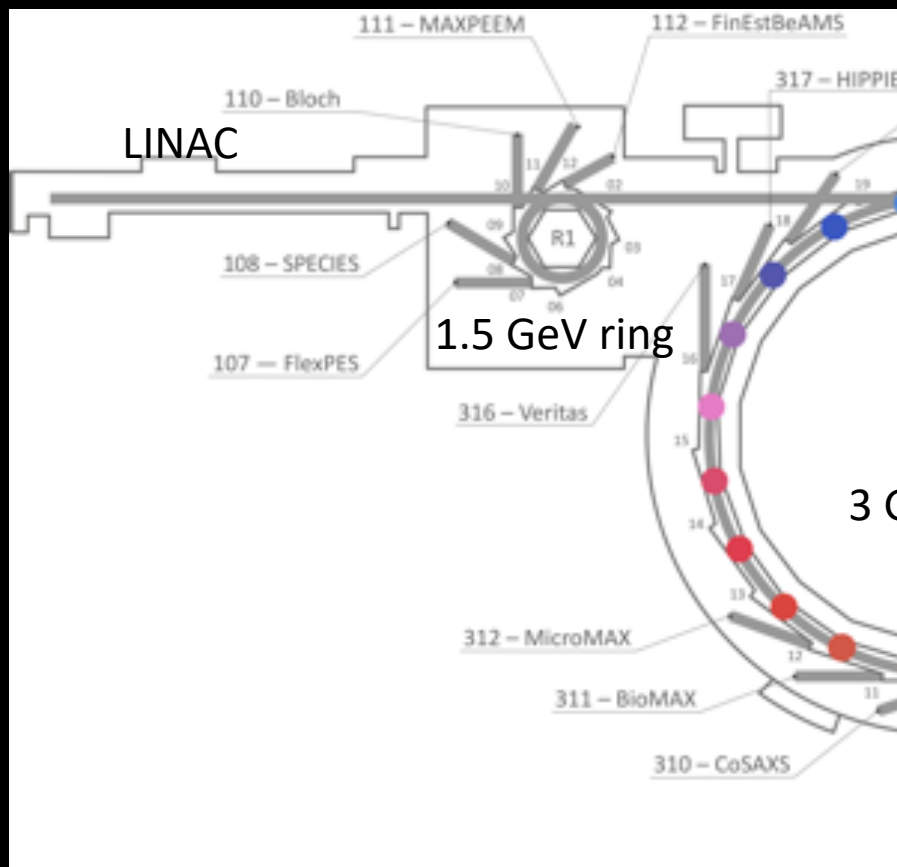
<http://www.csiro.au/en/Outcomes/Materials-and-Manufacturing/Maia-x-ray-microprobe-elemental-imaging-system/A-fresh-approach.aspx>

The future research facility landscape in Lund

- Imaging
- Diffraction
- Spectroscopy



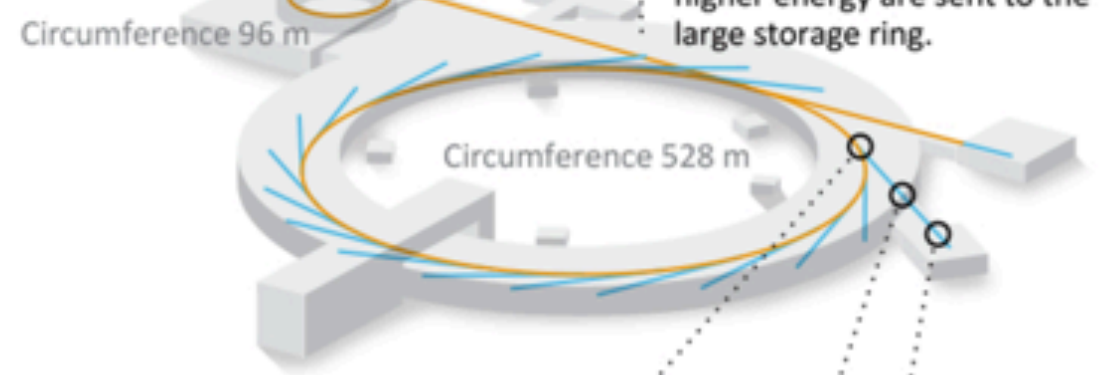




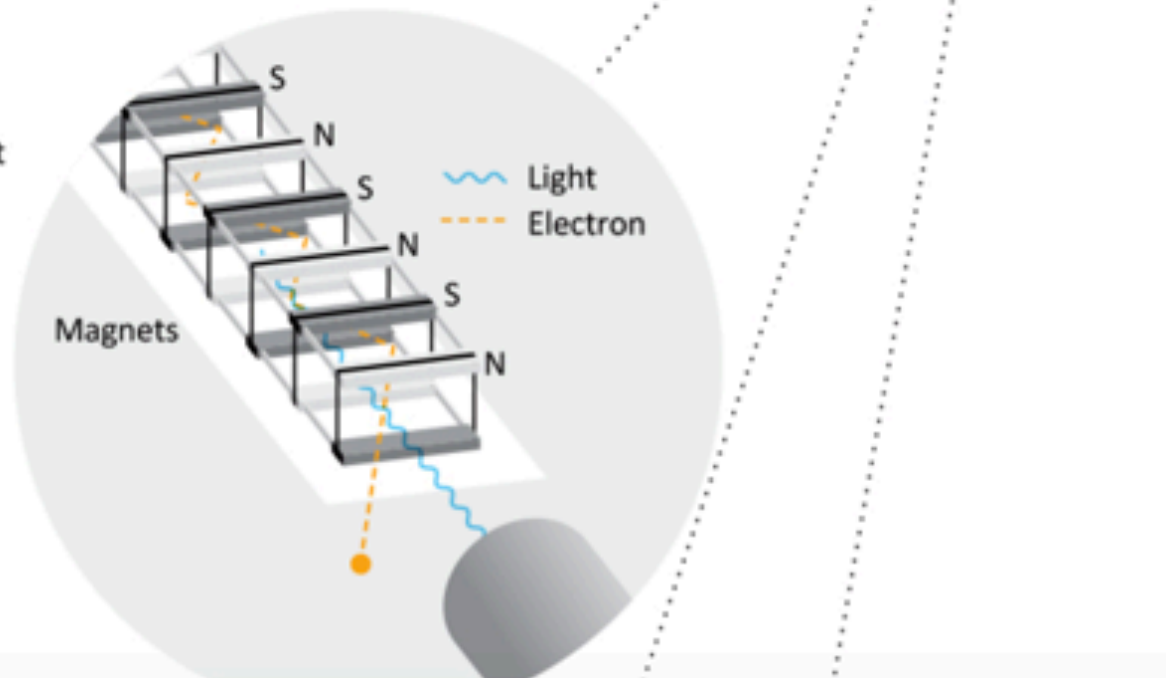
1 Here, in the electron gun, the electrons are accelerated to a speed close to that of light.

2 In the linear accelerator, the electrons' energy increases.

3 The electrons circulate in two rings. Electrons with lower energy are sent to the small storage ring. Electrons with higher energy are sent to the large storage ring.

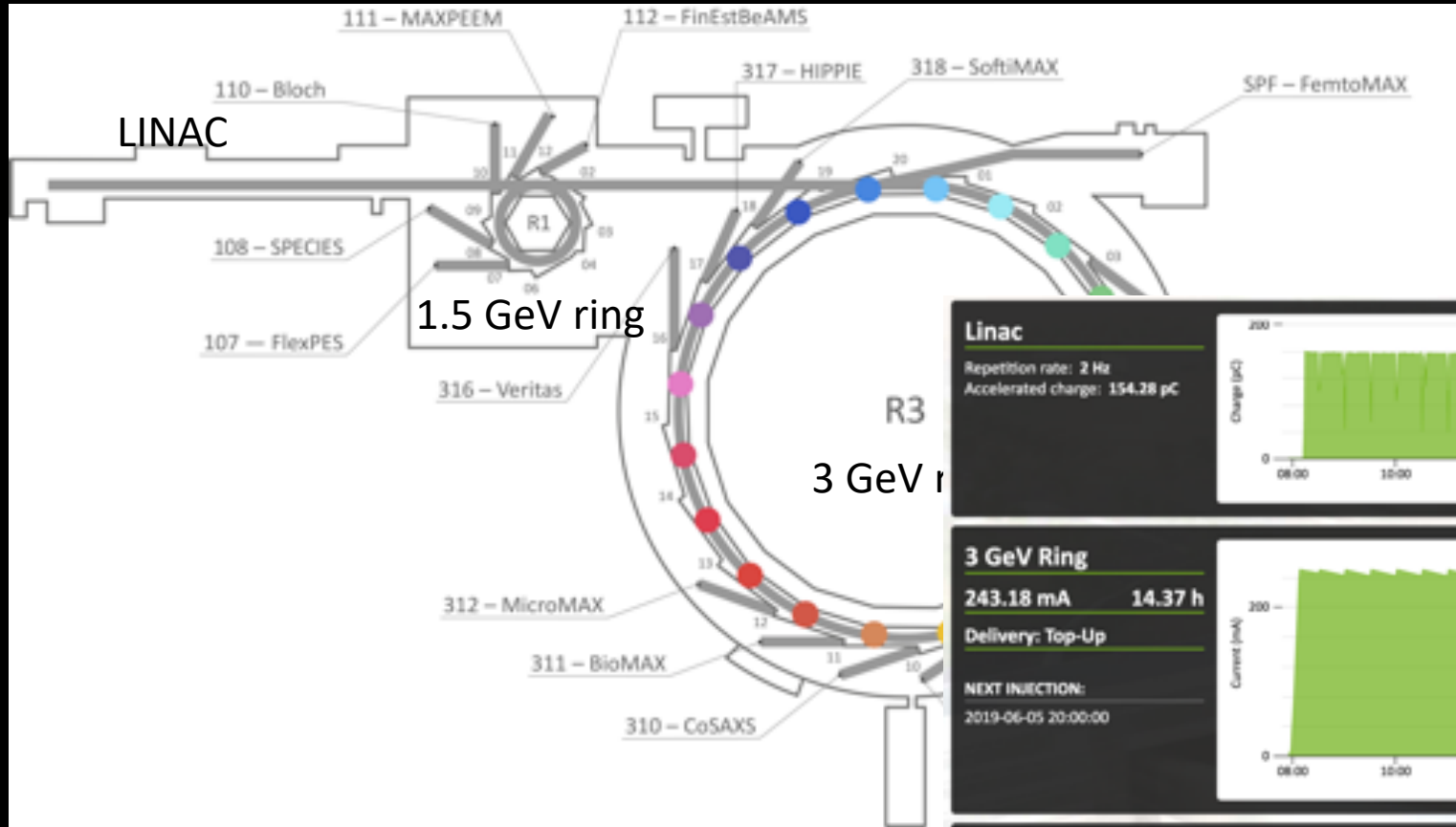


4 Magnets with different poles make the electrons bend. This releases energy in the form of light emitted in the direction of travel.





New milestone: 11 beamlines taking light simultaneously



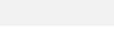


2019-06-05

Linac Repetition rate: 2 Hz Accelerated charge: 154.28 pC		FemtoMAX 3.50 33.56																
3 GeV Ring 243.18 mA 14.37 h Delivery: Top-Up NEXT INJECTION: 2019-06-05 20:00:00		<table border="1"> <tr><td>NanoMAX</td><td>5.16</td></tr> <tr><td>DanMAX</td><td>5.00</td></tr> <tr><td>BALDER</td><td>5.00</td></tr> <tr><td>CoSAXS</td><td>5.22</td></tr> <tr><td>BioMAX</td><td>5.22</td></tr> </table> <table border="1"> <tr><td>VERITAS</td><td>20.00</td></tr> <tr><td>HIPPIE</td><td>23.13</td></tr> <tr><td>SoftiMAX</td><td></td></tr> </table>	NanoMAX	5.16	DanMAX	5.00	BALDER	5.00	CoSAXS	5.22	BioMAX	5.22	VERITAS	20.00	HIPPIE	23.13	SoftiMAX	
NanoMAX	5.16																	
DanMAX	5.00																	
BALDER	5.00																	
CoSAXS	5.22																	
BioMAX	5.22																	
VERITAS	20.00																	
HIPPIE	23.13																	
SoftiMAX																		
1.5 GeV Ring 245.25 mA 11.20 h Delivery: Top-Up NEXT INJECTION: 2019-06-05 20:00:00		<table border="1"> <tr><td>FlexPES</td><td>42.80</td></tr> <tr><td>SPECIES</td><td>46.25</td></tr> <tr><td>BLOCH</td><td>46.25</td></tr> <tr><td>MAXPEEM</td><td>18.03</td></tr> <tr><td>FinEst</td><td>17.18</td></tr> </table>	FlexPES	42.80	SPECIES	46.25	BLOCH	46.25	MAXPEEM	18.03	FinEst	17.18						
FlexPES	42.80																	
SPECIES	46.25																	
BLOCH	46.25																	
MAXPEEM	18.03																	
FinEst	17.18																	



A. MAX IV beamlines (May 2019)

Legend: _____
 User Operation 
 Commissioning 
 Construction 

3.0 GeV Ring

NanoMAX
 Nanofocus & coherence

DanMAX 
 Imaging & diffraction

Balder
 EXAFS & RIXS

ForMAX
 Wood based material

CoSAXS
 SAXS & coherence

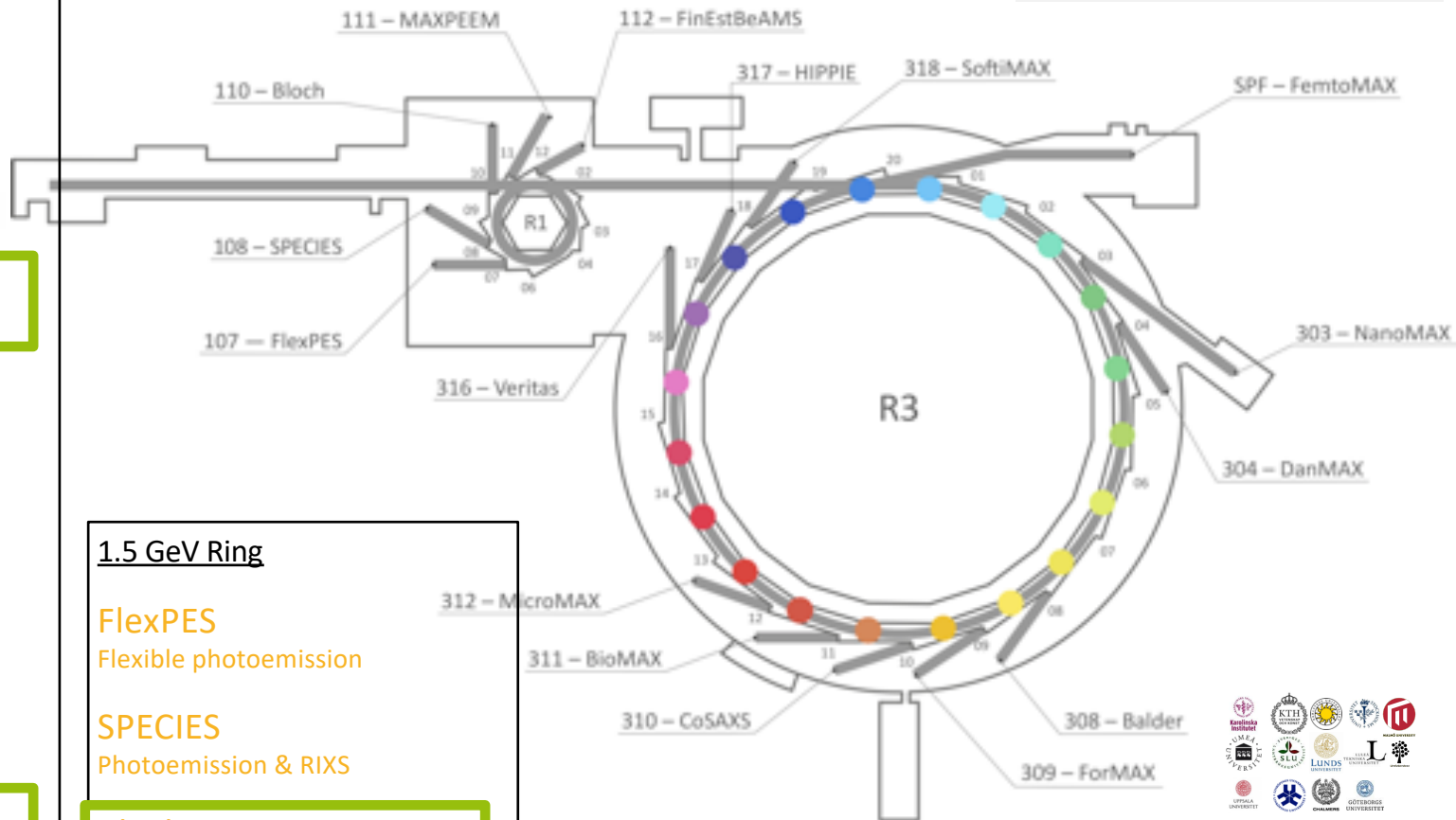
BioMAX
 Protein structure

MicroMAX
 Protein structure 

Veritas
 Excitations in solids & liquids

HIPPIE
 Operando spectroscopy

SoftiMAX
 Microscopy & coherence



1.5 GeV Ring

FlexPES
 Flexible photoemission

SPECIES
 Photoemission & RIXS

Bloch
 Electronic structure & surfaces

MAXPEEM
 Microscopy of surfaces

FinEstBeAMS 
 Gas phase & luminescence


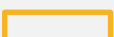

LINAC

FemtoMAX
 Ultrafast diffraction & spectroscopy





A. MAX IV beamlines (Sep 2019)

Legend: _____
 User Operation 
 Commissioning 
 Construction 

3.0 GeV Ring

NanoMAX
 Nanofocus & coherence

DanMAX 
 Imaging & diffraction

Balder
 EXAFS & RIXS

ForMAX
 Wood based material

CoSAXS
 SAXS & coherence

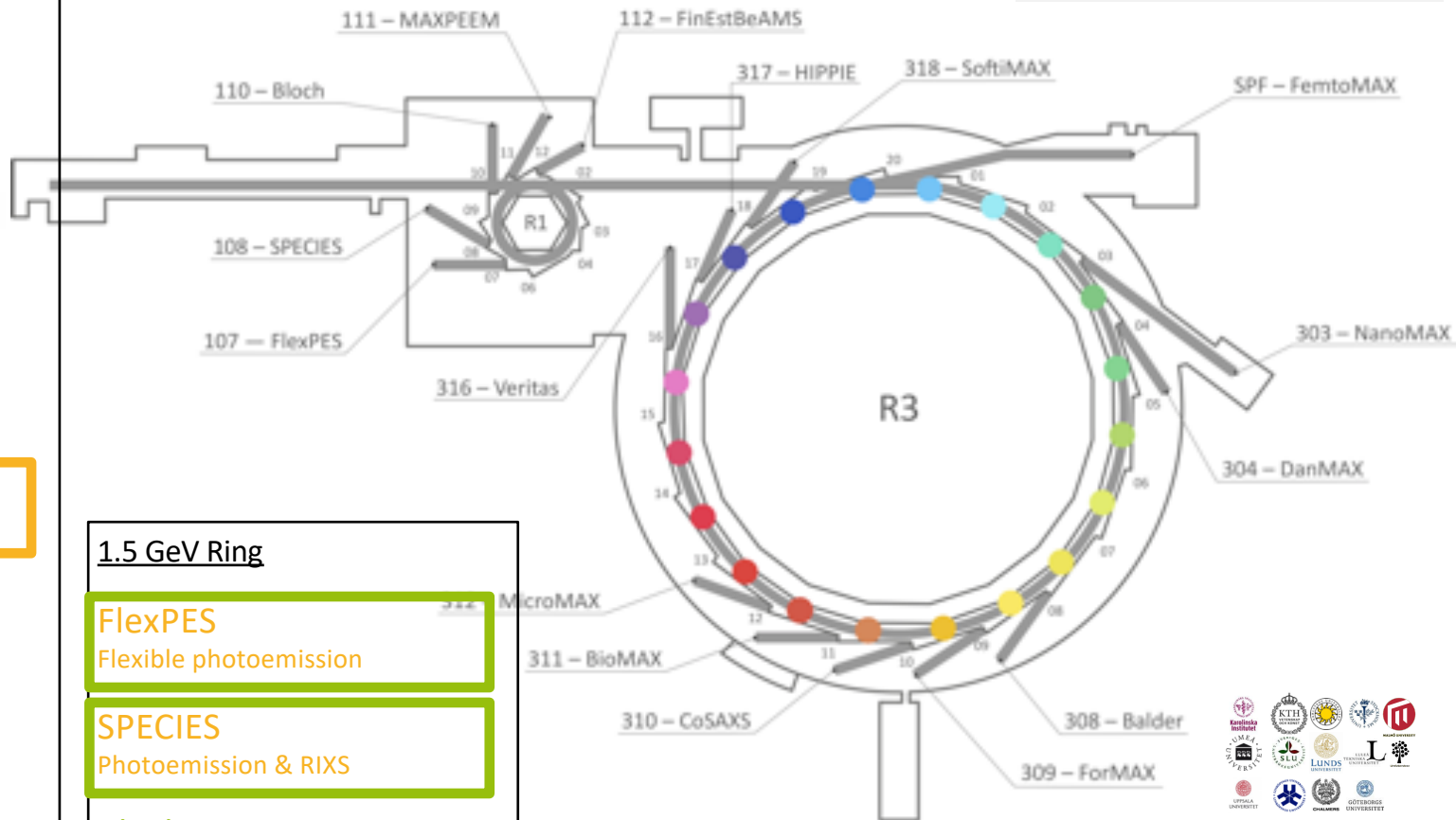
BioMAX
 Protein structure

MicroMAX
 Protein structure 

Veritas
 Excitations in solids & liquids

HIPPIE
 Operando spectroscopy

SoftiMAX
 Microscopy & coherence



1.5 GeV Ring

FlexPES
 Flexible photoemission

SPECIES
 Photoemission & RIXS

Bloch
 Electronic structure & surfaces

MAXPEEM
 Microscopy of surfaces

FinEstBeAMS 
 Gas phase & luminescence

LINAC

FemtoMAX
 Ultrafast diffraction & spectroscopy





A. MAX IV beamlines (Feb 2020)

Legend:

User Operation	
Commissioning	
Construction	

transitioning

3.0 GeV Ring

NanoMAX
Nanofocus & coherence

DanMAX
Imaging & diffraction

Balder
EXAFS & RIXS

ForMAX
Wood based material

CoSAXS
SAXS & coherence

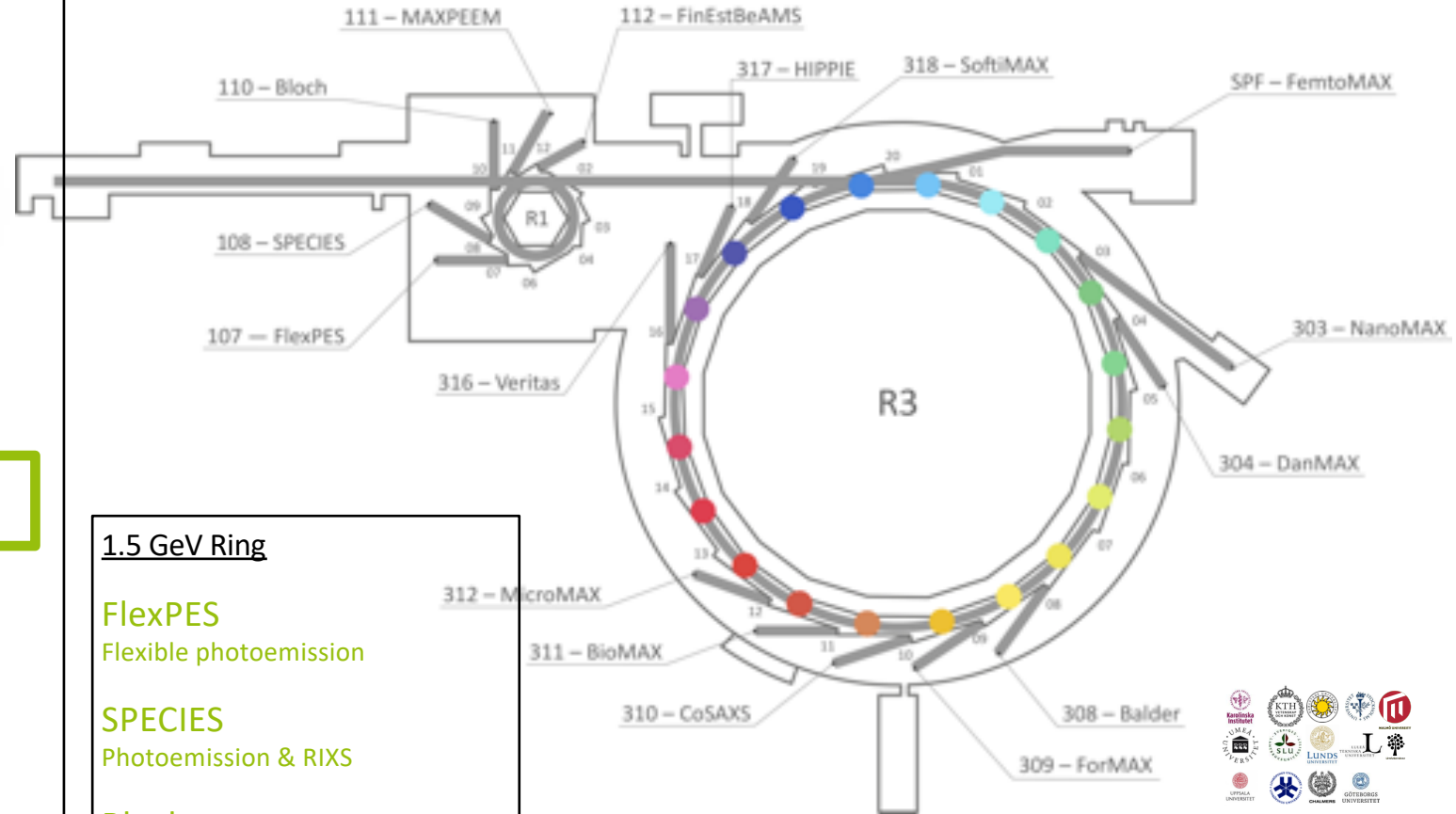
BioMAX
Protein structure

MicroMAX
Protein structure

Veritas
Excitations in solids & liquids

HIPPIE
Operando spectroscopy

SoftiMAX
Microscopy & coherence



1.5 GeV Ring

FlexPES
Flexible photoemission

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Photoemission & RIXS

Bloch
Electronic structure & surfaces

MAXPEEM
Microscopy of surfaces

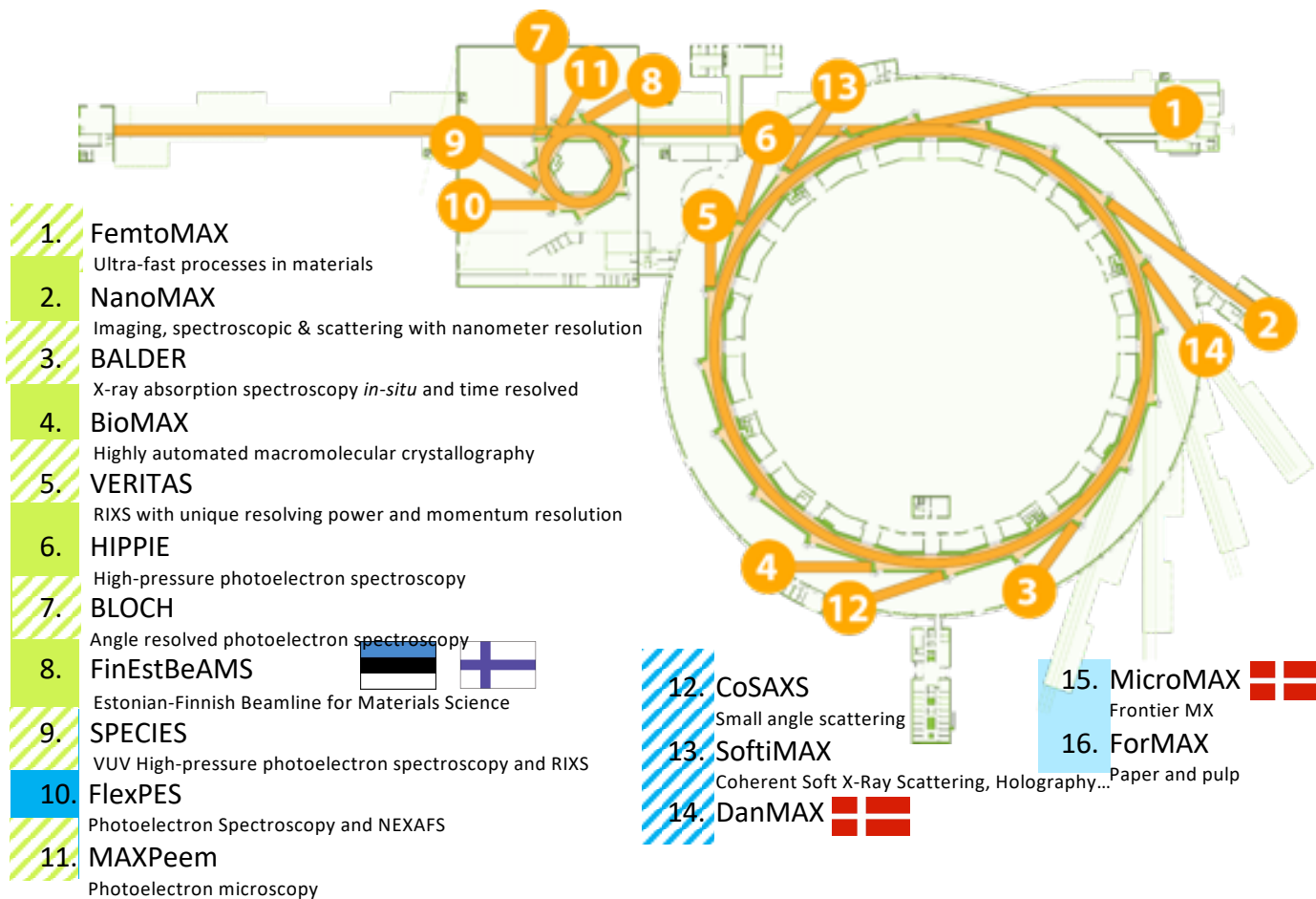
FinEstBeAMS
Gas phase & luminescence

LINAC

FemtoMAX
Ultrafast diffraction & spectroscopy



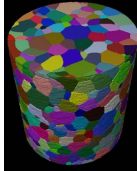
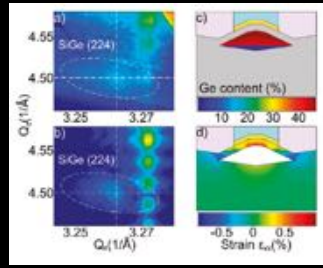
The 16 funded Beamlines



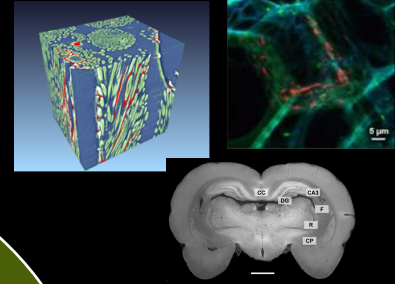
- 1. FemtoMAX
Ultra-fast processes in materials
- 2. NanoMAX
Imaging, spectroscopic & scattering with nanometer resolution
- 3. BALDER
X-ray absorption spectroscopy *in-situ* and time resolved
- 4. BioMAX
Highly automated macromolecular crystallography
- 5. VERITAS
RIXS with unique resolving power and momentum resolution
- 6. HIPPIE
High-pressure photoelectron spectroscopy
- 7. BLOCH
Angle resolved photoelectron spectroscopy
- 8. FinEstBeAMS
Estonian-Finnish Beamline for Materials Science
- 9. SPECIES
VUV High-pressure photoelectron spectroscopy and RIXS
- 10. FlexPES
Photoelectron Spectroscopy and NEXAFS
- 11. MAXPeem
Photoelectron microscopy

- 12. CoSAXS
Small angle scattering
- 13. SoftiMAX
Coherent Soft X-Ray Scattering, Holography...
- 14. DanMAX
- 15. MicroMAX
Frontier MX
- 16. ForMAX
Paper and pulp

	General Users		Endstation installation		Design
	Commissioning		Infrastruktur / Optics installation		



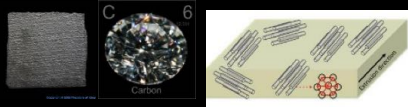
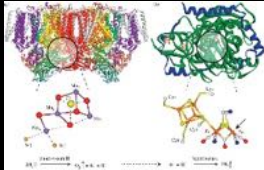
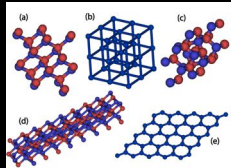
Geometrical or electronic structure or chemical composition



Imaging
NanoMAX
SoftiMAX
MAXPEEM

Scattering & Diffraction
BioMAX
CoSAXS
MicroMAX
DanMAX
ForMAX
FemtoMAX
BALDER

Spectroscopy
HIPPIE
VERITAS
ARPES
SPECIES
FLEXPES
FinEstBeams



Geometrical structure to atomic resolution

Electronic structure





News from MAXIV...

Investigating soil clues to water browning at Balder

Iron leaking from forest soil is thought to be a factor in the increasing brown coloration of nearby waters called browning. It has consequences ranging from their use as drinking water to the sight of water living organisms in a darker surrounding. A recent experiment at beamline Balder aims to contribute clues to a better [▶](#)

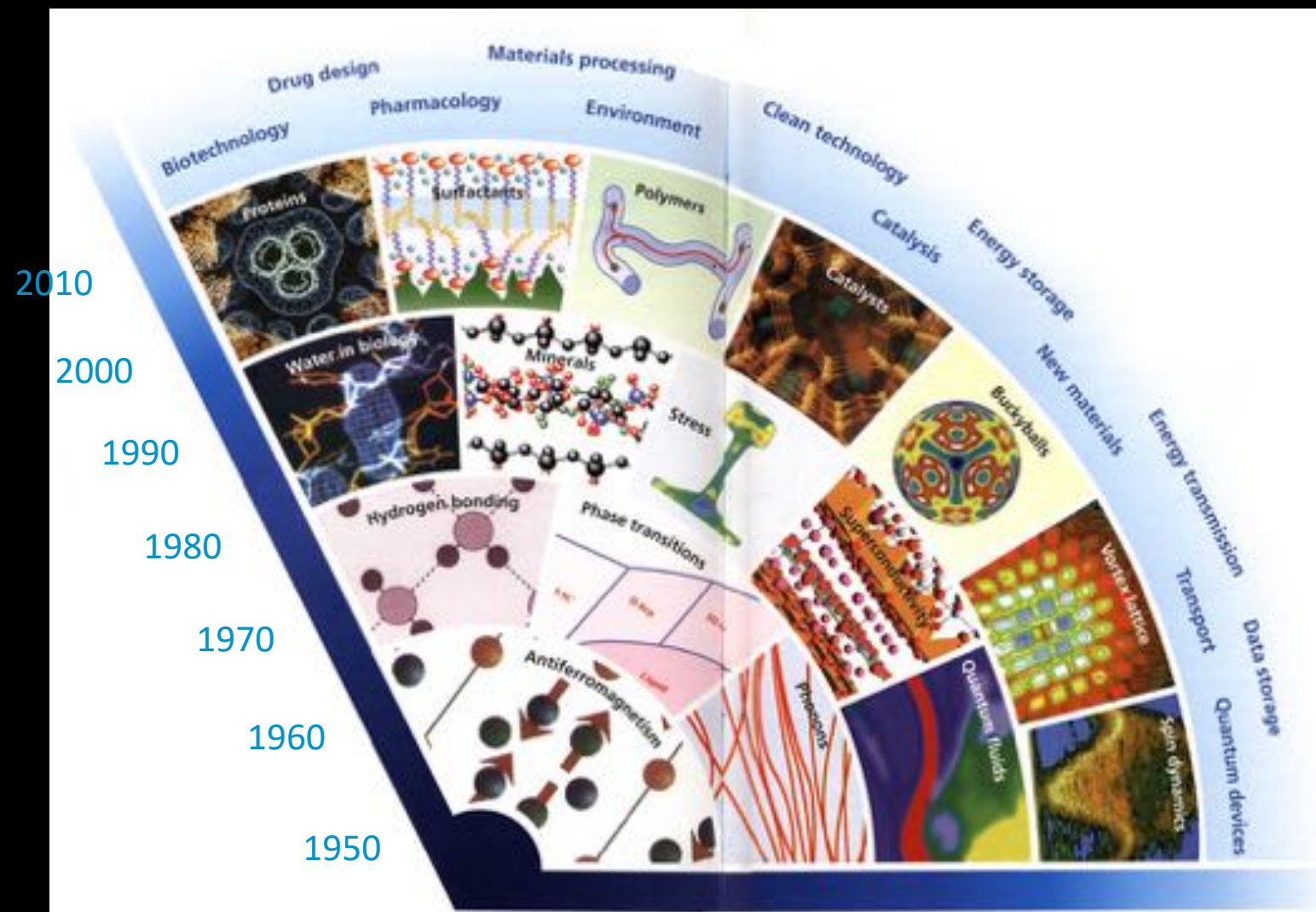


The future research facility landscape in Lund

- Imaging
- Diffraction
- Spectroscopy



Evolution of neutron science

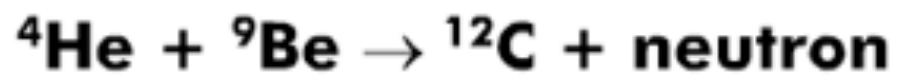
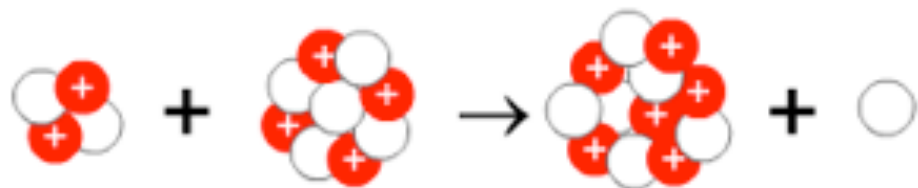


Source: ISIS target station 2 science case

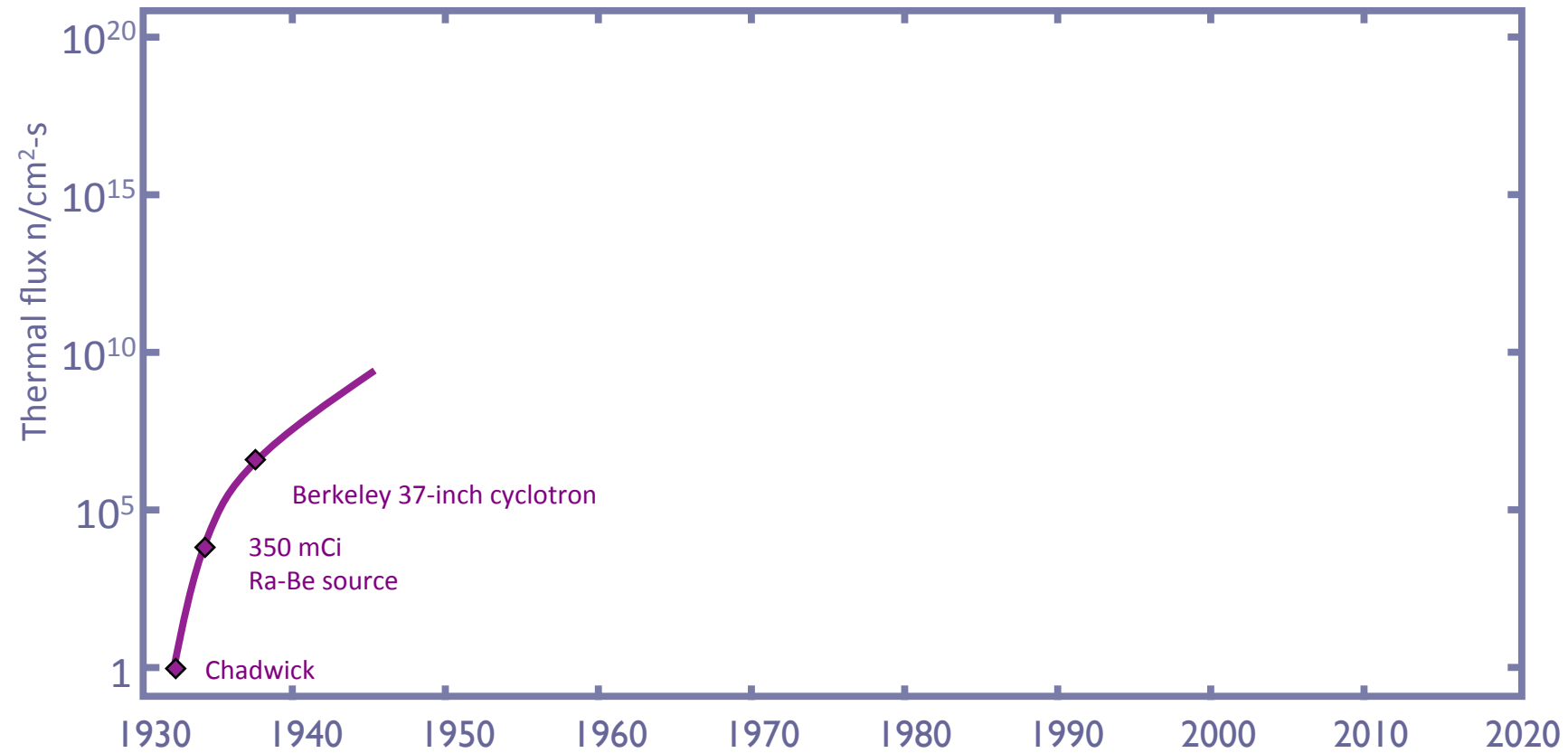
See also: <https://europanspallationsource.se/science-using-neutrons>



James Chadwick:
used Polonium as alpha emitter on Beryllium

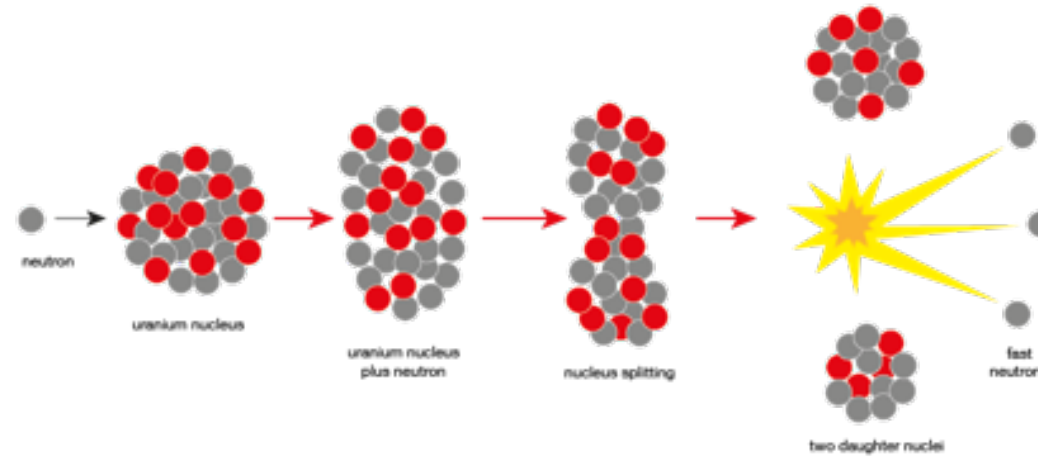


First Neutron Source



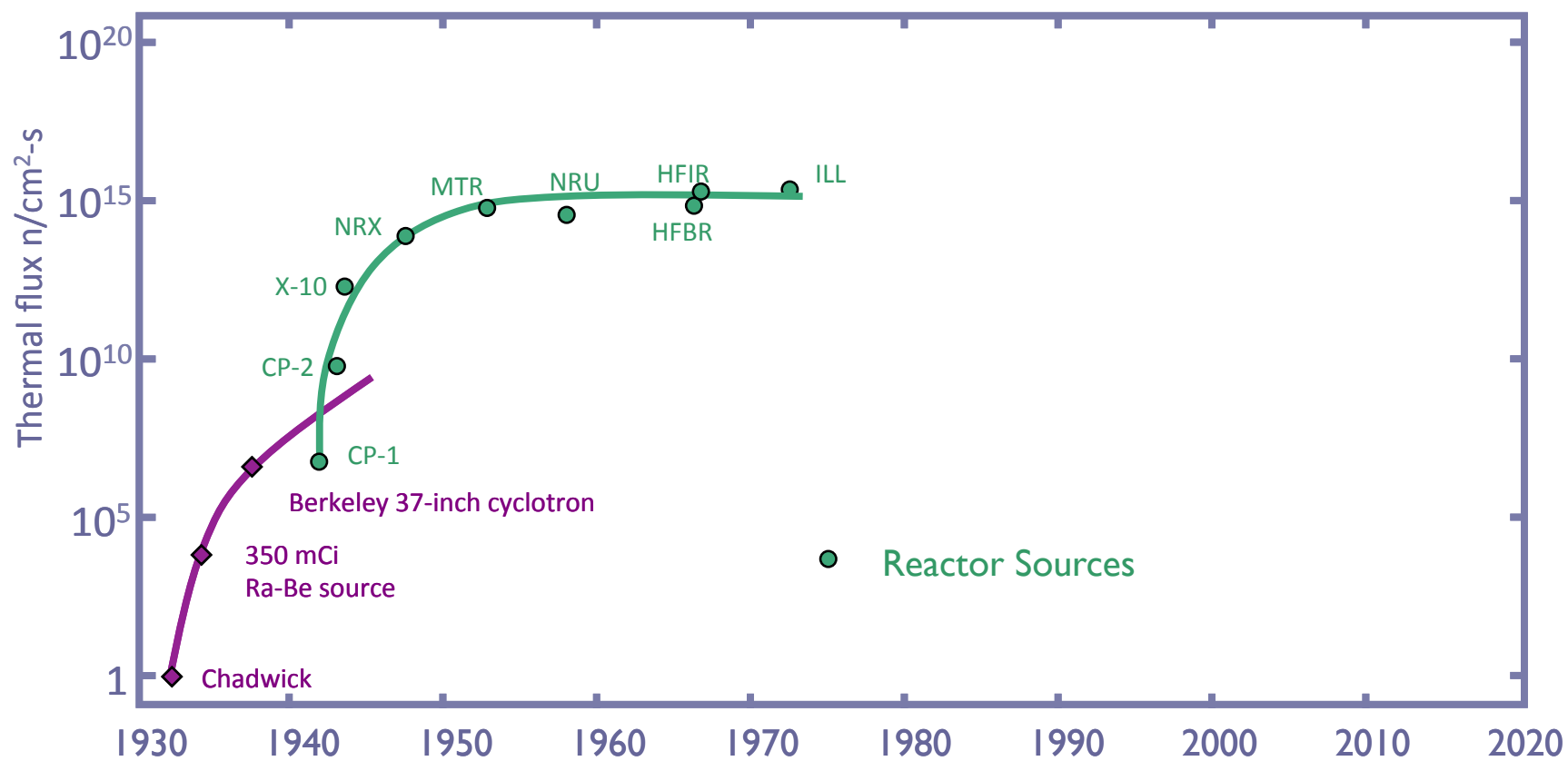
(Updated from *Neutron Scattering*, K. Sköld and D. L. Price, eds., Academic Press, 1986)

Neutron fission



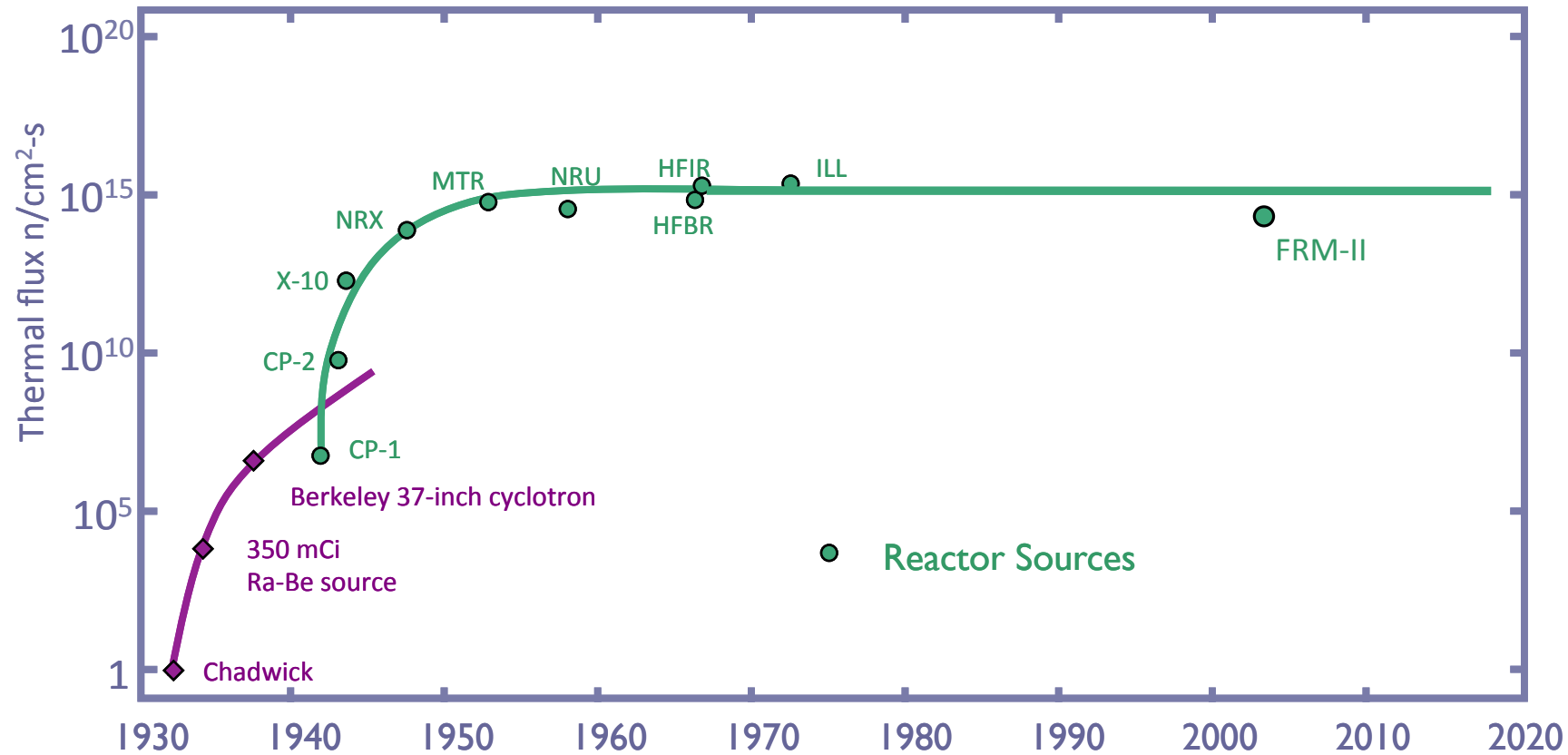
Explained theoretically in January 1939 by Lise Meitner and her nephew Otto Robert Frisch.

Evolution of neutron sources



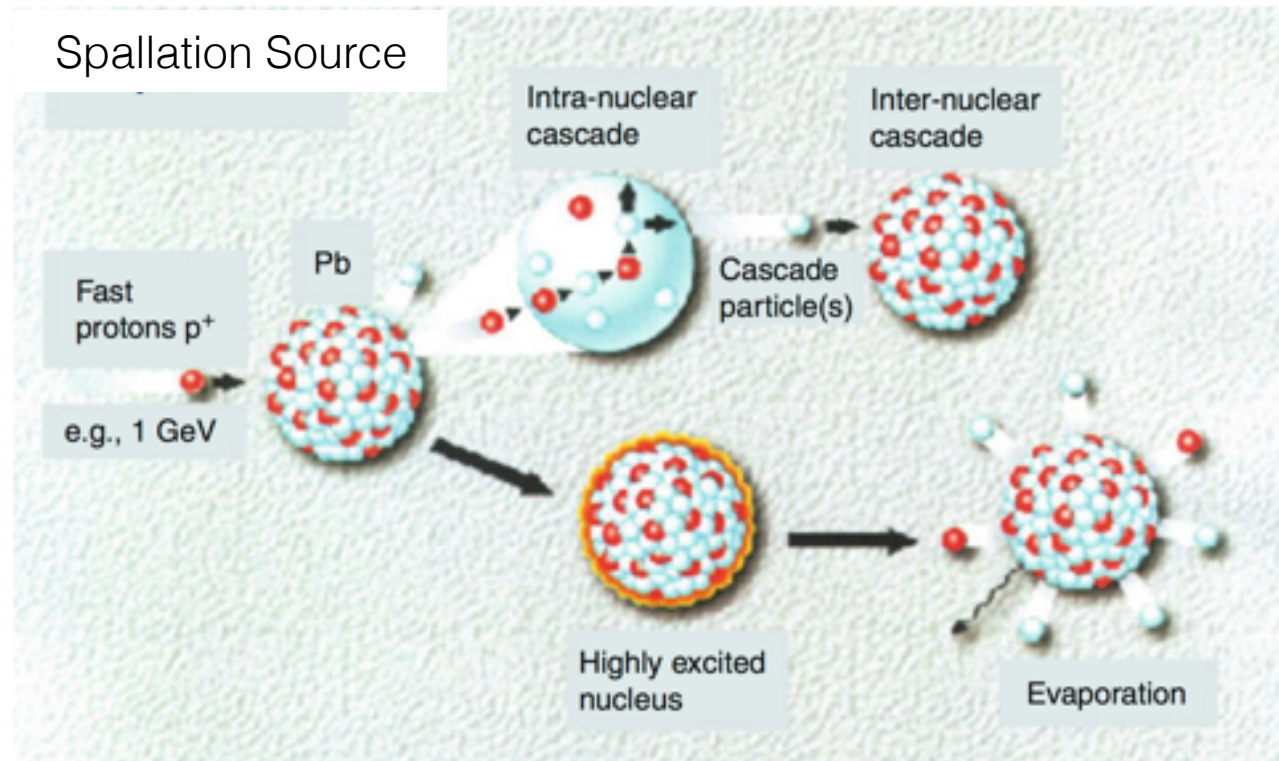
(Updated from *Neutron Scattering*, K. Sköld and D. L. Price, eds., Academic Press, 1986)

Evolution of neutron sources

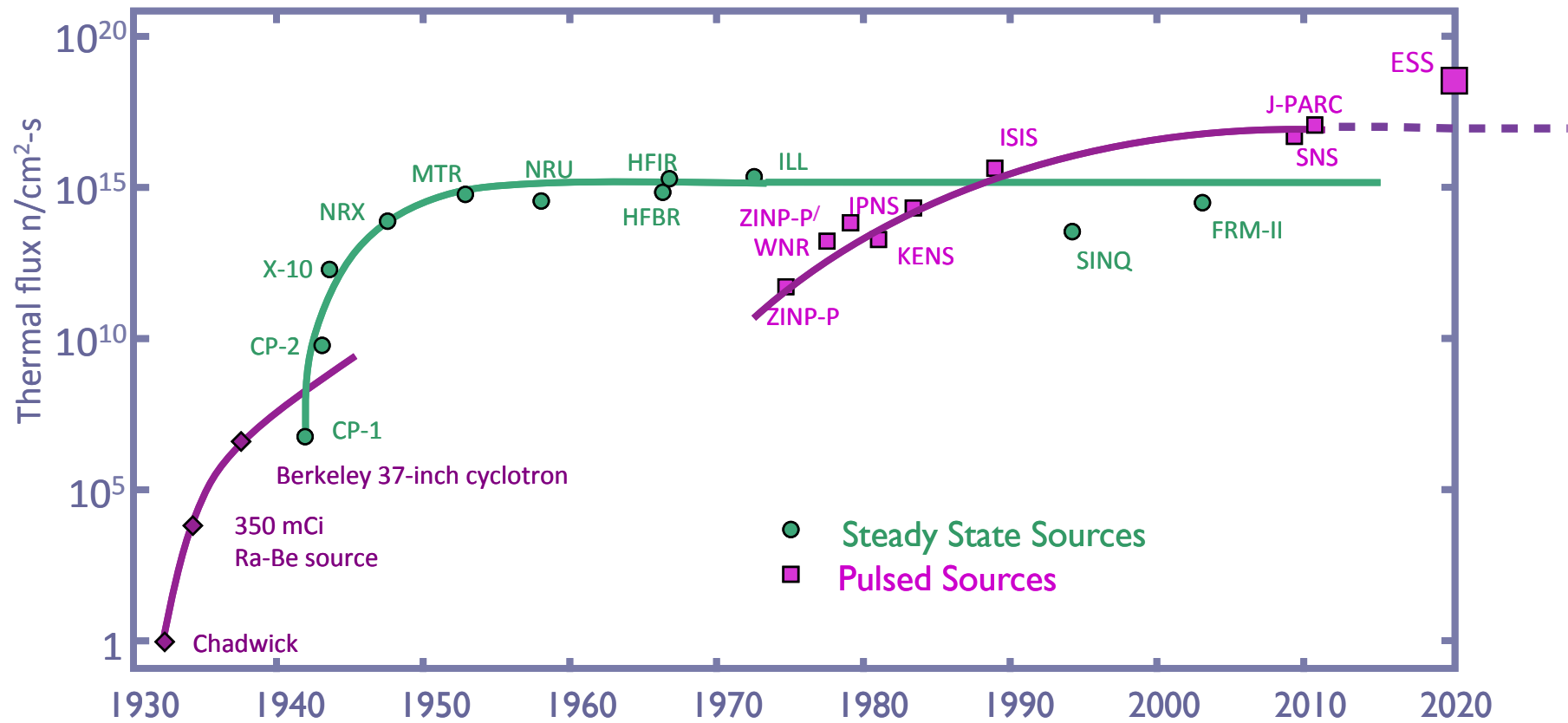


(Updated from *Neutron Scattering*, K. Sköld and D. L. Price, eds., Academic Press, 1986)

Spallation



Evolution of neutron sources



(Updated from *Neutron Scattering*, K. Sköld and D. L. Price, eds., Academic Press, 1986)

- Mass

Neutron: $m_n = 1.675 \times 10^{-27} \text{ kg}$

Electron: $m_e = 9.10 \times 10^{-31} \text{ kg}$

Photon : 0

- Energy at $\lambda = 5\text{\AA}$

Neutron: $E = 3.3 \text{ meV } (10^{-3})$

Electron: $E \sim 6 \text{ eV}$

Photon: $E \sim 2.5 \text{ keV } (10^{+3})$

- Mass

Neutron: $m_n = 1.675 \times 10^{-27} \text{ kg}$
 Electron: $m_e = 9.10 \times 10^{-31} \text{ kg}$
 Photon : 0

Whilst x-rays travel with the speed of light, neutrons have mass and so have a velocity that depends on their energy...

- Energy at $\lambda = 5\text{\AA}$

Neutron: **$E = 3.3 \text{ meV} (10^{-3})$**
 Electron: $E \sim 6 \text{ eV}$
 Photon: $E \sim 2.5 \text{ keV} (10^{+3})$

	Energy	Wavelength	Velocity
Ultracold neutrons	$E = 300 \text{ neV}$	$\lambda = 520 \text{ \AA}$	$v = 7.6 \text{ m/s}$
Cold neutrons:	$E = 1 \text{ meV}$	$\lambda = 9.0446 \text{ \AA}$	$v = 437 \text{ m/s}$
	$E = 5 \text{ meV}$	$\lambda = 4.0449 \text{ \AA}$	$v = 978 \text{ m/s}$
Thermal neutrons:	$E = 25 \text{ meV}$	$\lambda = 1.8089 \text{ \AA}$	$v = 2187 \text{ m/s}$
	$E = 50 \text{ meV}$	$\lambda = 1.2791 \text{ \AA}$	$v = 3093 \text{ m/s}$

- Mass

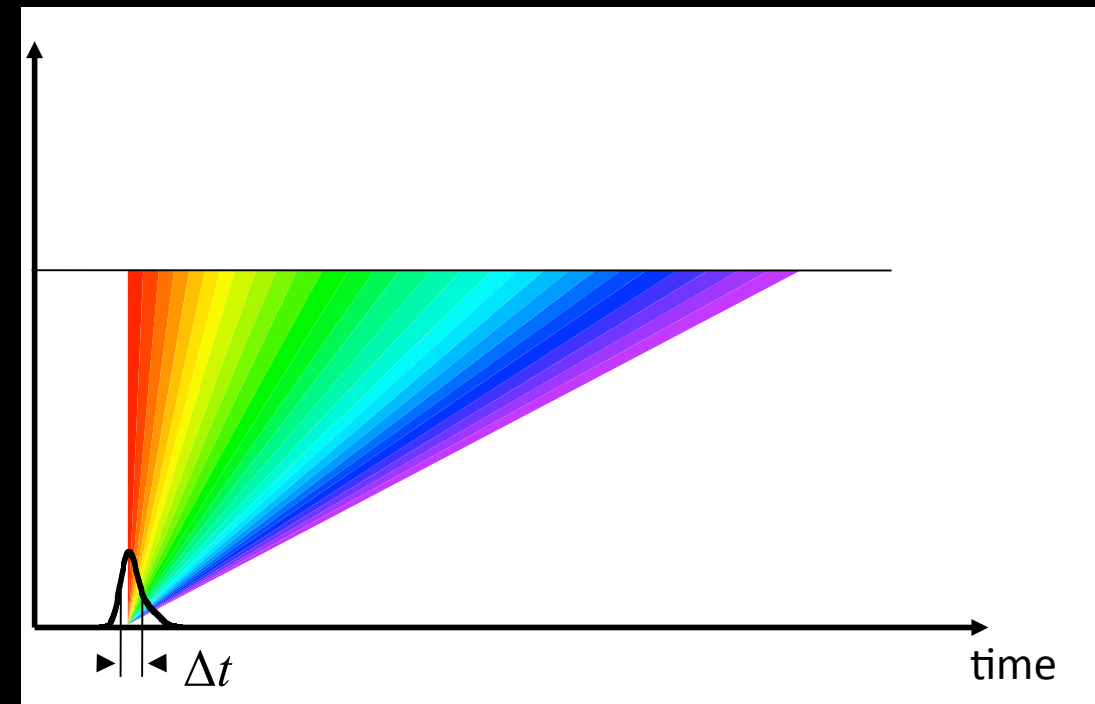
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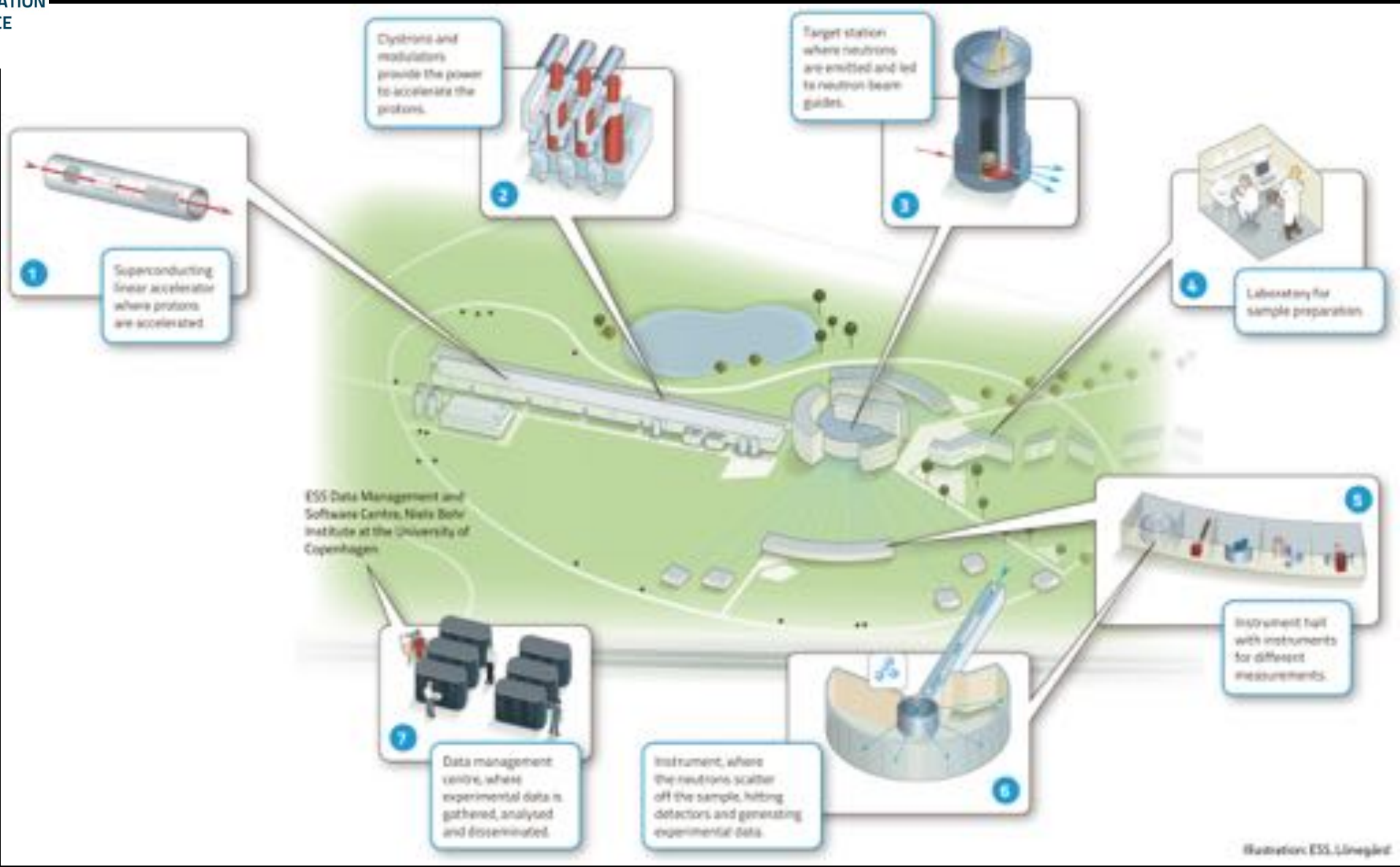
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Whilst x-rays travel with the speed of light, neutrons have mass and so have a velocity that depends on their energy...











































Different velocities can be utilised to look at different wavelengths/energies as a function of time, so-called “time-of-flight” measurements














ESS instrument suite (as envisaged in the technical Design Report, 2012)

Large-Scale Structures

Multi-Purpose Imaging	    
General-Purpose SANS	   
Broadband SANS	 
Surface Scattering	   
Horizontal Reflectometer	  
Vertical Reflectometer	   
Thermal Powder Diffractometer	   
Bispectral Power Diffractometer	   
Monochromatic Powder Diffractometer	  
Materials Science Diffractometer	 
Extreme Conditions Diffractometer	   
Single-Crystal Magnetism Diffractometer	 
Macromolecular Diffractometer	

Diffraction

Spectroscopy

Cold Chopper Spectrometer	  
Bispectral Chopper Spectrometer	   
Thermal Chopper Spectrometer	  
Cold Crystal-Analyser Spectrometer	   
Vibrational Spectroscopy	  
Backscattering Spectrometer	  
High-Resolution Spin-Echo	   
Wide-Angle Spin-Echo	   
Fundamental & Particle Physics	



life sciences



soft condensed matter



chemistry of materials



energy research



magnetism & superconductivity



engineering & geo-sciences



archeology & heritage conservation

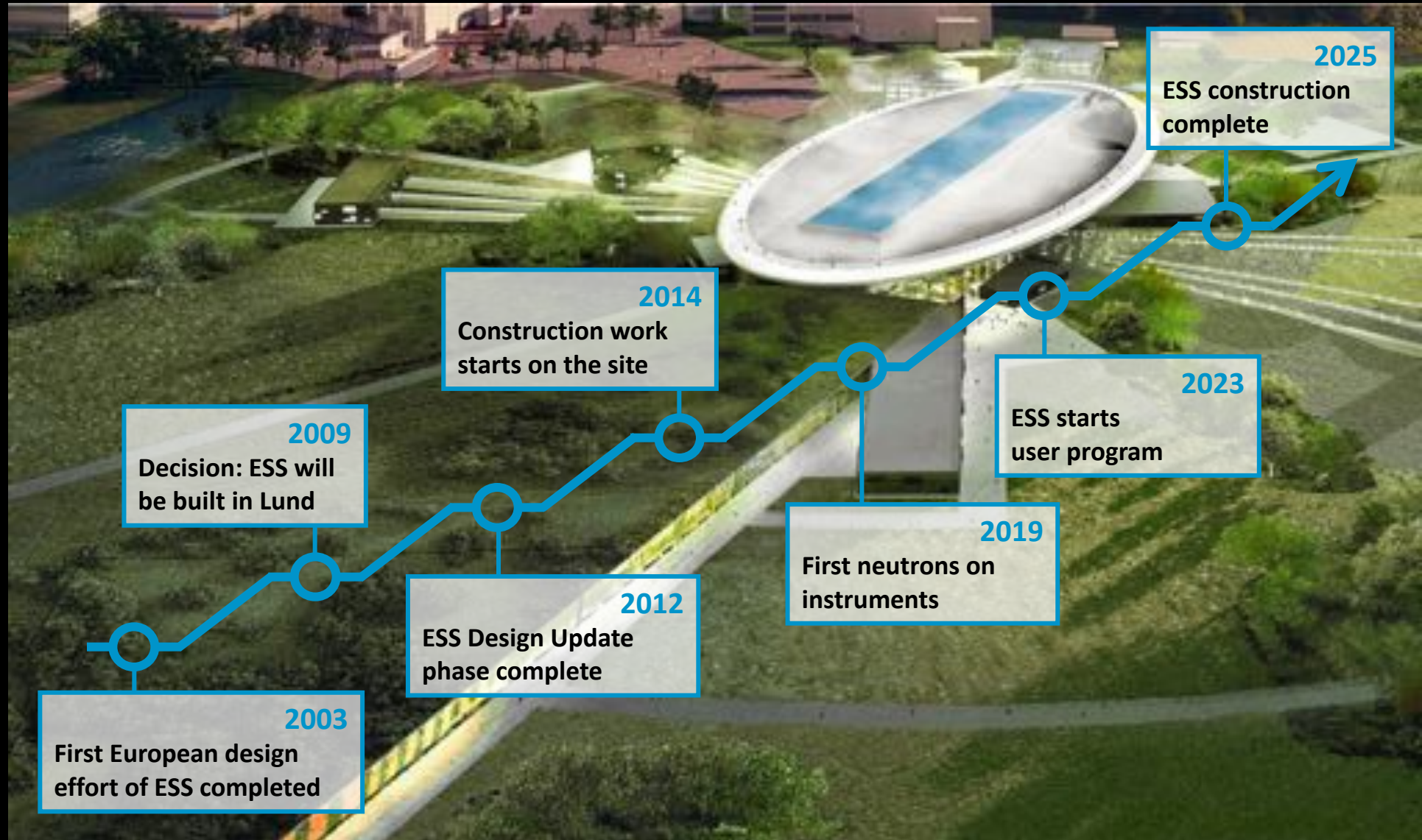


fundamental & particle physics

See also: <https://europeanspallationsource.se/science-using-neutrons>

(from Paul Henry, ESS)

Road to ESS



ESS: November 2015

ESS: October 2016

ESS: November 2017

ESS: October 2018

ESS: April 2019

ESS: June 2019

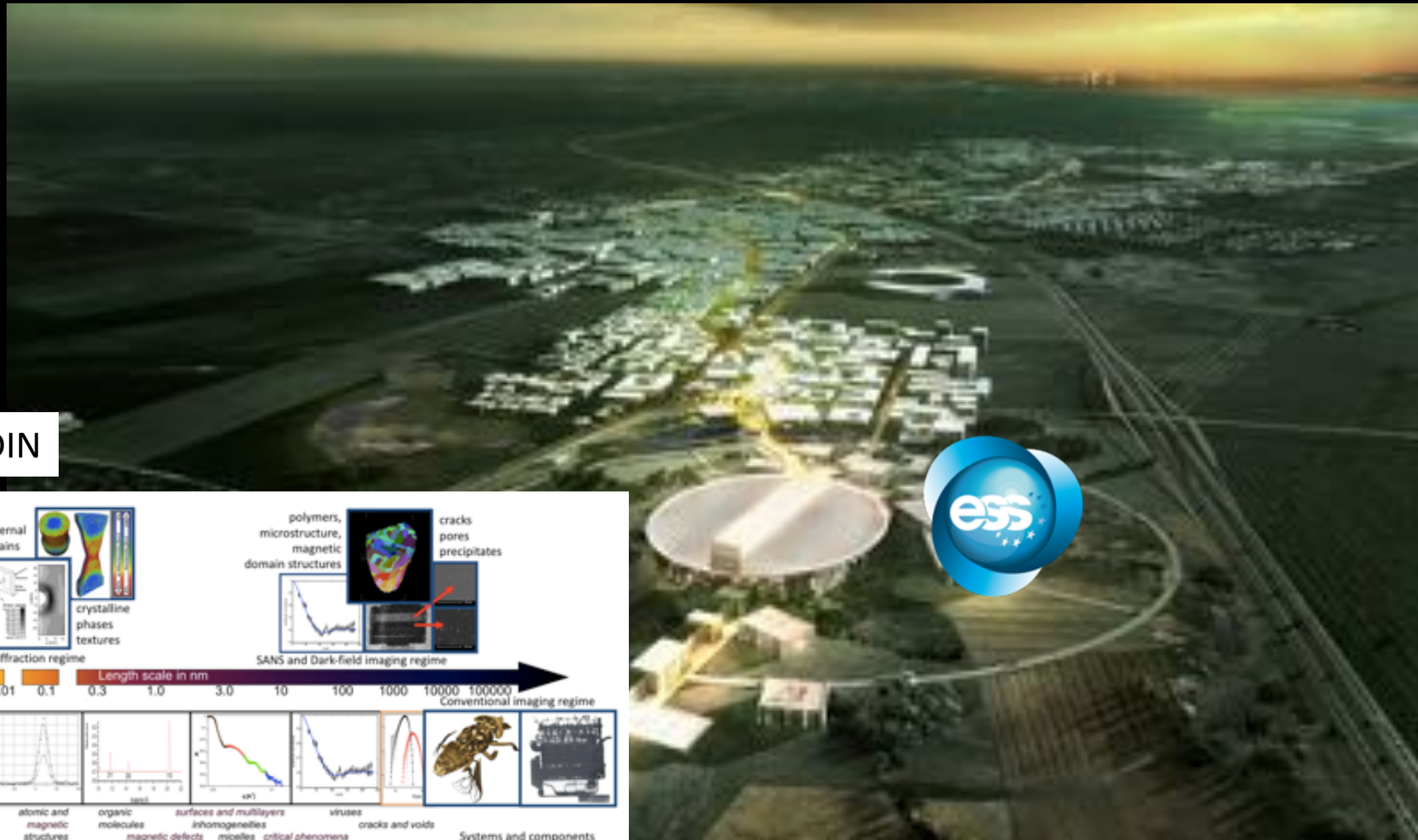


European Spallation Source (ESS)

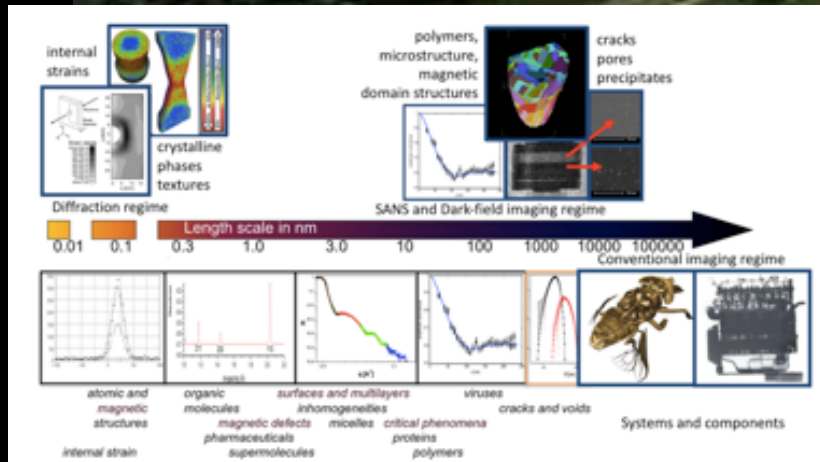


In 2020+

The future's bright!...

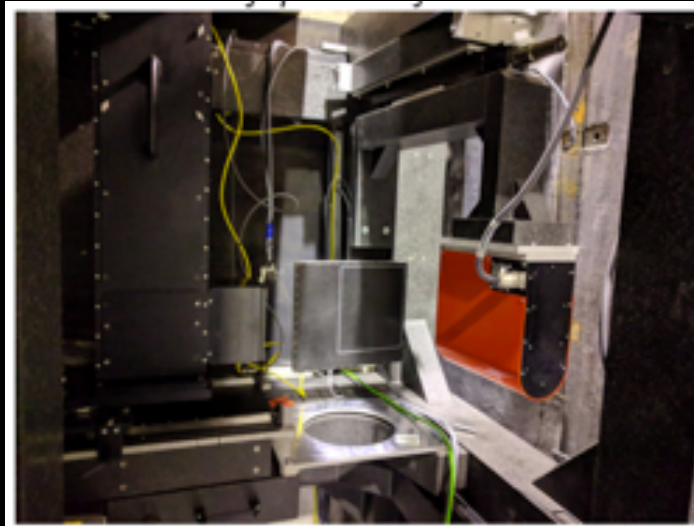
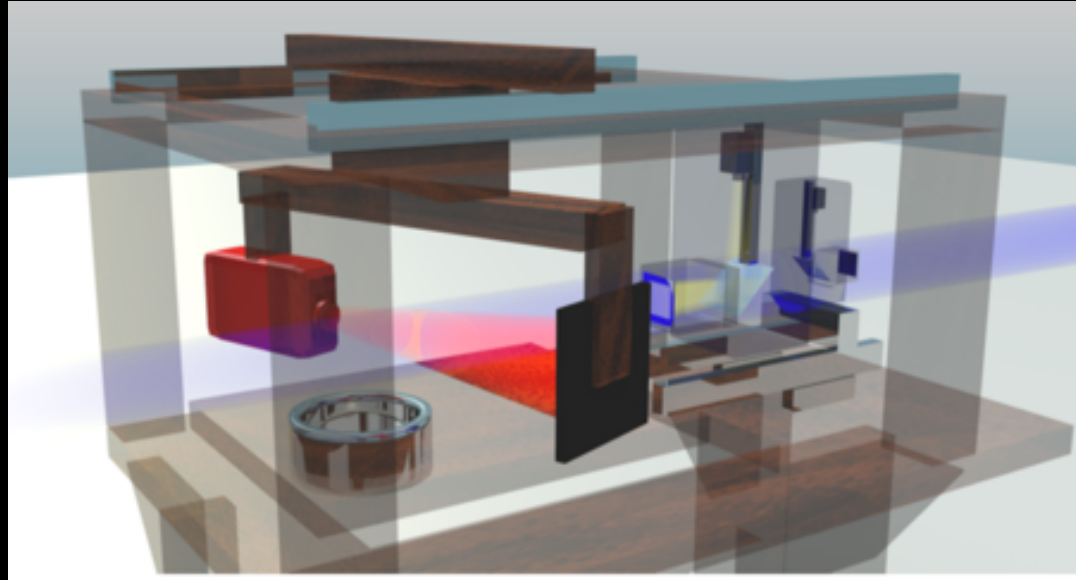


ODIN



→ Imaging programmed as one of first 3 instruments in user program!!!

Fully simultaneous x-ray & neutron tomography @ NeXT-Grenoble

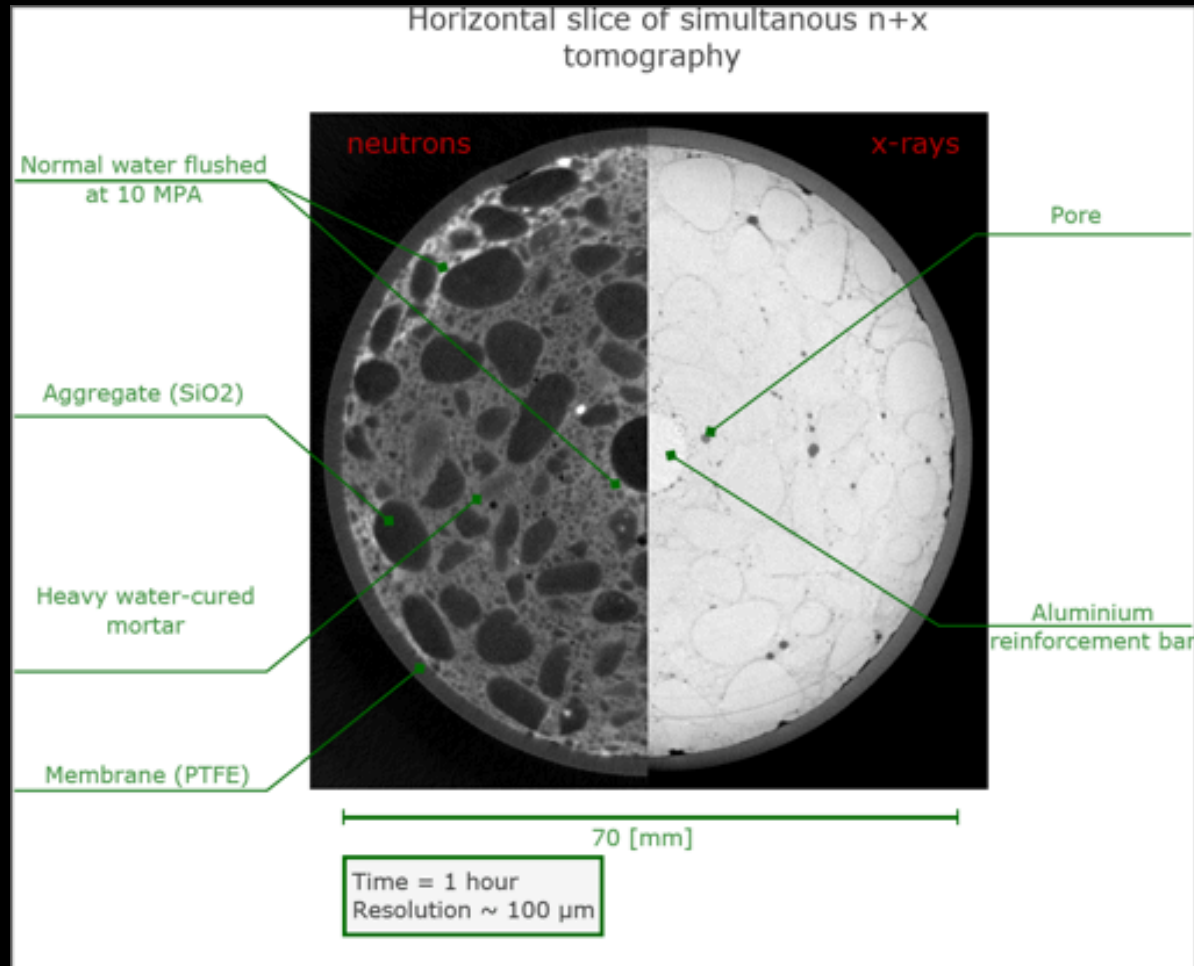


Simultaneous x-ray & neutron tomography

- Microfocus x-ray 75 W, 150 kV
- FOV: 25x30 mm max
- Resolution: down to 5 μm
- Pixels: $\sim 2200 \times 1800$

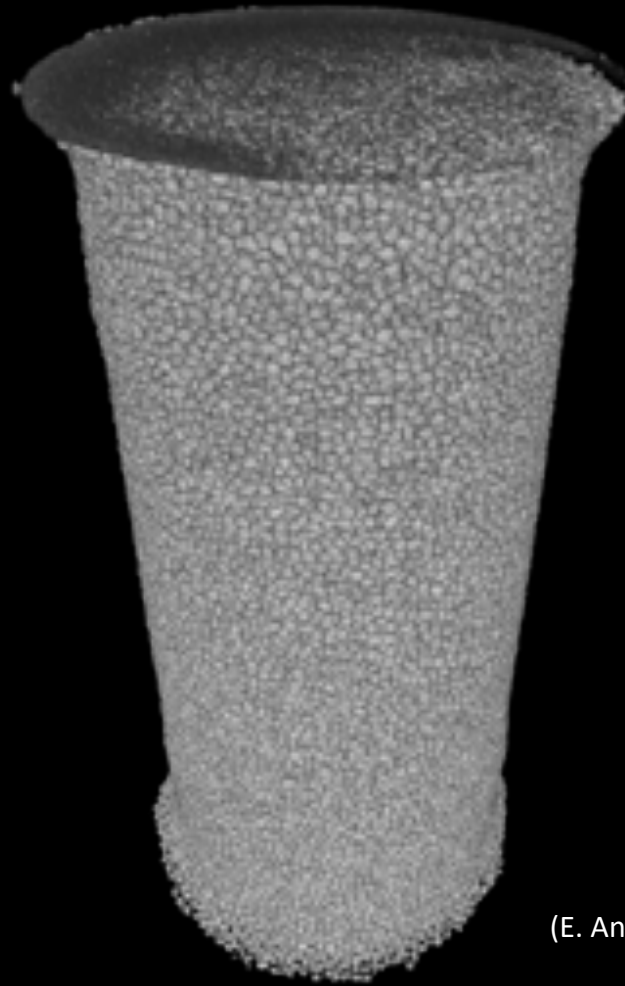
Possible to do simultaneous tomographies down to 10 μm resolution

Fully simultaneous x-ray & neutron tomography @ NeXT-Grenoble



+ In-house code for correlation of x-ray and neutron tomographies

We are good at making 3D images...



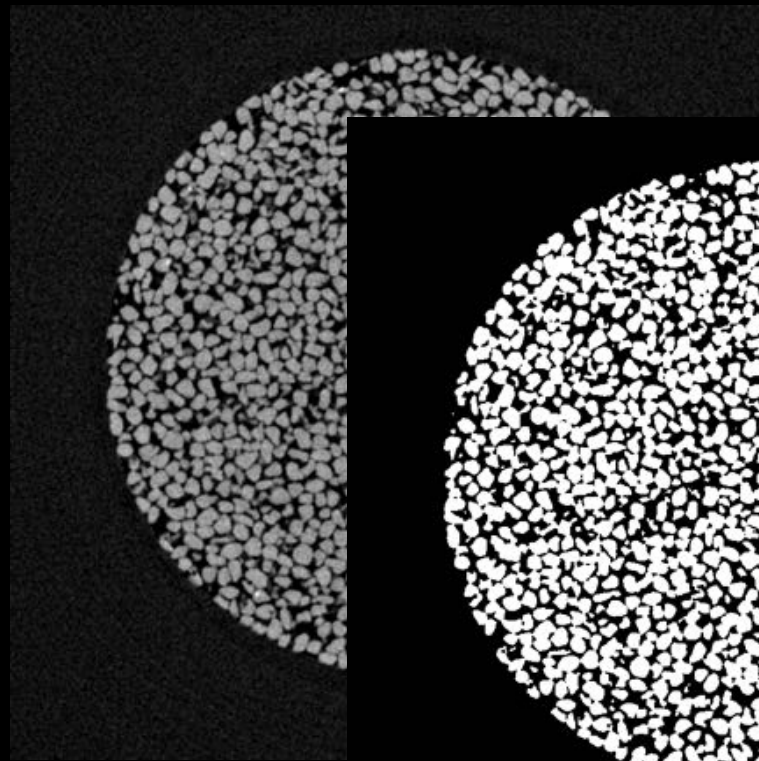
(E. Andò, CNRS Grenoble)

..which are very pretty... but so what!

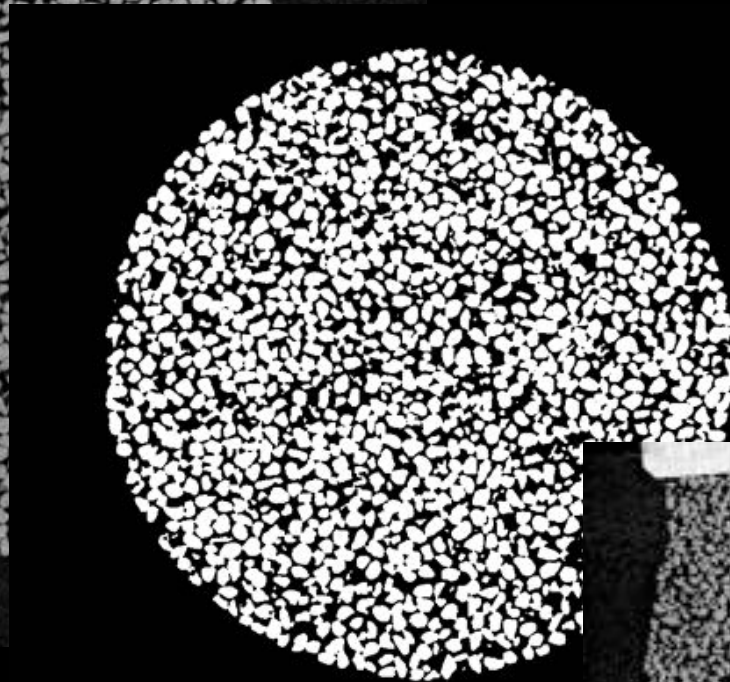
Challenge: to extract pertinent, quantified information to elucidate properties

Structural imaging and characterisation: 3D image analysis, e.g.,

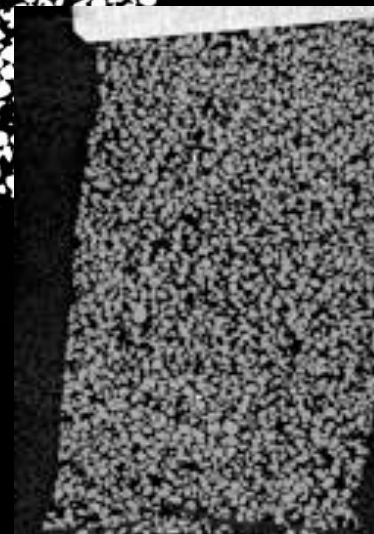
How do we see/identify and characterise microstructure?



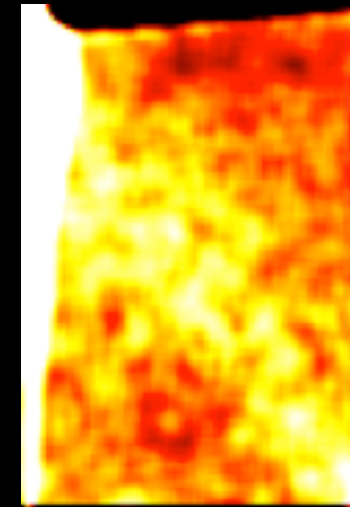
“Raw” image



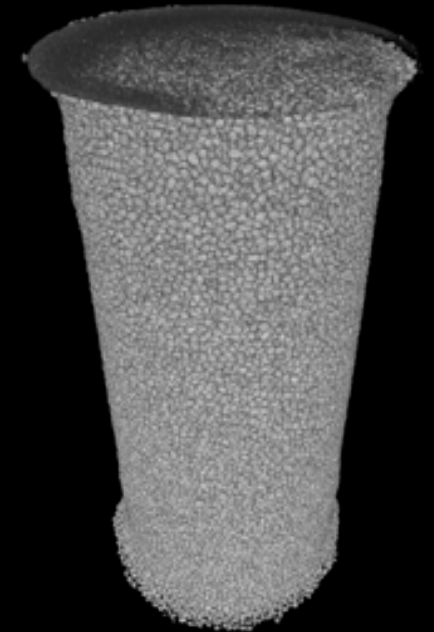
Binarise
(grains and voids)



Tomo

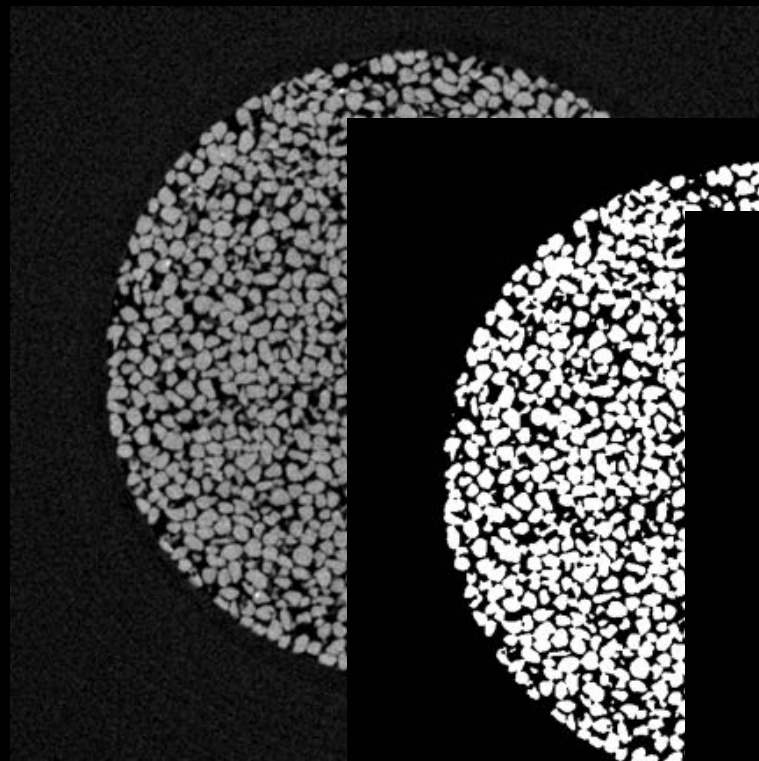


Porosity

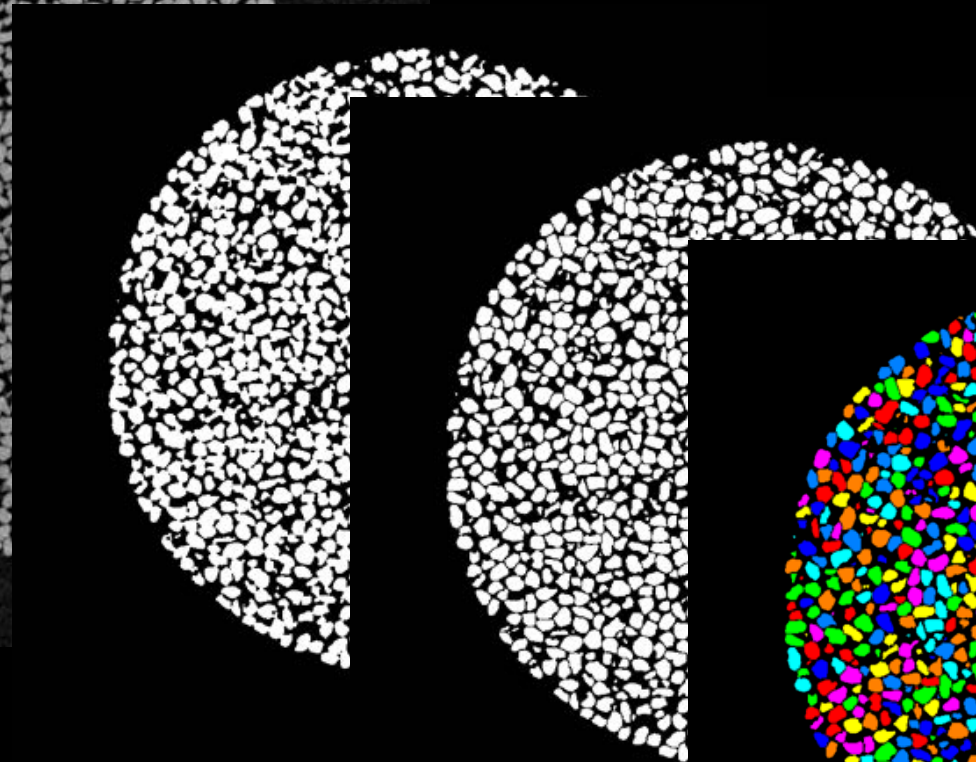


Structural imaging and characterisation: 3D image analysis, e.g.,

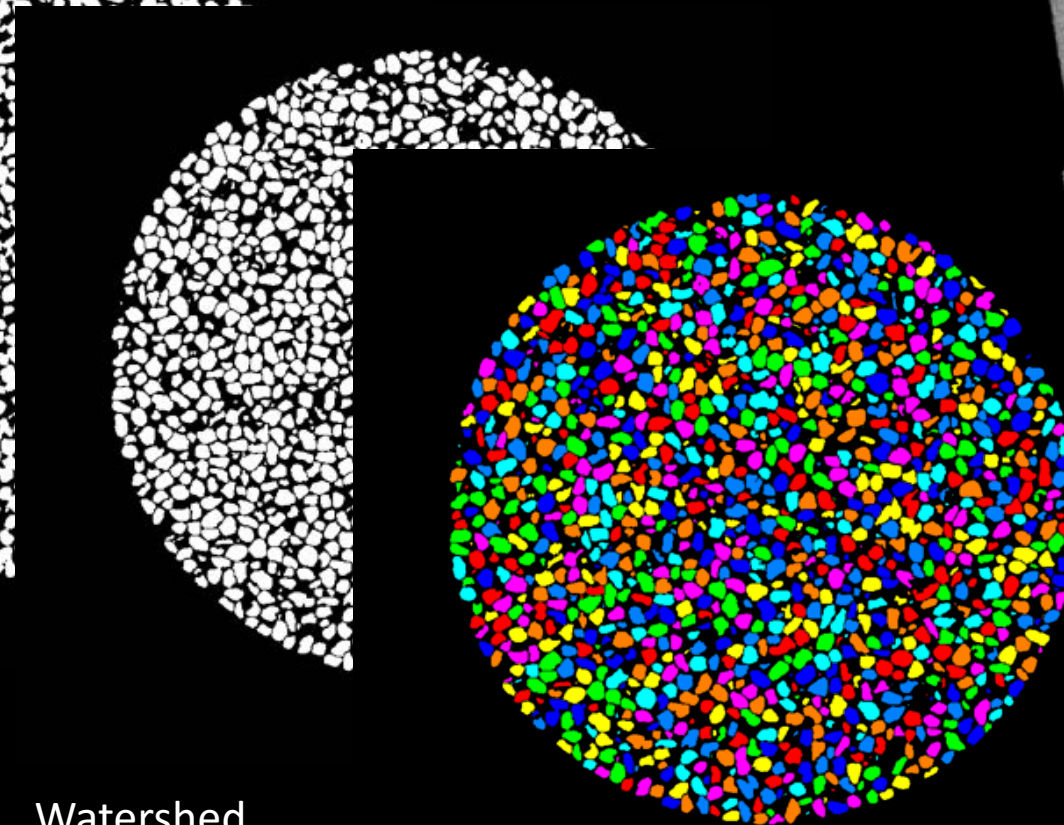
How do we see/identify and characterise microstructure?



“Raw” image

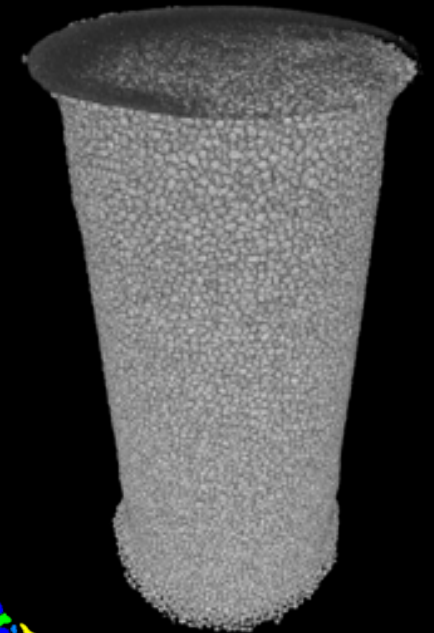


Binarise
(grains and voids)



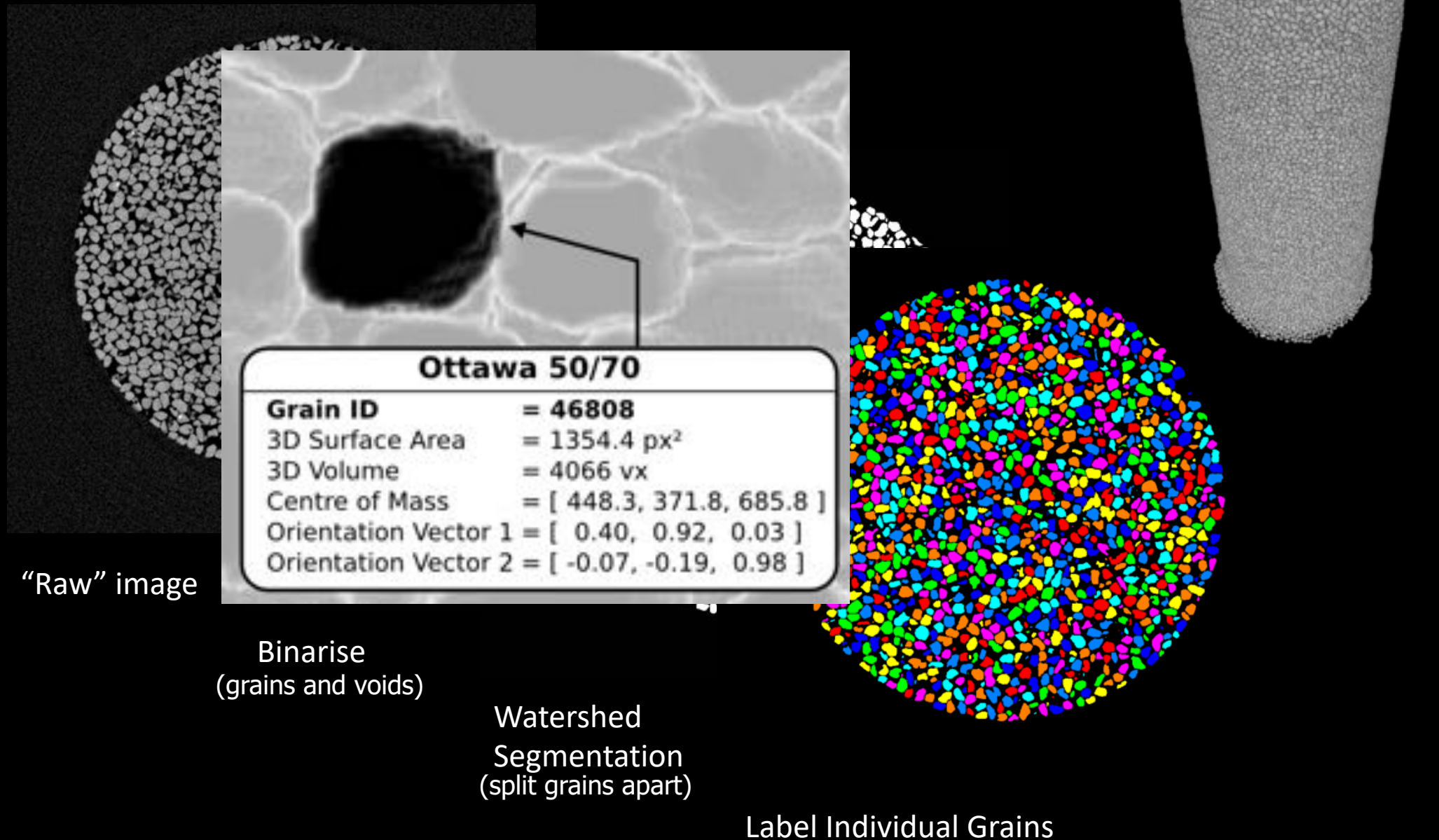
Watershed
Segmentation
(split grains apart)

Label Individual Grains

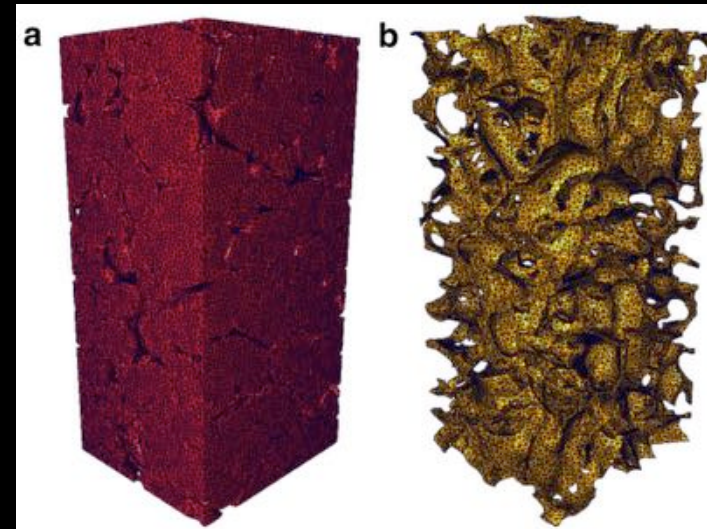
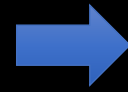


Structural imaging and characterisation: 3D image analysis, e.g.,

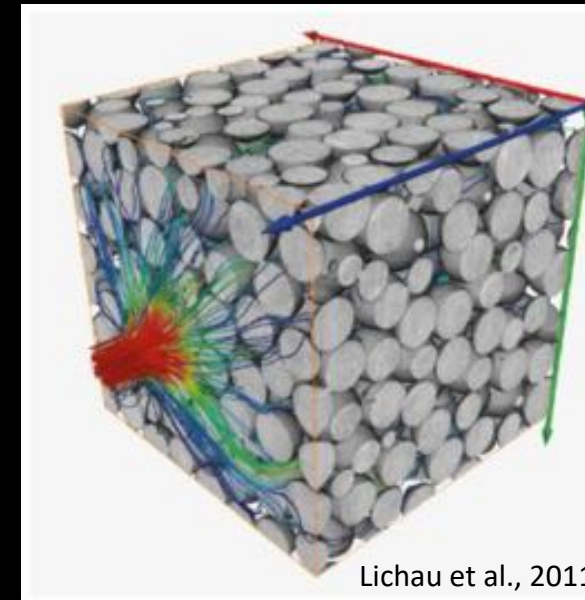
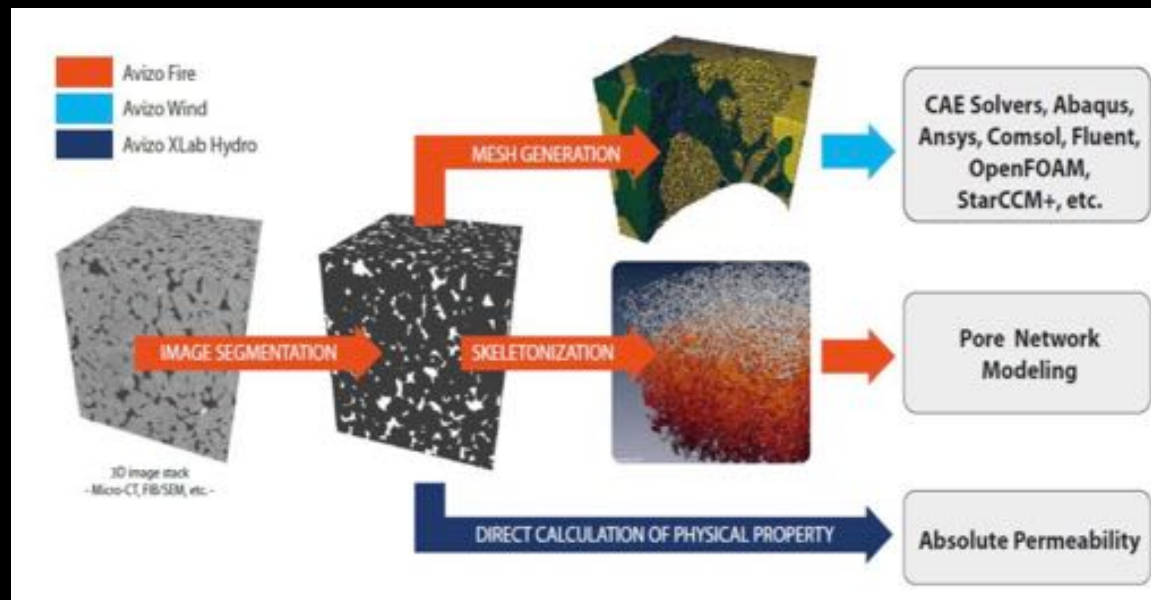
How do we see/identify and characterise microstructure?



Structural imaging and characterisation → models



Madi et al., 2006



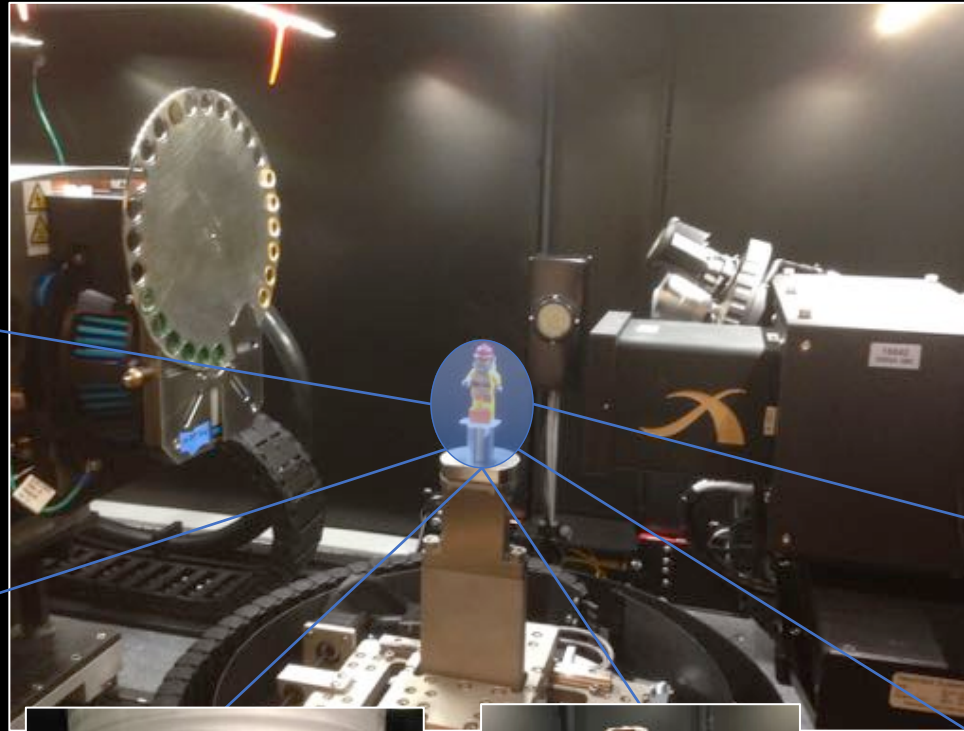
Lichau et al., 2011

4D imaging...



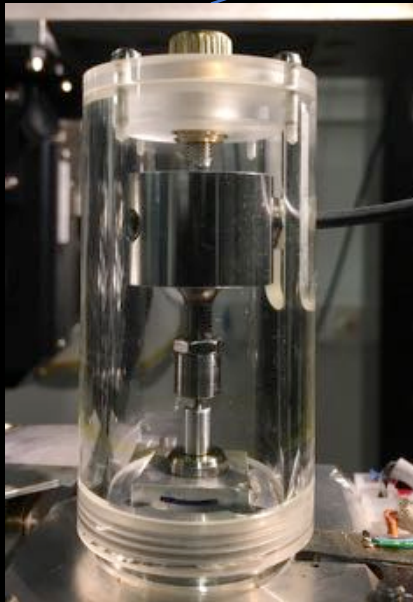


Humidity

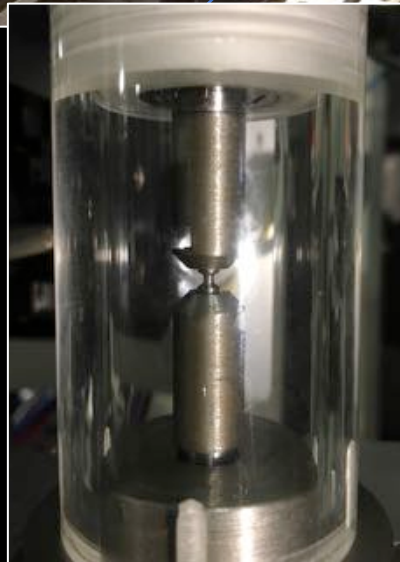


Others and Future:

- Pressure
- Fluid flow
- Heating
- Cooling (freezing)
- ...



Compression



Tension



Triaxial



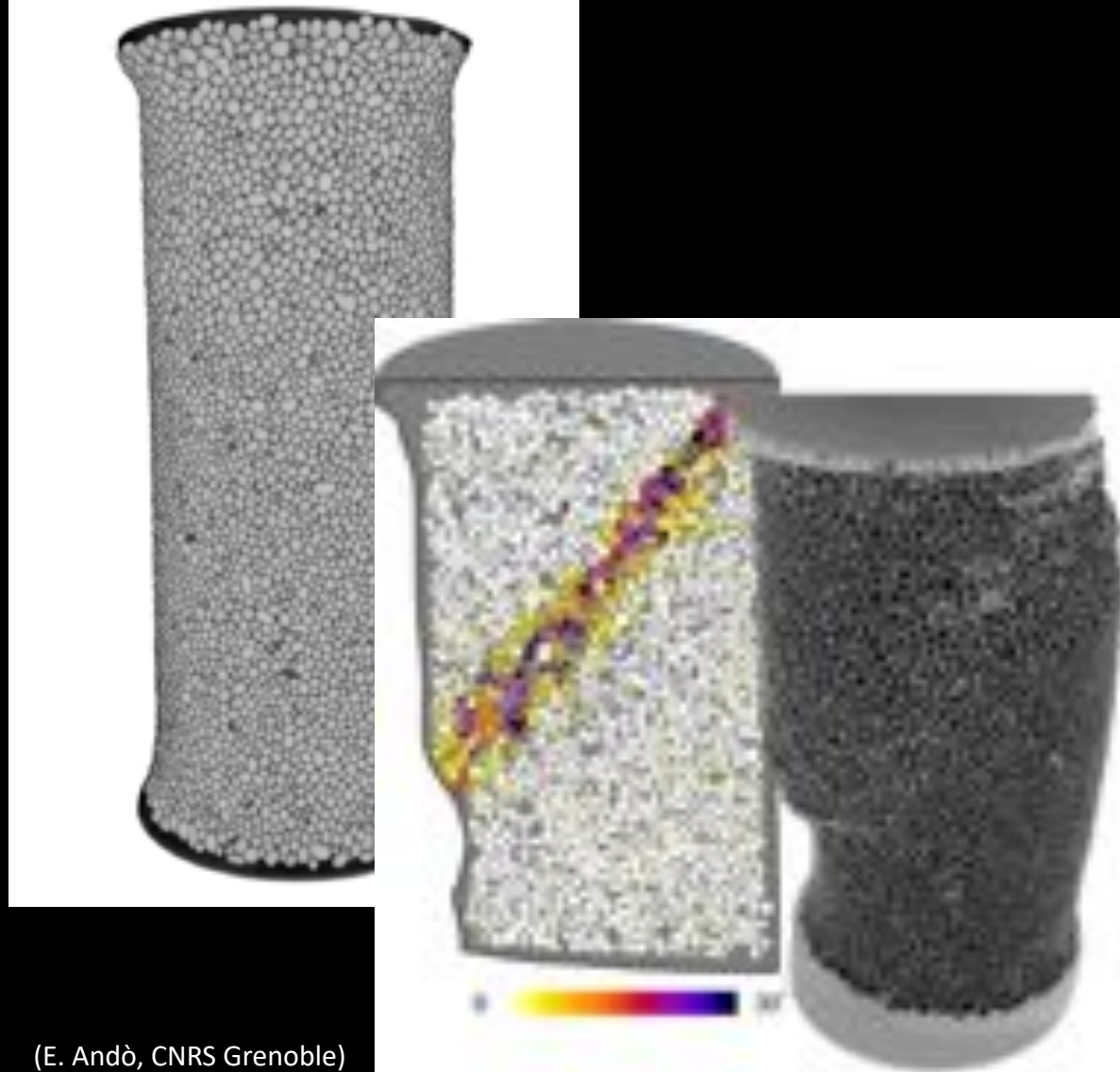
Electrochemical



Vacuum

4D imaging and in-situ experiments

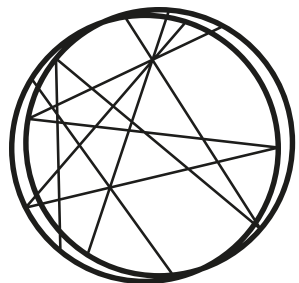
4D imaging of triaxial compression of a sample of oolitic sand (10's thousands grains)



(E. Andò, CNRS Grenoble)



Image by Basics (www.basics.land)



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