MAX IV

METALBEAMS WORKSHOP

# This is MAX IV !

Aymeric ROBERT

*Scientific Director – Physical Sciences*

NOV 2023

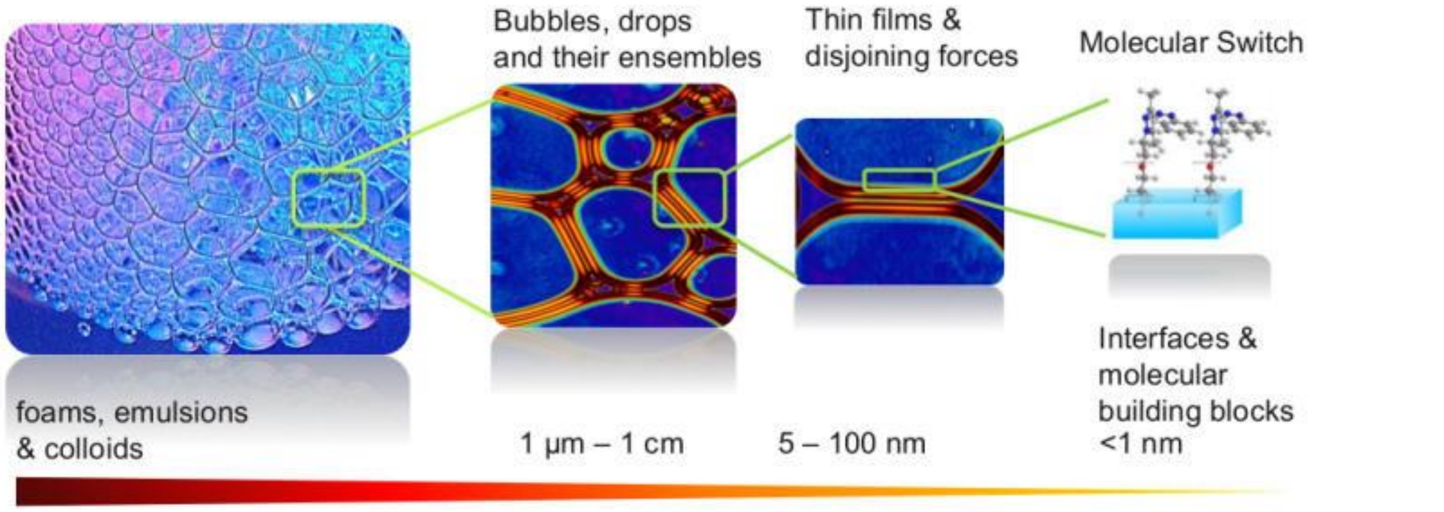
MAX IV

# Outline

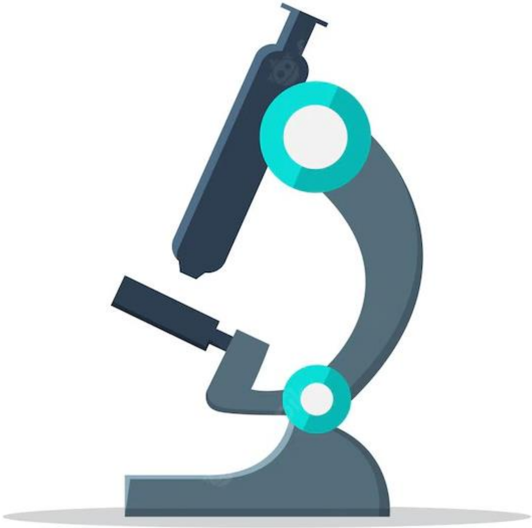
MAX IV - A nearly diffraction-limited synchrotron source

Examples from our Science Programme

# Understanding the structure and dynamics of matter




https://www.uni-muenster.de/SON/en/research/nanomaterials/b4.html



- Light
- Electrons
- Neutrons (ESS – European Spallation Source)
- X-rays (MAX IV)

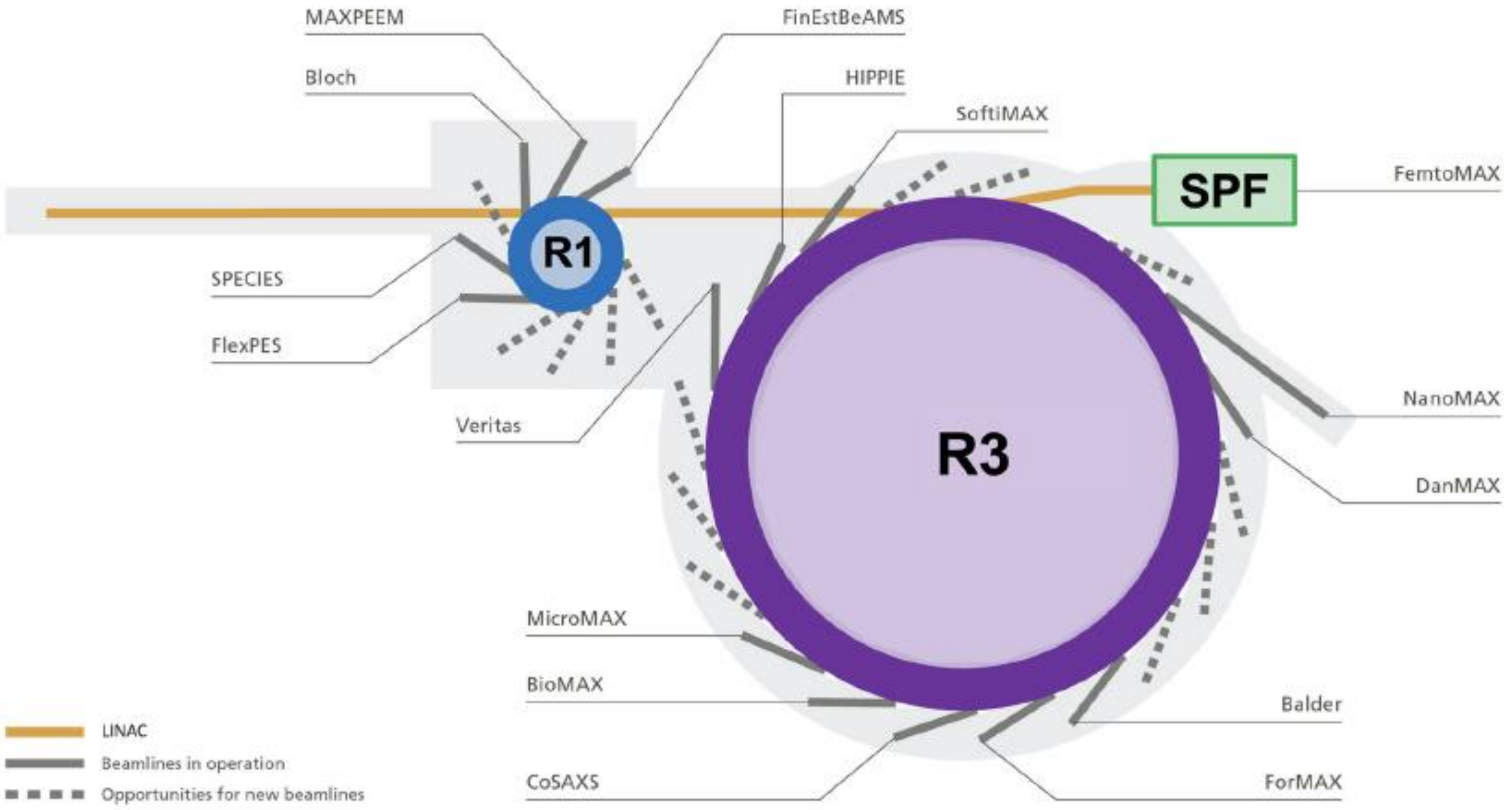
MAX IV

# Our X-ray Sources

## 3 Accelerators

**Linac** – Linear Accelerator
**R1** - 1.5GeV storage ring
**R3** - 3GeV storage ring

www.maxiv.lu.se

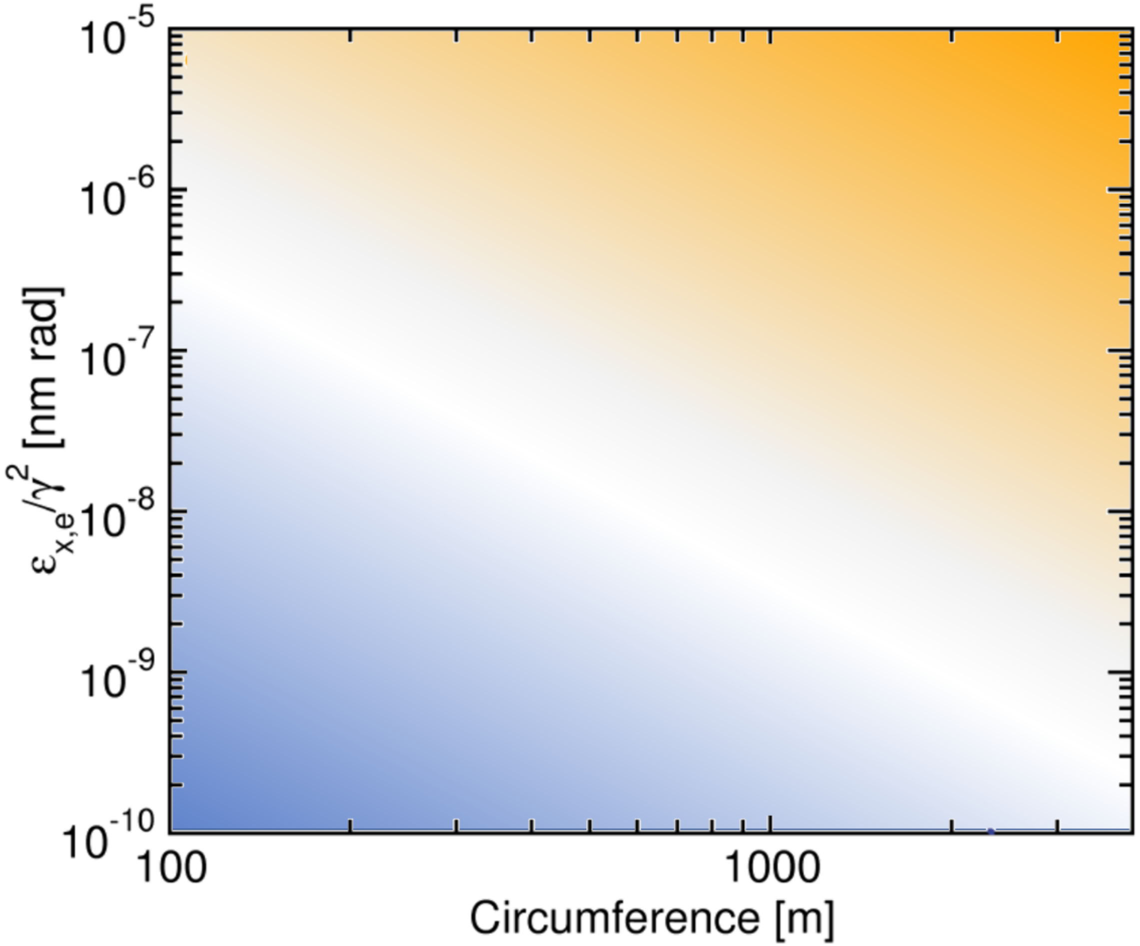



A. Robert *et al.*, "MAX IV Laboratory", *Eur. Phys. J. Plus* **138**, 495 (2023).

# Accelerators

- **1.5 GeV Storage Ring**
  - C = 100m , $\mathcal{E}\backsim$6 nmrad
  - Diffraction-limited X-rays at 16 eV
  - World-leading source of soft X-rays

- **3 GeV Storage Ring**
  - C = 528m , $\mathcal{E}\backsim$200–330 nmrad
  - Diffraction-limited X-rays at 300eV
  - First 4th generation storage ring



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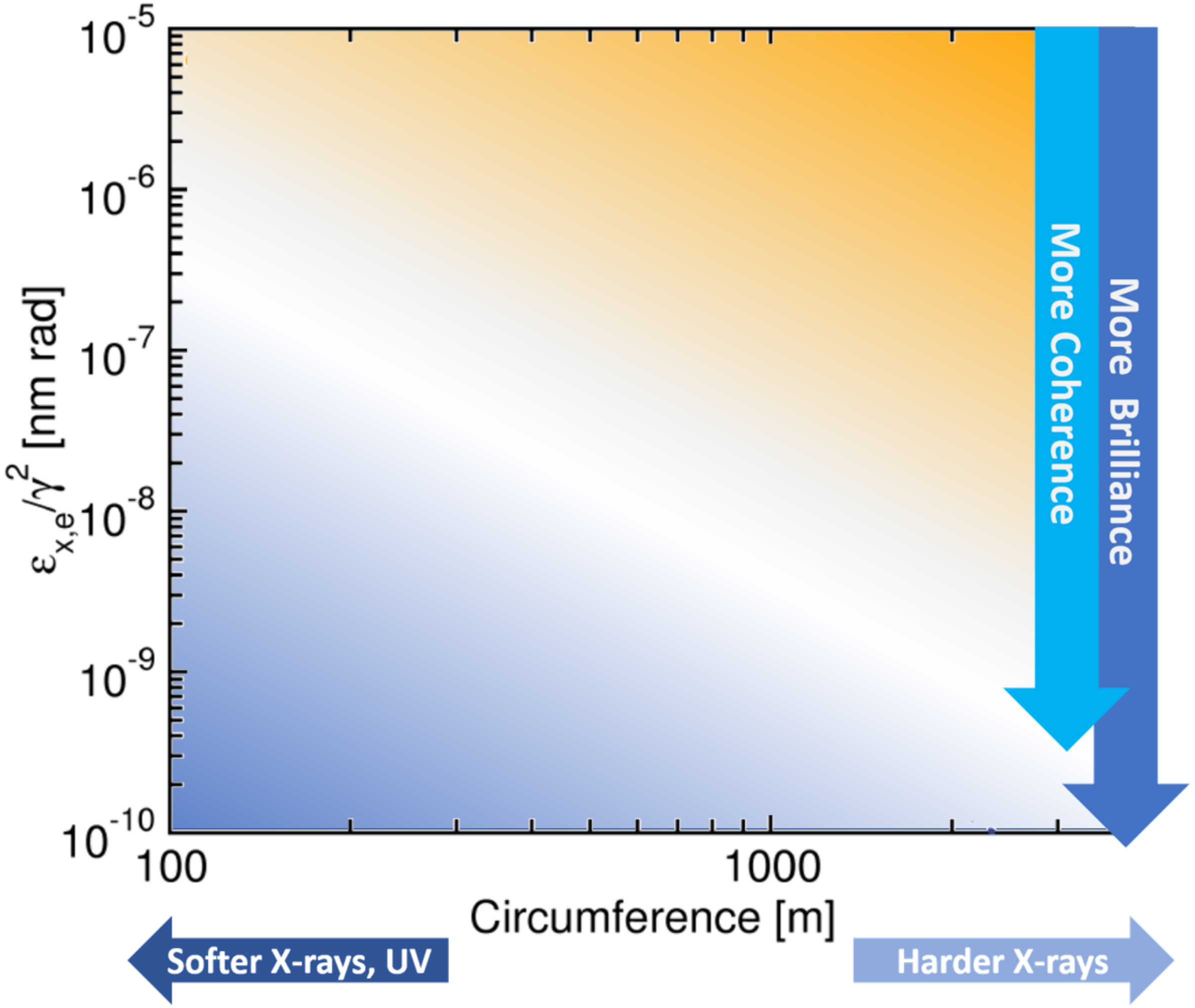

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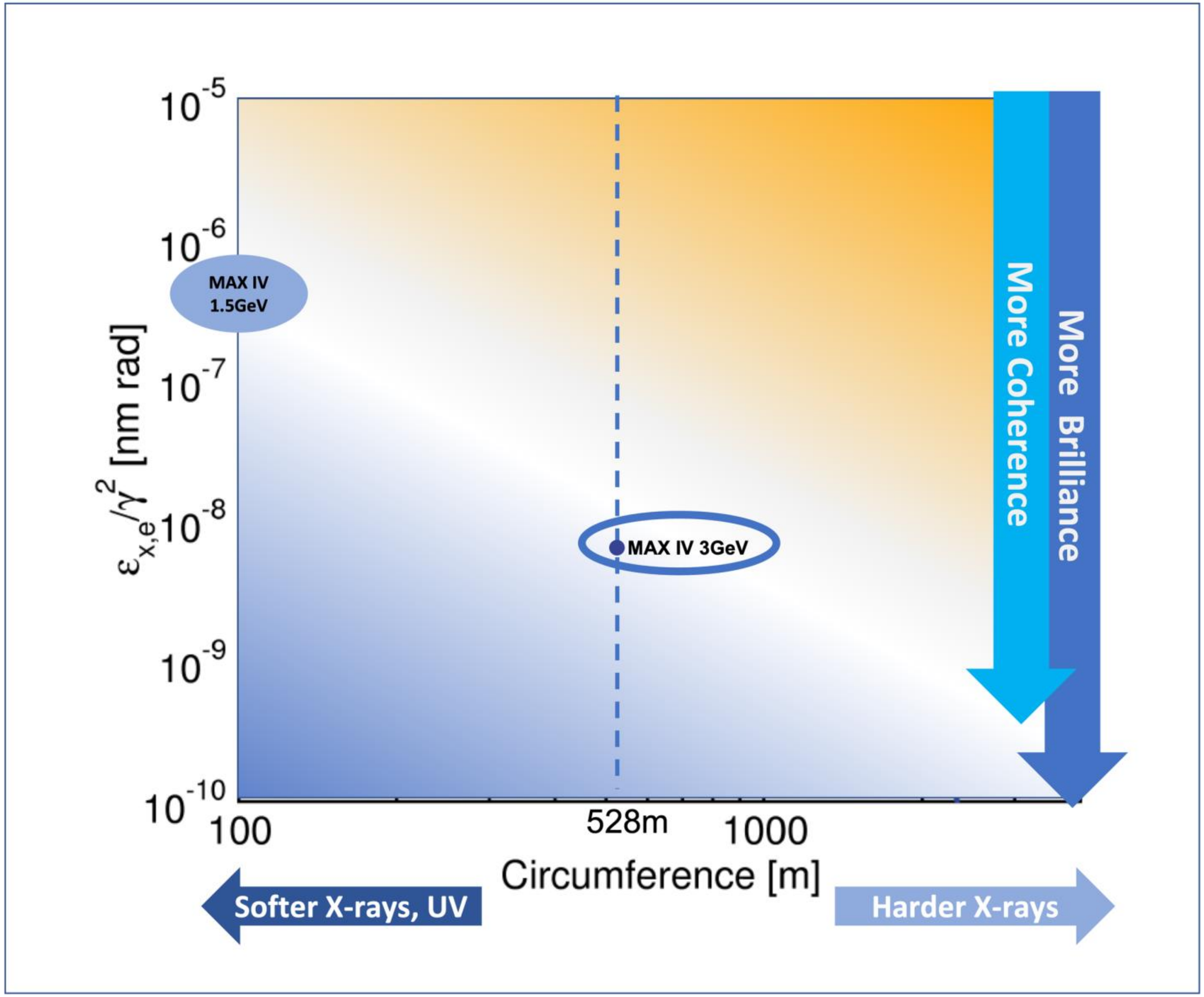

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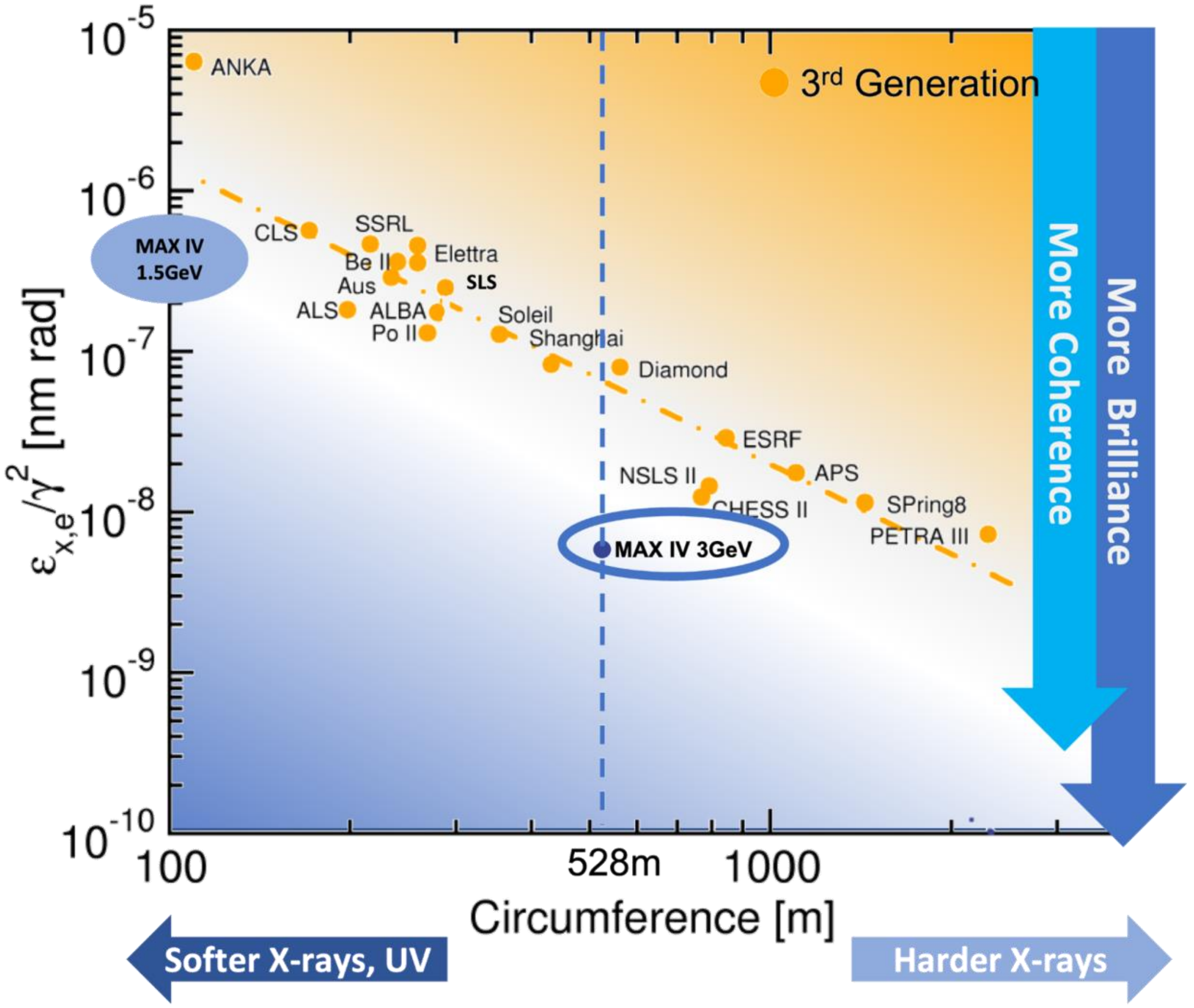

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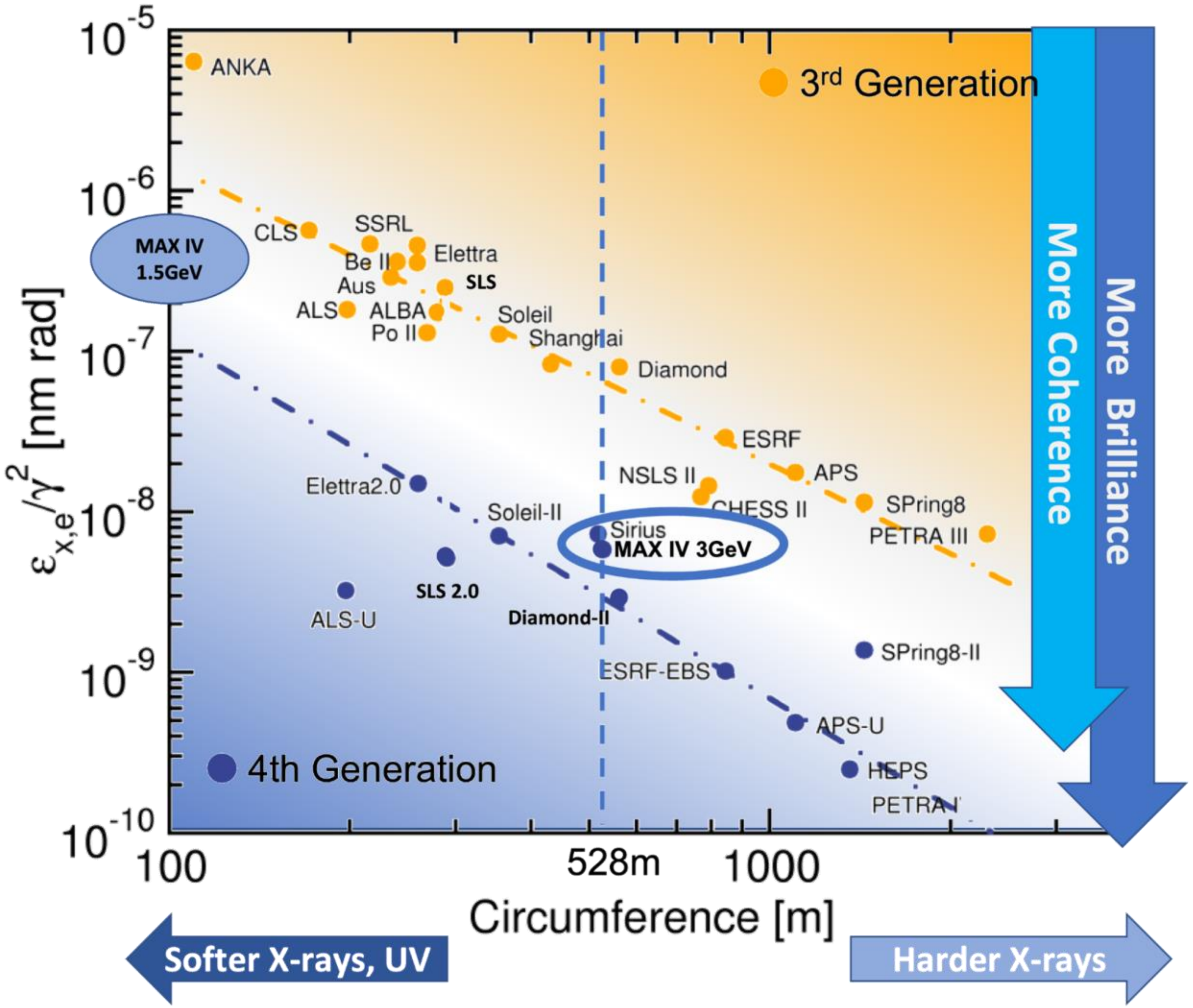

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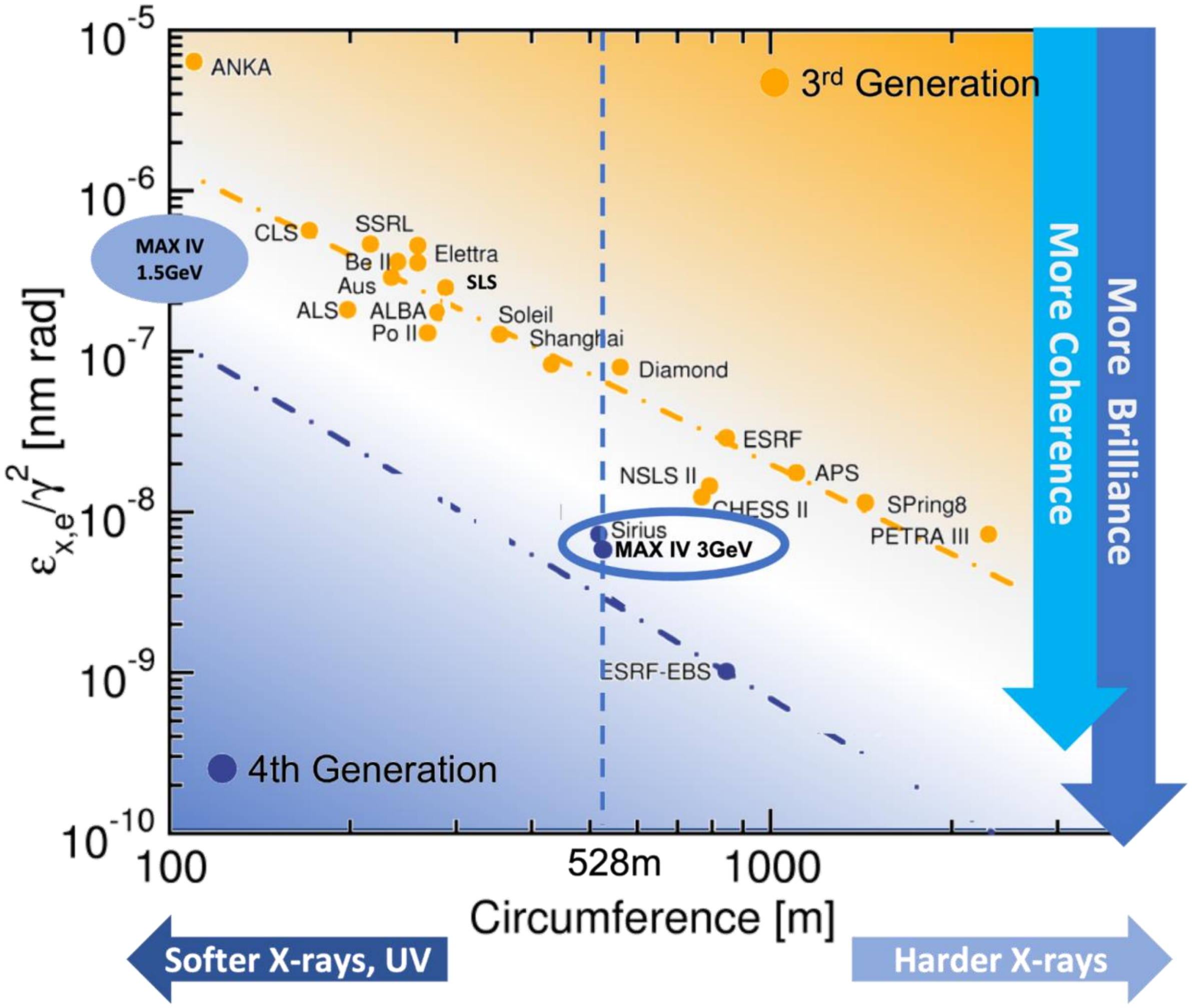
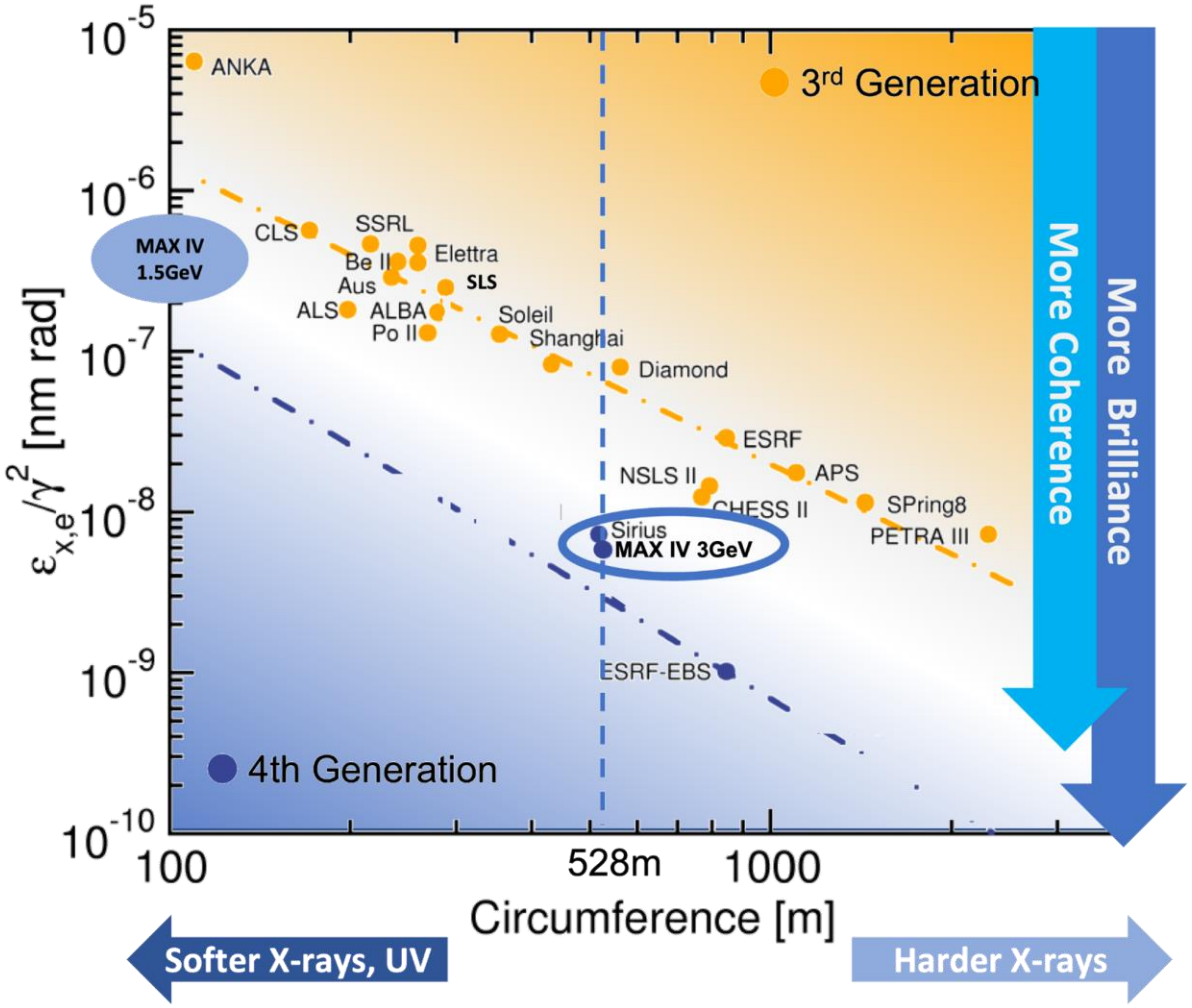



**Most 4$^{th}$ generation light sources will only be fully operational by the end of the decade**

# Other lightsources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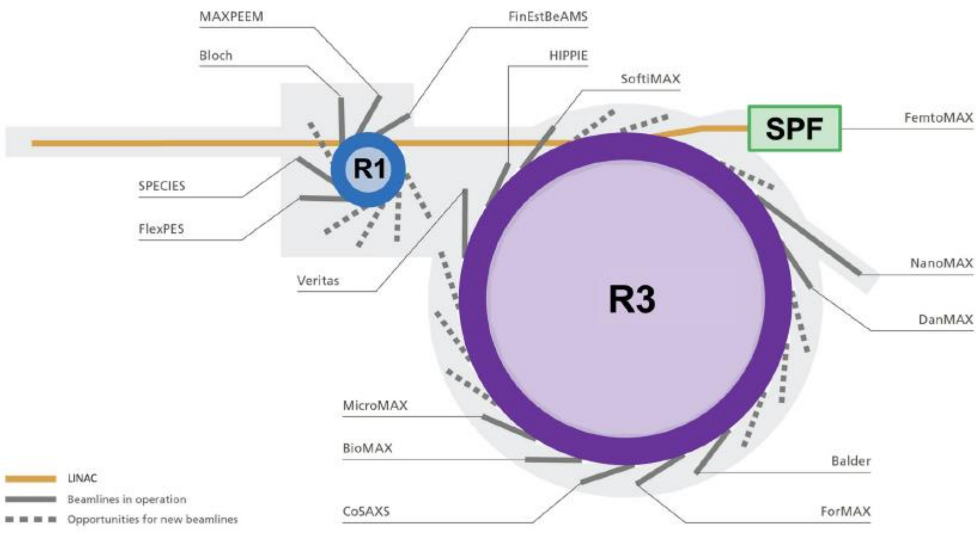
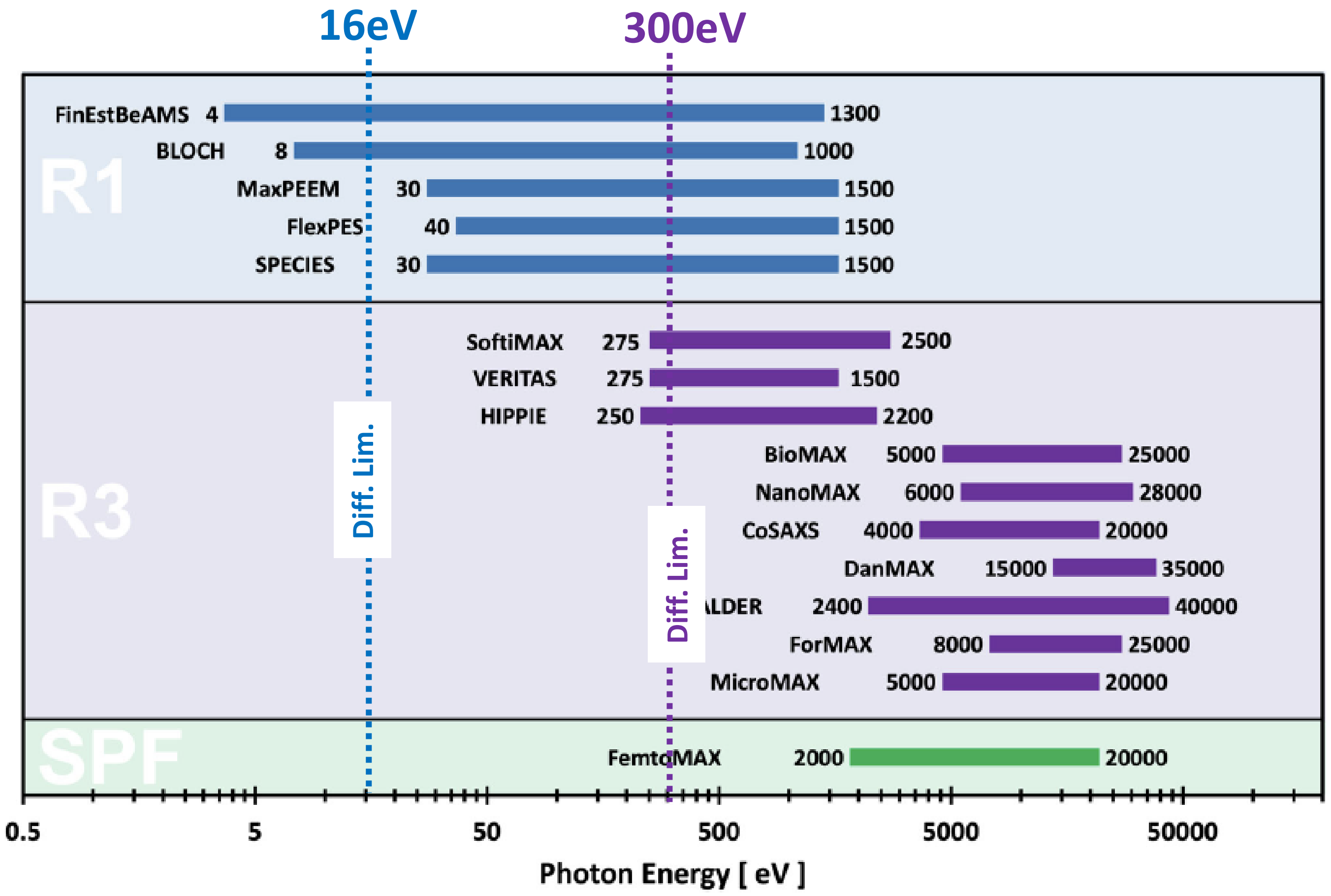
# Beamline Portfolio




**Soft X-rays**
**surface and sub-surface information**

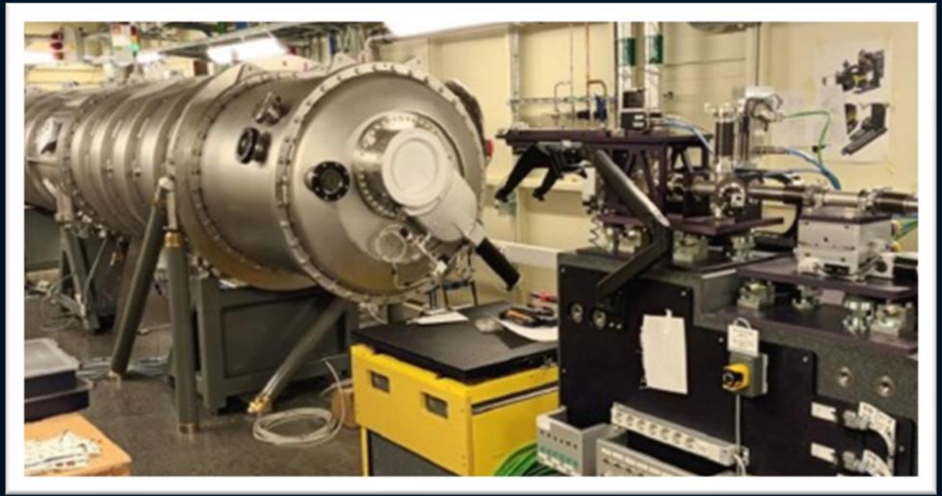
**Hard X-rays**
**bulk information and buried interfaces**

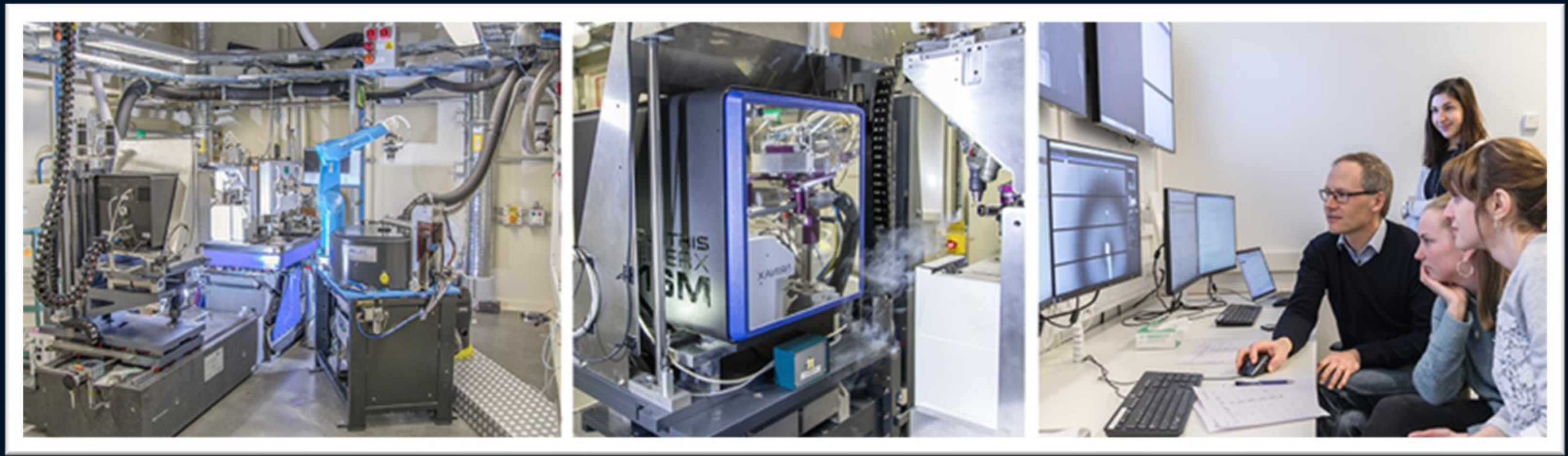
## 16 beamlines covering a broad X-ray energy range from 4 eV to 40 keV



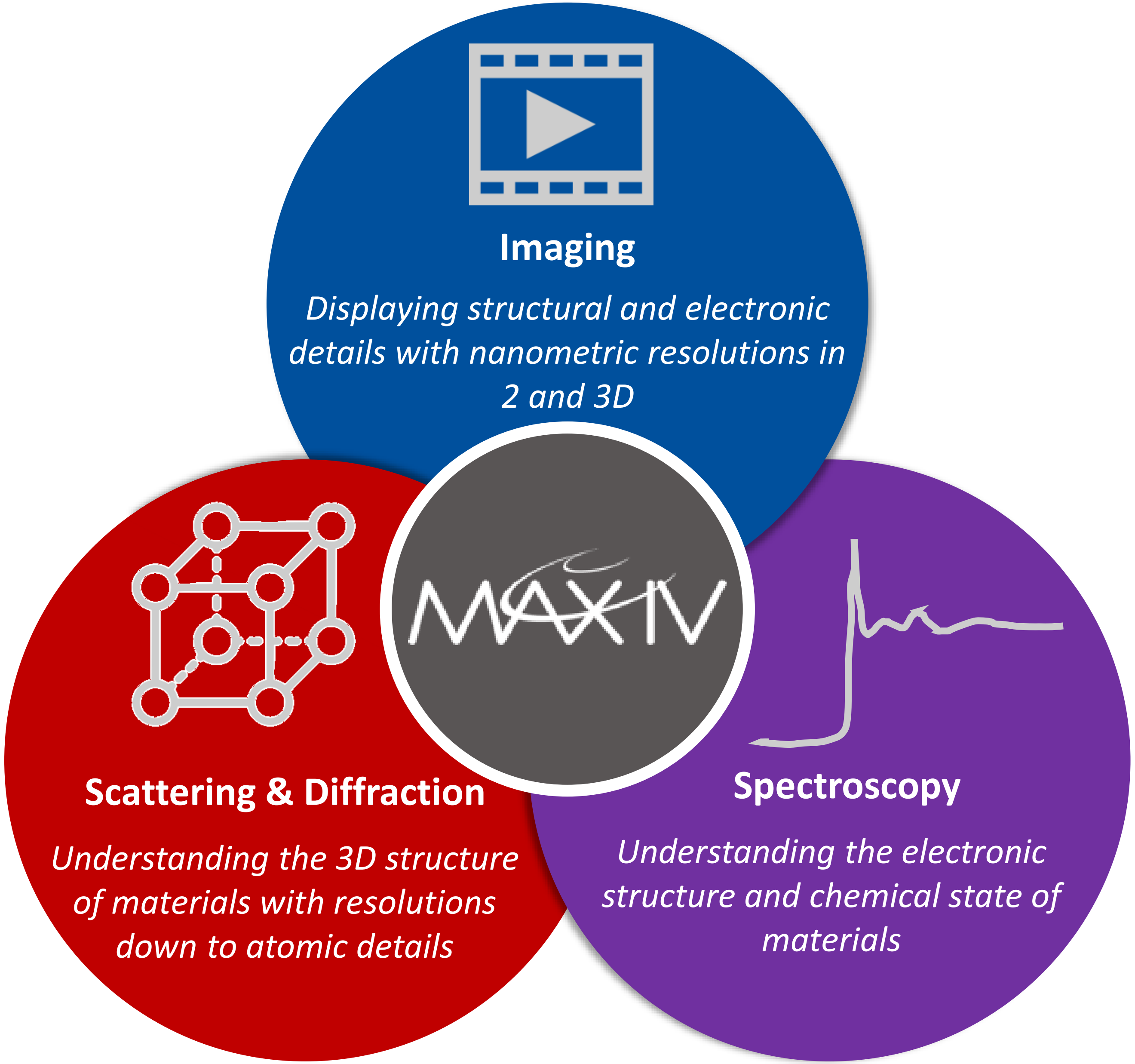

Research conducted at MAX IV, a Swedish national user facility, is supported by the Swedish Research Council under contract 2018-07152, the Swedish Governmental Agency for Innovation Systems under contract 2018-04969, and Formas under contract 2019-02496.

# Beamlines





# Materials science research with one of the most powerful X-ray User Facility




Measuring electrons (e-) or X-rays photons (ph)


# Spectroscopy

Ambient Pressure
X-ray photoelectron Spectroscopy

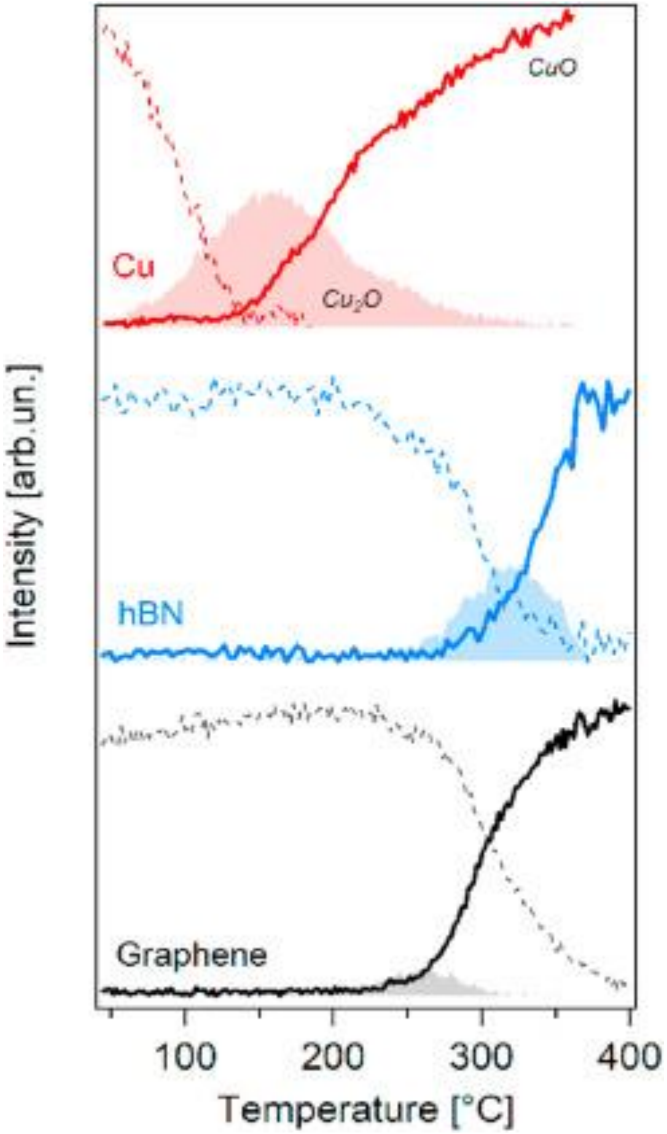
AP-XPS

HIPPIE

e- MAX IV

## Copper oxidation protection with graphene and hexagonal boron nitride

- Uncoated copper is oxidized by molecular oxygen to $Cu_2O$ near room temperature
- Both G and h-BN retard the oxidation temperature by 120 $^0$C
- h-BN forms a protective layer preventing intercalation of $O_2$.
- Protection is effective until the h-BN is rapidly and completely etched away.
- G allows intercalation of $O_2$ that leads to partial and slow oxidation of Cu to $Cu_2O$.
- Due to the low rate of $O_2$ intercalation, no CuO is formed until G is etched.




Evolution of XPS signals of metallic Cu, $Cu_2O$, and CuO in the presence of 2mbar $O_2$

M. Scardamaglia et al., CARBON **171** (2021) 610

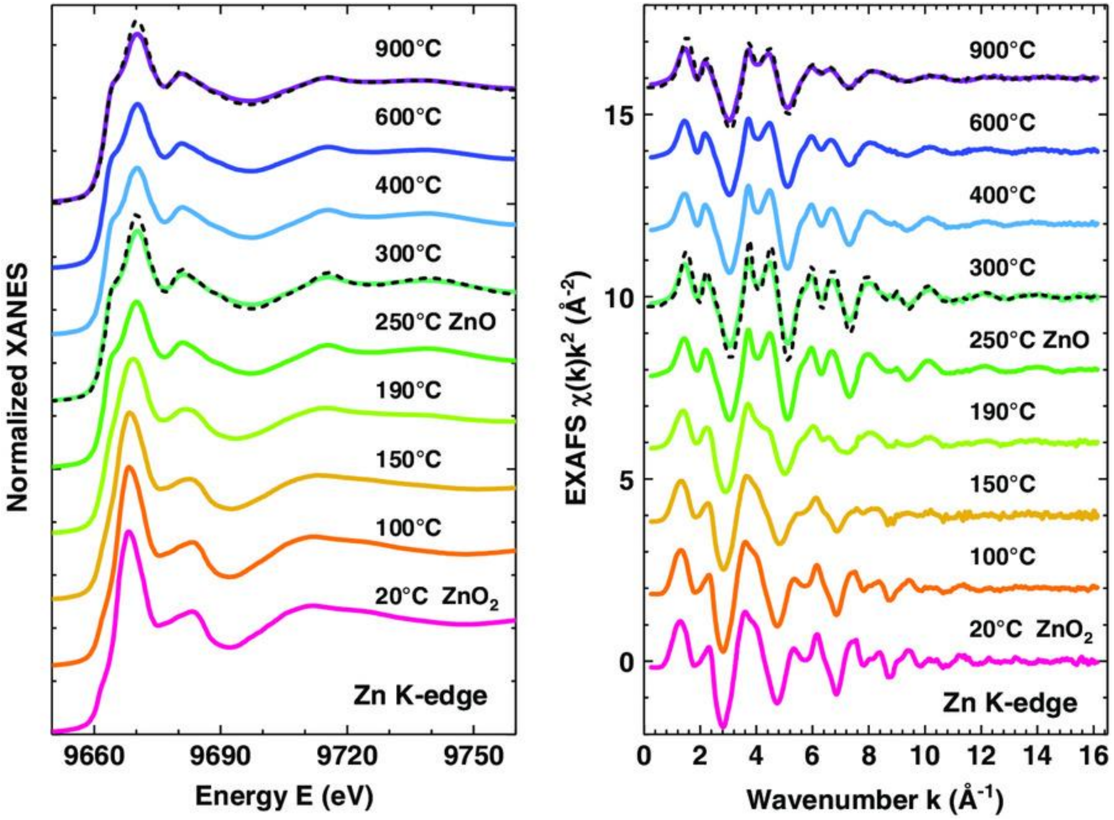
# Spectroscopy

X-ray Emission/Absorption Spectroscopies

XES - XAS
EXAFS

BALDER

X-ray absorption spectroscopy and X-ray emission spectroscopy are element specific techniques and provide atomic characterization of components, including local structure and electronic state.




In situ experimental Zn K-edge X-ray absorption near edge structure (XANES) and extended X-ray absorption fine structure (EXAFS) spectra obtained in the temperature range of 20–900 °C during the decomposition of $ZnO2$ to ZnO. The spectra for reference microcrystalline ZnO are shown by dashed lines at 300 and 900 °C for comparison.

**In Situ Study of Zinc Peroxide Decomposition to Zinc Oxide by X-Ray Absorption Spectroscopy and Reverse Monte Carlo Simulations**,
Kuzmin et al., Phys. Status Solidi B **259**, 2300001 (2022)

## Imaging

PhotoElectron Emission Microscopy

PEEM

# Surface imaging with structural, chemical, electronic, and magnetic contrast with nanometer spatial resolution

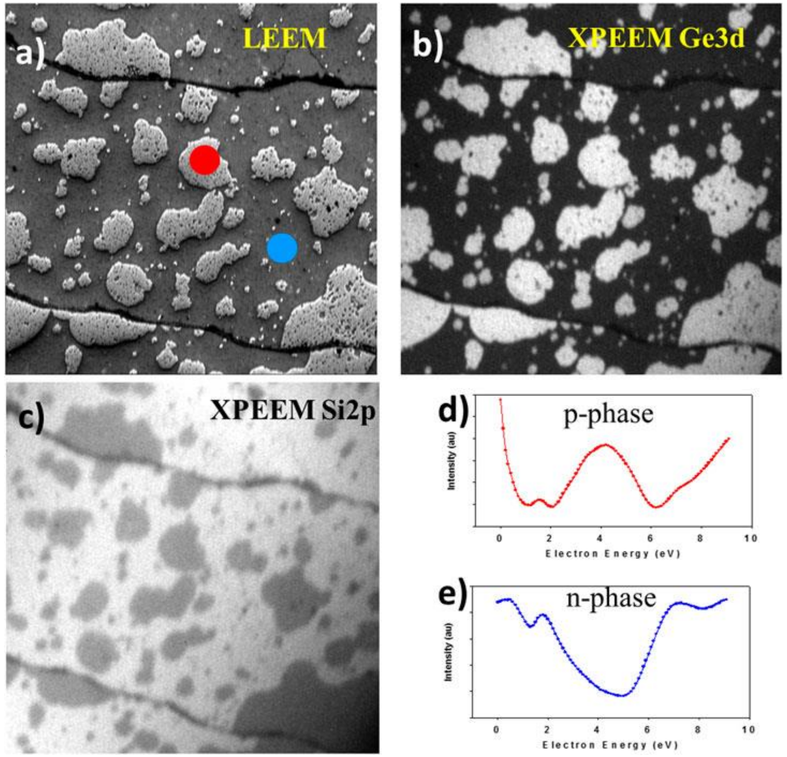



**FIGURE 1 |** The real space characterization of the mixed phase in Ge-intercalated graphene. **(A)** A LEEM image (electron energy 3.5 eV) showing the islands of the p-doped phase in the sea of the n-doped phase. The height difference between p- and n-doped phases in the LEEM image is emphasized by moving the contrast aperture slightly away from the optimal position. **(B)** Ge3d XPEEM image of the same area as in **(A)**. The white islands belong to the p-phase that has twice as much germanium compared to the n-phase. Photon energy hν = 100 eV and electron kinetic energy = 64 eV. **(C)** Si2p XPEEM image showing an extra attenuation of the Si2p photoelectrons going through the p-type islands. Photon energy hν = 150 eV and electron kinetic energy 45.2 eV. Field of view is 10 μm in all three images. **(D,E)** LEEM IV curves collected from areas marked by red and blue circles, respectively, in the LEEM image **(A)** displaying drastic difference in the reflectivity for p- and n-doped Ge-intercalated graphene.

MAXPEEM

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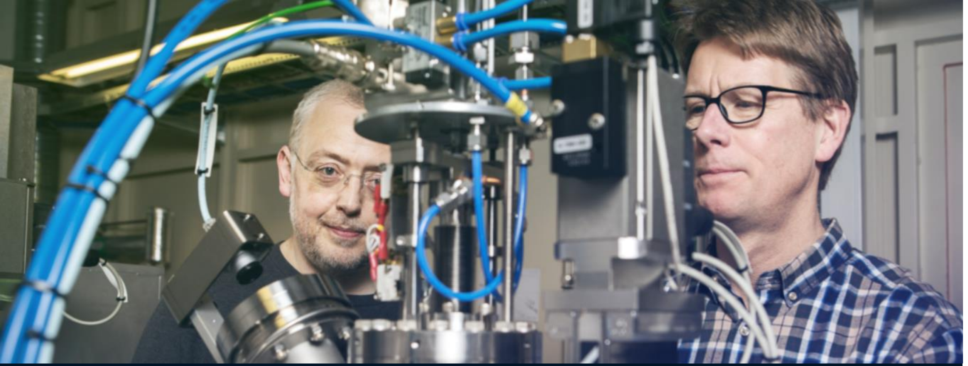
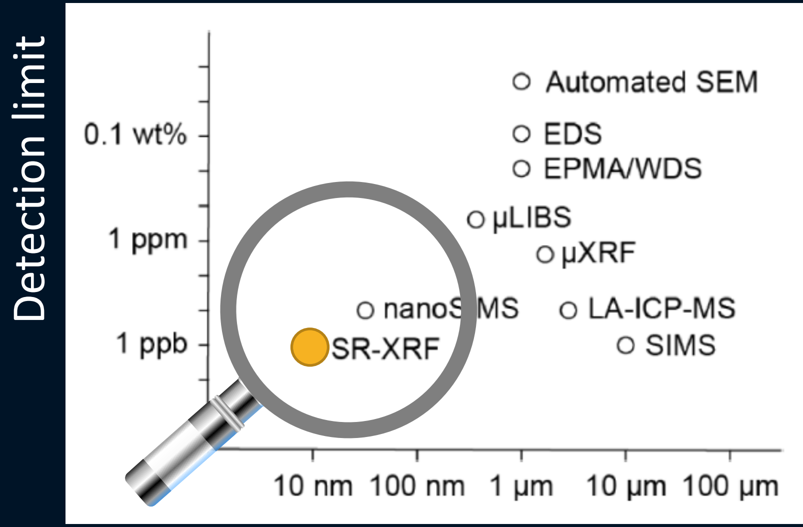
**Ambipolar Behavior of Ge-Intercalated Graphene: Interfacial Dynamics and Possible Applications,** Zakharov et al., Front. Phys. **9** 641168 (2021)



# Imaging - SDXM



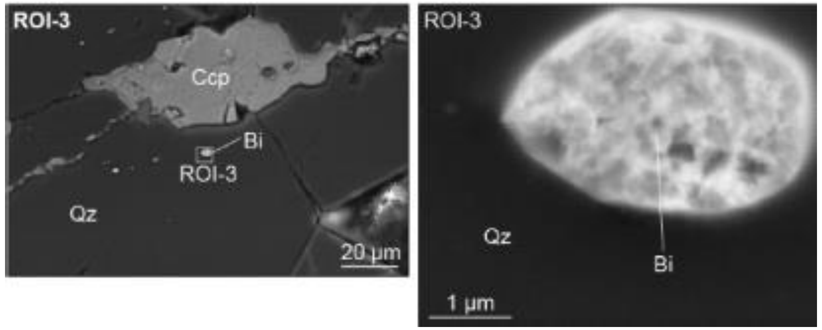

Resolution

SEM: Scanning Electron Microscopy
EDS: Energy Dispersive Spectrometry
WDS: Wavelength Dispersive Spectrometry
LA-ICP-MS: Laser Ablation inductively coupled plasma mass spectrometry
XRF: X-ray Fluorescence
LIBS: Laser Induced Breakdown Spectroscopy
EPMA: Electron Probe Micro-Analyzer
SIMS: Secondary Ion Mass Spectrometry

NANOMAX

ph MAX IV

## Investigating droplet-shaped Bismuth grain in a quartz vein with synchrotron radiation high-resolution fluorescence microscopy



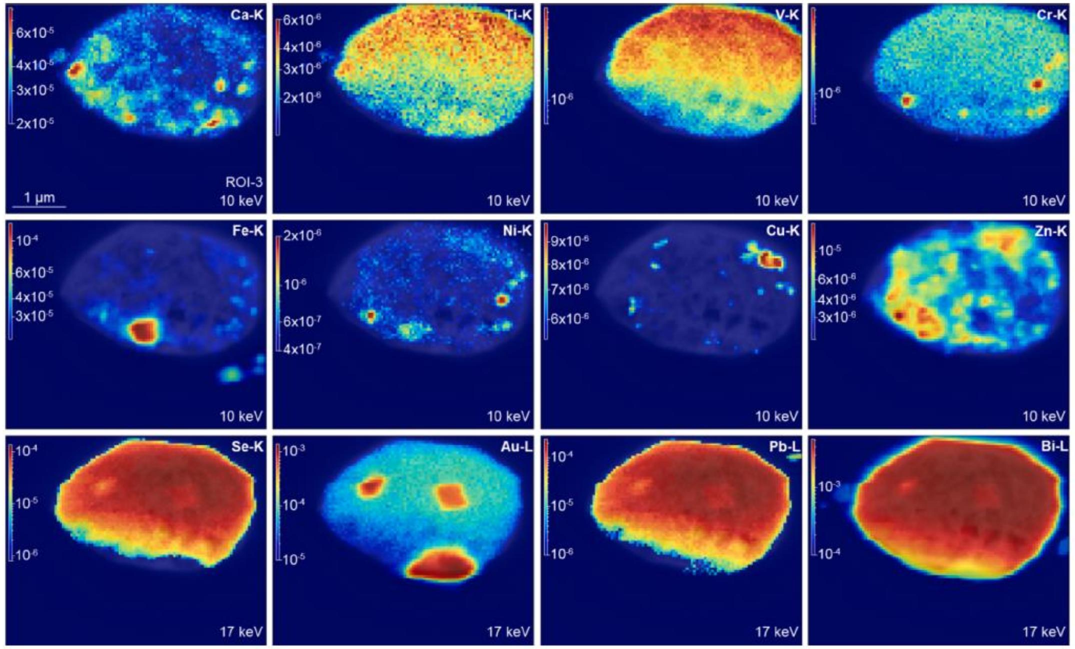
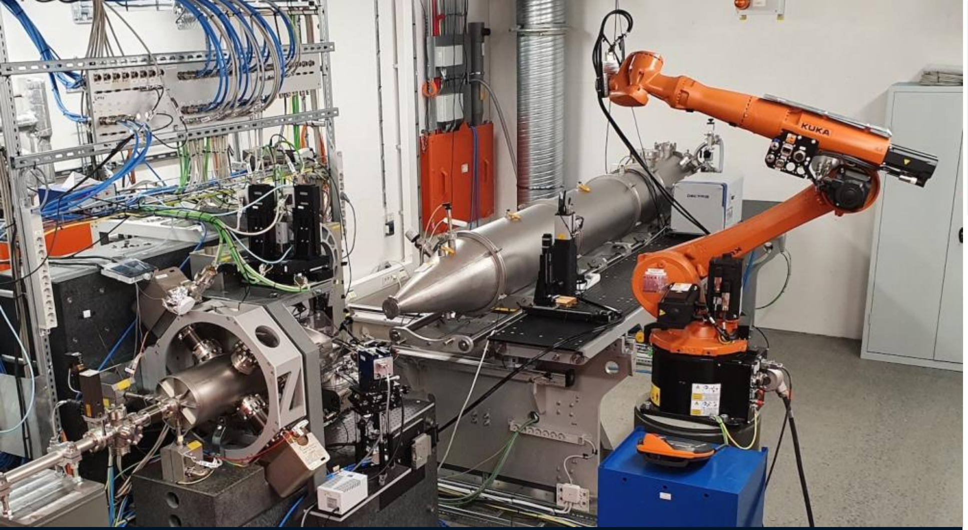




Fig. 10. Selected pseudo-quantitative SR-XFM element fluorescence maps of ROI-3. The scales are based on wt.% concentration but calibrated to an arbitrary set of values. This allows qualitative comparison between element maps. A logarithmic scale was used to better resolve weakly fluorescent features. A cut-off concentration was applied to all maps to separate features from background. Element fluorescence maps Ca-K to Zn-K are from the 10 keV scan, maps Se-K to Bi-L from the 17 keV scan.

Extreme resolution synchrotron X-ray fluorescence mapping of ore samples

M. Warlo *et al.*, Ore Geology Reviews **120**, 104620 (2022)



# Imaging

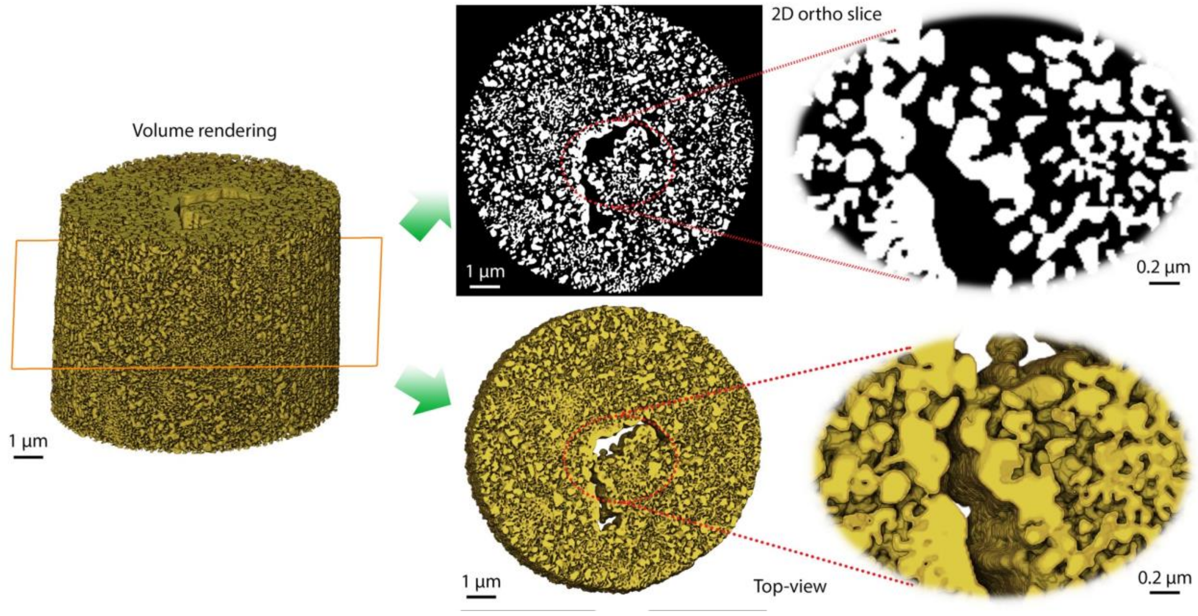
Tomographic Imaging

CT

DANMAX
FORMAX
NANOMAX

ph MAX IV

## Explore the hard X-ray coherence for high resolution and (hierarchical phase-contrast, full field, micro-, nano-, holo-) 3D computed tomography imaging




*3D rendering of hierarchically-structured monolithic nanoporous gold with approx. 23 nm spatial resolution obtained by ptychographic X-ray tomography, showing binary representation of gold and pores after image segmentation (above) and the resulting orthographic projection.*

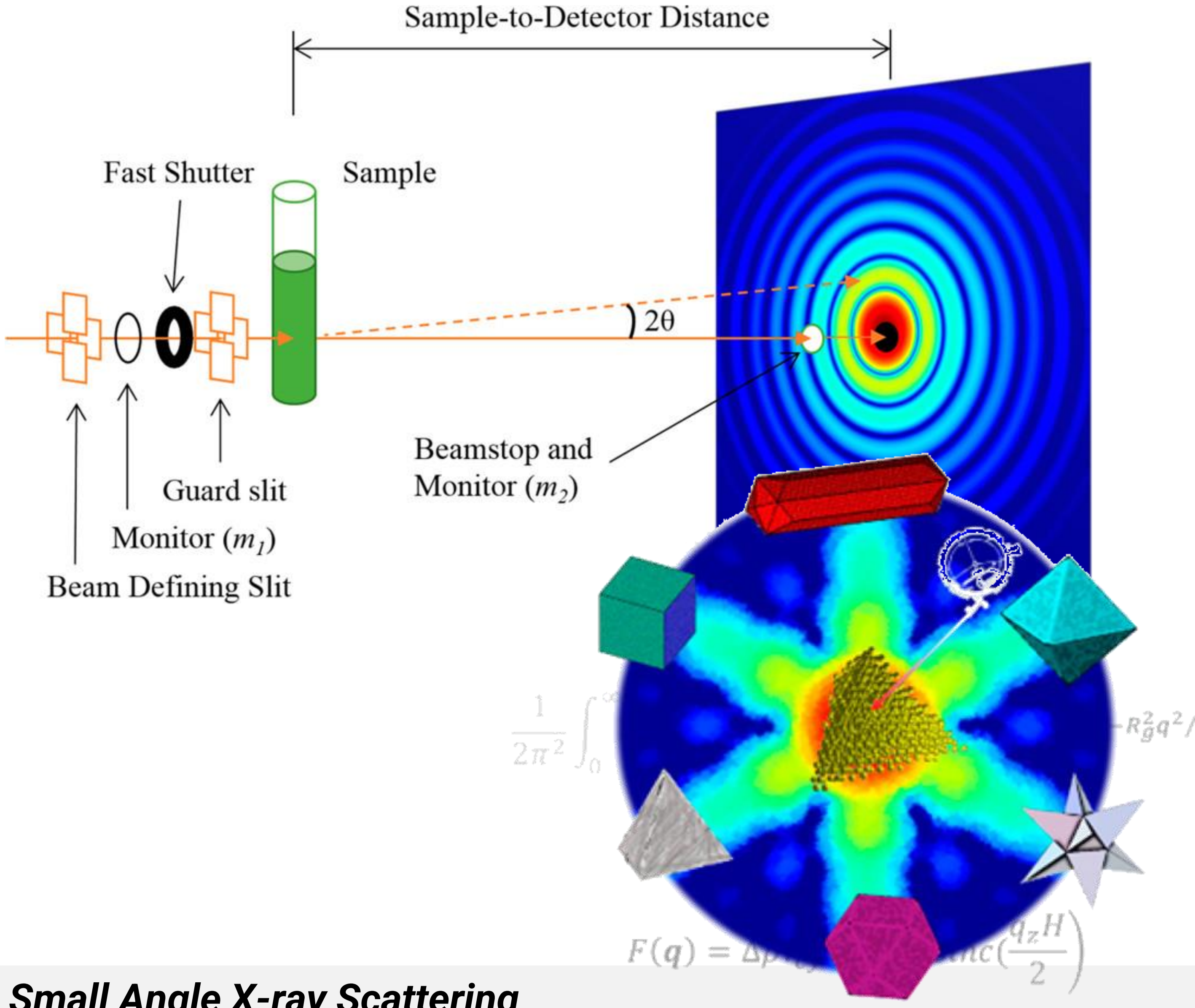
Correlative Multiscale 3D Imaging of a Hierarchical Nanoporous Gold Catalyst by Electron, Ion and X-ray Nanotomography, Fam et al., Chem. Cat. Chem. **10,** 2858 (2018)

# Understanding amorphous and disordered, complex systems with nanometric characteristic lengthscales

## Scattering

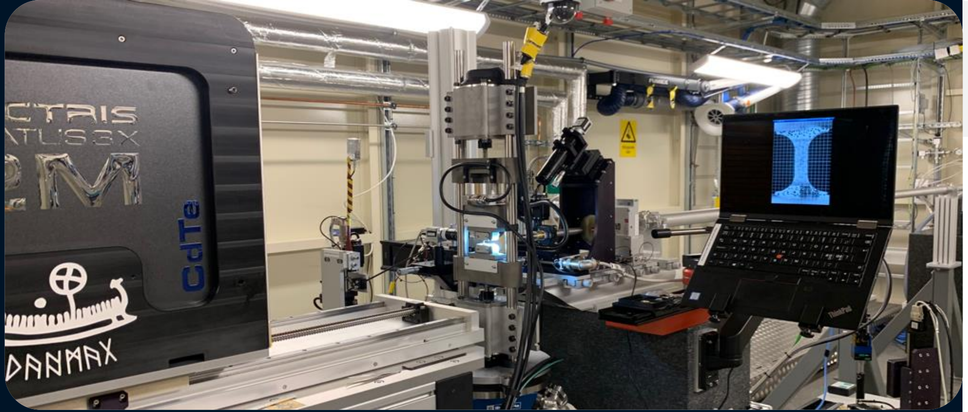
Small Angle X-ray Scattering

SAXS




COSAXS

*Li* et al., ***Small Angle X-ray Scattering for nanoparticle research,*** *Chem. Rev.* **16** (18), 11128 (2016)




# Scattering/Diffraction

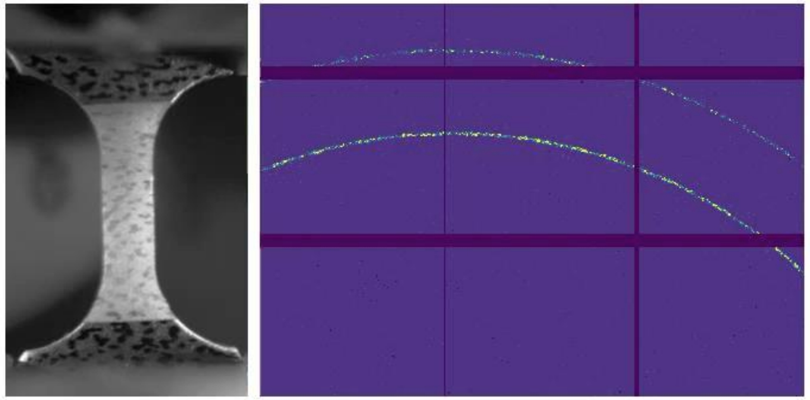
X-ray Diffraction

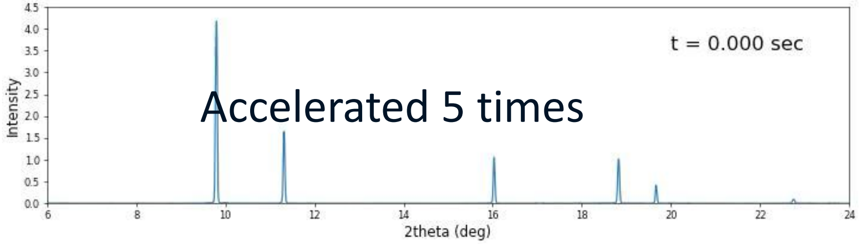
XRD

DANMAX

## **TR**ansformation **I**nduced **P**lasticity (TRIP) steels are used in many applications due to their outstanding combination of strength and ductility

Austenite to martensite phase transition observed at 250Hz





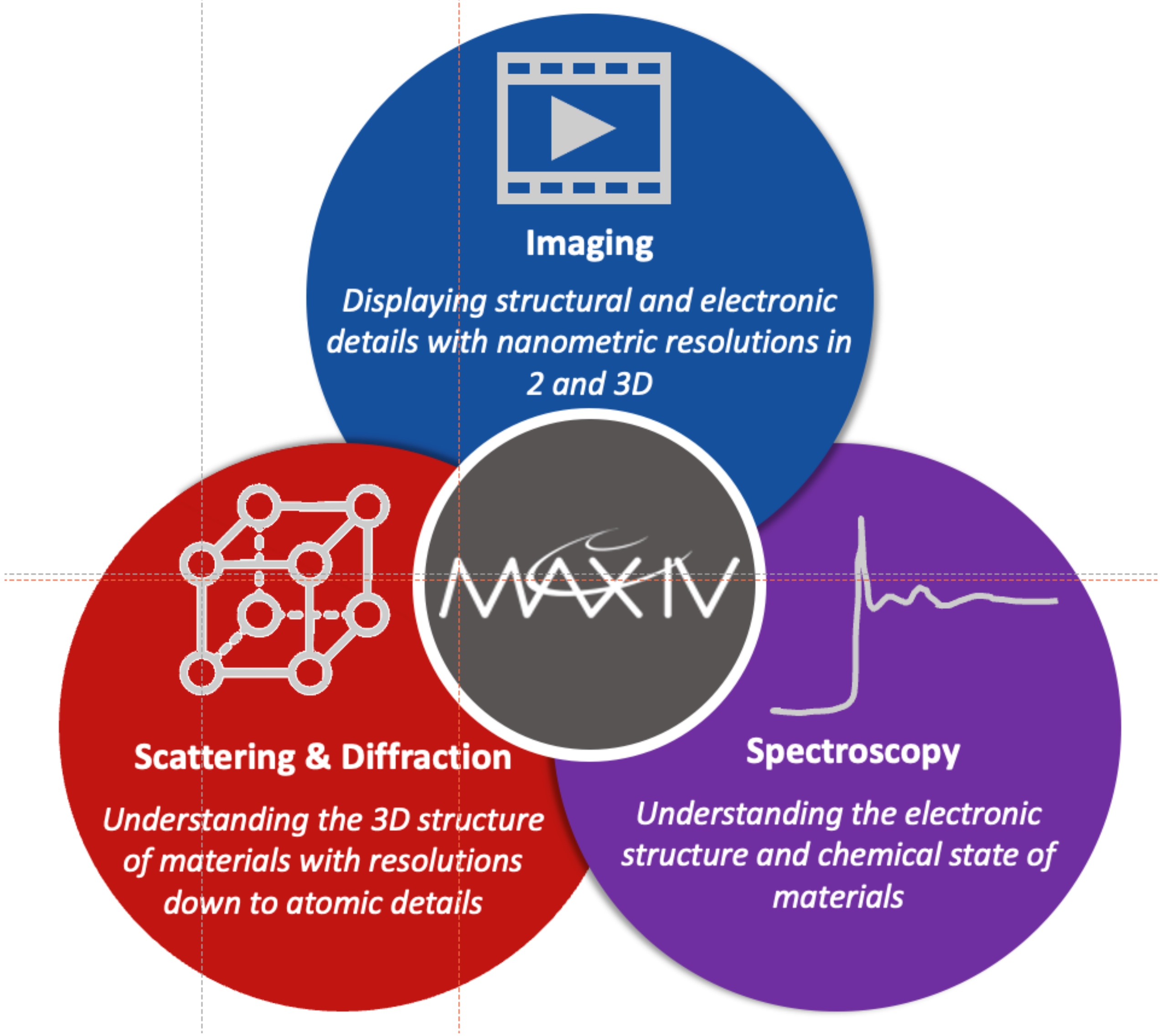


Volvo XC90
*www.volvocars.com*

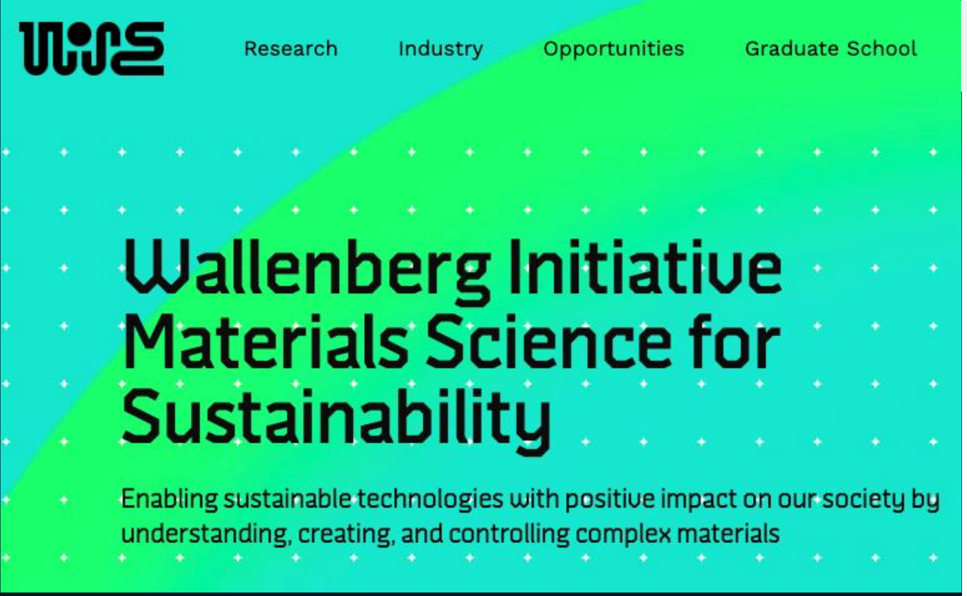

M. Hokka *et al.*, Tampere U. (Finland)

# Providing modern X-ray tools to support the current and future research needs of the user community.

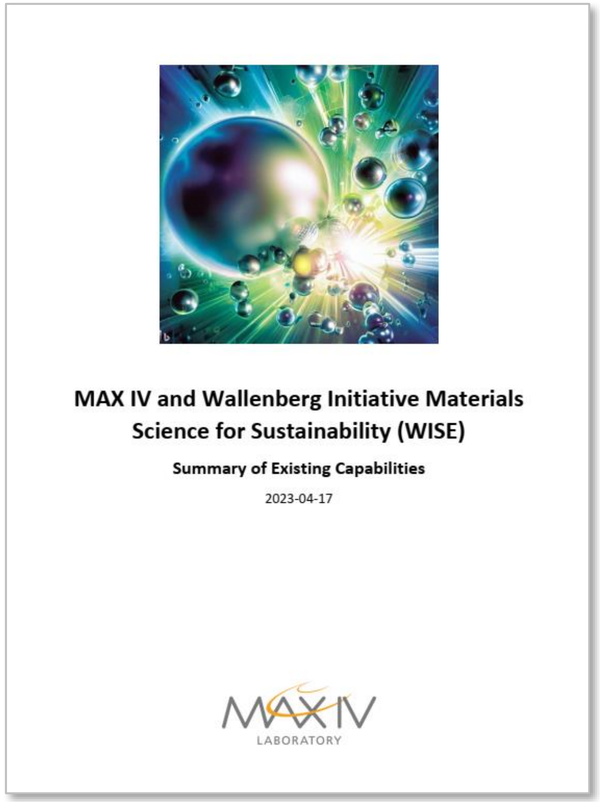
# This is MAX IV !




MAX IV




# Extending our materials science beamlines portfolio


MAX IV and Wallenberg Initiative Materials Science for Sustainability (WISE)

Summary of Existing Capabilities

2023-04-17

MAX IV LABORATORY

Download the document from maxiv.se or via the QR code:

## Imaging beamline

A hard X-ray tomography beamline dedicated to microstructure characterization and 4D imaging of materials.

## Diffraction beamline

A high-throughput, flexible diffraction beamline for fast and time-resolved structural characterization of surfaces, powders, and crystals.

## Spectroscopy beamline

A tender-to-hard X-ray spectroscopy beamline for *in situ* and *operando* characterization of surfaces and buried interfaces under realistic conditions.

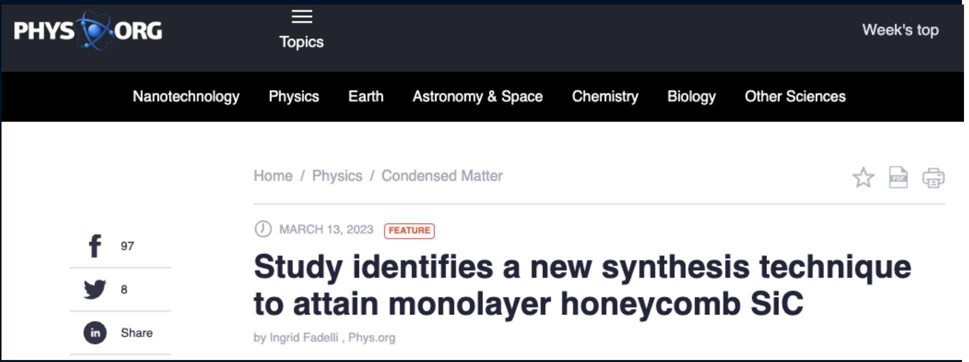
***WISE funds the Conceptual Design Reports of three new beamlines supporting materials science for sustainability.***

MAX IV

# Spectroscopy

## Angular Resolved PhotoElectron Spectroscopy

## ARPES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Home / Physics / Condensed Matter
MARCH 13, 2023 FEATURE
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### Study identifies a new synthesis technique to attain monolayer honeycomb SiC

by Ingrid Fadelli , Phys.org

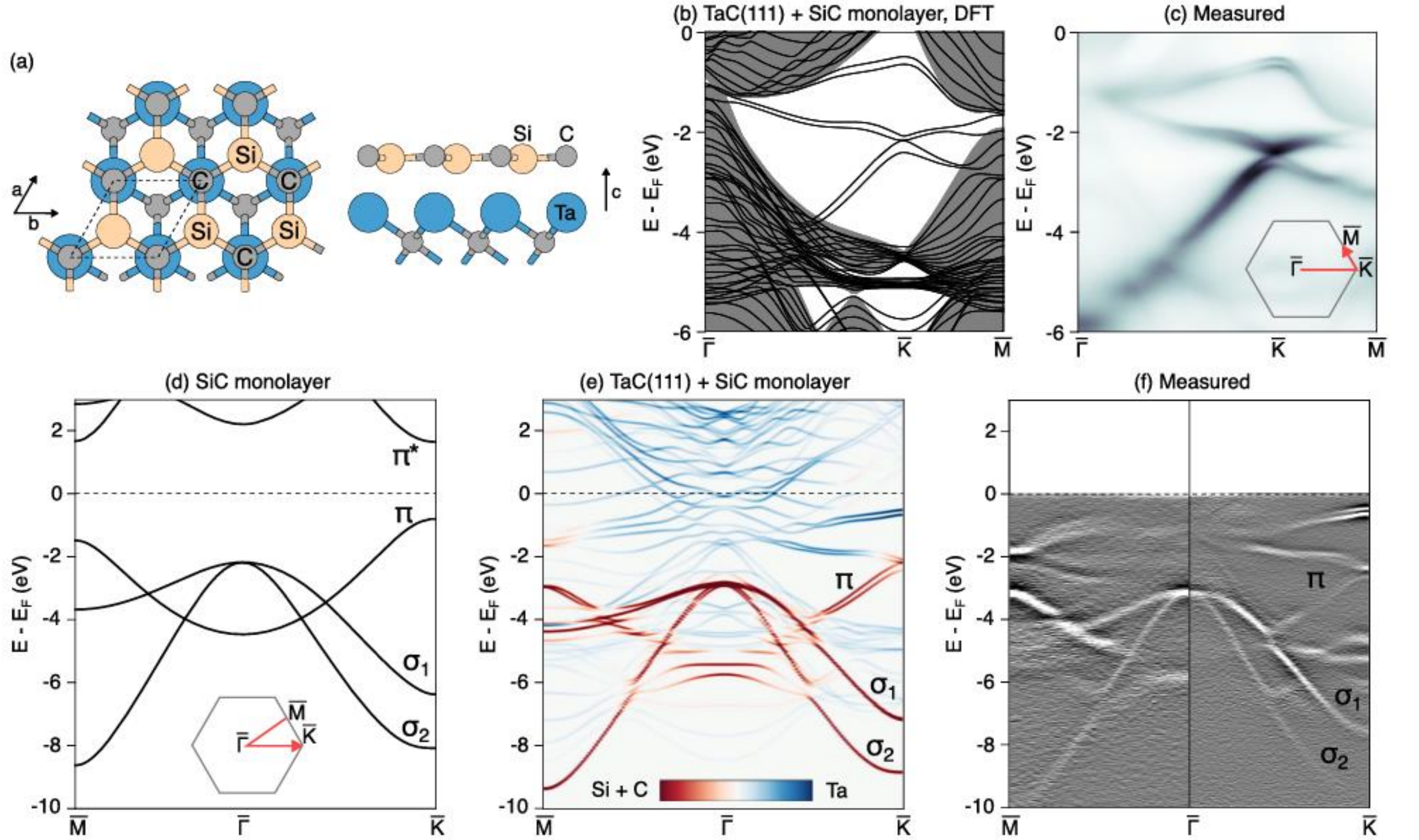


FIG. 3. (a) Schematic depiction of the honeycomb SiC structure. (b) Slab DFT band structure calculation for this structure along the $\bar{\Gamma}$-$\bar{K}$-$\bar{M}$ path. The surface-projected TaC bulk band structure is indicated by the shaded grey regions. (c) ARPES spectrum at $h\nu = 67$ eV, $T = 80$ K. (d) DFT band structure of a planar, freestanding SiC monolayer along the $\bar{M}$-$\bar{\Gamma}$-$\bar{K}$ path. (e) The same calculation for SiC atop TaC(111) as shown in (b), but sampling only the topmost two atomic layers and resolved into atomic character. (f) Corresponding experimental spectra, presented as a second derivative image. The $\bar{\Gamma}$-$\bar{M}$ slice is acquired from the second Brillouin zone with $h\nu = 138$ eV while the $\bar{\Gamma}$-$\bar{K}$ slice is with $h\nu = 44$ eV, both at $T = 80$ K.

BLOCH

e- MAX IV

C. M. Polley et al, Bottom-Up Growth of Monolayer Honeycomb SiC, *Physical Review Letters* ***130***, *076203* (2023)