



Joint French-Swedish school on X-rays and Neutrons techniques for the study of functional materials for energy

13-17 May 2019 Lund (Sweden)



1. history of MAX IV (we are at 4, why?),
2. why this synchrotron is particular,
3. how the beam is generated,
4. what instruments are present and for what kind of purpose/experience.

“...fit for “scattering” students”



Ana.Labrador@maxiv.lu.se

5/16/2019

MAX IV



A staff working environment (~250)

A tool/service for scientist & society (~3000)



A staff working environment (~250)

A tool/service for scientist & society (~3000)

Ana Labrador

2020

2010

MAX IV

2000

ESRF

1990

CERN

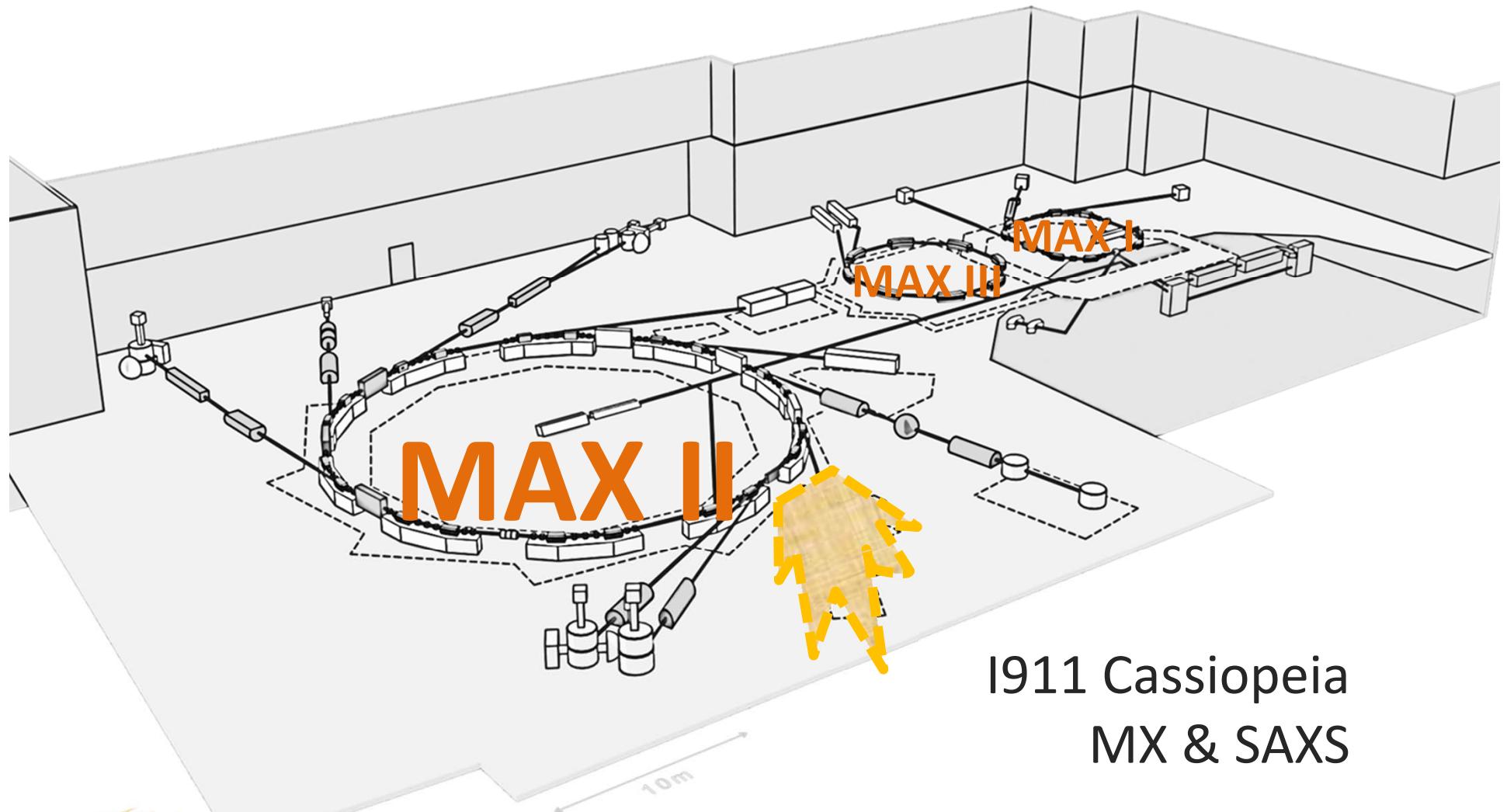
Why MAX IV?



MAX-lab on Ole Römers väg was in operation between 1986-2015



MAX-lab



I911 Cassiopeia
MX & SAXS



THE MACHINE OPERATORS



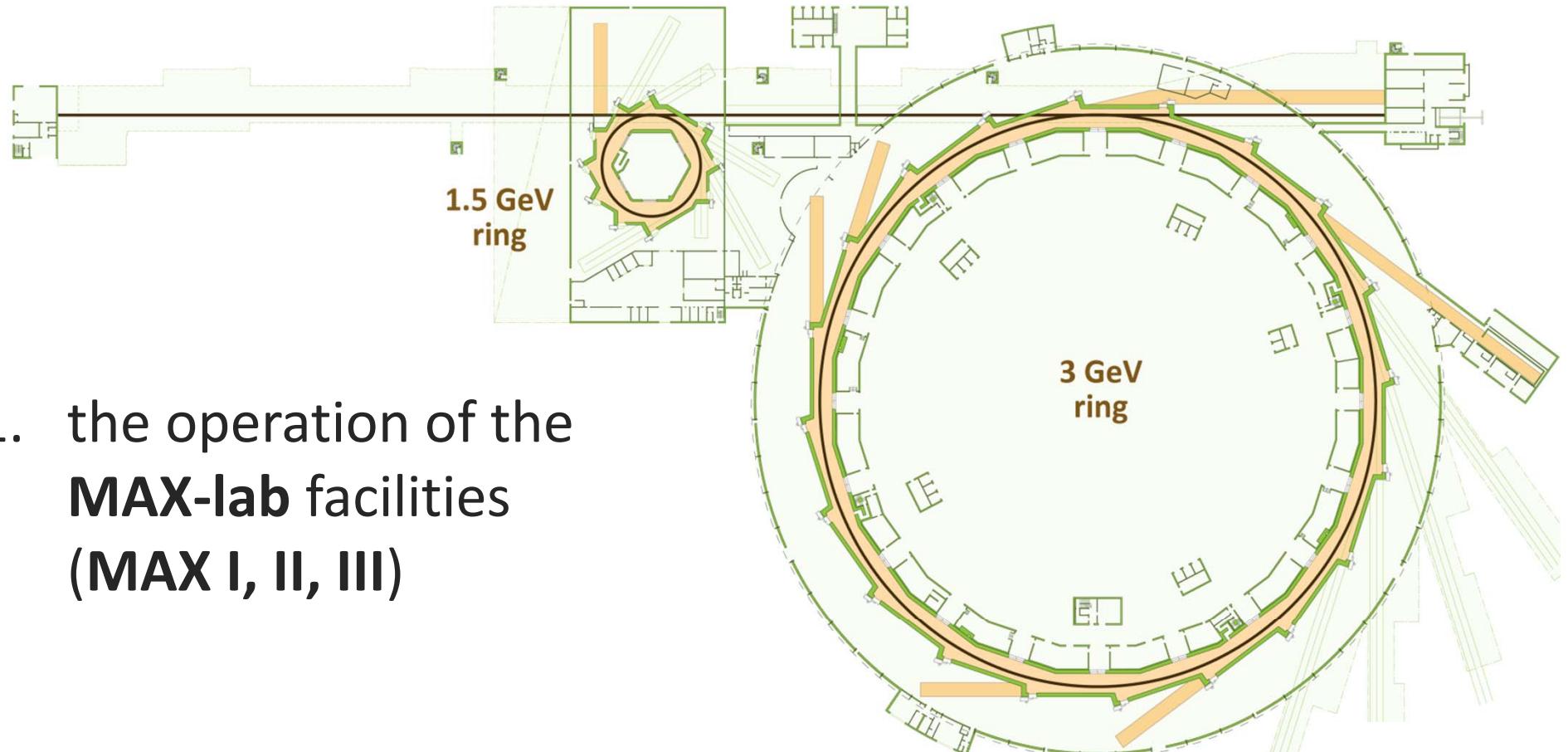
THE FIRST SEVEN BEAMLINES AT MAX IV

– and a more than thirty year long common history



Knut och Alice
Wallenbergs
Stiftelse

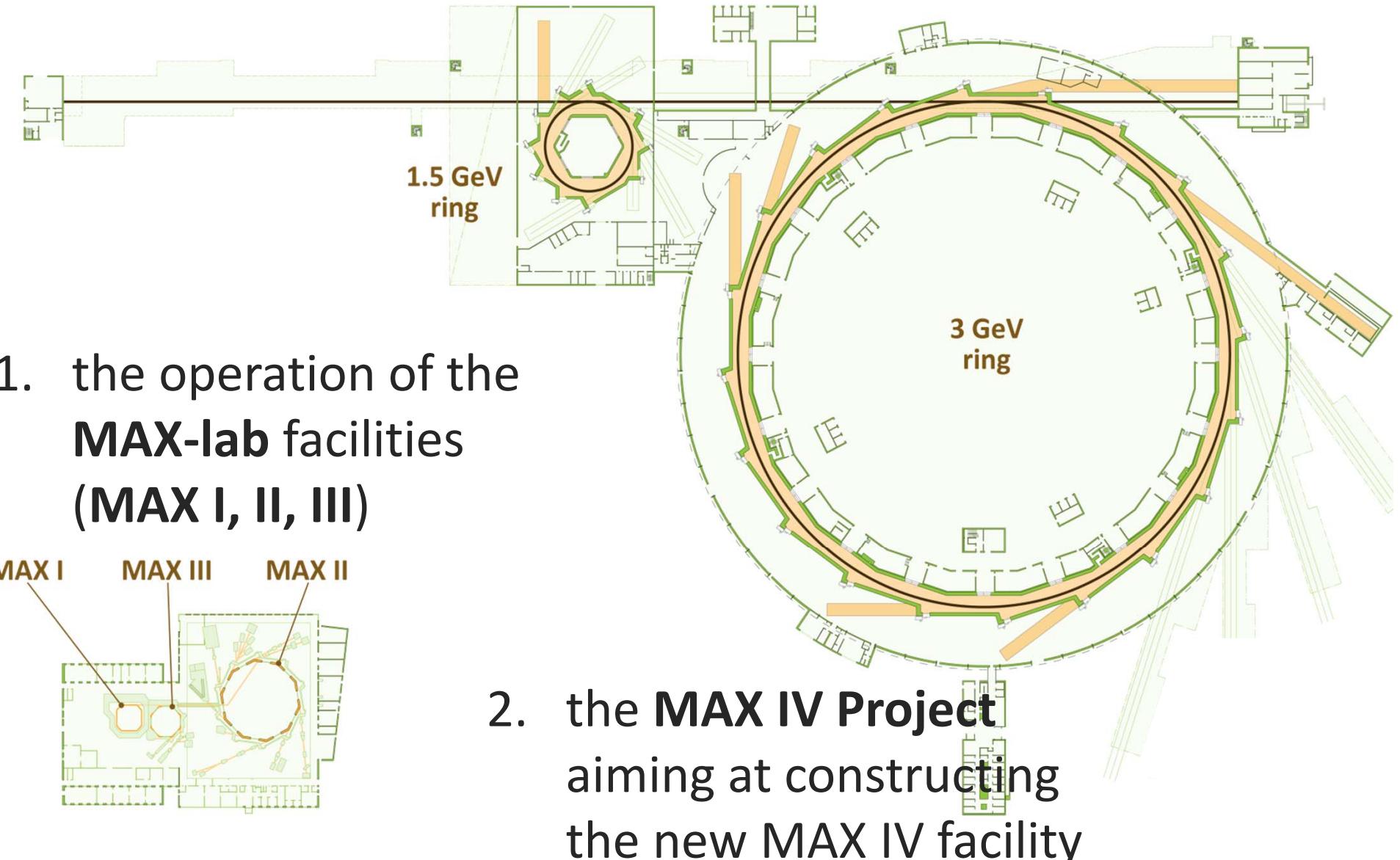
MAX IV Laboratory established in 2010 to include both



1. the operation of the **MAX-lab** facilities
(MAX I, II, III)

2. the **MAX IV Project**
aiming at constructing
the new MAX IV facility

MAX IV Laboratory established in 2010 to include both



THE FIRST SEVEN BEAMLINES AT MAX IV

– and a more than thirty year long common history

Balder

BioMAX

Bloch

FemtoMAX

Hippie

NanoMAX

Veritas

The users – our raison d'être

THE FIRST SEVEN BEAMLINES AT MAX IV

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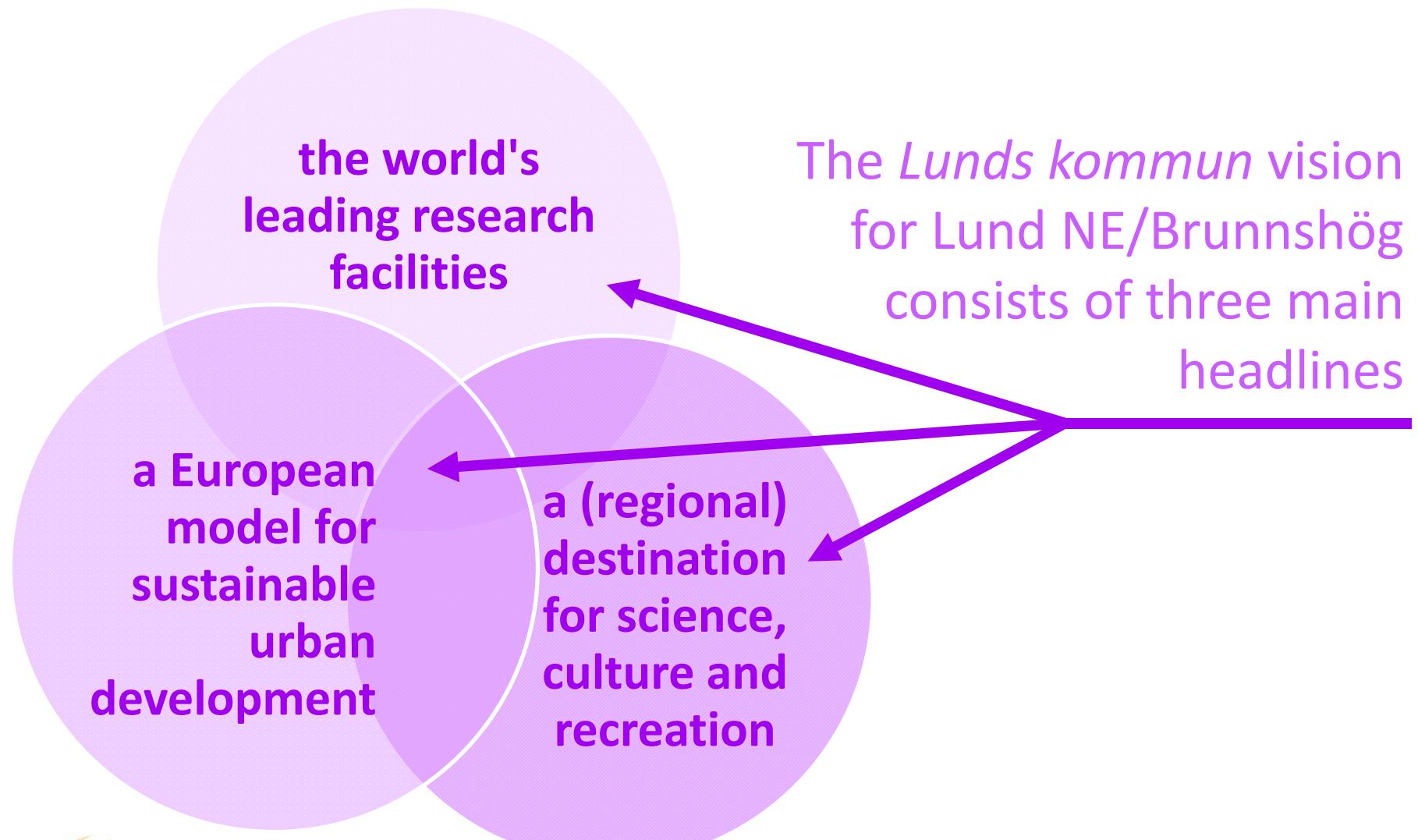
Hippie

NanoMAX

Veritas

The users – our raison d'être

Visions, Goals, Dreams





LUND

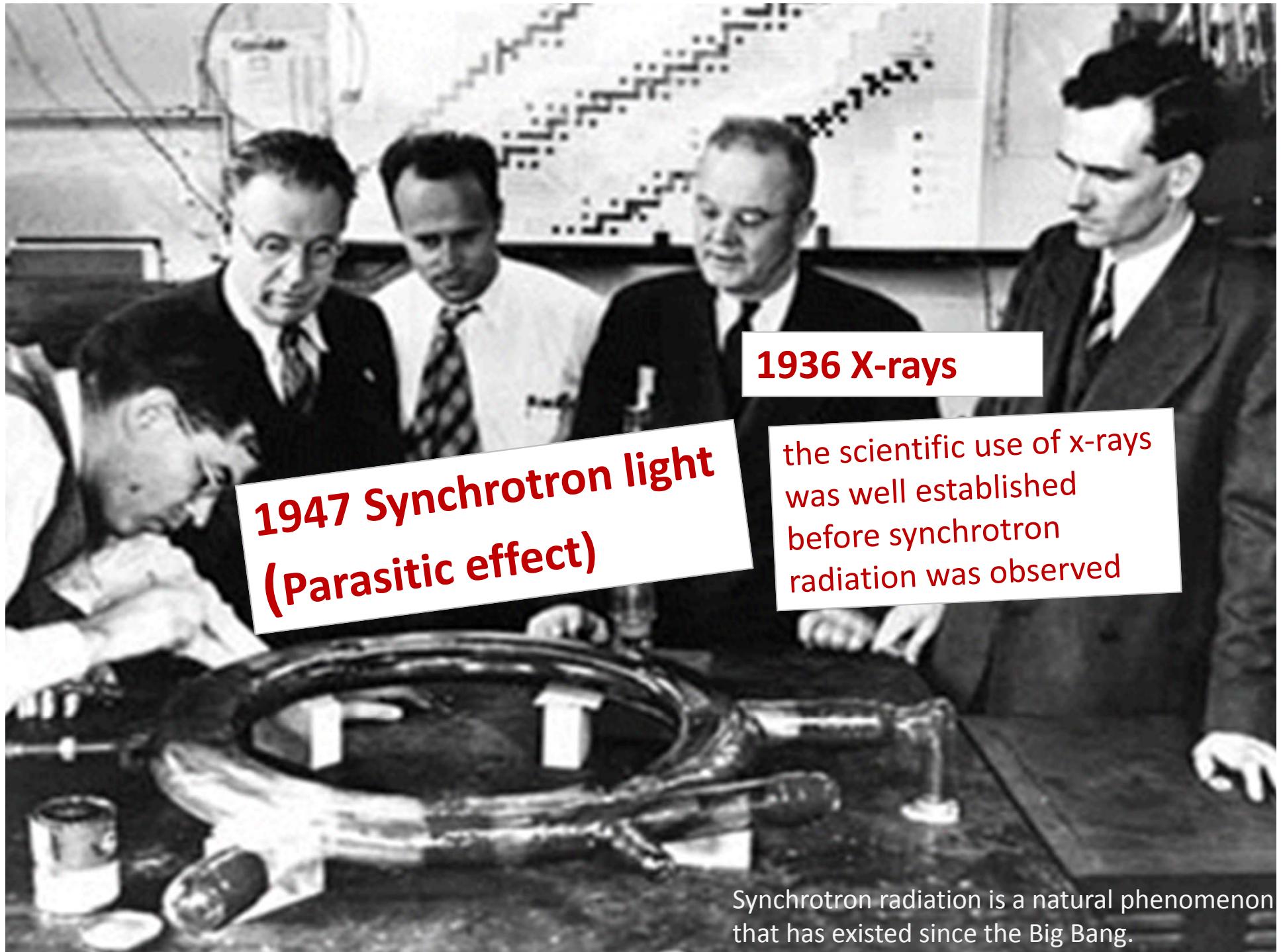


Brunnshög

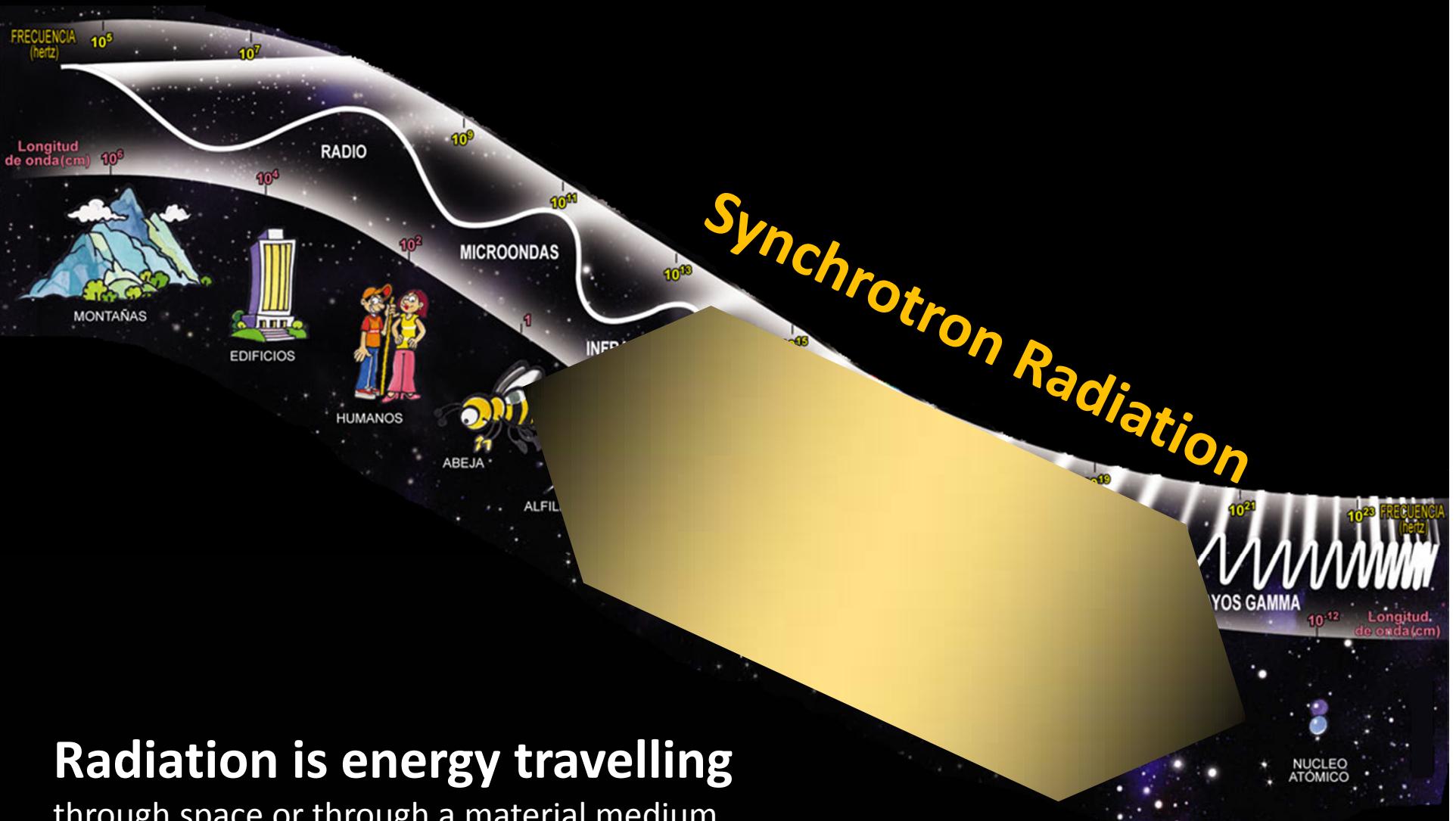


Why MAX IV?

1. many applications
2. unique tool
3. run by experts



Electromagnetic spectrum

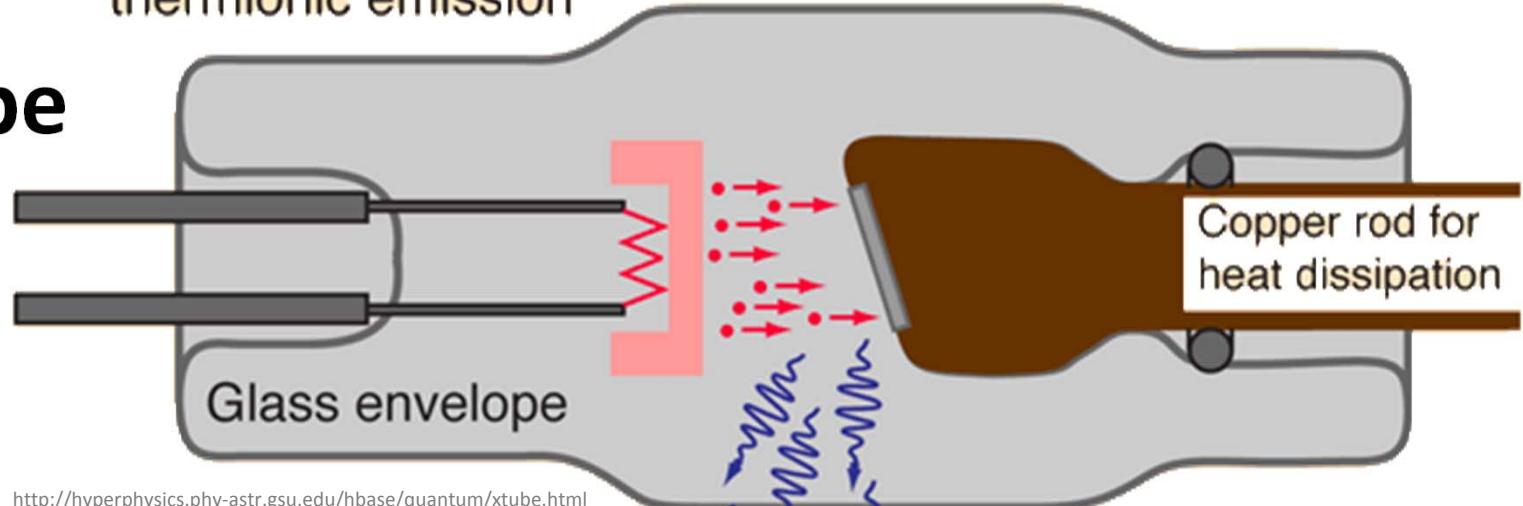


Radiation is energy travelling
through space or through a material medium
in the form of **waves or particles**

X-ray tube

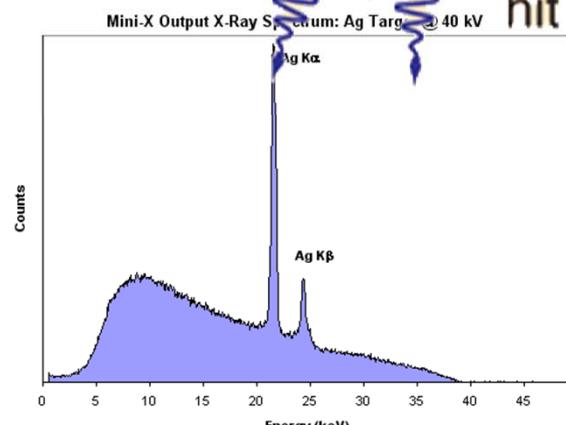
Heated filament
emits electrons by
thermionic emission

Electrons are accelerated
by a high voltage.



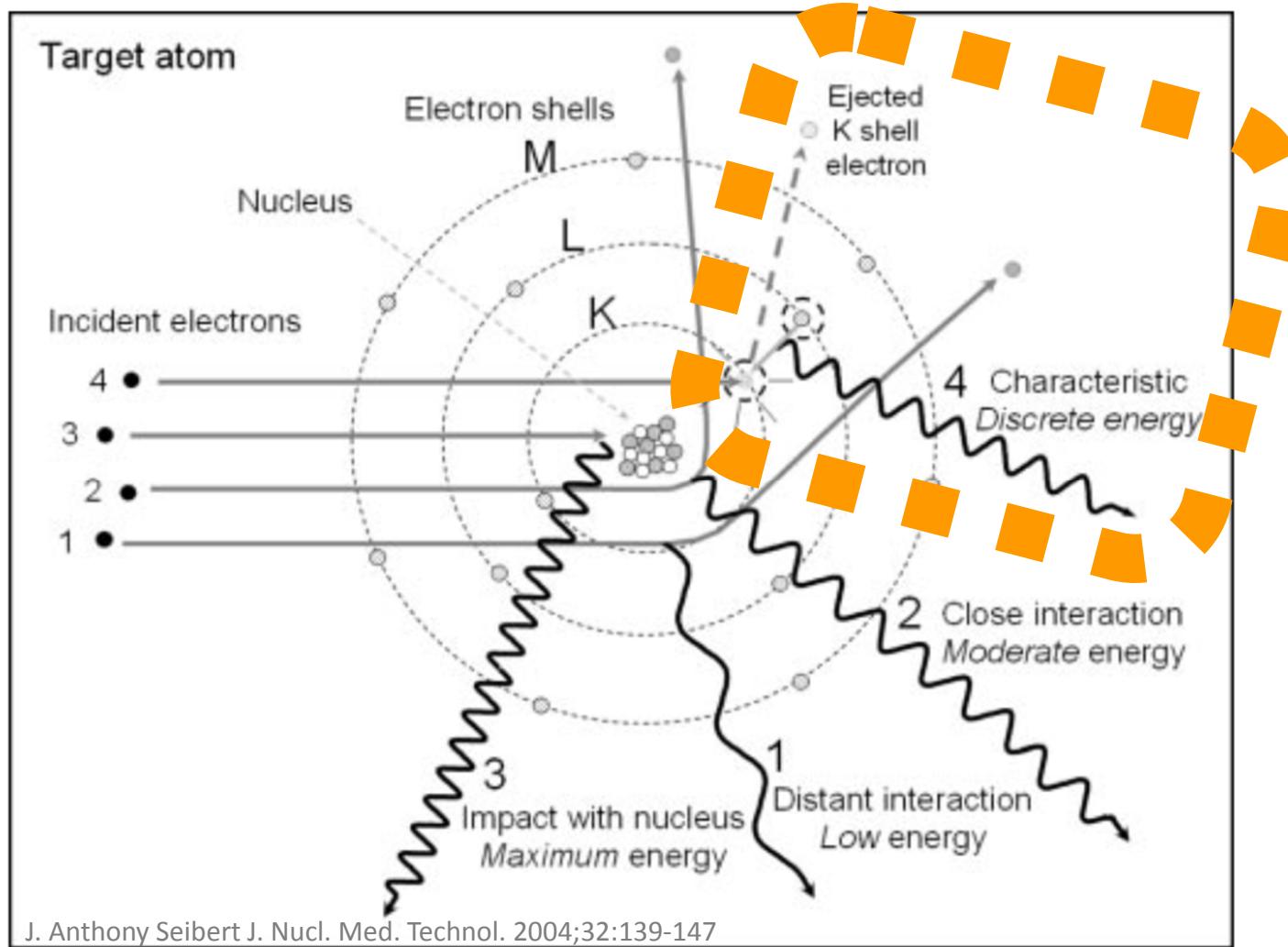
<http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/xtube.html>

x-rays produced when
high speed electrons
hit the metal target.



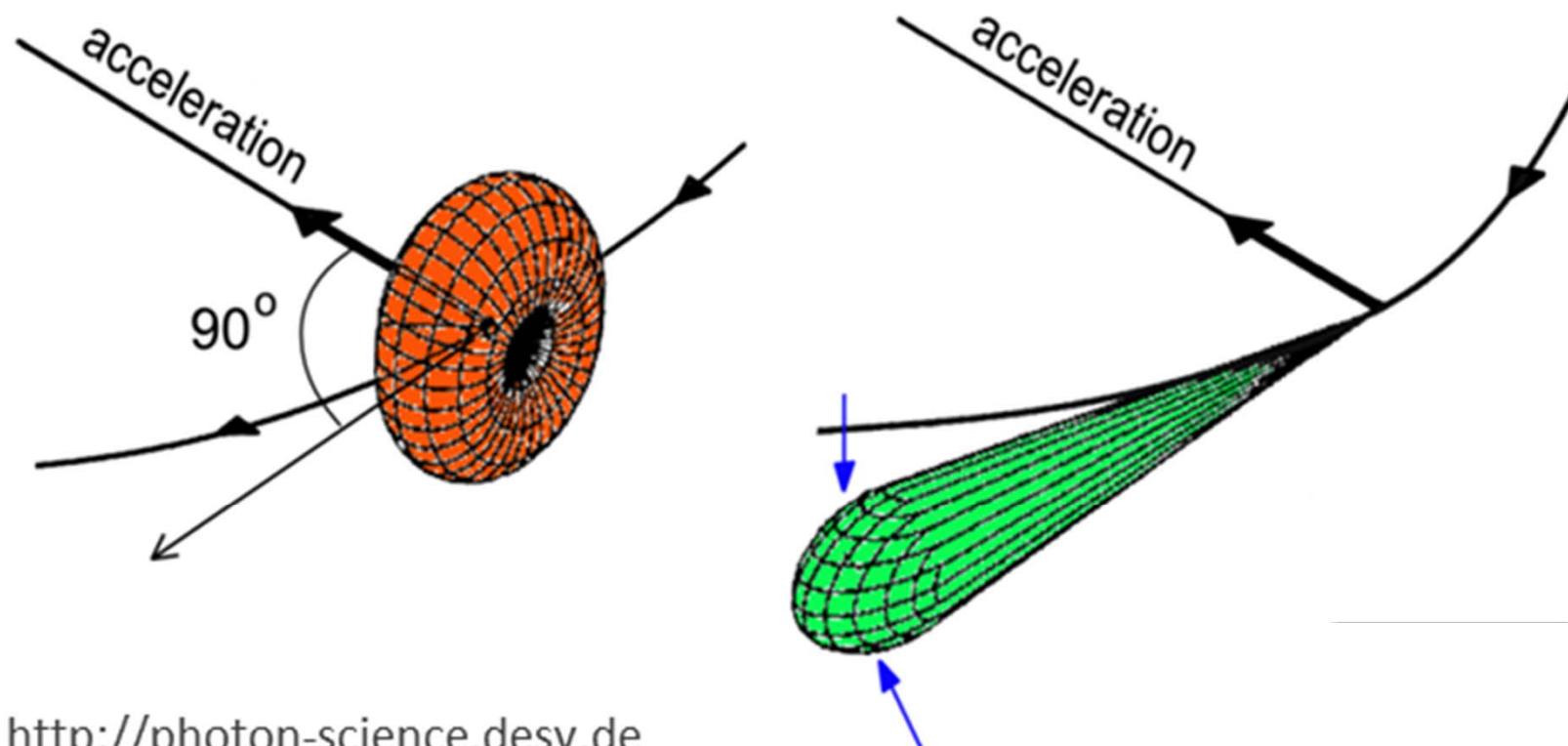
<http://amptek.com/cdte-application-note-characterization-of-x-ray-tubes>
5/16/2019

characteristic radiation emission



Radiation by moving charges

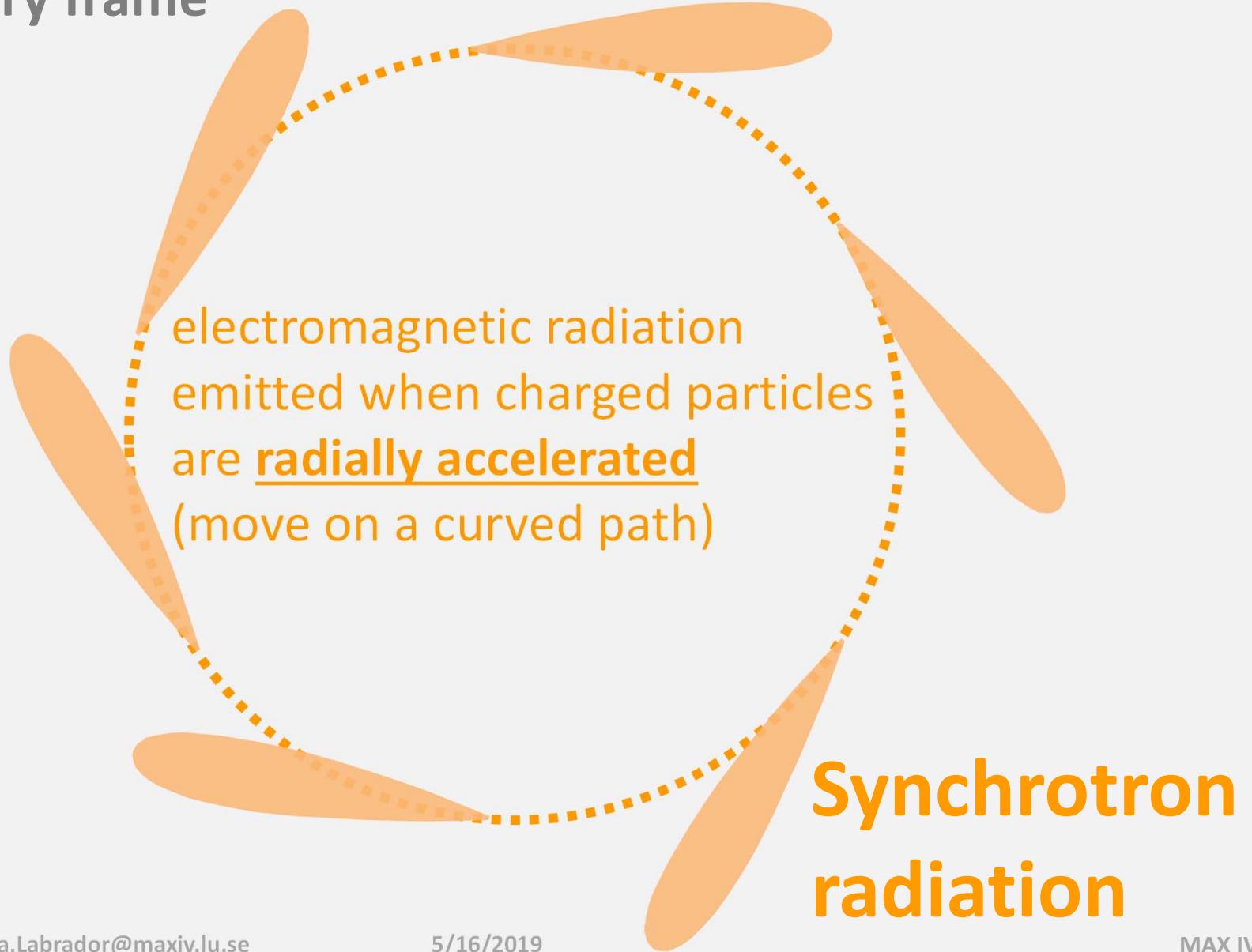
Center of mass frame Laboratory frame



<http://photon-science.desy.de>

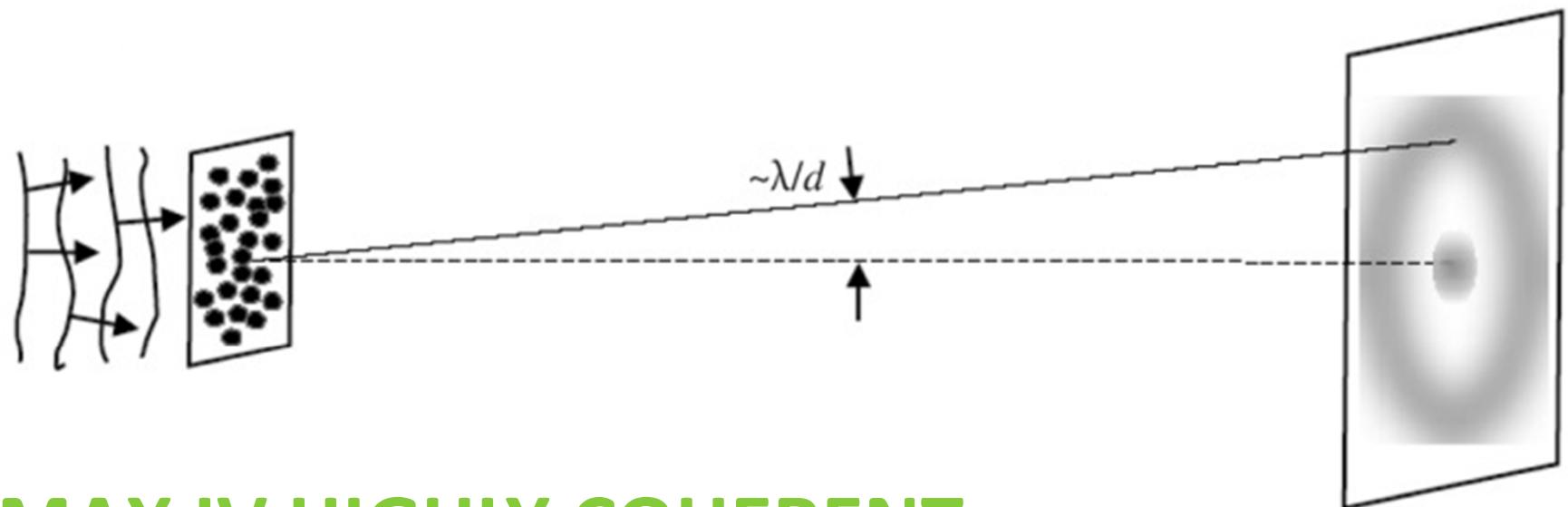
Radiation by moving charges

Laboratory frame

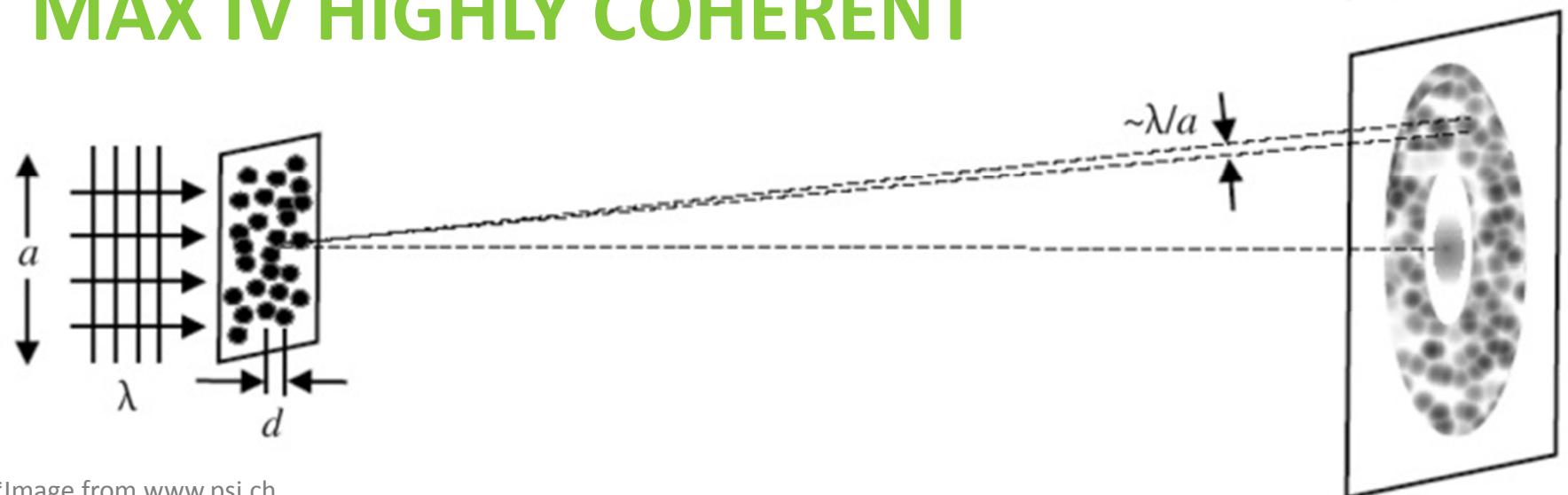


Basic Properties of Synchrotron Radiation

1. HIGH INTENSITY/BRIGHTNESS
2. BROAD ENERGY RANGE – Tunability
3. POLARIZATION (linear, elliptical, circular)
4. PULSED TIME STRUCTURE (0.01 - 1 nsec)
5. SMALL SOURCE SIZE (\leq mm DOWN TO nm)
6. HIGHLY COHERENT
7. HIGH STABILITY

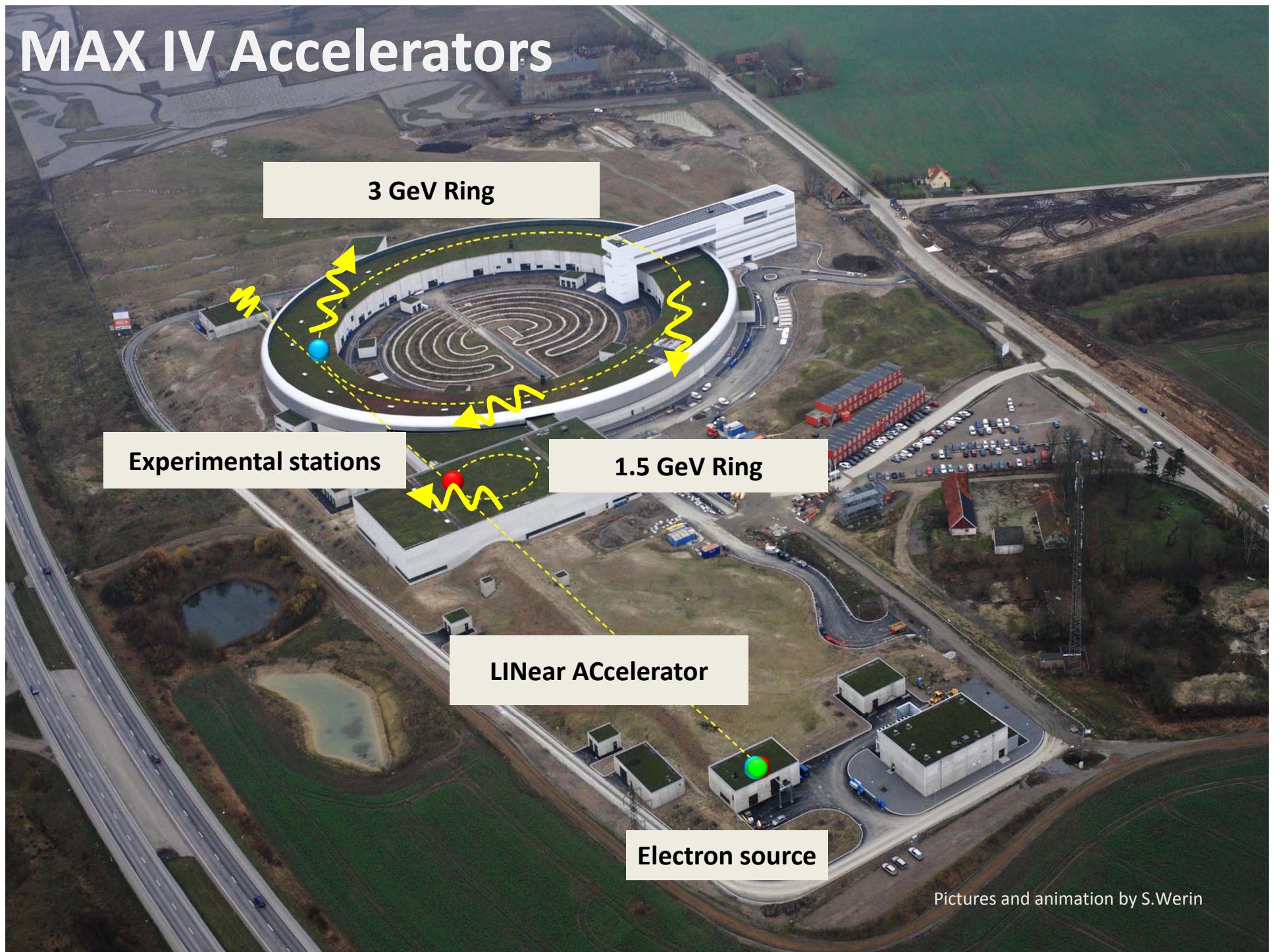


MAX IV HIGHLY COHERENT

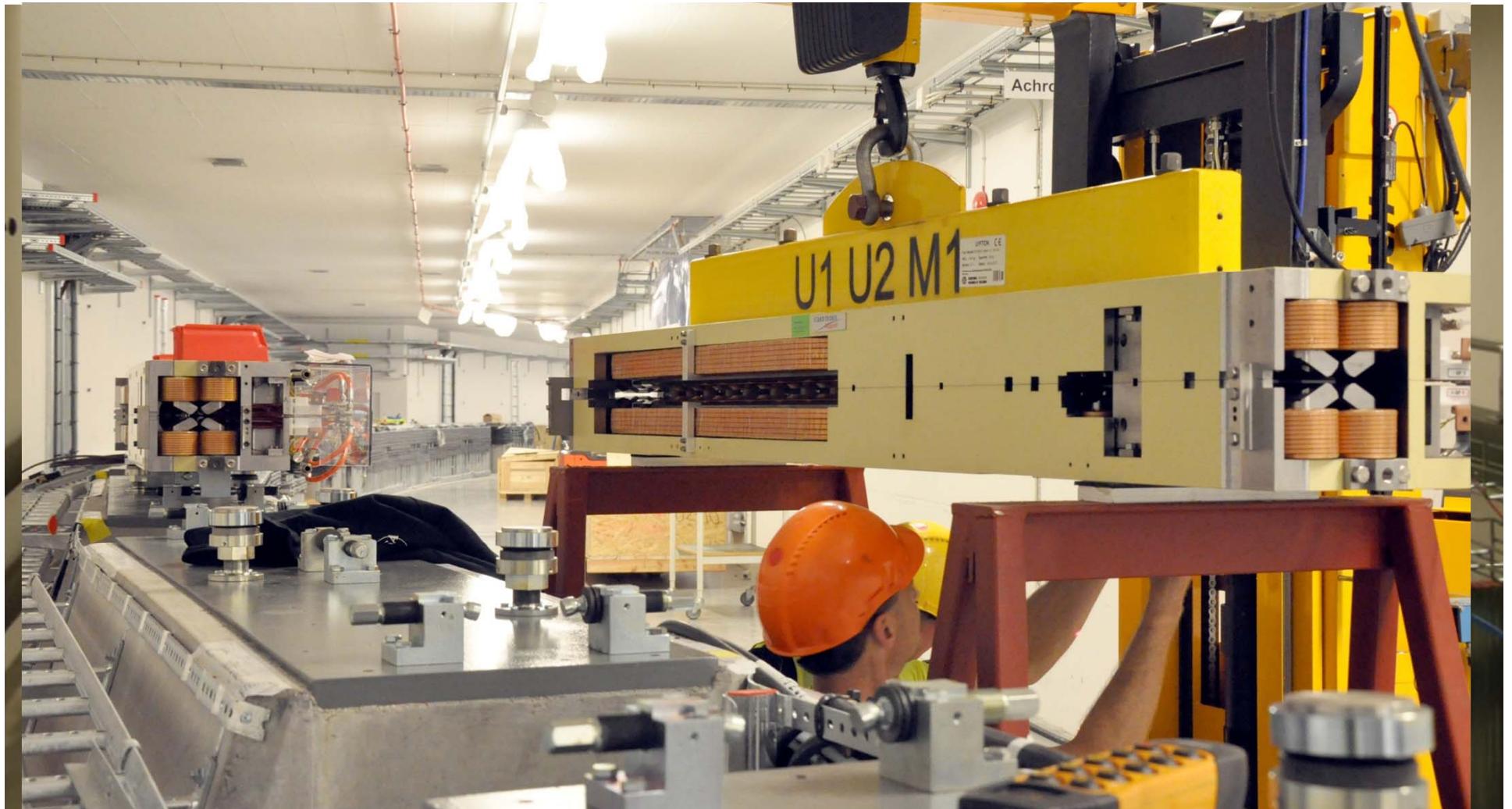


*Image from www.psi.ch

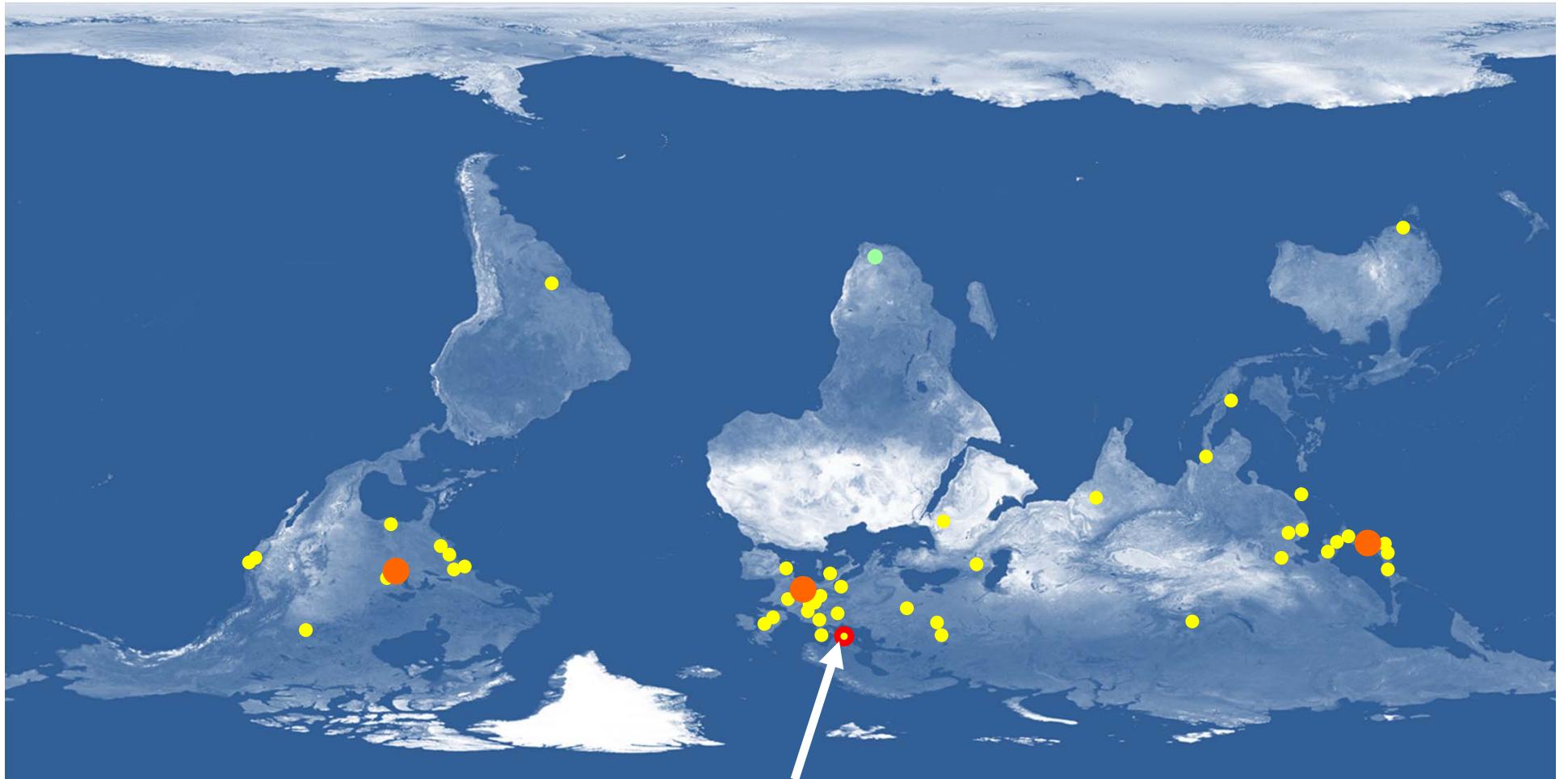
MAX IV Accelerators



Pictures and animation by S.Werin



Synchrotron light sources



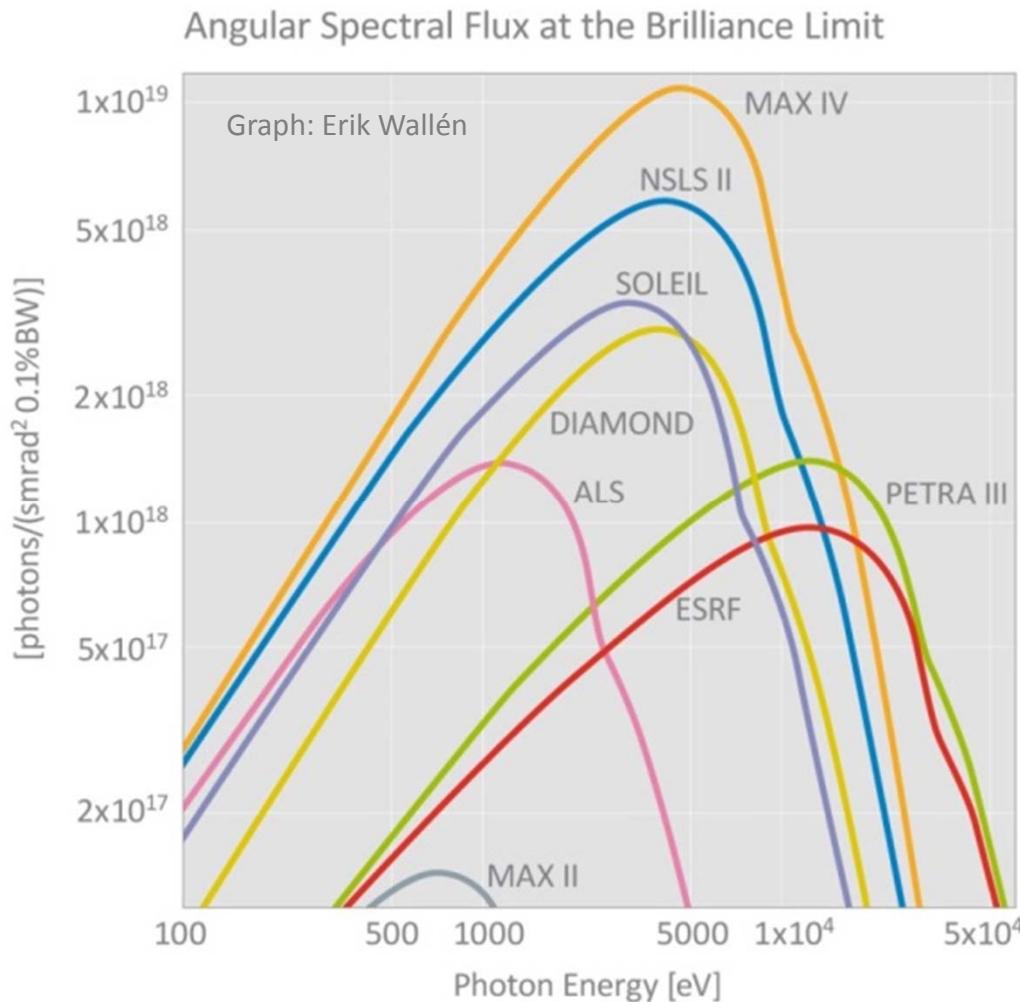
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5/16/2019

More photons and
highly collimated

MAX IV

It's all about the emittance!



Emittance $\equiv \varepsilon$

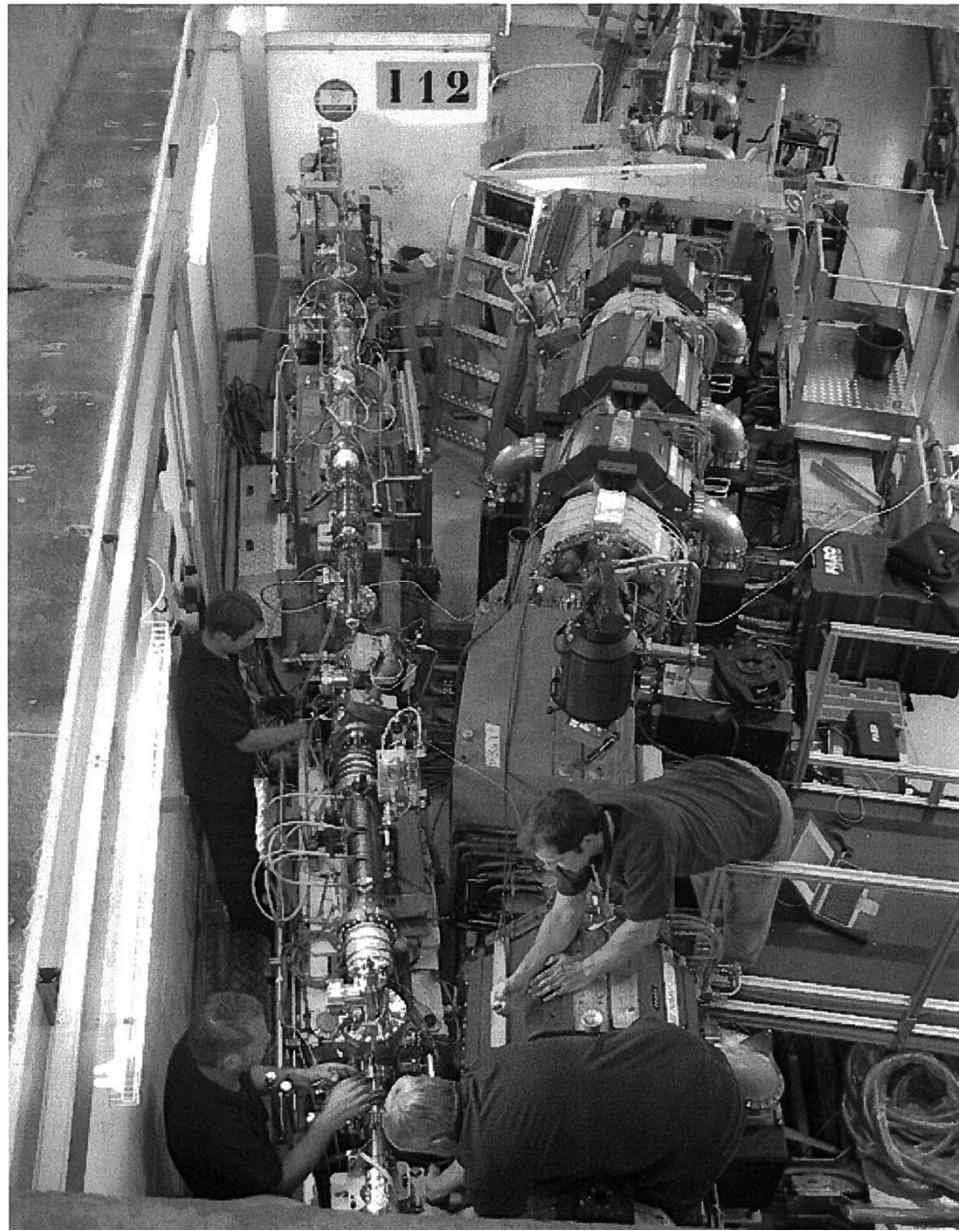
$$\varepsilon = C_q \frac{Energy^2}{N_{magnets}^3}$$

$$Brilliance \propto \frac{1}{\varepsilon^2}$$

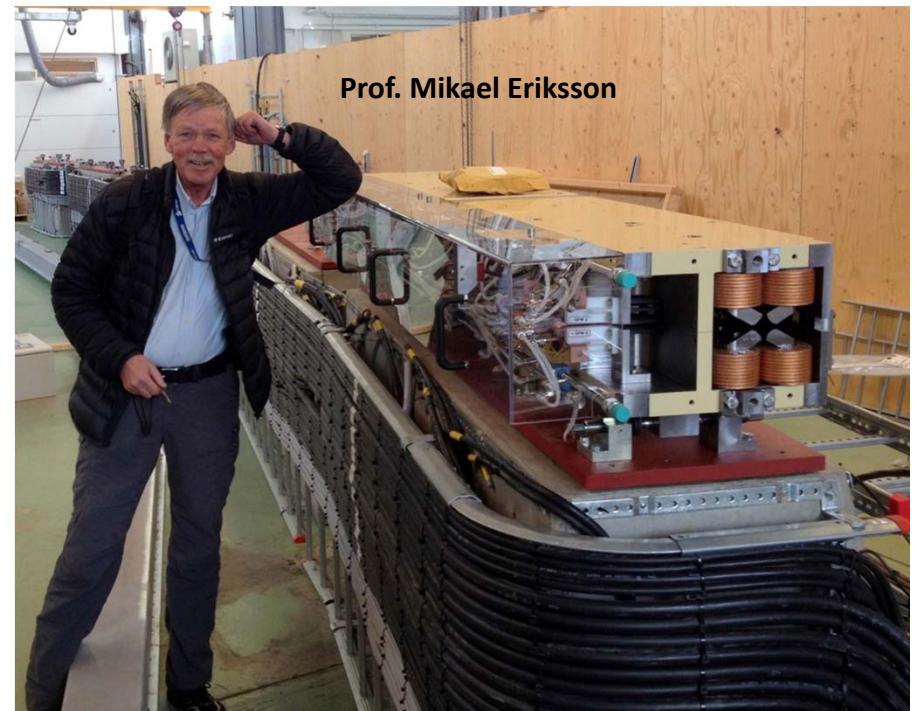
	MAX IV	Diamond	ESRF
Circumference [m]	528	561	844
Energy [GeV]	3	3	6
Nr of straights	20	22	30
Hor emittance [nm rad]	0.24	2.7	4
Current [mA]	500	300	200
Hor RMS beam size [μm]	45	123, 178	40-60
Vert RMS beam size [μm]	1-4	6-10	5-10

Brightness # of photons in given $\Delta\lambda/\lambda$ /sec, mrad θ , mrad ϕ , mm²

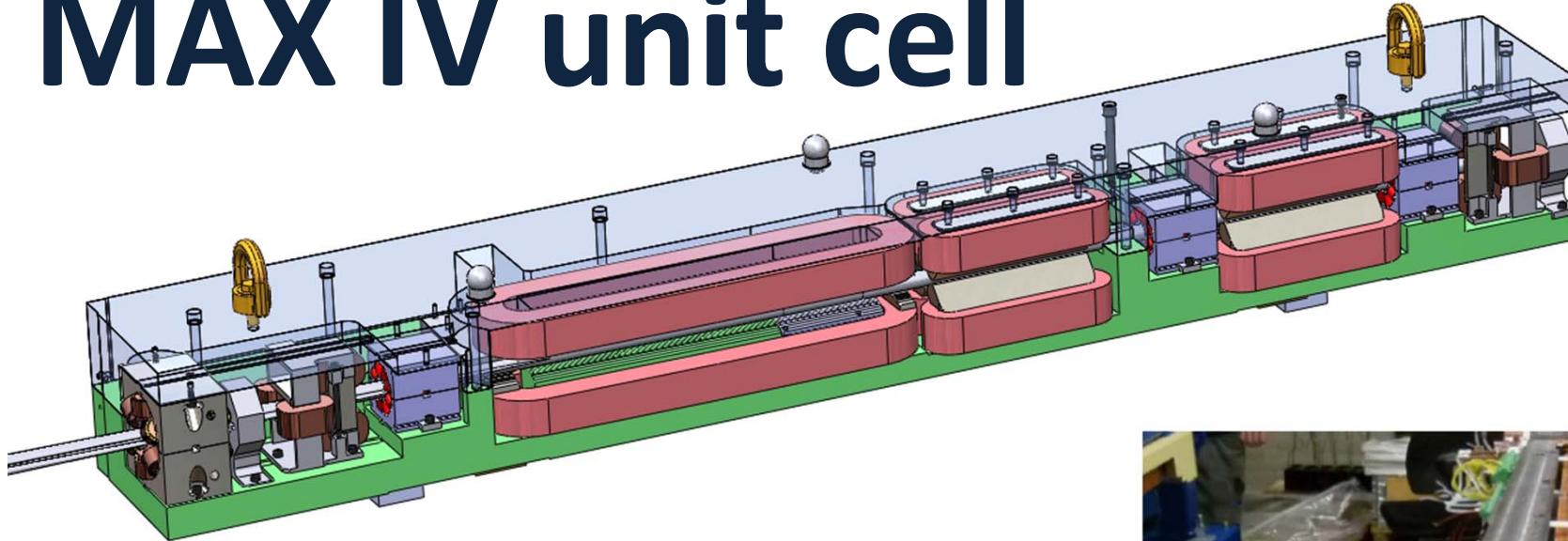
Previously



New design



MAX IV unit cell



- Many small gap dipole magnets
- Machined out of bulk!
- Strong focusing in each cell: quad-, sextu-, octopoles
⇒ complicated optics & dynamics & modeling
- Vacuum & magnets considered together

- Low field & small aperture dipole
- ✓ modest power consumption
- ✓ the synchrotron radiation losses small due to the low dipole fields.

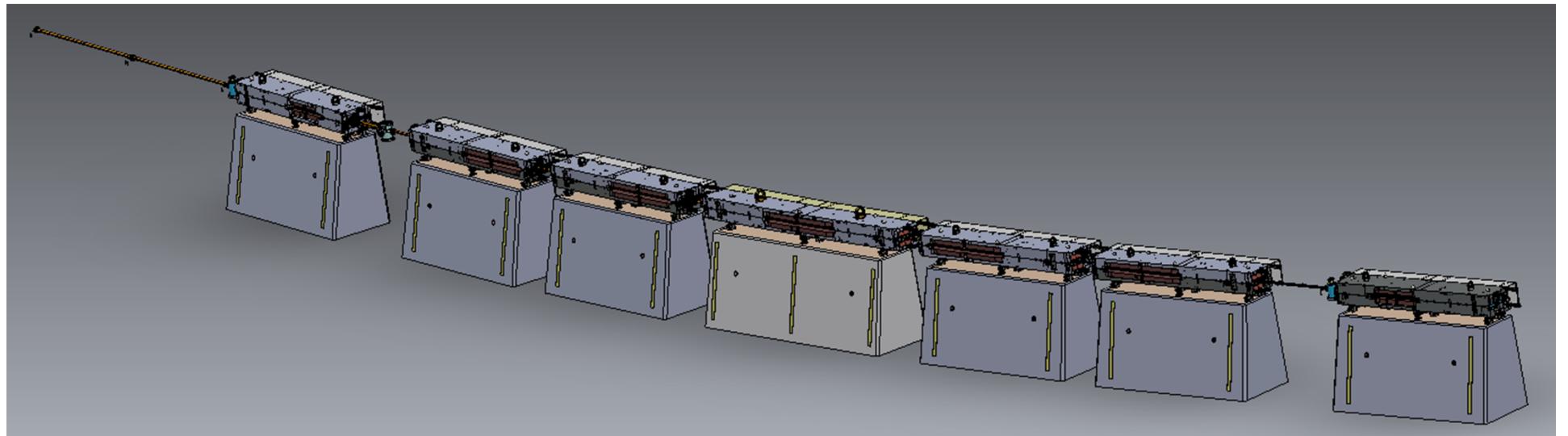


J. Synchrotron Rad. (2014). 21

D. Einfeld: Early history / P. Fernandes Tavares: MAX IV

The 7 bend achromat

Each **achromat** consists of five unit cells plus two matching cells

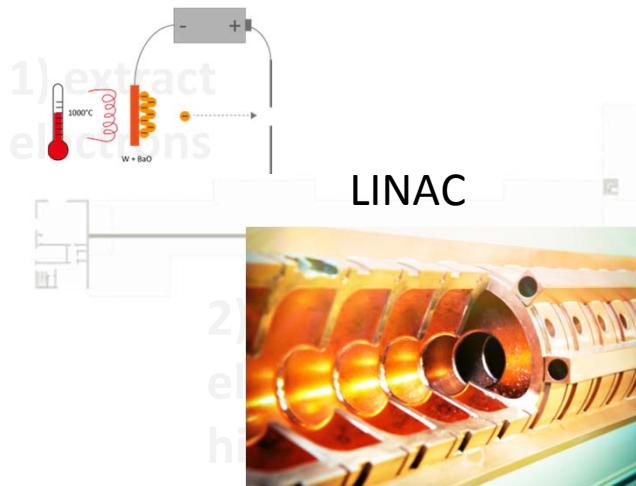




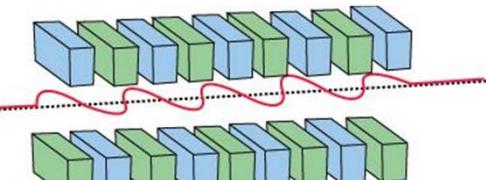
The 7 bend achromat

Each **achromat** consists of 5
unit cells plus 2 matching cells

Electron gun



**IDs: Insertion Devices
(undulator, wiggler)**

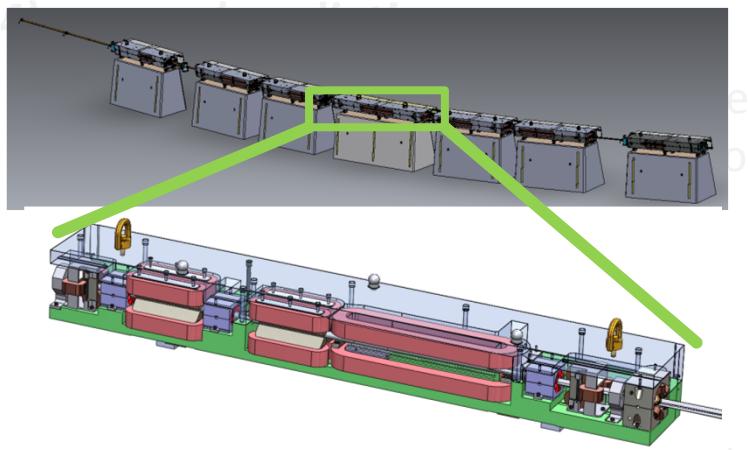


1) extract electrons
2) accelerate
3) induce, tune and optimize the radiation coming from high speed (relativistic) electrons

RF cavities



7 bend achromat



MAX IV has 2 electron guns

Thermionic RF gun produce electrons for the two rings

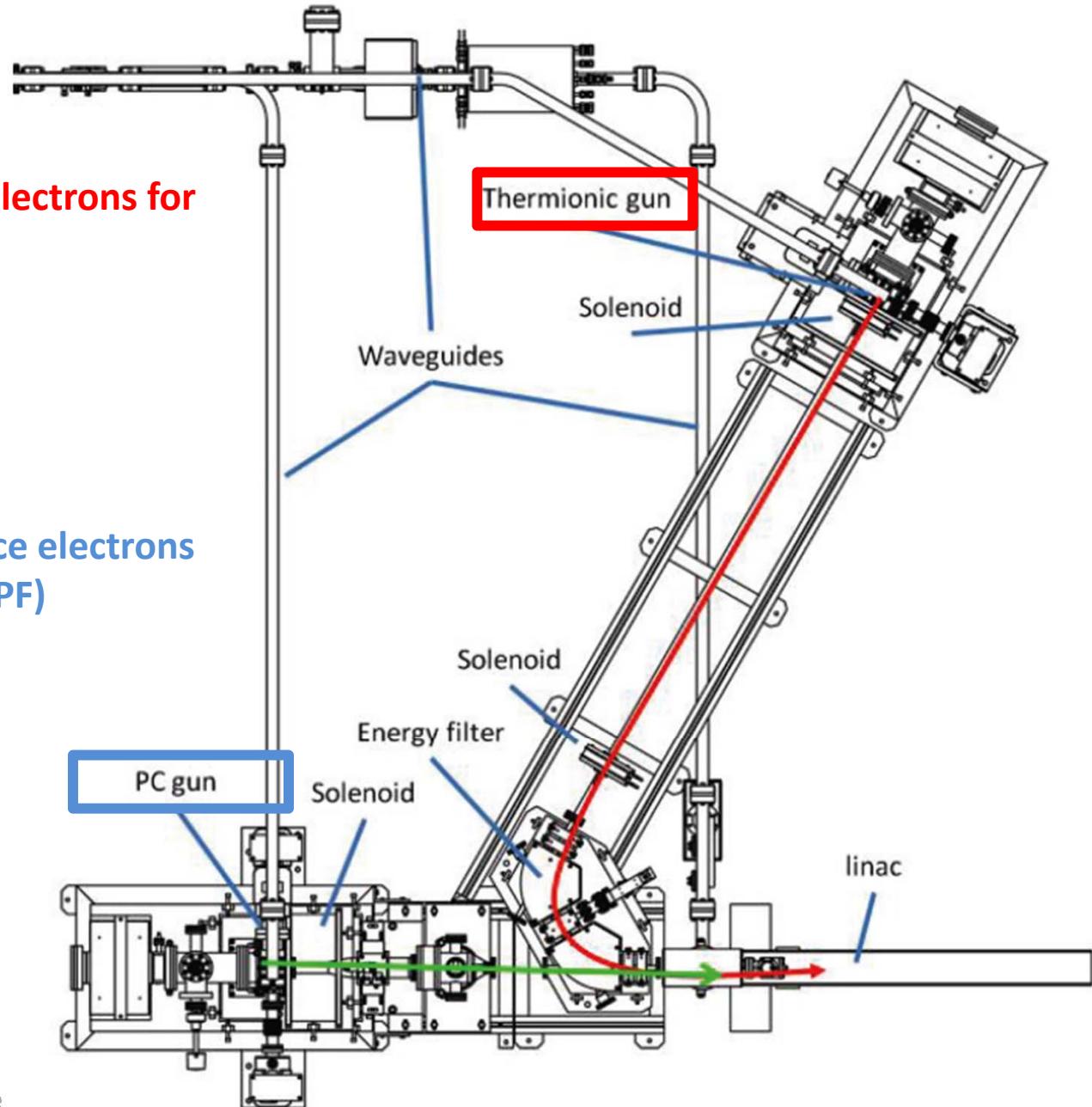
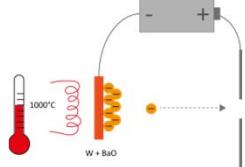


Photo cathode RF gun produce electrons for the Short Pulse Facility (SPF)

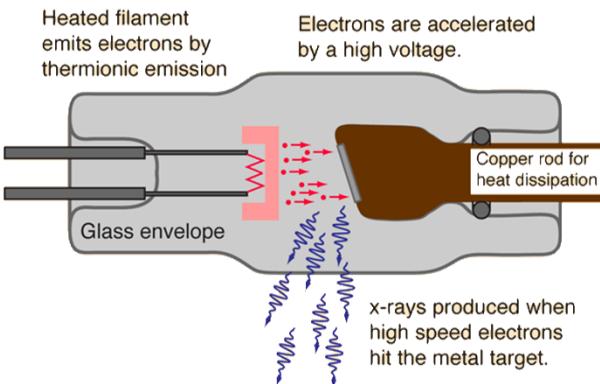




IDs: Insertion devices

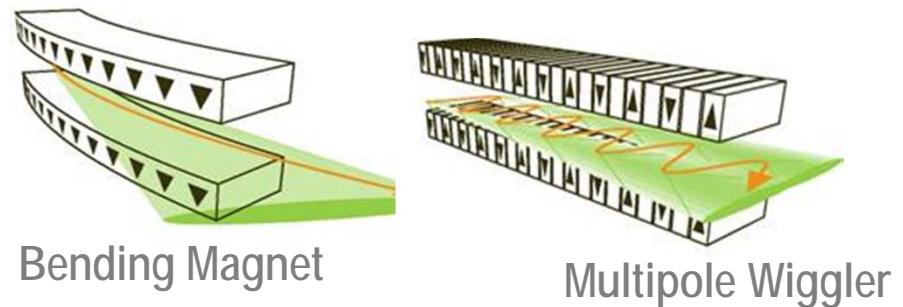


X-ray tube



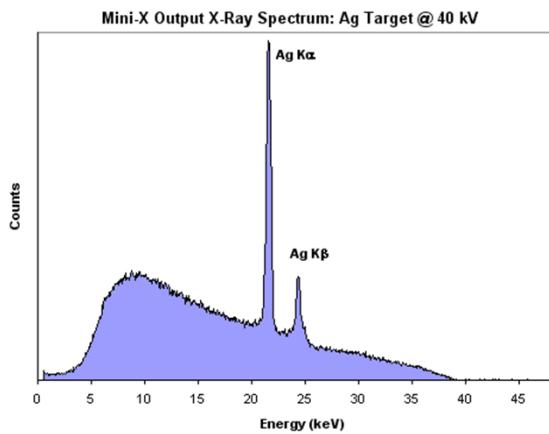
<http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/xtube.html>

Synchrotron X-rays

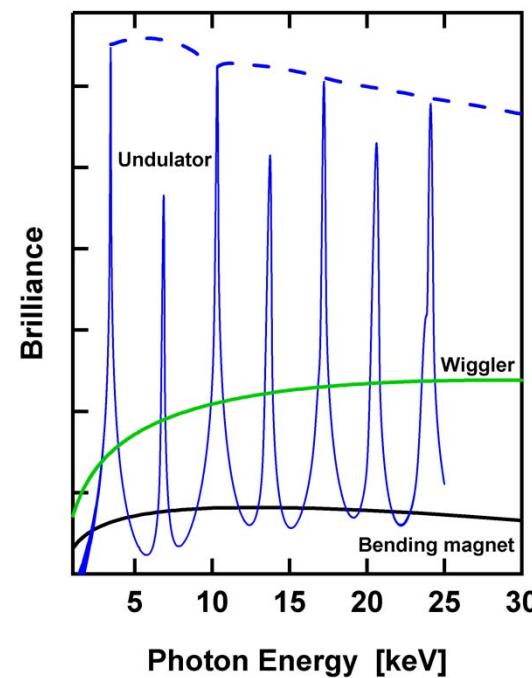


Bending Magnet

Multipole Wiggler



<http://amptek.com/cdte-application-note-characterization-of-x-ray-tubes>



Undulator

Insertion Device

(energy range & polarization)

X-ray Optics

(energy selection, focusing)

Endstation(s)

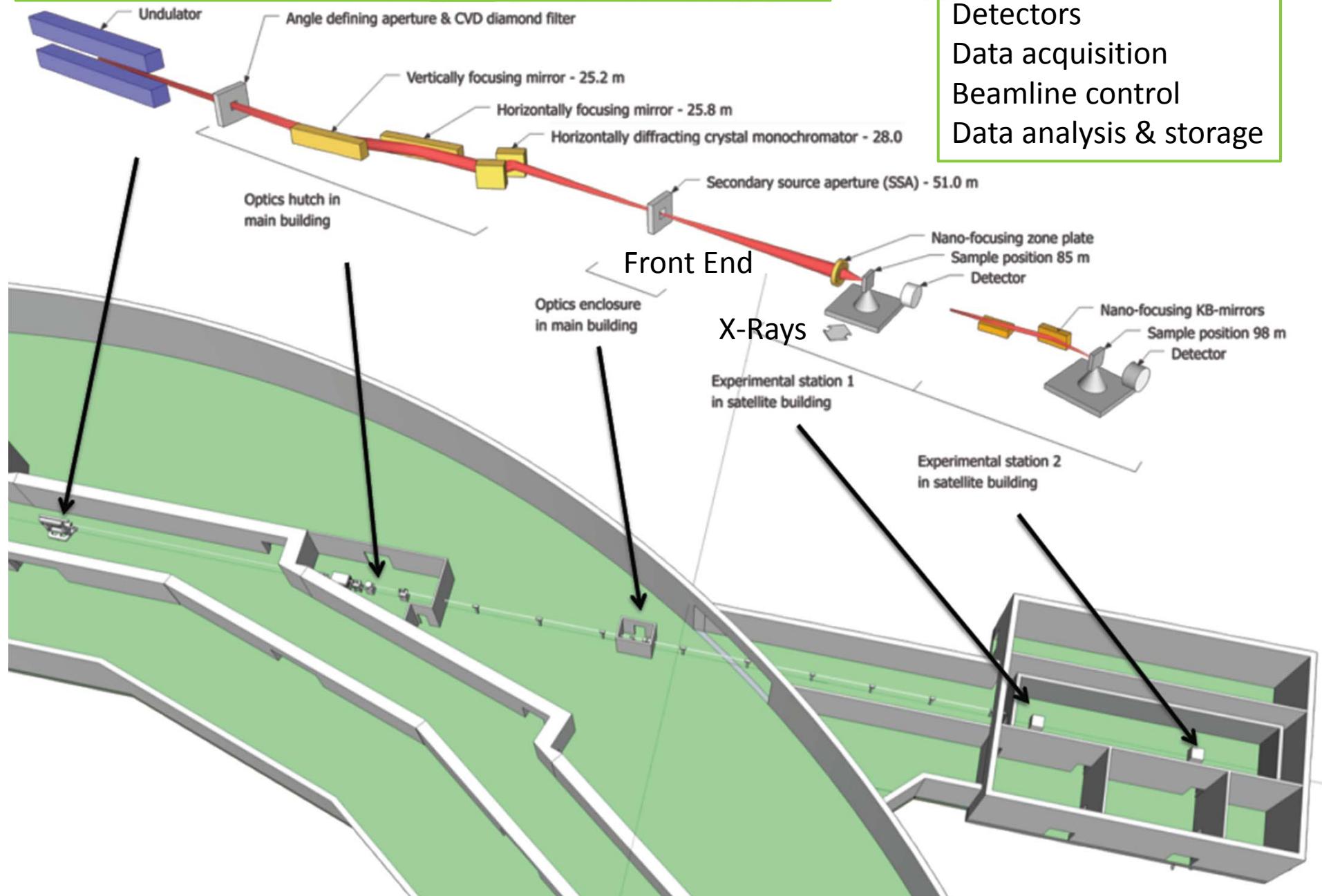
Sample environment

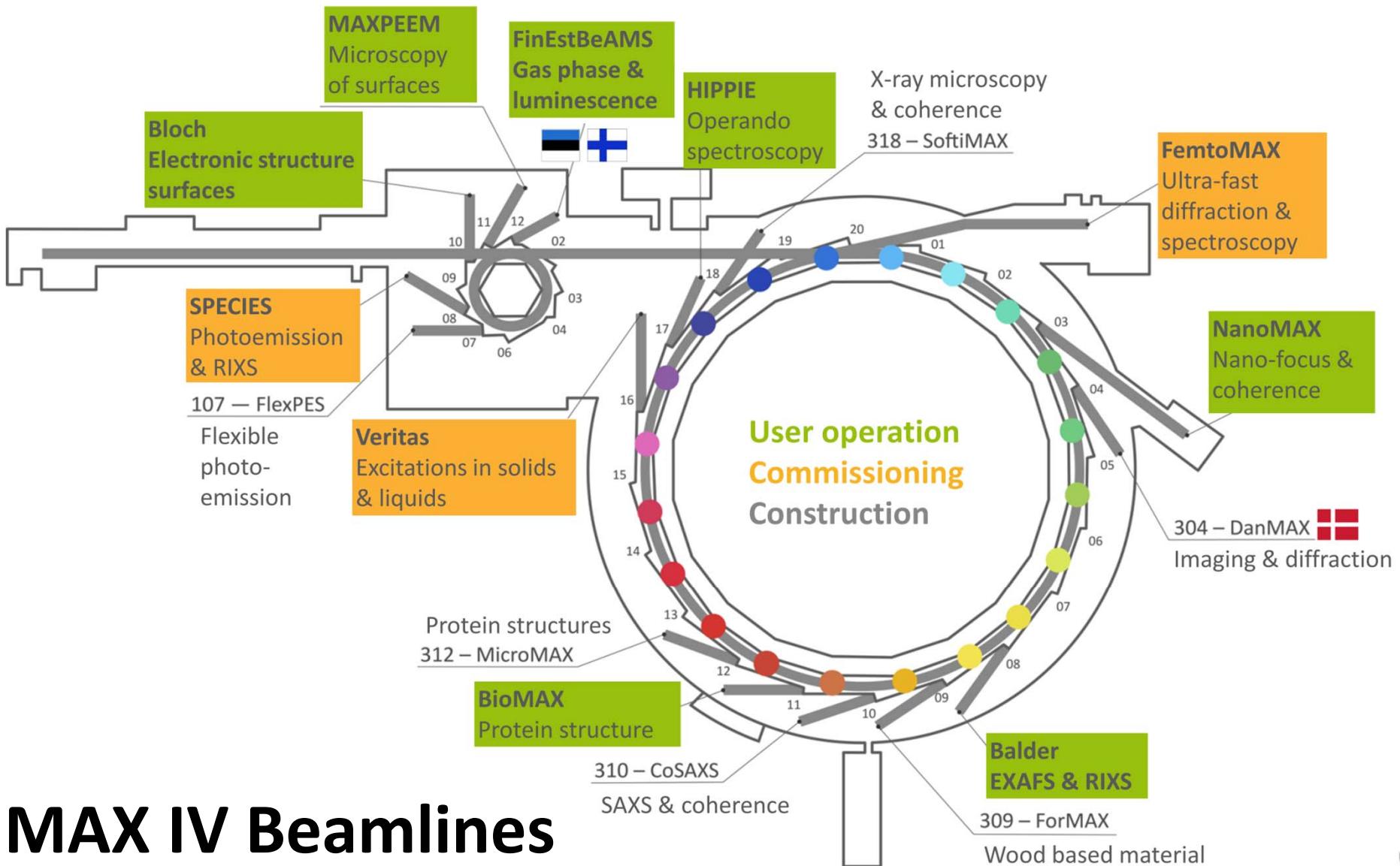
Detectors

Data acquisition

Beamline control

Data analysis & storage





MAX IV Beamlines

Many Beamlines

What they have in common?

What makes the difference?

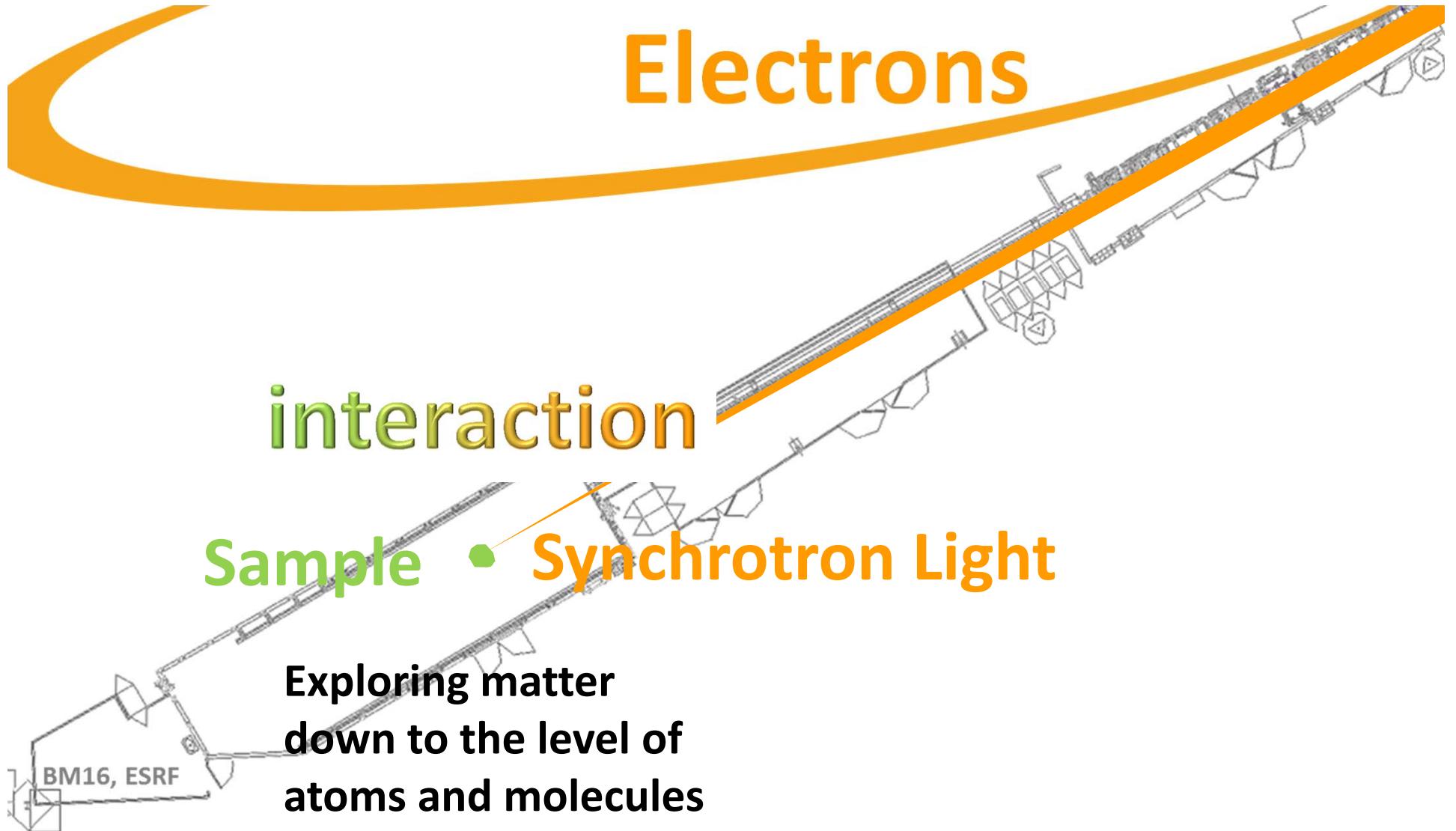
Electrons

interaction

Sample

Synchrotron Light

Exploring matter
down to the level of
atoms and molecules



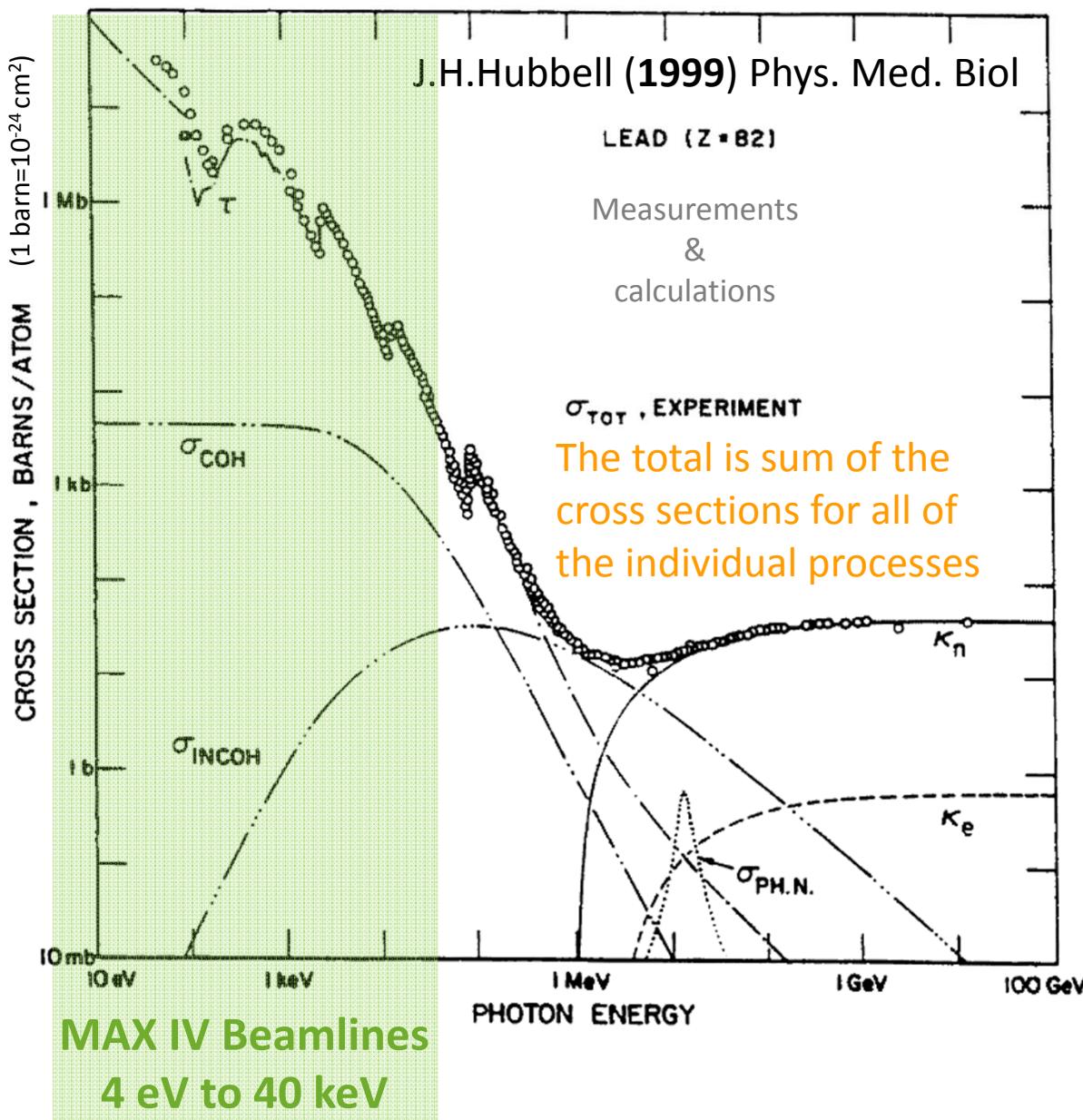
Range of the electromagnetic spectrum covered at MAX IV

Class			Frequency	Wavelength	Energy
	γ	Gamma rays	300 EH ζ	1 pm	1.24 MeV
Ionizing radiation	HX	Hard X-rays	30 EH ζ	10 pm	124 keV
	SX	Soft X-rays	3 EH ζ	100 pm	12.4 keV
	EUV	Extreme ultraviolet	300 PH ζ	1 nm	1.24 keV
Visible	NUV	Near ultraviolet	30 PH ζ	10 nm	124 eV
	NIR	Near infrared	300 TH ζ	1 μ m	1.24 eV
	MIR	Mid infrared	30 TH ζ	10 μ m	124 meV
	FIR	Far infrared	3 TH ζ	100 μ m	12.4 meV
	EHF	Extremely high frequency	300 GHz	1 mm	1.24 meV
Microwaves and radio waves	SHF	Super high frequency	30 GHz	1 cm	124 μ eV
	UHF	Ultra high frequency	3 GHz	1 dm	12.4 μ eV
	VHF	Very high frequency	300 MHz	1 m	1.24 μ eV
	HF	High frequency	30 MHz	10 m	124 neV
	MF	Medium frequency	3 MHz	100 m	12.4 neV
	LF	Low frequency	300 kHz	1 km	1.24 neV
	VLF	Very low frequency	30 kHz	10 km	124 peV
	ULF	Ultra low frequency	3 kHz	100 km	12.4 peV
	SLF	Super low frequency	300 Hz	1 Mm	1.24 peV
	ELF	Extremely low frequency	30 Hz	10 Mm	124 feV
			3 Hz	100 Mm	12.4 feV
			Present		
			Future		

Photoelectric effect

Coherent
Thomson (Rayleigh)
scattering

Incoherent
Compton scattering



these are competing possibilities... which one wins?

It depends on:

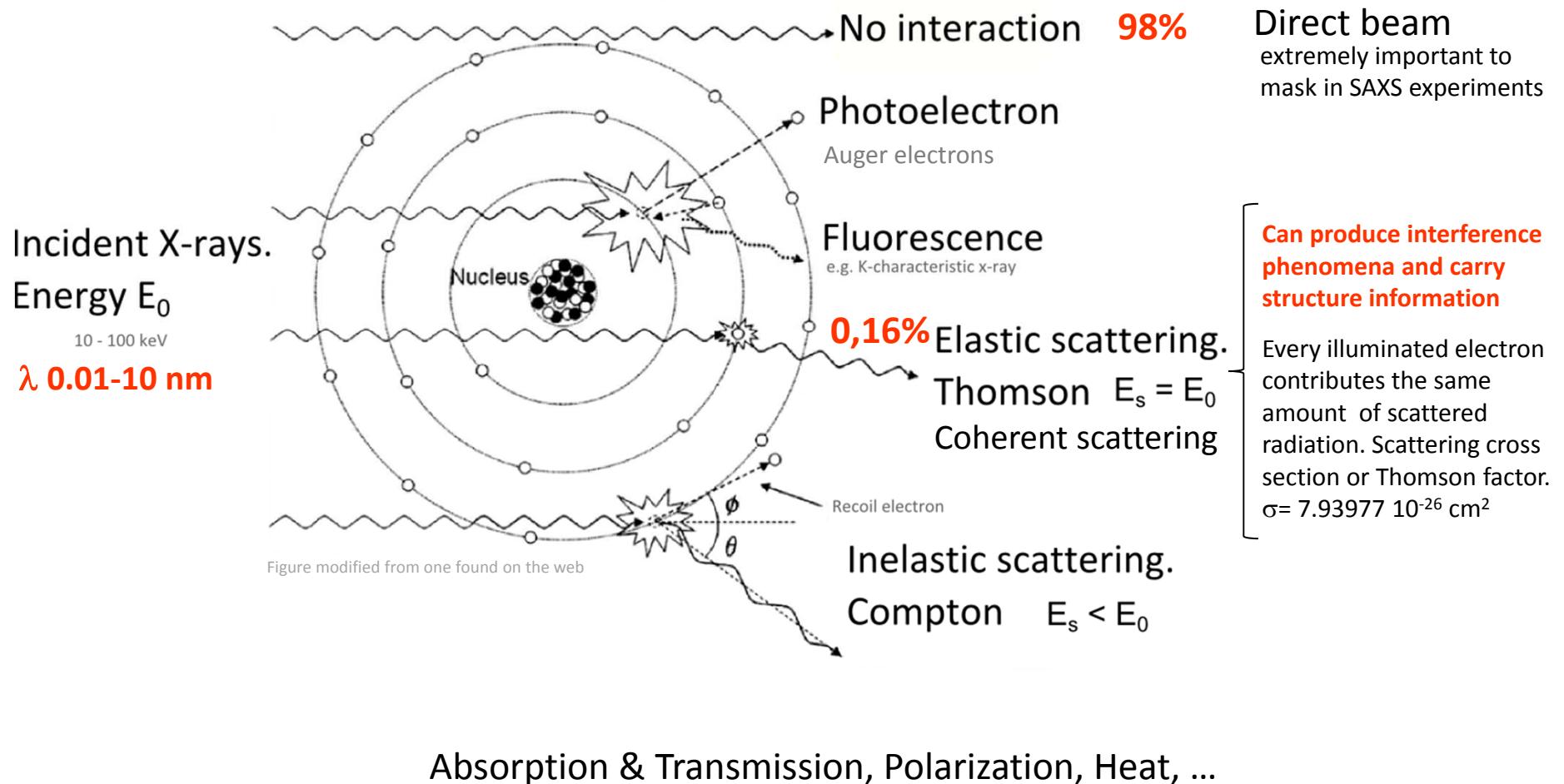
- ✓ the energy of the photon: $h\nu$
- ✓ the composition of the material: Z
- ✓ CHANCE! σ

Stochastic processes.

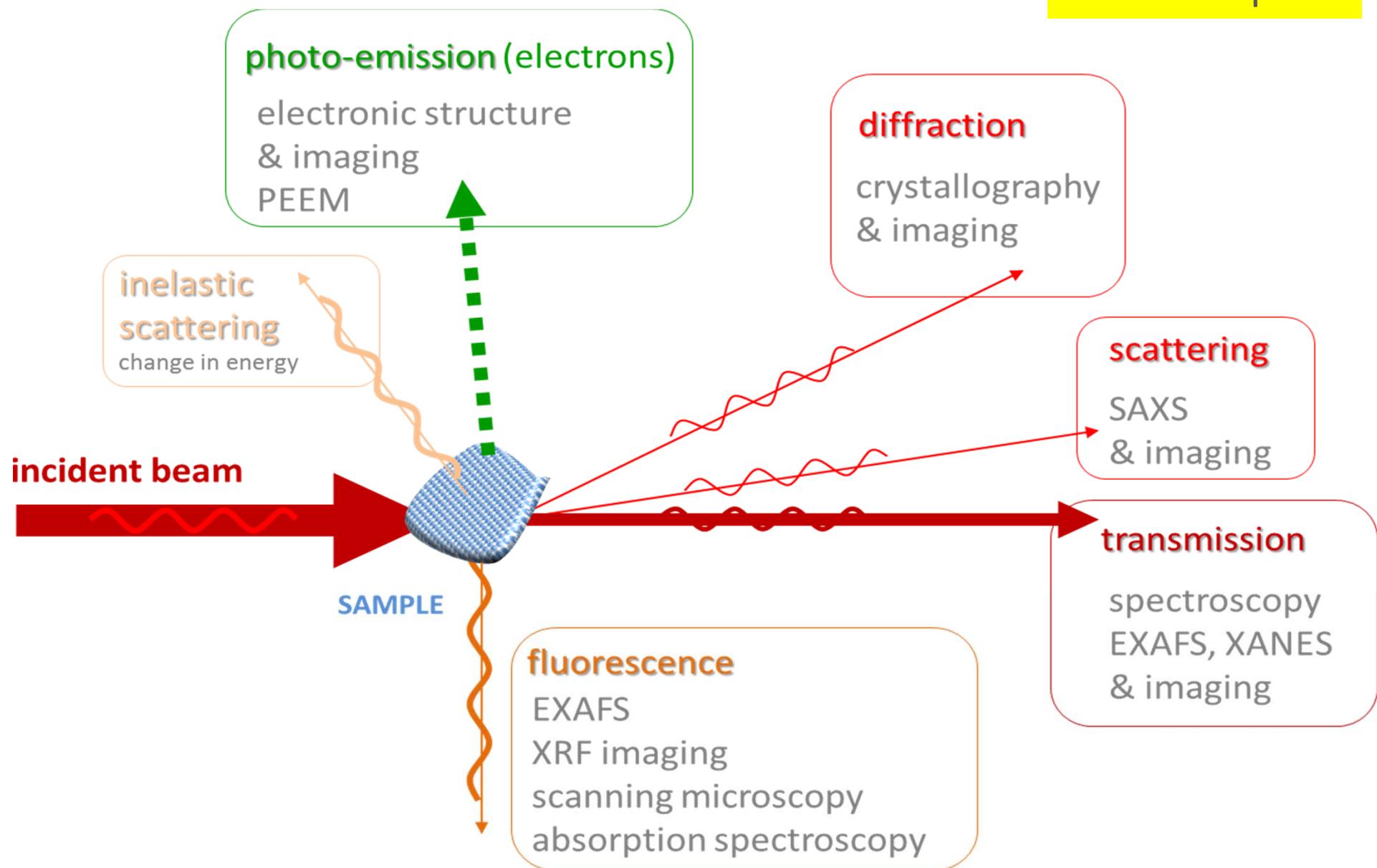
Single collisions are not reproducible,
however collisions are predictable:
collecting well enough number of
events one finds a well-behaved
probability distribution

Calculations of photon
interactions are given in
terms of **atomic cross
sections σ (cm²/atom)**

X-ray interaction with matter



still incomplete



Techniques using synchrotron radiation

X-ray absorption spectroscopy, including

X-ray magnetic circular dichroism

X-ray emission spectroscopy

Photoelectron spectroscopy, including

Angle-resolved photoemission spectroscopy

Vibrational spectroscopy

...

X-ray tomography

Synchrotron infrared microspectroscopy

Photoemission electron microscopy

Scanning x-ray microscopy

Phase contrast microscopy

...

Powder diffraction, crystallography

Small angle x-ray scattering

Inelastic x-ray scattering

Magnetic scattering

Time resolved x-ray scattering

...

X-ray lithography

List by no means complete!



Techniques using synchrotron radiation

Spectroscopy

X-ray absorption spectroscopy, including
X-ray magnetic circular dichroism
X-ray emission spectroscopy
Photoelectron spectroscopy, including
Angle-resolved photoemission spectroscopy
Vibrational spectroscopy

...

Imaging

X-ray tomography
Synchrotron infrared microspectroscopy
Photoemission electron microscopy
Scanning x-ray microscopy
Phase contrast microscopy

...

Scattering

Powder diffraction, crystallography
Small angle x-ray scattering
Inelastic x-ray scattering
Magnetic scattering
Time resolved x-ray scattering
...

Microfabrication

X-ray lithography

List by no means complete!



**How do we perceive
and learn about
the physical world?**

Interaction

two-way effect: two or more objects have an effect upon one another.

interactions of interactions within systems (interconnectivity): combinations of many simple interactions can lead to surprising emergent phenomena.

In **physics**, a fundamental interaction (depending on the nature of the interaction, it might also be called a fundamental force) is a process by which elementary particles interact with each other.

An interaction is often described as a physical field, and is mediated by the exchange of gauge bosons between particles.

Fundamental laws and concepts of nature

1. Conservation Laws

some particular measurable property of an isolated physical system does not change as the system evolves over time. This applies to:

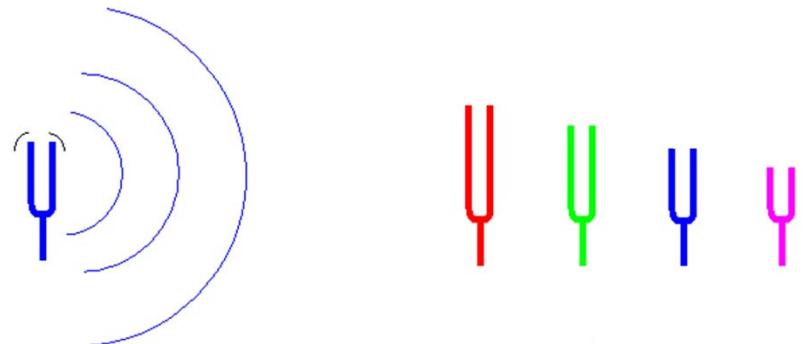
- Energy
- Linear momentum
- Angular momentum
- Electric charge
- ...?

2. Minimum total potential energy principle

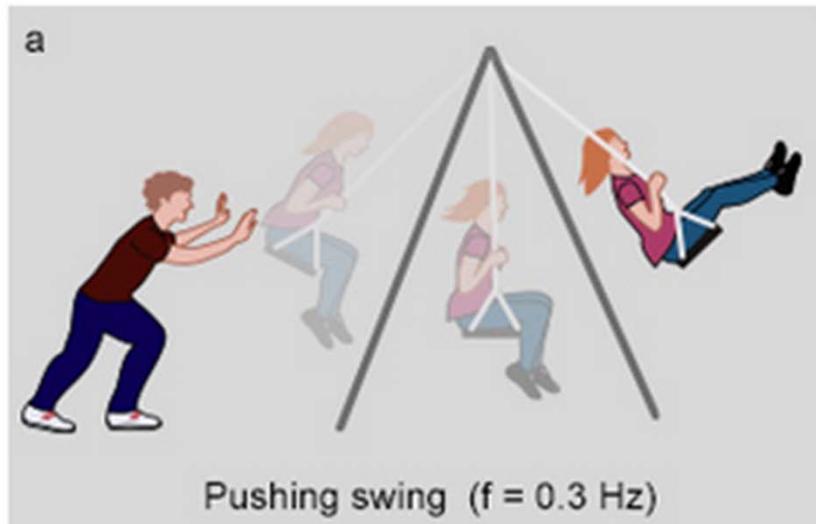
tendency to the most stable configuration

3. Natural Resonances

Everything can store extra energy,
if added energy...at the right frequency

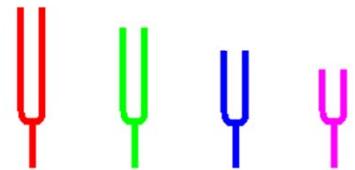
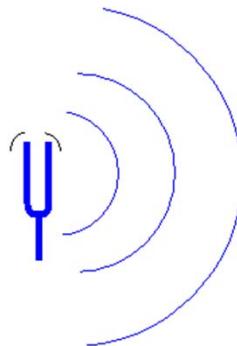


Matter vibrates! Atoms vibrate ... molecules vibrate ... solids vibrate ...

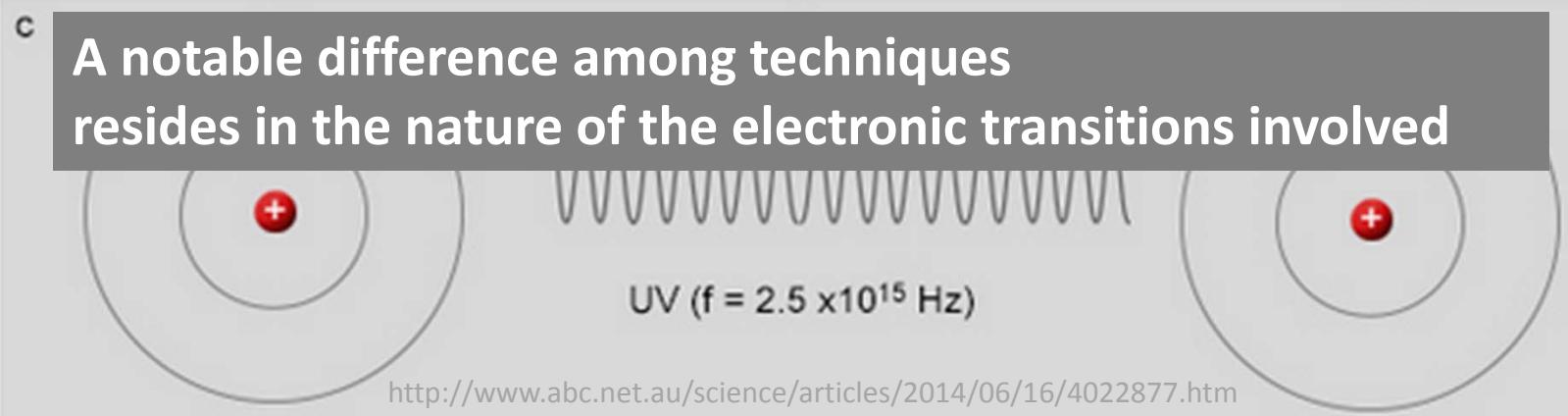
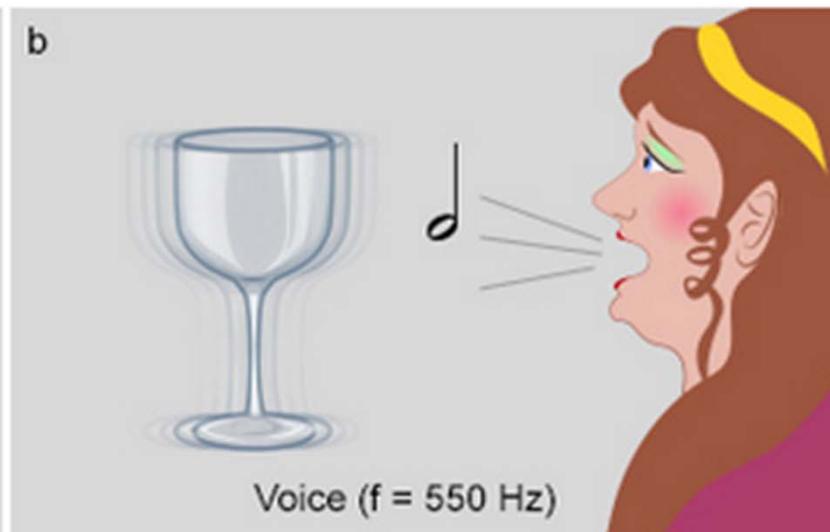
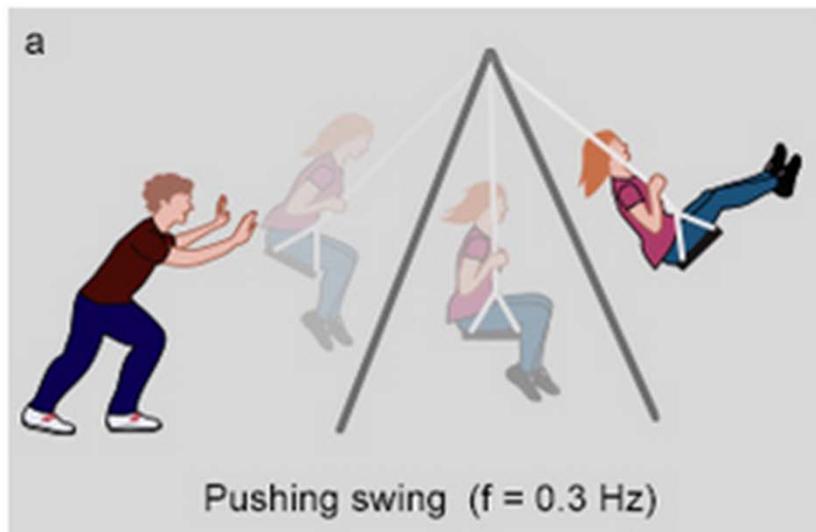


3. Natural Resonances

Everything can store extra energy,
if added energy...at the right frequency



Matter vibrates! Atoms vibrate ... molecules vibrate ... solids vibrate ...



Fundamental parameters
that we use to perceive
the physical world

Which information
can we extract?

- Energy Chemical
- Momentum Structural
- Position Imaging
- Time Dynamics

Can map any atom's position, identity, and dynamics

Fundamental parameters
that we use to perceive
the physical world

- Energy
- Momentum
- Position
- Time

Techniques that
we use to
measure them

Spectroscopy
Scattering
Diffraction
Imaging

Which information
can we extract?

Chemical
Structural
Imaging
Dynamics

Can map any atom's position, identity, and dynamics

Energy [kg·m²·s⁻²]

Momentum [kg·m·s⁻¹]

Position [m]

Angular Momentum

[kg·m²·s⁻¹]

...?

Time

Which information can we extract?

Chemical

SPECTROSCOPY techniques are used to study the **energies of particles that are emitted or absorbed by**

SPECTROSCOPY

- 01 Low-Energy Spectroscopy
- 02 Soft X-Ray Spectroscopy
- 03 Hard X-Ray Spectroscopy
- 04 Optics/Calibration/Metrology

Scattering and electron motion.

EXAFS, RIXS, XPS,...

Structural

SCATTERING or DIFFRACTION techniques make use of the **patterns of light produced** when x-rays are deflected by

SCATTERING

- 05 Hard X-Ray Diffraction
- 06 Macromolecular Crystallography
- 07 Hard X-Ray Scattering
- 08 Soft X-Ray Scattering

problems.

SAXS, MX, Powder,...

Imaging

IMAGING techniques use the light-source beam to obtain **pictures with fine spatial resolution** of the

IMAGING

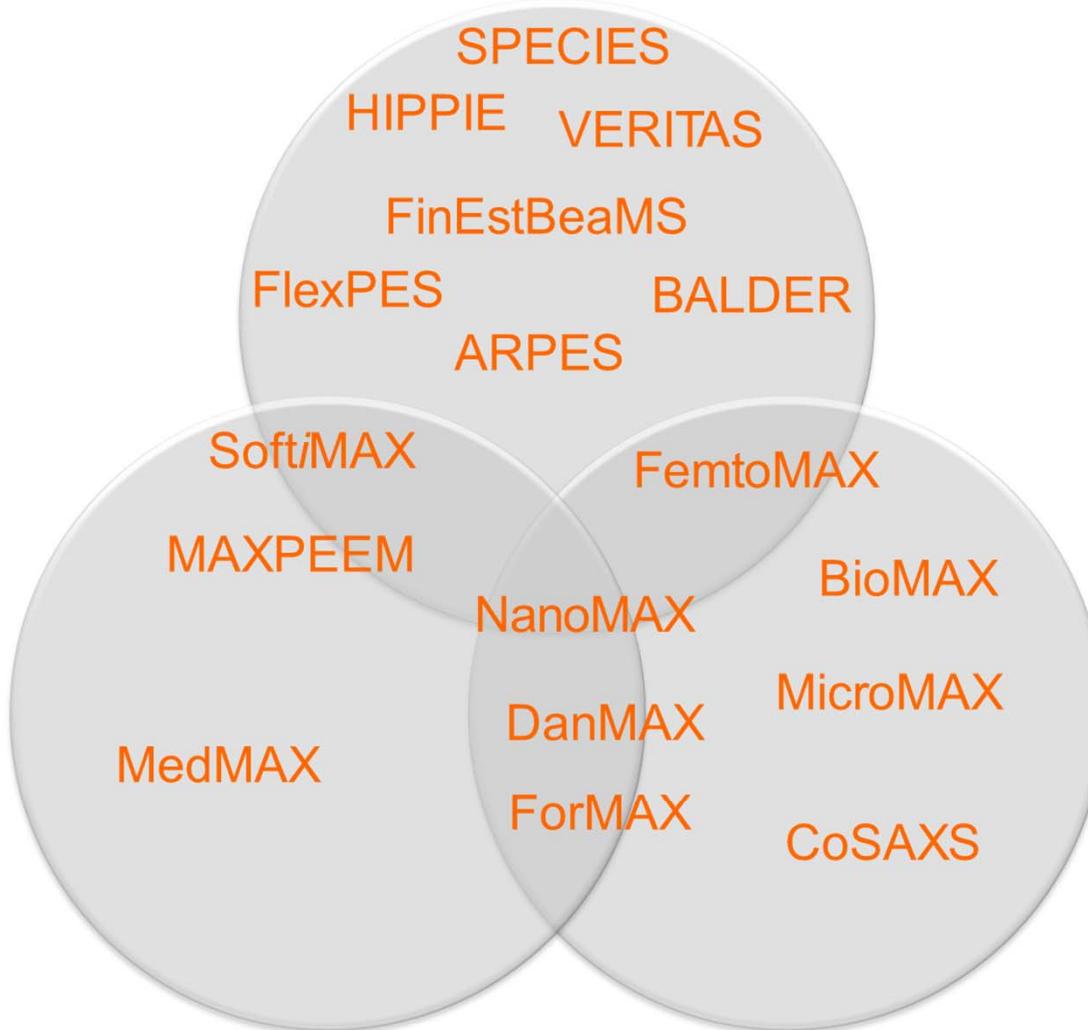
- 09 Hard X-Ray Imaging
- 10 Soft X-Ray Imaging
- 11 Infrared Imaging
- 12 Lithography

Radiography, and x-ray tomography.

Radiography (2D)
Tomography (3D), ...

Combination of techniques, In-situ, Kinetics, gracing incidence, etc.

Spectroscopy

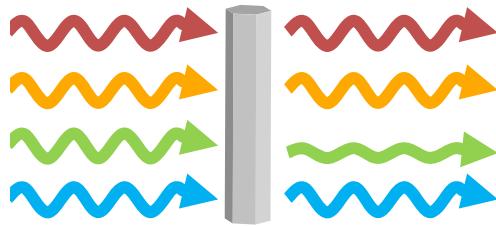


Imaging

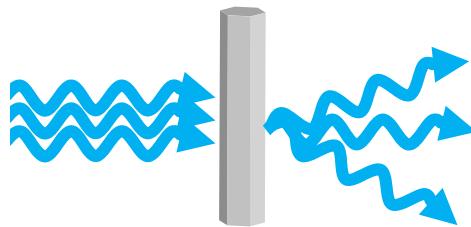
Diffraction/
Scattering

Techniques

Spectroscopy



Scattering & Diffraction



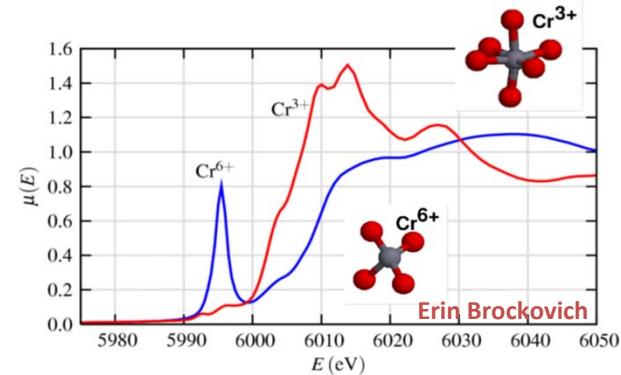
Imaging & Tomography



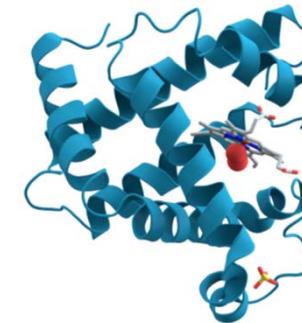
Ana.Labrador@maxiv.lu.se

Information obtained

Chemical: What's the material made of?

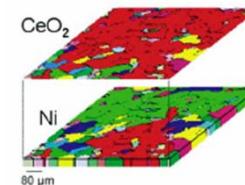


Structural: How are the atoms arranged?



Morphology: What does it look like?

in 2D and 3D?

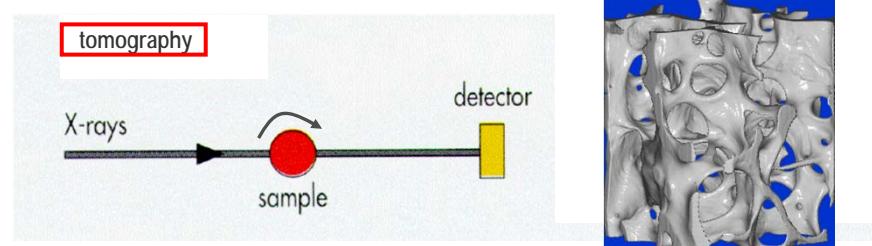
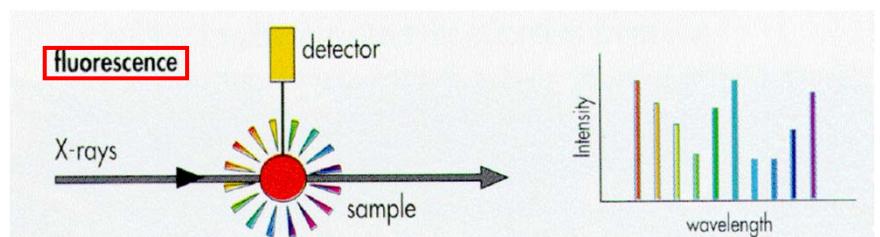
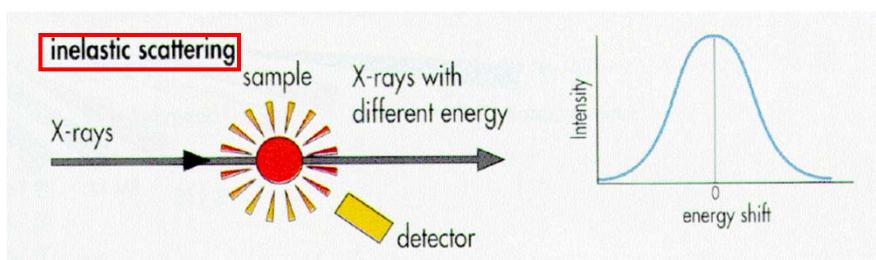
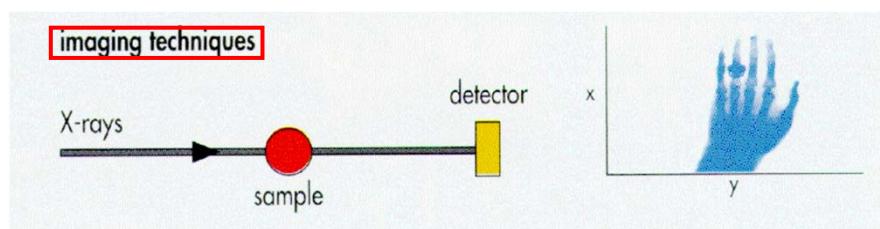
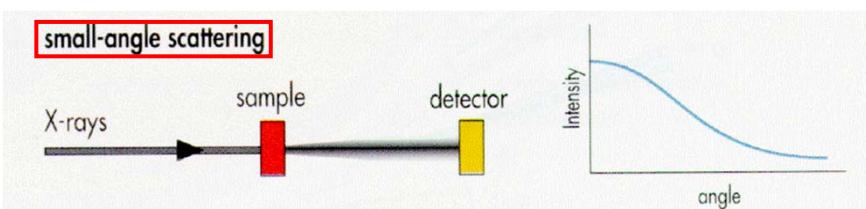
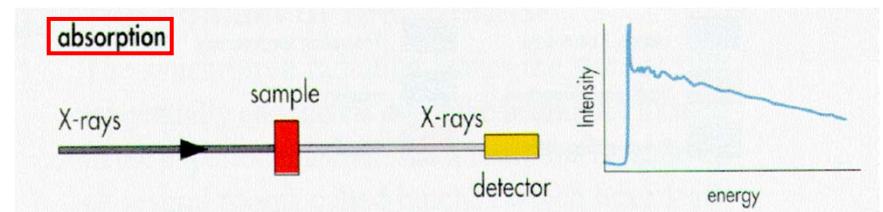
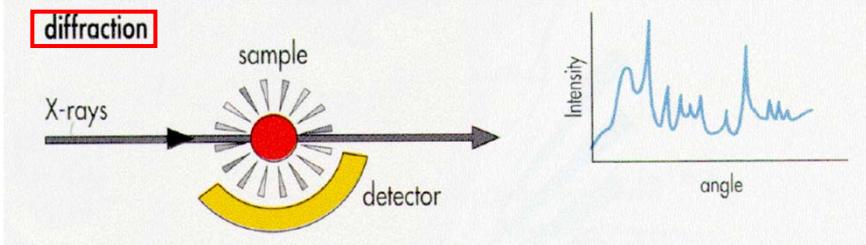


Orientation maps from a deposited oxide film and a textured nickel substrate obtained from x-ray Laue microdiffraction.



MAX IV

How to use the synchrotron light

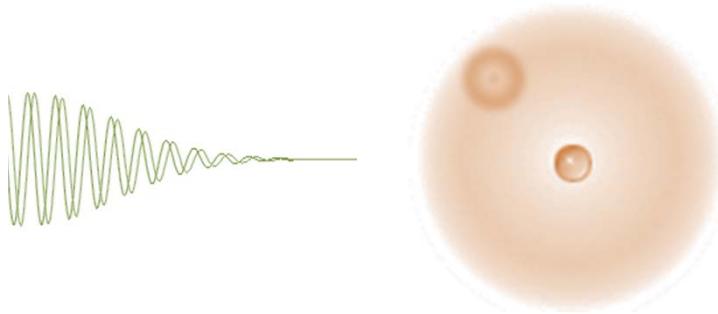


What can happen when a photon enters something that is not vacuum?



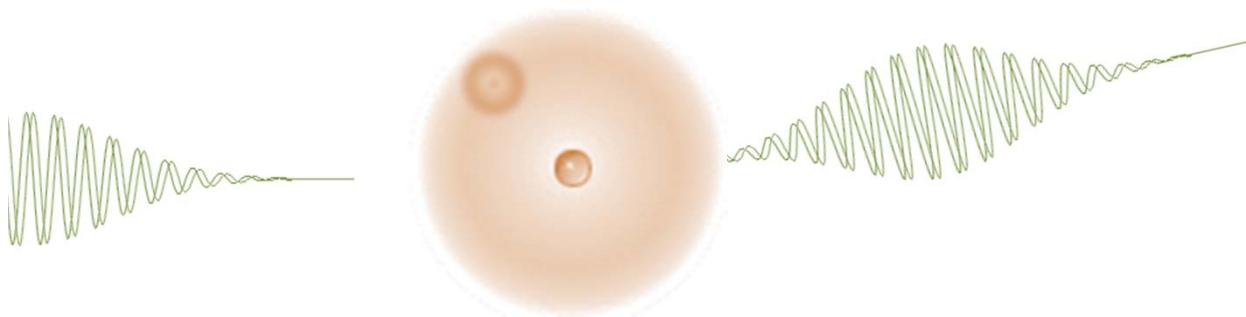
[BTW: Scientists create light from vacuum
November 17, 2011, Chalmers Univ. of Technology]

What happens to the photon



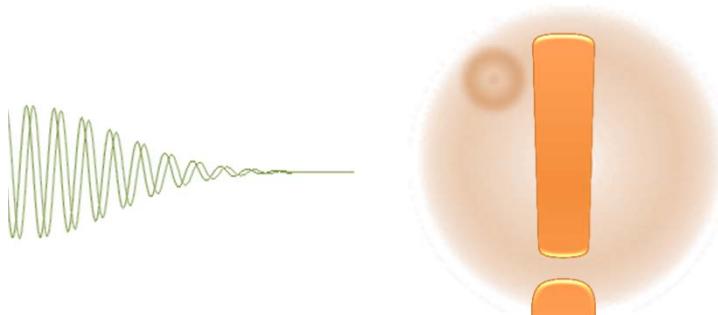
Nothing. It passes through
as it don't see the atom

'direct beam'



The photon changes
direction

scattering

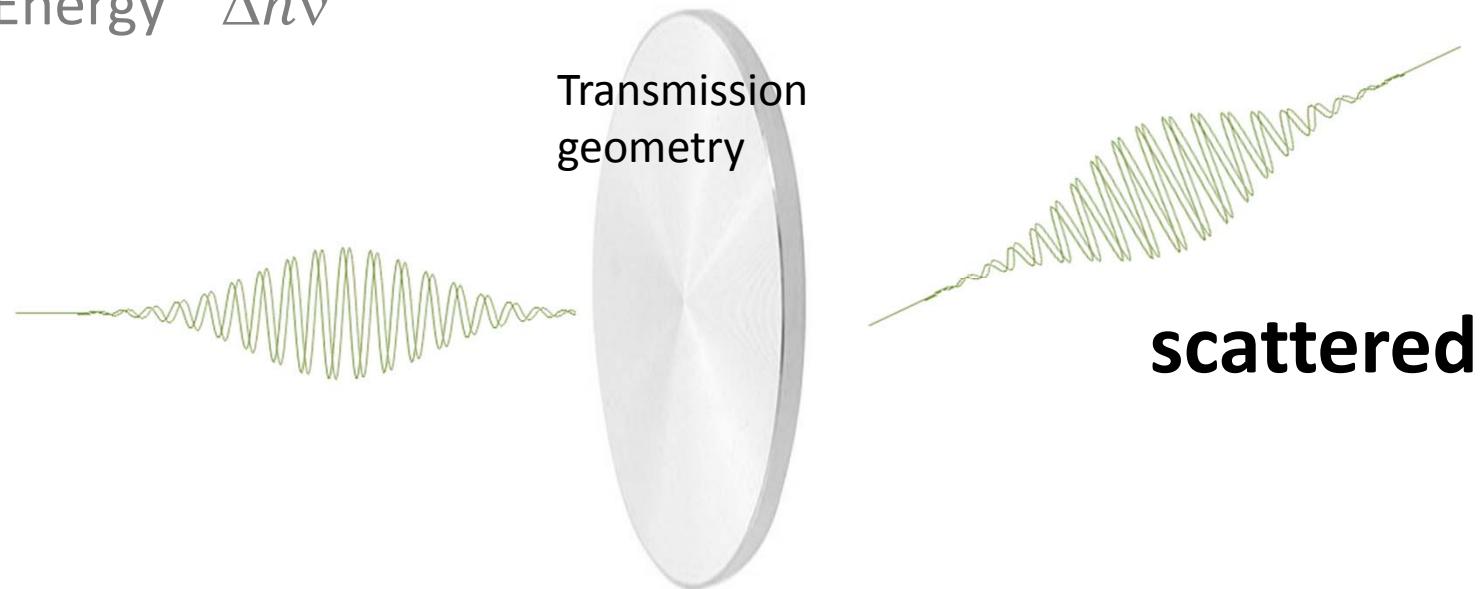


The photon disappears?

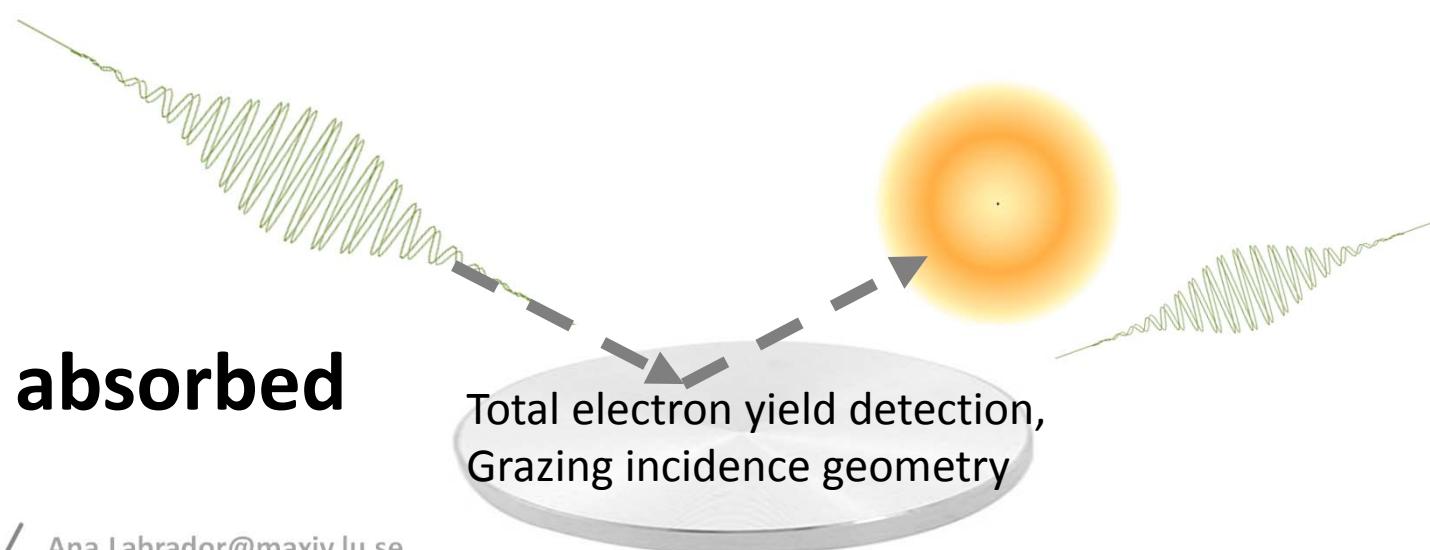
**absorption
emission**
MAX IV

Fix Energy $h\nu$

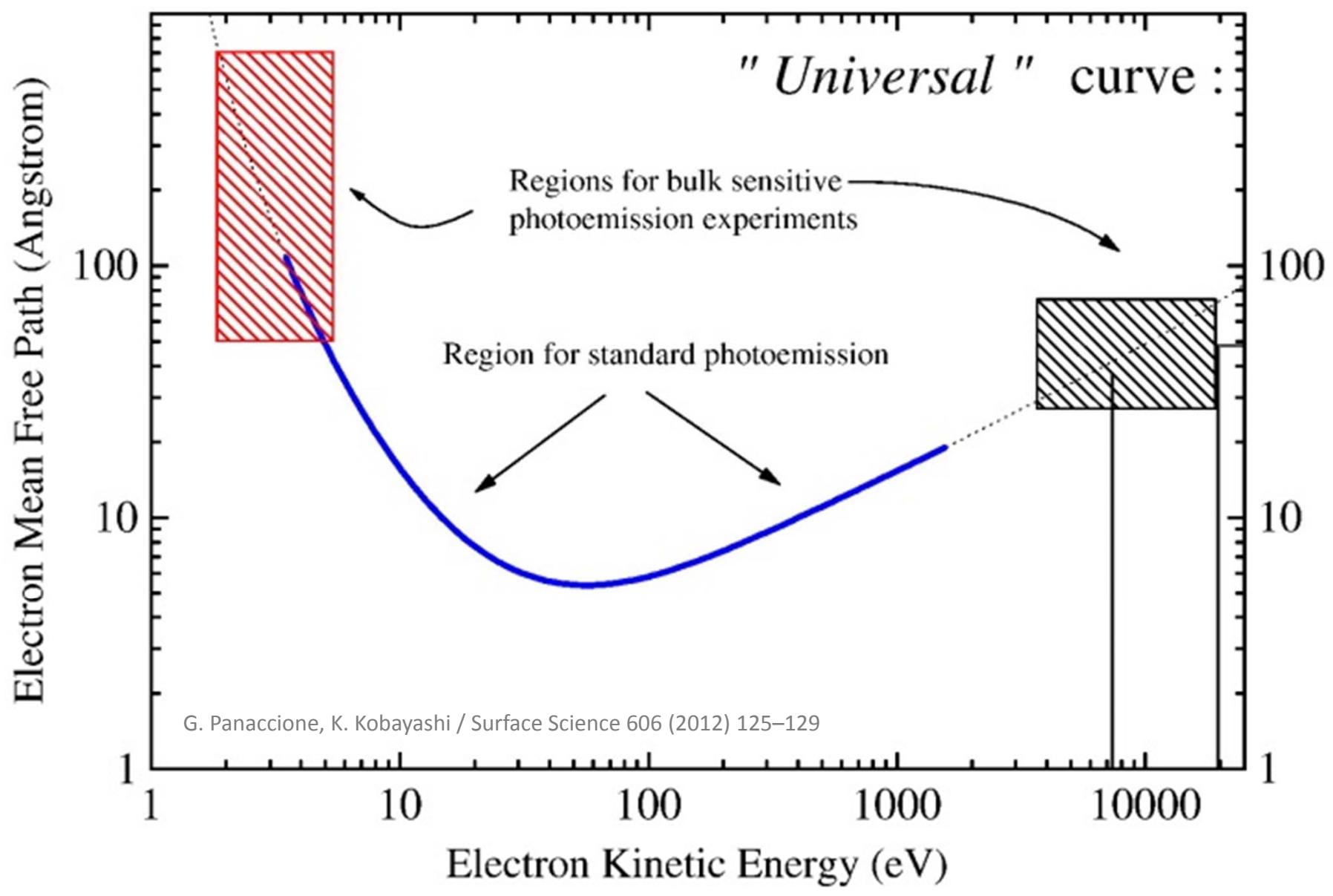
Varied Energy $\Delta h\nu$



scattered



absorbed



* UHV techniques developments 1970

Can map any atom's position, identity, and dynamics

High penetration power

Non-destructive

"Real" samples under "real" conditions

High flux

Time resolution,

3D -> 4D imaging

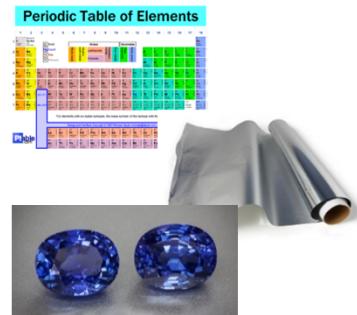
Statics -> Dynamics

In-situ and

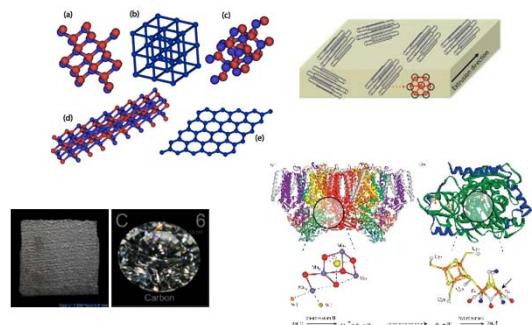
In operandi

Materials -> Processes

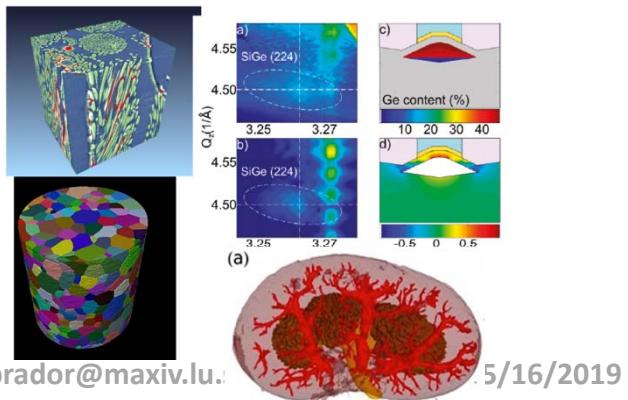
Chemistry - Spectroscopy



Structure - Scattering



Morphology - Imaging



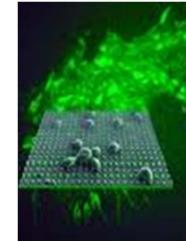
High penetration power
Non-destructive
"Real" samples under "real" conditions

High flux
Time resolution,
3D → 4D imaging
Statics → Dynamics

In-situ and
In operandi
Materials → Processes

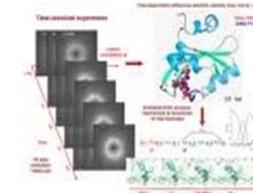
Applications -general

High spatial resolution (< a few nanometer)



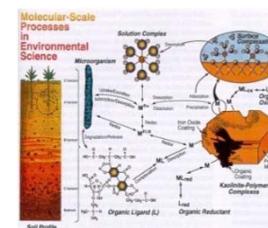
Nano engineering
Electronics
Fibers
Composites
Micro-fluidics

Time resolved studies (< femtoseconds 10^{-15} s)



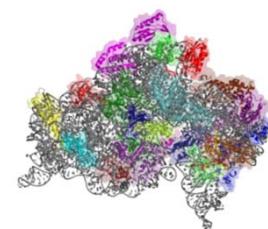
Phase transitions
Catalysts
Energy storage
Photo-biology

High chemical sensitivity (dilute samples or detailed electronic structure)



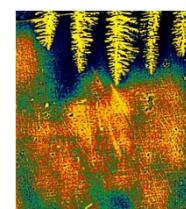
Environmental Sc.
Films and interfaces
Gases
Superconductors
Magnetism

Collimated beam -> complex structures



Pharmacy (Proteins/
viruses)
Polymers
Cellulose

Coherence -> new possibilities for X-ray imaging



Metallurgy
Medicine

Synchrotron radiation

in our life



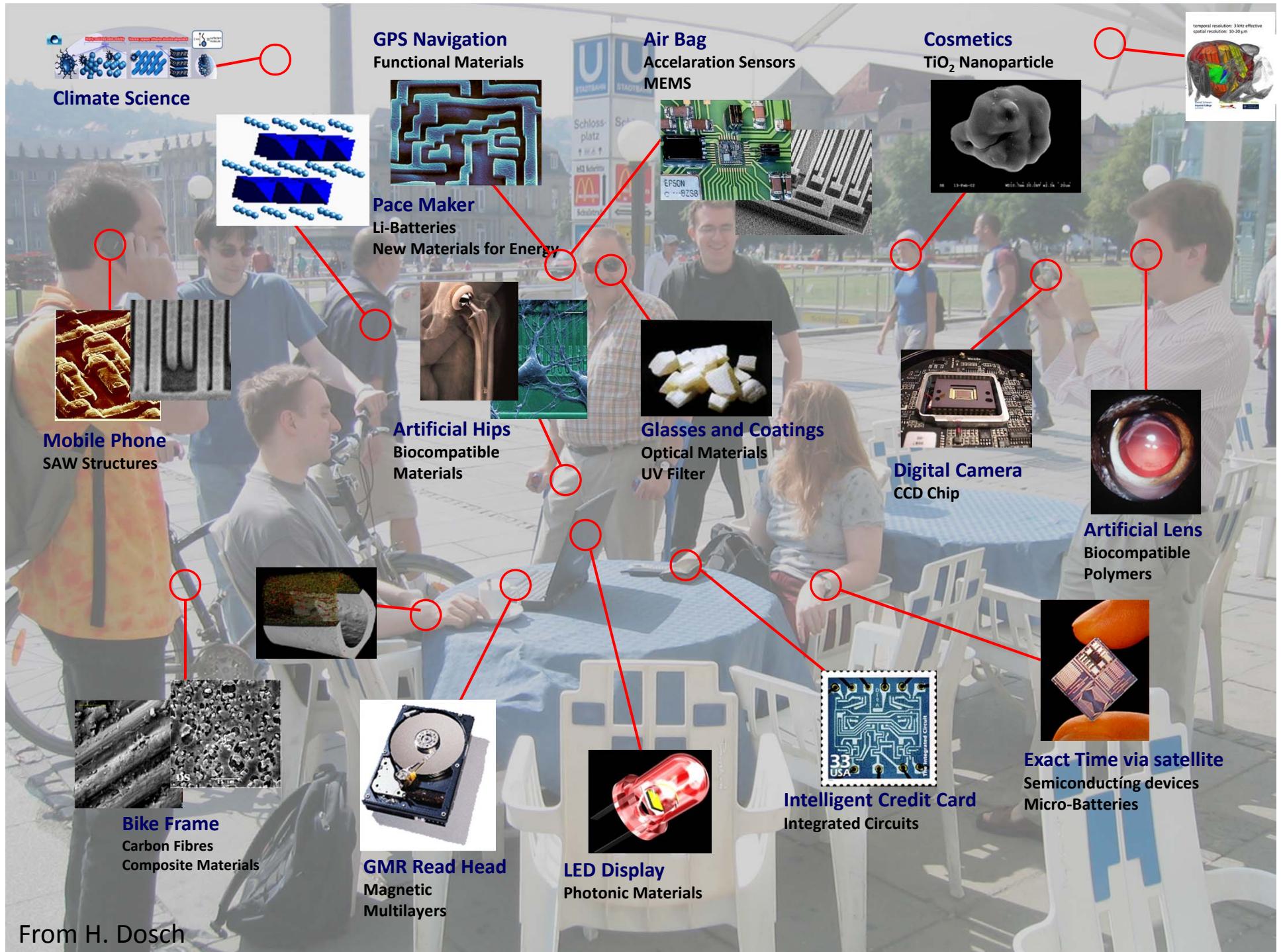
Image Courtesy of NASA

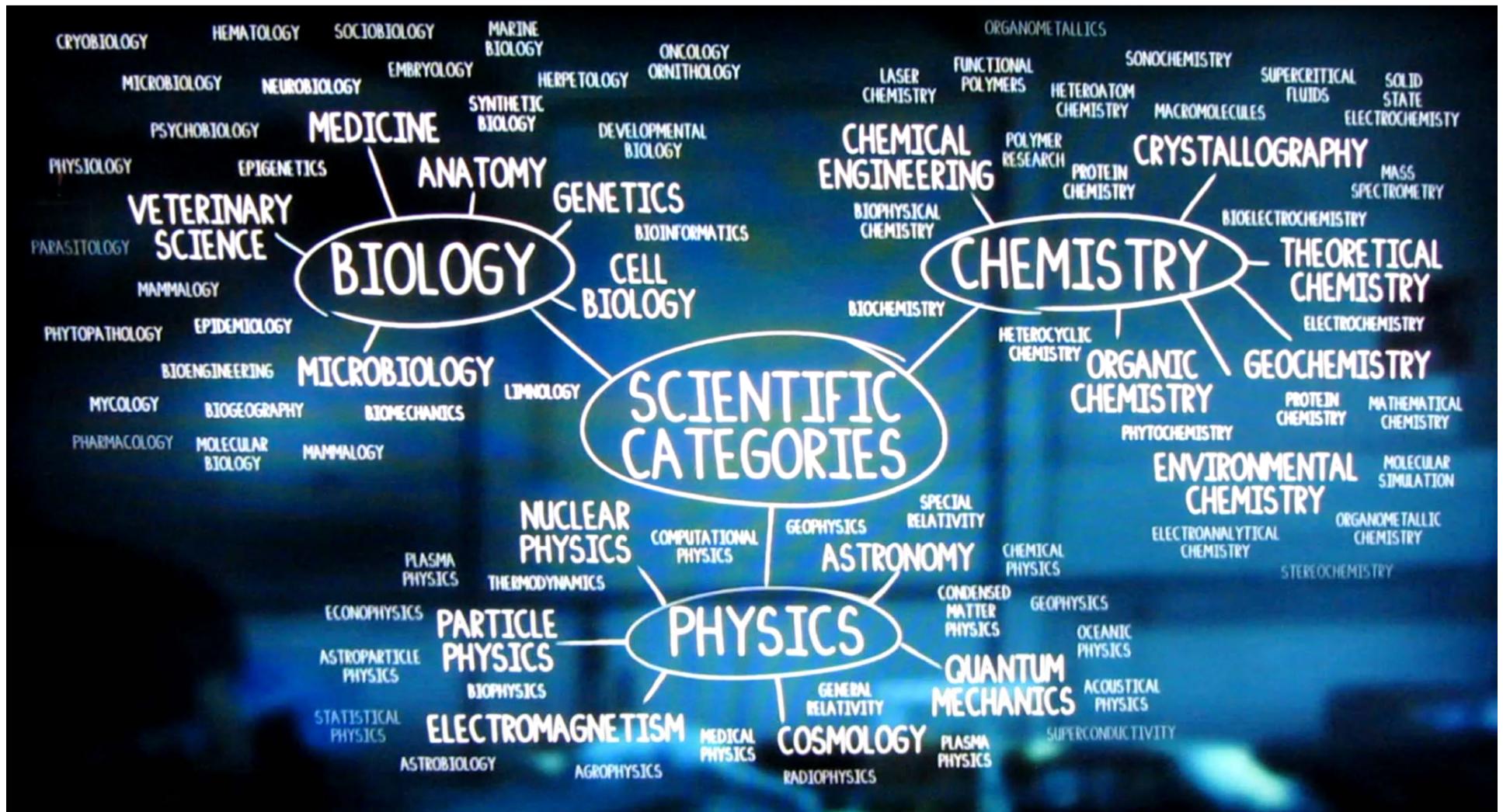
Synchrotron Radiation in our Lives



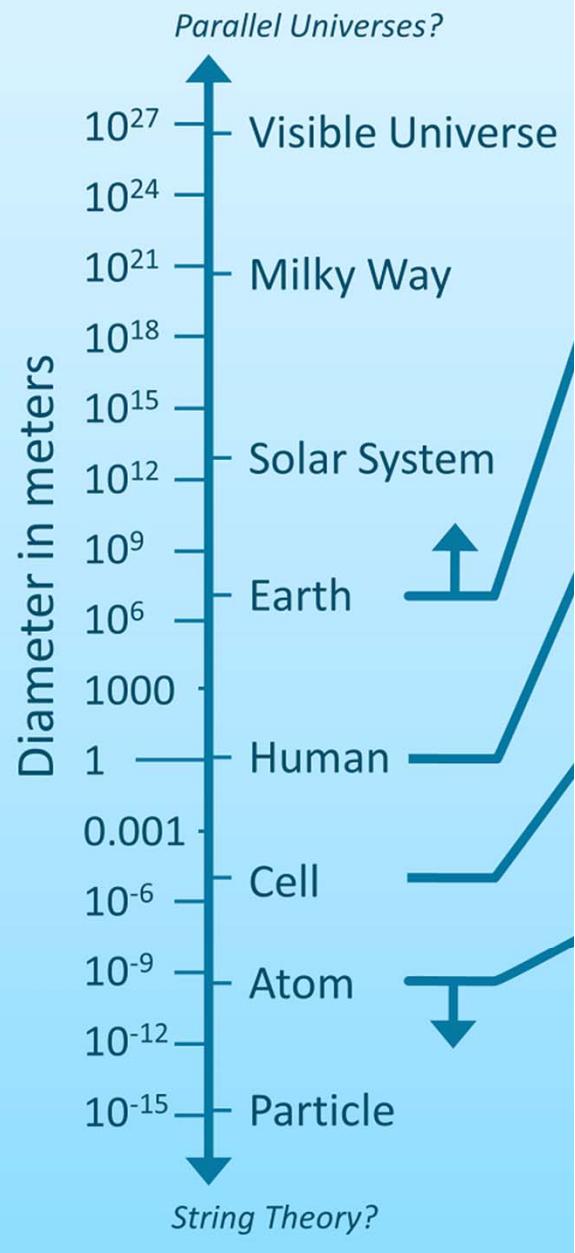
AL adapted from From H. Dosch, MPI

Une journée typique à Stuttgart

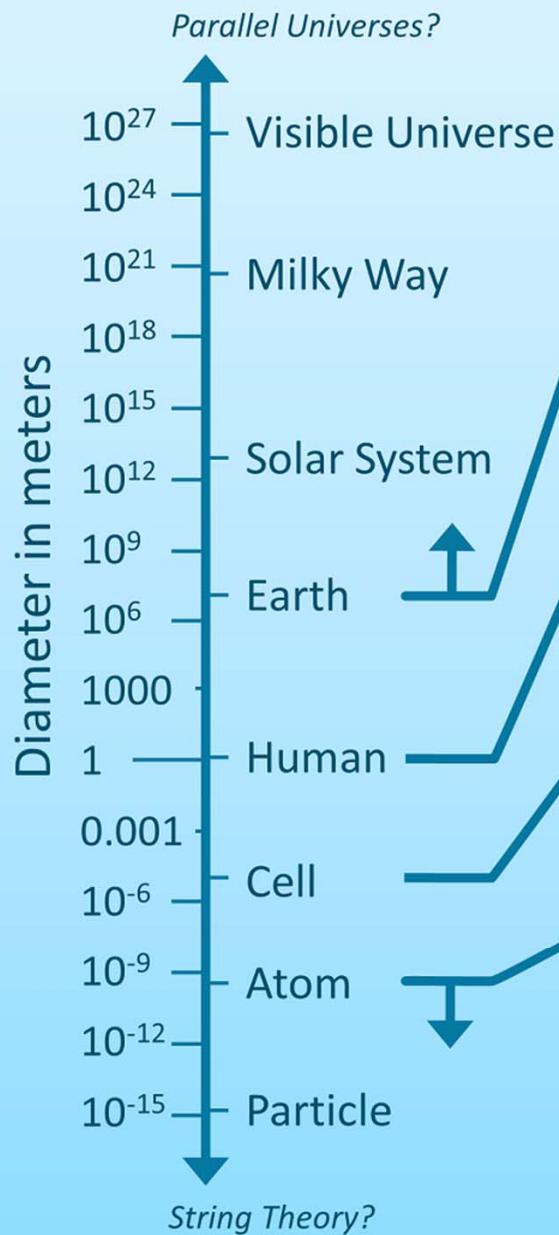




Scale of the Universe



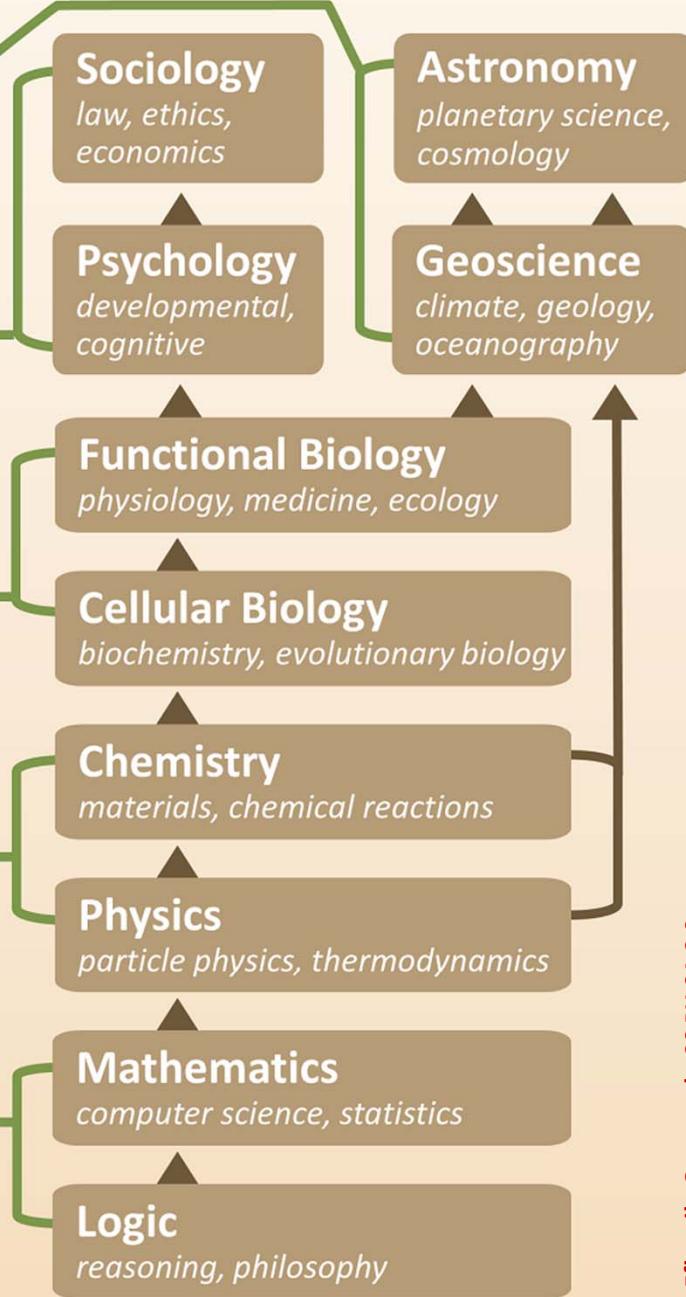
Scale of the Universe



Branches of Science



Hierarchy of Science



taking up user operation at a growing number of beamlines

taking up user operation at a growing number of beamlines

We already have the tools and methods for

- structural biology,
- low-density matter,
- surfaces under ambient conditions,
- coherent nano imaging
- low energy luminescence
- ...

We started offering new capabilities for:

- chemistry,
- catalysis ,
- environmental research,
- surface structure determination on micro- and nanoscales,
- band-structure investigations.

...

Climate science

10% of fine particles over London
are fatty acid molecules
released into the air from cooking



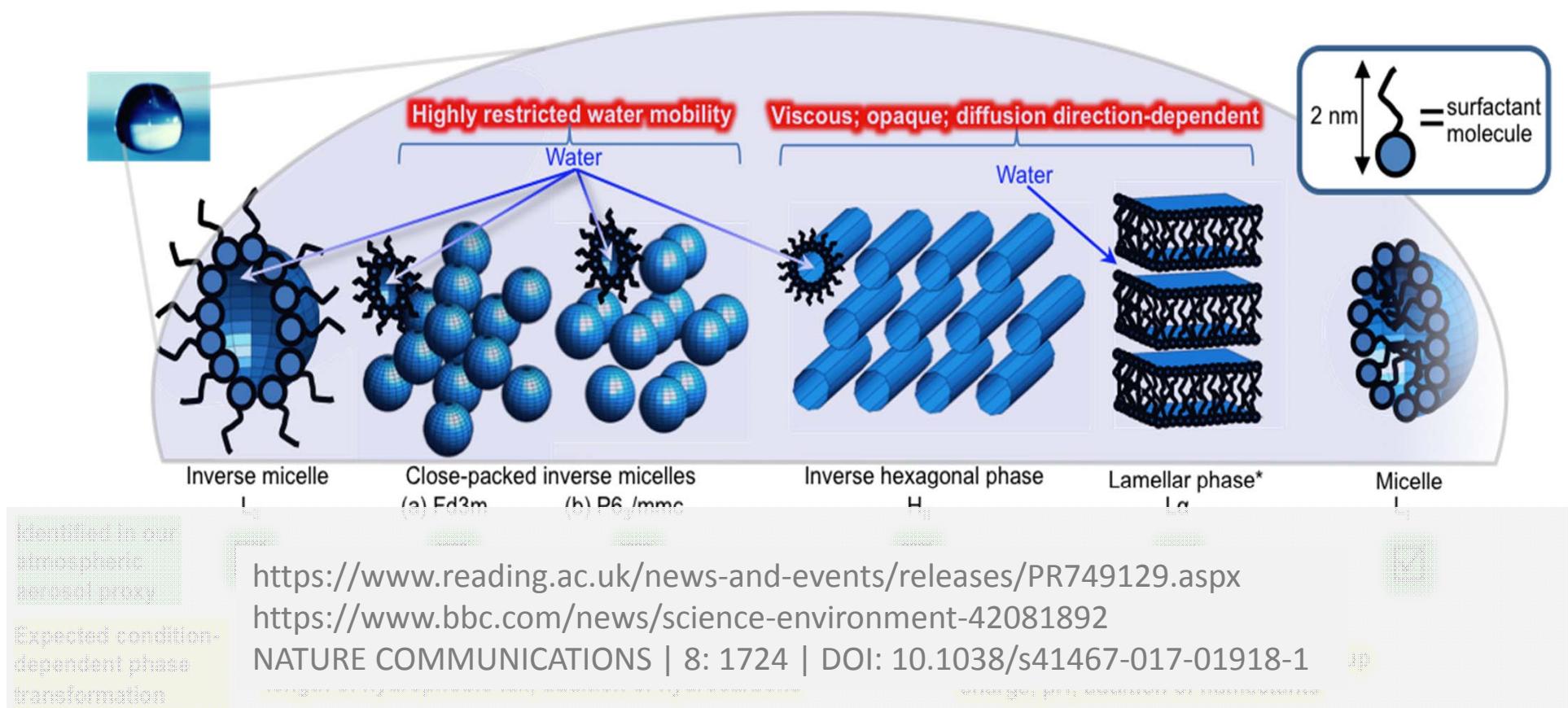
Synchrotron X-ray experiment

atmospheric aerosol droplet
of brine and oleic acid



Ultrasonic levitator

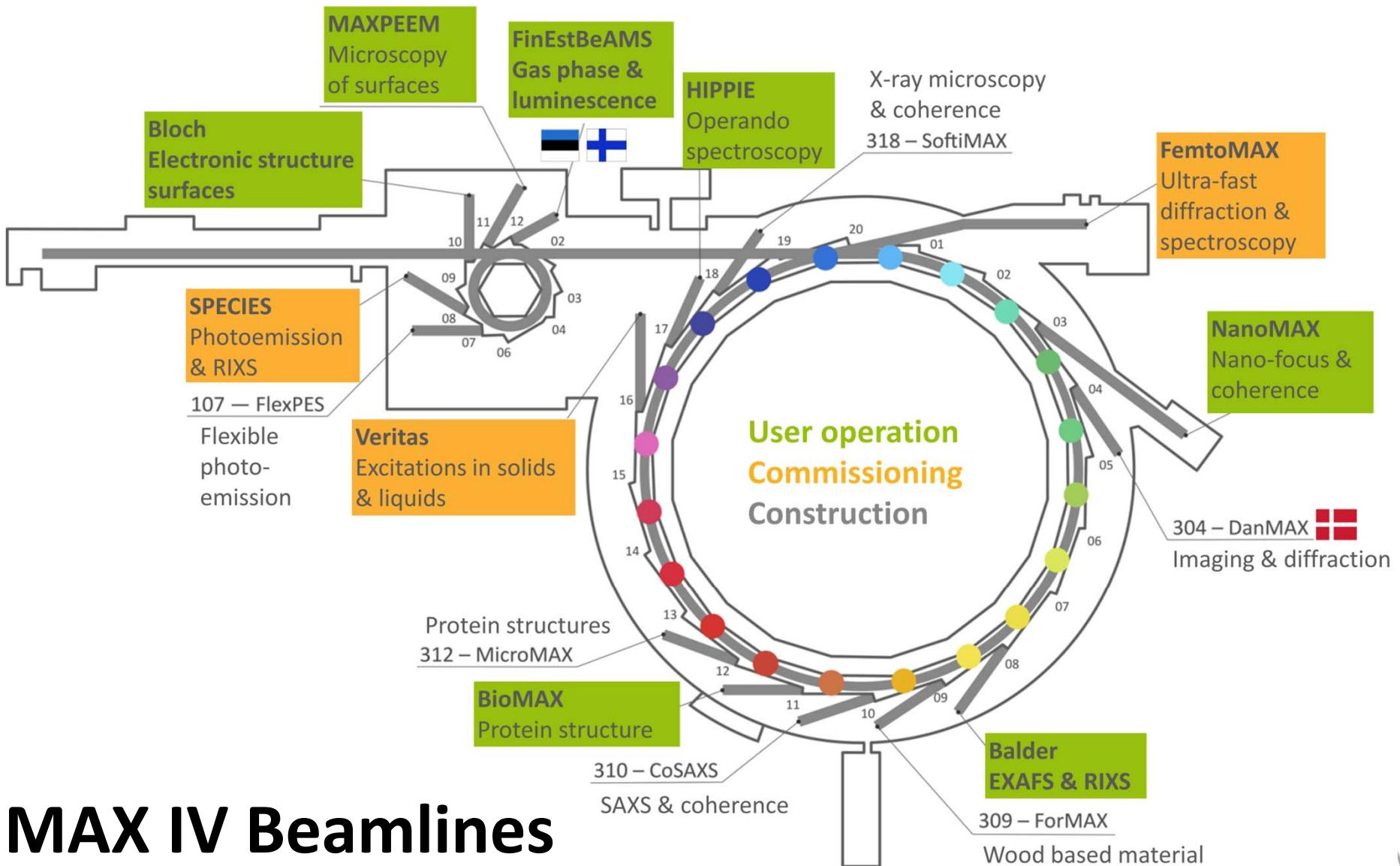
Self assembled 3D structures



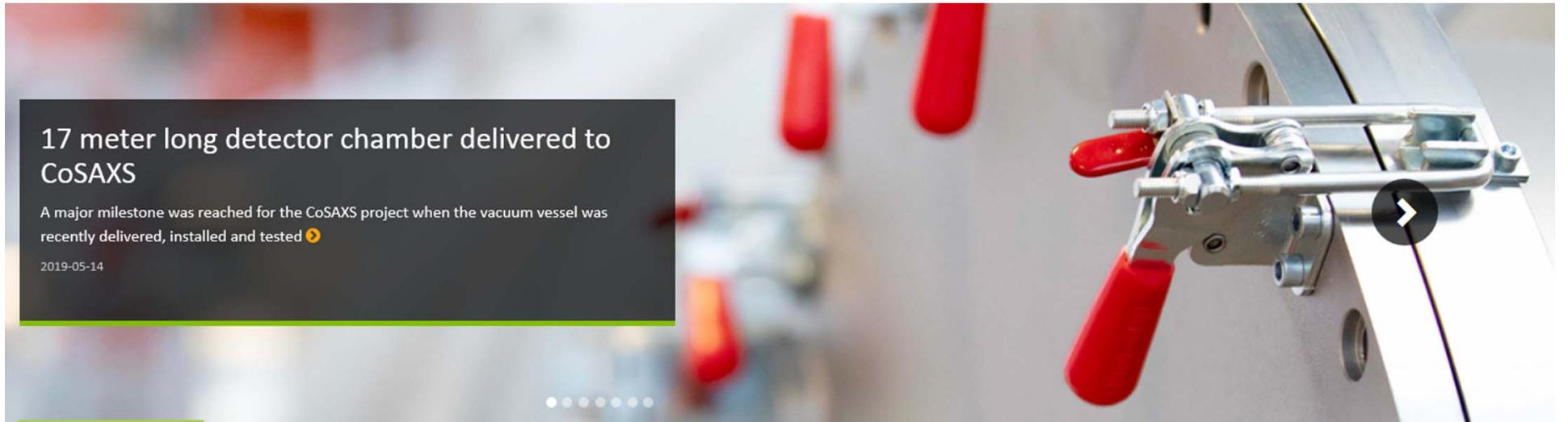
Self assembled 3D structures

Insight on further physical properties fundamental to atmospheric research, such as viscosity, diffusion or optical transparency.

“molecules from burning fat
could counteract global warming”



MAX IV Beamlines

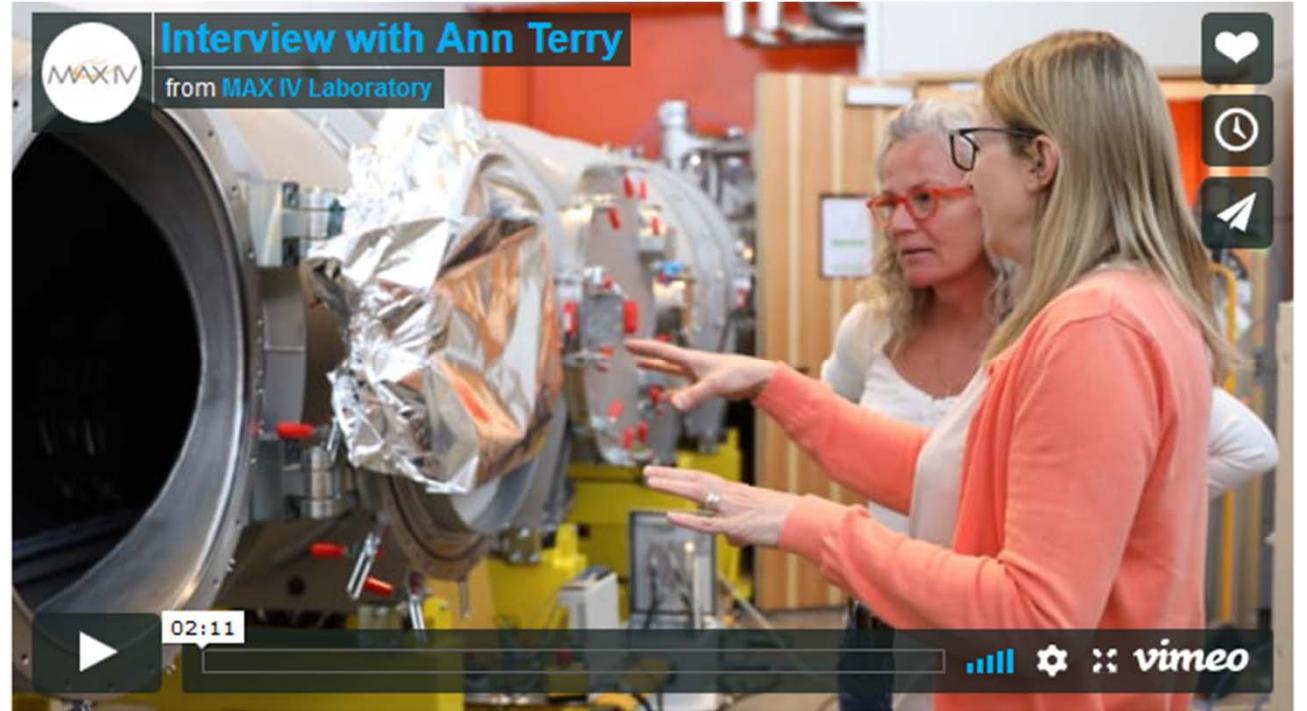


17 meter long detector chamber delivered to CoSAXS

A major milestone was reached for the CoSAXS project when the vacuum vessel was recently delivered, installed and tested

2019-05-14

17 meter long detector chamber delivered to **CoSAXS**



From crystal and fiber diffraction to solution scattering

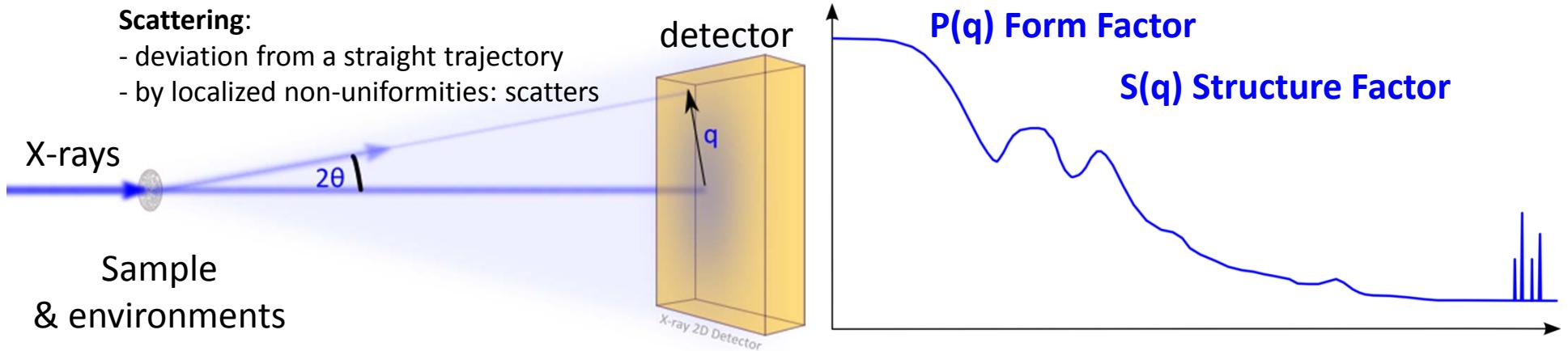
Interference patterns of objects vary along with the samples' nature, including the symmetry of matrix of molecules embedded and the freedom of molecules in the matrix.

	Single Crystal	Fiber/ Membrane	Powder/ Micro-crystals	Solution
Sample states				
Interference pattern				

Slide borrowed . Apologies for missing the source

SAXS in a nutshell

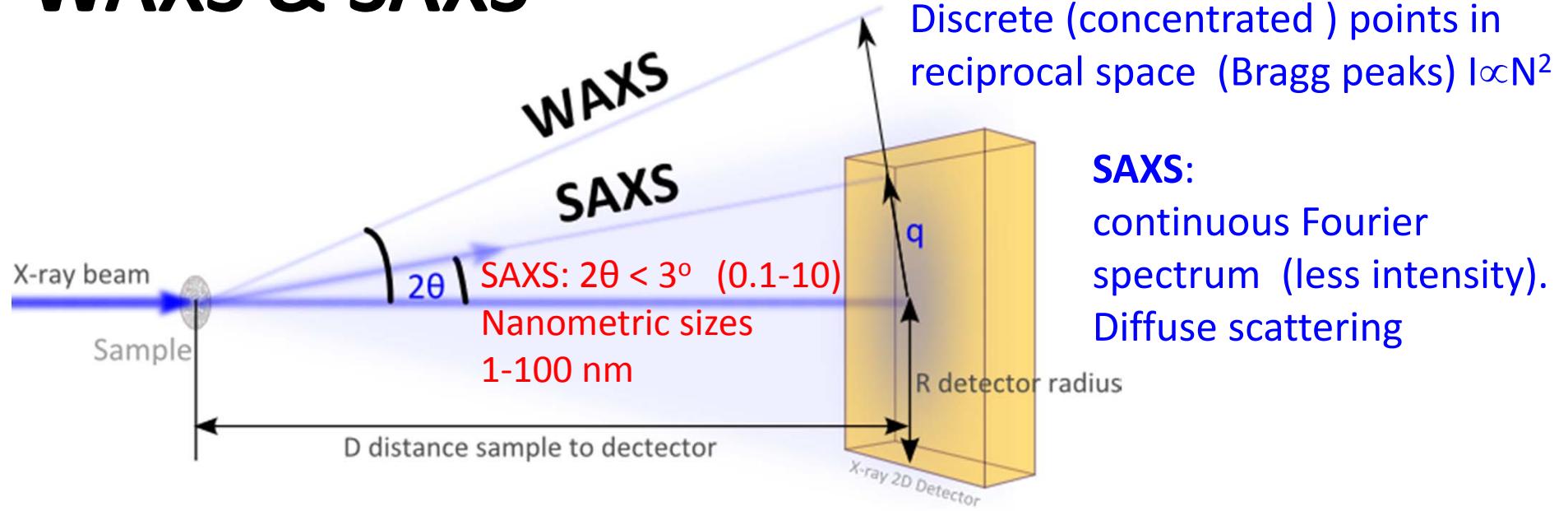
SAXS (Small-Angle X-ray Scattering) has become a key technique providing morphological information at molecular level (few to hundred nm) and the possibility of studying a diversity of samples in their own natural environment or under well controlled conditions.



interference patterns on
detector encodes the
distances among scatters

researchers can work backwards to
discern the molecular morphologies
that scattered the X-rays.

WAXS & SAXS



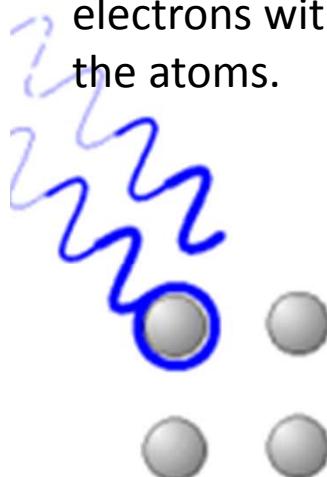
Same physical phenomena

$\lambda = 0.15 \text{ nm}$	$D [\text{m}]$	Topics
WAXS	0.05-0.2	Arrangement of chain segments
MAXS	0.2-1	Liquid-crystalline structure, rigid-rod polymers
SAXS	1-3	Nanostructure 3 -50 nm
GISAXS reflection mode		Probes the particles on the surface layer
ASAXS		
USAXS	6-15	Nanostructure 15 nm -2 μm

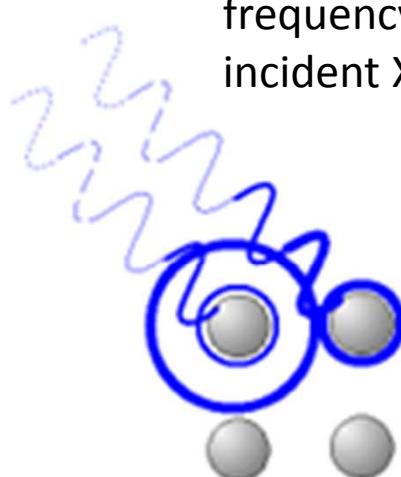
X-ray scattering by atoms:

Incident plane waves are reemitted as spherical waves

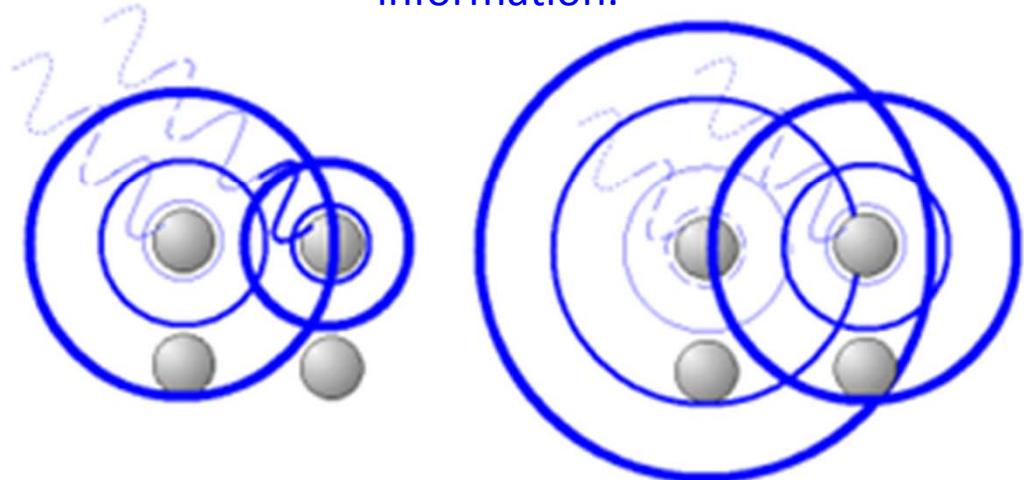
The EM field of the incident X-ray beam **exerts a force** on the electrons within the atoms.



The electrons start **oscillating***, therefore emitting spherical waves at the same frequency as the incident X-rays



Emitted waves of neighbour atoms oscillate synchronous to each other: **coherent waves** whose interference pattern at the detector carries structural information.



- Measure averages
- Large particles scatter more...
- Aggregation/repulsion sensitive...

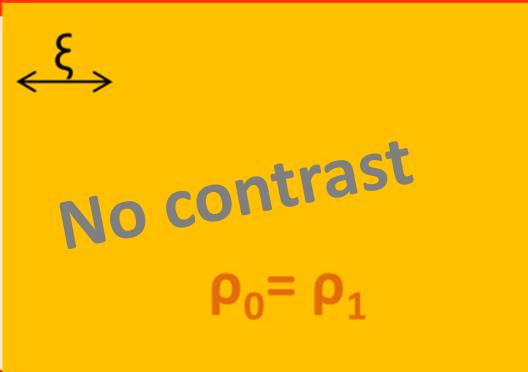
*free electron approx.

X-ray photon (10^4 eV) >>>
electron binding energy (~ 10 eV)

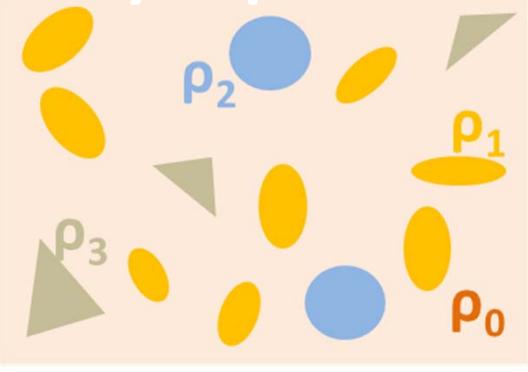
Monodisperse



Identical in shape and size.



Polydisperse

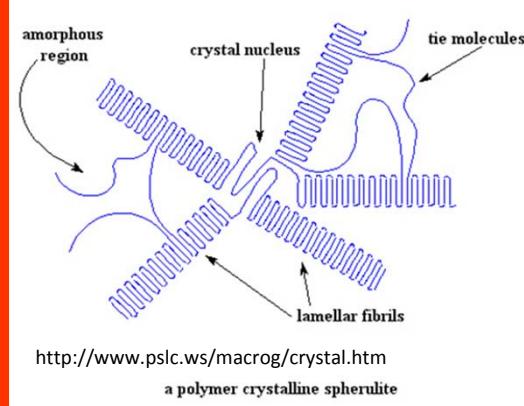


Different shape and size

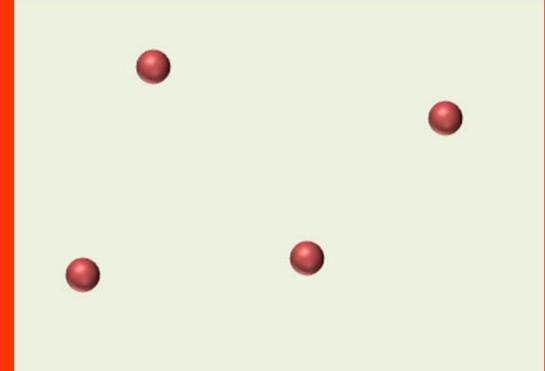
Samples

Solids, liquids, gas, gels,
Heterogeneous domains,
...

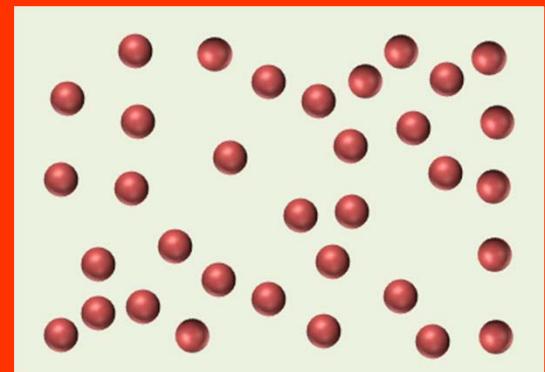
Amorphous & Crystalline



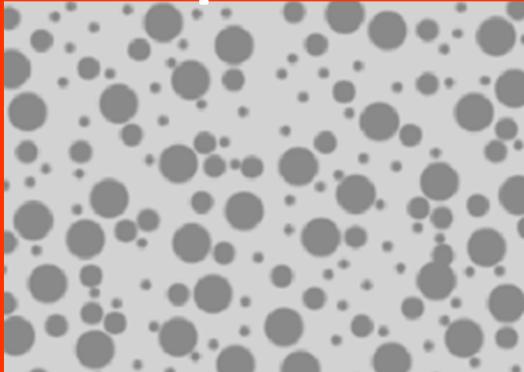
Dilute



Concentrate

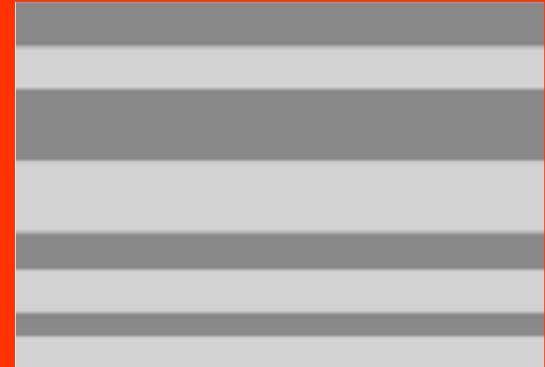


Isotropic



No preferential orientation

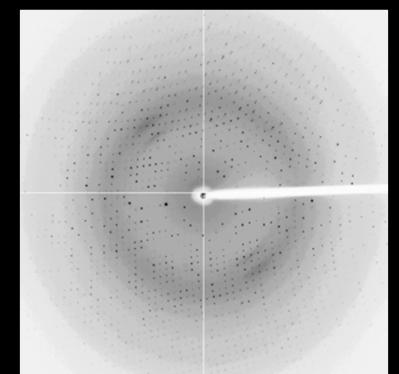
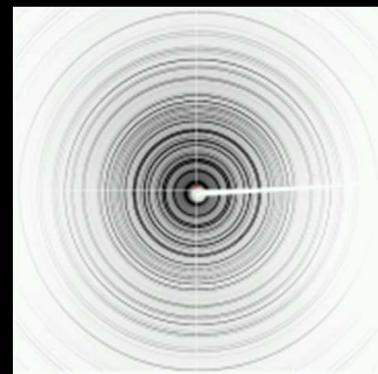
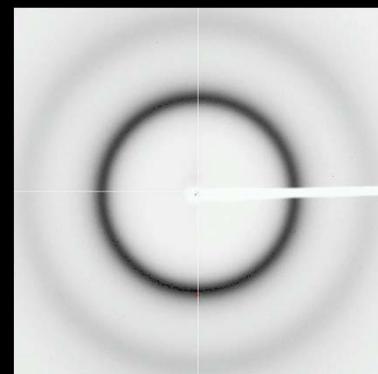
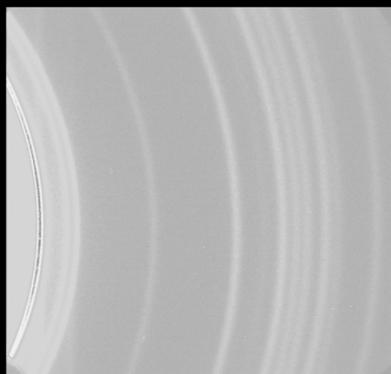
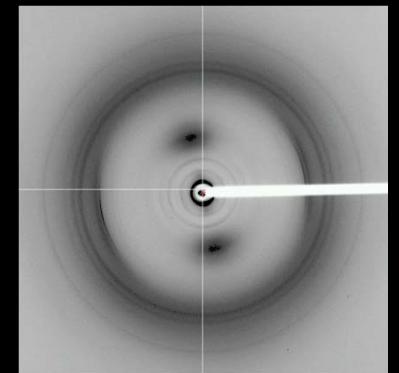
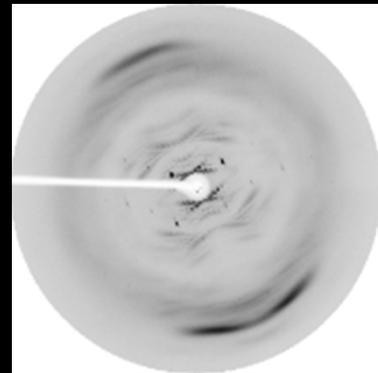
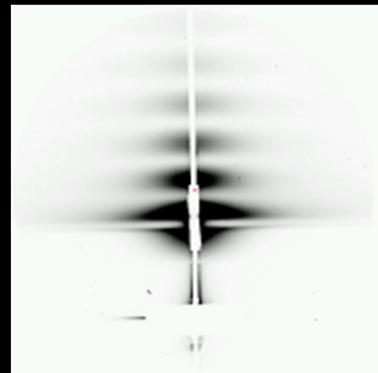
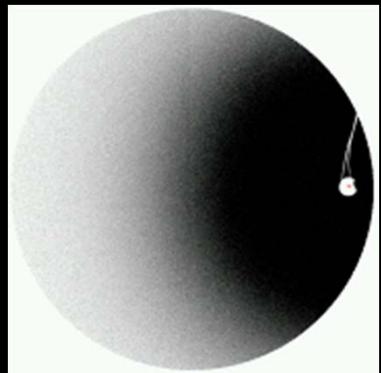
Anisotropic



Oriented

Scattered patterns

scattering



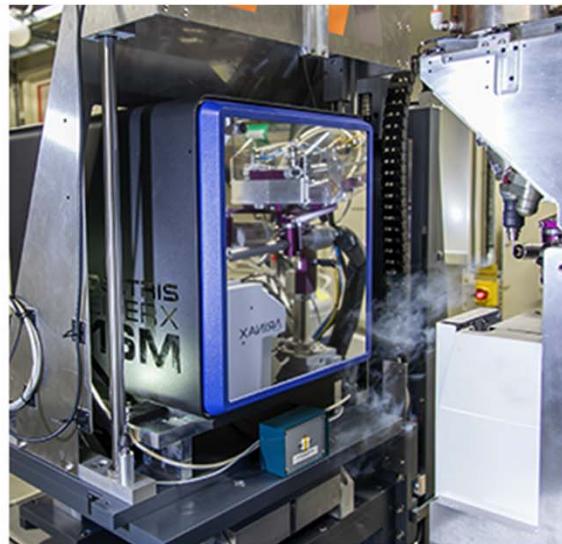
diffraction

BM16, ESRF

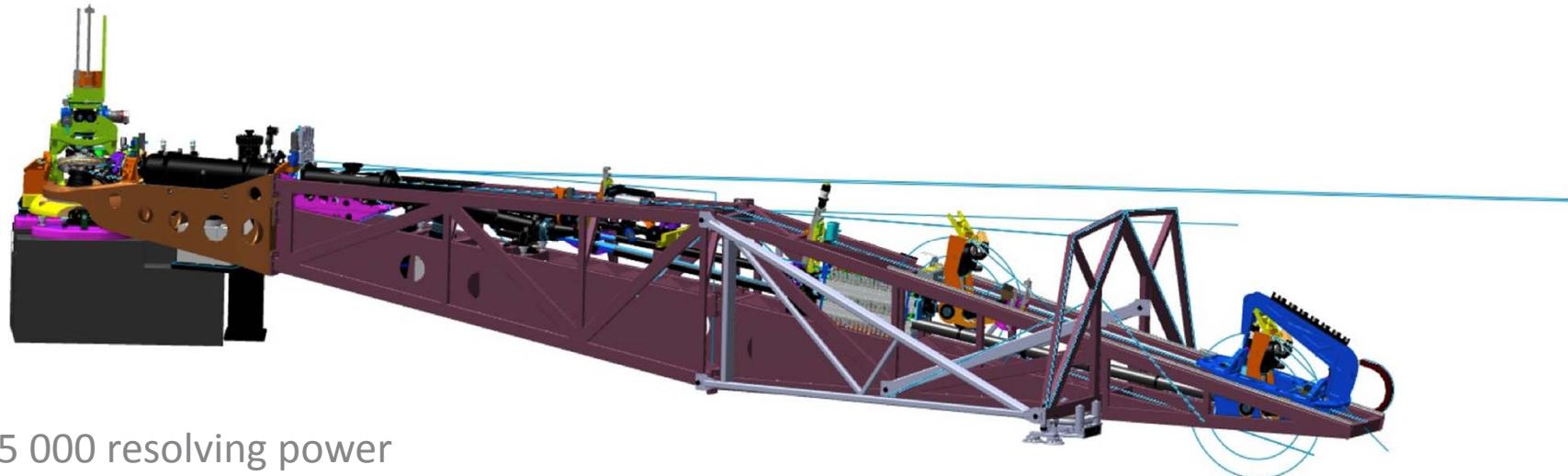
MAX IV

BioMAX a high throughput beamline

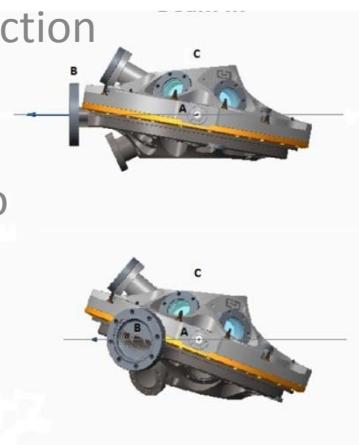
for structural Biology



The VERITAS spectrometer



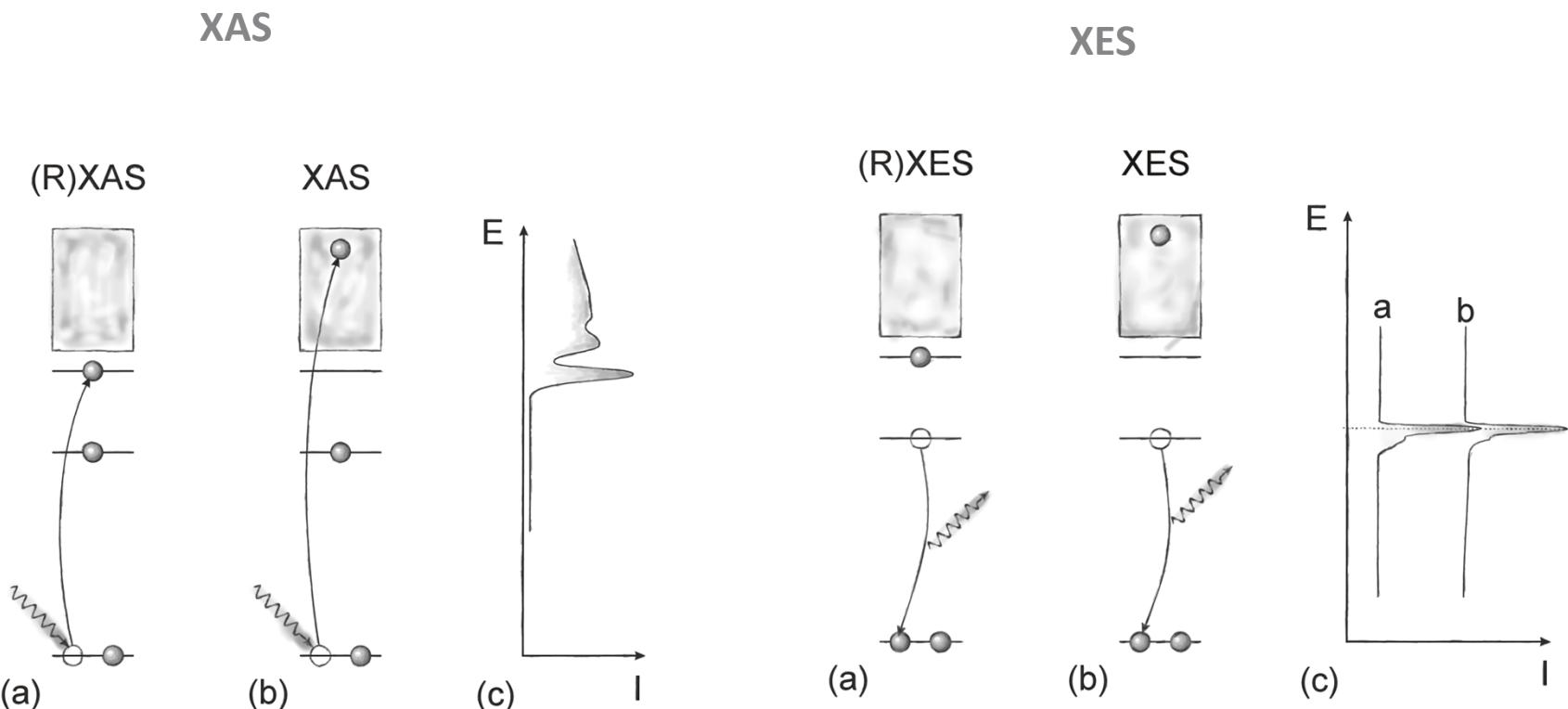
- > 35 000 resolving power
- 270 – 1600 eV
- 10 m long
- 980 mm long collimating mirror to increase collection efficiency
- 2 cylindrical gratings
- +/- 60 degrees rotation in the horizontal plane to monitor momentum transfer
- Q-chamber manufactured and tested at Uppsala University
- Polarization detection possible.



Slide from Conny Såthe

MAX IV

X-ray Absorption and Emission



Slide from Conny Såthe

RIXS: Resonant Inelastic X-ray Scattering

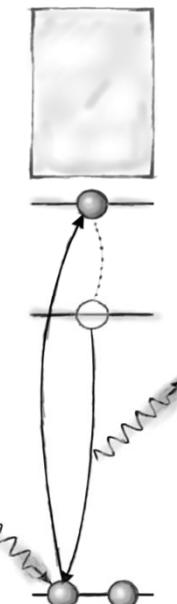
- Photon in – Photon out

Two step model not
Always a good enough
approximation.

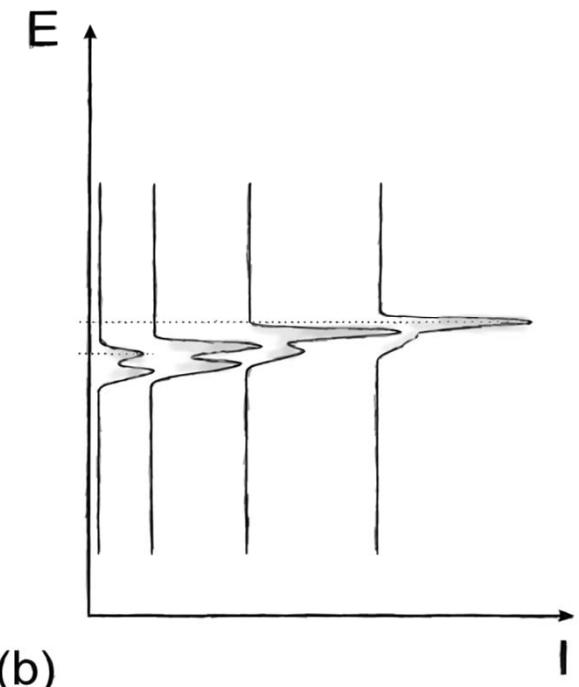
Kramers-Heisenberg
formula derived in 1925.

Γ_i is the intrinsic lifetime
of the intermediate state

RIXS



(a)



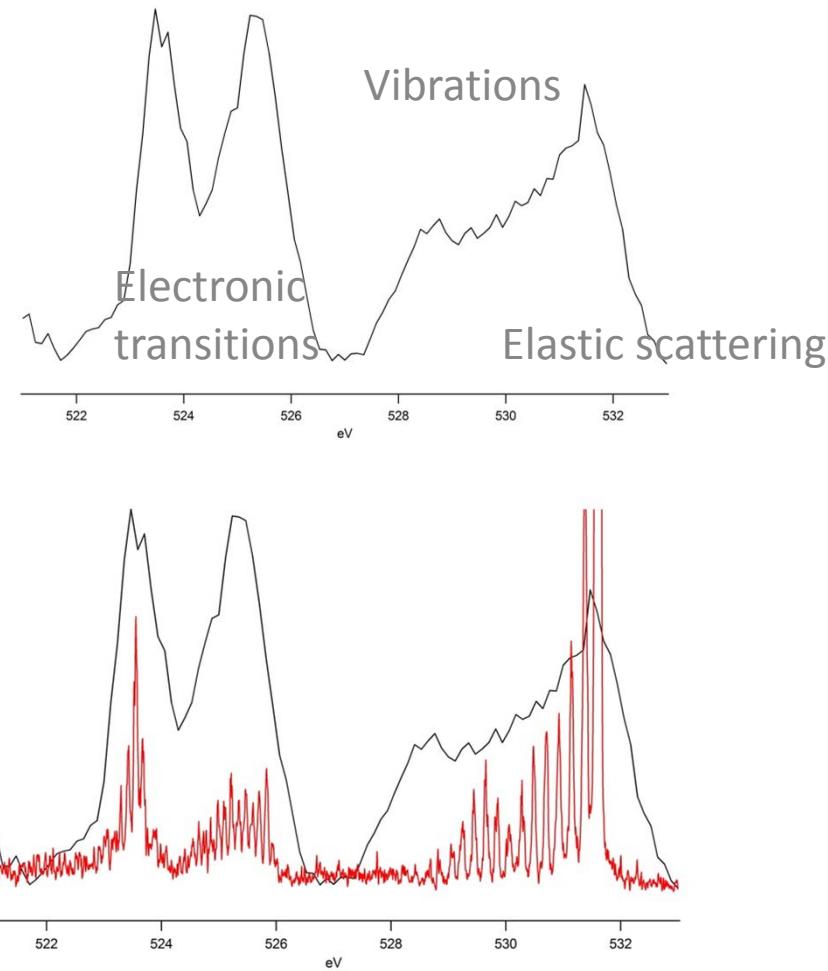
(b)

$$T_{0 \rightarrow f}(h\nu_1, h\nu_2) \propto \sum_f \left| \sum_i \frac{\langle \Psi_f | \hat{D} | \Psi_i \rangle \langle \Psi_i | \hat{D} | \Psi_0 \rangle}{E_0 - E_i + h\nu_1 + \frac{i \cdot \Gamma_i}{2}} \right|^2 \delta(E_0 - E_f + h\nu_1 - h\nu_2)$$

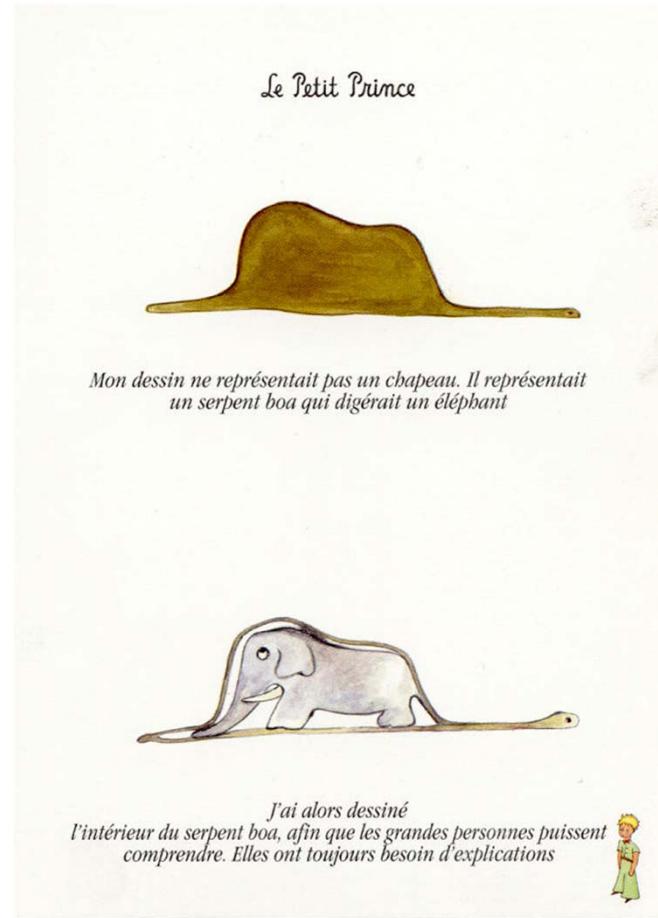
Slide from Conny Såthe

How has resolution changed the game?

O-K RIXS on π^* of NO

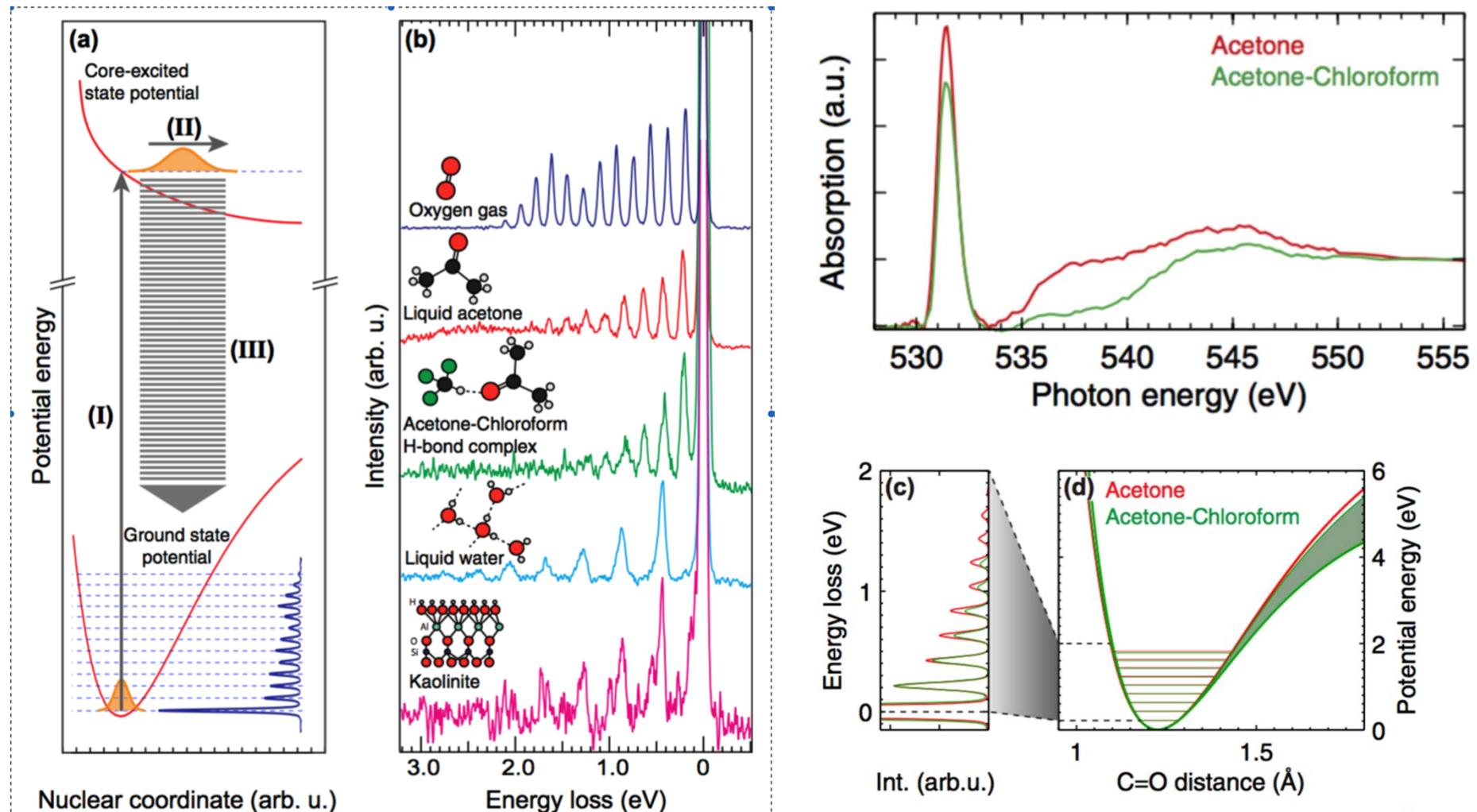


Le Petit Prince



Slide from Conny Såthe

RIXS RESONANT INELASTIC SCATTERING on molecular systems



Slide from Conny Såthe

constantly on the move

Milky way
Solar System
Earth's spin at equator

$$c = 2.998 \cdot 10^8 \text{ m/s} = 3 \cdot 10^5 \text{ km/s}$$

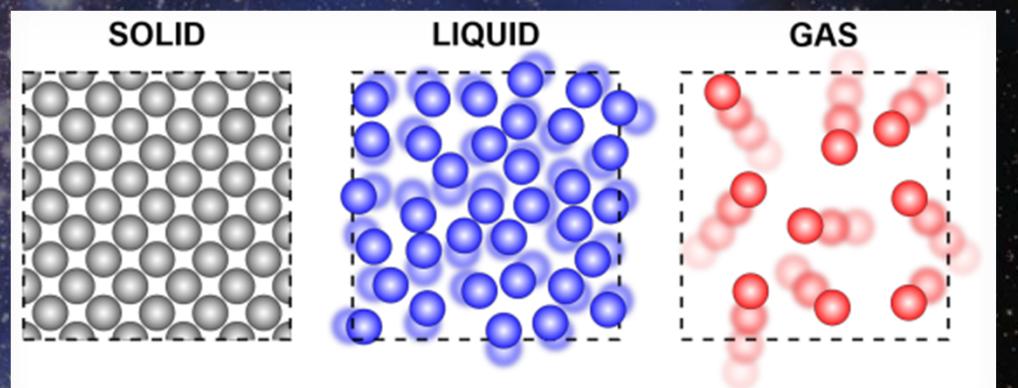
600 km/s (2.1 million km/h)

828.000 km/h

1.600 km/h

...and accelerating

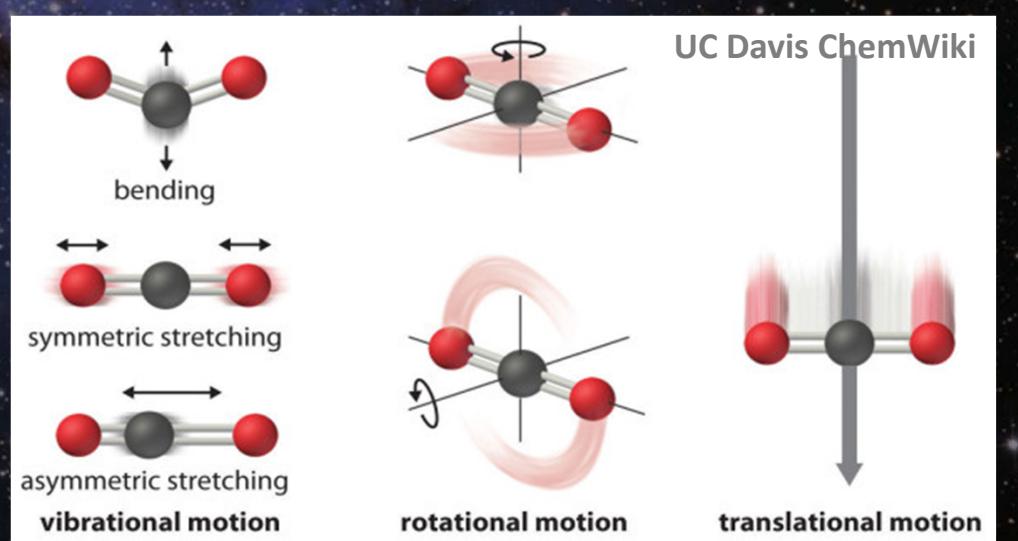
Matter is as well in a continual state of motion



The degree to which the particles move is determined by the amount of energy they have and their relationship to other particles.

? m/s

Frequency: -> fs



BLOCH

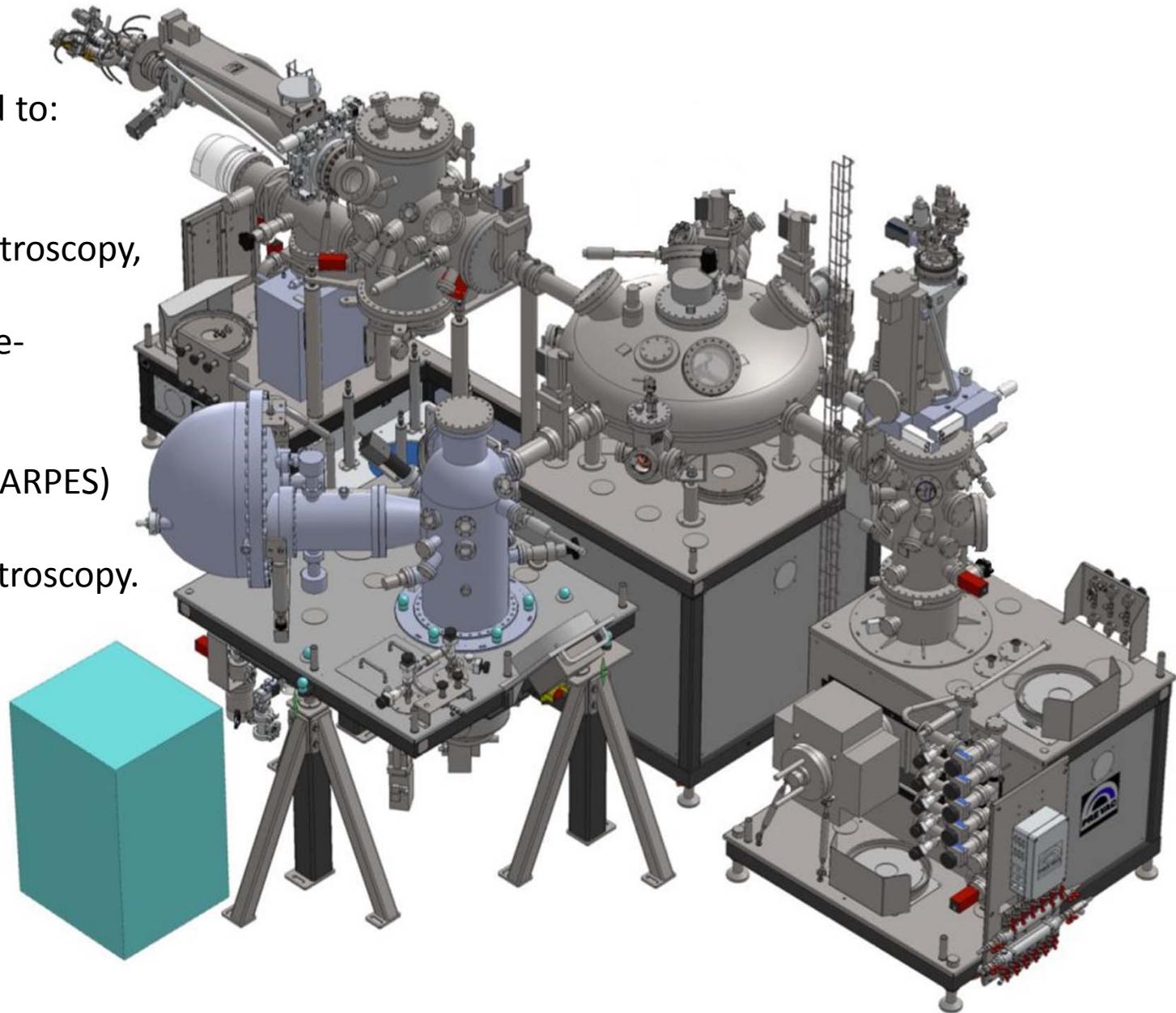
Beamline dedicated to:

high resolution
photoelectron spectroscopy,

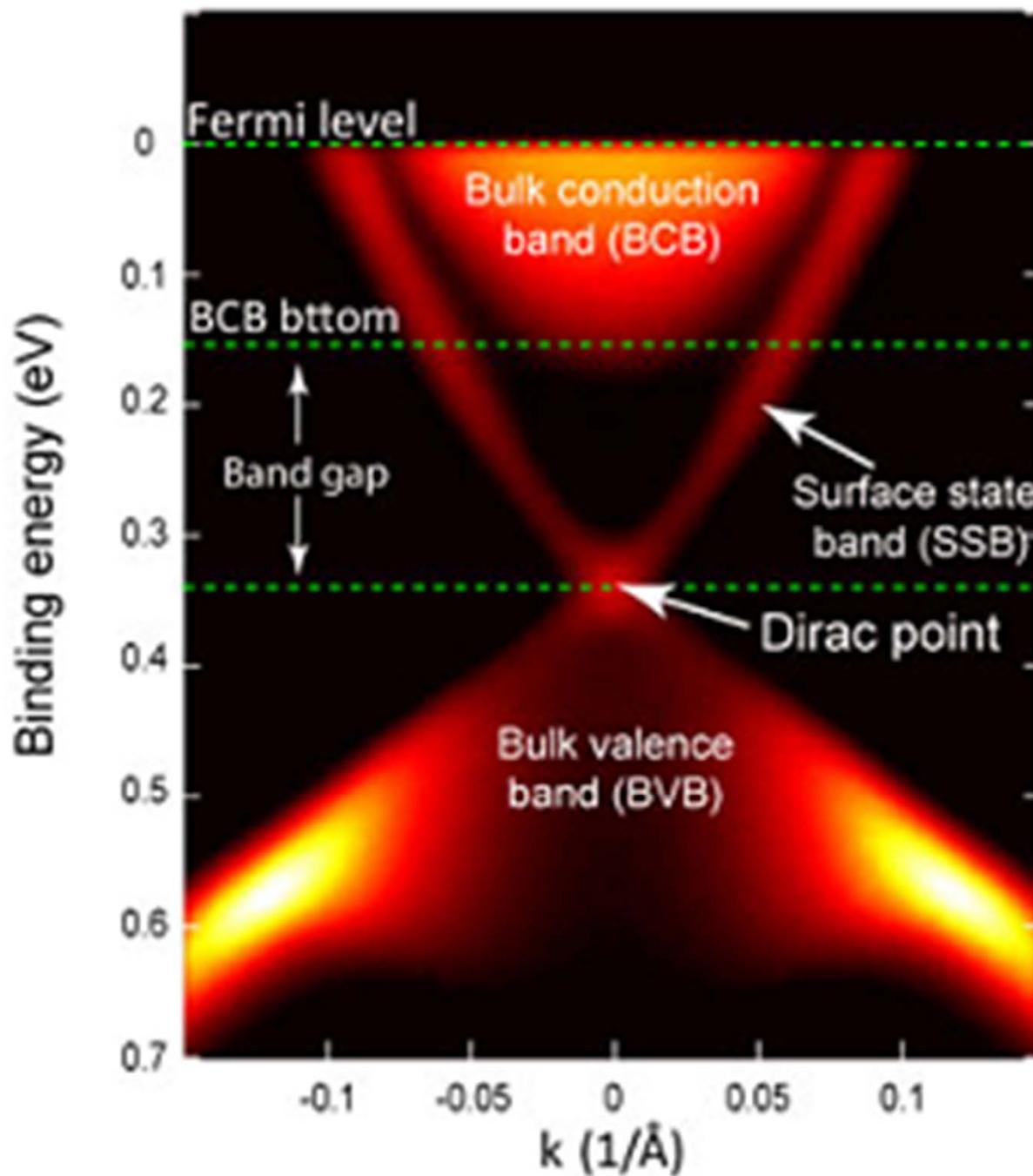
encompassing angle-
resolved (ARPES),

spin resolved (spin-ARPES)

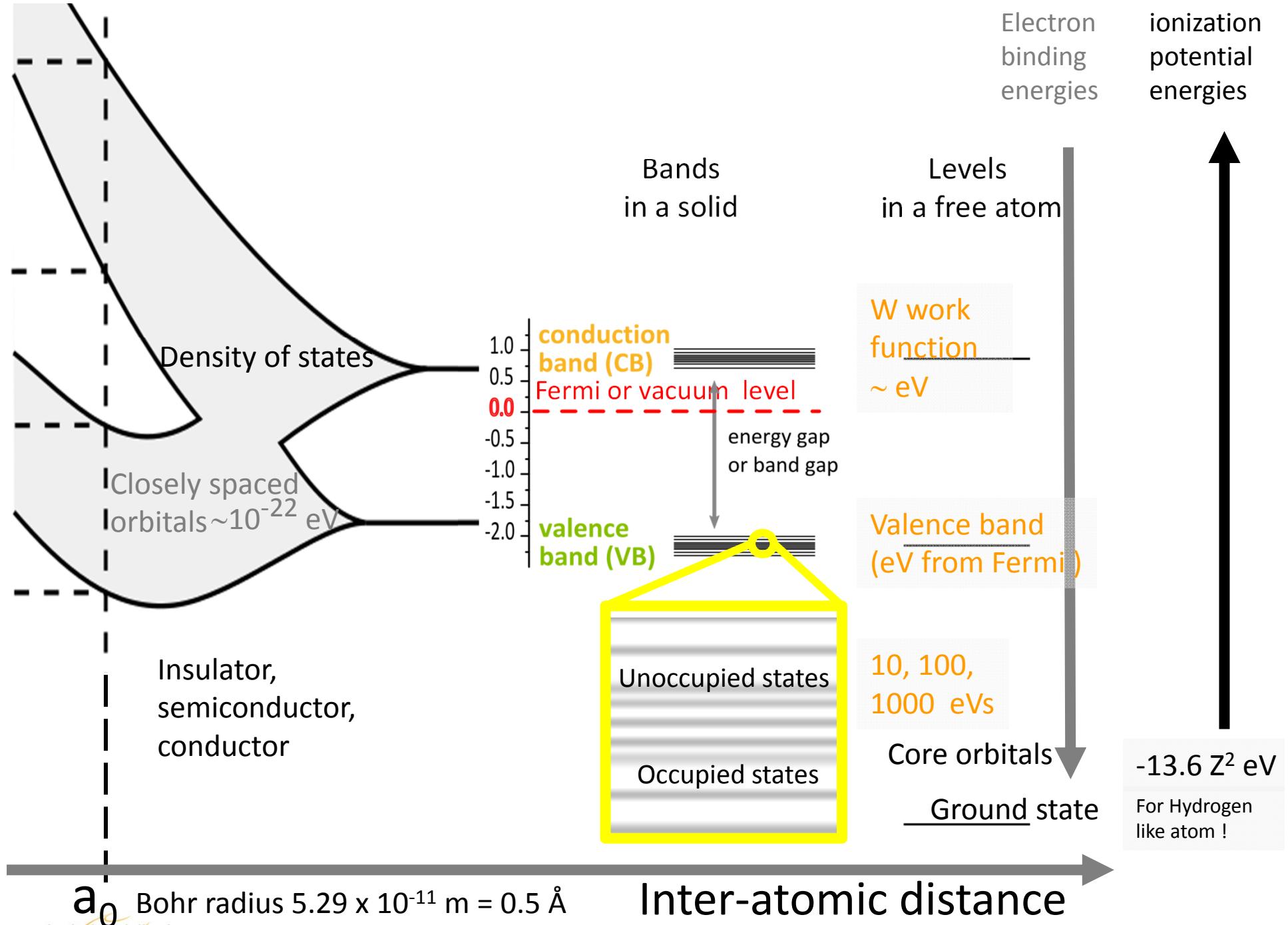
and core-level spectroscopy.



https://www.ece.nus.edu.sg/stfpage/eleyang/proj_ti.html



¹ Y. Chen, J. Analytis, J.-H. Chu, Z. Liu, S.-K. Mo, X.-L. Qi, H. Zhang, D. Lu, X. Dai, and Z. Fang, Science 325, 178 (2009).



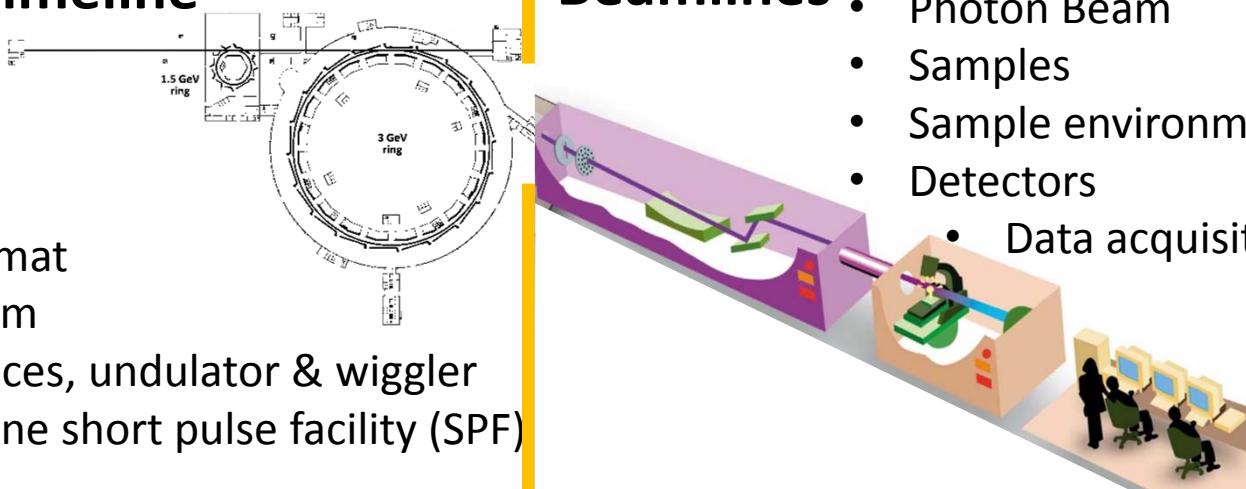
Short review and explanation of relevant concepts: radiation and matter

- Historical overview
- Electromagnetic radiation
 - Synchrotron light
- The atomic model: electron cloud
- Interaction of x-rays and matter ~ SR techniques

MAX IV facility overview

Team, tasks, timeline Technologies

- ✓ Electron gun
- ✓ Linac
- ✓ 7 bend achromat
- ✓ Vacuum system
- ✓ Insertion devices, undulator & wiggler
- ✓ Two rings & one short pulse facility (SPF)



Beamlines

- Photon Beam
- Samples
- Sample environment
- Detectors
- Data acquisition & analysis

Use of the facility

Science & research

**3 broad categories &
Lots of examples!!!!!!**

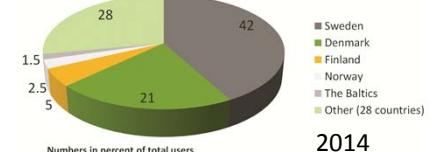


Ana.Labrador@maxiv.lu.se

Access to MAX IV

- Academy
- Industry
- Training & education
- Users-to-be
- Collaborations, ...

5/15/2019



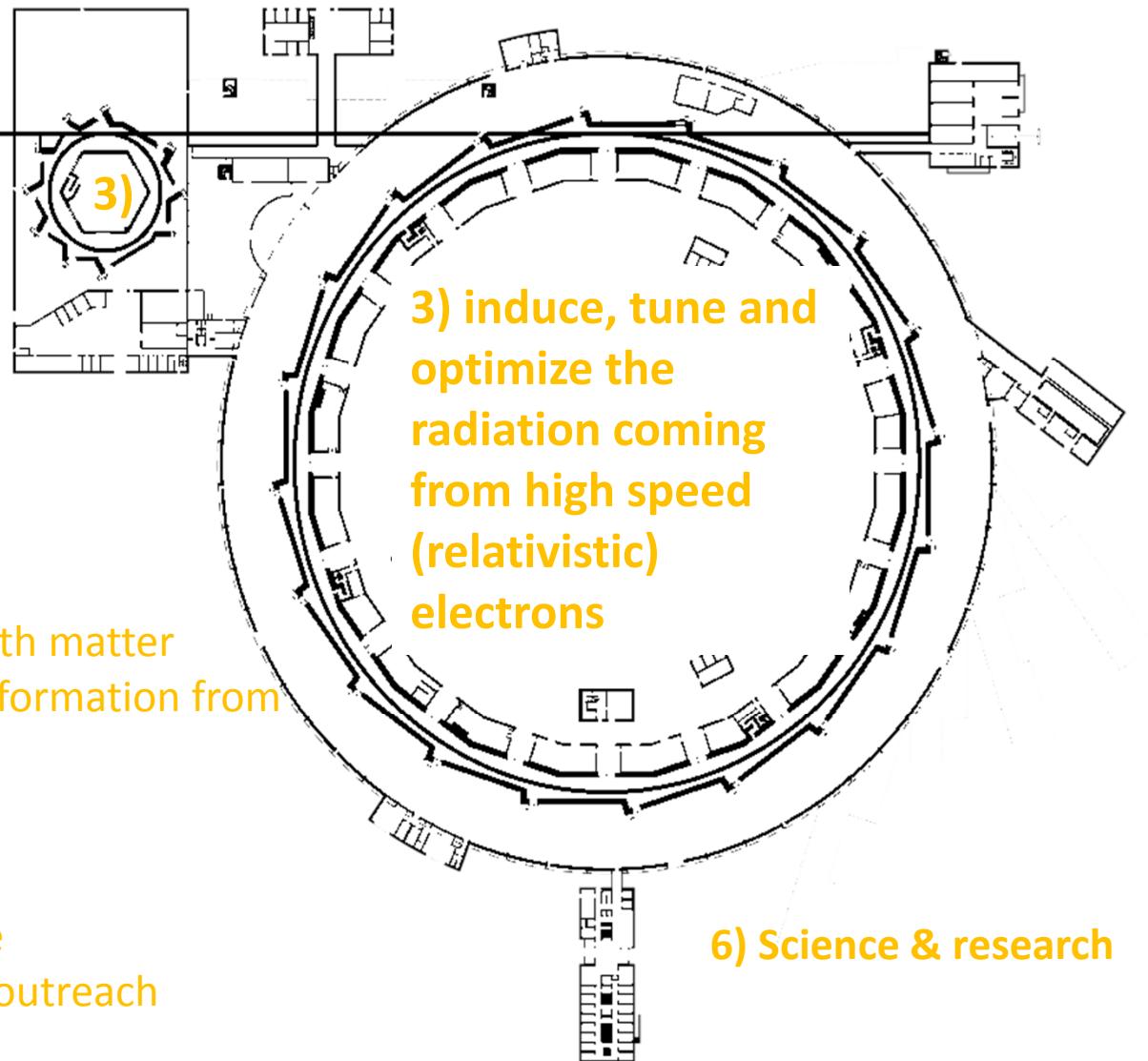
MAX IV

MAX IV in a nutshell

1) extract electrons



2) accelerate electrons to high speeds



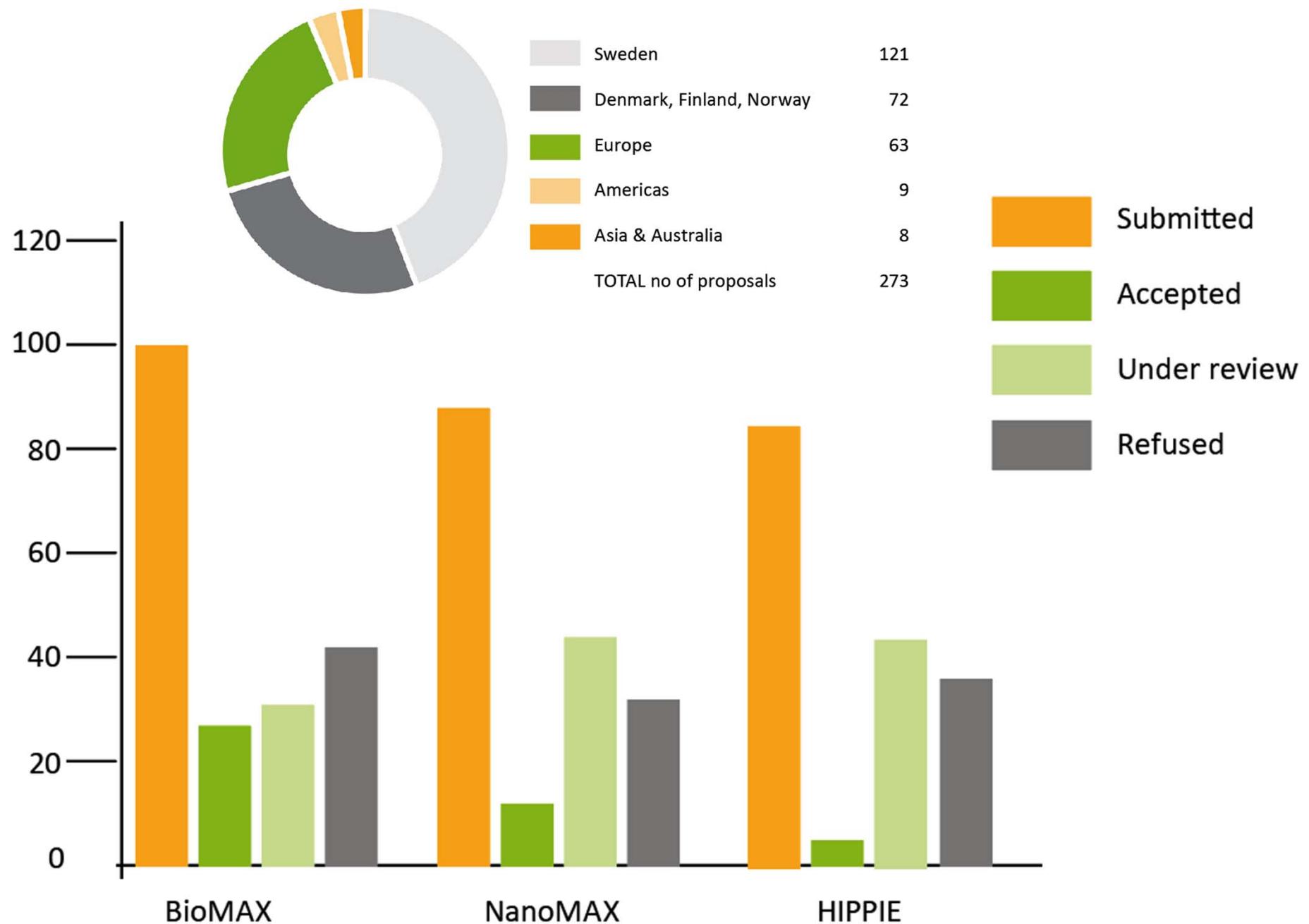
4) use such radiation

- How radiation interacts with matter
- How to extract valuable information from that interaction

5) use it well

- Train and educate
- Disseminate and outreach

6) Science & research



**Many things to explore, to understand,
which had been achieved through
decades of developments and breakthroughs
in science and engineering**

particles fields interactions forces

Higher speeds

Classical Mechanics

Newton, 17th century

Wave

Huygens 1668, diffraction
Young 1801, interference

Hertz 1887

Quantum Mechanics

Schrödinger (1926 electron cloud model), Heisenberg 1927, Bohr, (~1920)
JJ Thomson (~1900) Compton (1923)

Classical electrodynamics

Maxwell (~1860)

Wave-particle duality

Relativistic Mechanics

Einstein, (1905 Photoelectric, Nobel 1921)

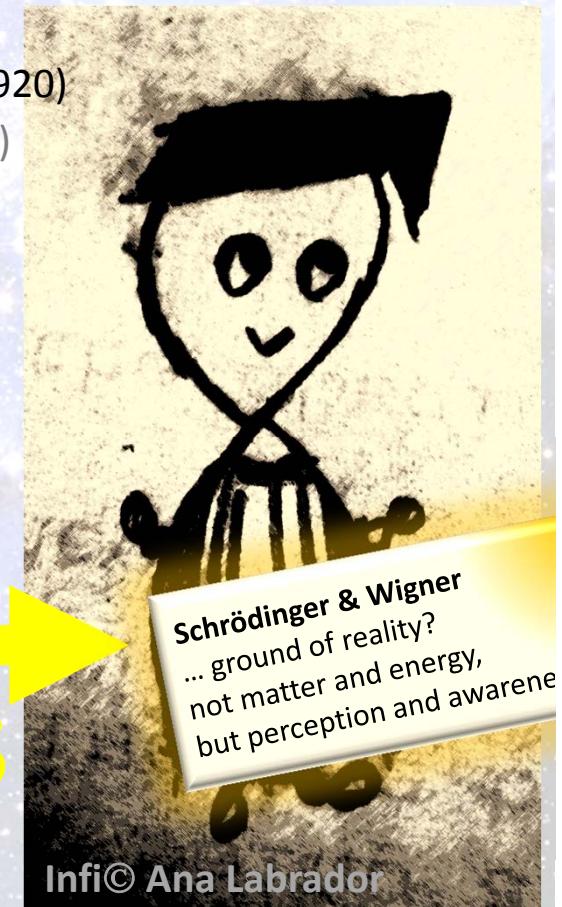
(Special relativity)

Planck (1900)

Quantum Field Theory

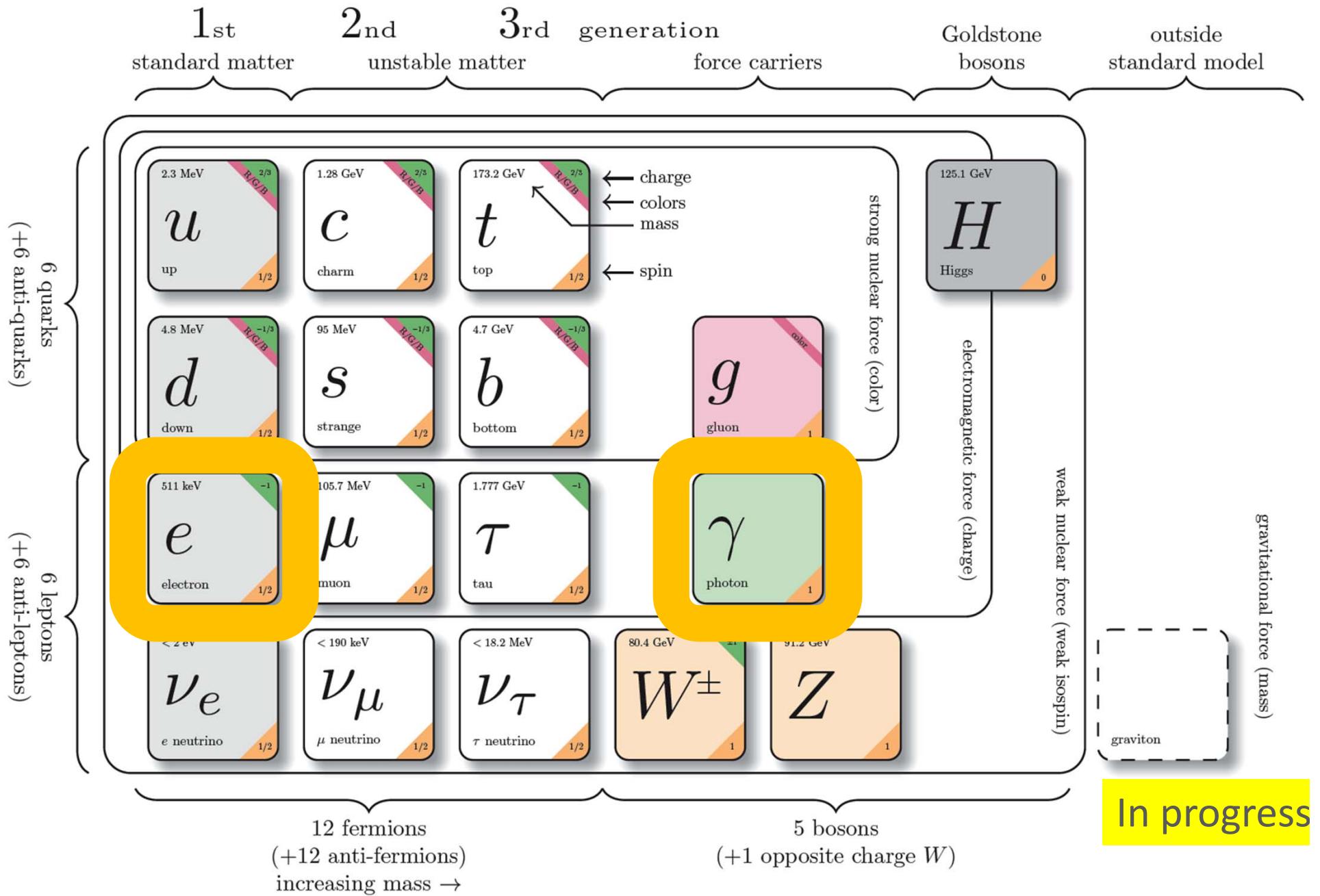
Dirac, Pauli, Schwinger, Feynman,
(~1930-...)

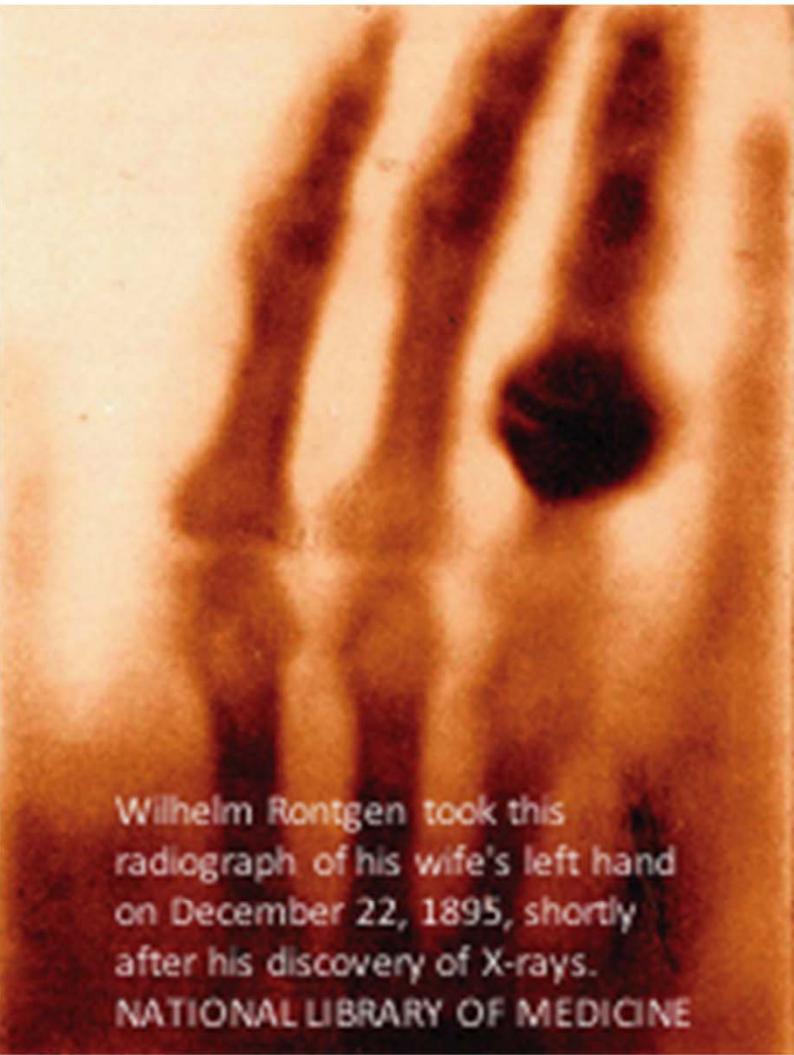
Smaller distances



Mechanics tells us how a system will behave when subjected to a given force. Kind of forces: Strong, Electromagnetic, Weak, Gravitational, more?

Standard model

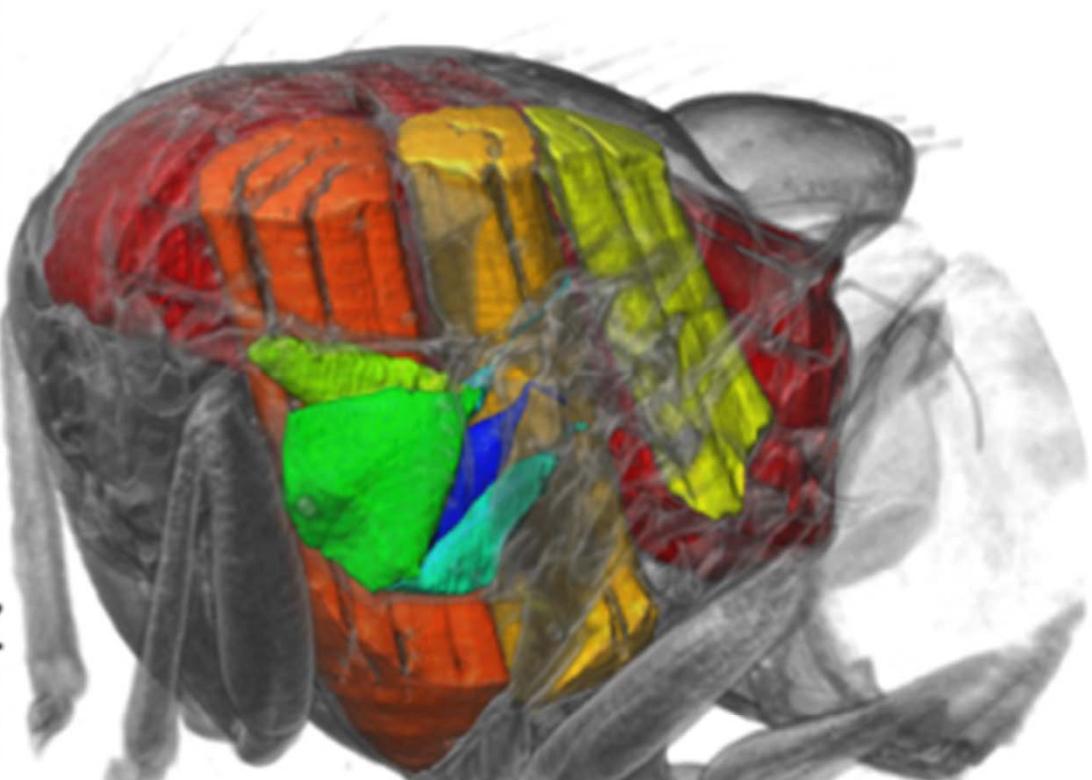




Wilhelm Rontgen took this radiograph of his wife's left hand on December 22, 1895, shortly after his discovery of X-rays.

NATIONAL LIBRARY OF MEDICINE

temporal resolution: 3 kHz effective
spatial resolution: 10-20 μm



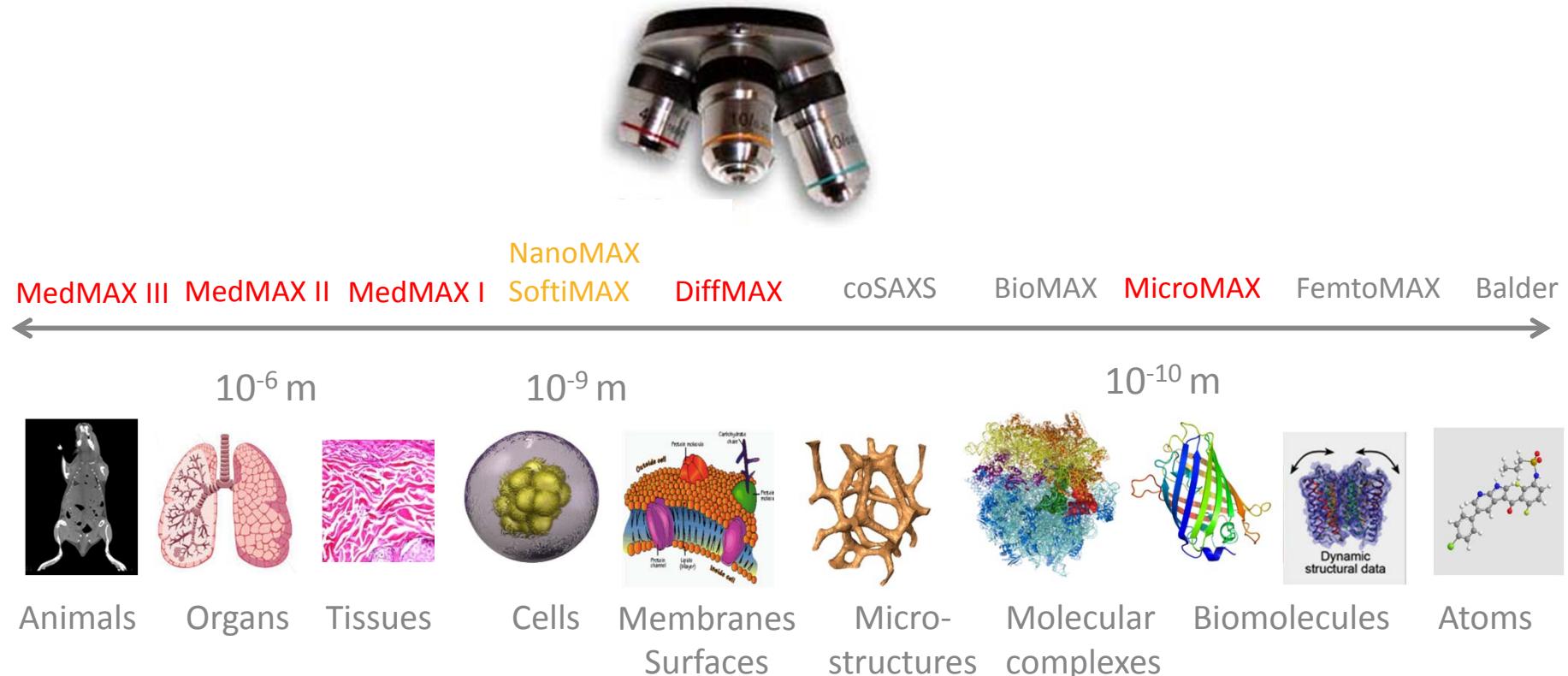
Daniel Schwyn
Imperial College London

Rajmund Mokso


Simon Walker


MAX IV LIFE

Biology at different length and time scales



“in/ex vivo”

Small animals/
disease models

Histology/
Histopathology

Cellbiology

“In solution”

Molecular Medicine/
Chemical Biology

Molecular Biology/
Biochemistry



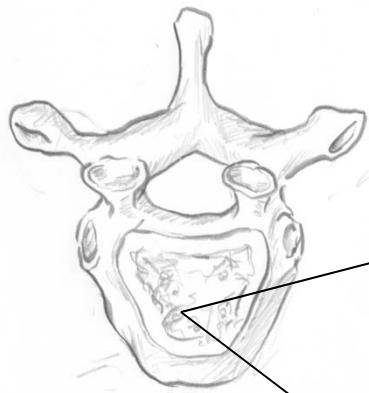
Cortical bone



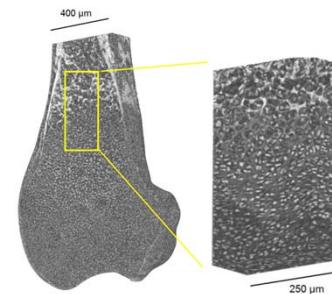
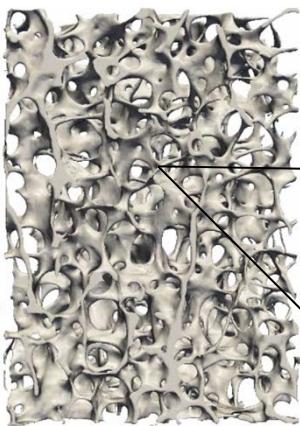
Kevin Mader

Exploring the bone with coherent X-ray methods

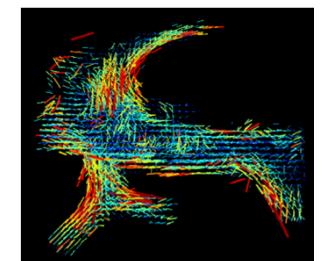
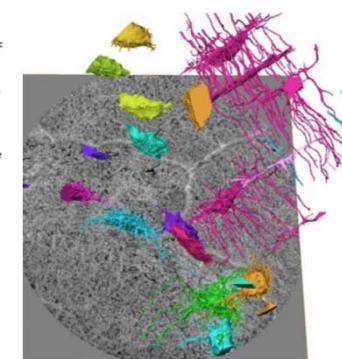
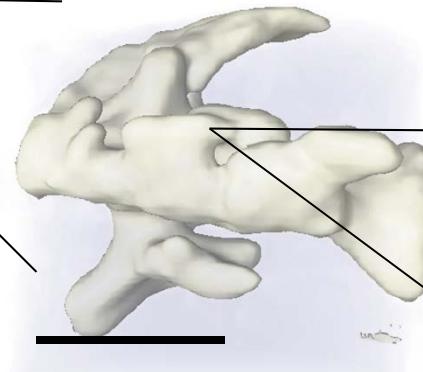
Human vertebra



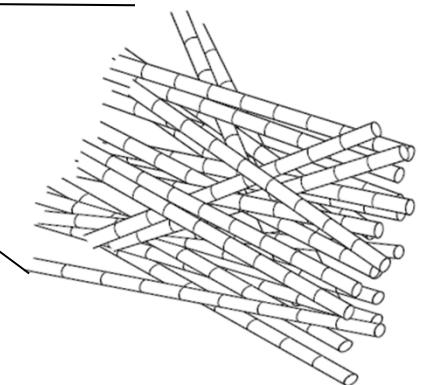
Trabecular bone



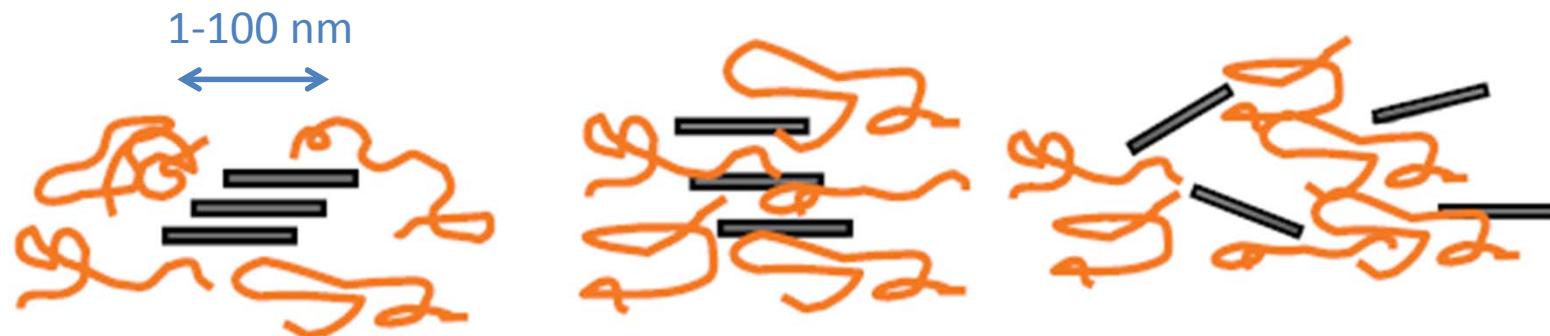
Single trabecula
mm scale



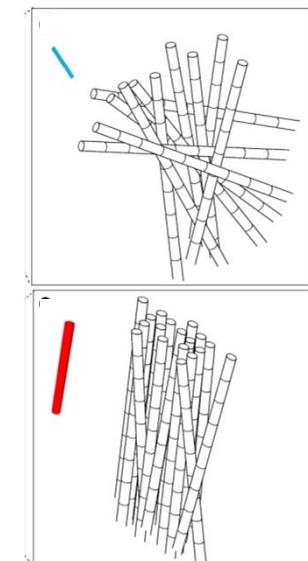
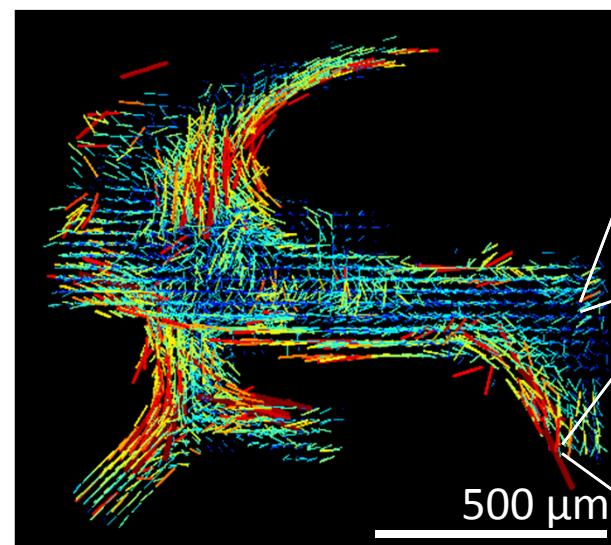
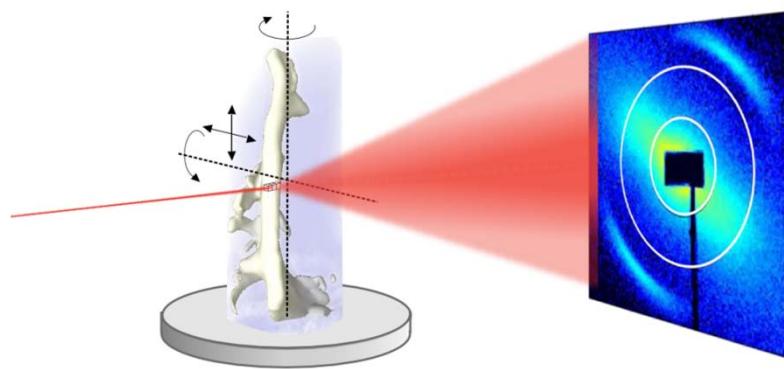
Collagen fibrils
nm scale



CoSAXS: Coherent Small Angle Scattering



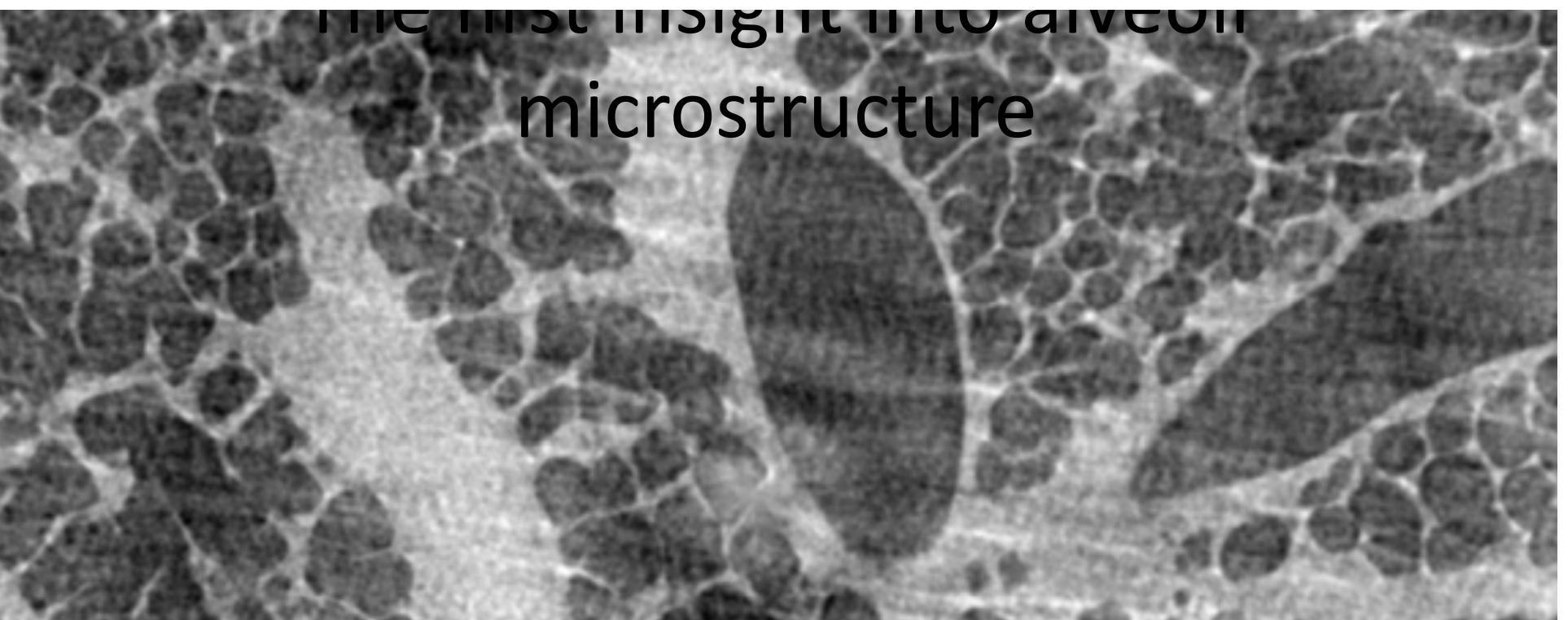
SAXS tensor tomography



Liebi, M. et al. Nanostructure surveys on macroscopic specimens by small-angle scattering tensor tomography. *Nature* **527**, 349 (2015)

THE FIRST INSIGHT INTO avCOT

microstructure

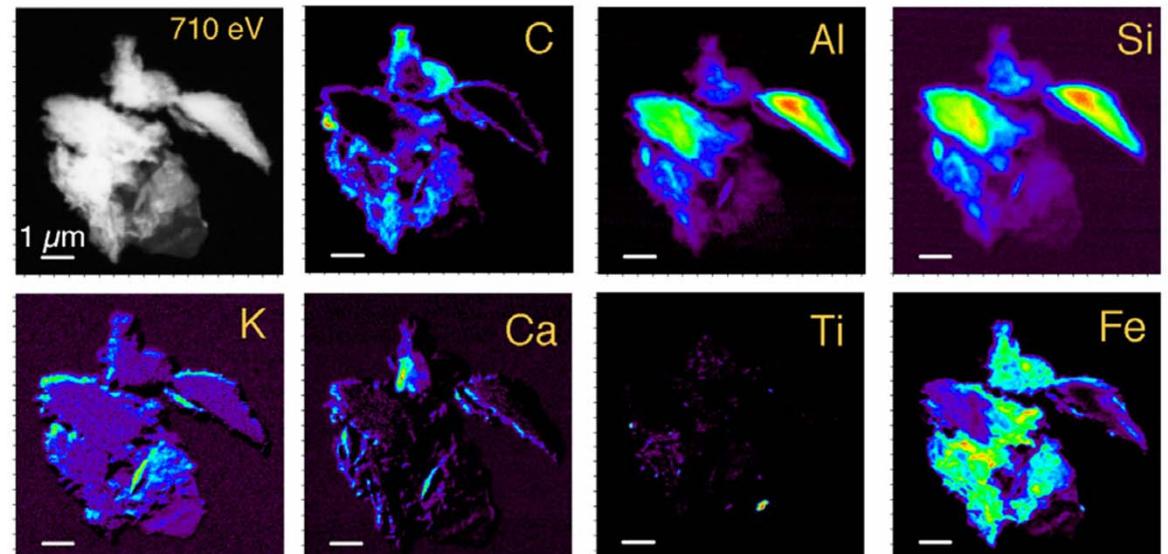


Collaboration between Anders Larsson from Uppsala Uni. Hospital, SLS and ESRF.

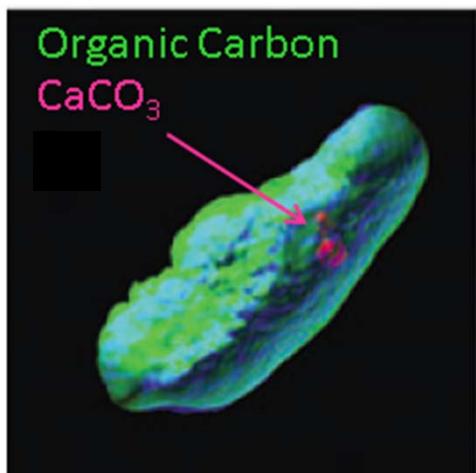
110 1 mm

Lovric et al. Sci. Rep. 2017

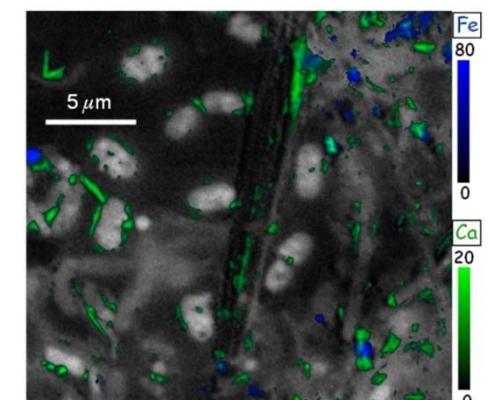
Microscopy: element specific



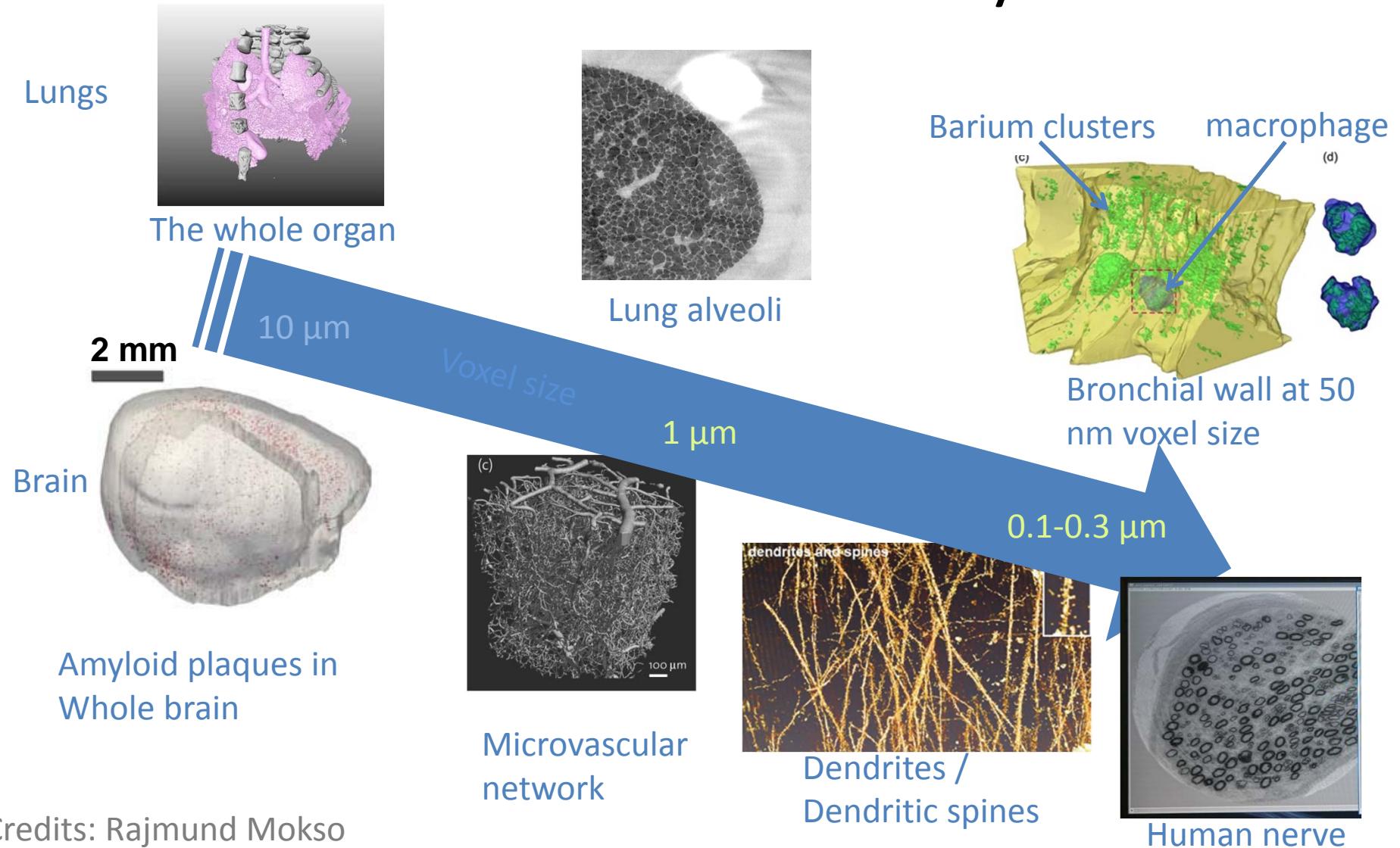
Elemental correlations within soil microaggregates,
J. Wan, et al. Geochim. Cosmochim. Acta 71, 5439 (2007)



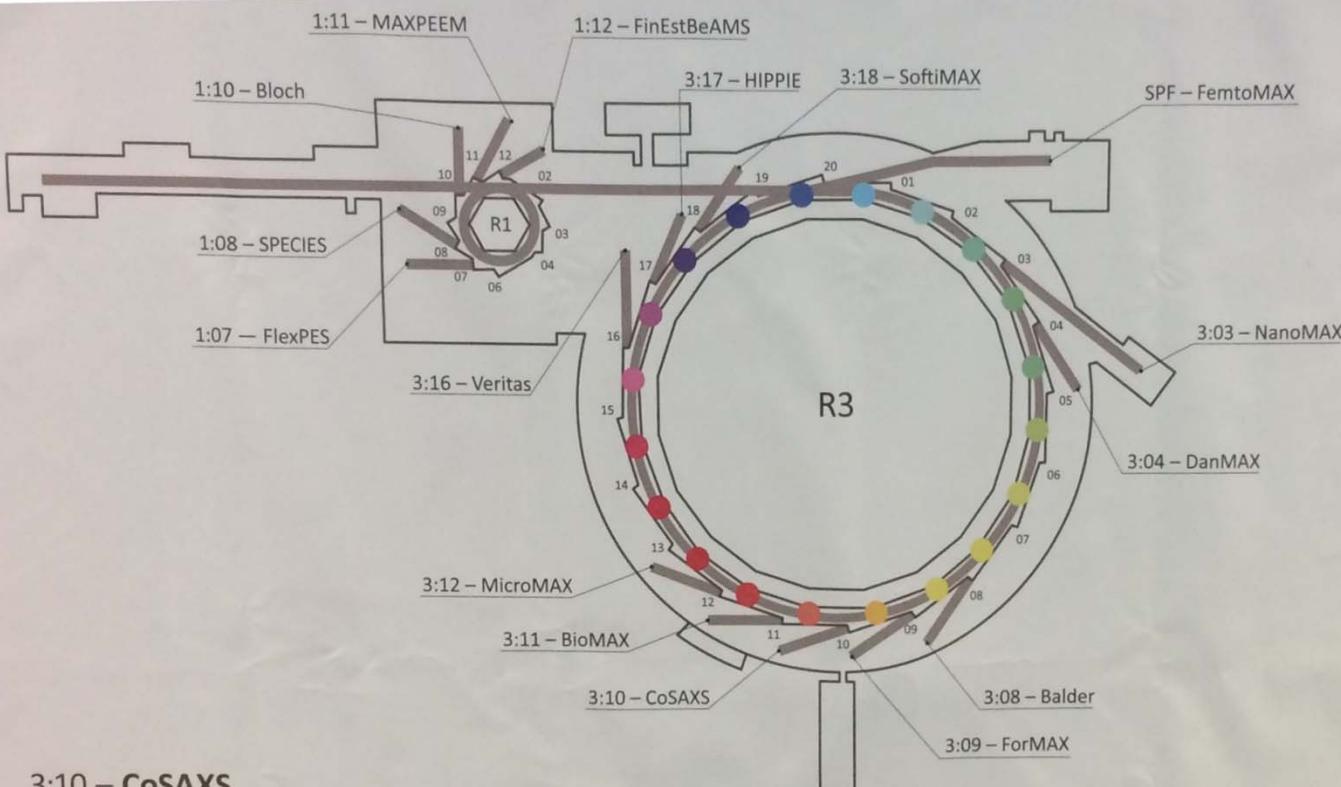
Nutrients in soil/plant uptake;
Phytoremediation;
Metals in microbes/tissue...



BioMedMAX: imaging life dynamics at the micrometer scale and beyond



Credits: Rajmund Mokso



3:10 – CoSAXS

Methods: Small/Wide angle X-ray scattering (SAXS/WAXS), X-ray Photon Correlation Spectroscopy (XPCS), Coherent Diffraction Imaging
Main areas served: soft matter and life science

3:11 – BioMAX

Methods: Macromolecular crystallography (MX), high throughput and in-situ screening
Main areas served: structural biology

3:12 – MicroMAX

Methods: Macromolecular serial crystallography, time-resolved studies
Main areas served: structural biology

3:16 – Veritas

Methods: Resonant Inelastic X-ray Scattering (RIXS)
Main areas served: physics, chemistry and materials science

1:07 – FlexPES

Methods: X-ray Photoelectron Spectroscopy (XPS), X-ray Absorption Spectroscopy (XAS)
Main areas served: physics, chemistry and nanoscience

1:08 – SPECIES

Methods: Ambient Pressure X-ray Photoelectron Spectroscopy (XPS) and Resonant Inelastic X-ray Spectroscopy (RIXS)
Main areas served: physics, chemistry, catalysis, corrosion, materials science

1:10 – Bloch

Methods: Angle Resolved Photoelectron Spectroscopy (ARPES)
Main areas served: physics, nanoscience and materials science

1:11 – MAXPEEM

Methods: X-ray Photoemission Electron Microscopy (XPEEM), Low Energy Electron Microscopy (LEEM), X-ray Photoelectron Spectromicroscopy (μ -XPS), X-ray absorption spectromicroscopy (μ -XAS), nano-ARPES, X-ray magnetic circular dichroism (XMCD).
Main areas served: physics, chemistry and nanoscience, material science

1:12 – FinEstBeAMS

Methods: Photoelectron-Photoion Coincidence Spectroscopy (PEPICO), Ion Time-of-Flight Mass Spectroscopy (TOF), X-ray Photoelectron Spectroscopy (XPS), Photoluminescence Spectroscopy (PL)
Main areas served: low density matter research, atmospheric physics, materials science and physics

3:17 – HIPPIE

Methods: Ambient Pressure X-ray Photoelectron Spectroscopy (APXPS)
Main areas served: chemistry, catalysis, corrosion, electrochemistry, materials science and physics

3:18 – SoftiMAX

Methods: Scanning Transmission X-ray Microscopy (STXM), Coherent X-ray Imaging (Ptychography, Holography, etc.)
Main areas served: environmental science, soft matter, energy materials, biomaterials, nanoscience and materials science

SPF – FemtoMAX

Methods: Femtosecond X-ray Scattering, EXAFS and spectroscopy
Main areas served: physics, chemistry and accelerator development

3:03 – NanoMAX

Methods: X-ray Nanoprobe, Scanning X-ray Microscopy, X-ray Diffraction (XRD), Coherent Diffraction Imaging, X-ray Fluorescence
Main areas served: nanoscience, materials science and biomaterials

3:04 – DanMAX

Methods: (in situ) Full field X-ray microscopy, microtomography, Powder X-ray Diffraction (PXRD)
Main areas served: material science, hard condensed matter, energy materials, chemistry, geoscience

3:08 – Balder

Methods: (in-situ) X-ray Absorption Spectroscopy (XAS) with simultaneous X-ray Emission Spectroscopy (XES) combined with additional methods such as FTIR and RAMAN
Main areas served: materials science, chemistry, catalysis, environmental science, energy research and cultural heritage

3:09 – ForMAX

Methods: Small/Wide angle X-ray scattering (SAXS/WAXS), scanning SAXS/WAXS, full-field imaging
Main areas served: wood-based materials science, soft matter



Sample preparation

