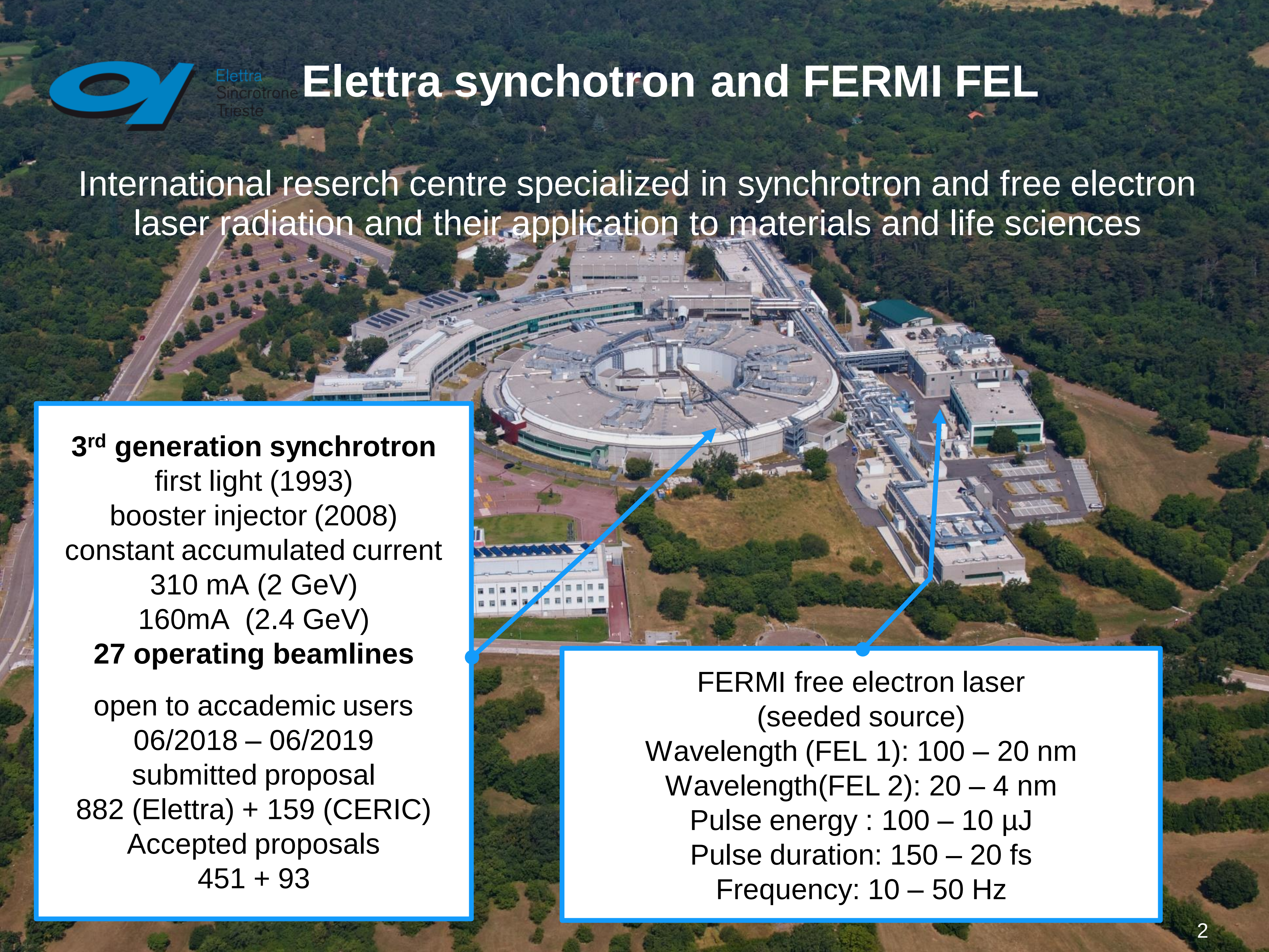
Elettra
Sincrotrone
Trieste

Exploring matter with soft x-rays: research opportunities at the Elettra synchrotron and FERMI FEL

Andrea Locatelli
andrea.locatelli@elettra.eu



Elettra Sincrotrone Trieste

Elettra synchotron and FERMI FEL

International reserch centre specialized in synchrotron and free electron laser radiation and their application to materials and life sciences

3rd generation synchrotron
first light (1993)
booster injector (2008)
constant accumulated current
310 mA (2 GeV)
160mA (2.4 GeV)
27 operating beamlines

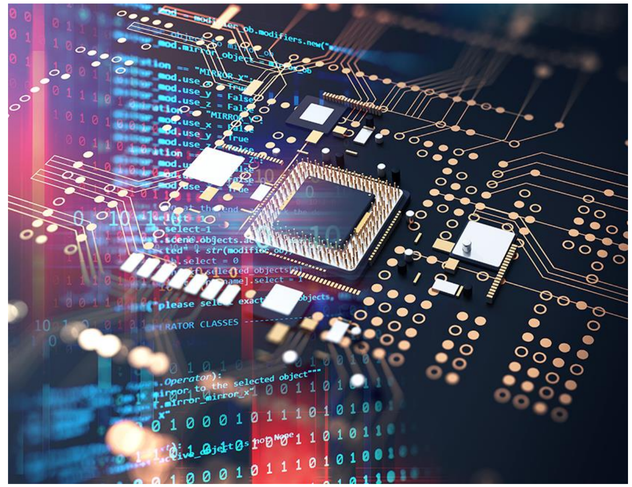
open to accademic users
06/2018 – 06/2019
submitted proposal
882 (Elettra) + 159 (CERIC)
Accepted proposals
451 + 93

FERMI free electron laser
(seeded source)
Wavelength (FEL 1): 100 – 20 nm
Wavelength(FEL 2): 20 – 4 nm
Pulse energy : 100 – 10 µJ
Pulse duration: 150 – 20 fs
Frequency: 10 – 50 Hz

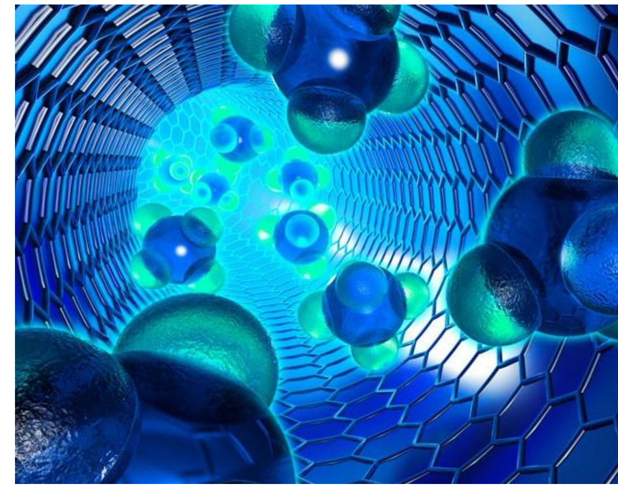
Elettra Sincrotrone Trieste

Outlook – Basic and applied research topics @ Synchrotrons and FELs

Energy

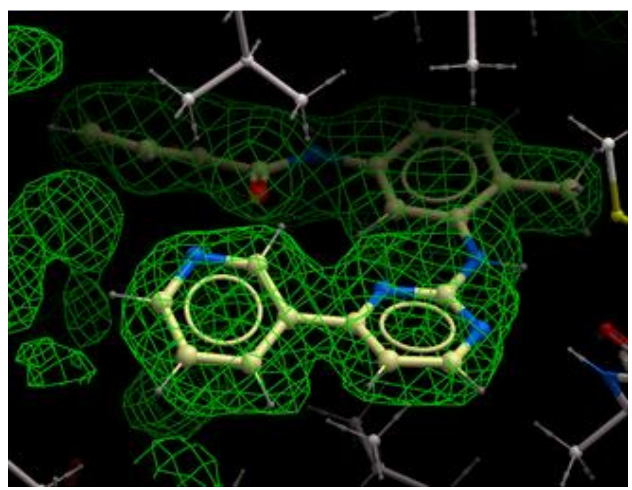


Technology

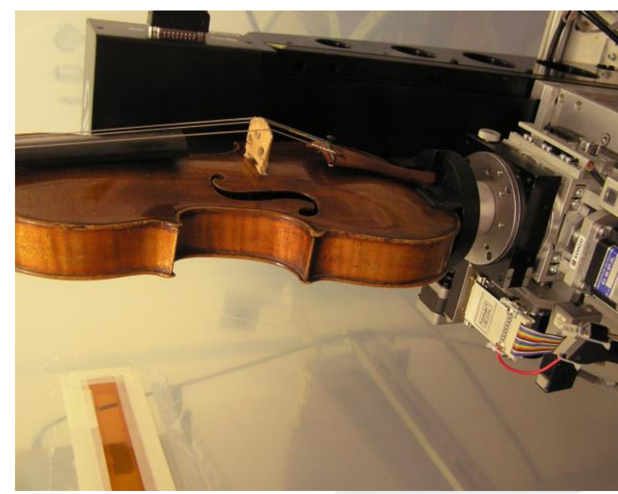


Materials

Environment



Health & Biosciences



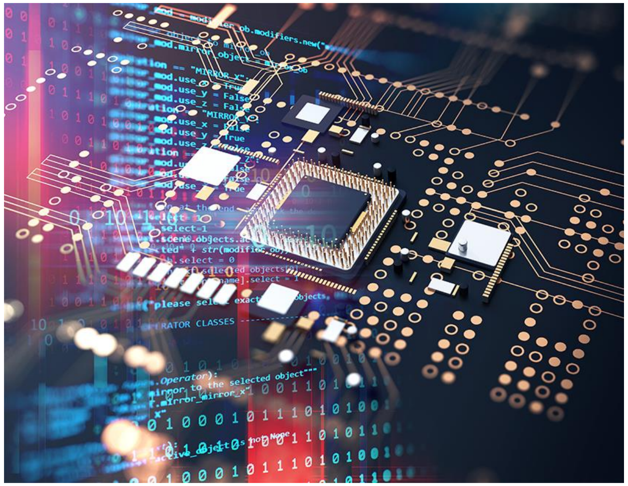
Cultural heritage

Talk by Lisa Vaccari

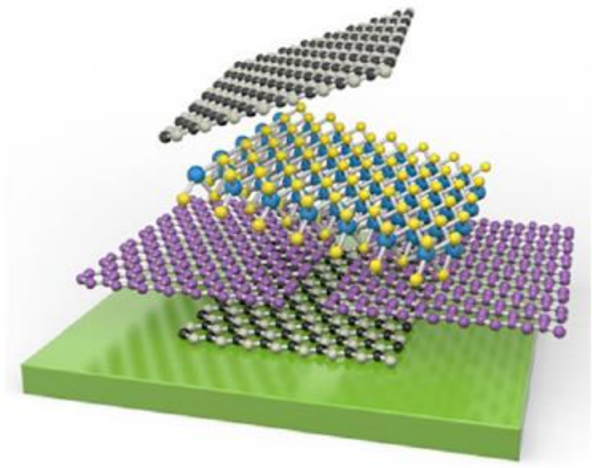
Outlook – Basic and applied research topics @ Synchrotrons and FELs

Elettra Sincrotrone Trieste

Energy



Technology



Materials

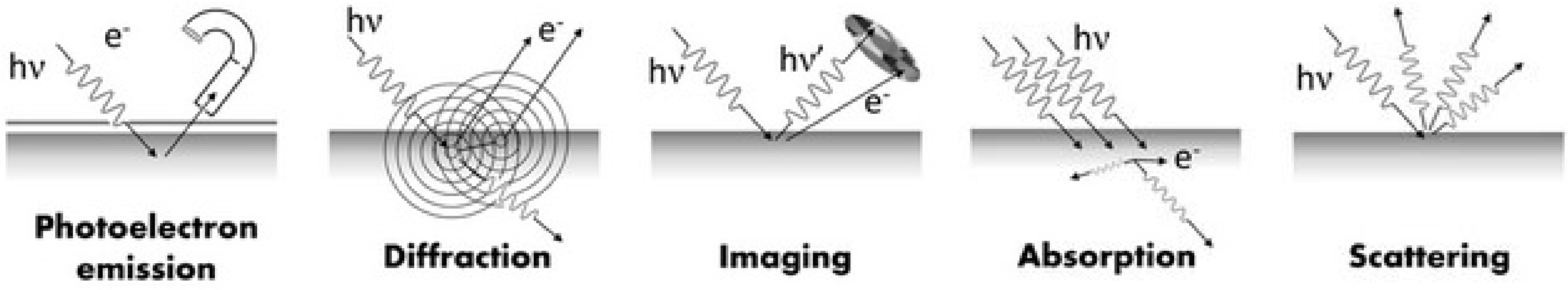
Electronic and optical devices
Magnetic devices
Metamaterials
Catalysis
Electro-chemistry, Fuel cells
Batteries
Super alloys
.....

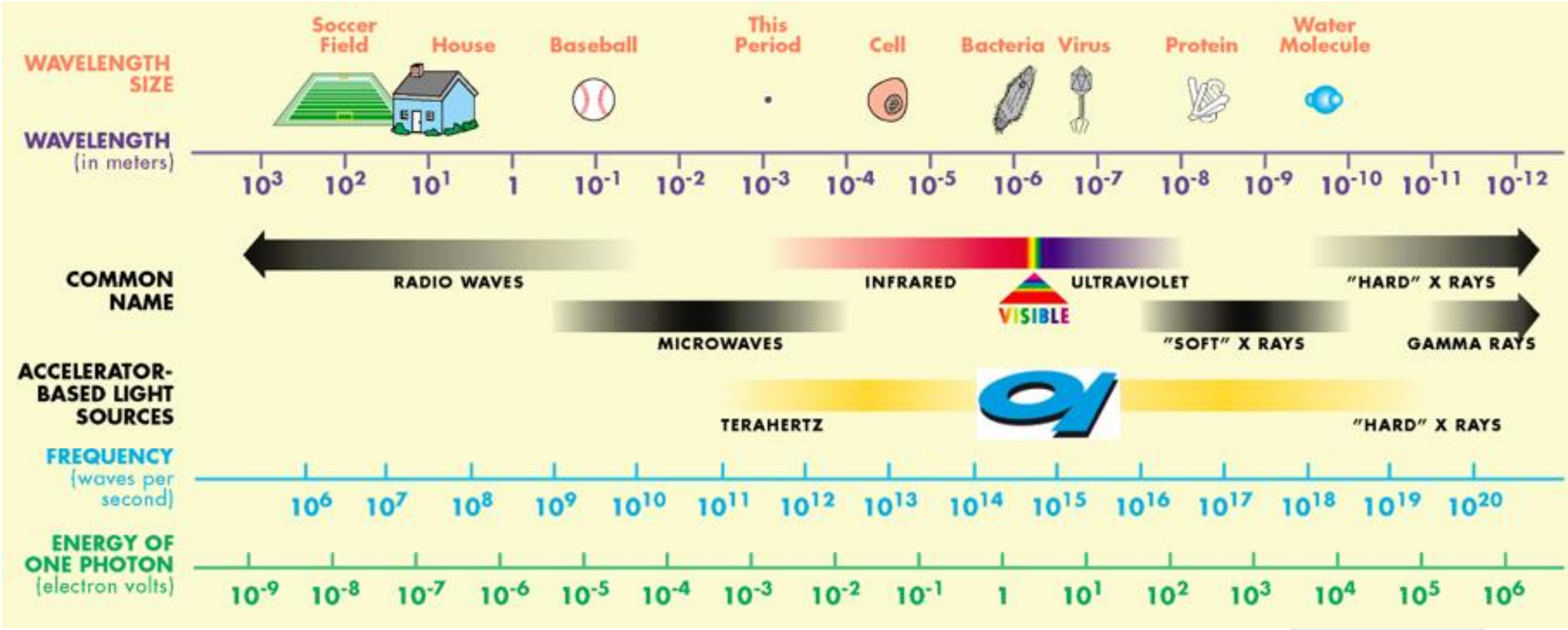
representative model systems

Elettra
Sincrotrone
Trieste

Characterization techniques at synchrotrons

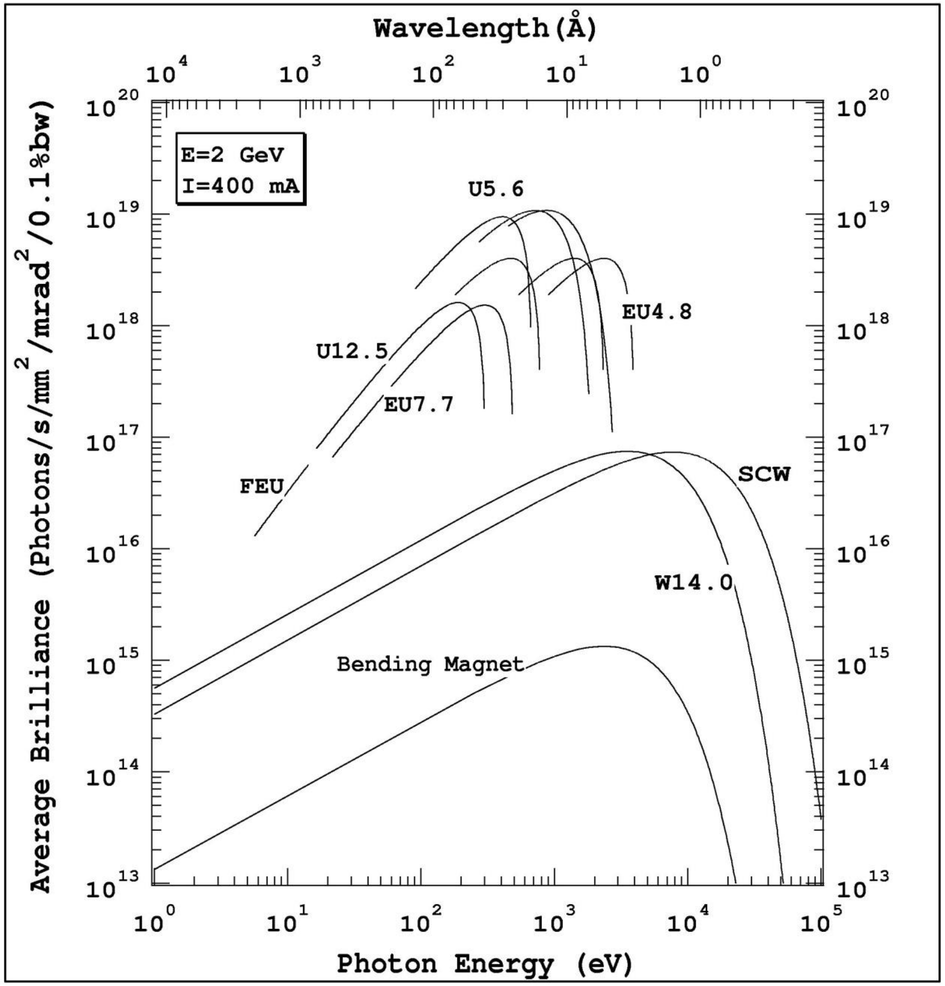
We explore the matter by shining light on it and detecting particles





Properties of Synchrotron Light

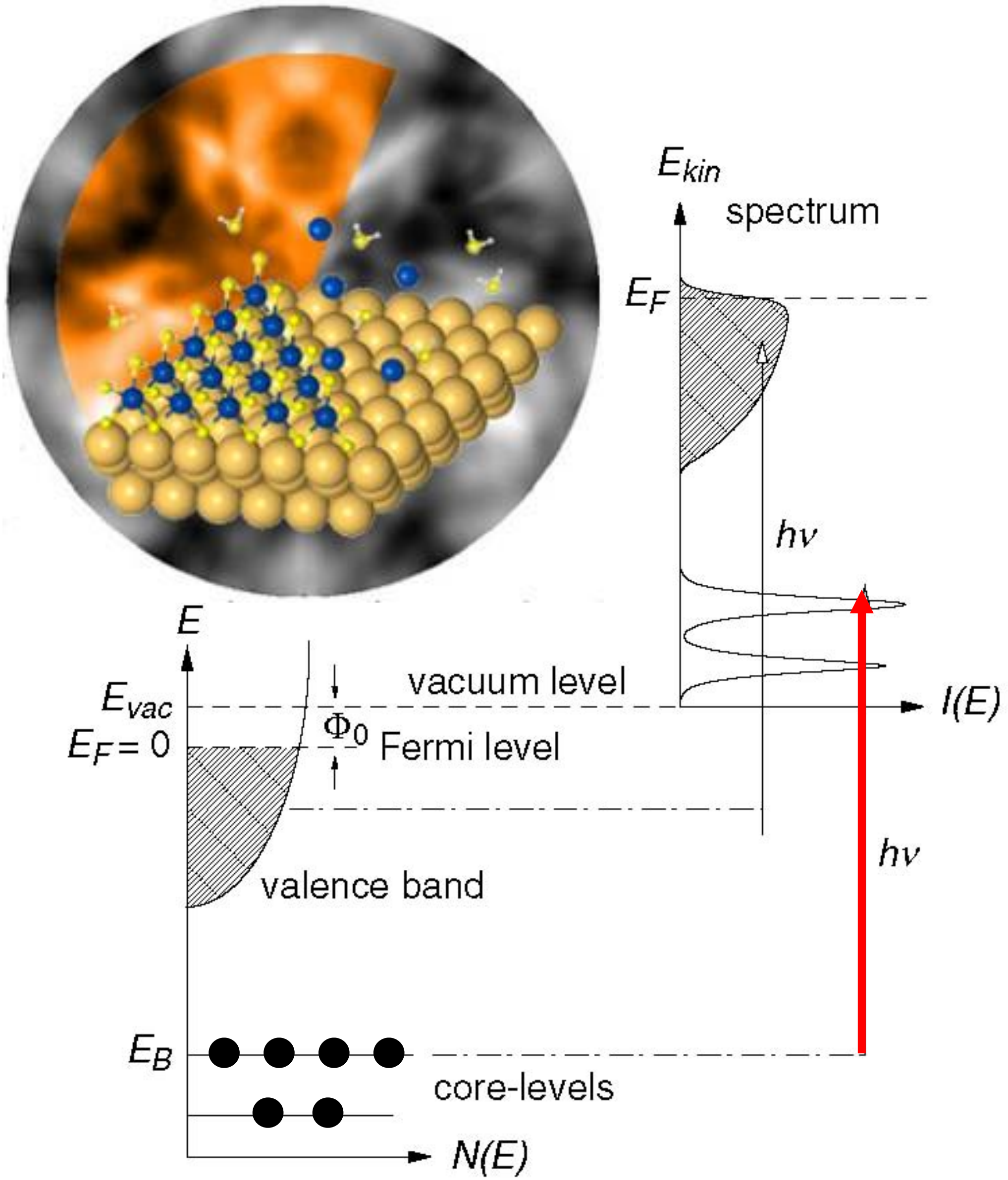
- High intensity
- Tunability
- Broad spectral range
- Narrow angular collimation
- Coherence
- High degree of polarization
- Pulsed time structure
- Quantitative control



Synchrotron radiation makes it quantitative!

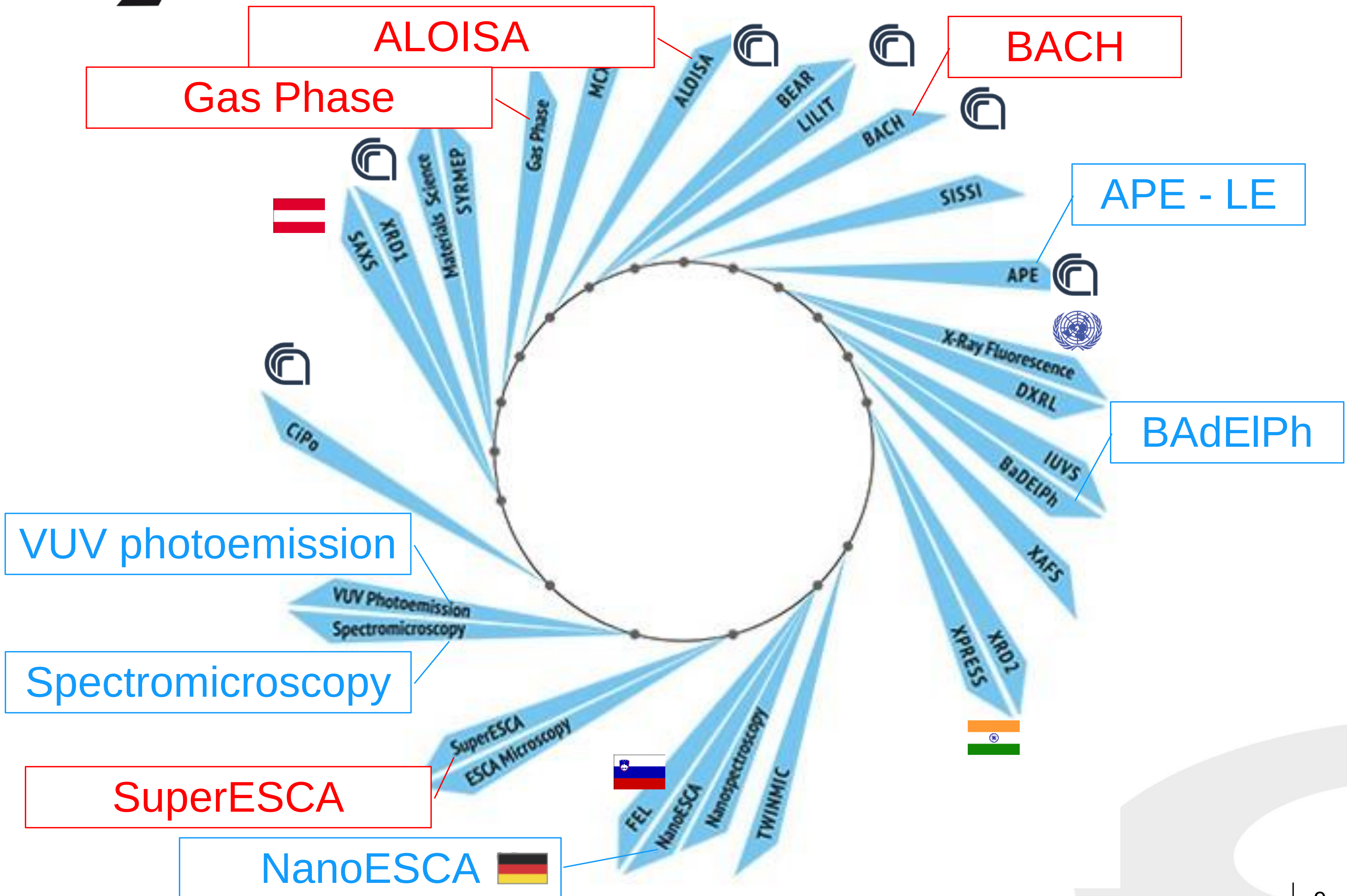
$$J = f(h\nu, \varepsilon, \Theta, \Phi; E^{e}_{kin}, \sigma, \theta_e, \varphi_e; x, y)$$

Photoelectron spectroscopy

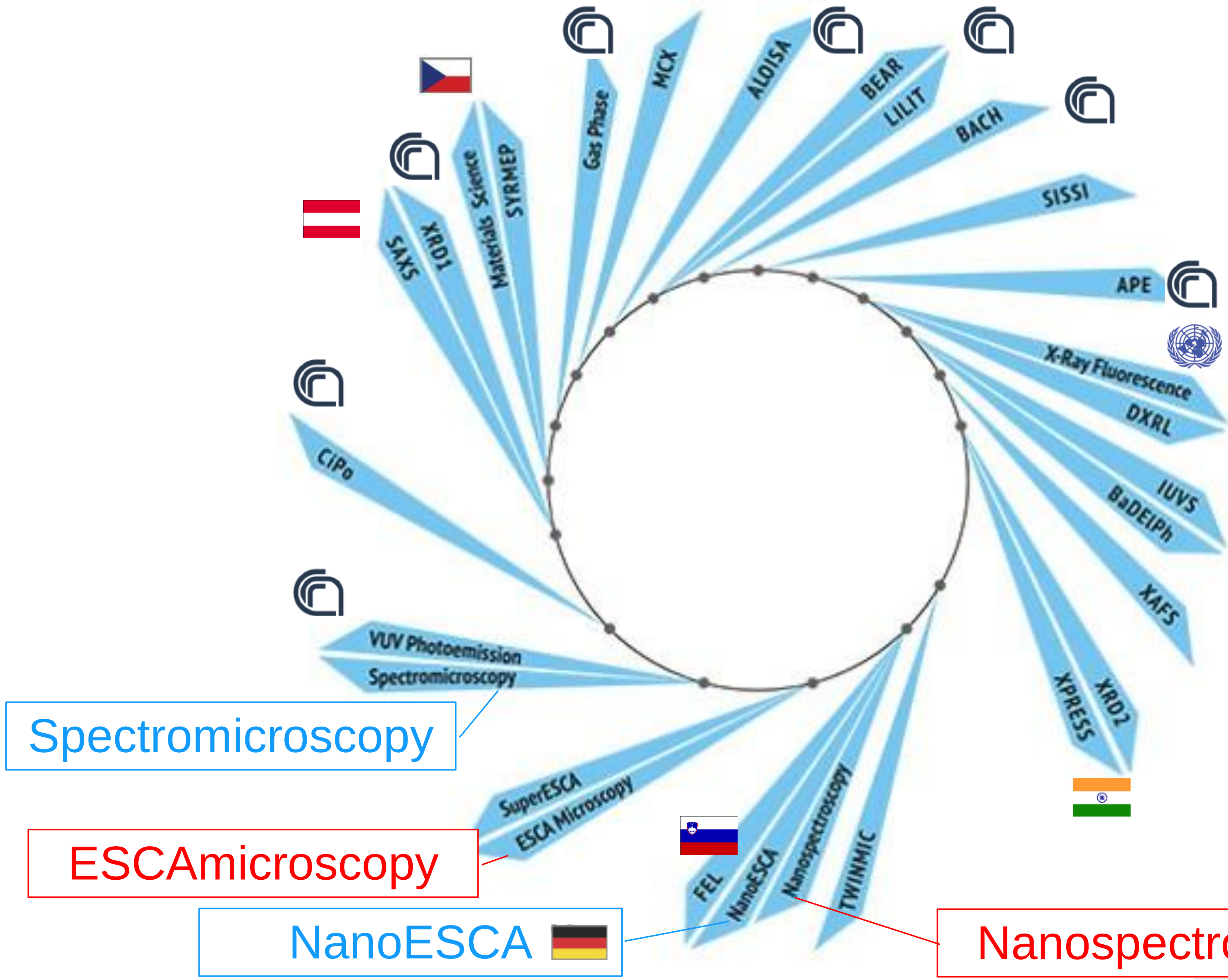


- ❑ Surface Chemistry (XPS or ESCA)
  - element specific and quantitative
  - sensitive to chemical environments
  - surface sensitive
- ❑ Electronic Structure (ARPES)
- ❑ Short range order (XPD)
  - Sensitive to structure

XPS, XAS and ARPES @ Elettra

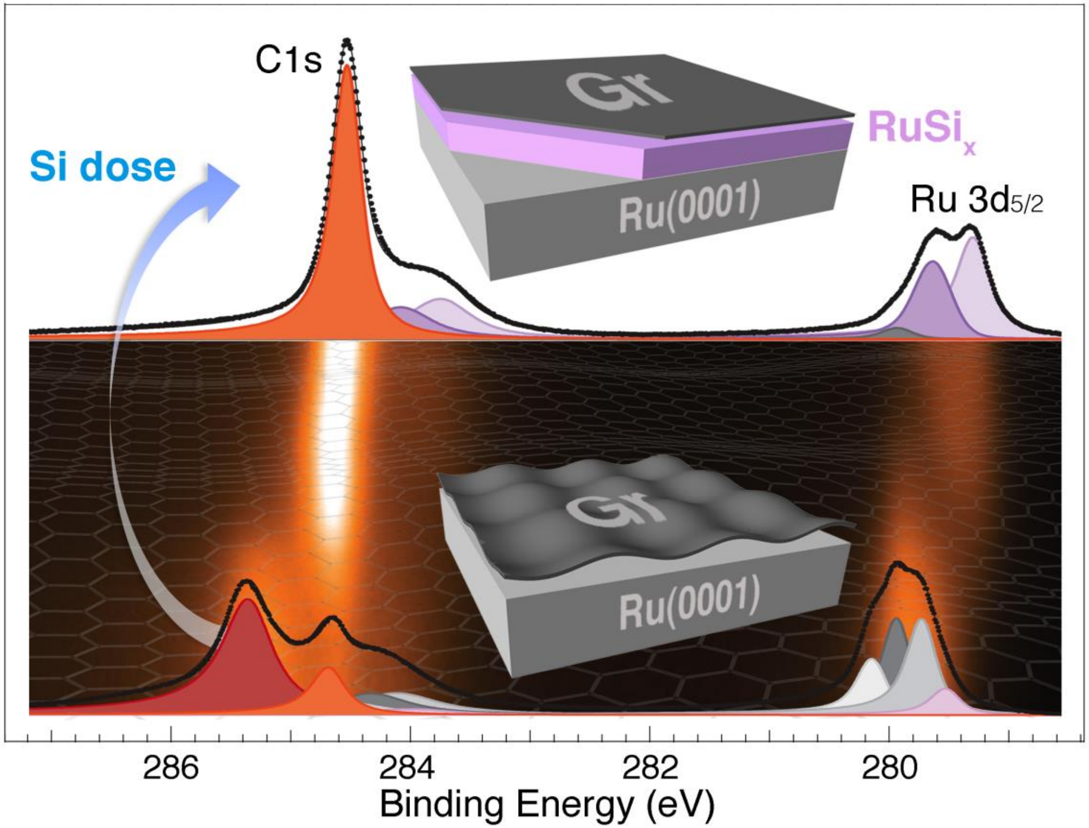


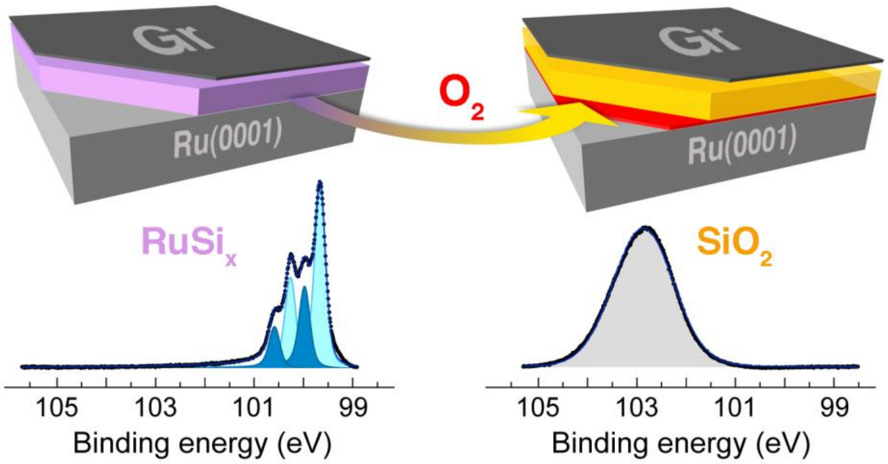
Photoelectron Spectromicroscopes



Elettra Sincrotrone Trieste

Transfer-Free Electrical Insulation of Epitaxial Graphene





Real time XPS

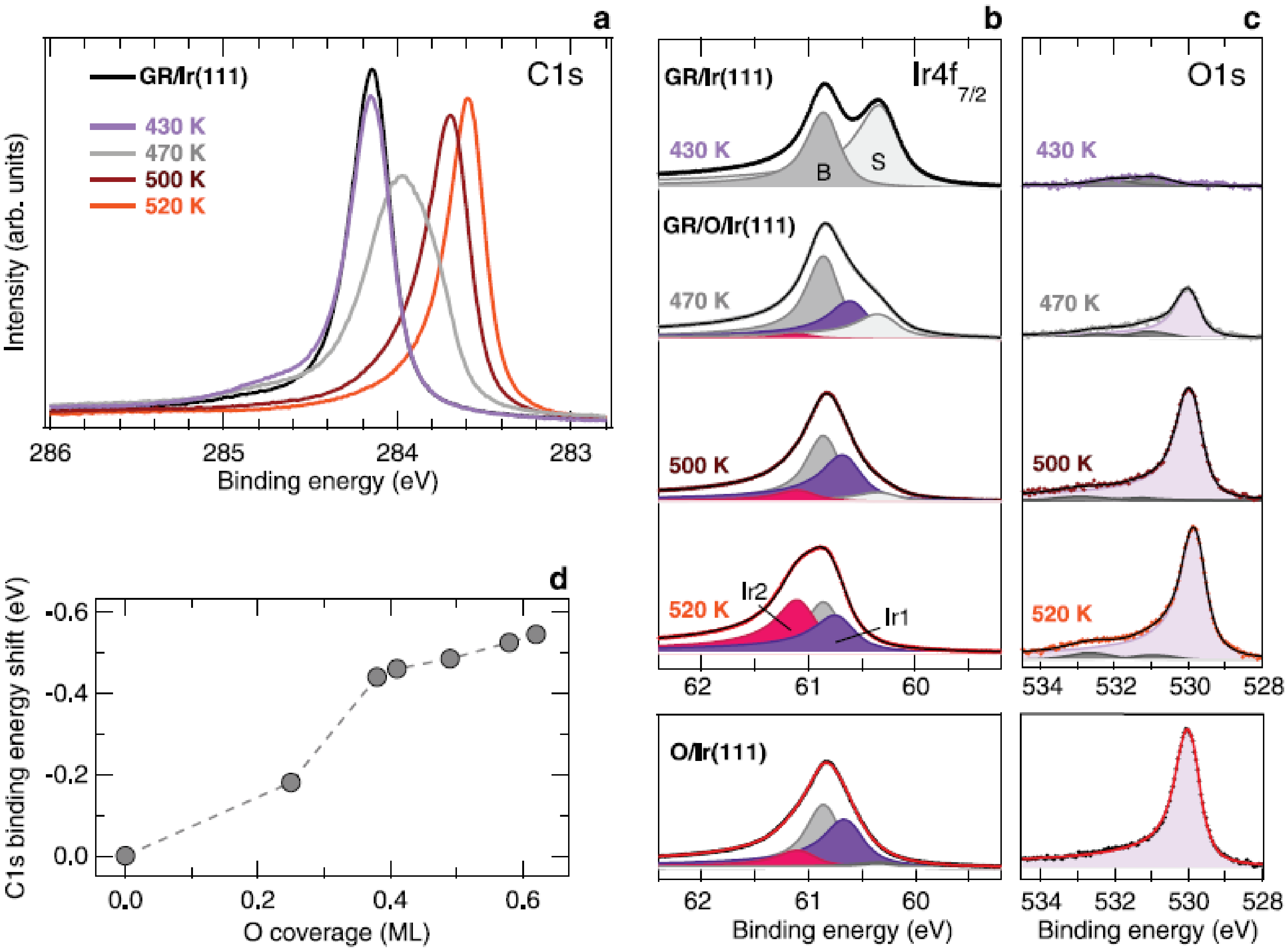
Contact:
silvano.lizzit@elettra.eu

Stepwise intercalation of silicon and oxygen, allows the synthesis of a SiO_2 film below a graphene layer epitaxially grown on Ru(0001). XPS was used to follow the reaction steps, which lead to a electrically insulated graphene layer, decoupled from the substrate

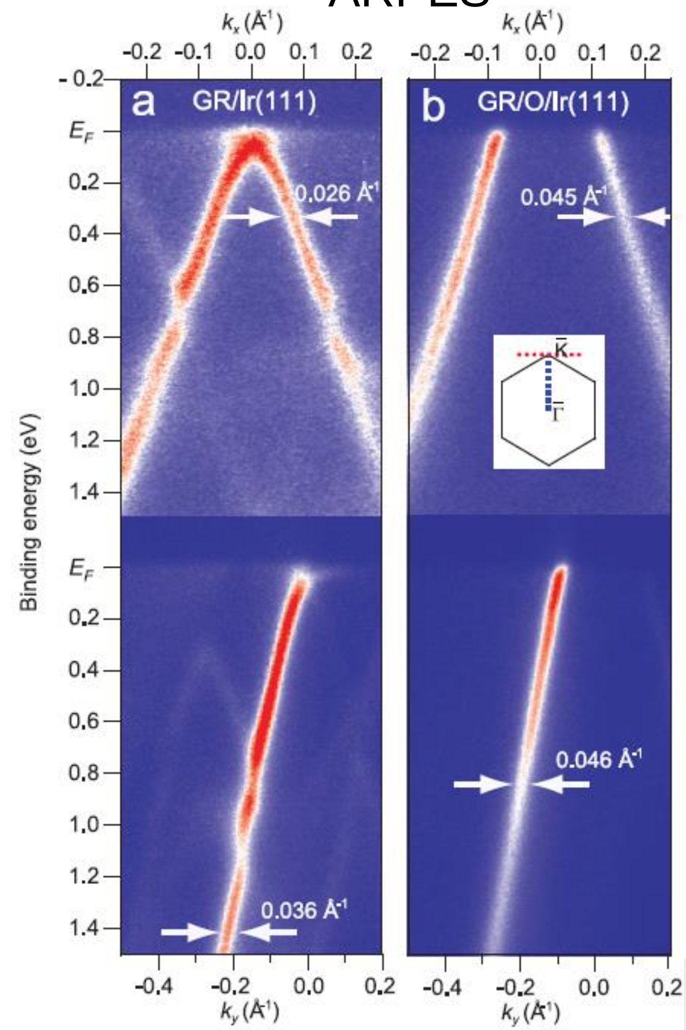
S. Lizzit, et al., Nano Lett. **12**, 4503 (2012).
10.1021/nl301614j

Lifting and substrate-decoupling of graphene by intercalation

Real-time HR X-ray Photoemission Spectroscopy (HR-XPS)



ARPES



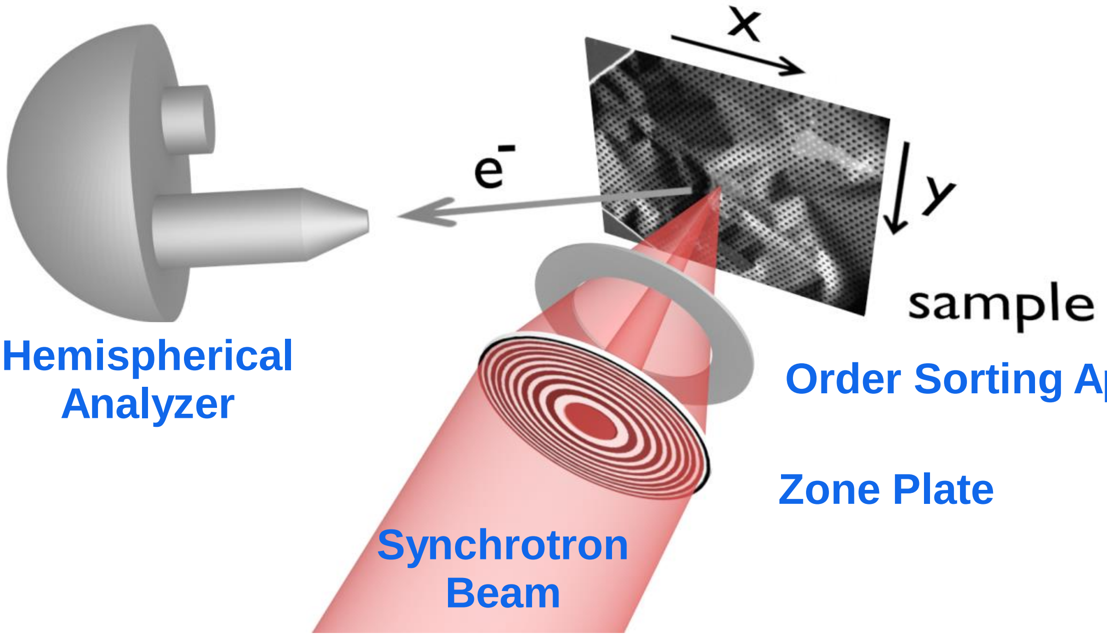
O induces graphene decoupling from Ir

p - doping

R. Larciprete et al., ACS Nano 6, 9551 (2012).

ESCA microscopy beamline

Scanning Photoelectron Microscope (SPEM)



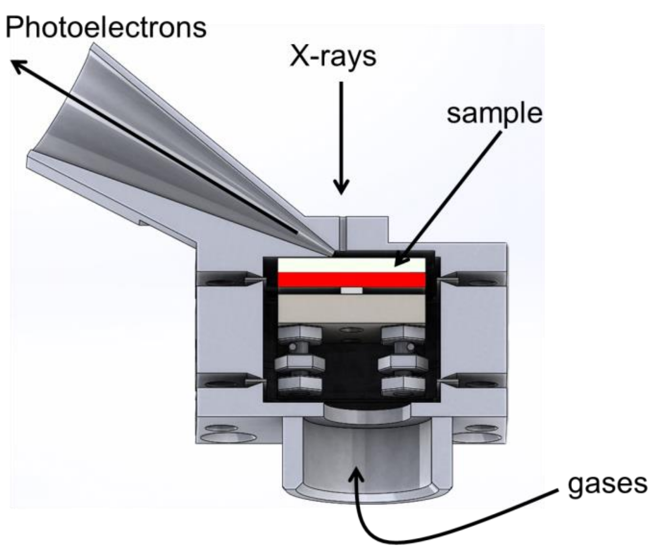
- Linearly Polarised Undulator
- Photon energy range: 400 – 1200 eV
- Overall Energy resolution: ~180meV @ 500 eV
- Beam Spot size at the sample: > 130 nm @ 500 eV

Contact:
luca.gregoratti@elettra.eu

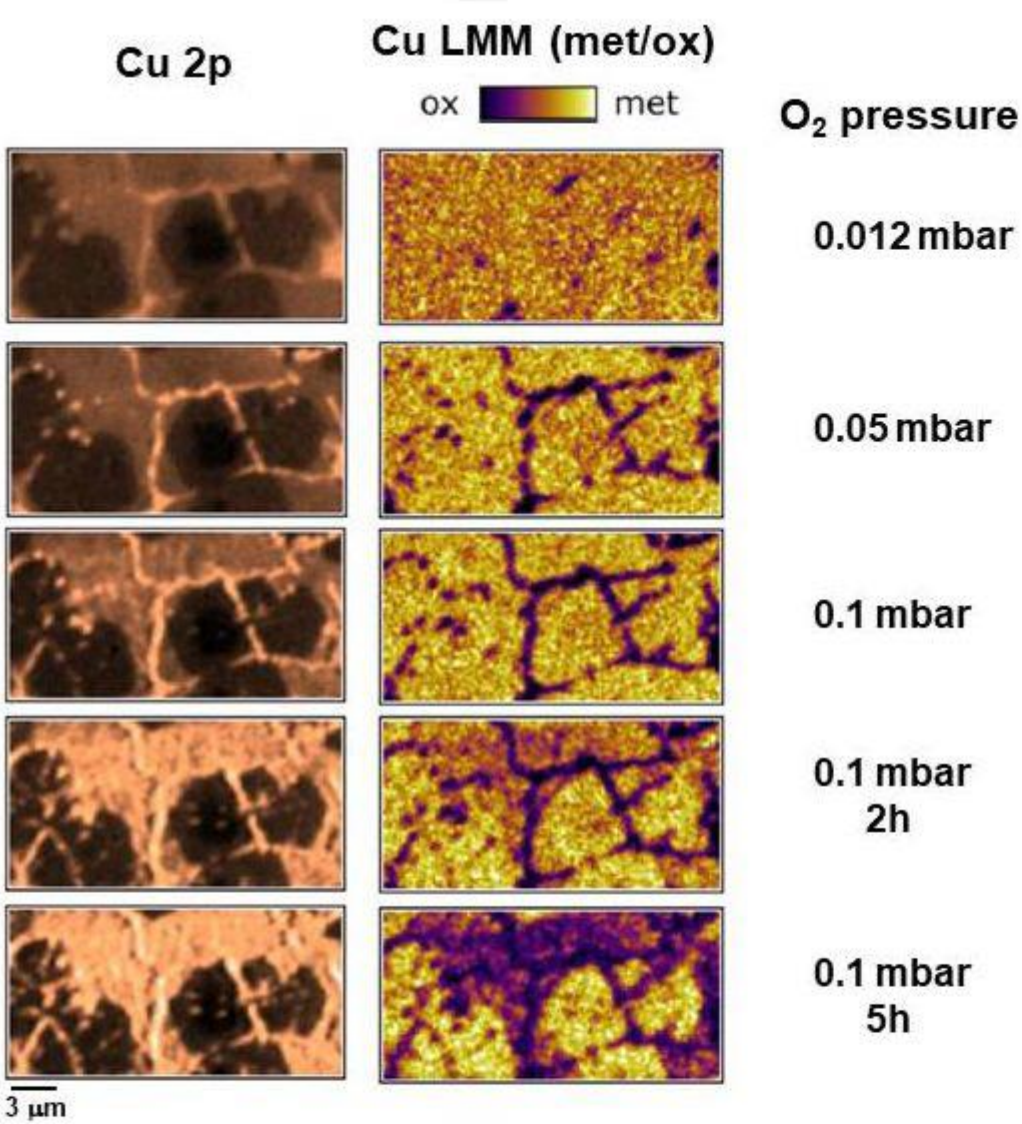
https://www.elettra.eu/elettra-beamlines/escamicroscopy.html

Operando photoemission microscopy

Highlighting the Dynamics of Graphene Protection toward the Oxidation of Copper Under Operando Conditions



Near Ambient Pressure Cell for NAP-XPS spectromicroscopy
(custom set up for pressure up to 1 mbar)



M. Scardamaglia et al., ACS Appl. Mater. Interfaces 11, 29448 (2019)

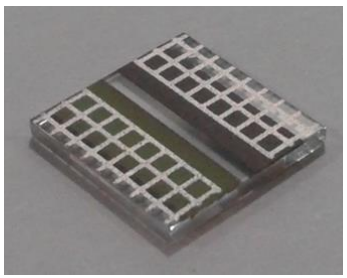
Characterization of a single-chamber solid oxide fuel cell

Elettra Sincrotrone Trieste

(in collaboration with B. Bozzini, Università del Salento, Italy)

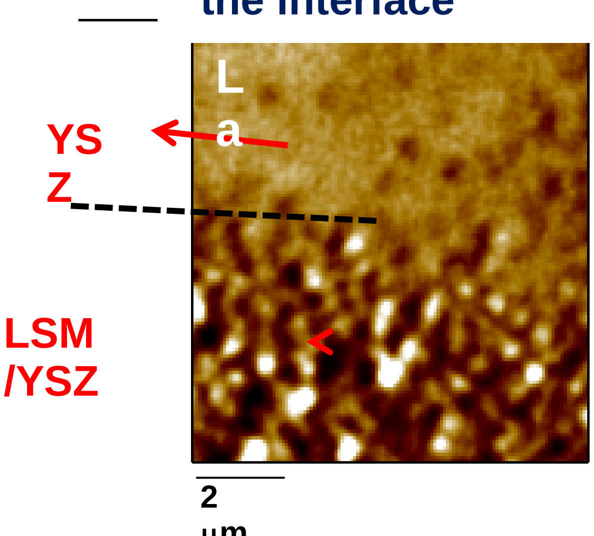
- *In operando* near-ambient pressure characterization of an operating single chamber solid oxide fuel cell (SC-SOFC)

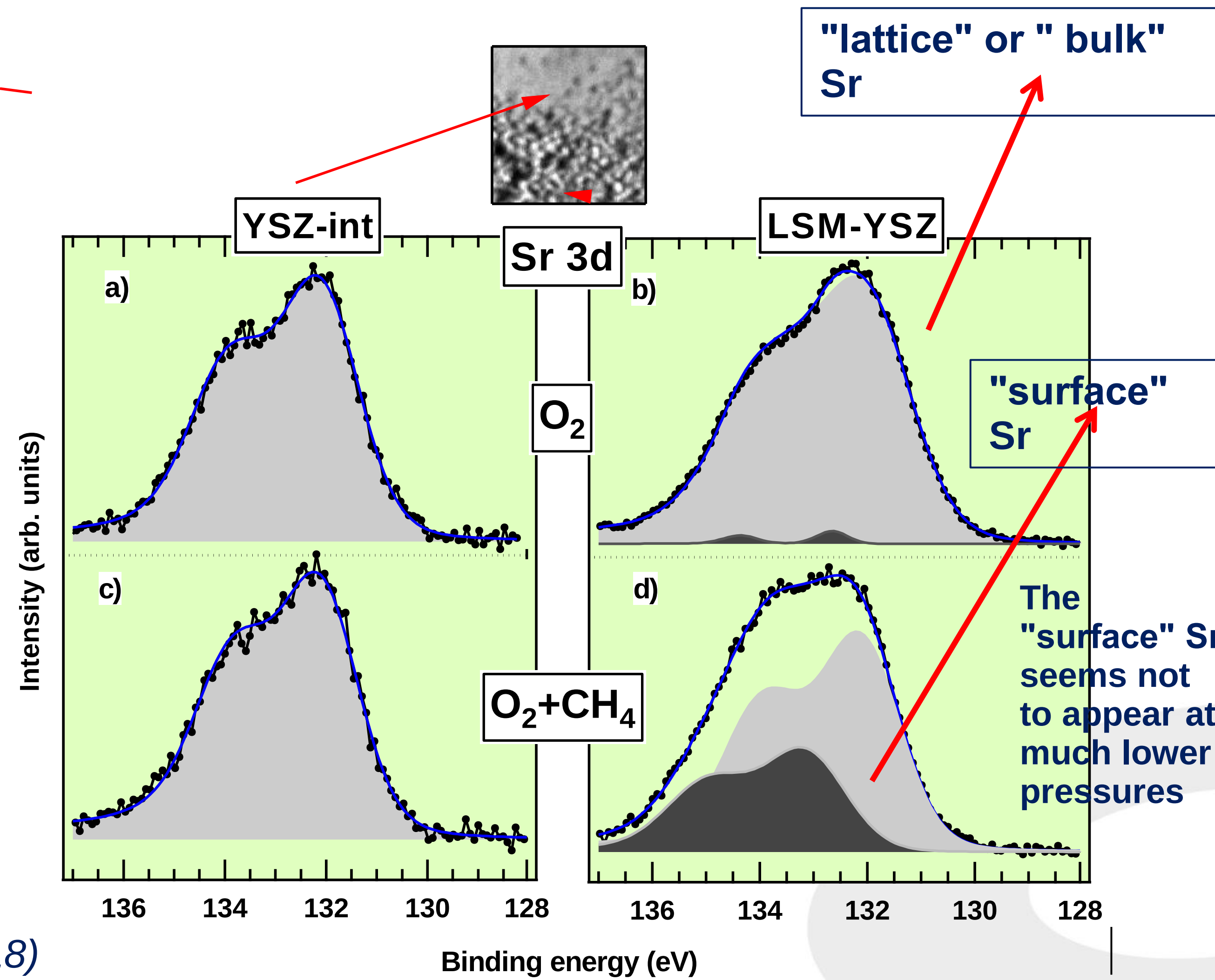
T= 923 K with a CH_4/O_2 gas mixture; P_{max}=0.1 mbar



NiO – anode
LSM – cathode
YSZ – electrolyte

SPEM map of the interface

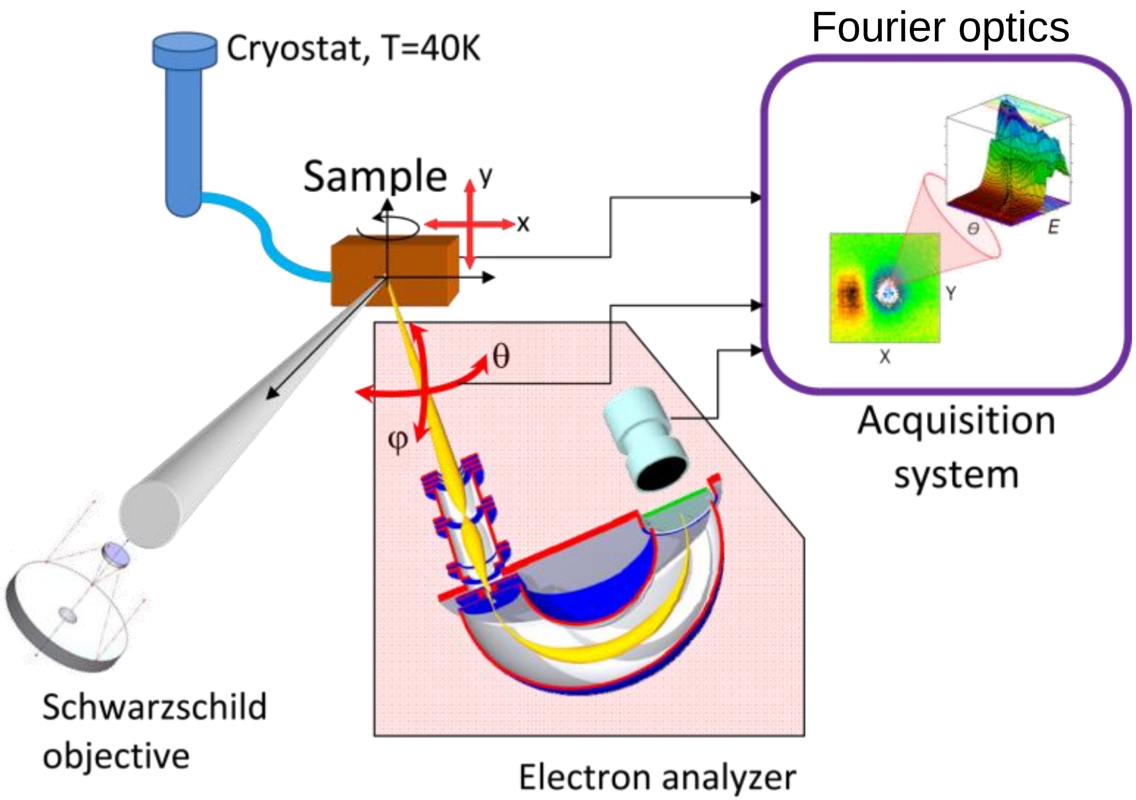


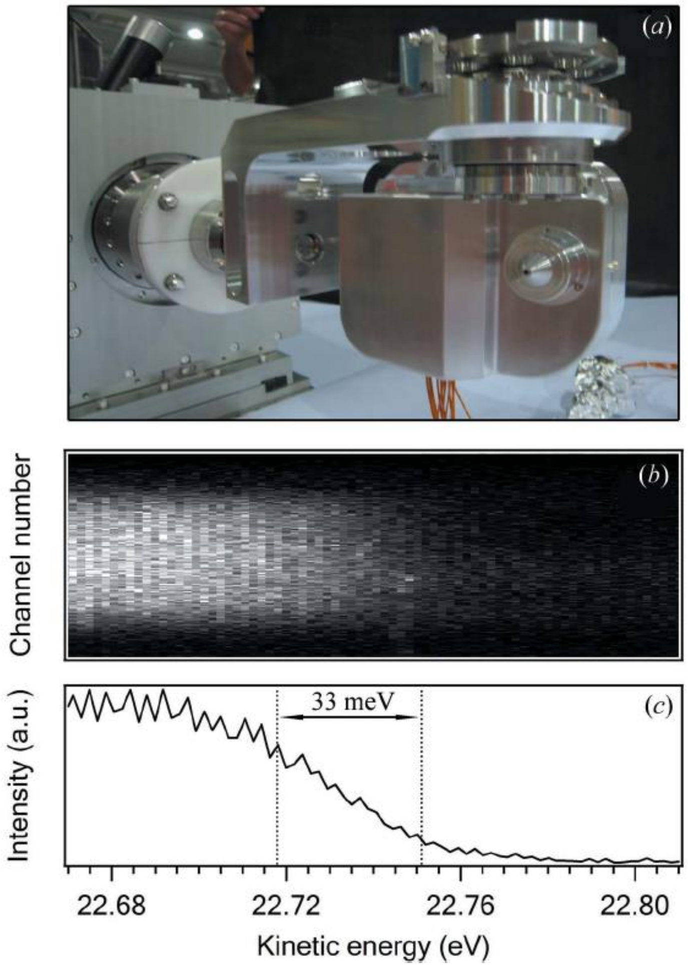


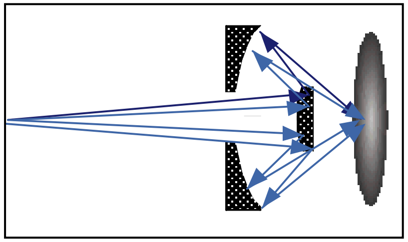
B. Bozzini et al. Topics in Catalysis (2018)

Spectromicroscopy beamline

microspot angle resolved x-ray photoemission spectroscopy





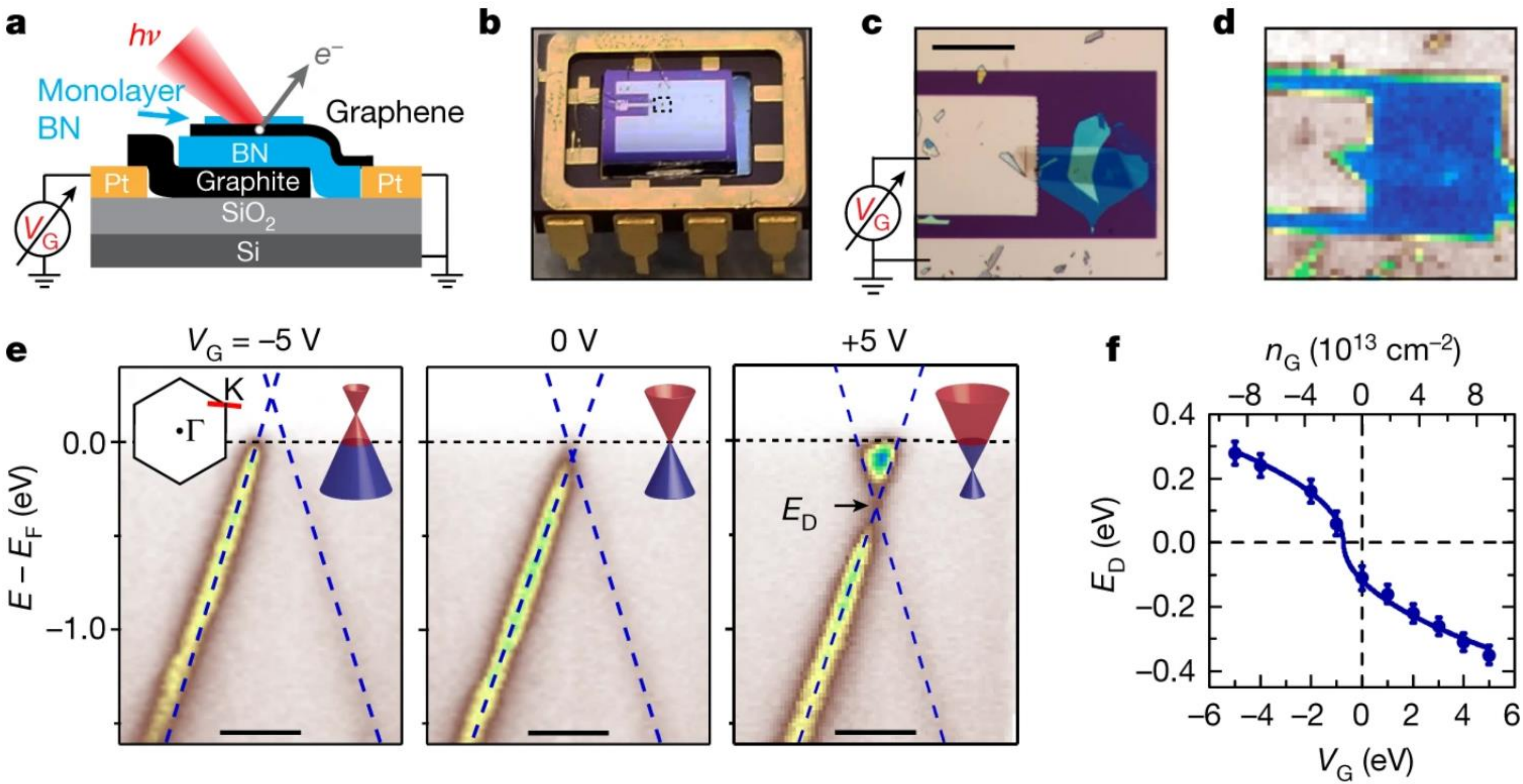


Resolution, 0.6 μm
25-50 meV, ±0.3° .
High photon flux>10^{10-11} ph sec^{-1}
Two possible energies: 27 eV with <1% scattered background and 74 eV with <20% scattered background.
Vacuum <$1.5x10^{-10}$ mbar.

Contact:
alexei.barinov@elettra.eu

Dudin *et al.*, *Journal of Synchrotron Radiation, Vol. 17 - 4 (2010)*

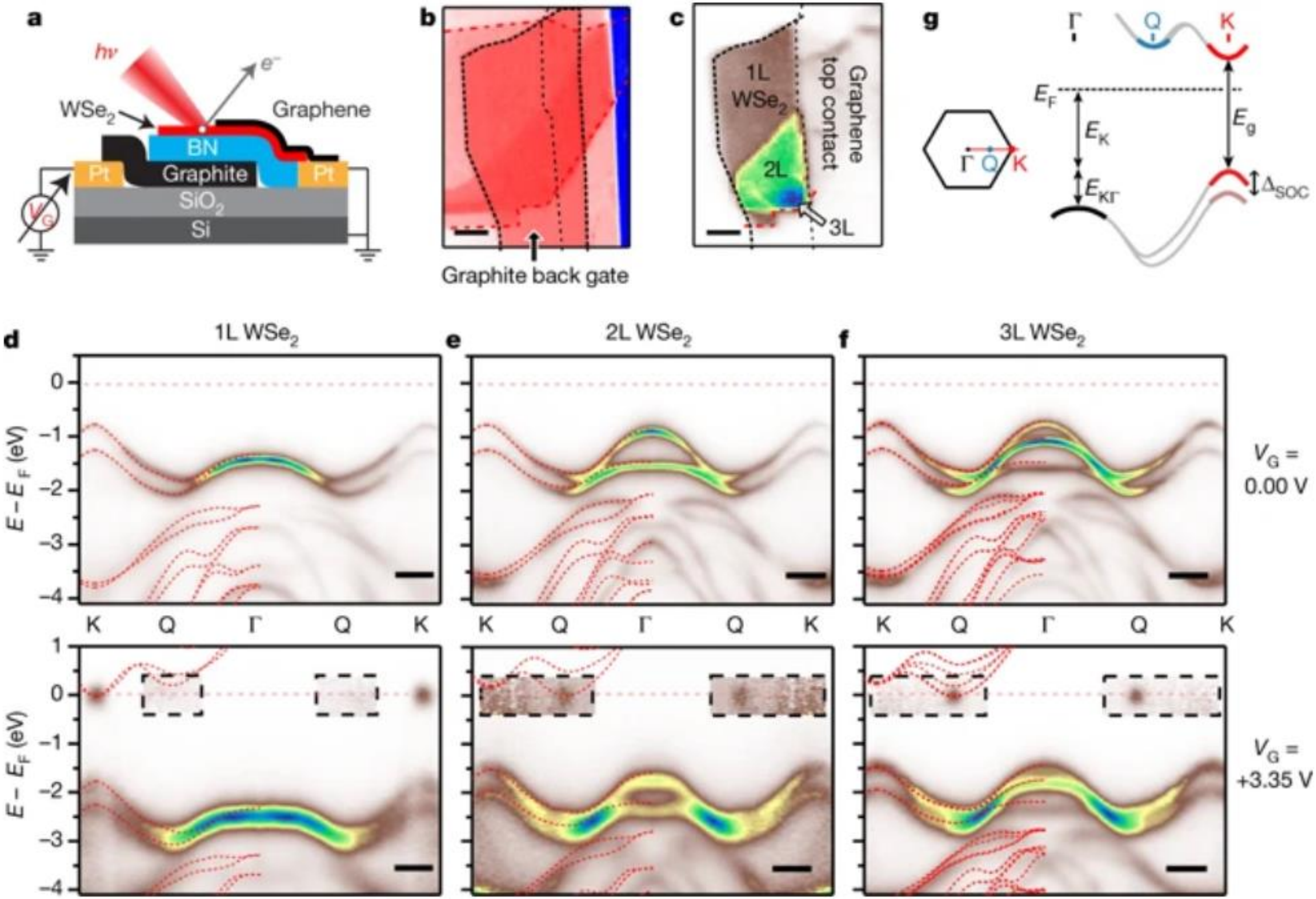
Visualizing electrostatic gating of monolayer graphene



LETTER
https://doi.org/10.1038/s41586-019-1402-1

P. Nguyen *et al.*, **Nature 572**, 220–223 (2019)

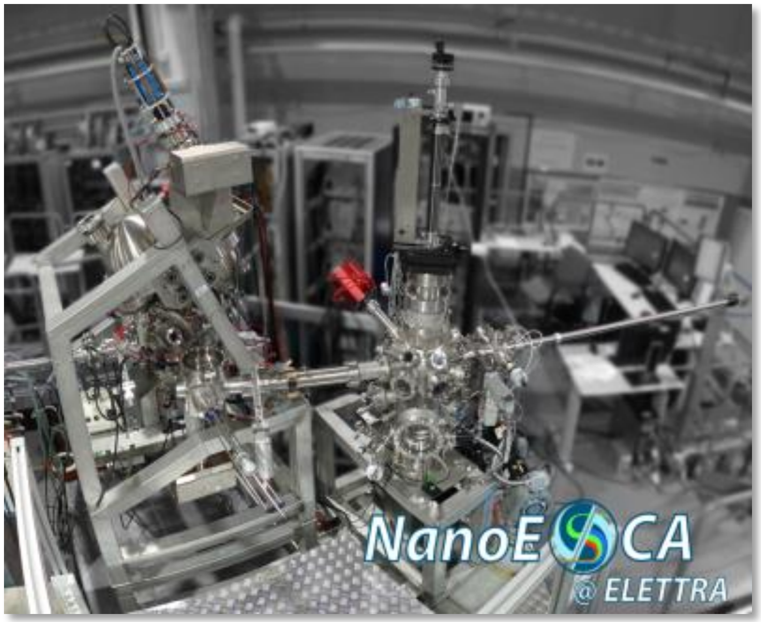
Visualizing electrostatic Layer-number-dependent CBE in WSe_2

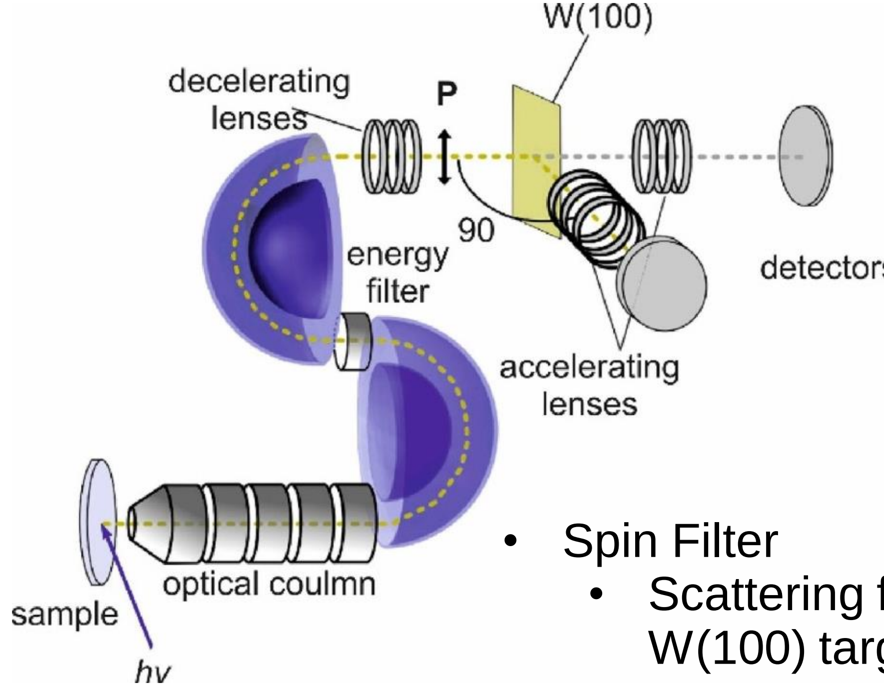


P. Nguyen *et al.*, **Nature 572**, 220–223 (2019)

NanoESCA beamline

microspot angle resolved x-ray photoemission spectroscopy

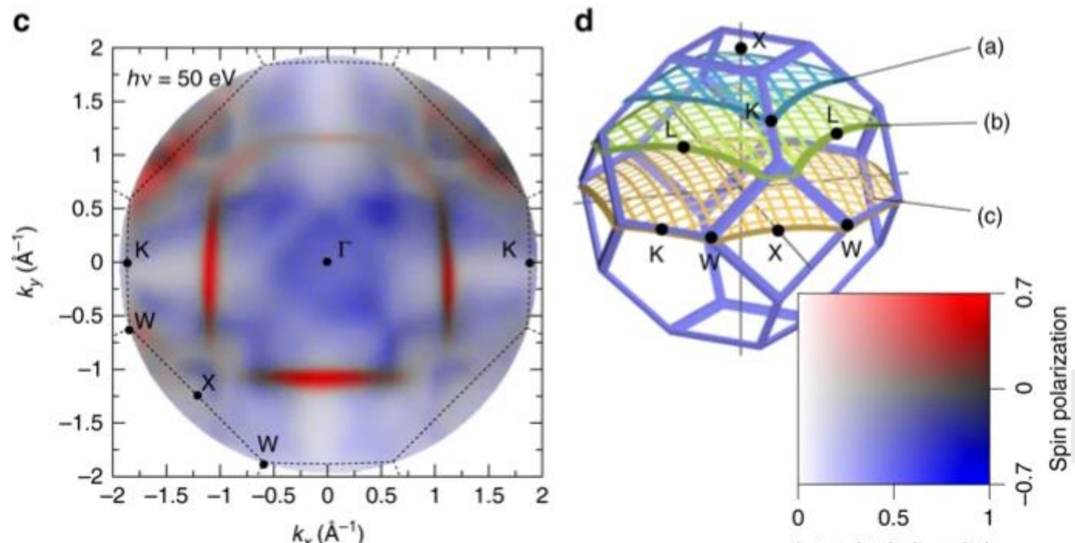




- Spin Filter
  - Scattering from W(100) target

- hv: 20 – 1000 eV, ***s p*** and **c+/c-** pol.
- Energy Filter: ΔE ~ 70 meV
  - ➢ **Real Space** (100 nm)
  - ➢ **Reciprocal Space**
  - ➢ µ-ARPES: spot size ~ 12-4 µm

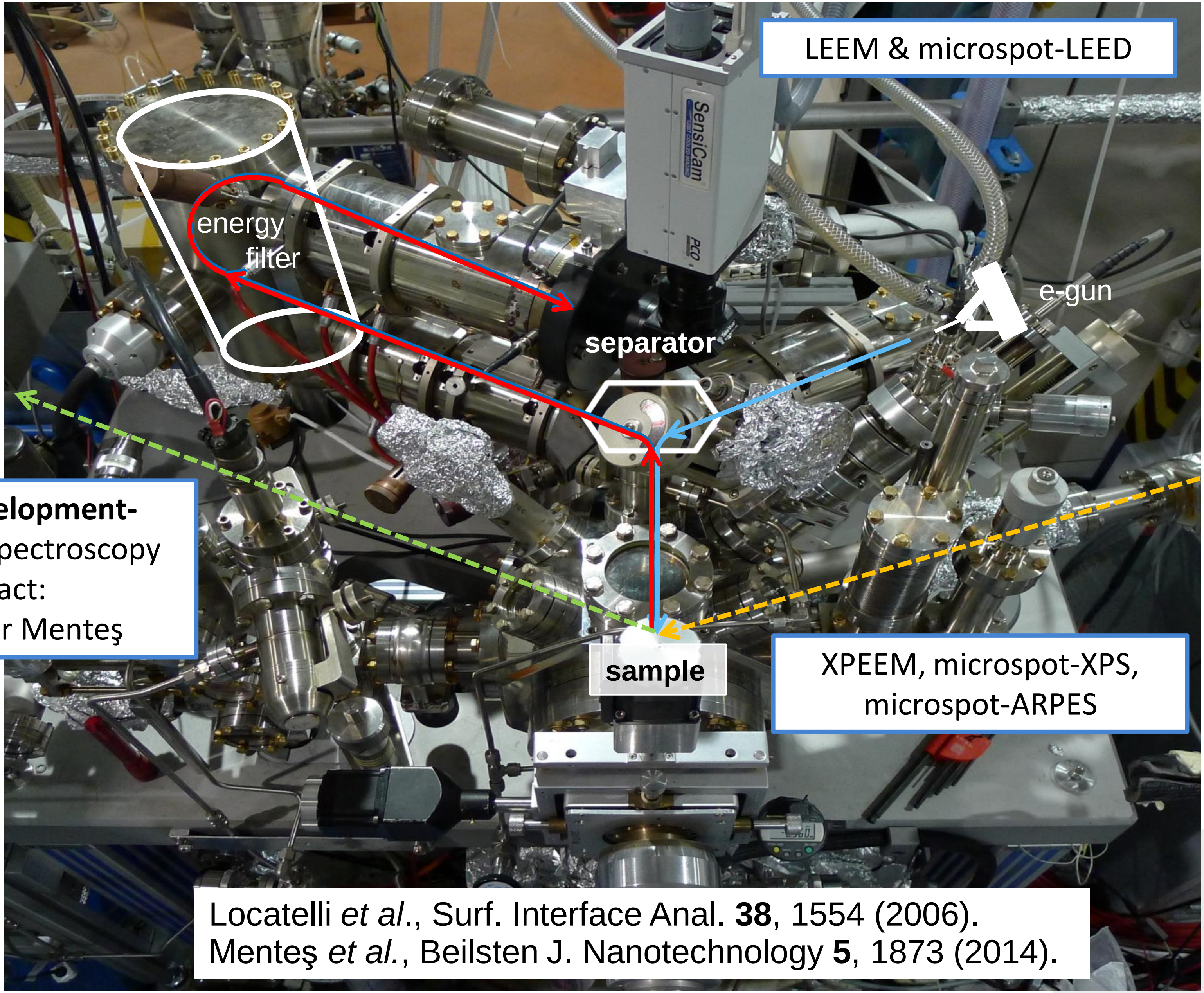
Contact: vitaliy.feyer@elettra.eu



C. Tusche *et al.*, *Nature Communications, Vol. 9 - 1, pp. 3727 (2018)*

The SPELEEM @ Nanospectroscopy

Full-field, soft x-rays (25-1000eV) or low energy electrons as probe



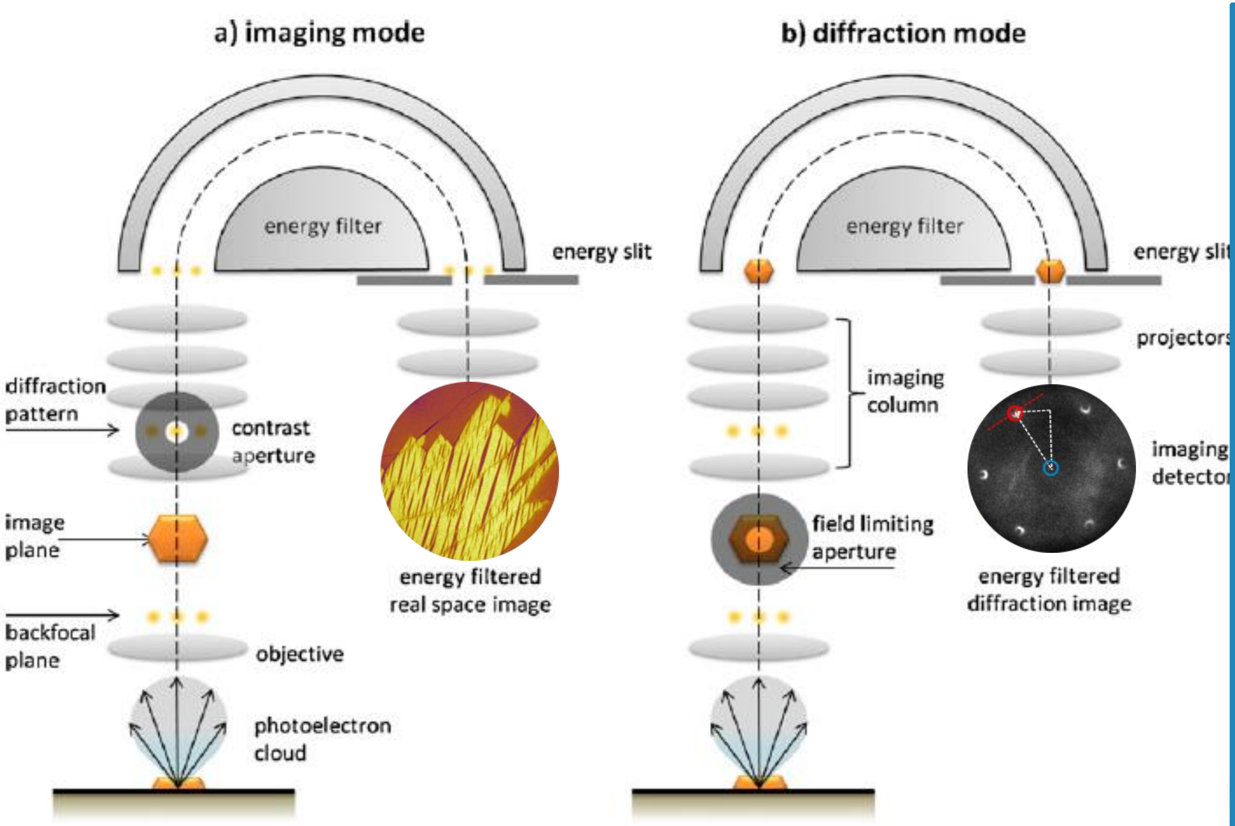
-under development-
CDI @ Nanospectroscopy
Contact:
Tevfik Onur Menteş

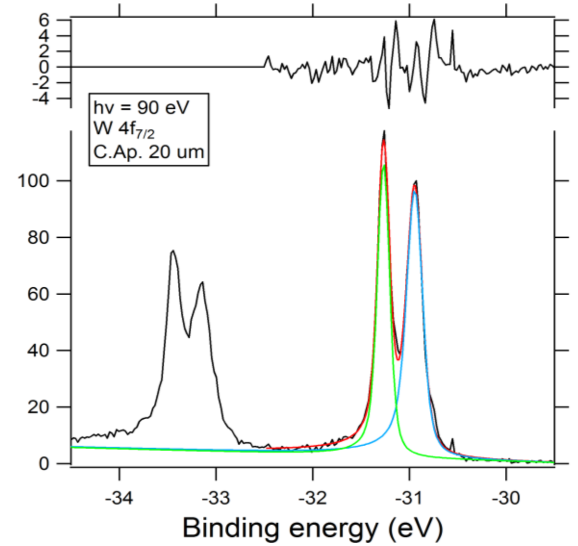
Locatelli *et al.*, Surf. Interface Anal. **38**, 1554 (2006).
Menteş *et al.*, Beilsten J. Nanotechnology **5**, 1873 (2014).

SPELEEM multi-method analysis

Elettra Sincrotrone Trieste

Spectroscopic imaging XAS-PEEM / XPEEM / LEEM	microprobe-diffraction ARPES / LEED	microprobe-spectroscopy Fast-XPS





T. O. Menteş et al.
Beilstein J. Nanotechnol. 5, 1873–1886 (2014).

energy resolution
µXPS : 0.11 eV

spatial resolution
LEEM : 10 nm
XPEEM : 25 nm

energy resolution
XPEEM : 0.3 eV

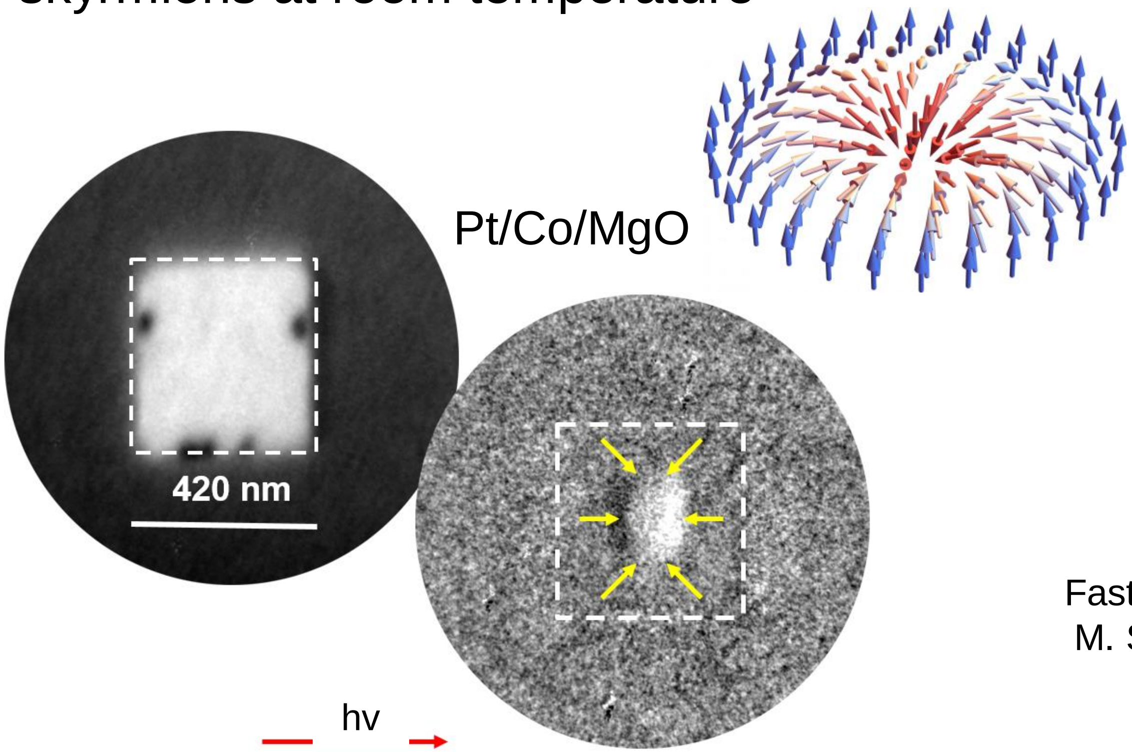
Detector blanking available for time-resolved XMCD-PEEM: see Ultramicroscopy 202, 10-17 (2019)

Limited: to 2 microns in dia.
Energy resolution:
ARPES: 0.3 eV
angular resolution
ARPES: 0.01 Å^{-1}

Contact:
andrea.locatelli@elettra.eu

SPELEEM examples: magnetic imaging at high lateral resolution

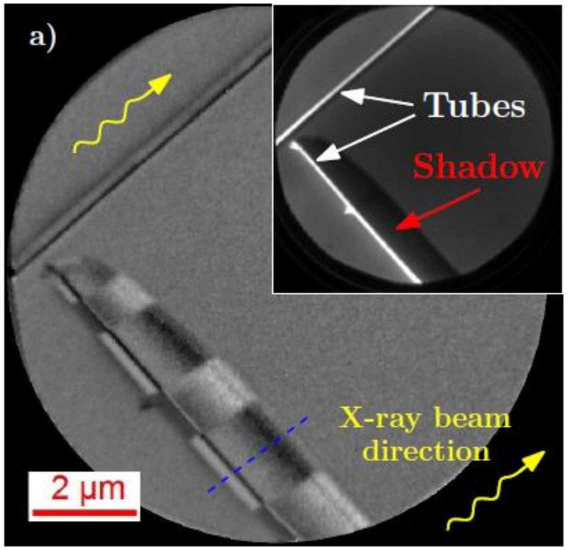
✓ First observation of chiral skyrmions at room temperature



O. Boulle *et al*., Nat. Nanotech. **11**, 449–454 (2016)
doi: 10.1038/nnano.2015.315

More recently, «Current-Driven Skyrmion Motion and SHE»
R. Juge *et al*., Phys Rev. Appl. 12. 044007 (2019)

✓ Magnetism in Nanowires



Fast Domain Wall Motion in cylindrical magnetic NW
M. Schöbitz *et al*., Phys Rev. Lett., accepted (2019)

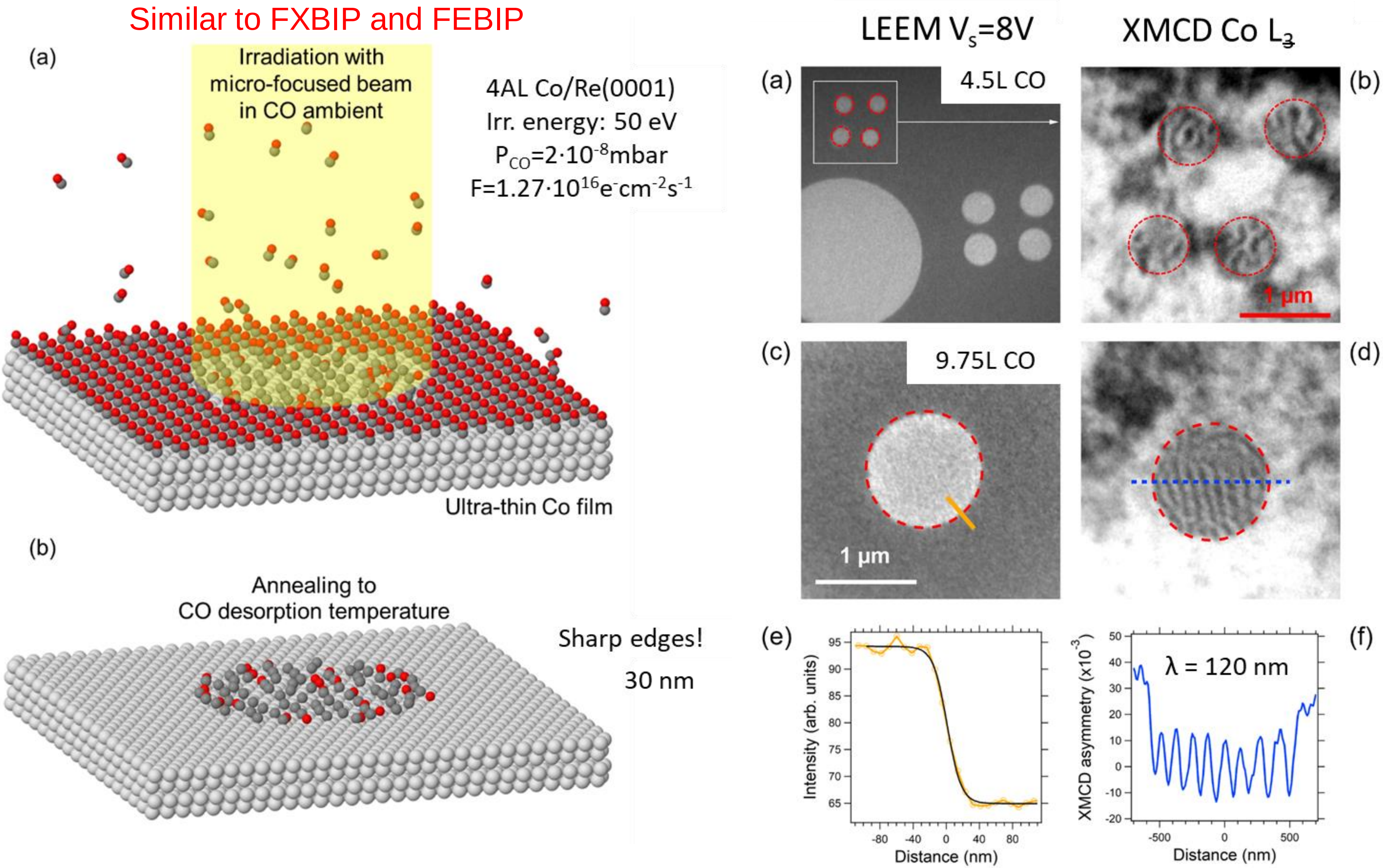
Flux-closure domains in high aspect ratio electroless-deposited CoNiB nanotubes
M. Staňo *et al*., SciPost Phys. 5, 038 (2018)

Quantitative analysis of shadow XMCD-PEEM
S. Jamet *et al*., Phys. Rev. B 92, 144428 (2015)

Bloch-point DW in cylindrical magnetic NW
S. Da Col *et al*., Phys. Rev. B 89, 180405(R) (2014).

electron-beam assisted carbon lithography

Similar to FXBIP and FEBIP

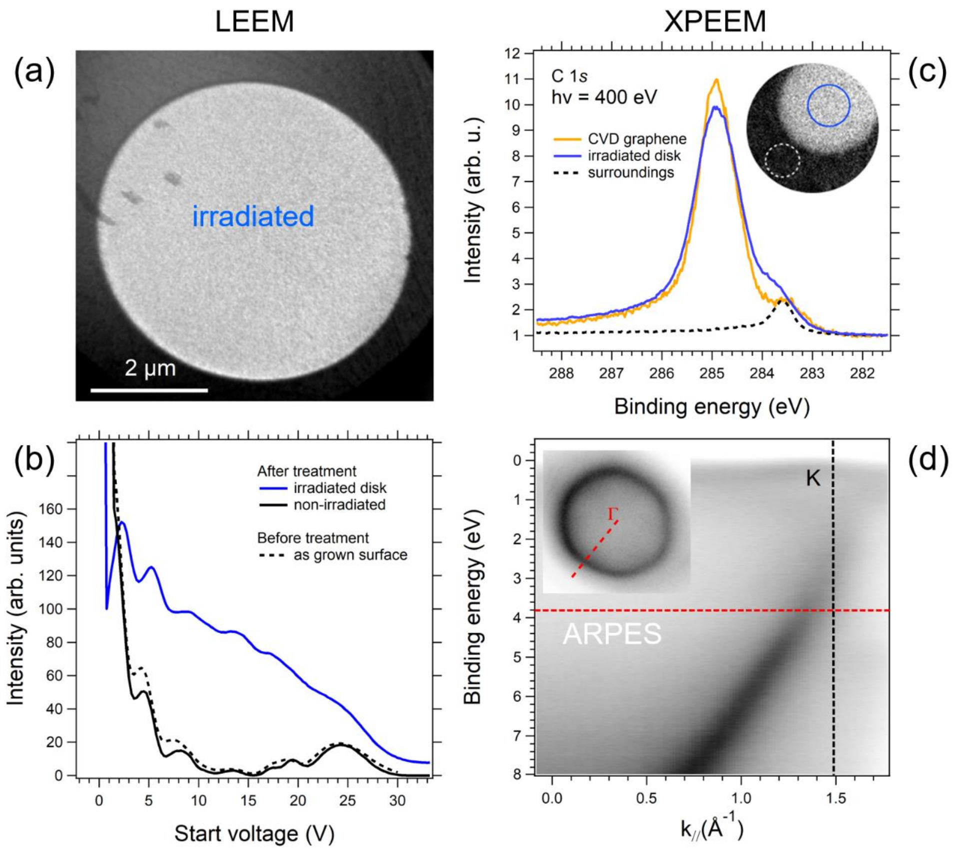


P. Genoni et *al.*, ACS Applied Materials & Interfaces **10**(32), 27178–27187 (2018)

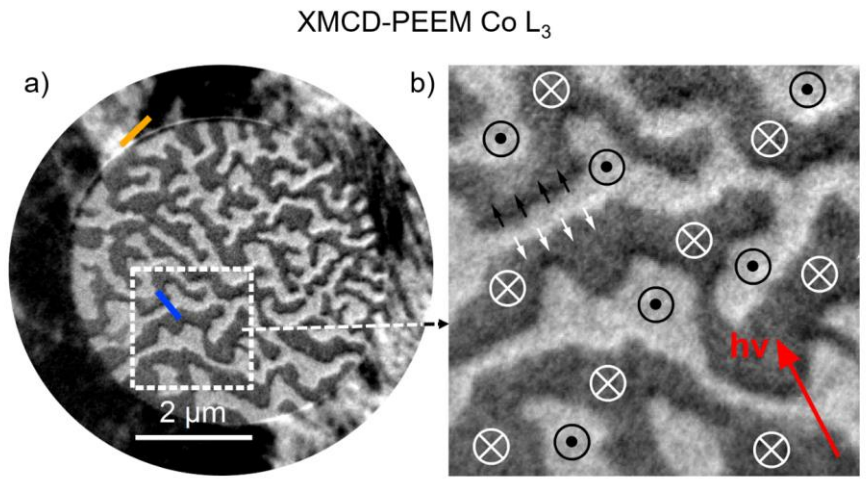
Chemistry and magnetism of gr/Co/Re(001)

Elettra Sincrotrone Trieste

CO exposures of the order or in excess of 1000 L → ML amount of carbon on the surface, which transforms to graphene upon annealing at 380° C.



✓ enhanced perpendicular magnetic anisotropy

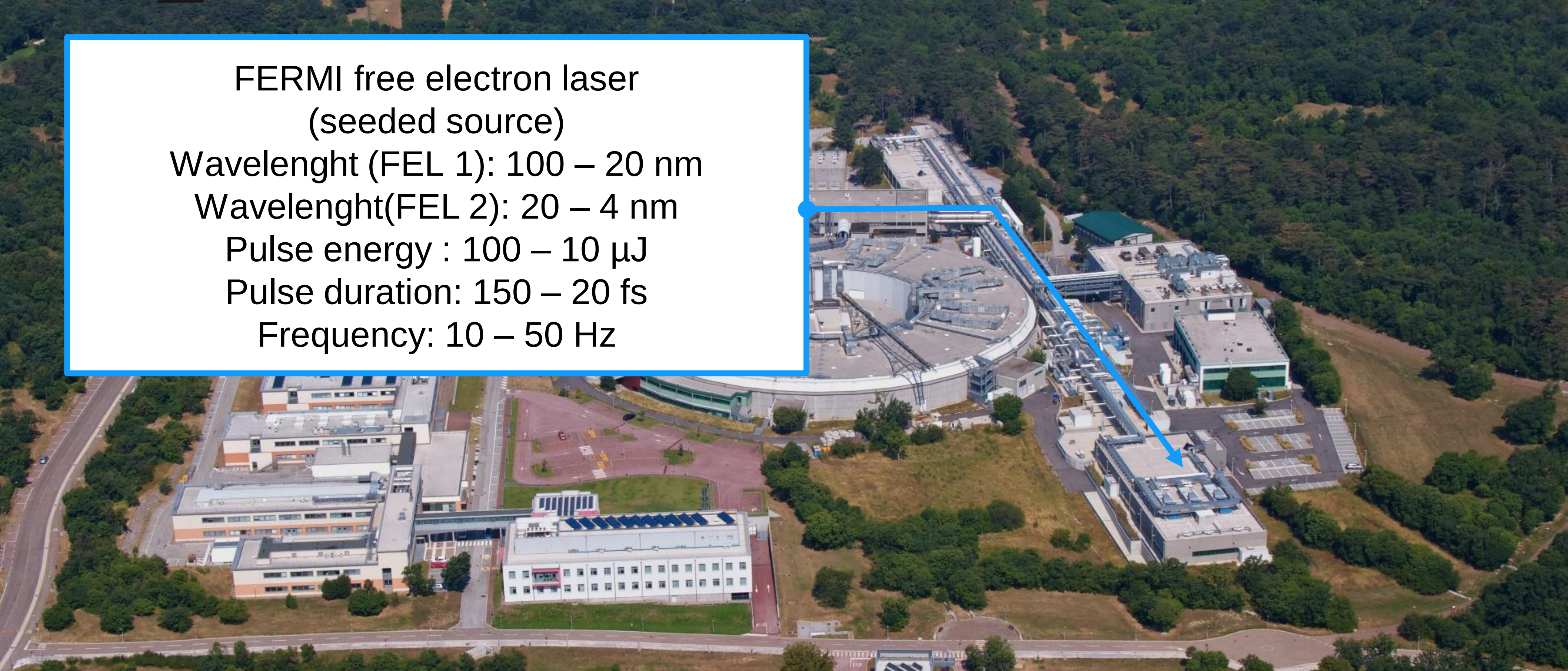


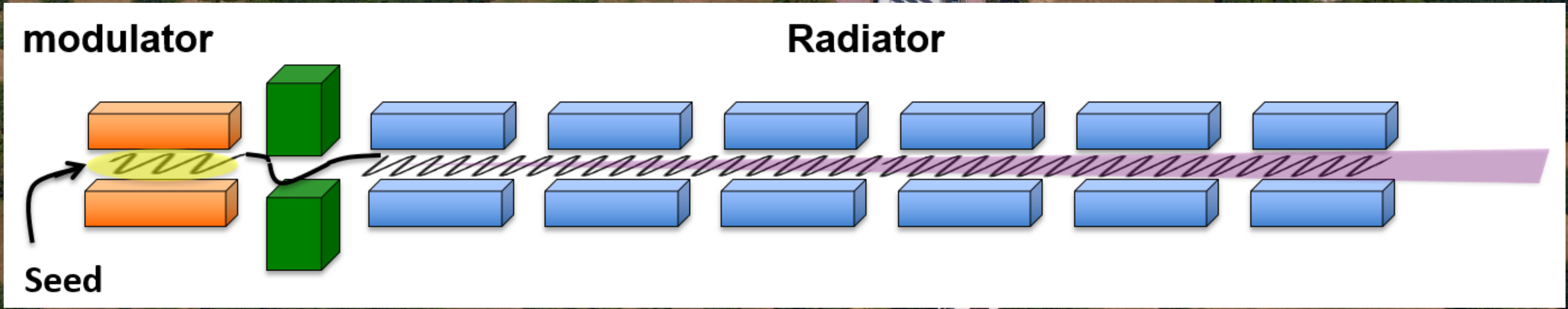
- Neél magnetic domains with right handed chirality
- Dzyaloshinskii-Moriya interaction →
- Skyrmion bubbles observed upon magnetization reversal

P. Genoni *et al*., ACS Applied Materials & Interfaces 10(32), 27178–27187 (2018)
F. Genuzio *et al*.,
J. Phys. Chem. C 123(13), 8360-8369 (2019);
IEEE Transactions on Magnetics 55(2), 1-4 (2019);

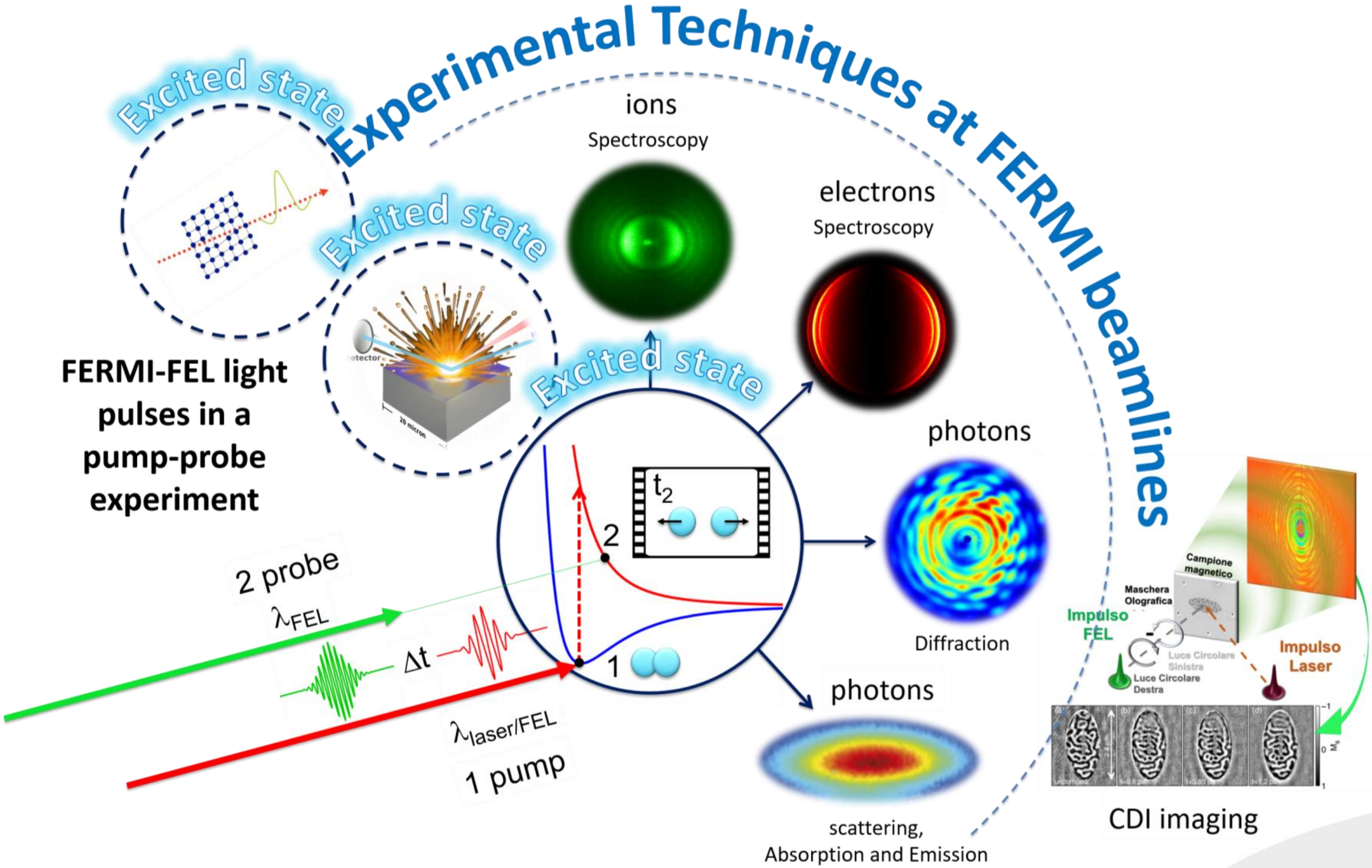
The FERMI FEL @ Elettra

FERMI free electron laser
(seeded source)
Wavelenght (FEL 1): 100 – 20 nm
Wavelenght(FEL 2): 20 – 4 nm
Pulse energy : 100 – 10 µJ
Pulse duration: 150 – 20 fs
Frequency: 10 – 50 Hz





The FERMI FEL opens new fronteers for science



FERMI beamlines

Low Density Matter (LDM)

- ✓ dilute systems, matter under extreme irradiation conditions (multiple electronic excitation, multiple ionization, Coulomb explosion, non-linear optics)

Diffraction and Projection Imaging (DiProI)

- ✓ Time-resolved Coherent Diffraction Imaging (CDI), Resonant CDI

EIS-TIMEX

- ✓ fundamental properties of dense matter under metastable and/or extreme thermodynamic conditions with sub-ps time resolution

EIS-TIMER

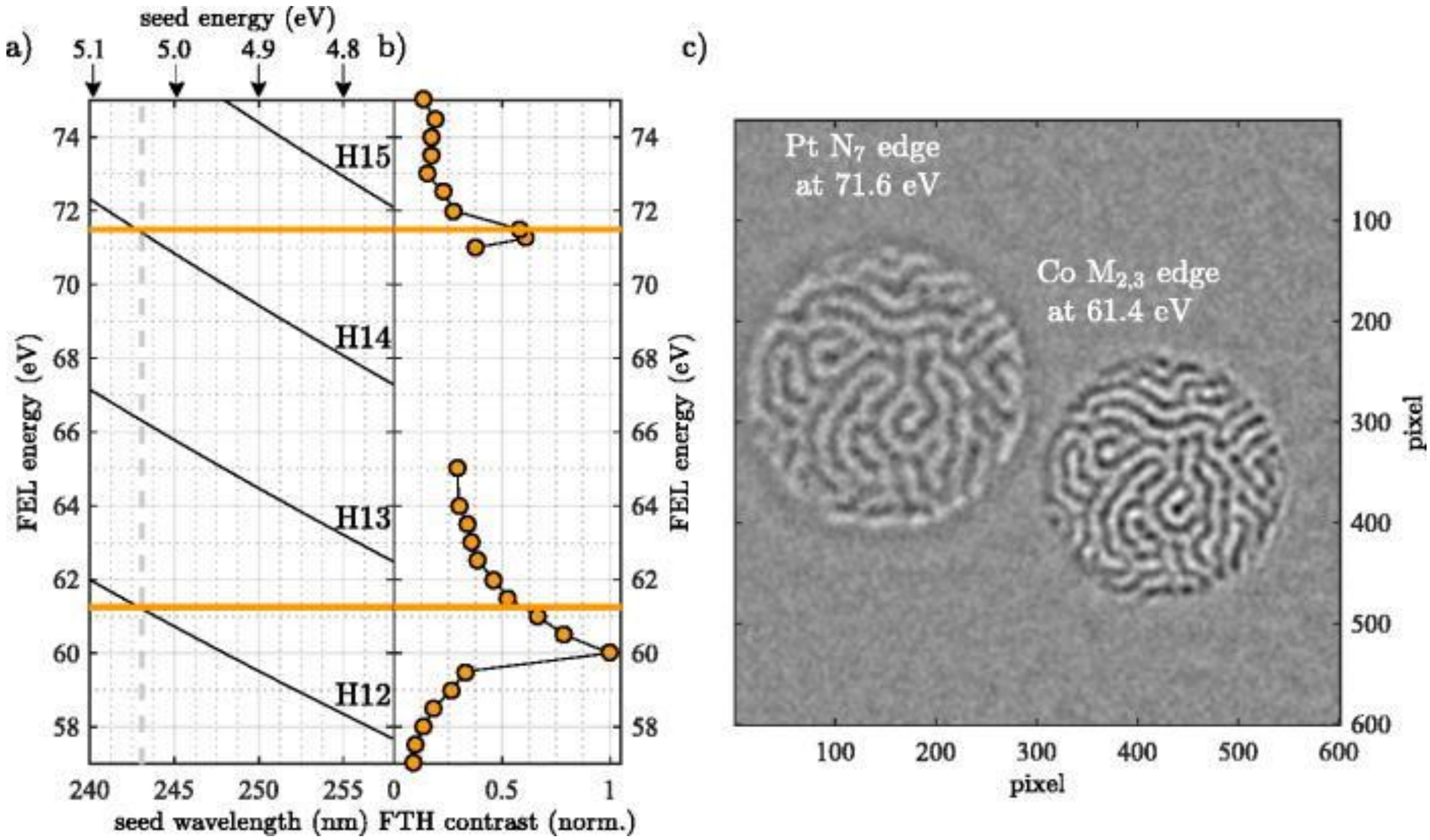
- ✓ FEL-based extreme ultraviolet transient grating experiments (XTG)

MAGNE-DYN

- ✓ transient magnetic states of matter by exploiting the time structure, the full coherent-variable polarization properties

- ✓ Off-line instruments: **T-REX, TeraFERMI**

FT holography with magnetic sensitivity at the DiProI beamline



F. Willems *et al*., Structural Dynamics 4, 014301 (2017); https://doi.org/10.1063/1.4976004
See also: C. von Korff Schmising et al. Phys. Rev. Lett. 112, 217203 (2014).

Elettra
Sincrotrone
Trieste

Summary

Material chatacterization highlights

Elettra photoemission spectrometers and microscopes

- ❑ Real time ESCA
- ❑ Nanometer-range lateral resolution
- ❑ PEEM imaging with magnetic sensitivity
- ❑ in operando capability / near-ambient pressure
- ❑ microprobe ARPES (also spin-resolved)

FERMI FEL beamlines

- ❑ Dynamic processes / excited states
- ❑ fs to attosecond time scale

M.P. Kumar *et al., Nature (2020)*
doi: 10.1038/s41586-020-2005-6

nature

Article | Published: 10 February 2020

Attosecond pulse shaping using a seeded free-electron laser

[Postdoctoral position for the EIS-TIMER beamline at FERMI]
[Postdoctoral Position at DiProI beamline at FERMI]

Thank you for the attention!

www.elettra.eu