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

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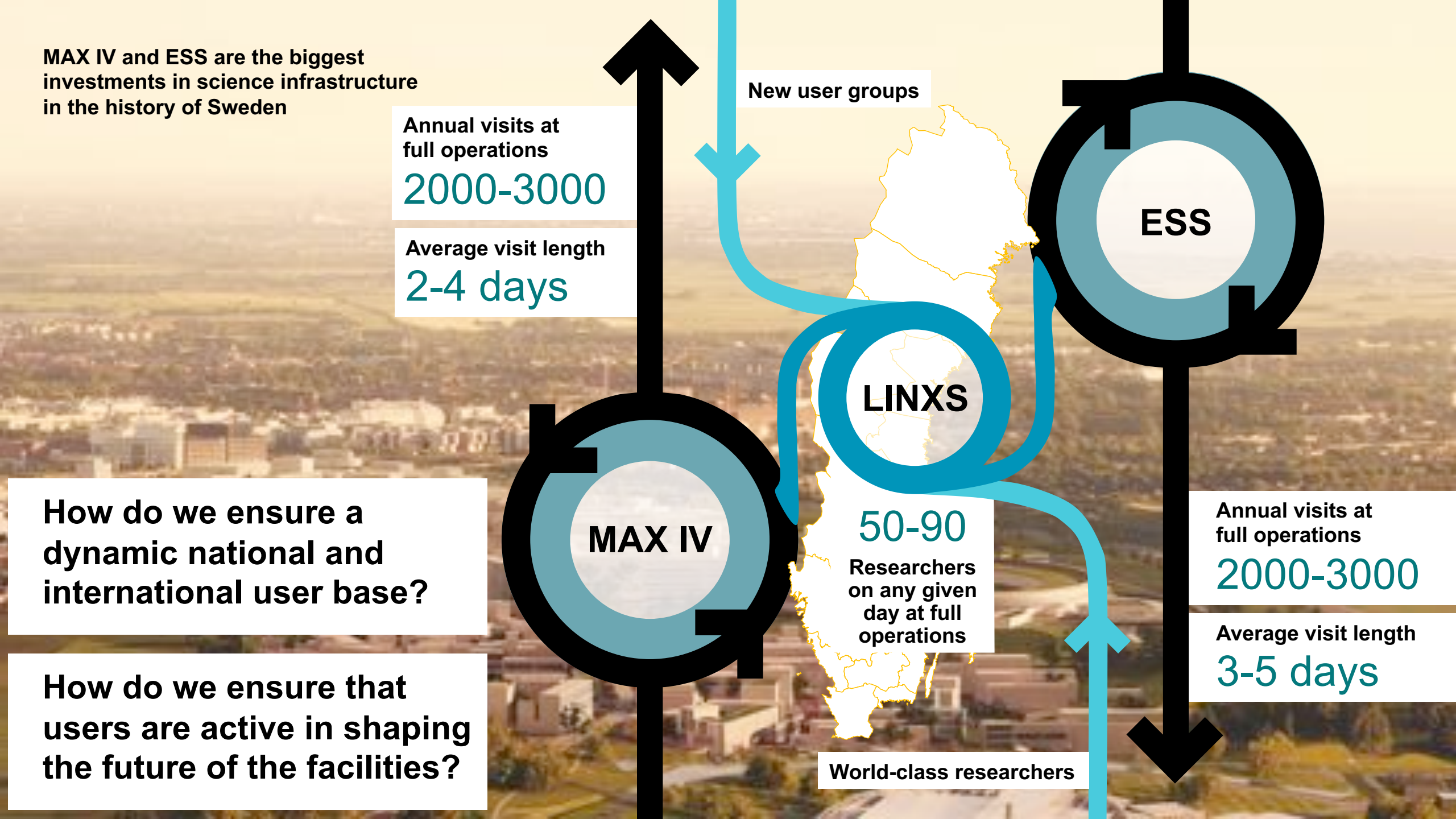


How do we ensure a dynamic national and international user base?

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

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

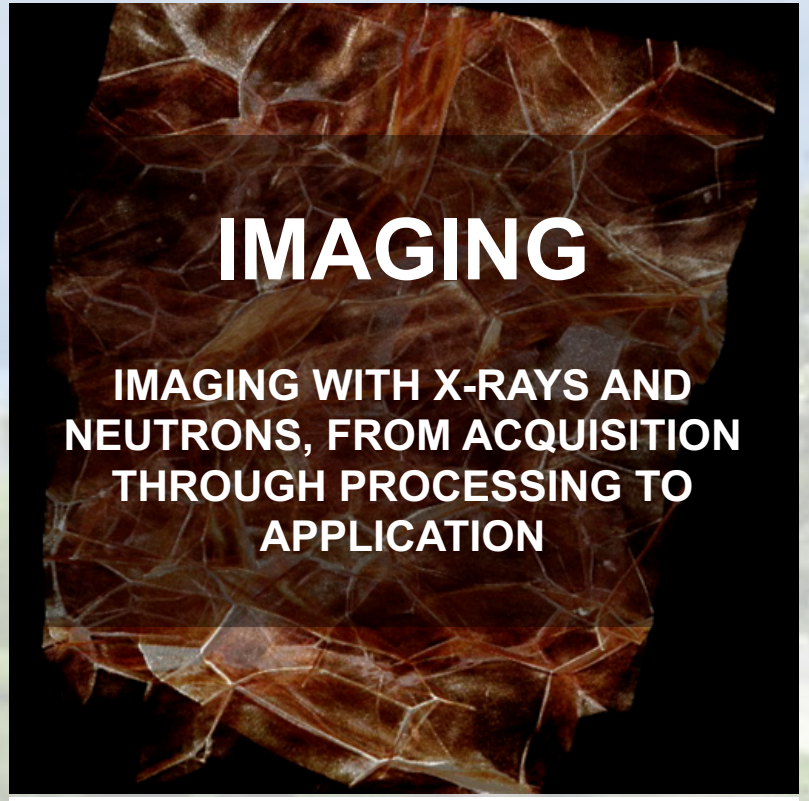
LINXS is an advanced study institute dedicated to becoming the nucleus for national and international scientific activities in Science Village Scandinavia situated between MAX IV and ESS.

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

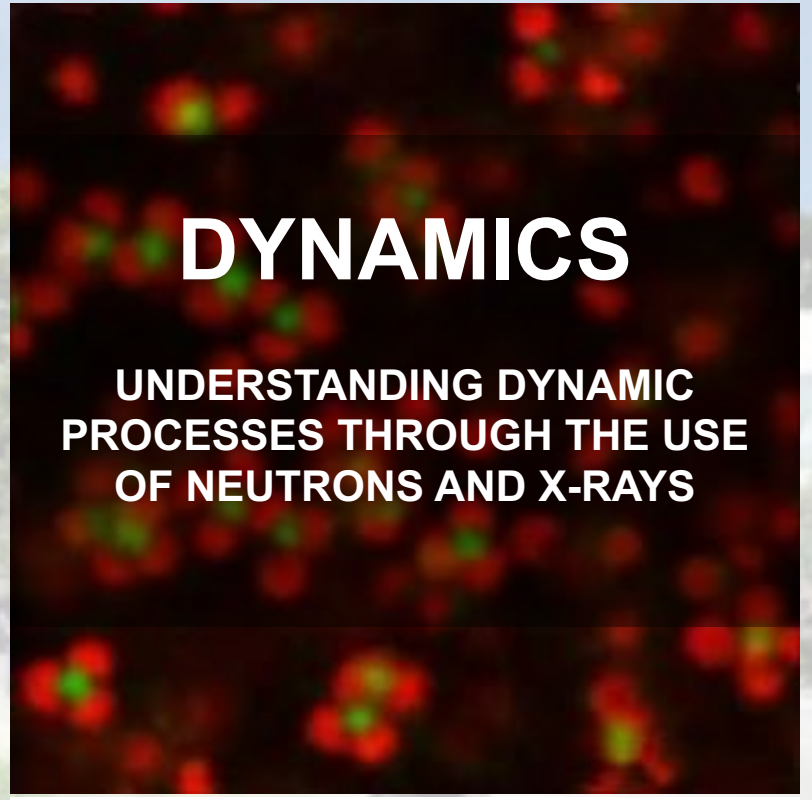
LINXS is built on a stream of highly motivated world-leading scientists invited for short-term focused topical research visits.

More info: www.linxs.se/about

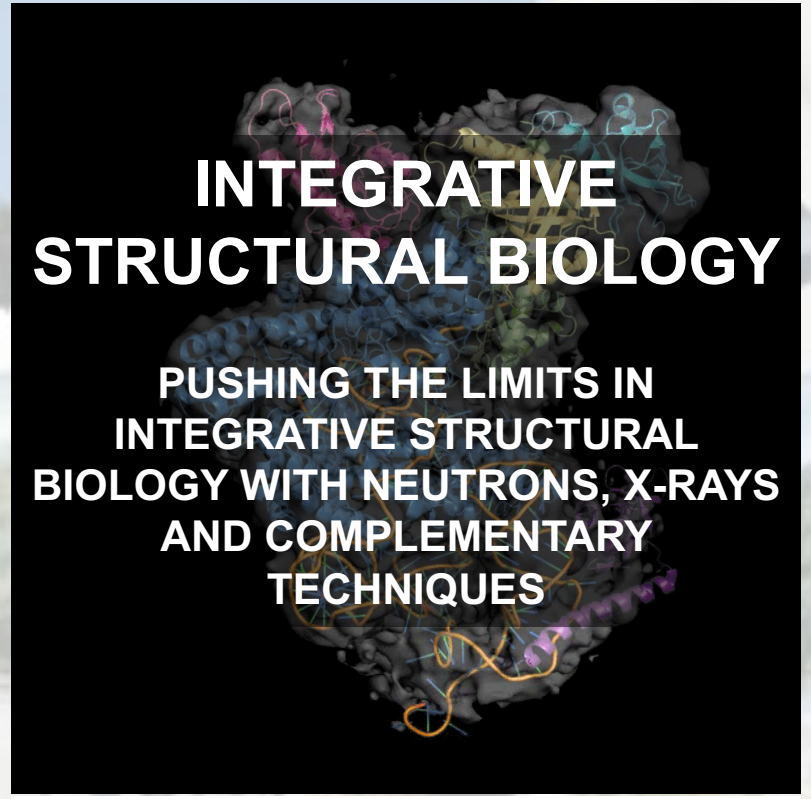
CURRENT THEMES & Working Groups



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

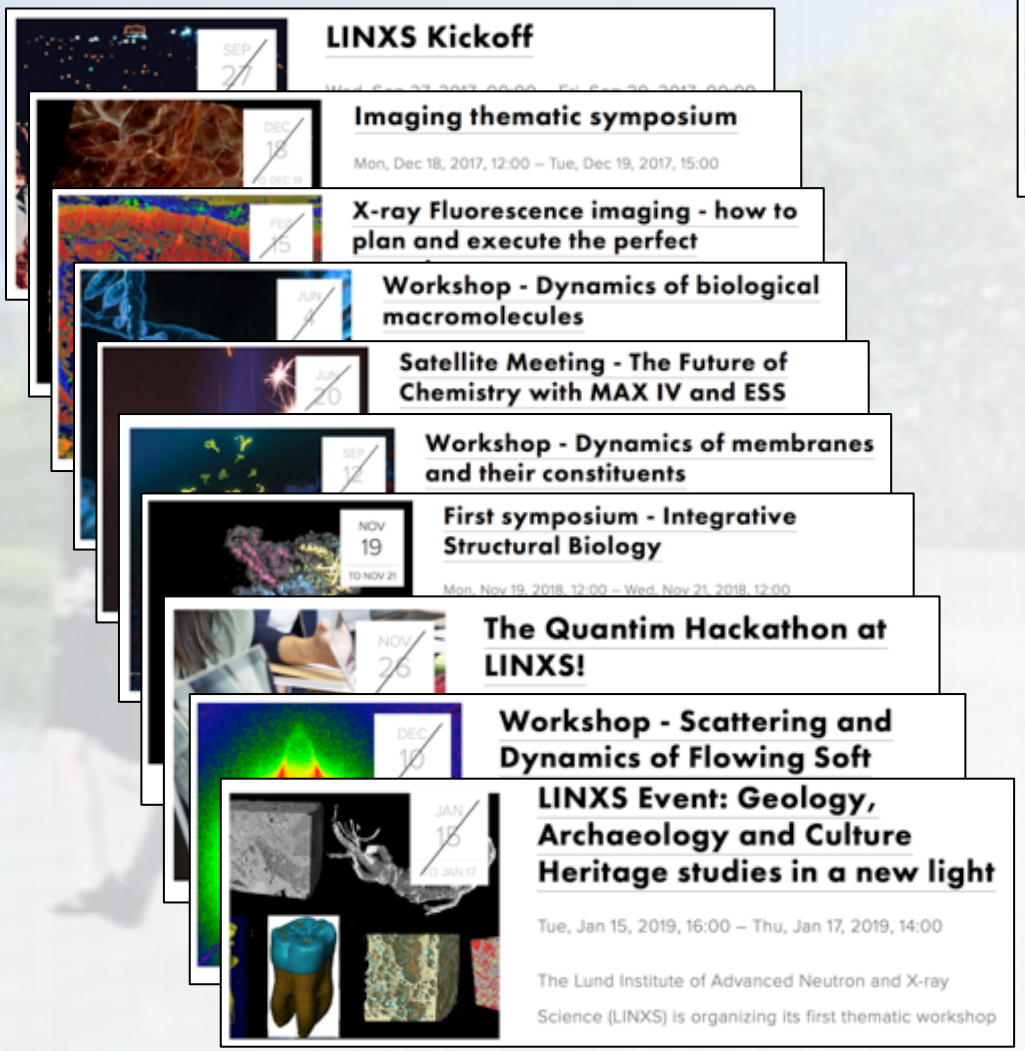


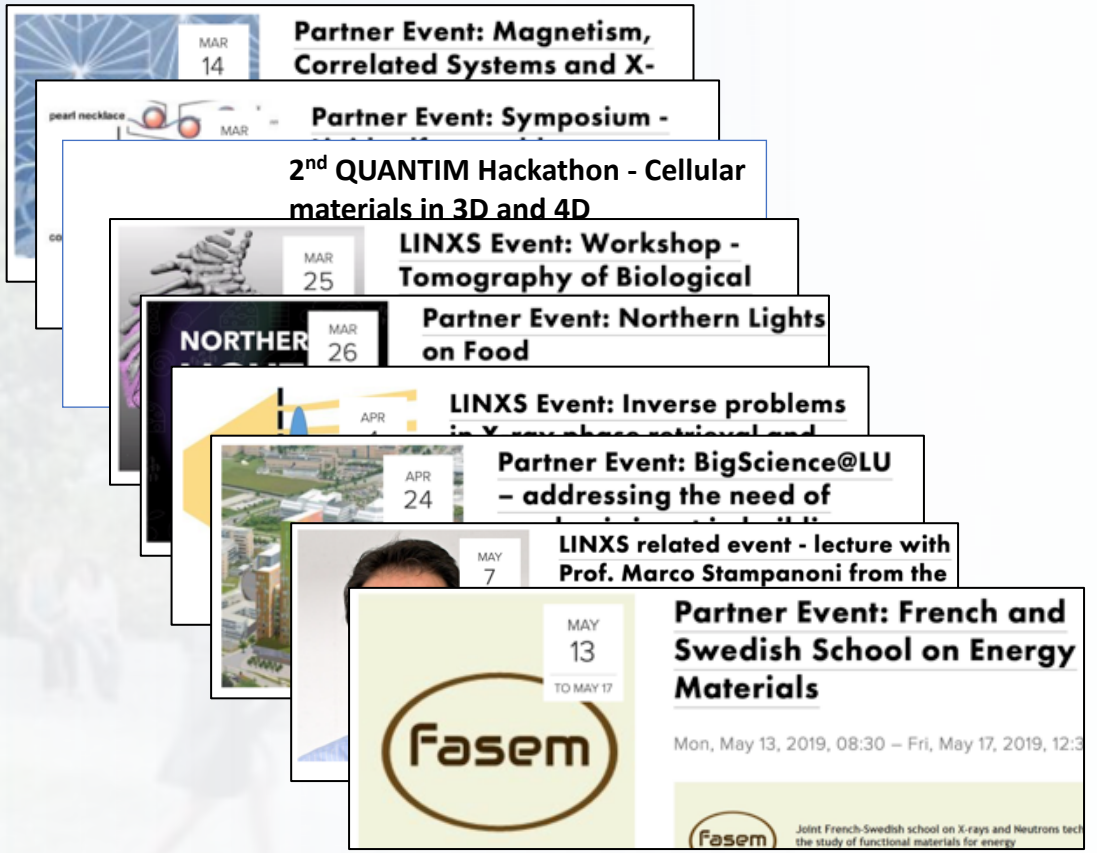
- **Biocompute**
- **Time resolved** ISB
- **Membrane proteins**
- **AMYLOID**: an integrative approach

More info: www.linxs.se

SCIENTIFIC ACTIVITIES

Previously





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

SCIENTIFIC ACTIVITIES – recent/upcoming events

- 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)

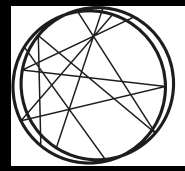
http://www.linxs.se

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

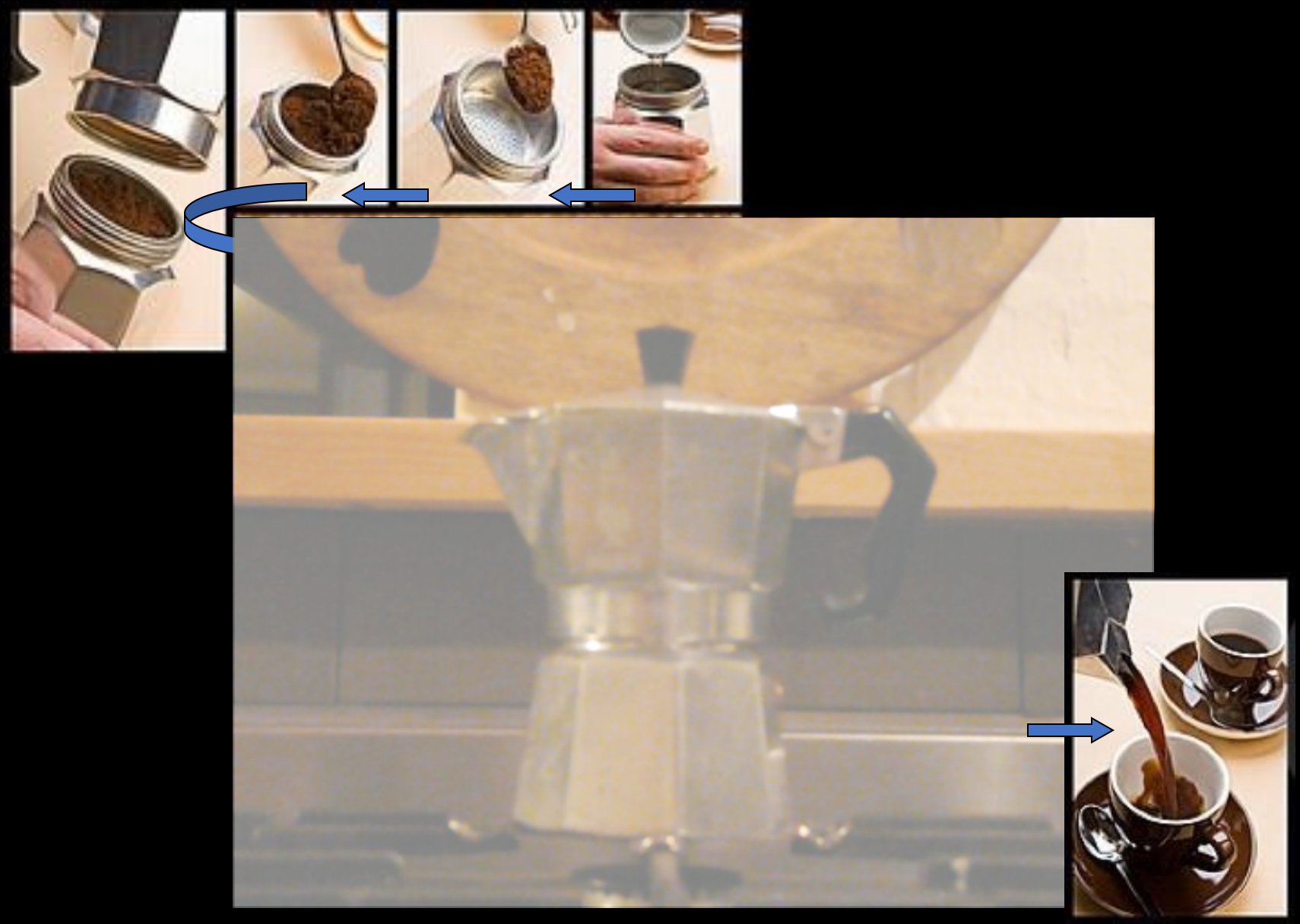
Stephen Hall[1,2,3]

[1]Lund Institute of advanced Neutron and X-ray Science

[2]Division of Solid Mechanics, Lund University

[3]4D Imaging Lab @ LTH

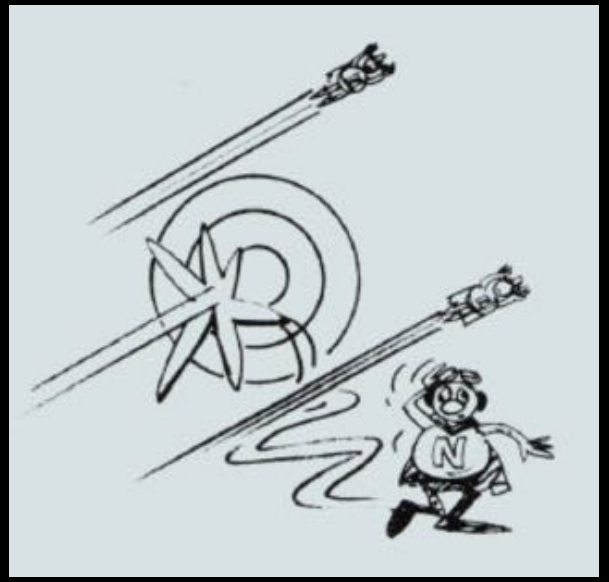
A quick experiment to start….

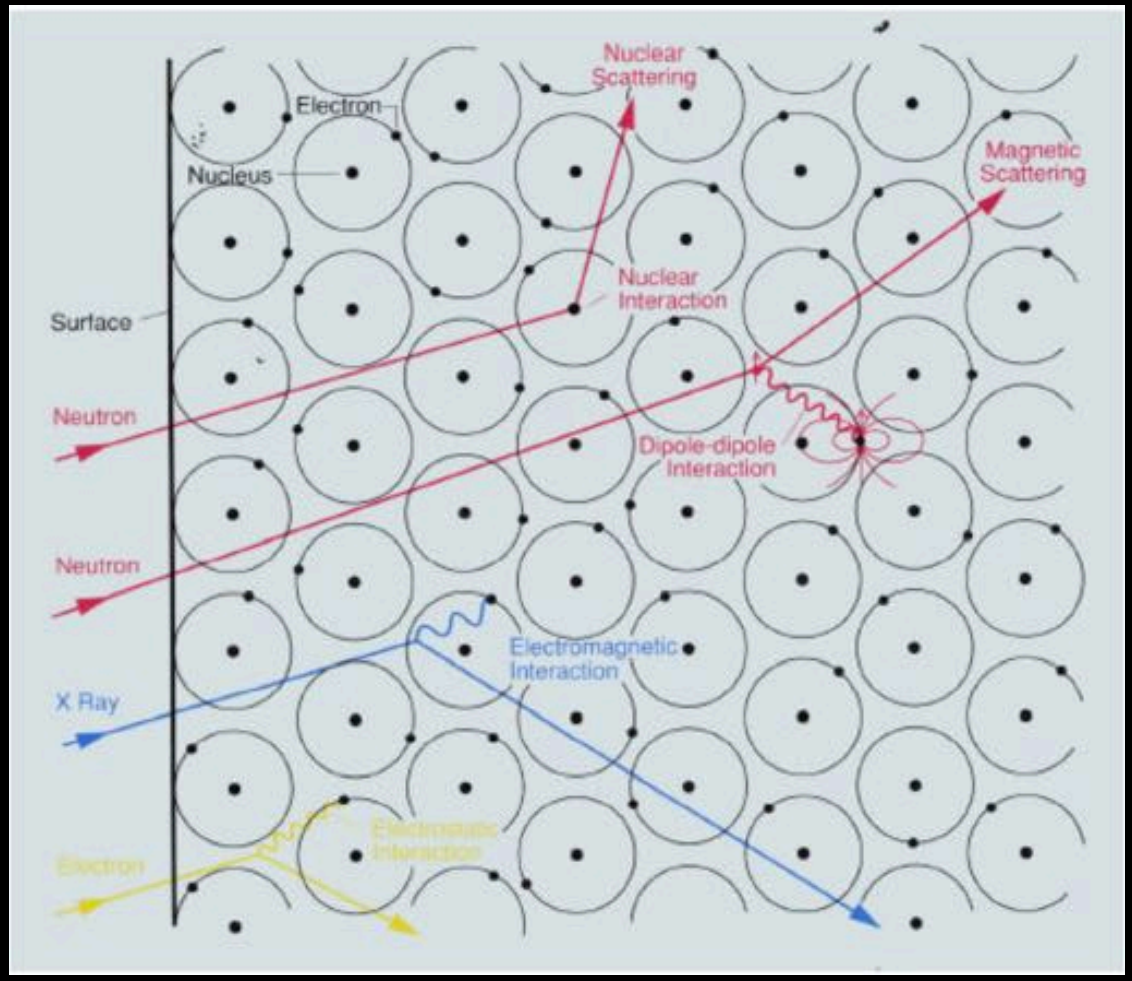


3:48

Time-resolved neutron radiography of coffee being made

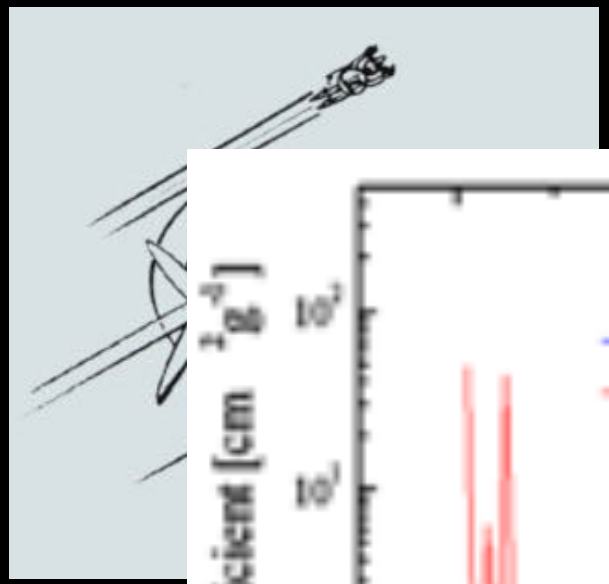
Neutron, x-ray and electron interaction mechanisms

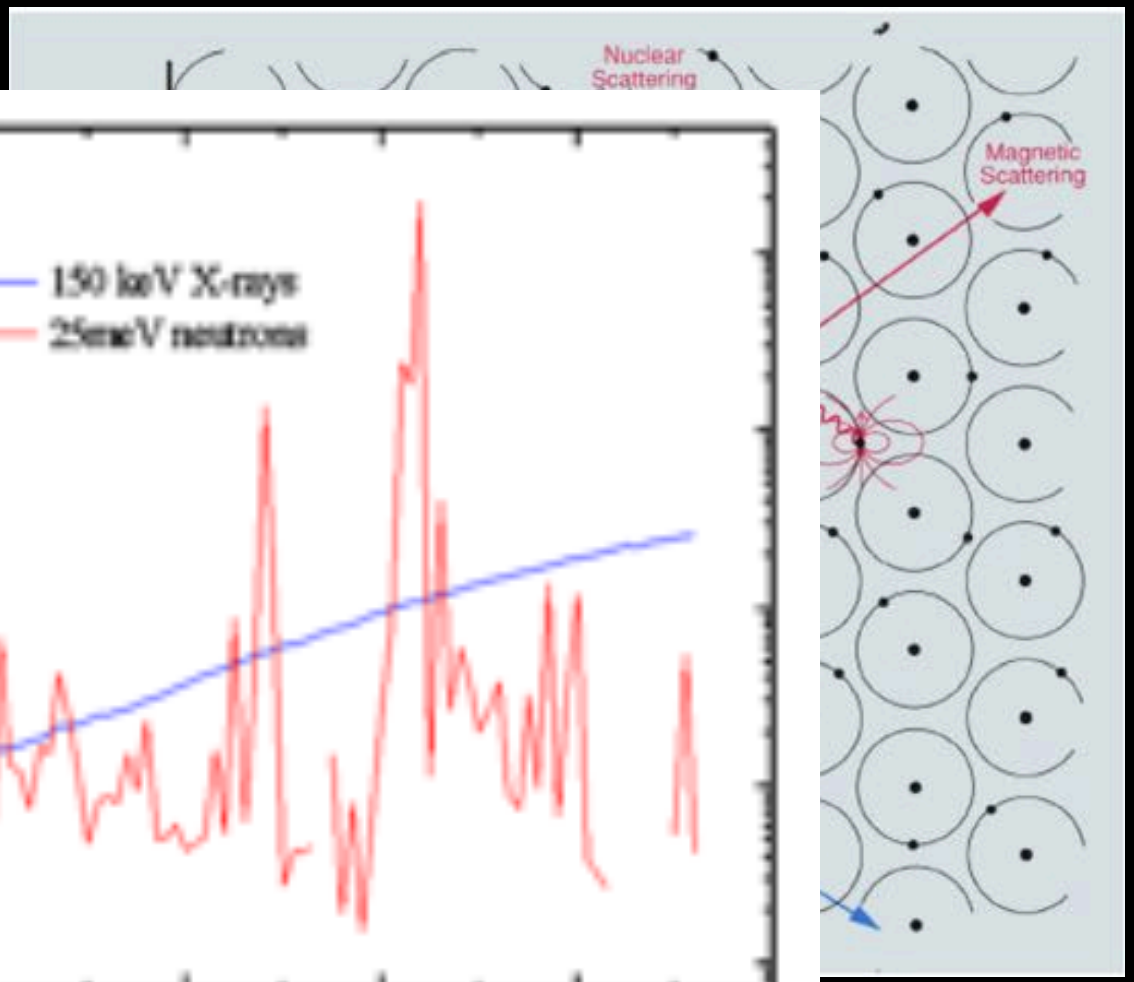




After R. Pynn (Los Alamos National Laboratory)

Neutron, x-ray and electron interaction mechanisms

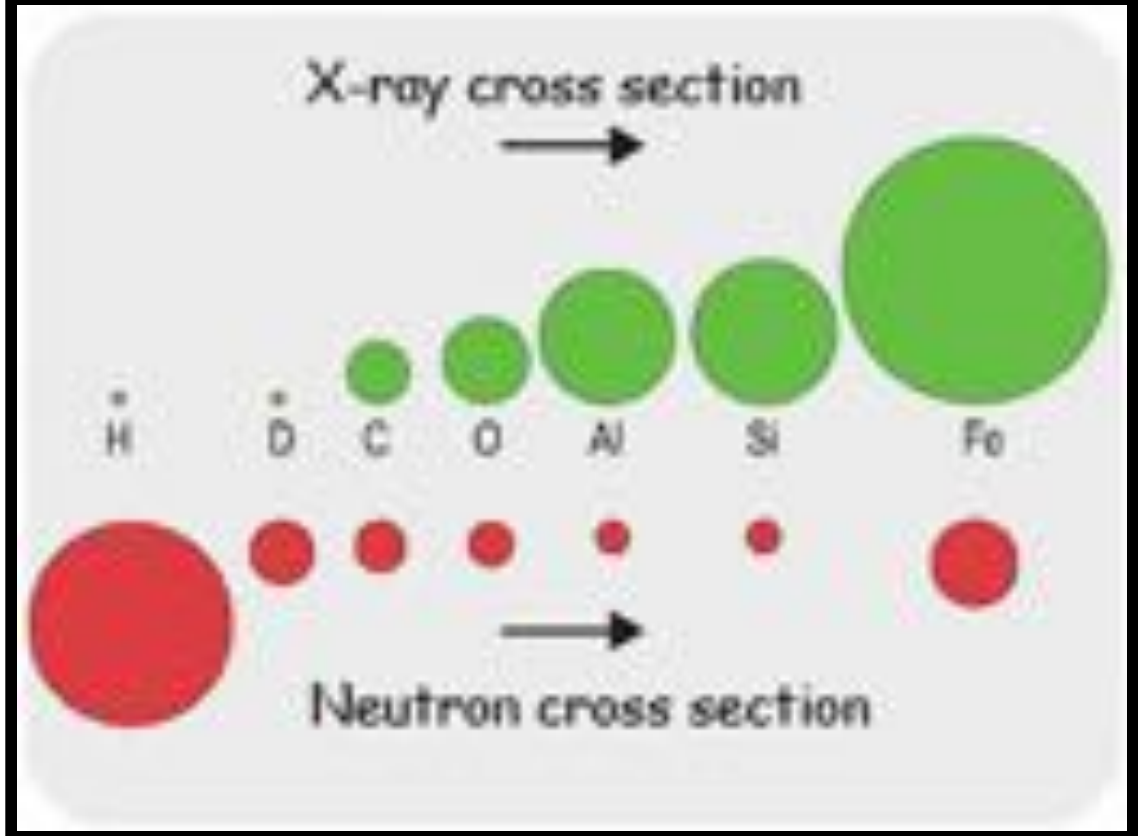


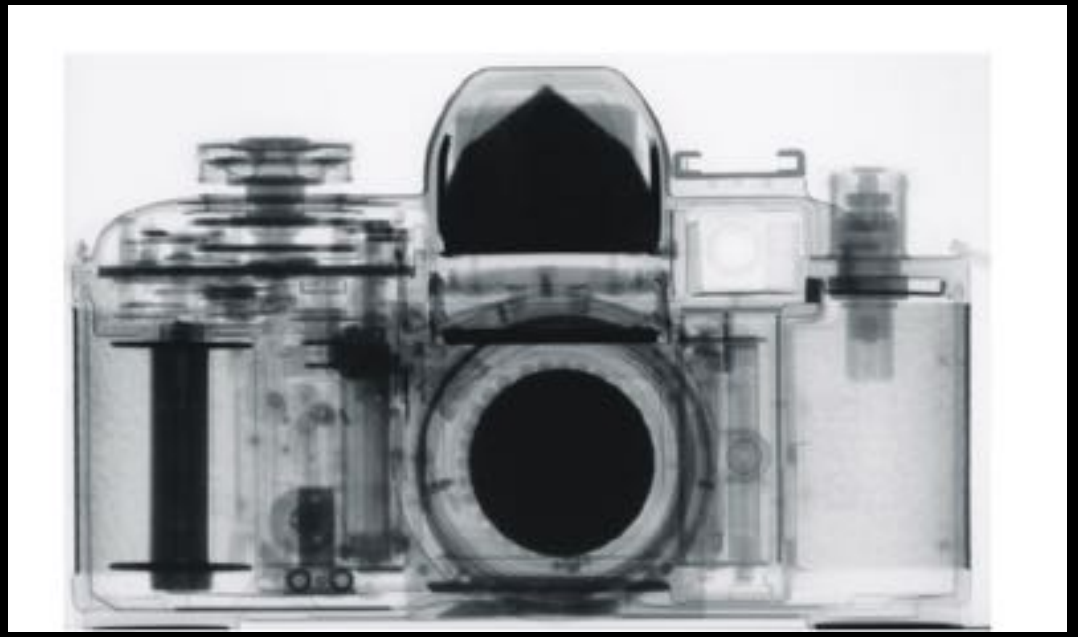


After R. Pynn (Los Alamos National Laboratory)

Neutrons ~~"versus"~~ x-rays

Neutrons complement x-rays (and vice versa)



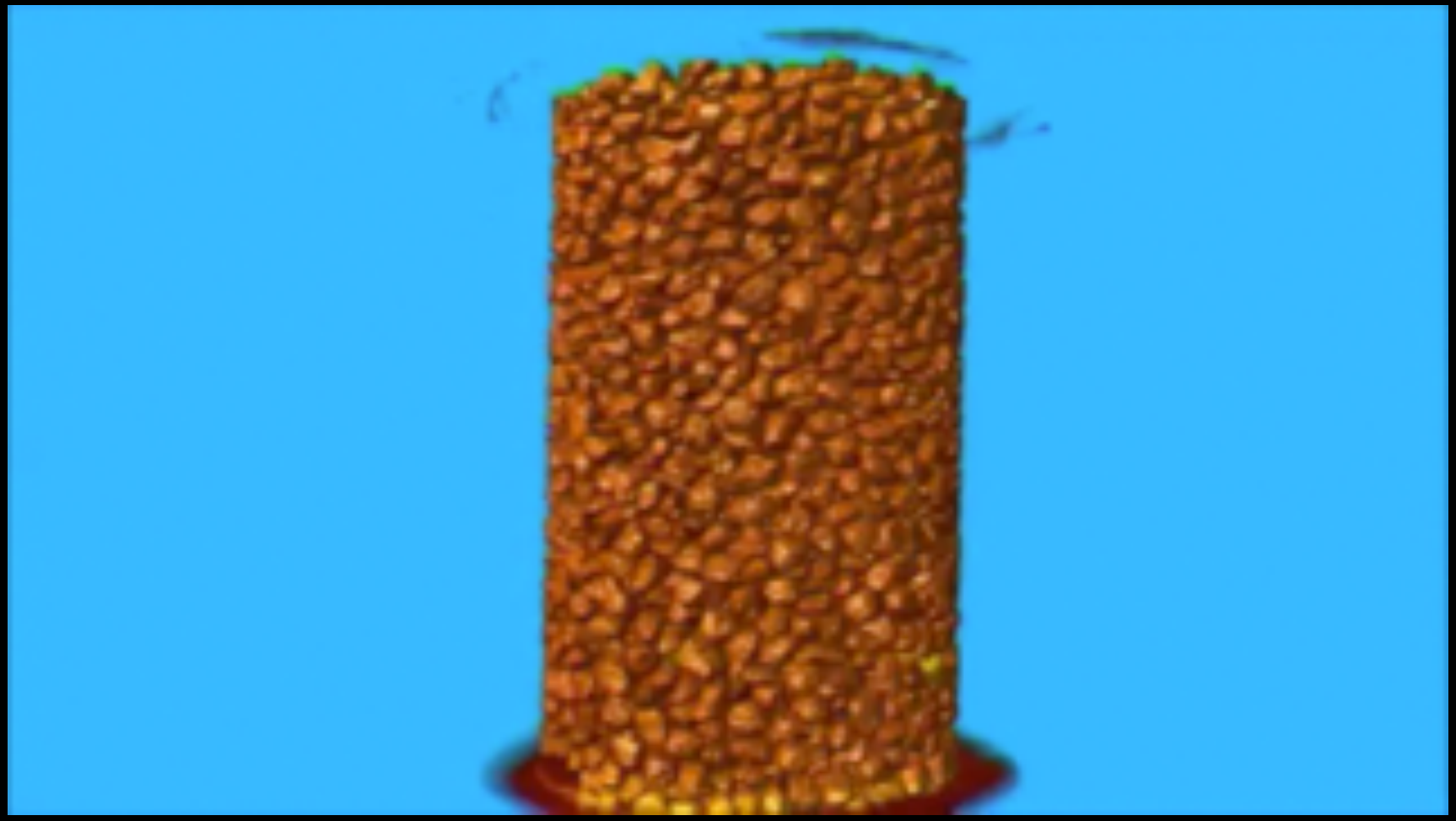


X-ray Imaging History

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

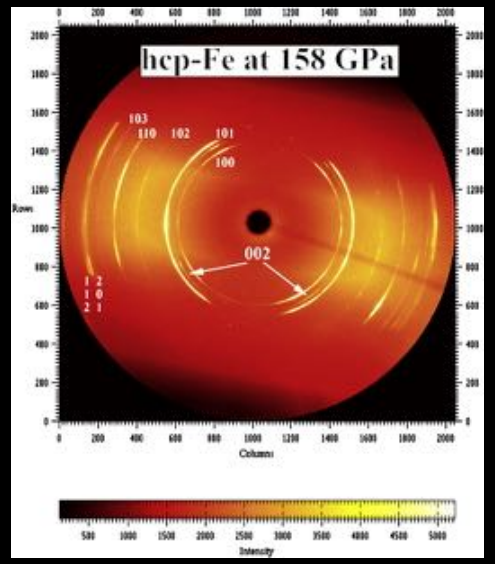
Hand mit Ringen (Hand with Rings): print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Professor Ludwig Zehnder of the Physik Institut, University of Freiburg, on 1 January 1896 (http://en.wikipedia.org/wiki/X-ray)

Structural imaging in by tomography



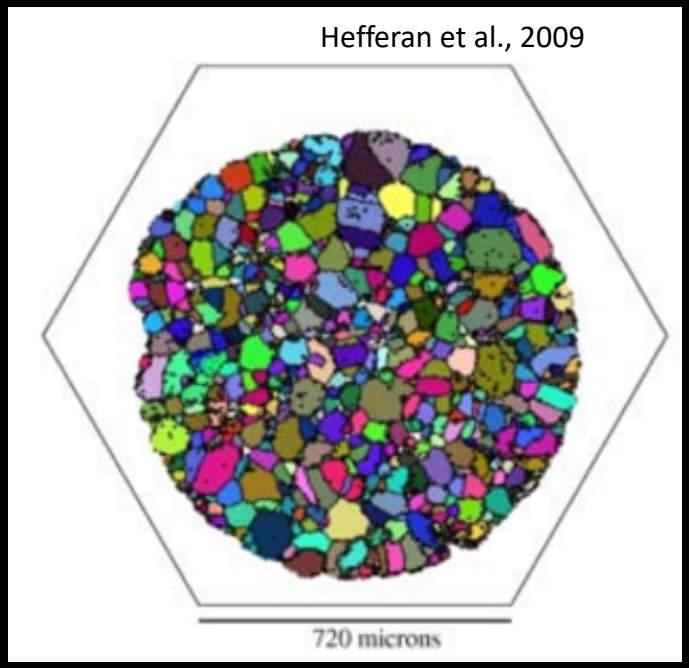
Structural mapping and texture by scattering

Atomic structure, Orientation…



Lin et al. (2010)

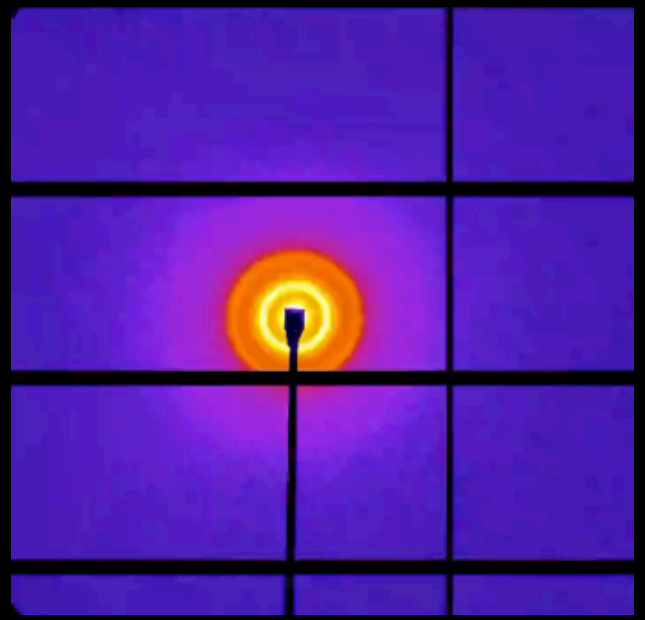
3D diffraction
- grain structure and orientations in polcrystalline materials



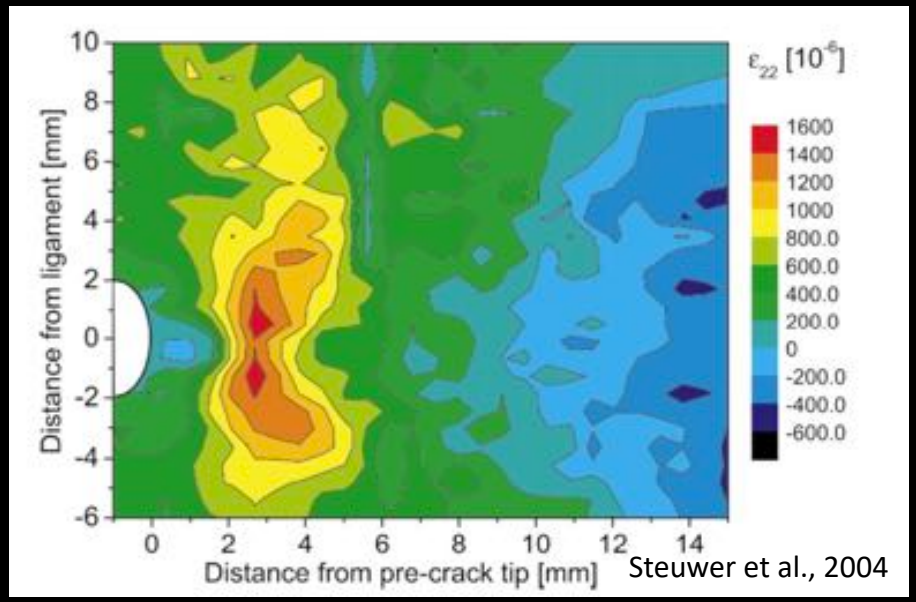
Hefferan et al., 2009

Molecular structures from small angle scattering

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



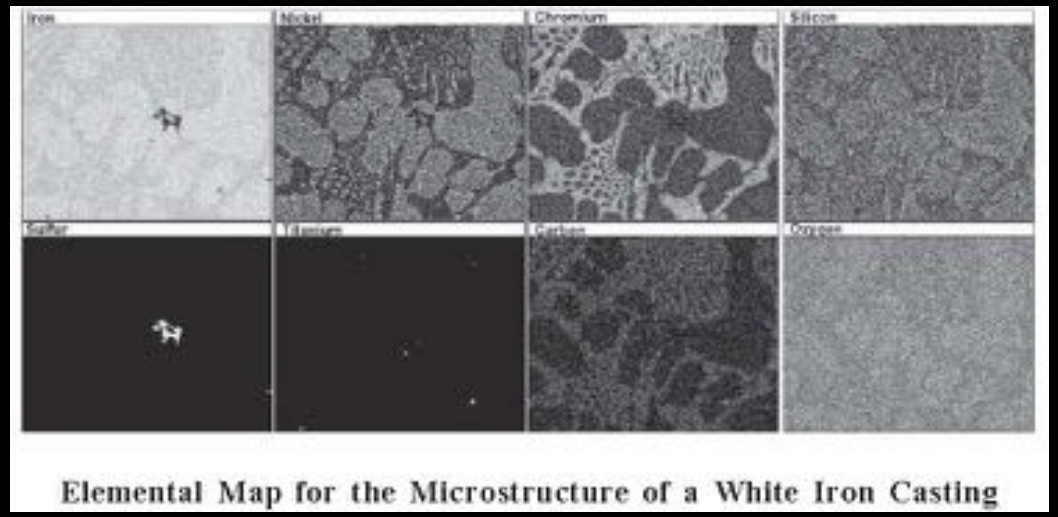
Diffraction scanning , e.g., for strain



Steuwer et al., 2004

Chemical mapping

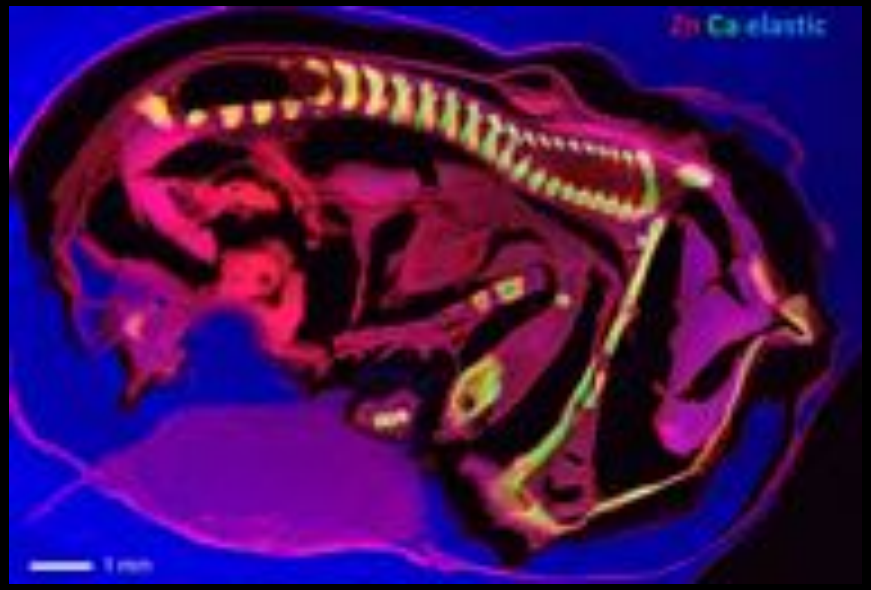
Energy dispersive imaging



Elemental Map for the Microstructure of a White Iron Casting

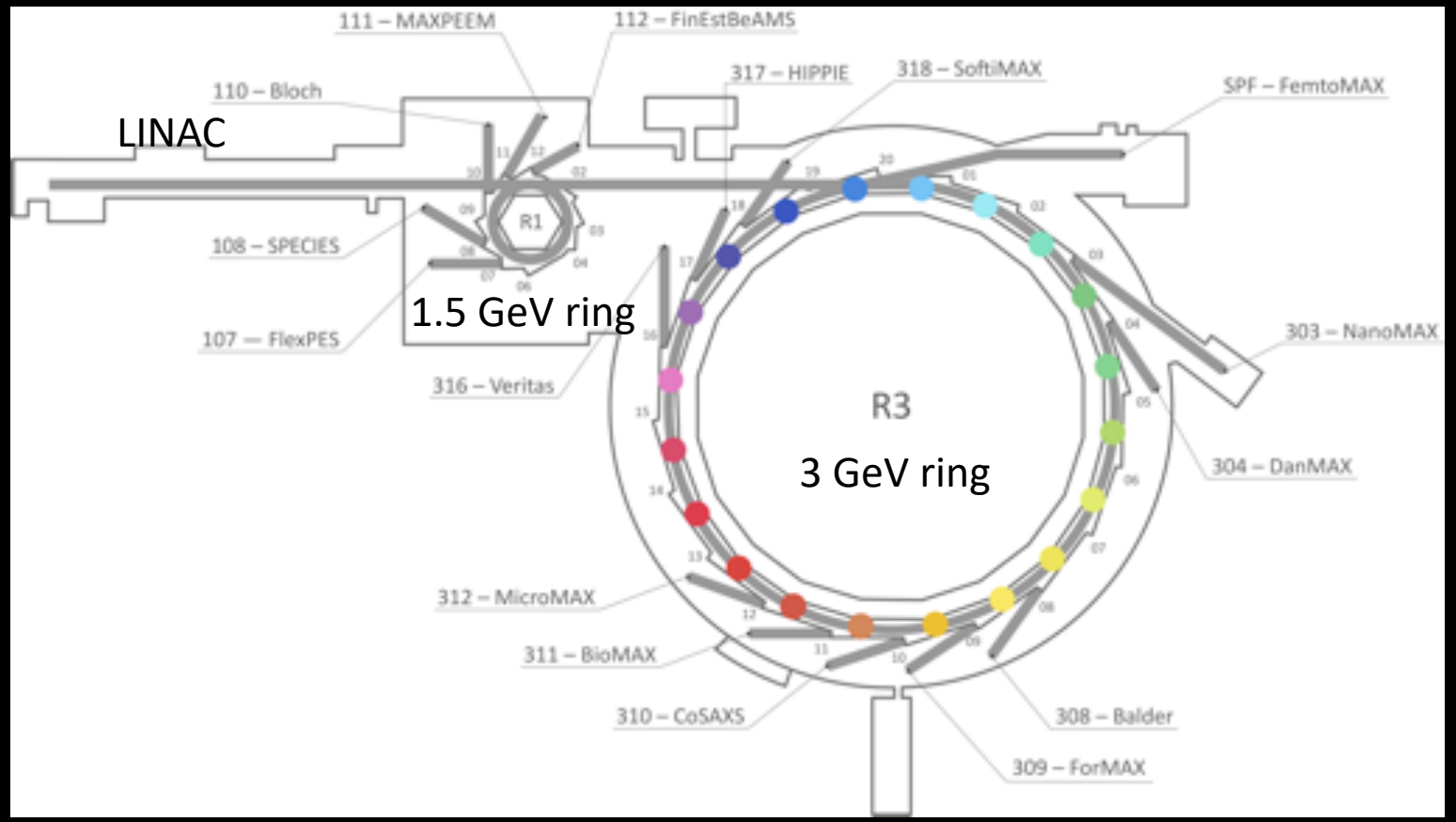
Energy dispersive x-ray spectroscopy
http://mee-inc.com/eds.html

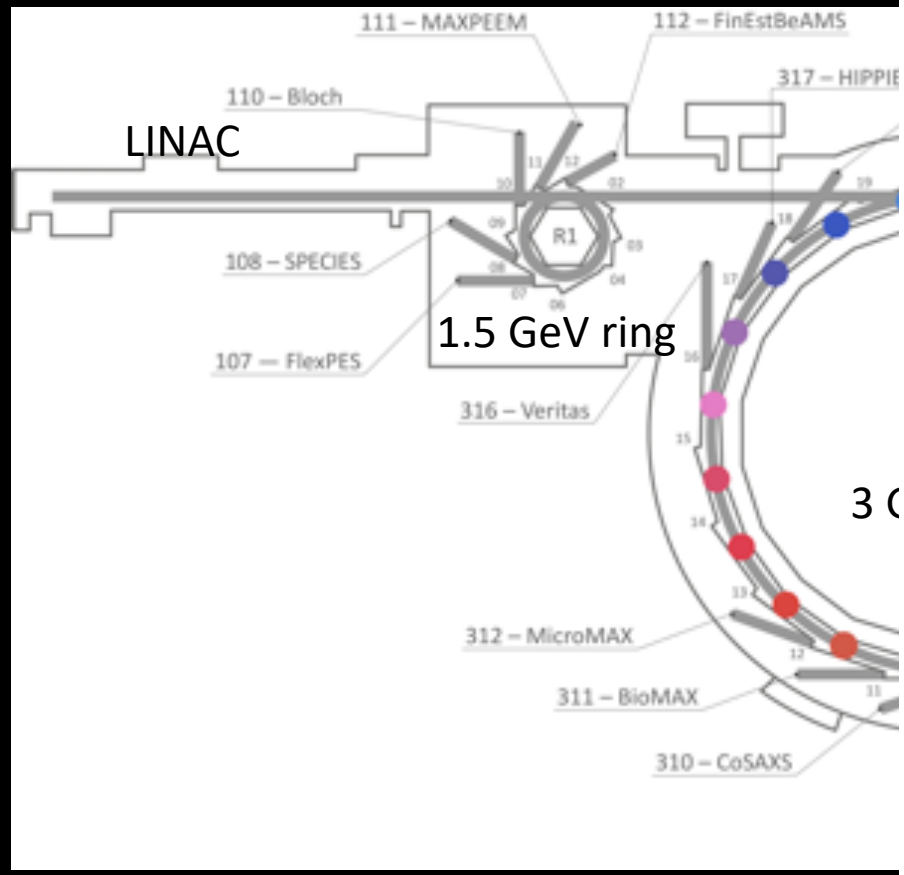
X-ray Fluorescence



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


111 – MAXPEEM
112 – FinEstBeAMS
317 – HIPPIE
318 – SoftiMAX
SPF – FemtoMAX
110 – Bloch
LINAC
R1
108 – SPECIES
1.5 GeV ring
107 – FlexPES
316 – Veritas
303 – NanoMAX
R3
3 GeV ring
304 – DanMAX
312 – MicroMAX
311 – BioMAX
310 – CoSAXS
308 – Balder
309 – ForMAX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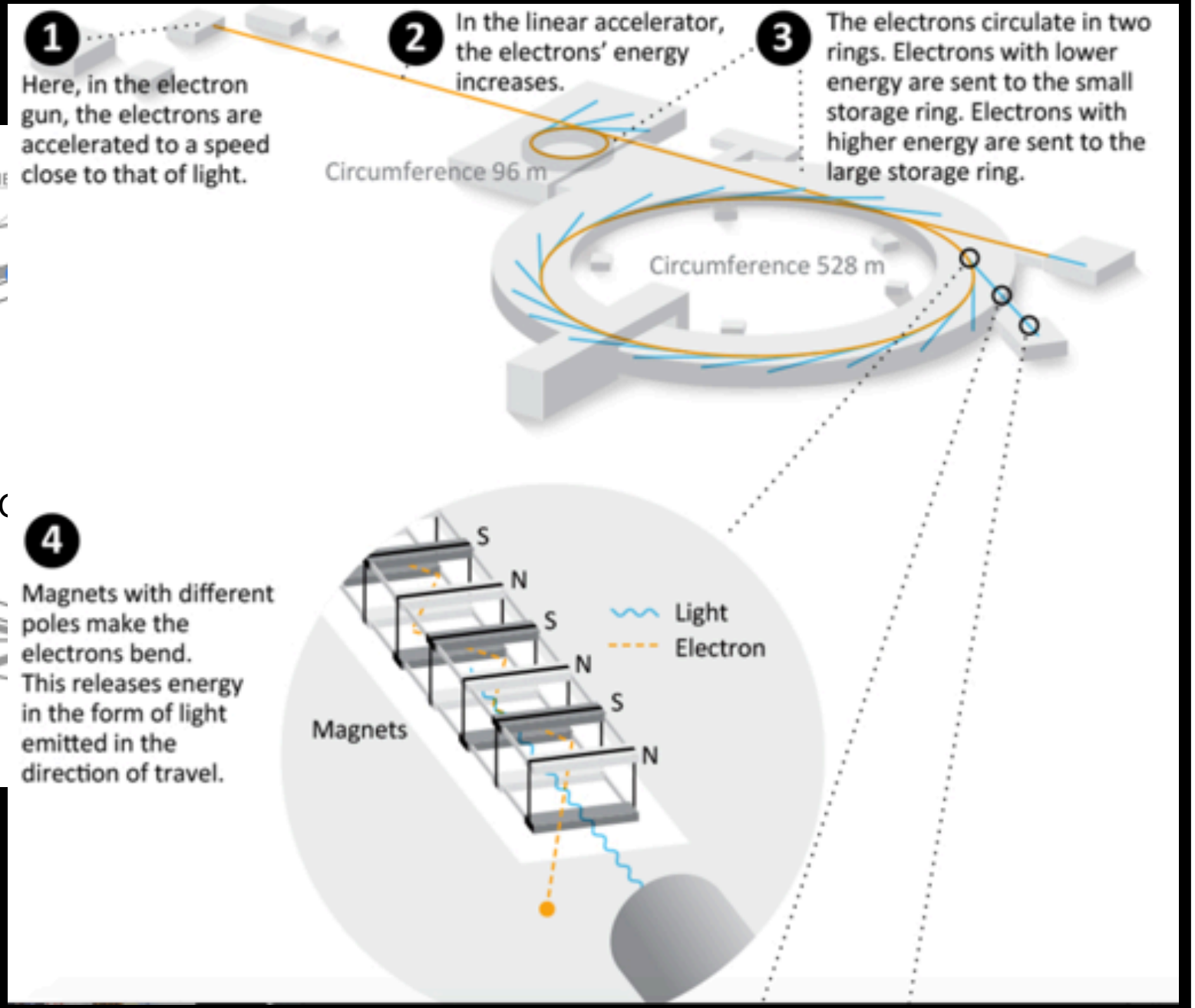
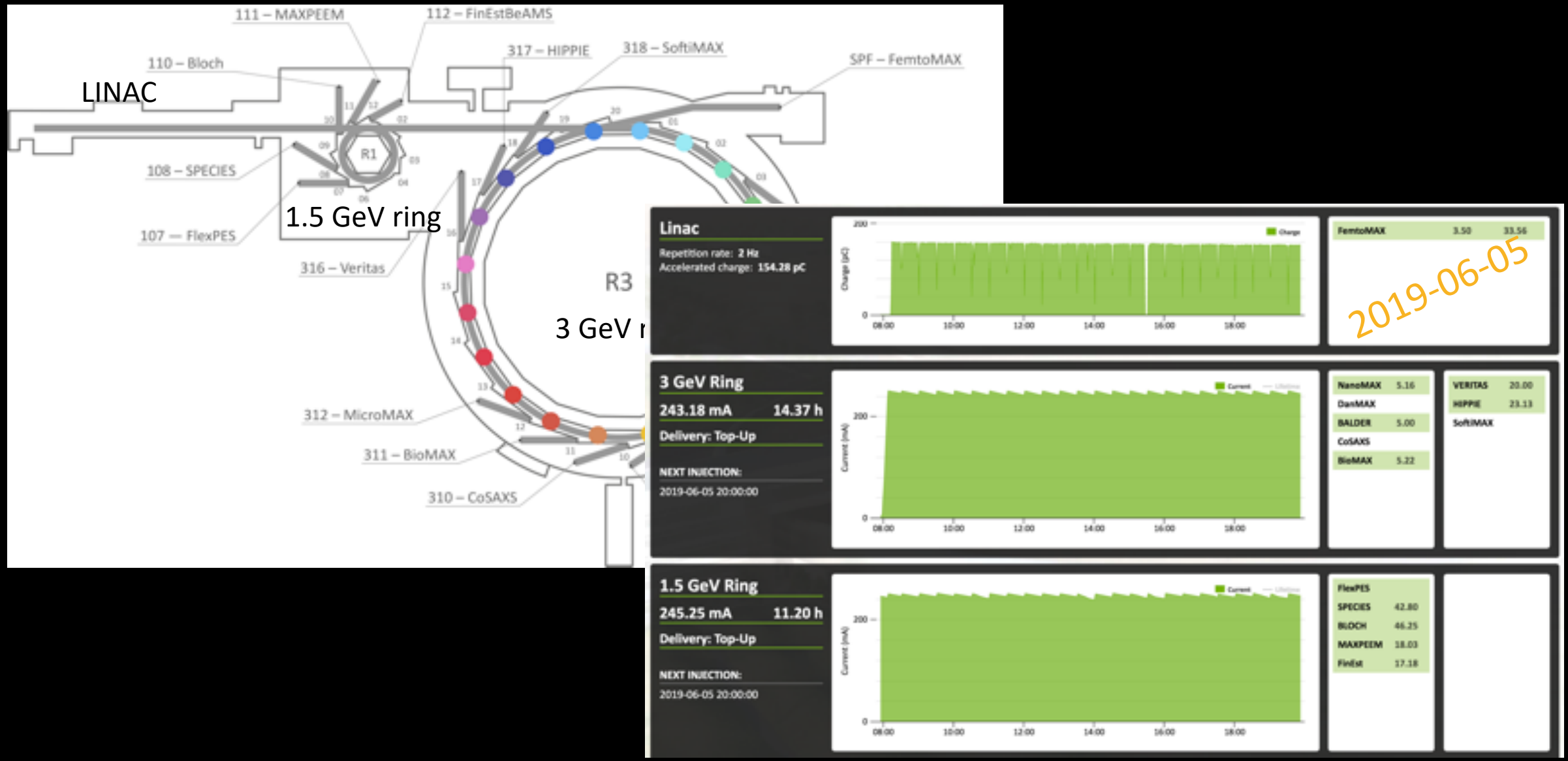

1
Here, in the electron gun, the electrons are accelerated to a speed close to that of light.
2
In the linear accelerator, the electrons' energy increases.
3
The electrons circulate in two rings. Electrons with lower energy are sent to the small storage ring. Electrons with higher energy are sent to the large storage ring.
Circumference 96 m
Circumference 528 m
4
Magnets with different poles make the electrons bend. This releases energy in the form of light emitted in the direction of travel.
S
N
S
N
S
N
Magnets
Light
Electron

New milestone:
11 beamlines taking light simultaneously



A. MAX IV beamlines (May 2019)

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

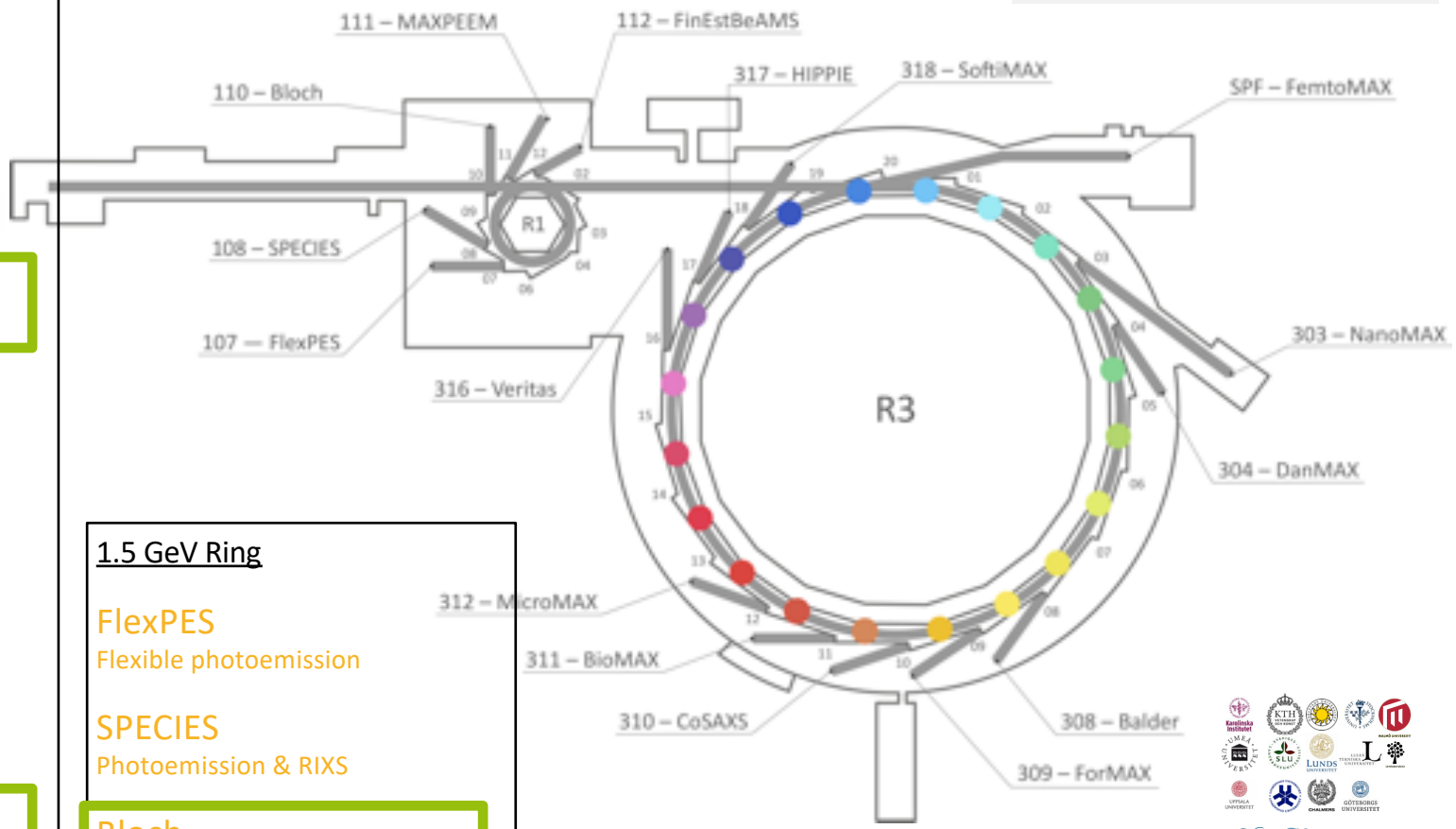
BioMAX
Protein structure

MicroMAX
Protein structure

Veritas
Excitations in solids & liquids

HIPPIE
Operando spectroscopy

SoftiMAX
Microscopy & coherence



1.5 GeV Ring

FlexPES
Flexible photoemission

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
transitioning

3.0 GeV Ring

NanoMAX
Nanofocus & coherence

DanMAX
Imaging & diffraction

Balder
EXAFS & RIXS

ForMAX
Wood based material

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SAXS & coherence

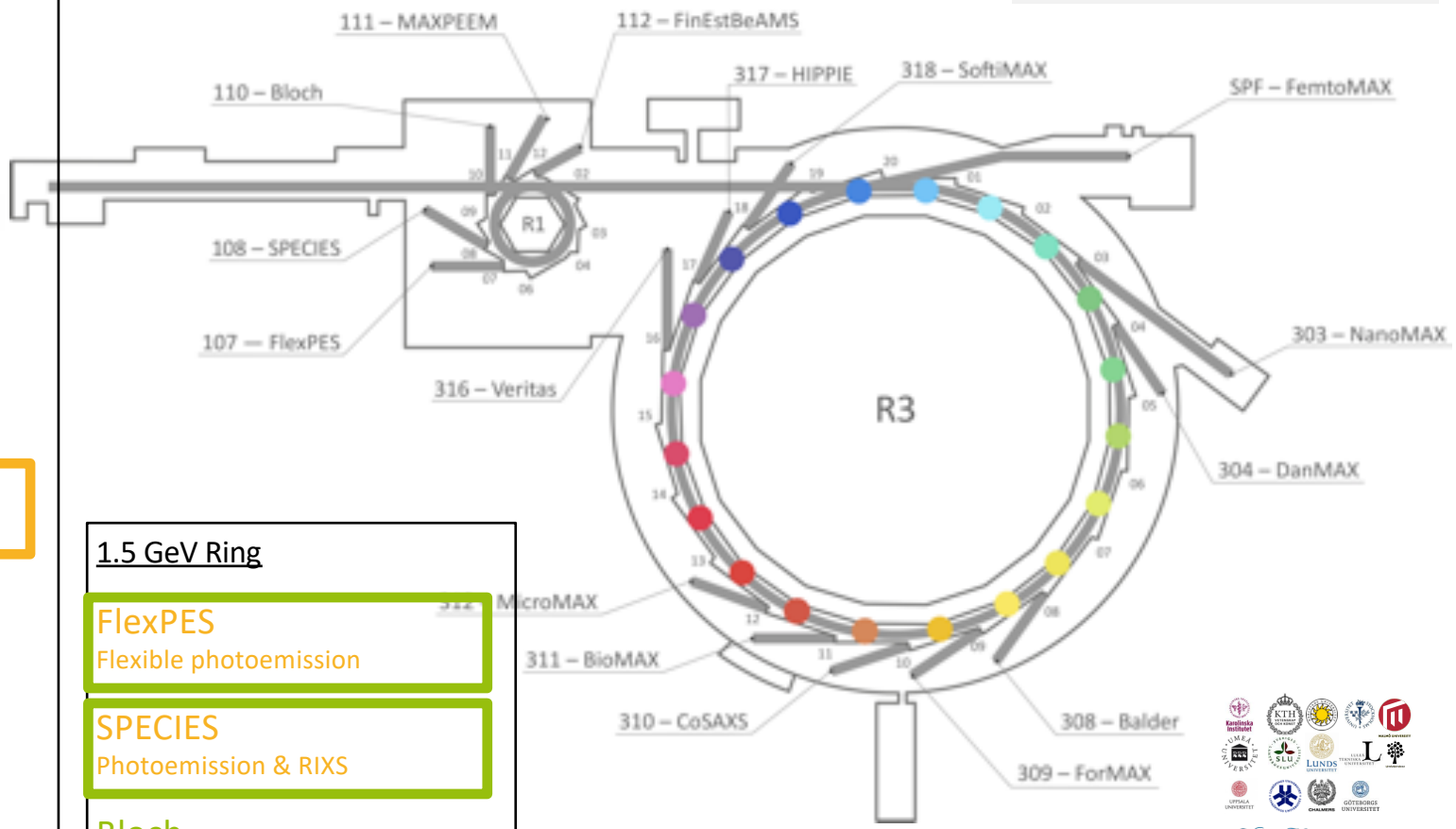
BioMAX
Protein structure

MicroMAX
Protein structure

Veritas
Excitations in solids & liquids

HIPPIE
Operando spectroscopy

SoftiMAX
Microscopy & coherence



1.5 GeV Ring

FlexPES
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Photoemission & RIXS

Bloch
Electronic structure & surfaces

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Microscopy of surfaces

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Gas phase & luminescence

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Ultrafast diffraction & spectroscopy

A. MAX IV beamlines (Feb 2020)

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Construction
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3.0 GeV Ring

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Nanofocus & coherence

DanMAX
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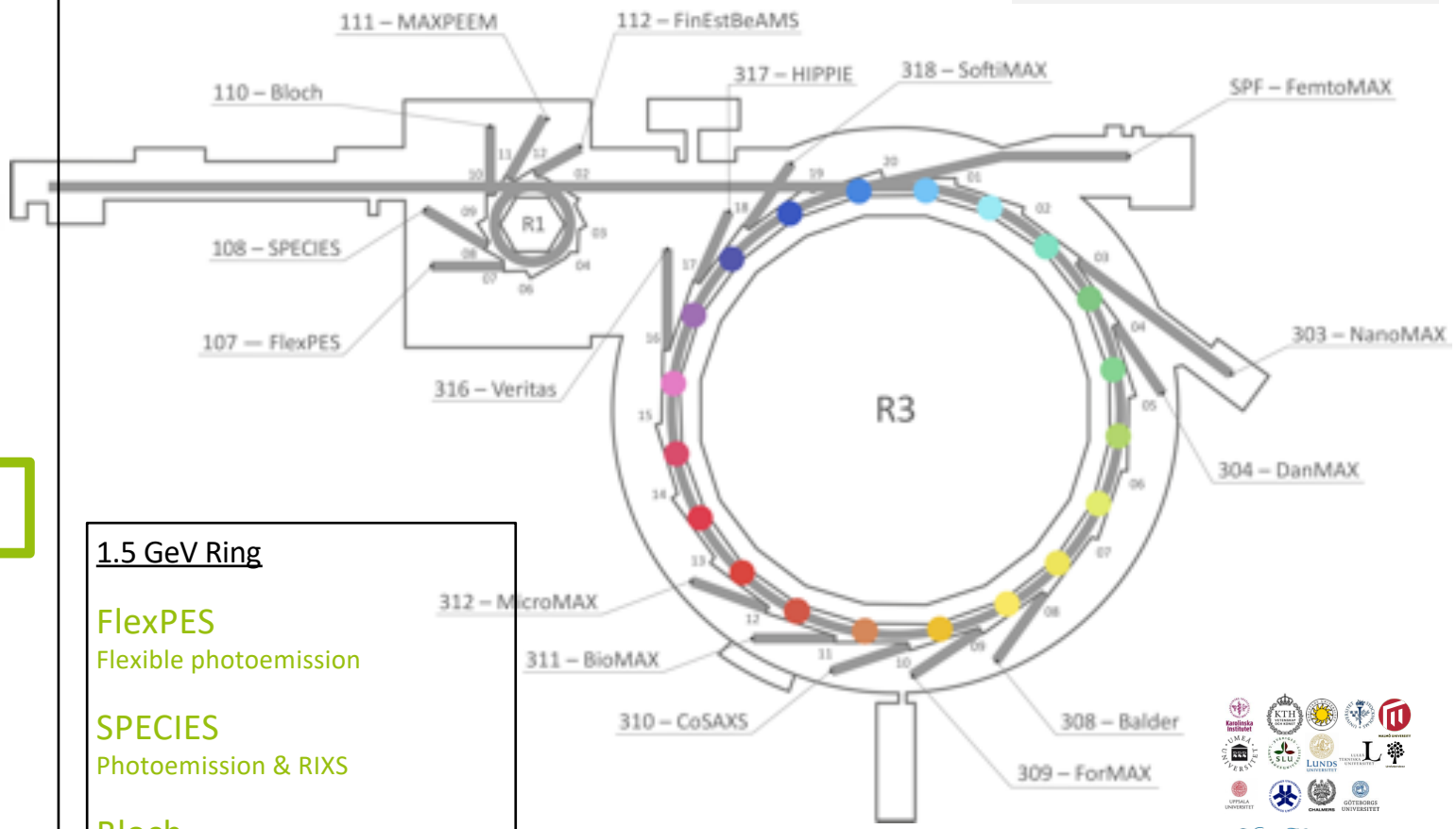

1.5 GeV Ring

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Flexible photoemission

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Photoemission & RIXS

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Electronic structure & surfaces

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Microscopy of surfaces

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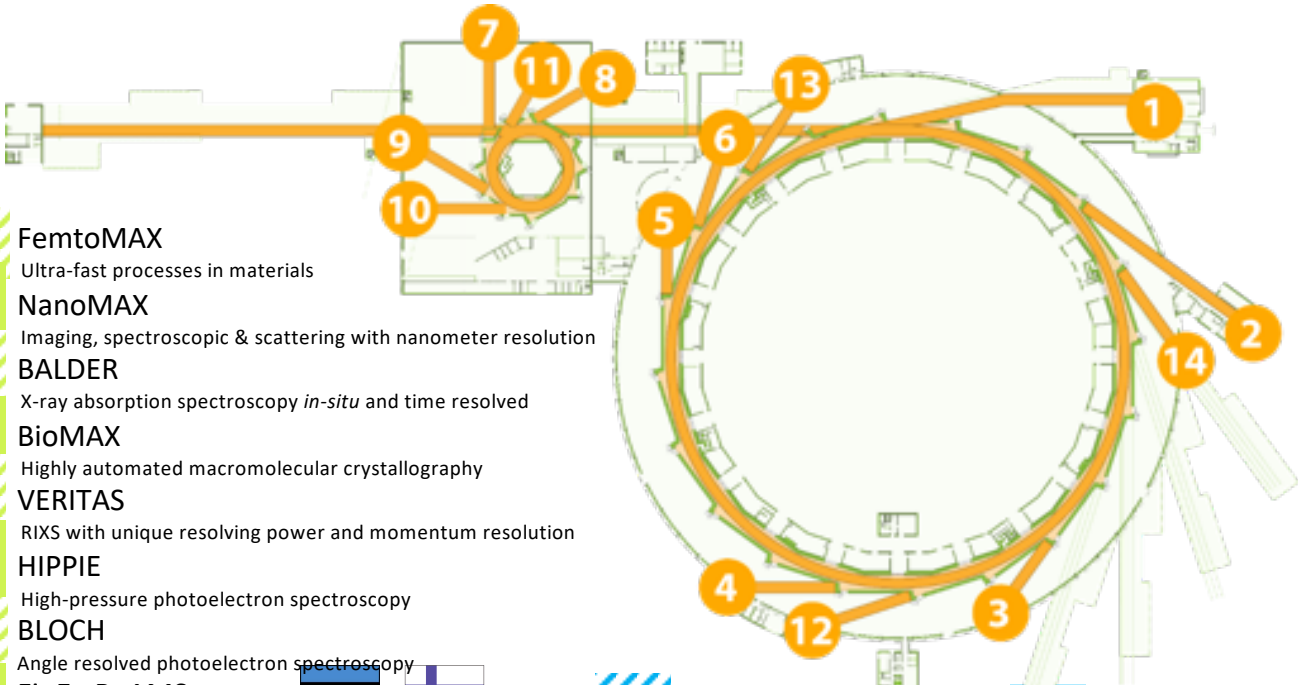
Gas phase & luminescence

LINAC

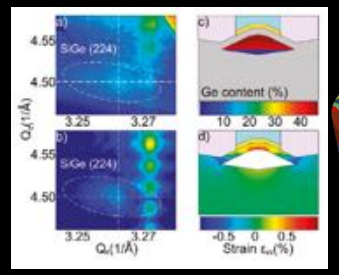
FemtoMAX
Ultrafast diffraction & spectroscopy

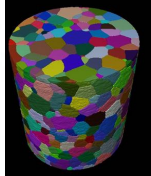
The 16 funded Beamlines



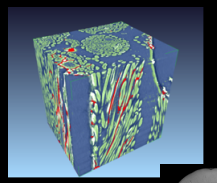
1. FemtoMAX
   Ultra-fast processes in materials
2. NanoMAX
   Imaging, spectroscopic & scattering with nanometer resolution
3. BALDER
   X-ray absorption spectroscopy *in-situ* and time resolved
4. BioMAX
   Highly automated macromolecular crystallography
5. VERITAS
   RIXS with unique resolving power 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

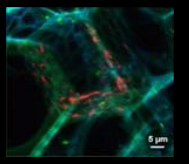
General Users
Endstation installation
Design
Commissioning
Infrastrukture / Optics installation

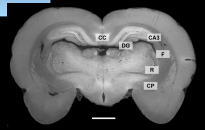




Geometrical or electronic structure or chemical composition







Imaging

NanoMAX

SoftiMAX

MAXPEEM

DanMAX

ForMAX

Scattering & Diffraction

BioMAX

CoSAXS

MicroMAX

FemtoMAX

BALDER

Spectroscopy

HIPPIE

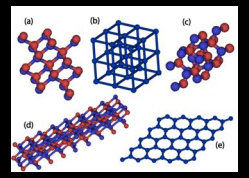
VERITAS

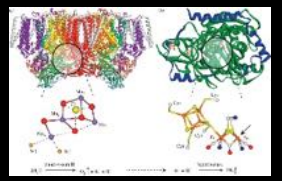
ARPES

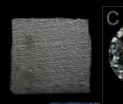
SPECIES

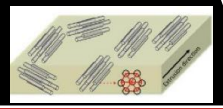
FLEXPES

FinEstBeams

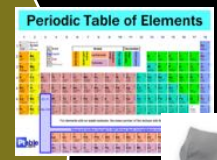


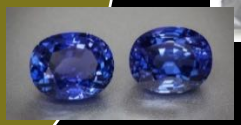






Geometrical structure to atomic resolution





Electronic structure

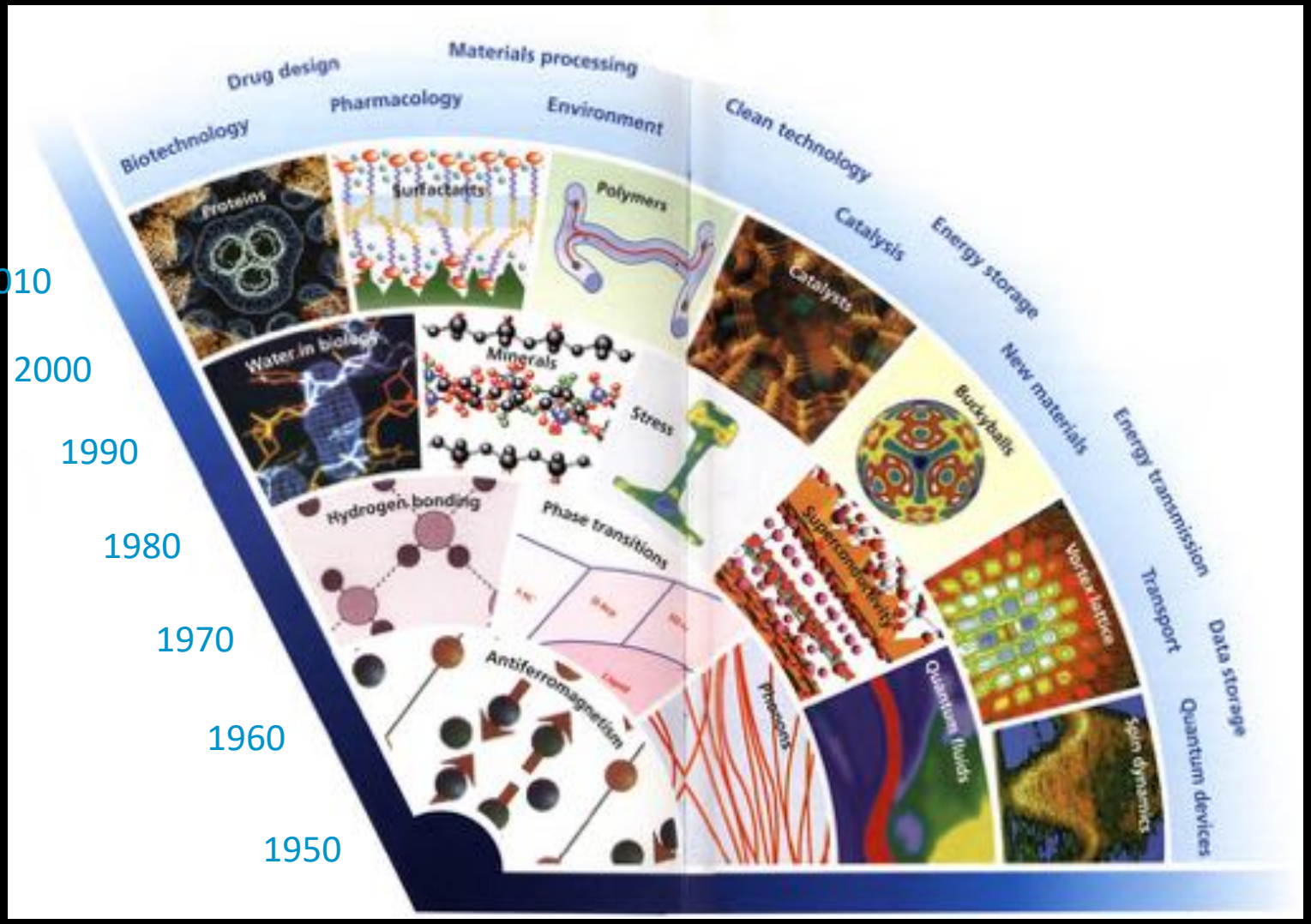
News from MAXIV…

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

Evolution of neutron science



Source: ISIS target station 2 science case

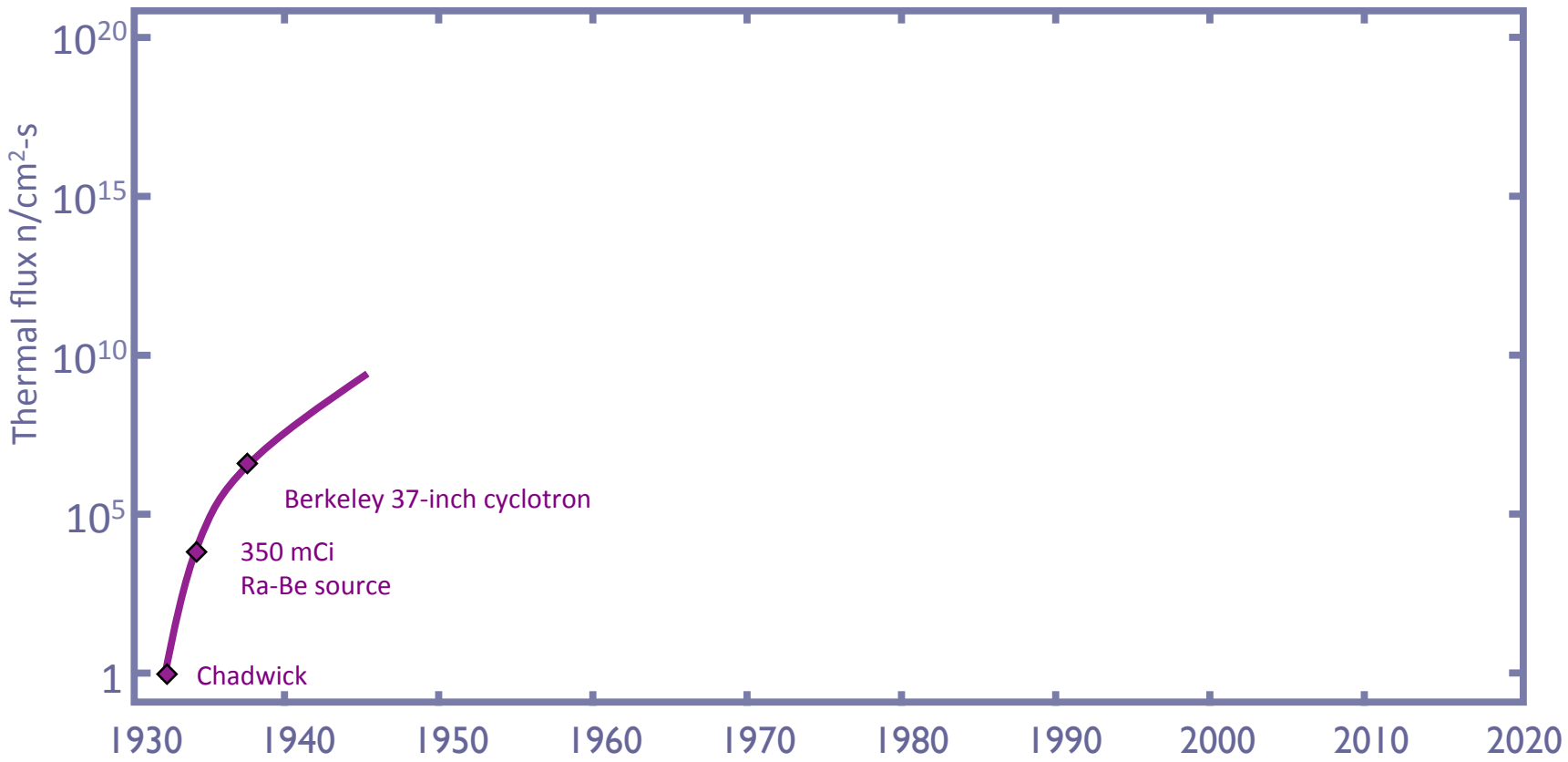
See also: https://europeanspallationsource.se/science-using-neutrons

James Chadwick:
used Polonium as alpha emitter on Beryllium

$^{4}He + {}^{9}Be \rightarrow {}^{12}C + neutron$

(slide courtesy of P. Deen, ESS)

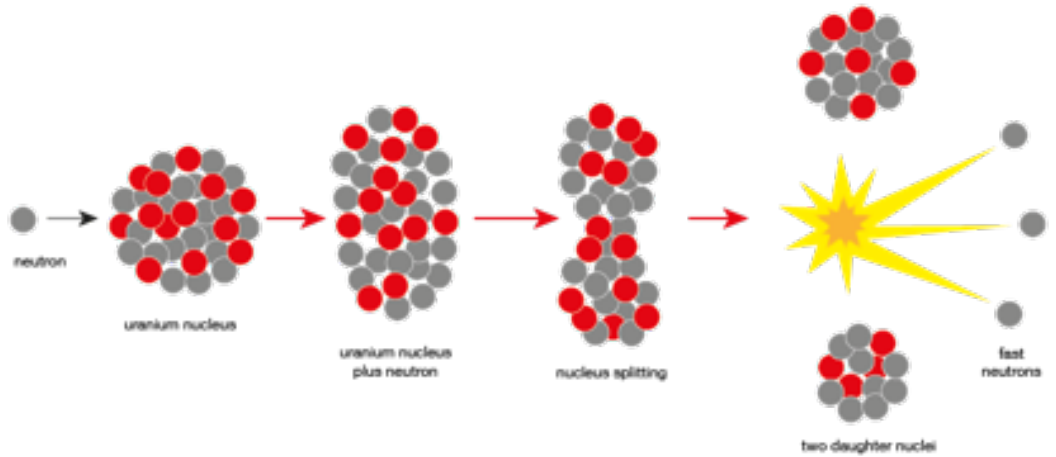
First Neutron Source



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

(slide courtesy of P. Deen, ESS)

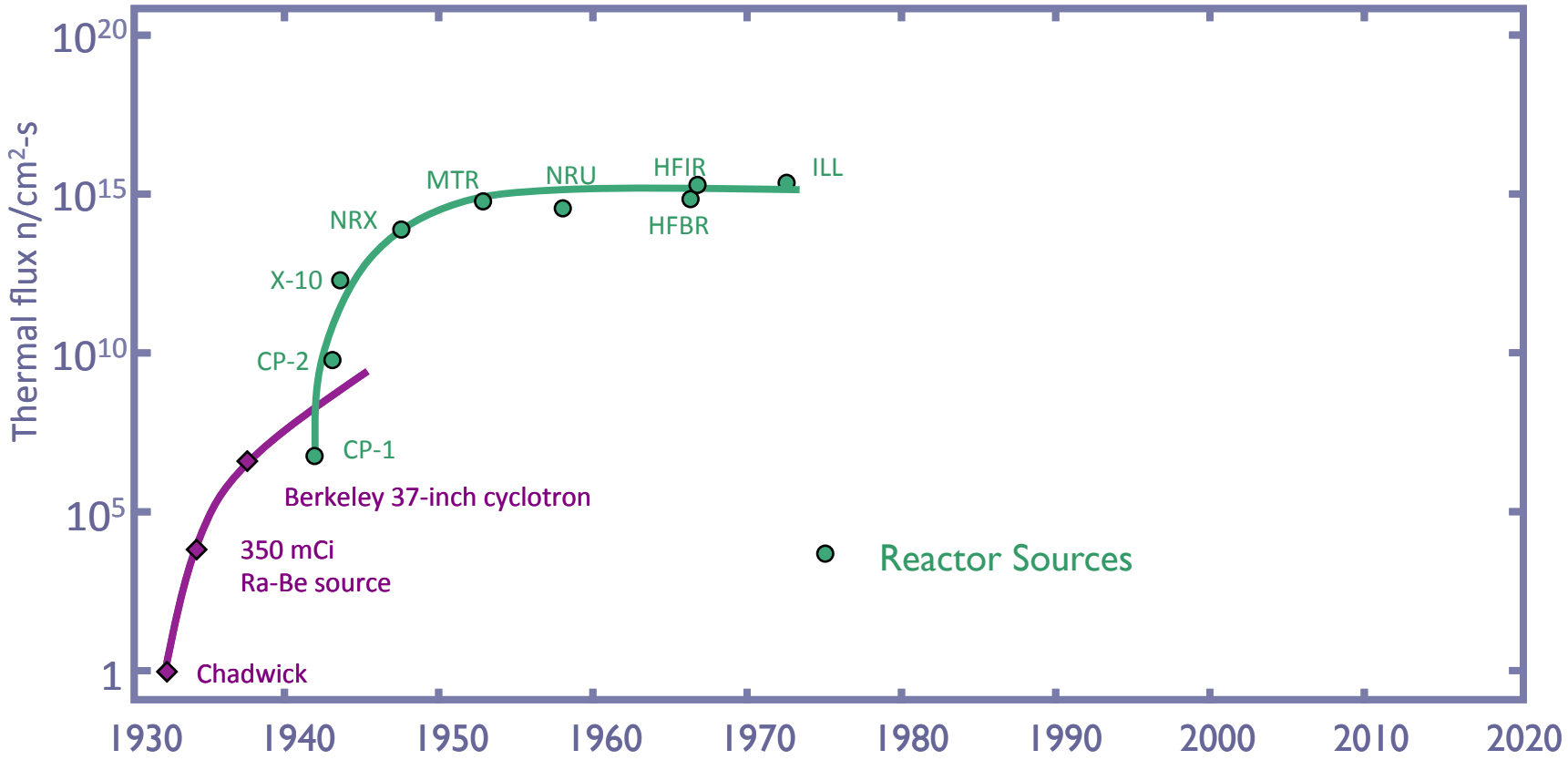
Neutron fission



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

(slide courtesy of P. Deen, ESS)

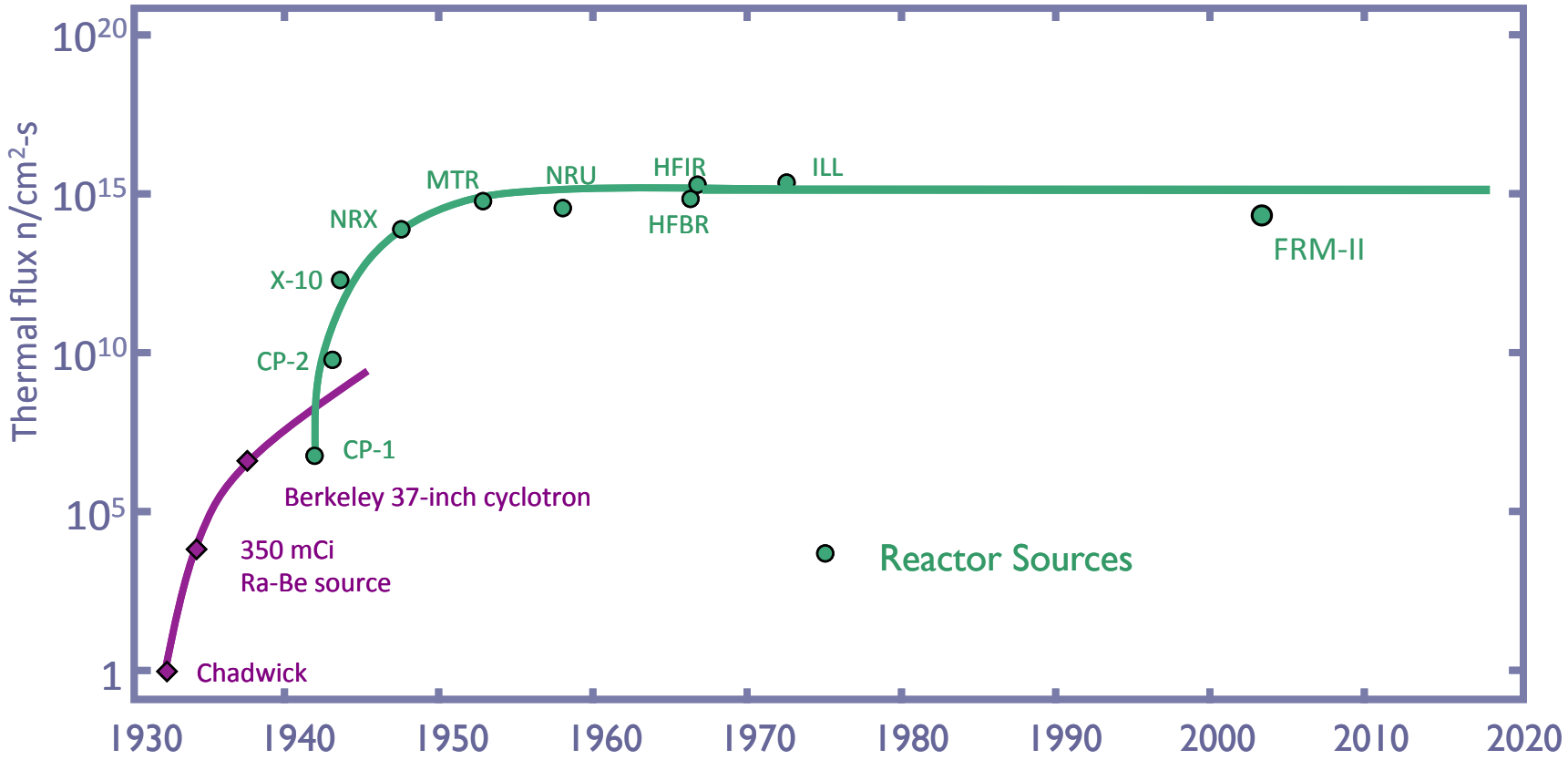
Evolution of neutron sources



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

(slide courtesy of P. Deen, ESS)

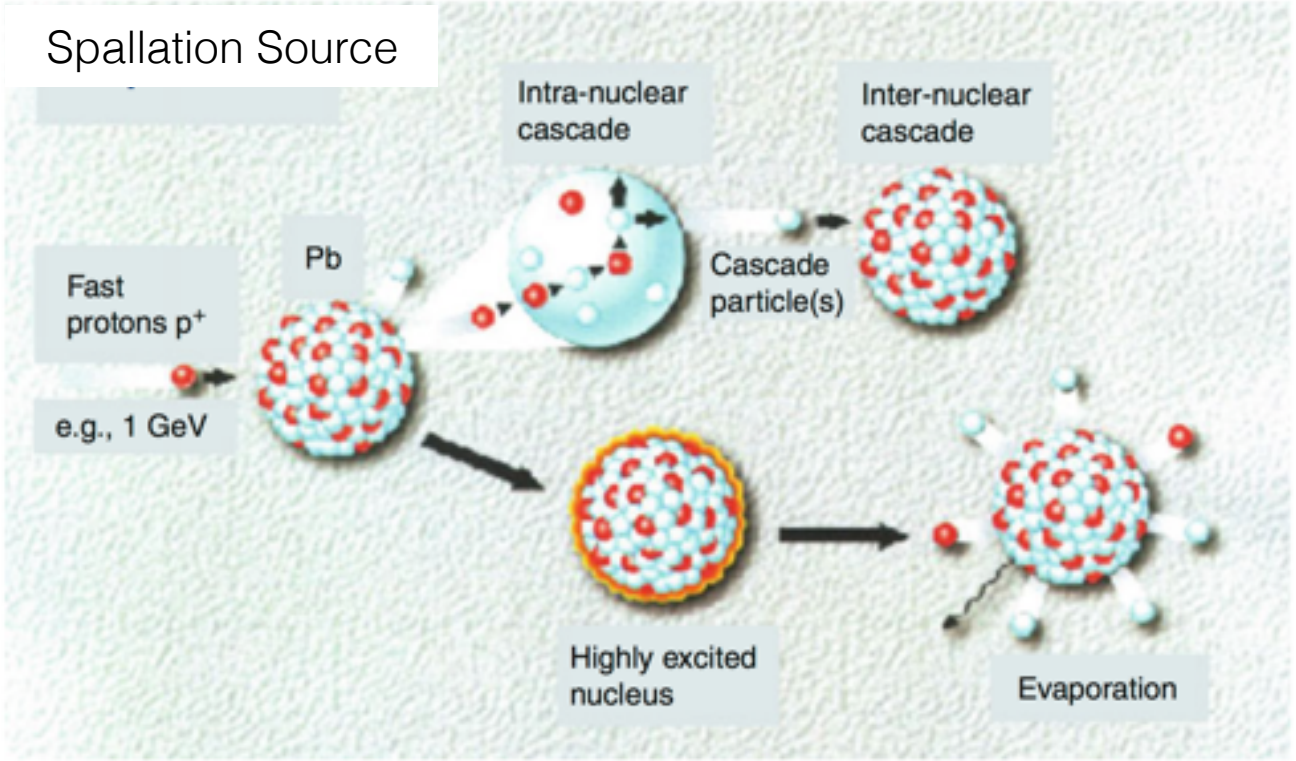
Evolution of neutron sources



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

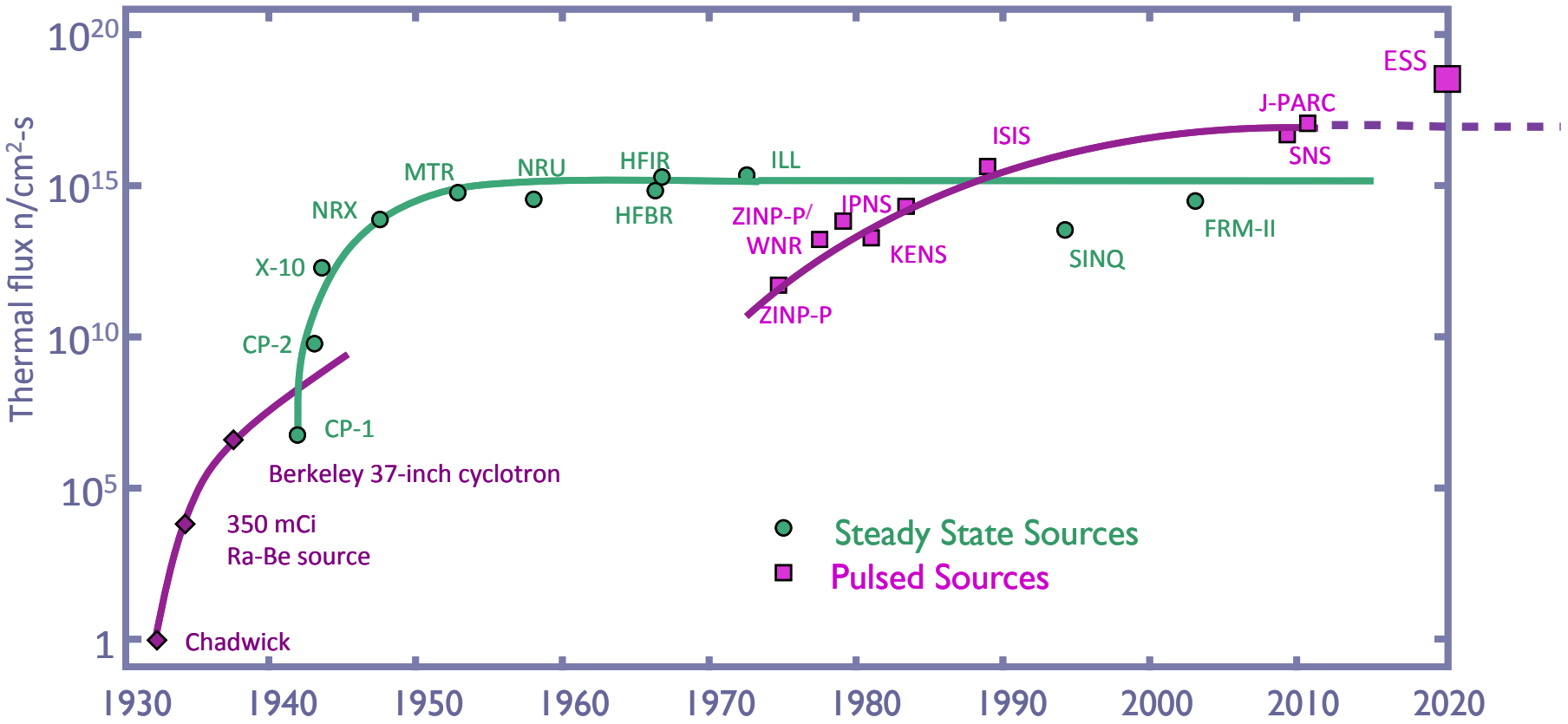
(slide courtesy of P. Deen, ESS)

Spallation



(slide courtesy of P. Deen, ESS)

Evolution of neutron sources



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

(slide courtesy of P. Deen, ESS)

- **Mass**

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

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

  Photon : 0

- **Energy at λ =5Å**

  Neutron: **E=3.3 meV (10^{-3})**

  Electron: E ~ 6 eV

  Photon: E ~2.5 keV **(10^{+3})**

- **Mass**

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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…

	Energy	Wavelength	Velocity
Ultracold neutrons	**E= 300 neV**	**λ=520 Å**	**v=7.6 m/s**
Cold neutrons:	**E= 1meV**	**λ=9.0446 Å**	**v=437 m/s**
	E= 5meV	**λ=4.0449 Å**	**v=978 m/s**
Thermal neutrons:	**E=25meV**	**λ=1.8089 Å**	**v=2187 m/s**
	E=50meV	**λ=1.2791 Å**	**v=3093 m/s**

- **Mass**

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

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

  Photon : 0

- **Energy at λ =5Å**

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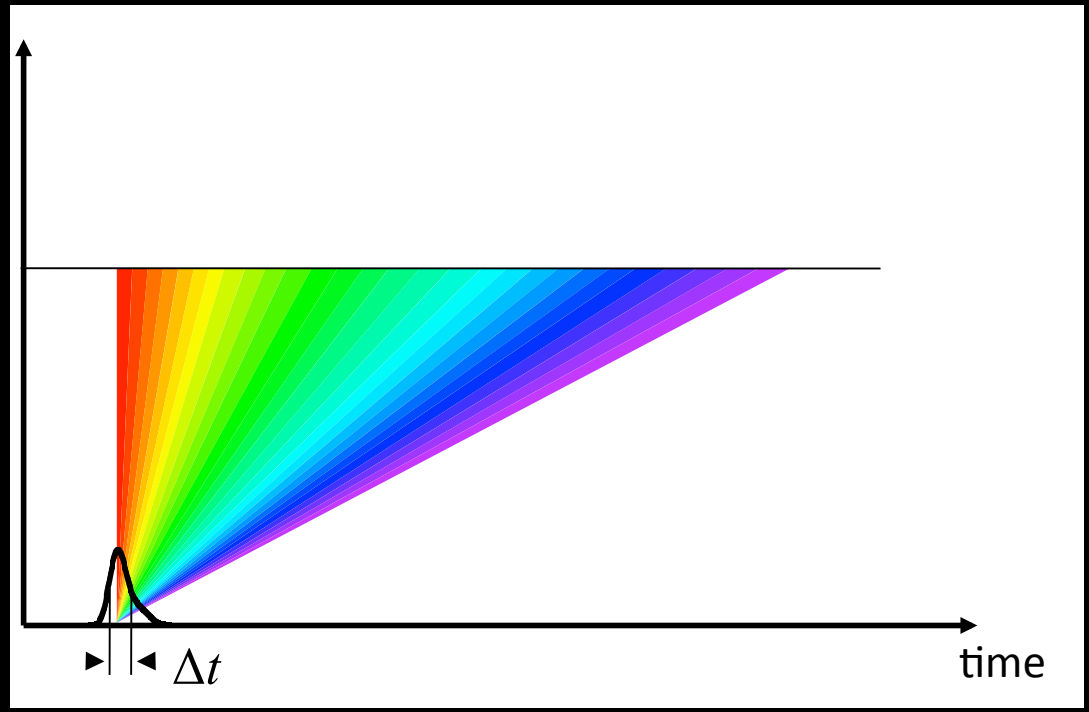
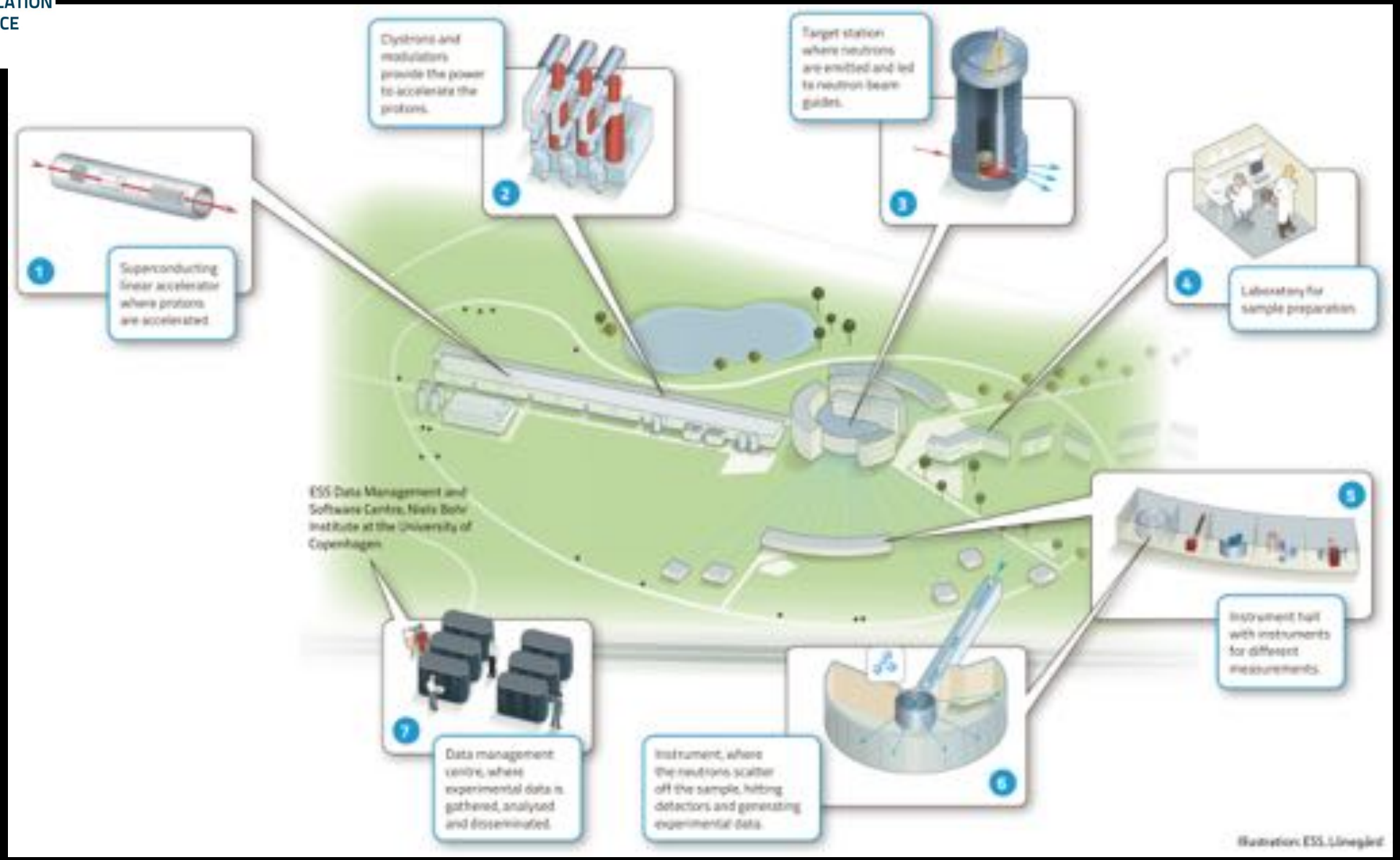
Whilst x-rays travel with the speed of light, neutrons have mass and so have a velocity that depends on their energy…



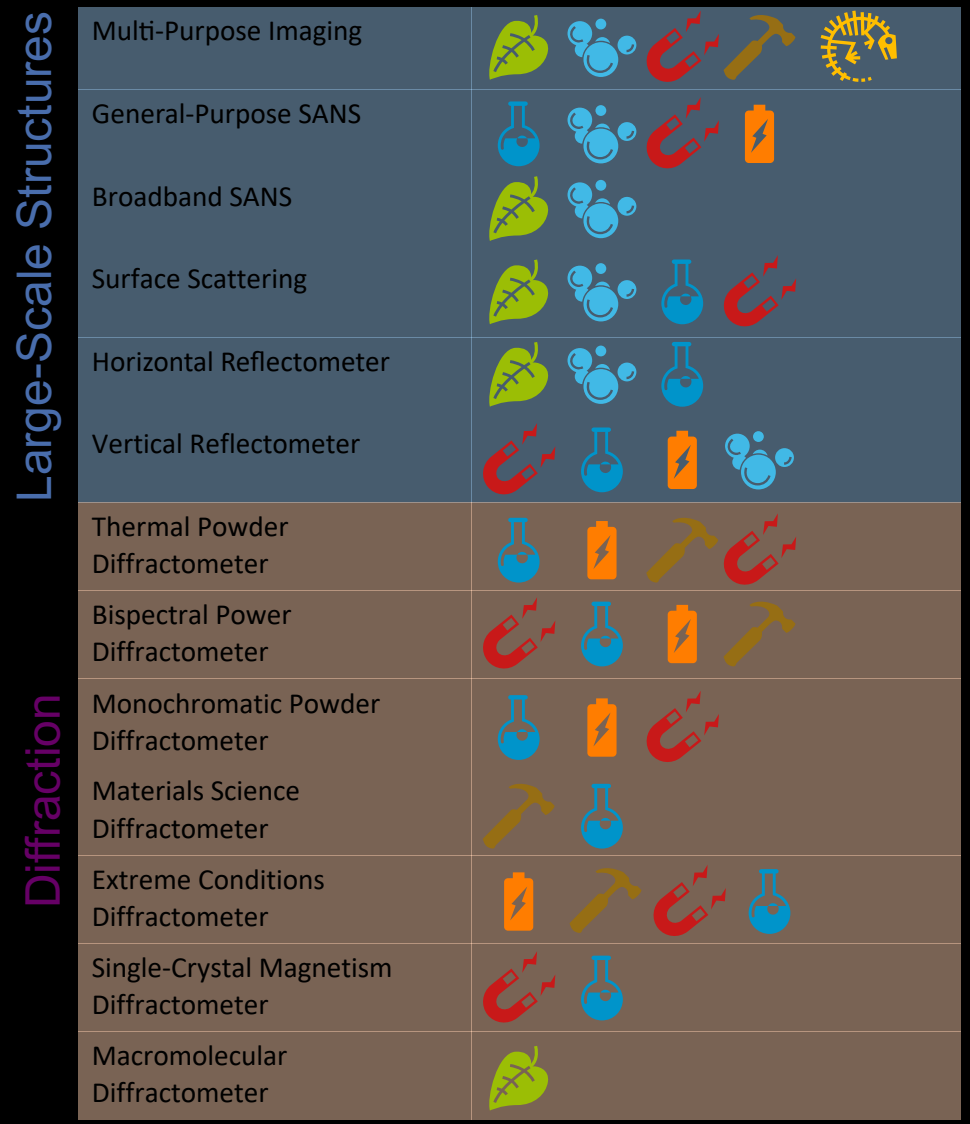
Different velocities can be utilised to look at different wavelengths/energies as a function of time, so–called “time-of-flight” measurements

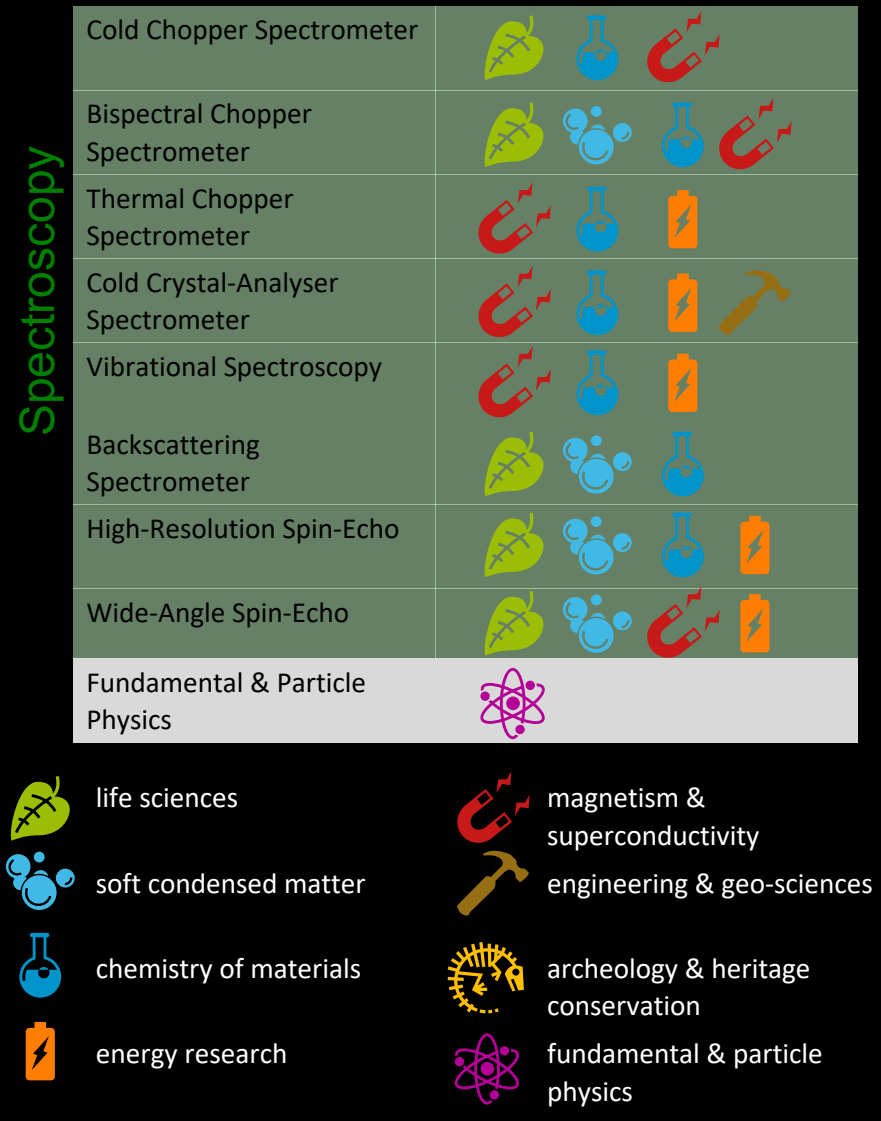
EUROPEAN SPALLATION SOURCE



Check out videos at : https://europeanspallationsource.se/media-bank

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

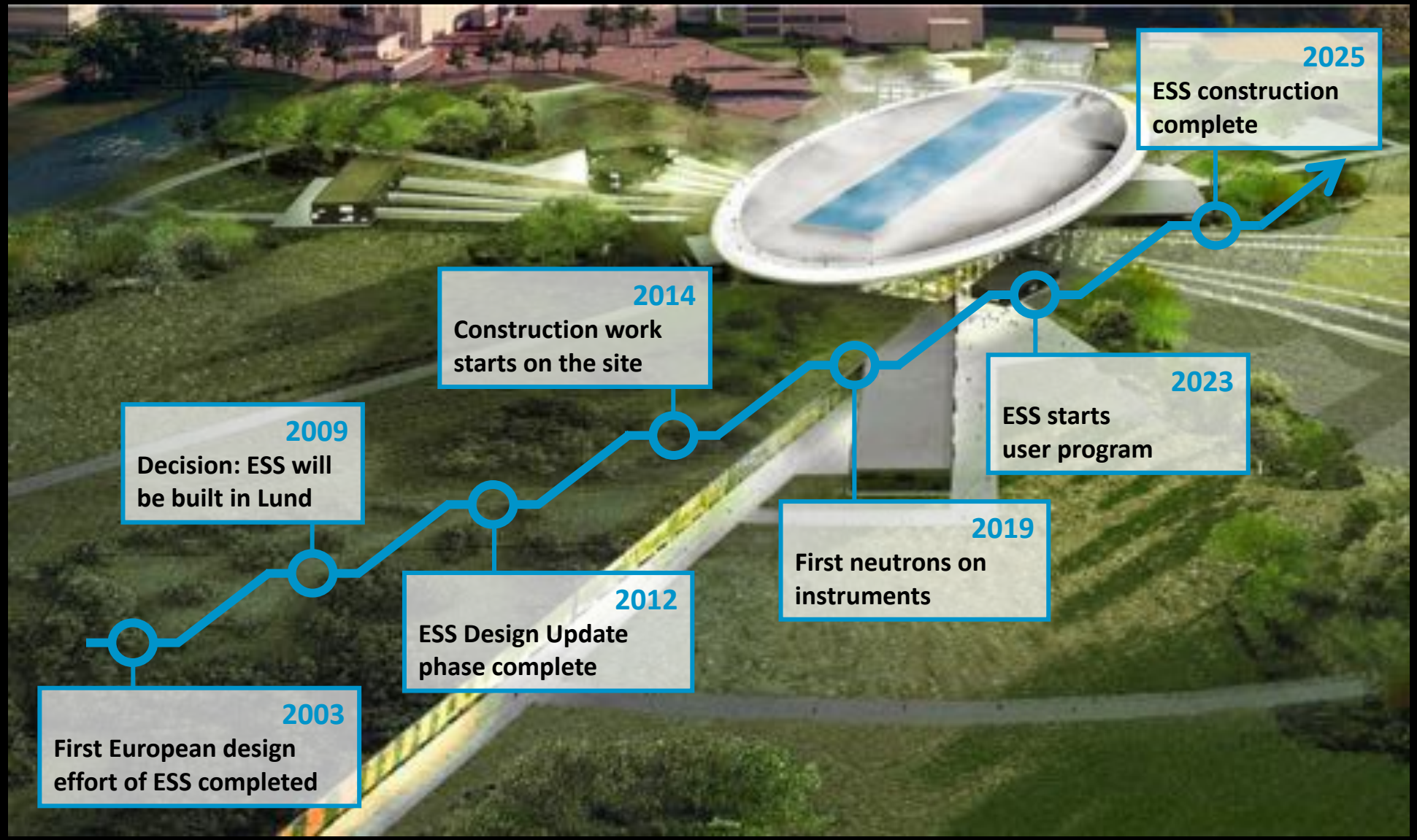




See also: https://europeanspallationsource.se/science-using-neutrons

(from Paul Henry, ESS)

Road to ESS


2003
First European design effort of ESS completed
2009
Decision: ESS will be built in Lund
2012
ESS Design Update phase complete
2014
Construction work starts on the site
2019
First neutrons on instruments
2023
ESS starts user program
2025
ESS construction complete

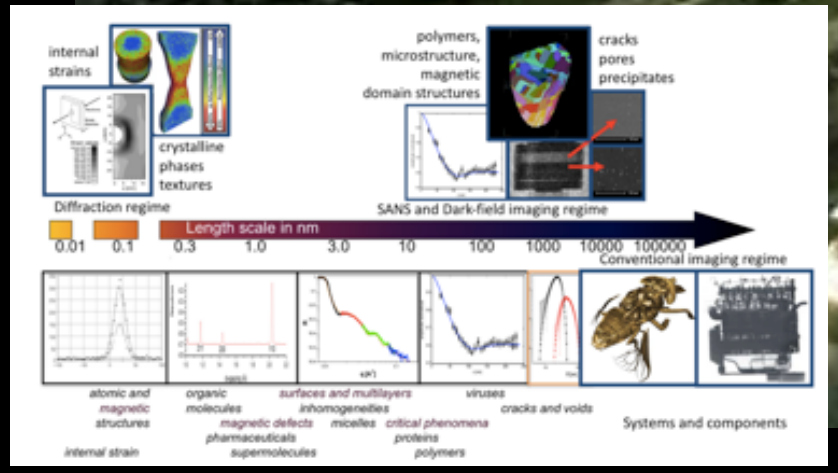

ESS: November 2015
ESS: October 2016
ESS: November 2017
ESS: October 2018
ESS: April 2019
ESS: June 2019

European Spallation Source (ESS)

In 2020+

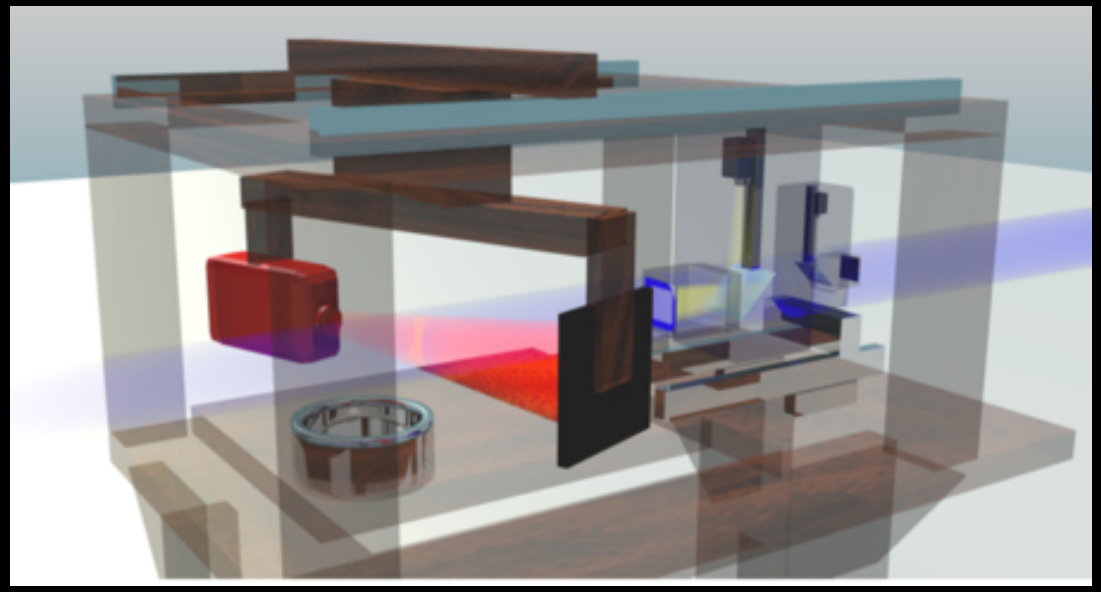
The future’s bright!...

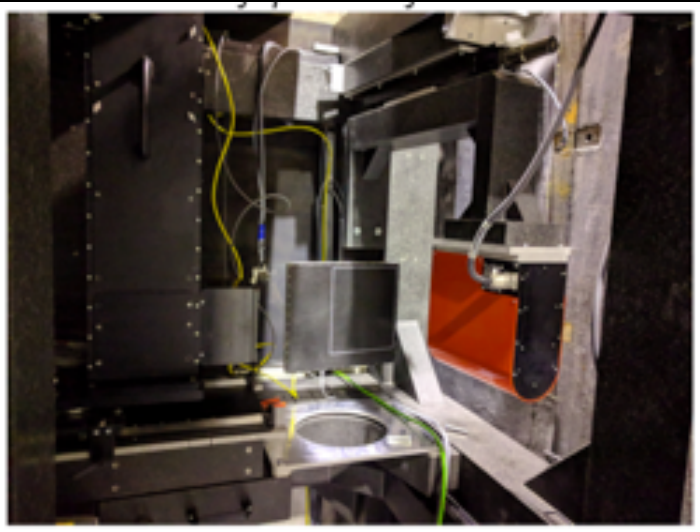
ODIN



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

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



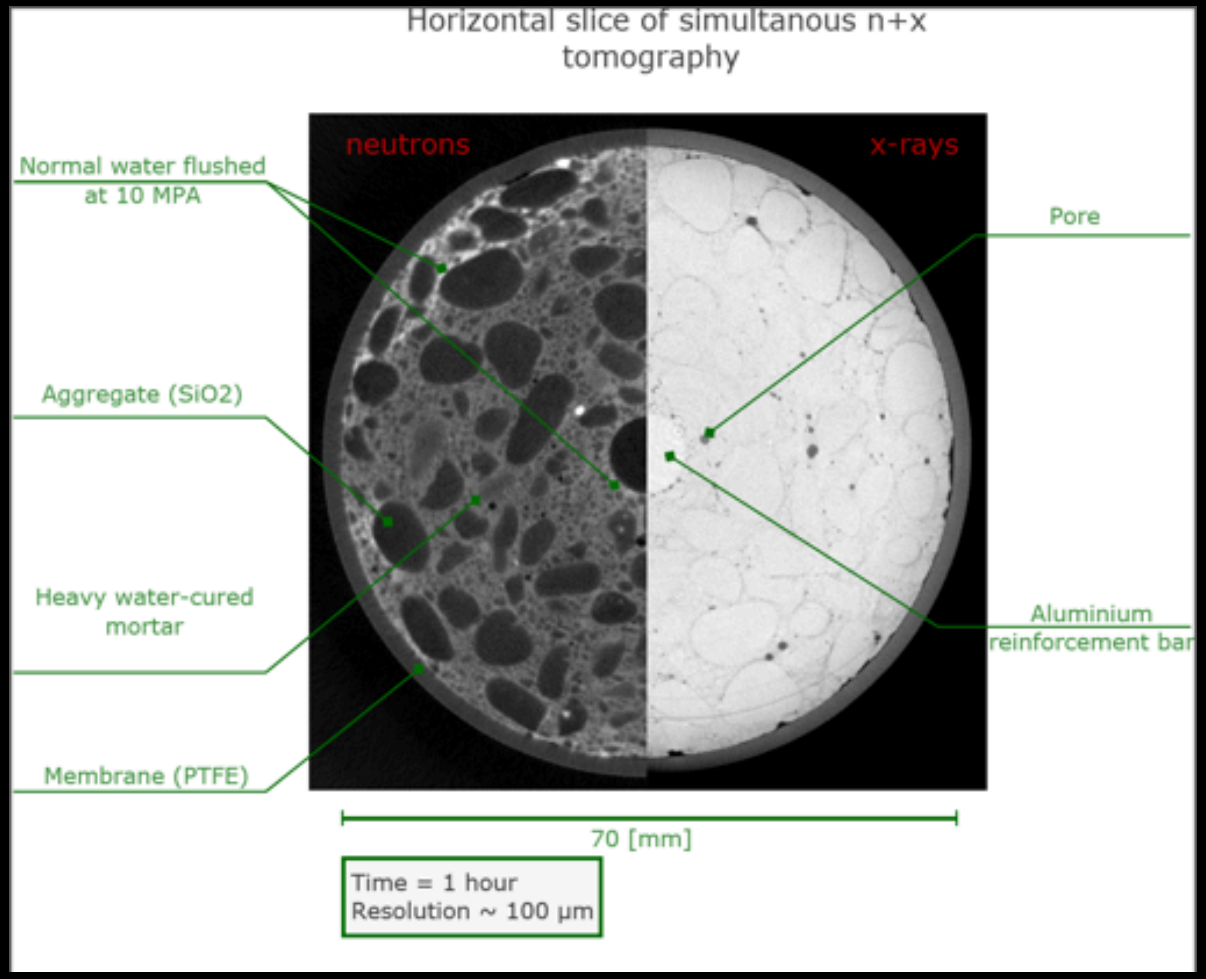


Simultaneous x-ray & neutron tomography

- Microfocus x-ray 75 W, 150 kV
- FOV: 25x30 mm max
- Resolution: down to 5 μm
- Pixels: $\sim$ 2200x1800

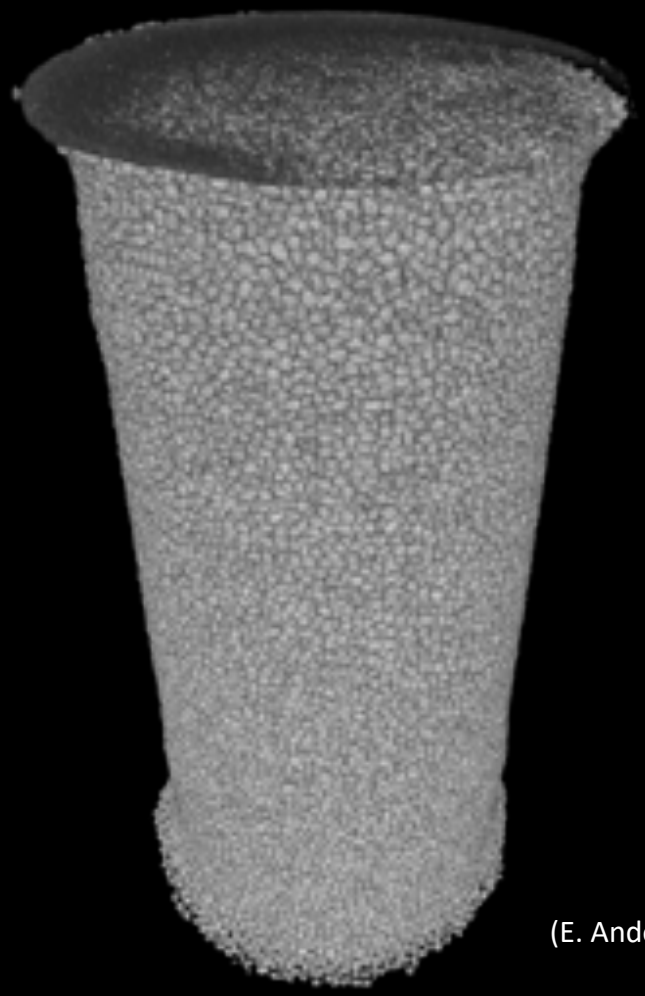
Possible to do simultaneous tomographies down to 10 µm resolution

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…



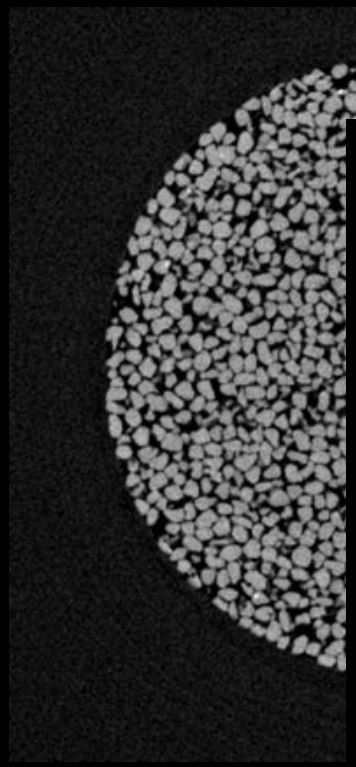
(E. Andò, CNRS Grenoble)

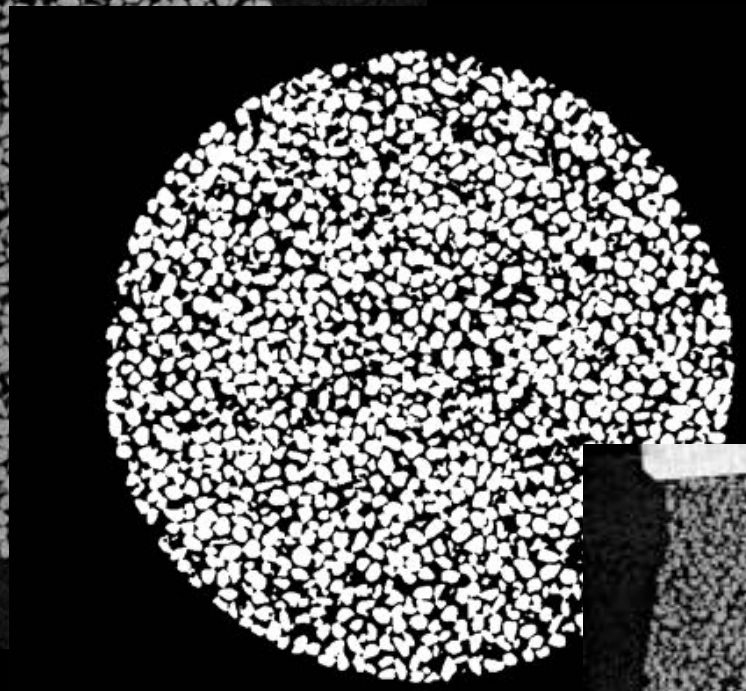
..which are very pretty… but so what!

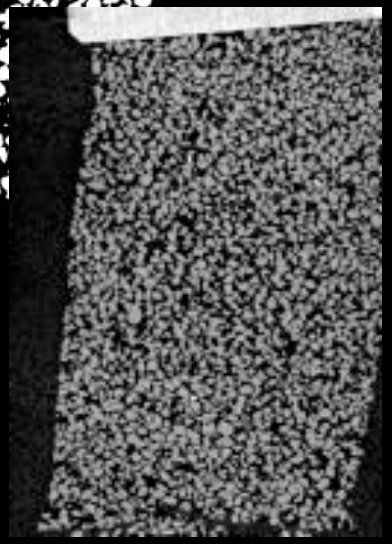
Challenge: *to extract pertinent, quantified information to elucidate properties*

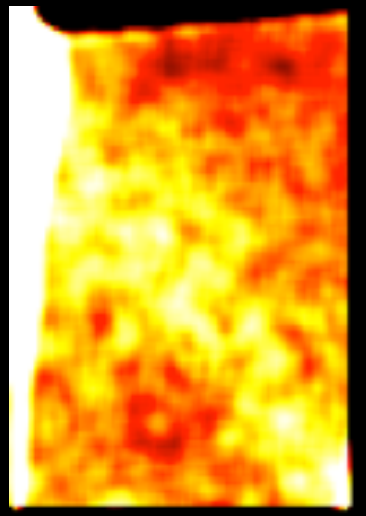
Structural imaging and characterisation: 3D image analysis, e.g.,

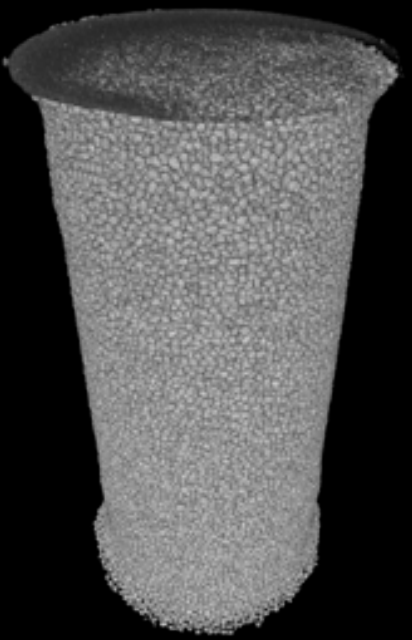
How do we see/identify and characterise microstructure?











"Raw" image

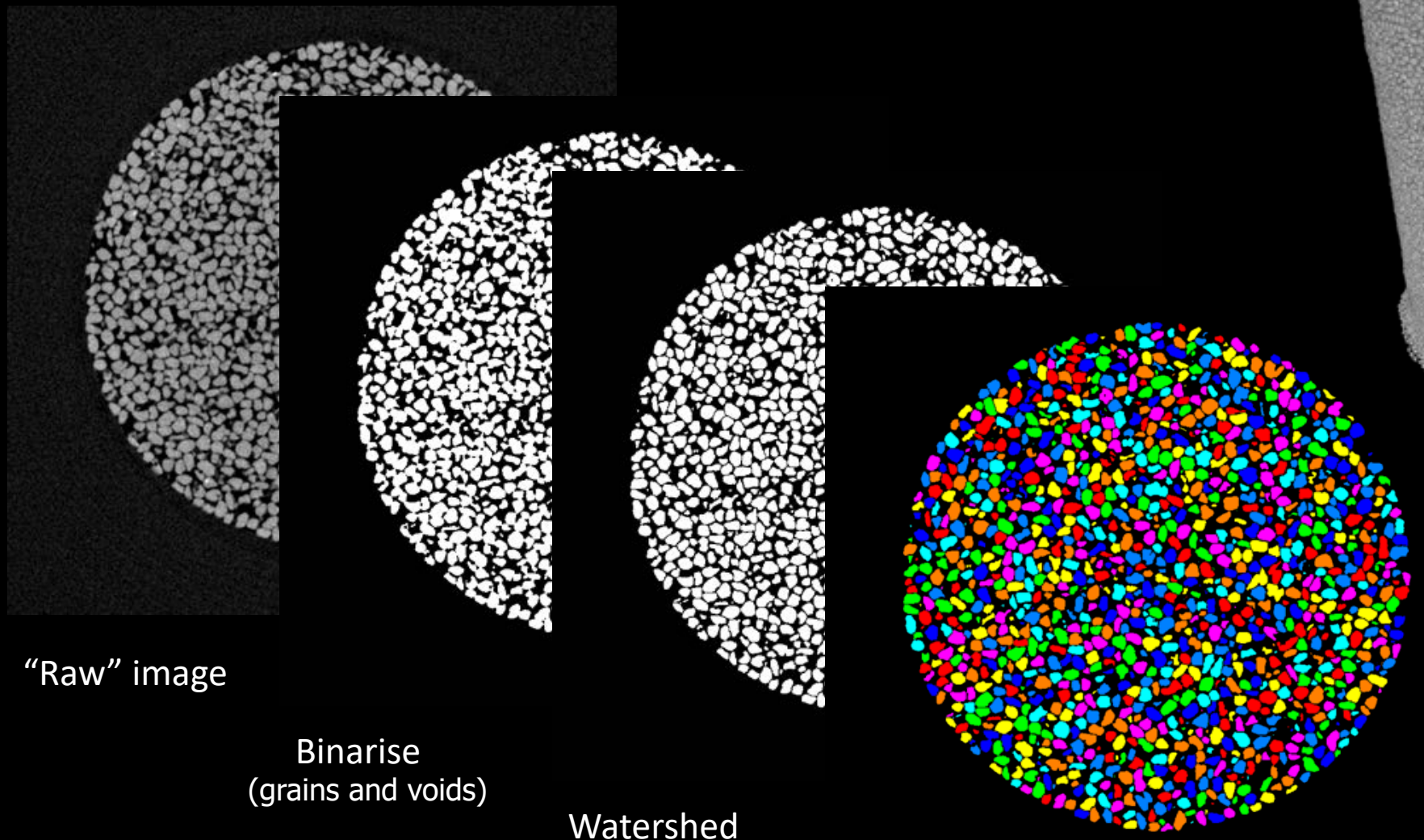
Binarise
(grains and voids)

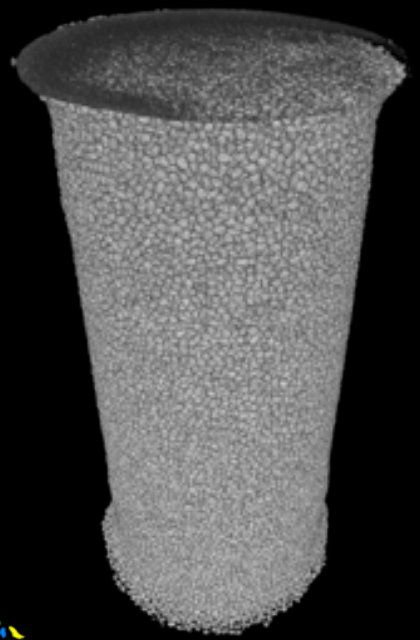
Tomo

Porosity

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

How do we see/identify and characterise microstructure?





"Raw" image

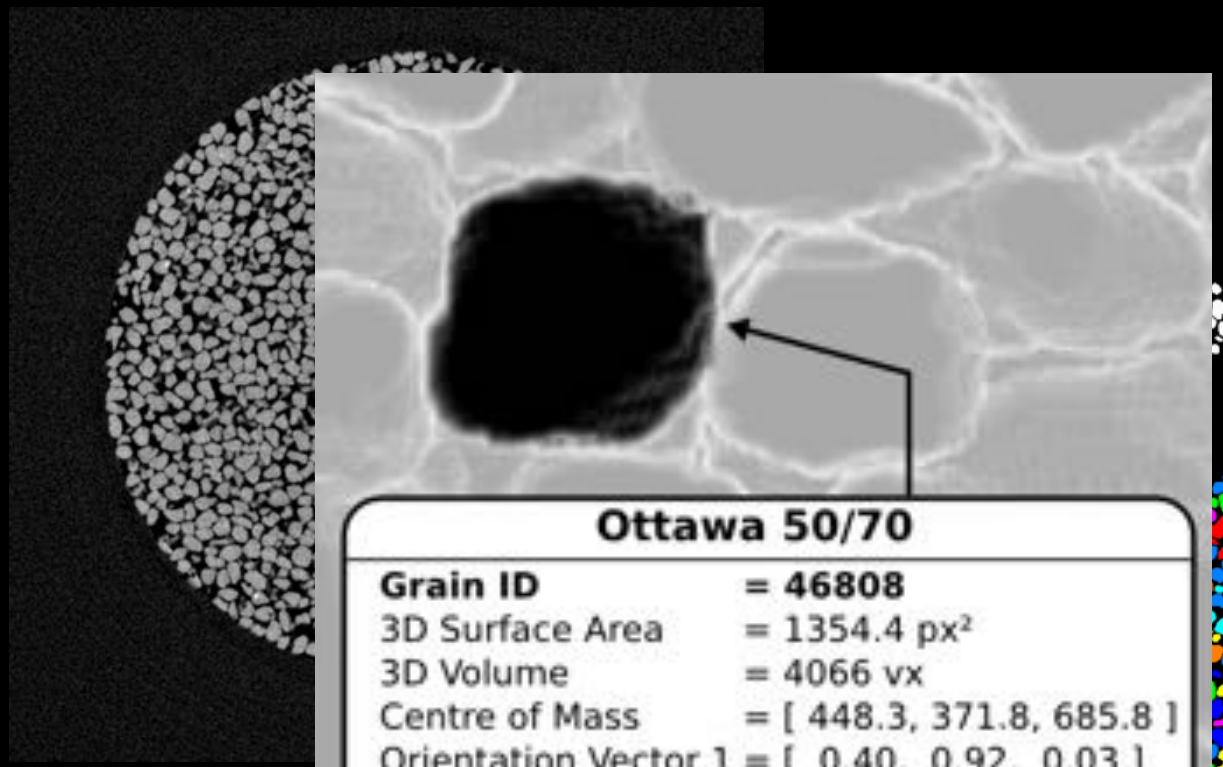
Binarise
(grains and voids)

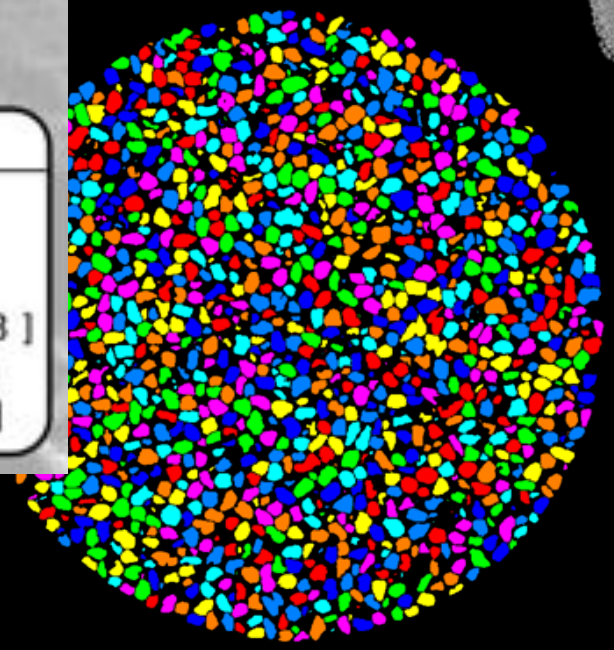
Watershed
Segmentation
(split grains apart)

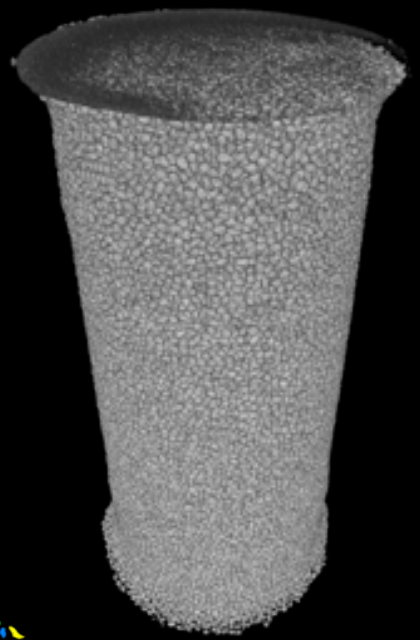
Label Individual Grains

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

How do we see/identify and characterise microstructure?







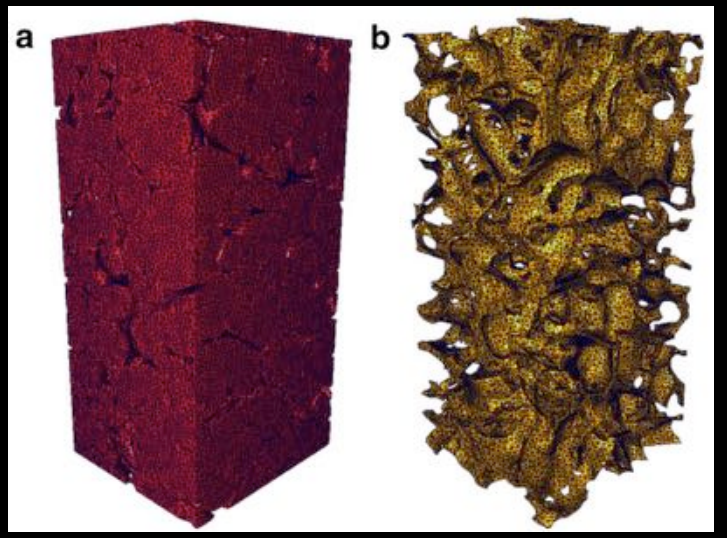
"Raw" image

Binarise
(grains and voids)

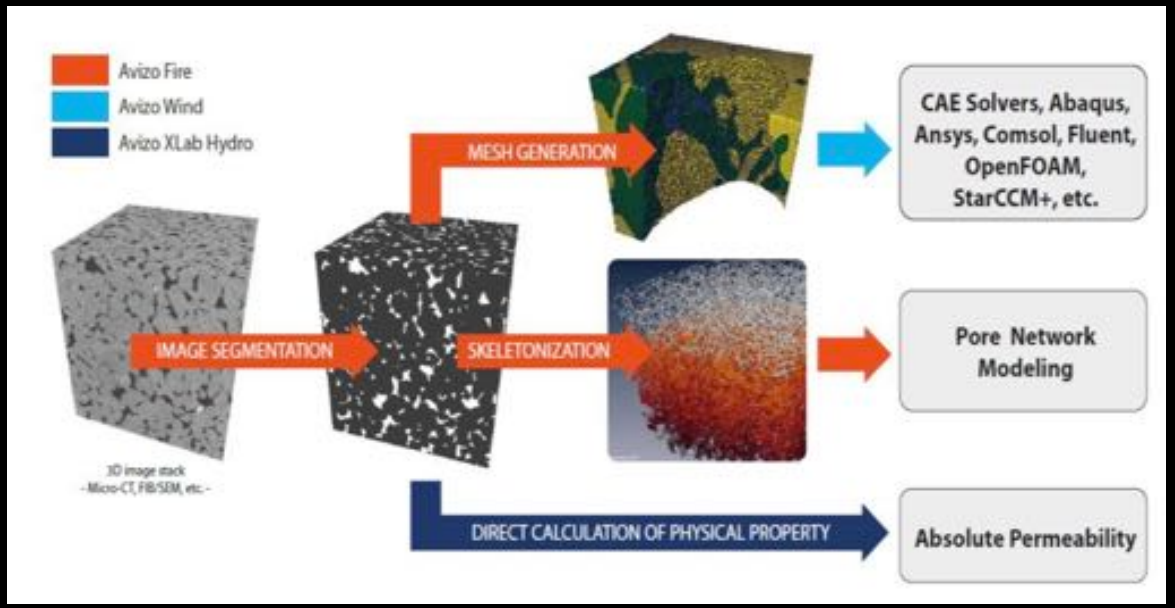
Watershed
Segmentation
(split grains apart)

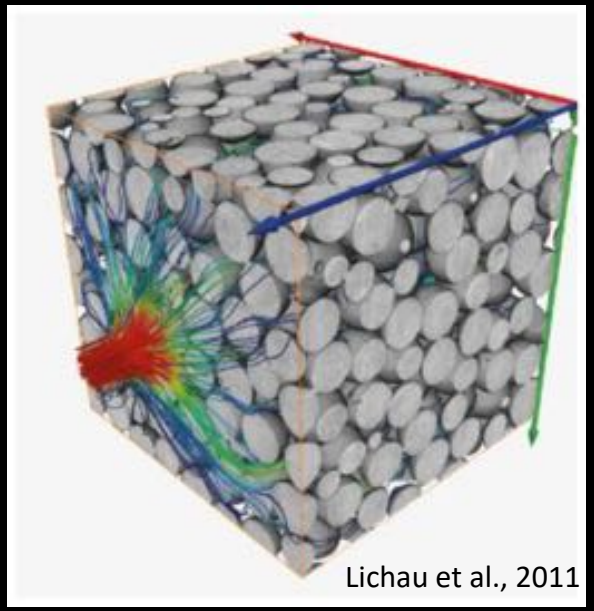
Label Individual Grains

Structural imaging and characterisation → models



Madi et al., 2006





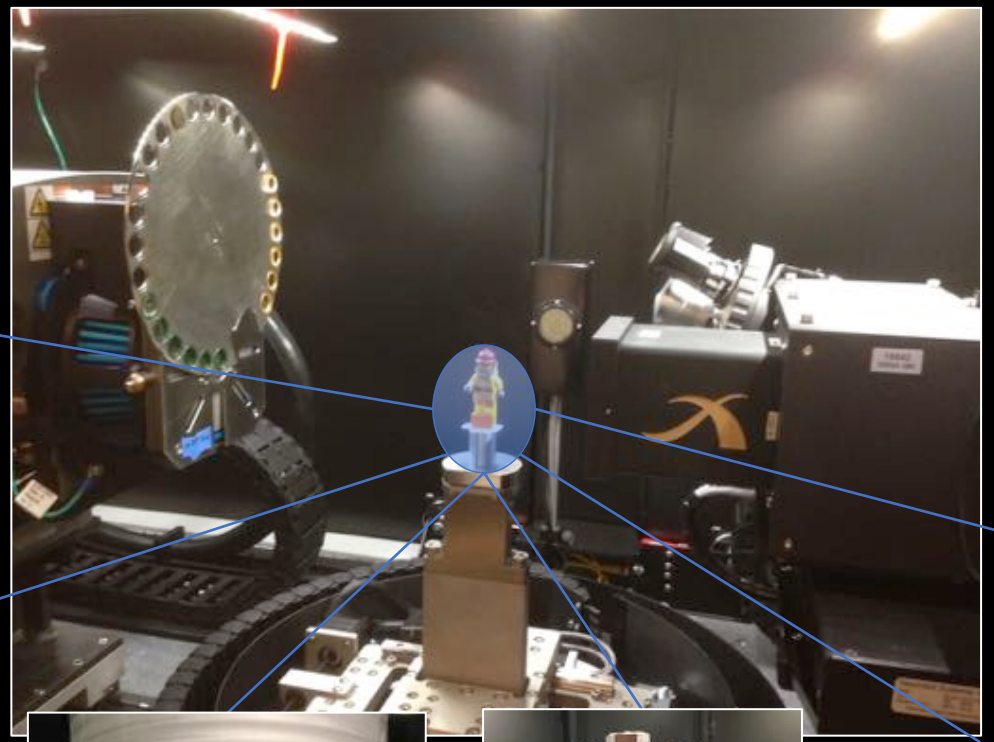
Lichau et al., 2011

4D imaging…

In-situ devices @ 4D Imaging Lab

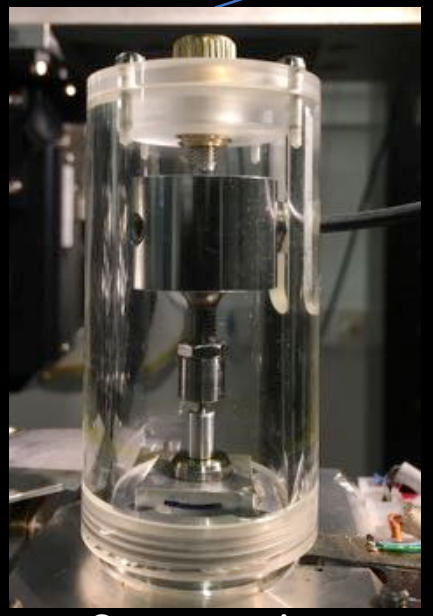
4D IMAGING LAB@LTH

Humidity

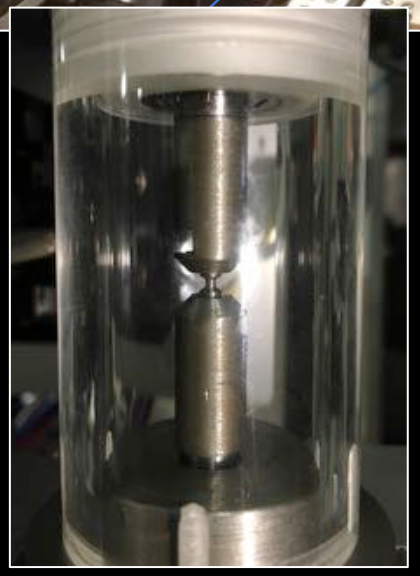


Others and Future:

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



Compression



Tension

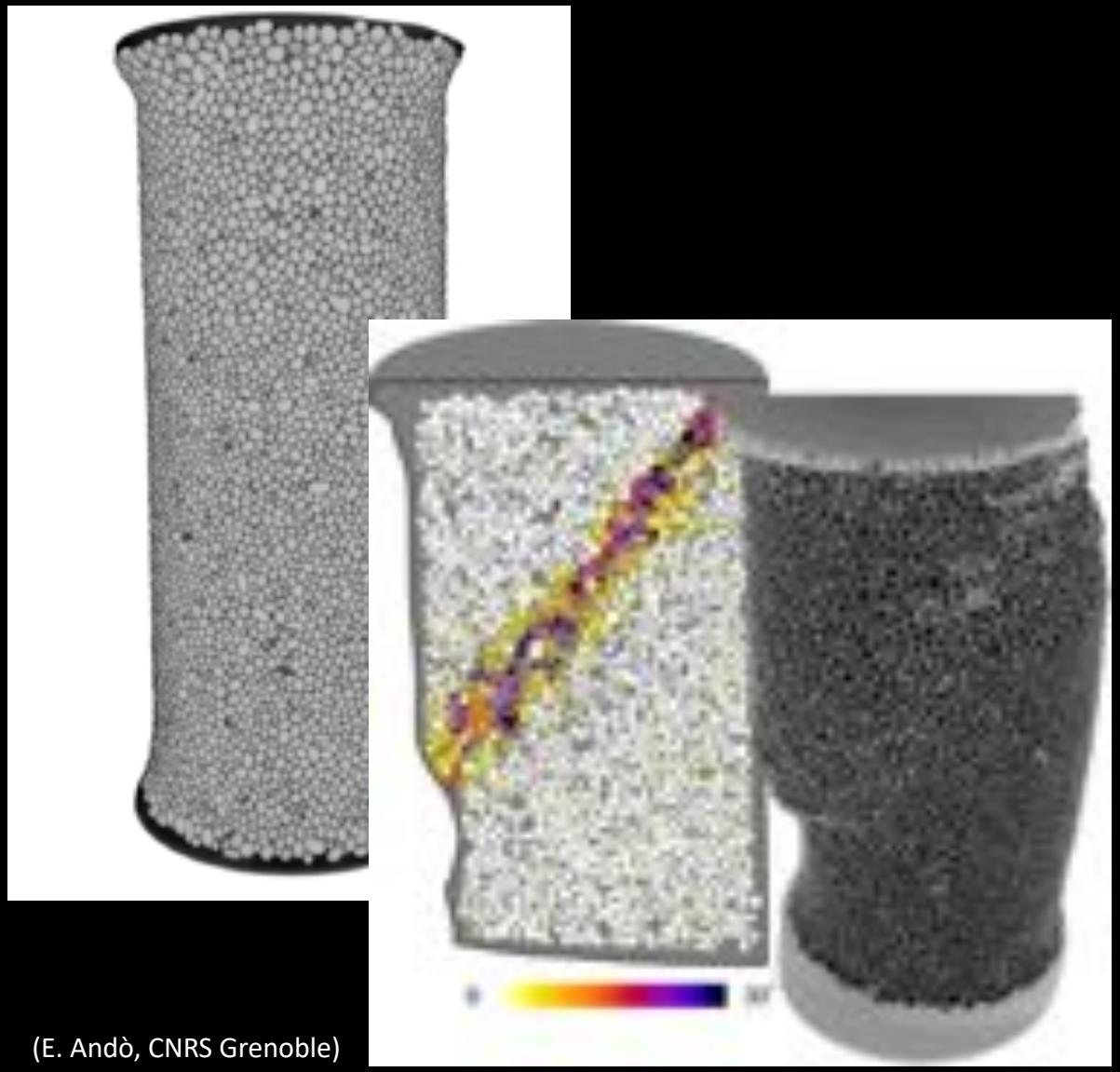
Triaxial

Electrochemical

Vacuum

4D imaging and in-situ experiments

4D imaging of triaixal 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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