UNIVERSITÀ
DEGLI STUDI DI TRIESTE

SURFACE SCIENCE LABORATORY

Elettra Sincrotrone Trieste

# When each atom matters: the quest for novel tailored nanomaterials

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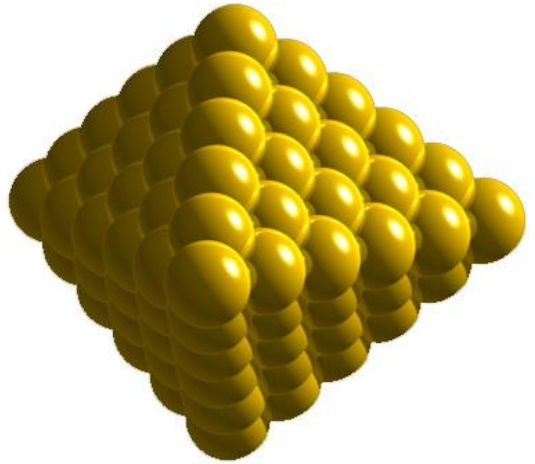
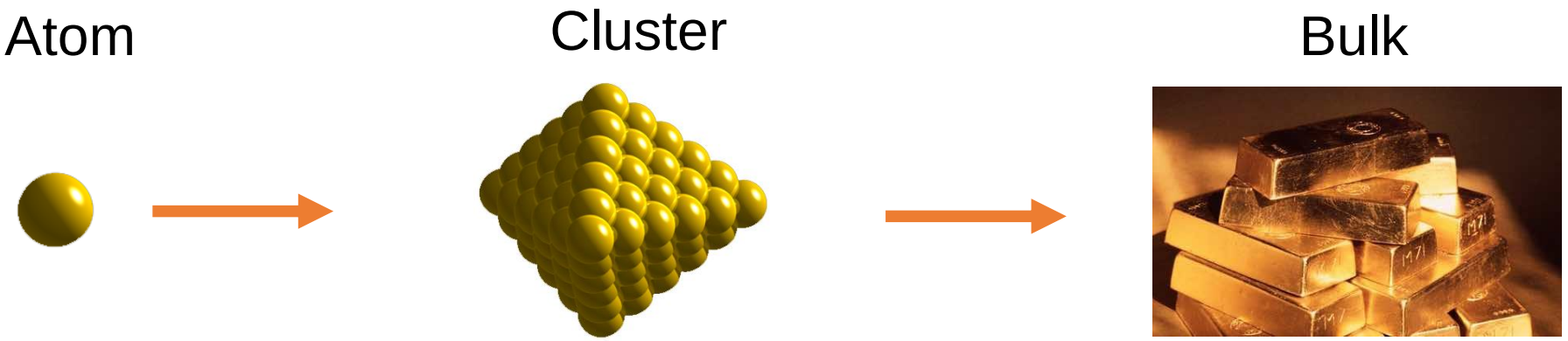


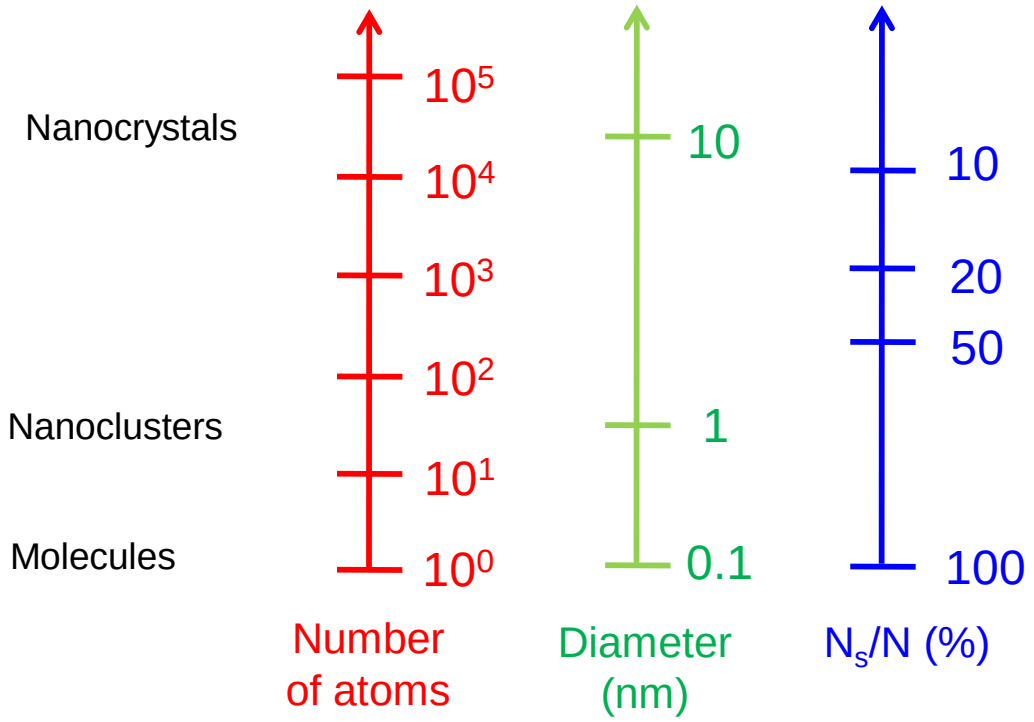
Bilateral Workshop *Nanotechnology and nanoApplication*

February 5th – 6th, 2020, Ljubljana, Slovenia

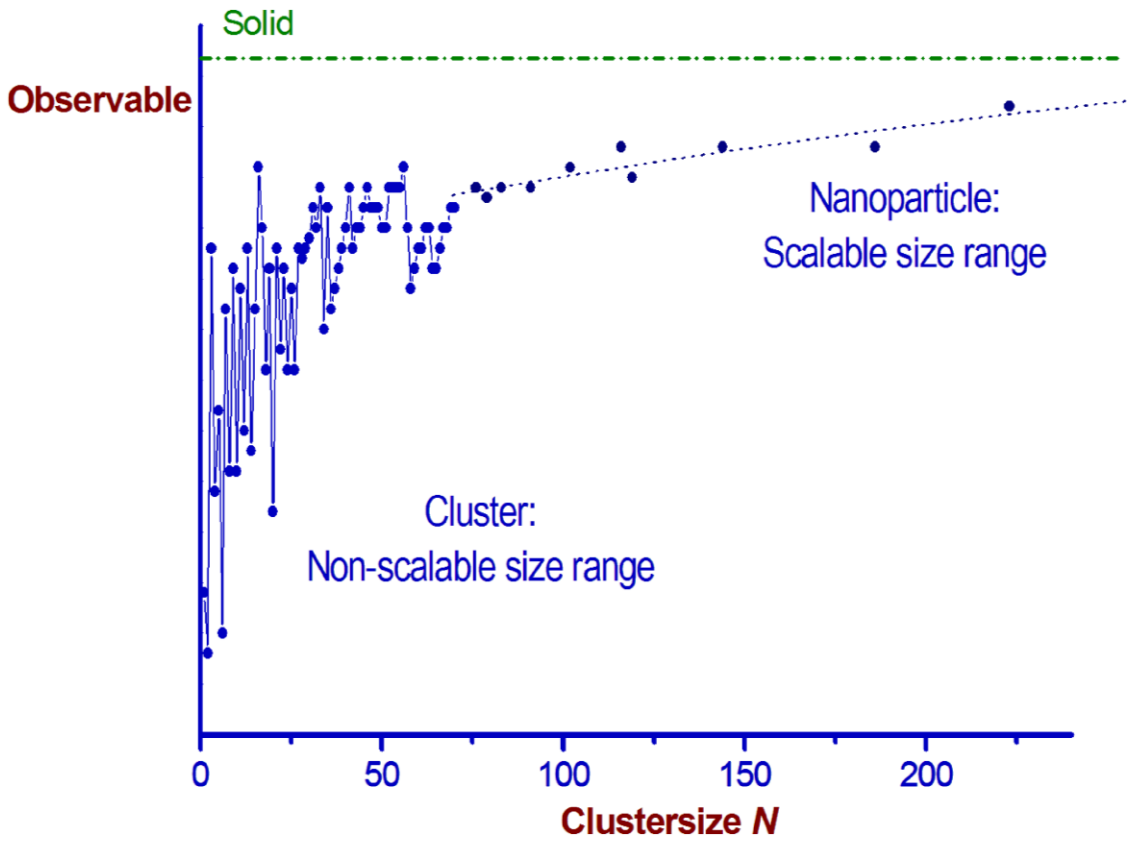



Clusters as aggregates of a well-defined number of atoms.

| Cluster/ Particle Size | N | Diameter (nm) | Ns/N |
|---|---|---|---|
| Large/ Nanoparticle | >10000 | > 9 | ≤0.20 |
| Medium/ Nanoparticle | 100-10000 | 2 - 9 | 0.86-0.20 |
| Small/ Cluster | 2-100 | < 2 | ≥0.86 |



# Scalable vs non-scalable size regime




In the regime of large sizes (N>100), many particle properties vary smoothly with cluster size.

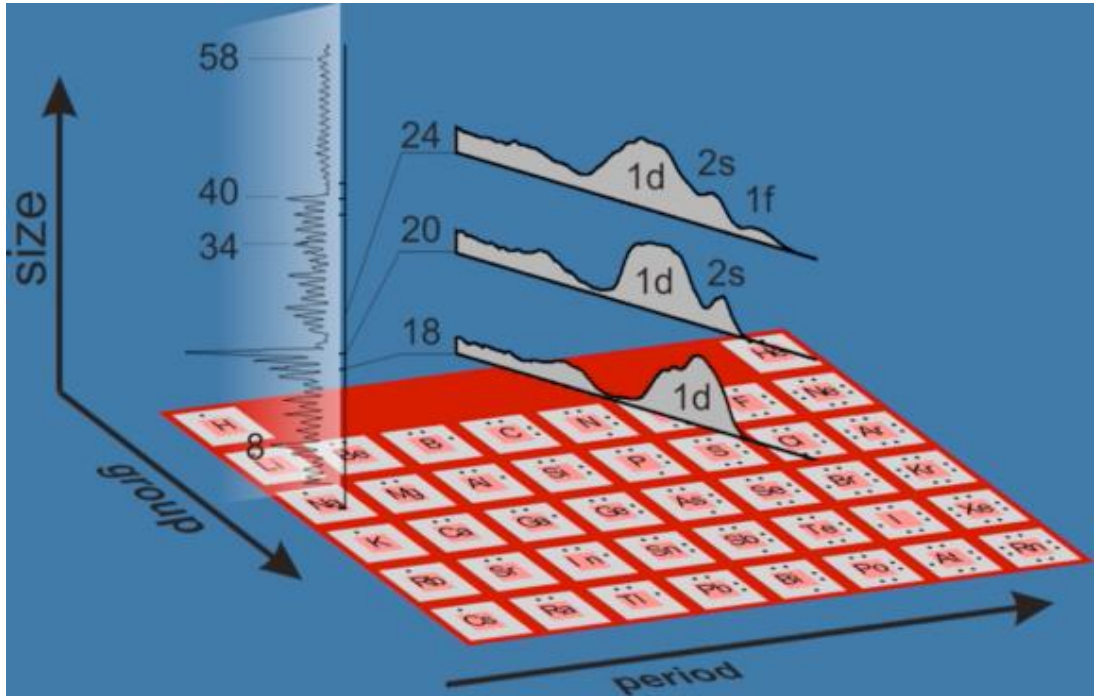
Large deviations (oscillations around the smooth trend) are observed for many properties in the medium and for all properties in the small cluster size regimes (N<100).

Quantum-size effects
Surface effects

Observables: Ionization Potentials, Electron Affinities, Melting Temperatures, Binding energies

# New Physics and Chemistry

$Na_7$ Halogen-like
$Na_8$ Rare gas-like
$Na_9$ Alkali-like




• Distinct and strongly size-dependent electronic structures (band gap tuning).

• Unique structures, non-comparable to crystallites.

• Phase Transitions.

• Size-dependent chemical reactivity.

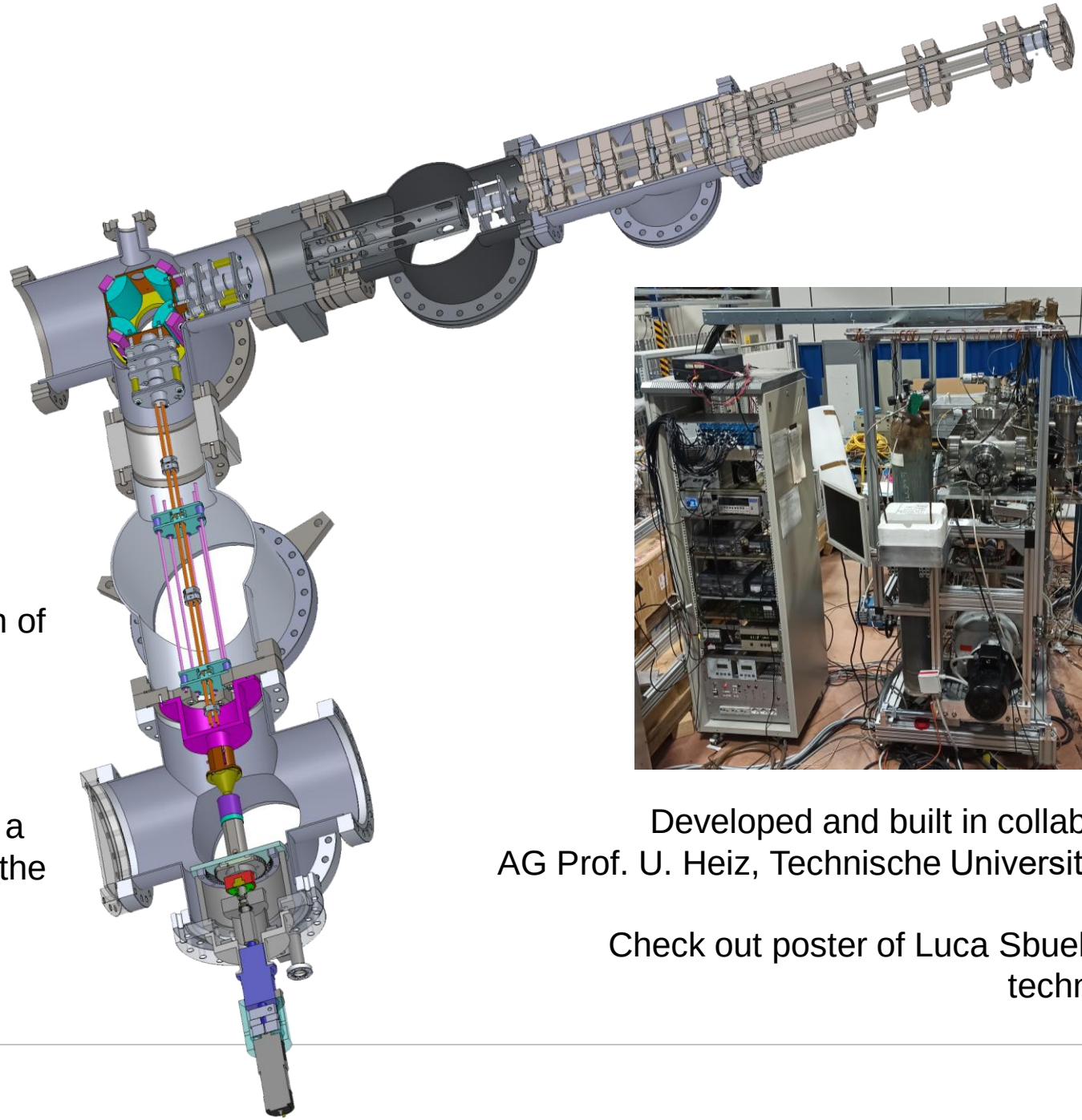
• Unique and size-dependent magnetic properties.

• Electronic and geometrical structure highly dependent on chemical environment and composition (oxidation state and alloying).

# ENAC Cluster Source

Exact Number of Atoms in each Cluster

Home-built source at Surface Science Lab at Elettra and Department of Physics, University of Trieste.



- Cluster source based on laser ablation.
- Rotating target ablated by laser pulse.
- High-density He jet pulsed on the target, causing a supersonic adiabatic expansion of the ion plasma.
- Positively charged clusters are selected.
- A quadrupole mass spectrometer acts as a mass filter by allowing only particles with the selected m/e ratio to pass.

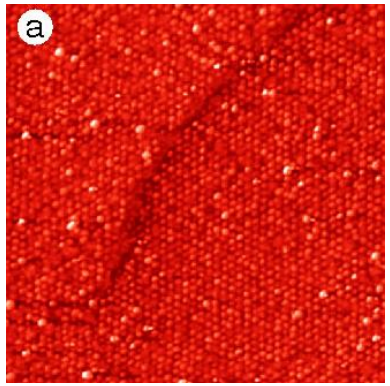


Developed and built in collaboration with AG Prof. U. Heiz, Technische Universität München

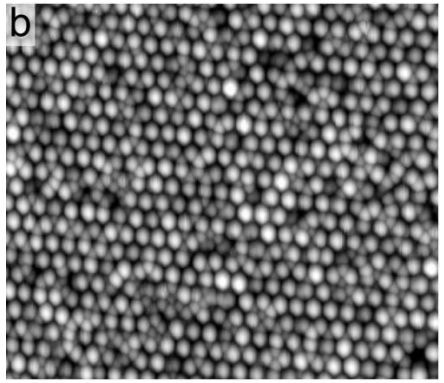
Check out poster of Luca Sbuelz with more technical details.

# Choosing a substrate

## Ultra-thin oxide films

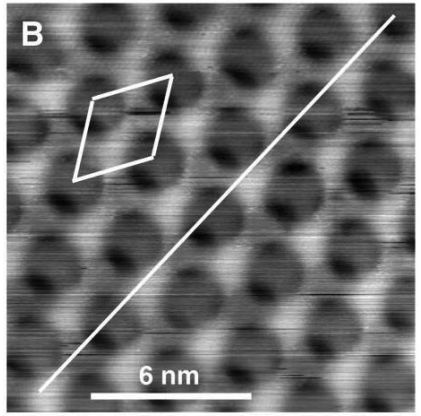


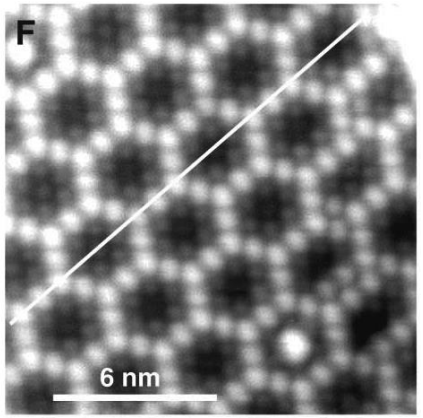

C. Becker et al.,
New J. Phys. 4, 75 (2002).




M. Schmid et al.,
Phys. Rev. Lett. 99, 196104 (2007).

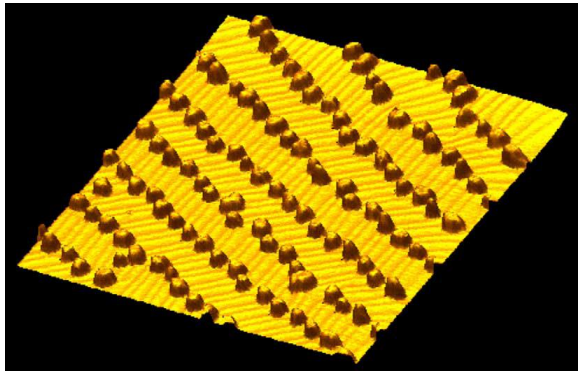
## Boron Nitride nanomesh



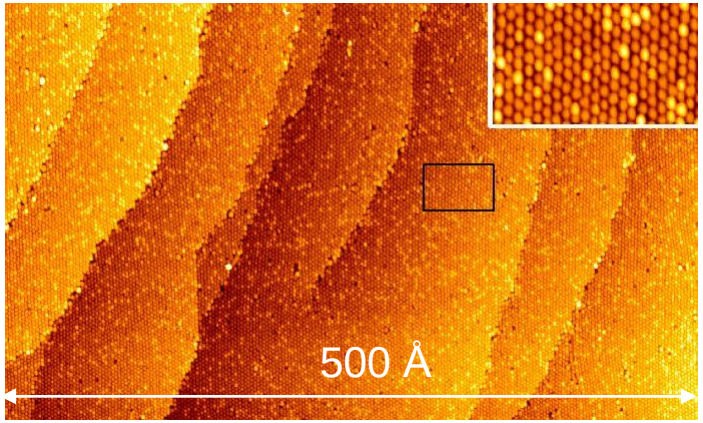

M. Corso et al.,
Science 303, 217 (2004);

## Reconstruction of solid surfaces



S. Padovani,
Appl. Surf. Sci. 42 (2000) 164.

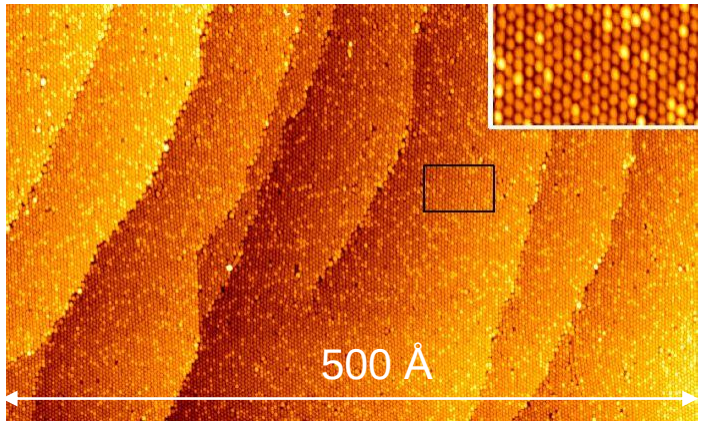
## Epitaxial graphene

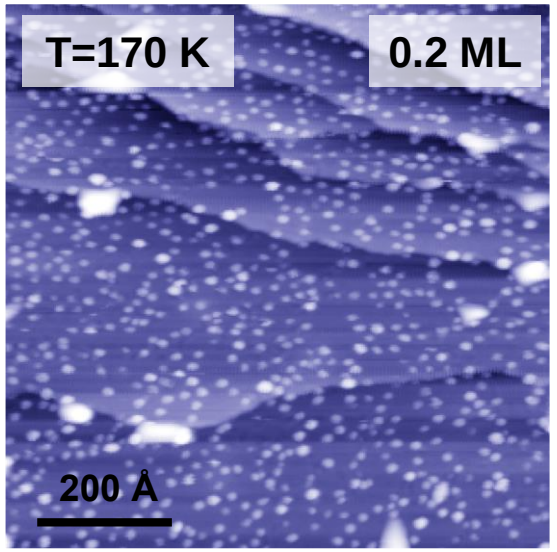


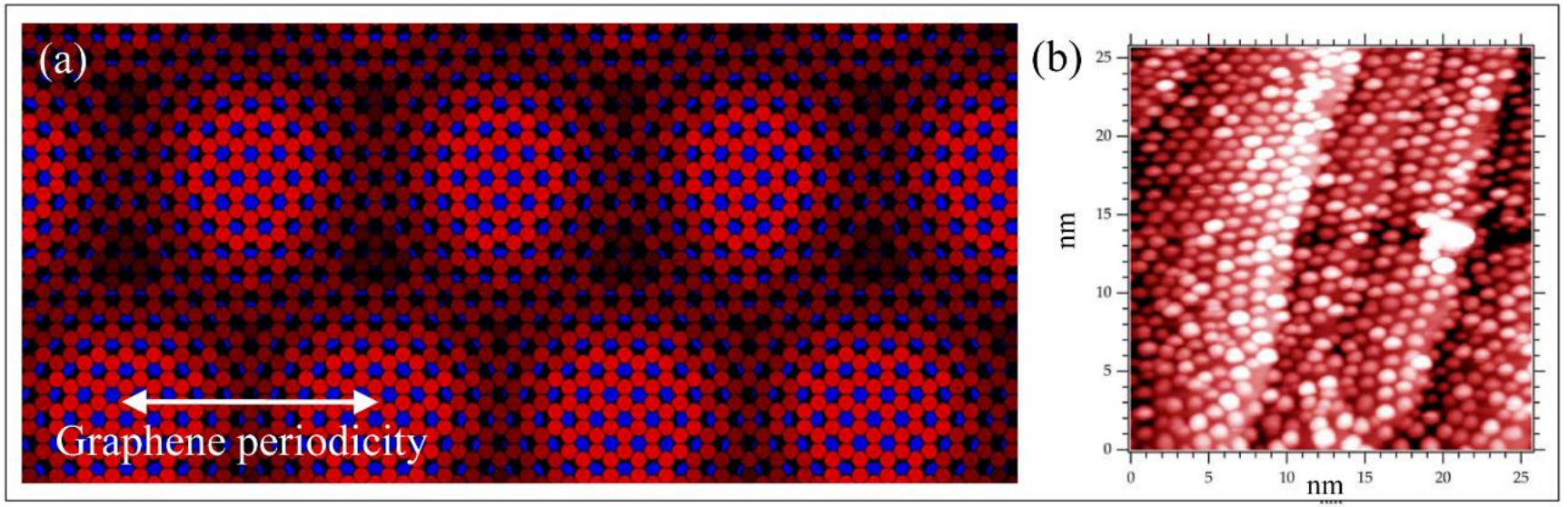

A. T. N'Diaye et al.,
New J. Phys. 11, 103045 (2009)

# Choosing a substrate

Epitaxial graphene on Ir(111)



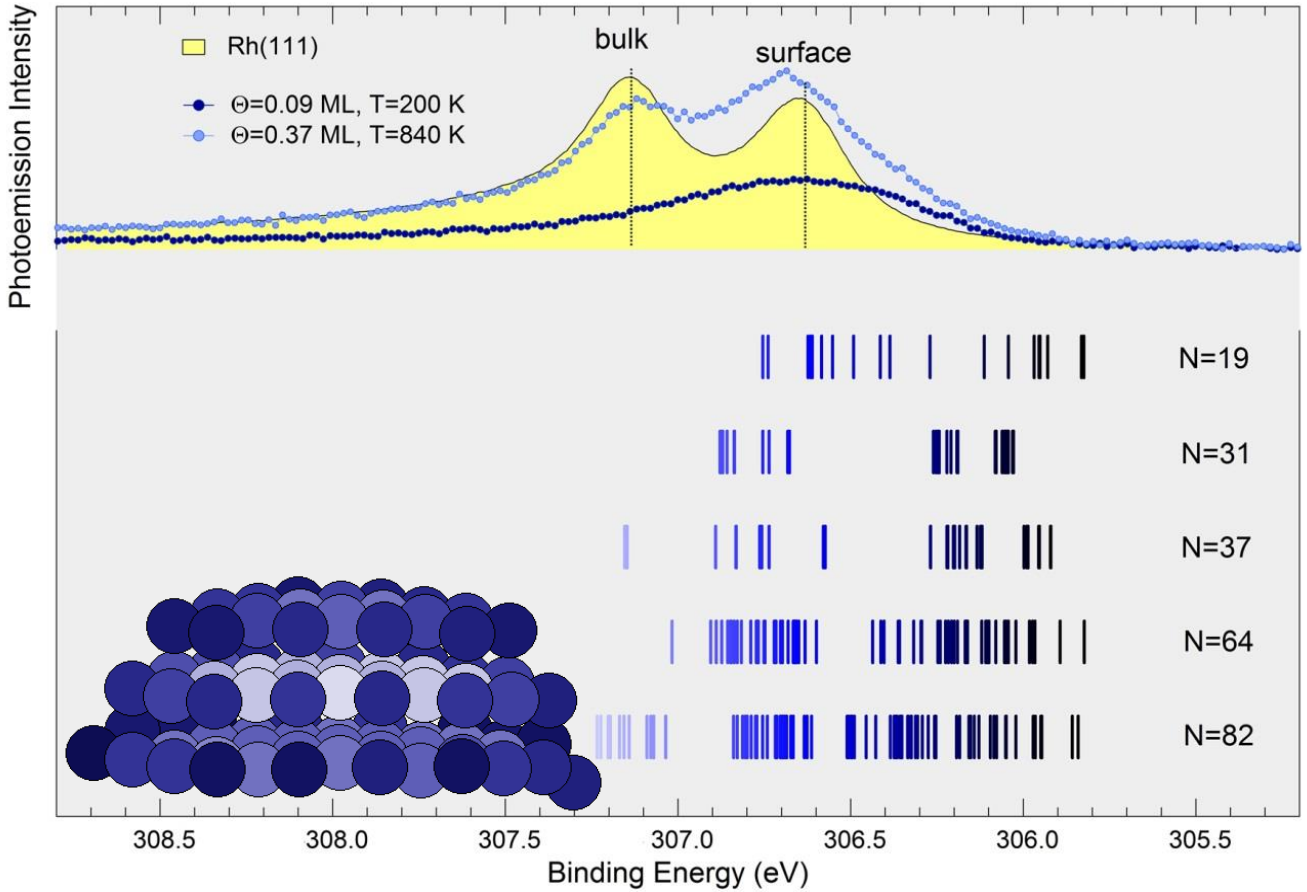




A. Cavallin et al., ACS Nano 6, 3034 (2012).

# Geometry of the clusters

A major issue! Calculations are available.

High-resolution core-level photoelectron spectroscopy combined with photoelectron diffraction.

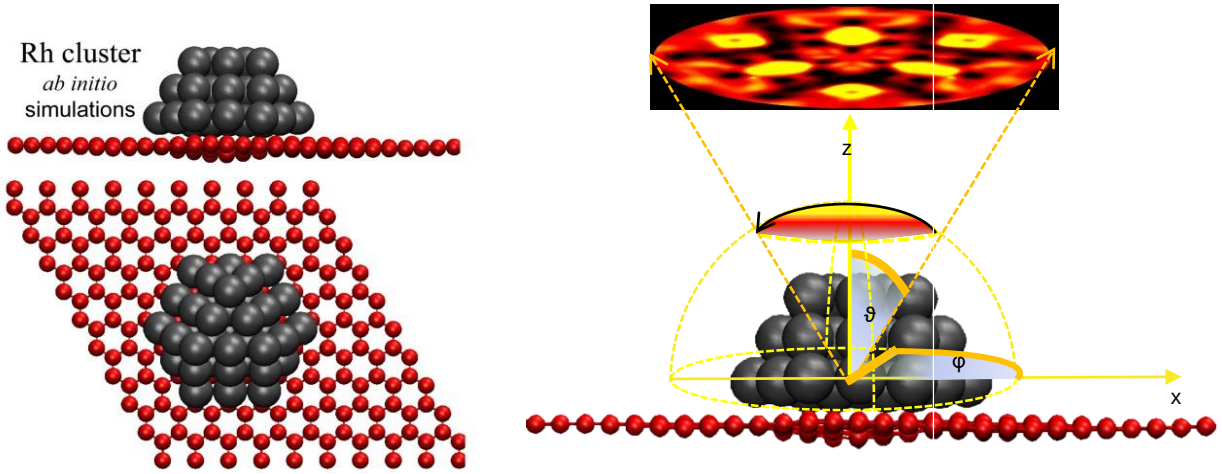


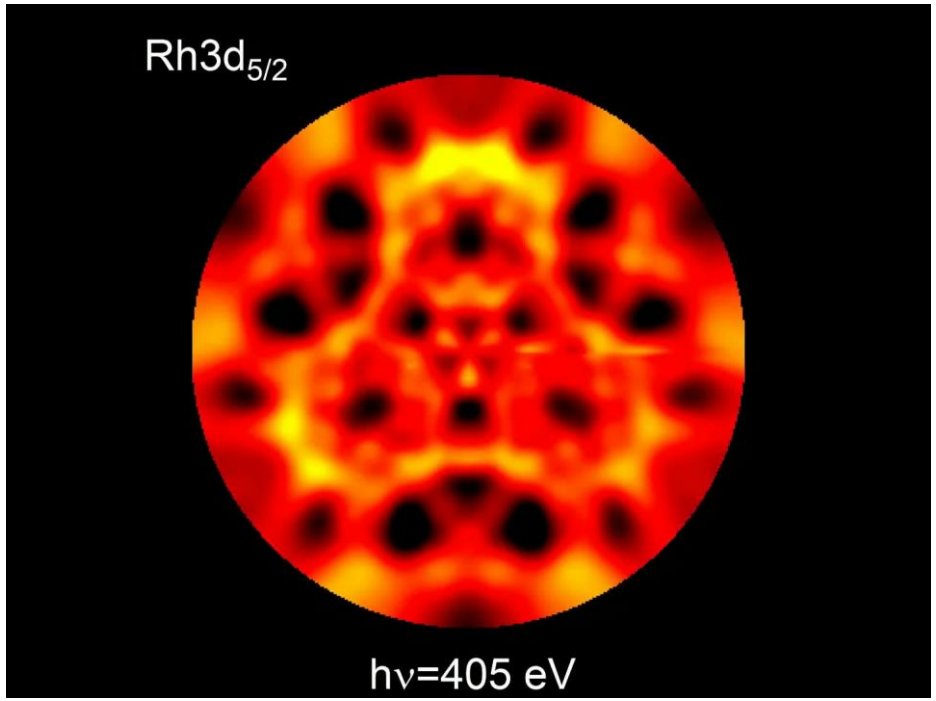

A. Cavallin et al., ACSNano 6, 3034 (2012).

# Geometry of the clusters

High-resolution core-level photoelectron spectroscopy combined with photoelectron diffraction.

X-ray Photoelectron Diffraction



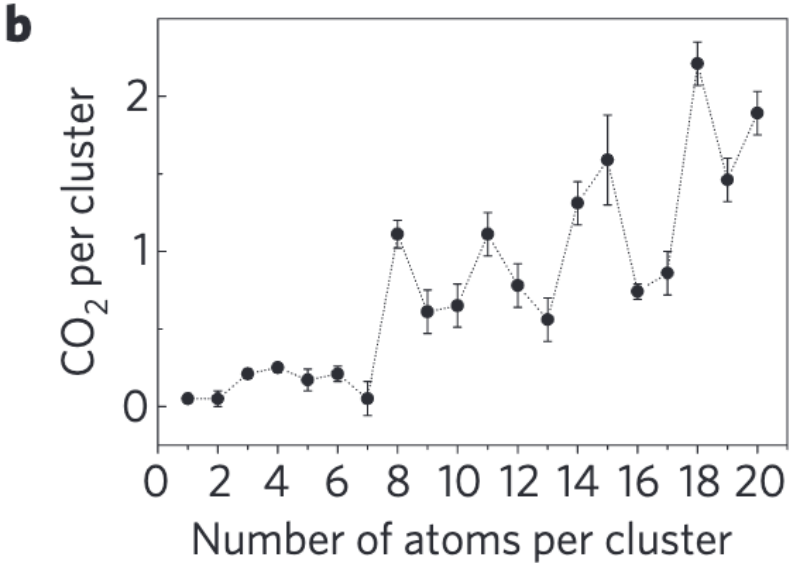




Experiments will be carried out at SuperESCA beamline@ELETTRA

# Reactivity/Catalysis

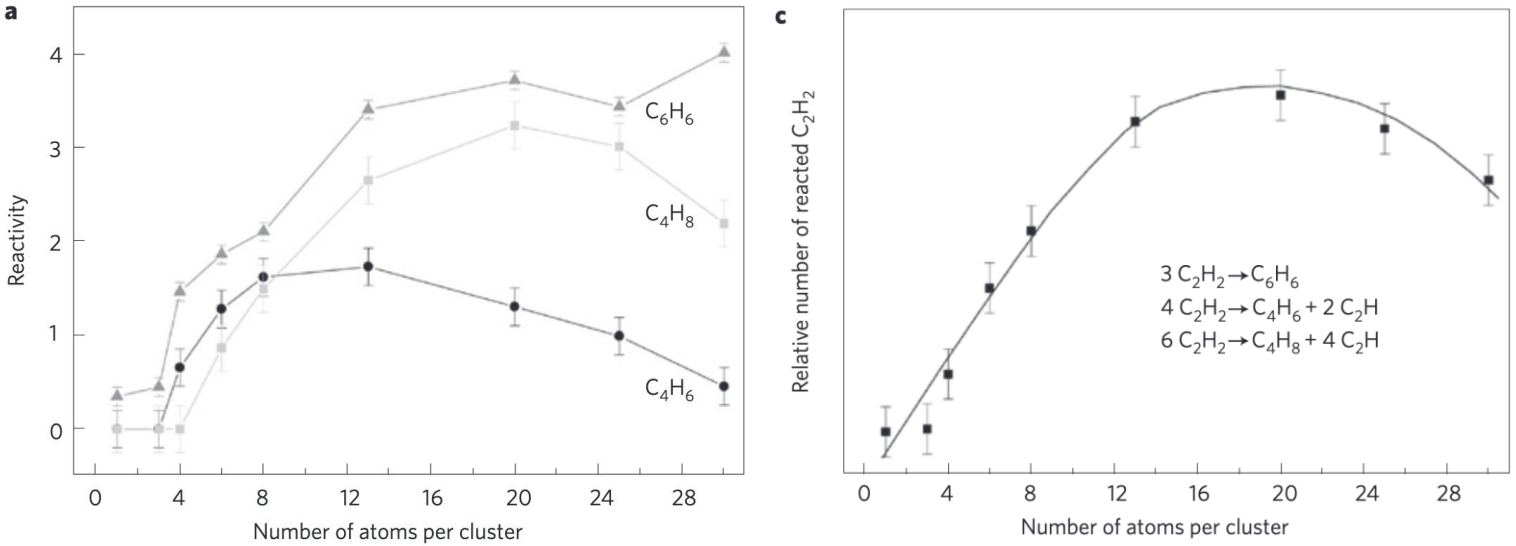
Adsorbate coordination, oxidation state, charge state, influence of gaseous ambient, photochemistry.

CO oxidation w/ MgO-supported Au clusters




A Sanchez et al., J. Phys. Chem. A 103, 9573-9578 (1999)

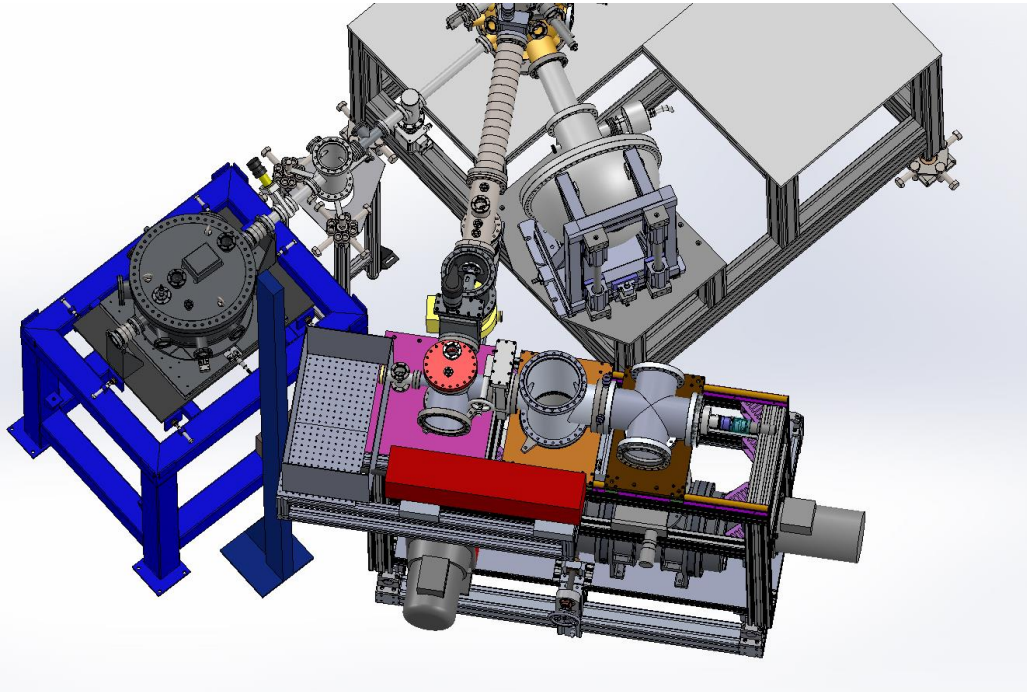
Pd atoms and clusters on MgO in UHV: polymerization of $C_2H_2$

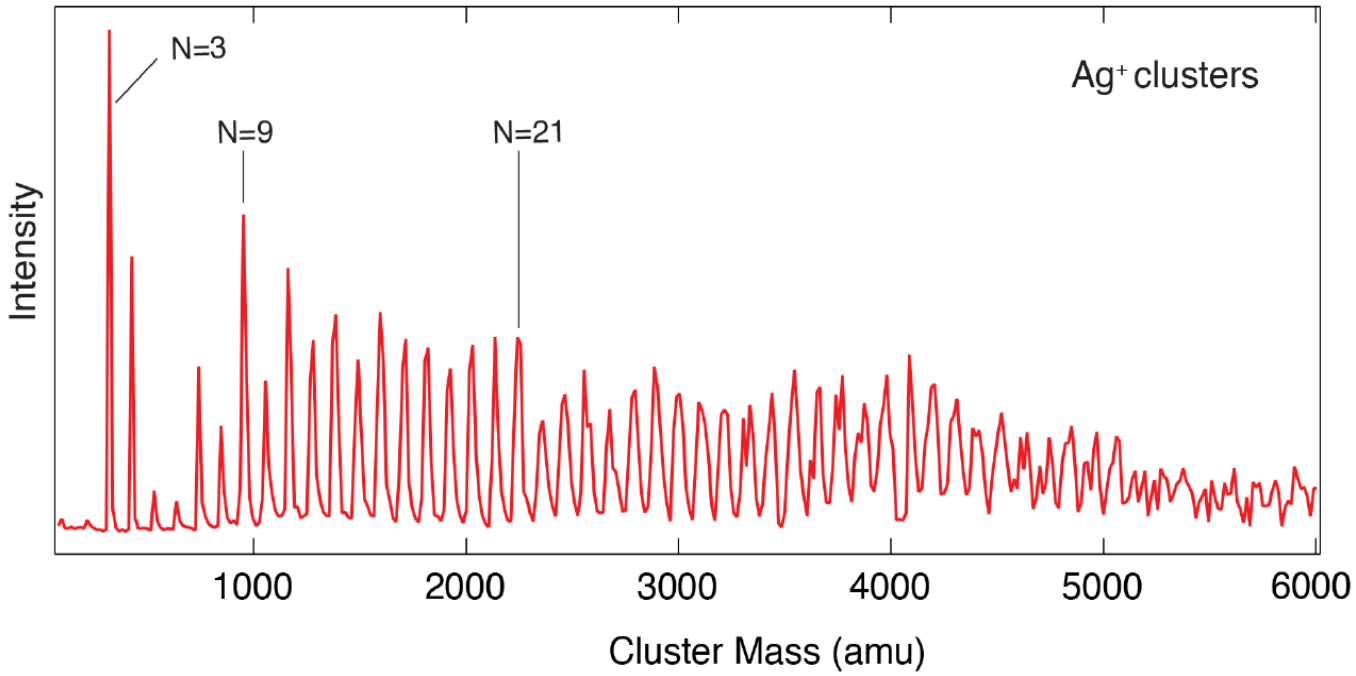



S Gilb, M Arenz, U Heiz, Low Temp. Phys. 32, 1097 (2006)

# Coming next

Moving the ENAC cluster source to SuperESCA beamline@Elettra.
*In-situ* studies of the geometry and reactivity of Ag clusters towards oxidation.

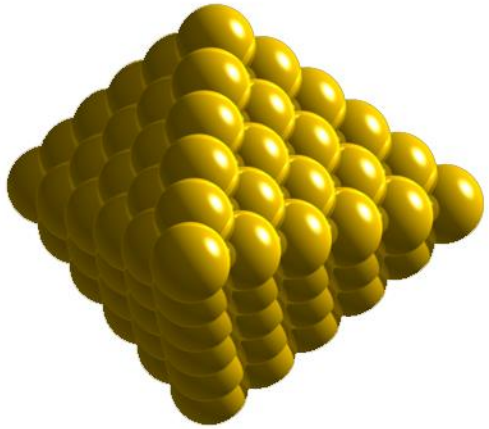




# In conclusion

The study of size-selected nanoclusters (N<100) opens up the possibility to unravel several fascinating and appealing properties in catalysis, reactivity, magnetism, strongly depending on the size and geometry of these objects.

The combination of our instrument with a synchrotron radiation facility constitutes an unique setup to investigate these very elusive objects.



We are looking forward to interaction and cooperation with the international scientific community, to broaden the possibilities of our project.

SURFACE SCIENCE LABORATORY

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Luca Sbuelz
Federico Loi
Eugenio Nicolini

# Thank you for your attention!

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