Institut Ruđer Bošković

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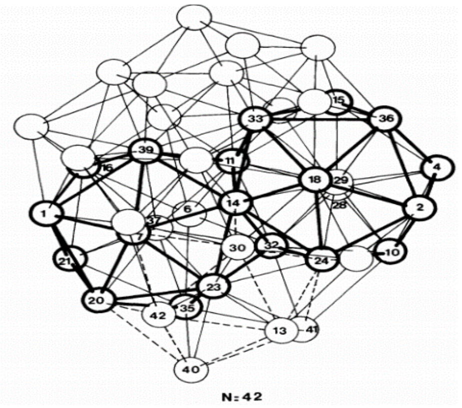
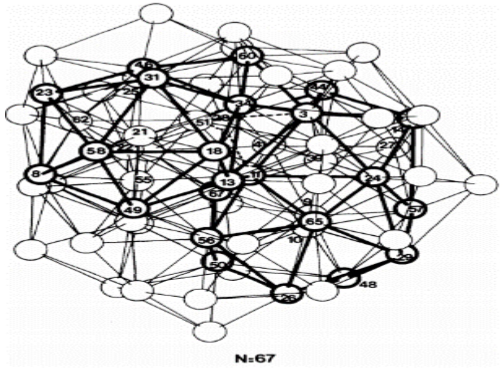
EXPERIMENTAL STUDY O THE CRATER FORMTAION UNDER GOLD CLUSTERS



Fares Boussahoul, Milko Jakšić, *Messaoud Benguerba*, Serge Della Negra,
Isabelle Ribaud, Dominique Jacquet, Maja Mičetić , Zdravko Siketić



Presented by : Sabrina GOUASMIA BOUSSAHOUL

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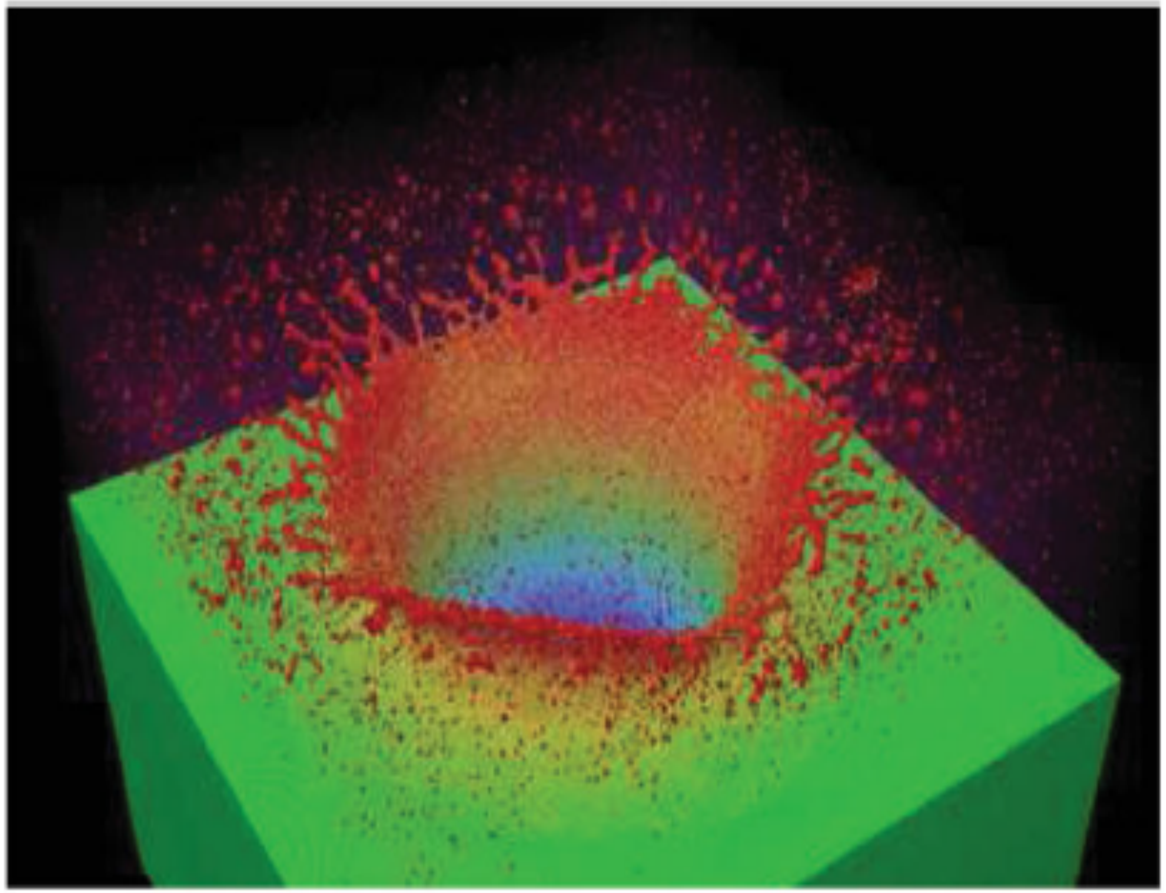
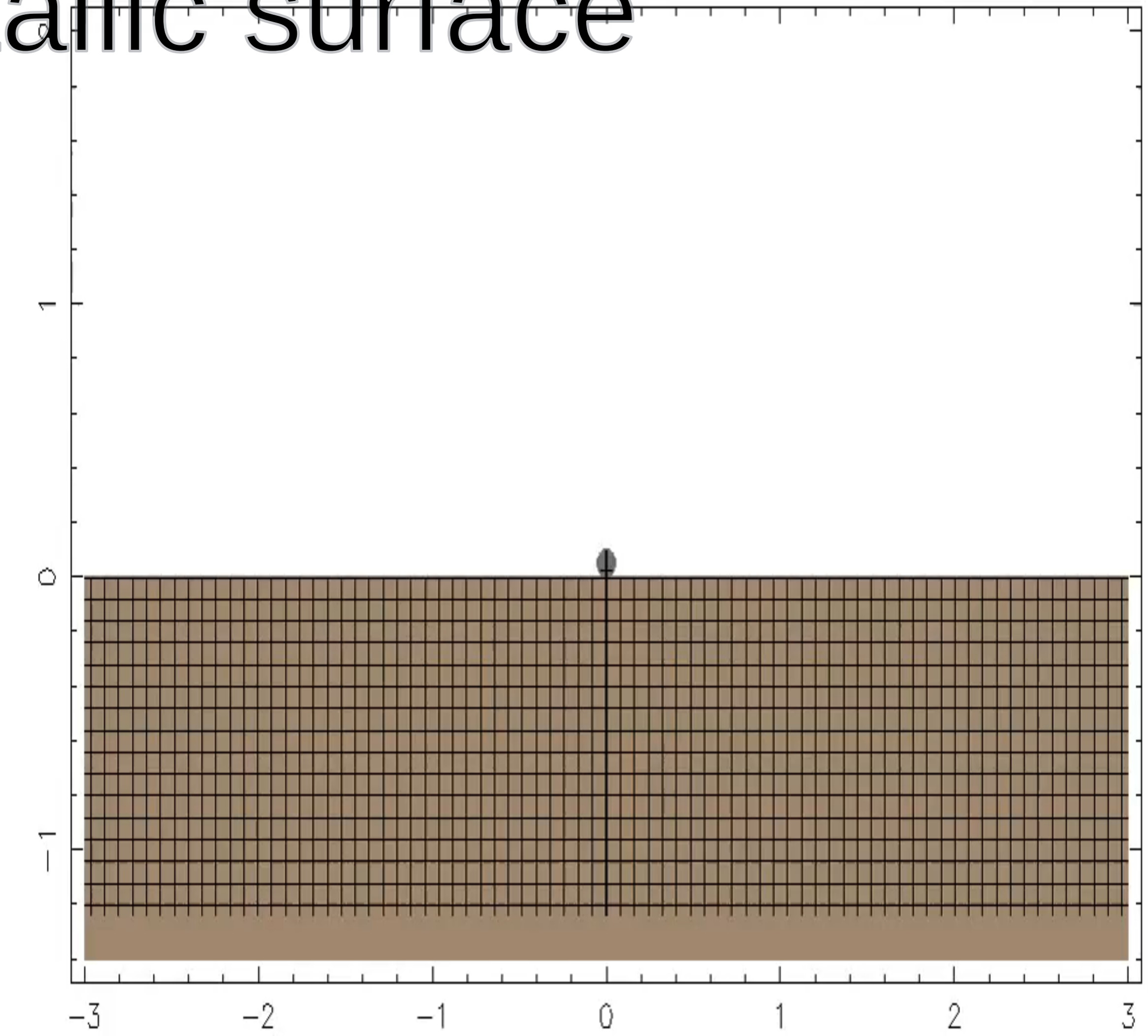
OUTLINE

- Presentation of the study of the crater formation theoretically
- Experimental study of the crater formation
- Conclusion

Crater Formation Under Cluster Impact_metallic surface





Molecular dynamics simulations

- Spherical shape

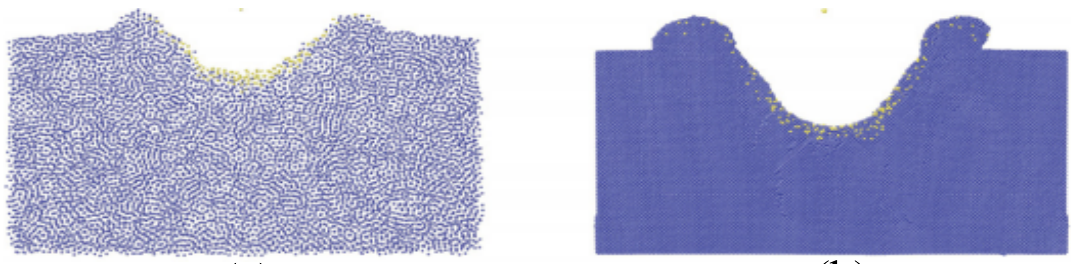
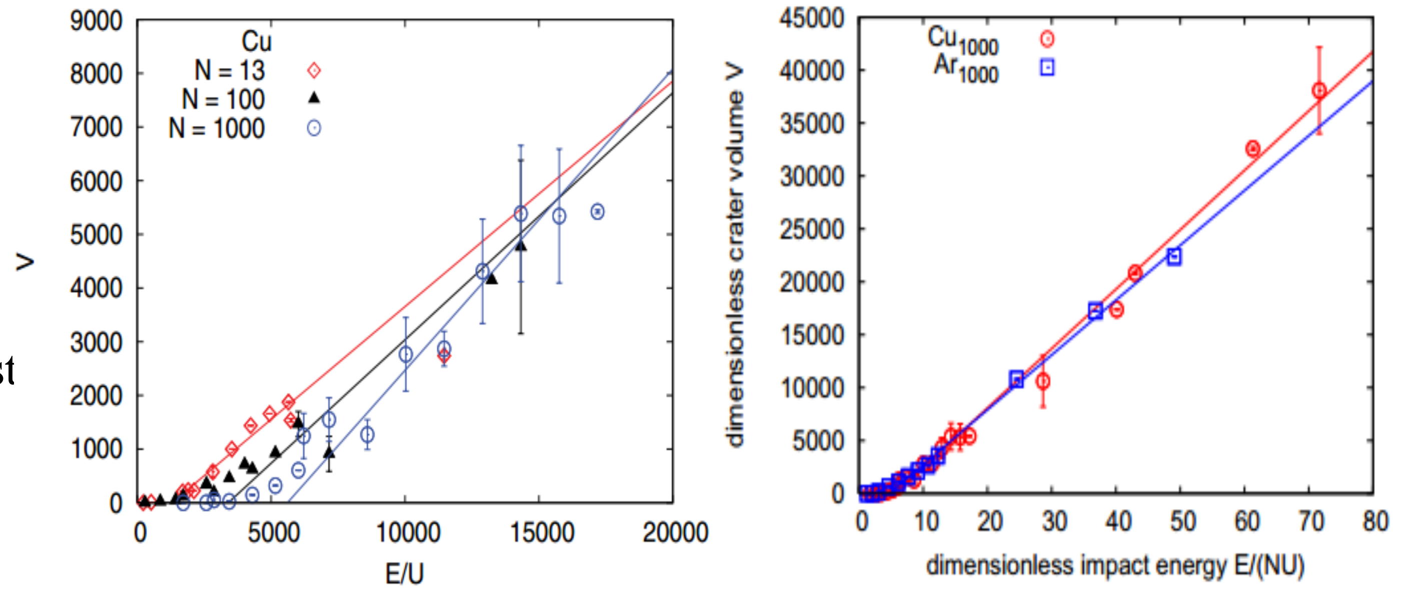


Fig.: Molecular-dynamics view on craters formed by clust impact.

(a) Ar1000 on an amorphous Ar target.

(b) Cu10 000 on Cu target [1]



- During the formation of the crater, there is formtaion of a compression region :

High pressure,
High temperature.

- The obtained results gave evidence that beyond a threshold energy the crater volume increases linearly with impact energy scaled to the cohesion energy [.
- Mathematic fitting of the simulated data

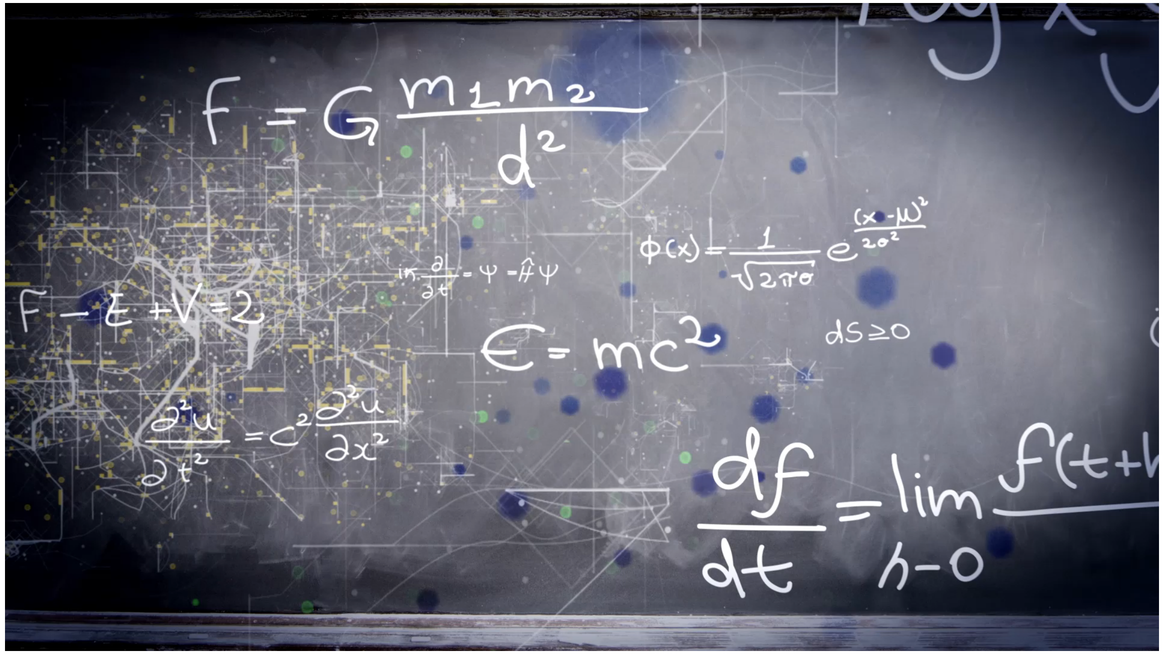
In order to build our theoretical model, we started from this observation for which we supposed that this observation may be interpreted as being a

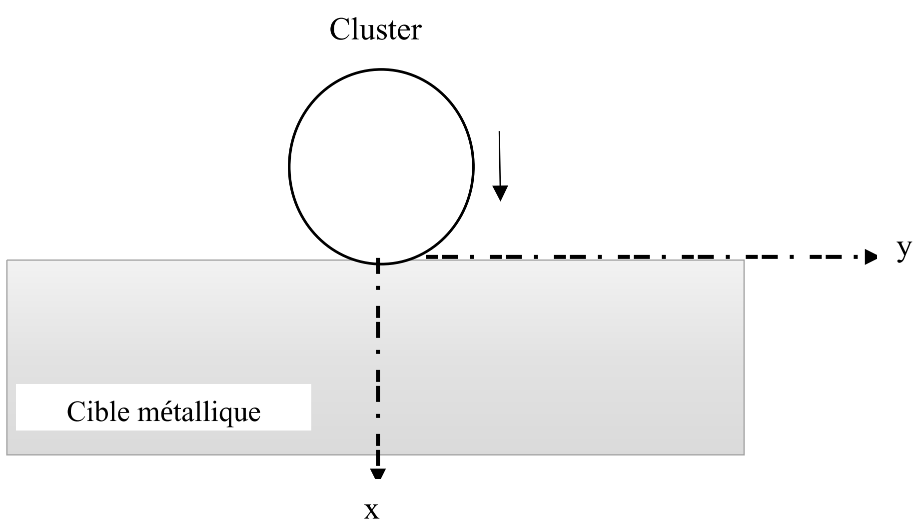
Signature of shock wave generated just after impact of cluster on the surface

[1]: C. Anders, G. Ziegenhain, C.J. Ruestes, E.M. Bring Urbassek, New J. Phys. 14 **(2012)** 083016.

Modelisation of the Cratering process Spherical model

Physical mechanism of the crater formation is explained by the collective ejection of particles within the conditions of shock wave generated upon impact of cluster





Approximations:

- Spherical cluster (size *n*, mass m_0 and radius r_0)
- Normally impacting into a planar surface with a velocity ,
  Where :speed of sound in the target
- Shock wave generation at the impact

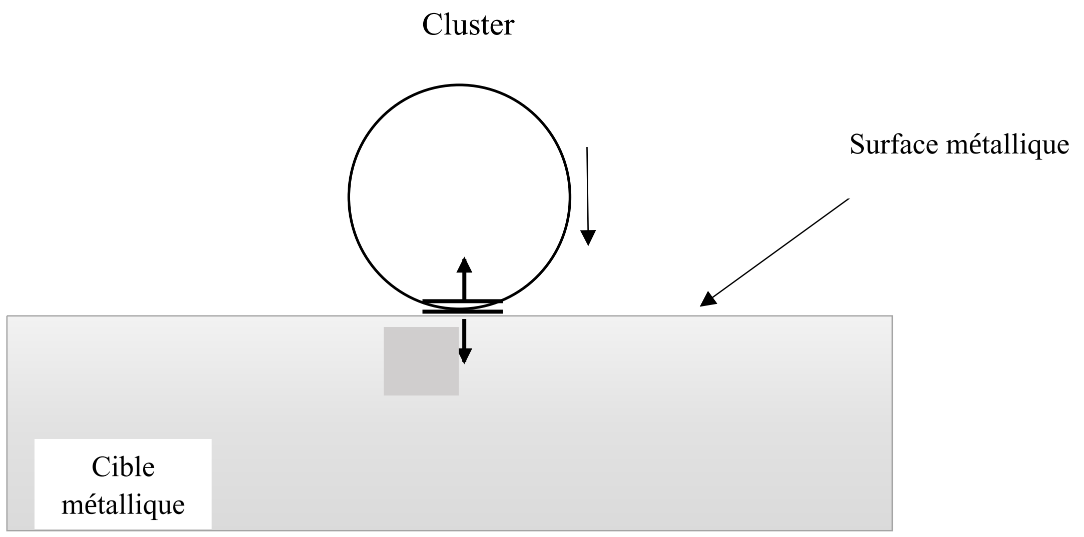
Crater formation process :

I. *Contact stage*

At the cluster impact on the surface, and due to a high velocity impact and to a large energy density depositing in the target, two shock waves are generated

downward in the target

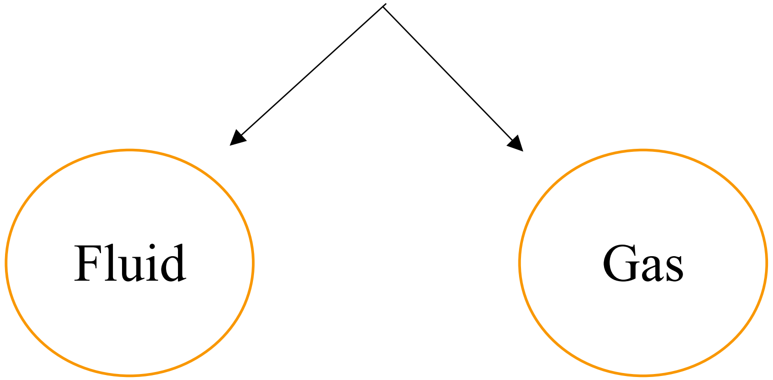
Backward into the cluster

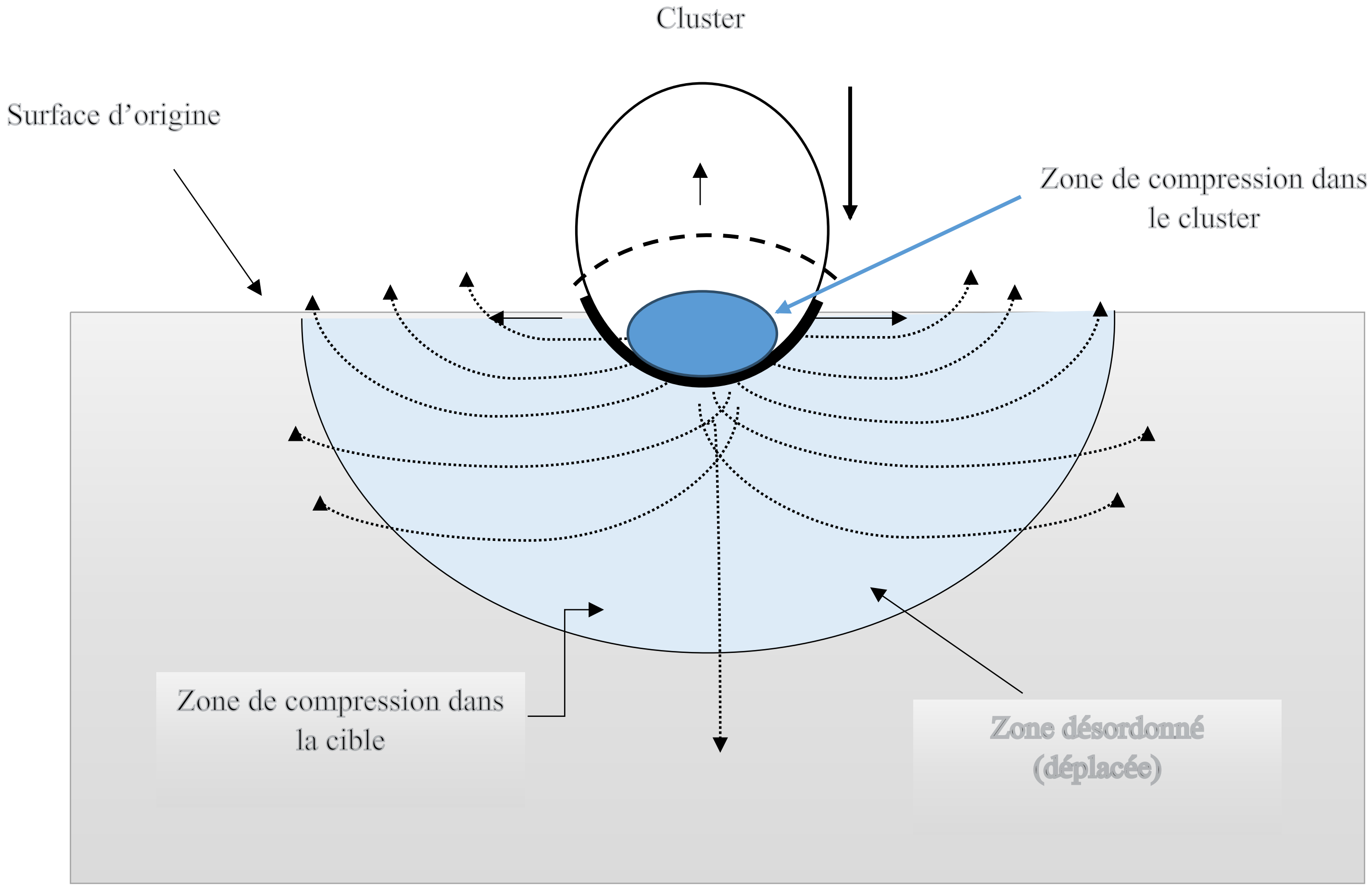


II. Compression stage

- Immediately after contact stage, the rapid movement of the cluster pushes the target material which results in the creation of a disordered zone under the action of shock waves,

- Under the shock compression, the material shocked passes from its initial solid state to a new state characterized by high pressure high temperature and high density.



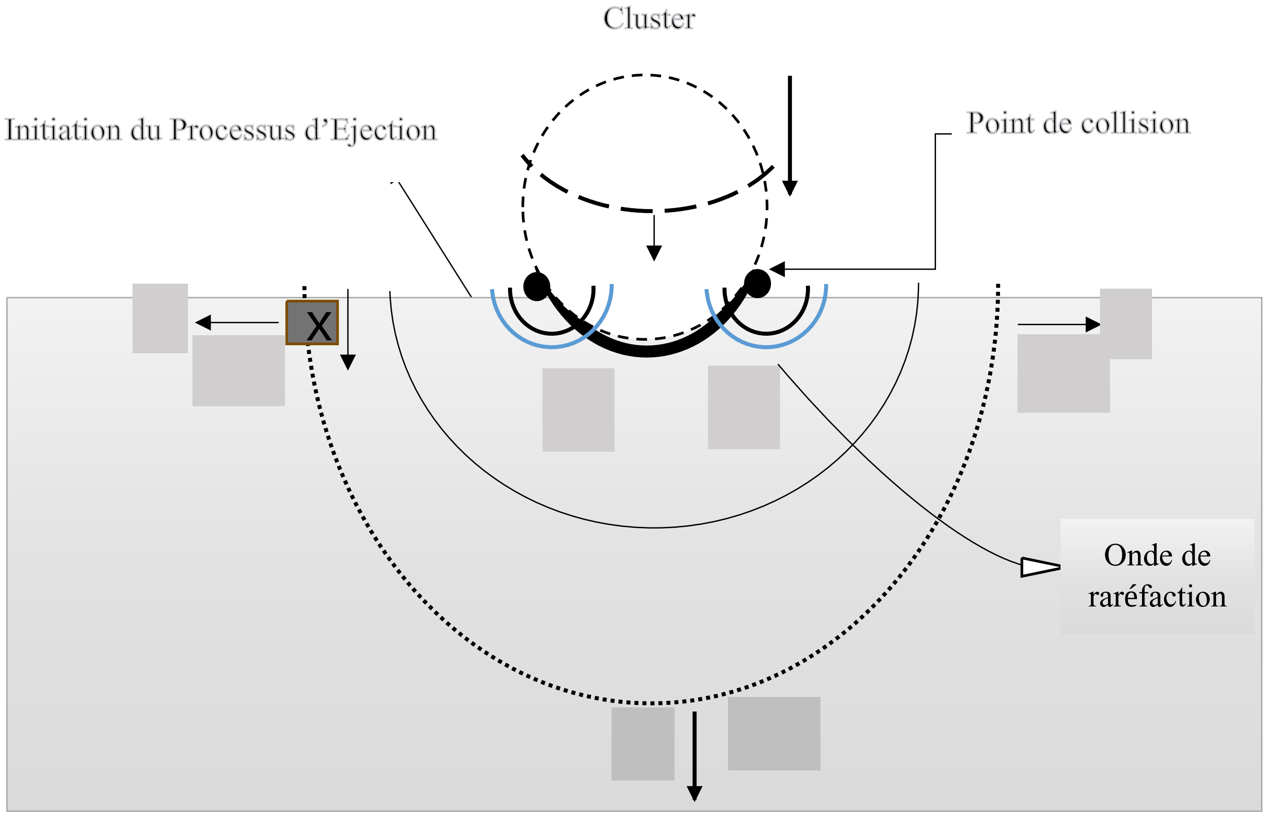


III. Rarefaction and Excavation stage « Jetting process »

❑ When the shock wave catches up with the point of collision (point h) it detaches itself from this point under the condition:

→ Leading to the ejection of the particles [2]

Is the collision point velocity



❖ This condition ensures that the shock wave detaches from the collision point allowing for rarefaction waves to propagate into the shocked material inducing collective ejection of particles.

,

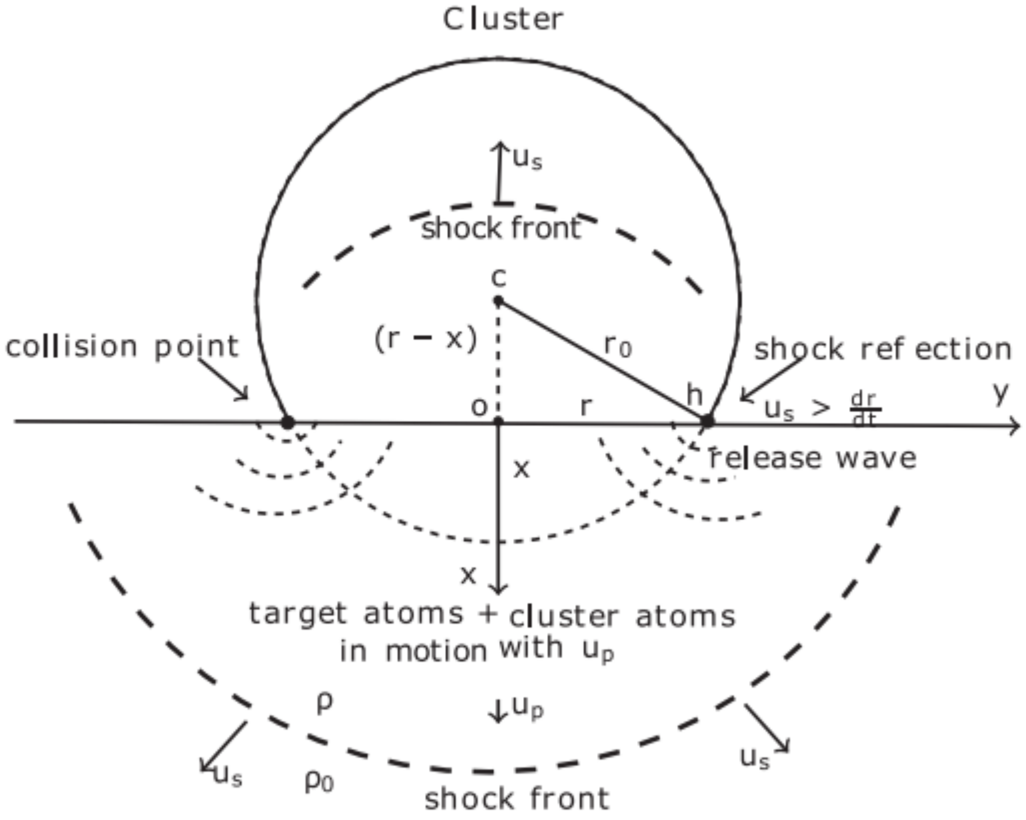
[2] :J.A. Ang, Int. J. Impact Eng. 10 (1990) 23–33

Crater Volume

- Breaks up under the action of pressure
- Penetration of a certain depth **x** behind the shock wave.
- Accordingly, the cluster is decelerated under the force given by :

where is the cross sectional area

This radius can be deduced as a function of x from triangle in which



The cluster penetration velocity can be obtained using equation of motion under initial conditions t = 0, x = 0,

Approximation 1: spherical crater appears as a result of shock wave produced at the cluster impact [3,4]

This time is

Cluster penetrate a small distance x

Cluster breaks up at the impact on the surface

Cu_n → Cu surface
Au_n → Au surfaces

Approximation 2: The dynamical process of crater formation is probably initiated during the time where the rarefaction wave takes to encompass the shocked volume

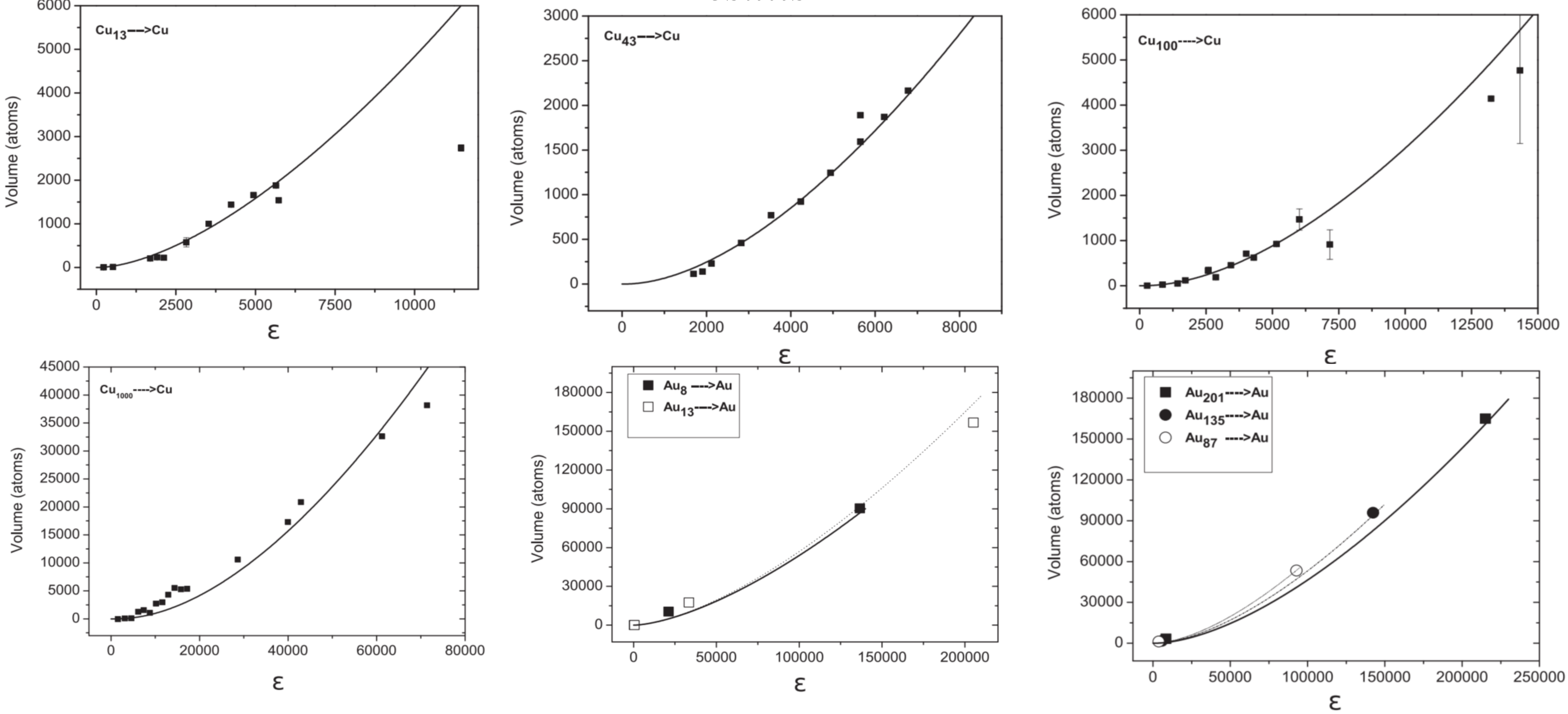
Ar_n → Ar solid surface
Ar_n → Metallic surfaces

Where :

- n : cluster size
- , : atomic density of cluster and the target.
- : penetration velocity.
- : sound velocity.
- : Sublimation Energy

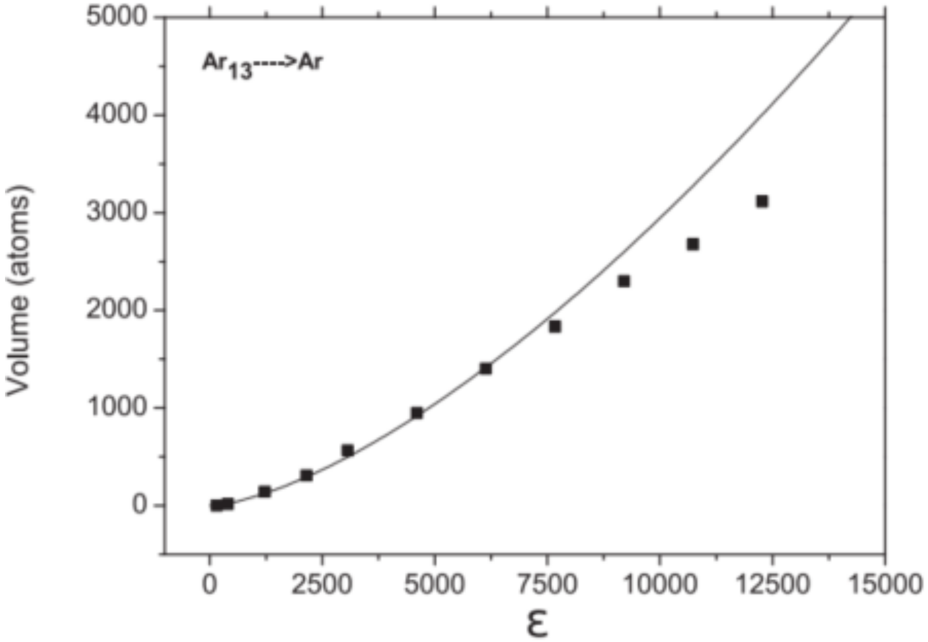
[3]: Y. Yamaguchi, J. Gspann, Phys. Rev. B 66 (2002) 155408.
[4]: J. Samela, K. Nordlund, Phys. ReV. Lett. 101 (2008) 027601

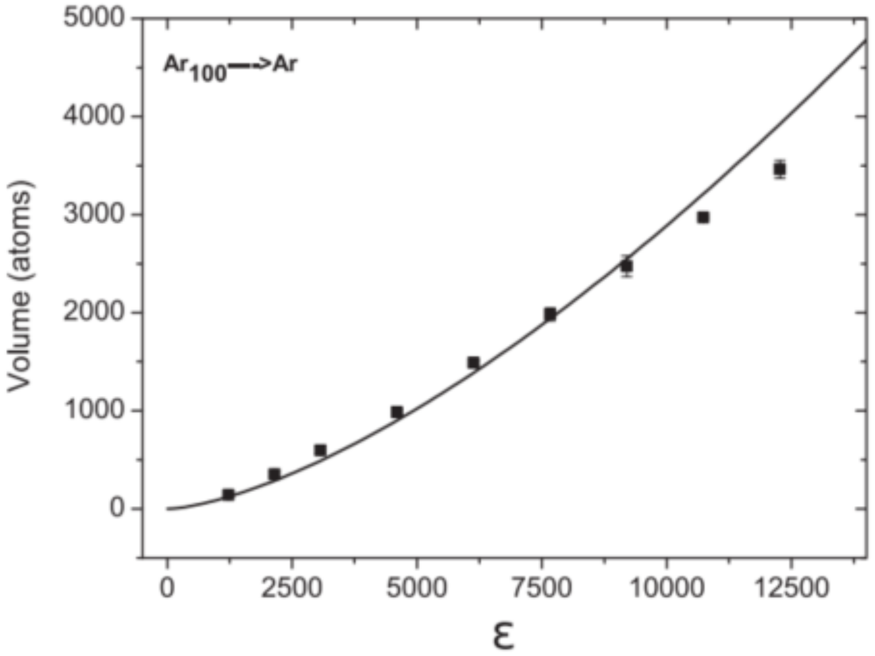
Results

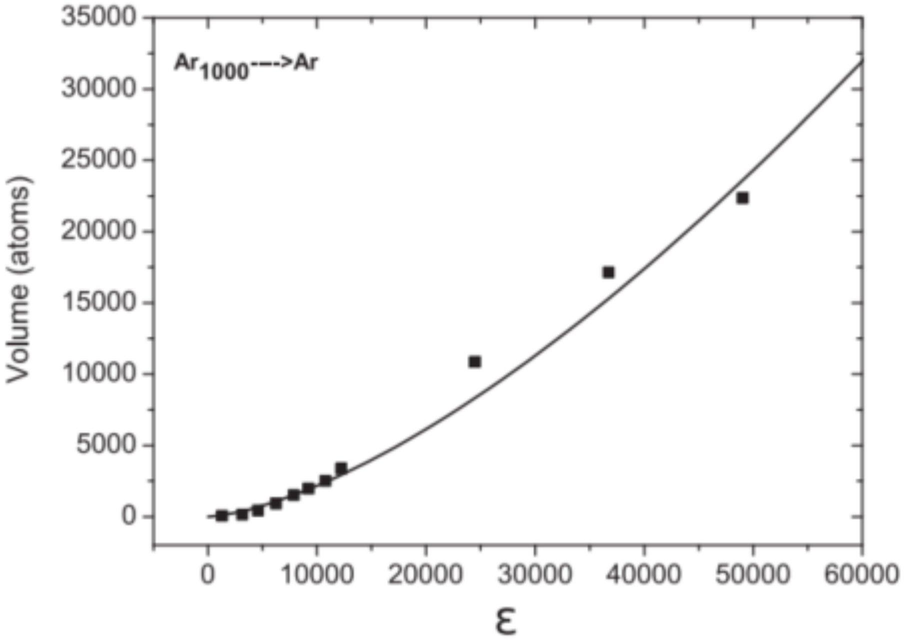


Figures: Dependence of crater volume in atoms on the scaled impact energy for *Cu*13, *Cu43* clusters. Solid squares are the dynamic molecular simulation [1] and solid line is the curve calculated from the model

[1]: C. Anders, G. Ziegenhain, C.J. Ruestes, E.M. Bringa, H.M. Urbassek, New J. Phys. 14 **(2012)** 083016.







[5]: S. Gouasmia, M. Benguerba, Nucl. Instrum. Methods B 447 (2019) 43–49.

Conclusions

- The Spherical model has been successfully applied to reproduce many simulated data in the KeV range by molecular dynamics simulations without any free parameter. Emax=1 MeV

- S. Gouasmia, M. Benguerba, Nucl. Instrum. Methods B 447 (2019) 43–49.

- Theoretical basis which may help understand nano-sized modifications leading to surface craters formation under shock wave conditions generated by self impact of high velocity copper, gold and argon clusters.

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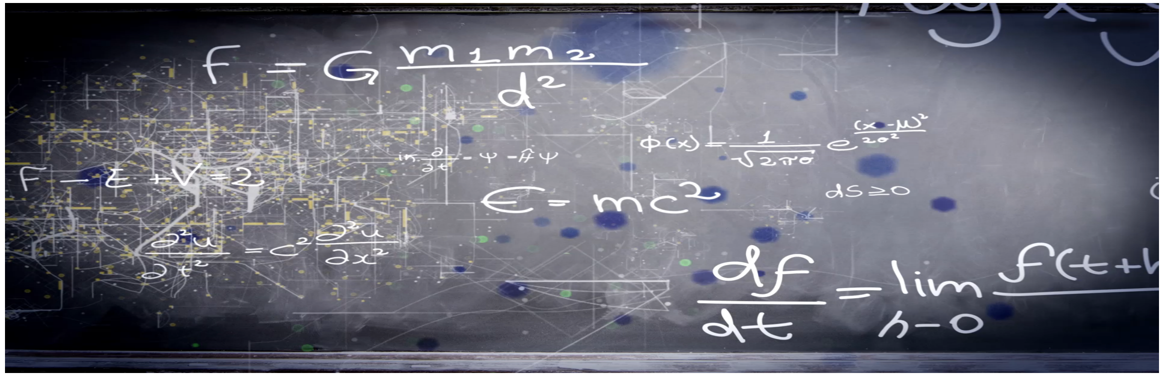
Study experimental of the crater formation under Gold cluster ions

Objectif: Validation of the theoretical model at high energy

Other Conditions

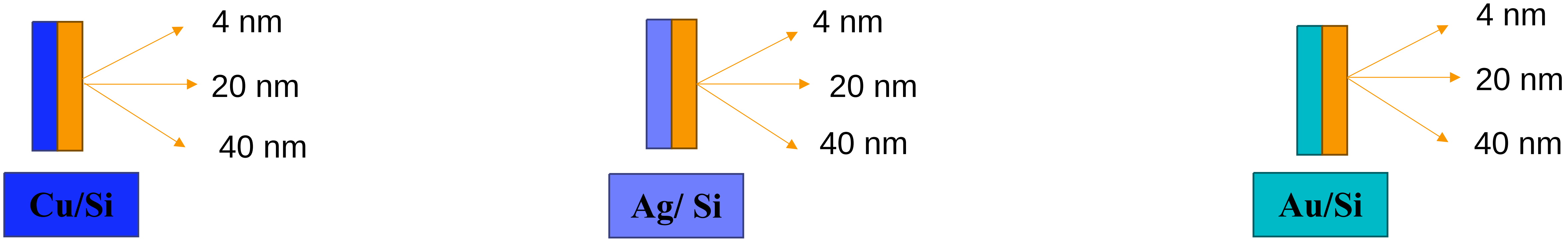


Other surfaces

Under the shock wave condition

Samples preparation

❑ CMS-18 system for preparation of thin layers by magnetron sputtering process



- 3 samples for each one

: Sublimation Energy

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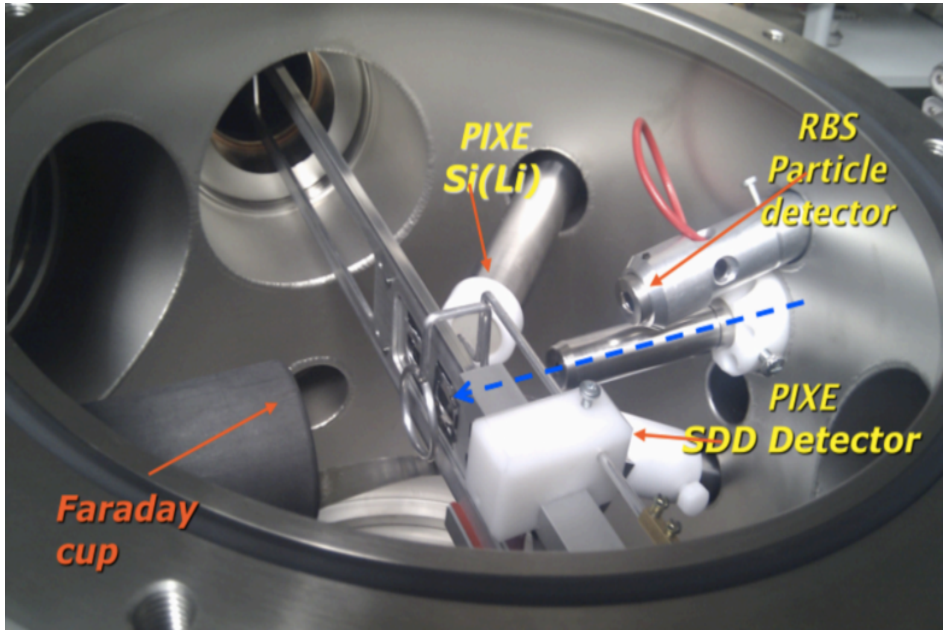
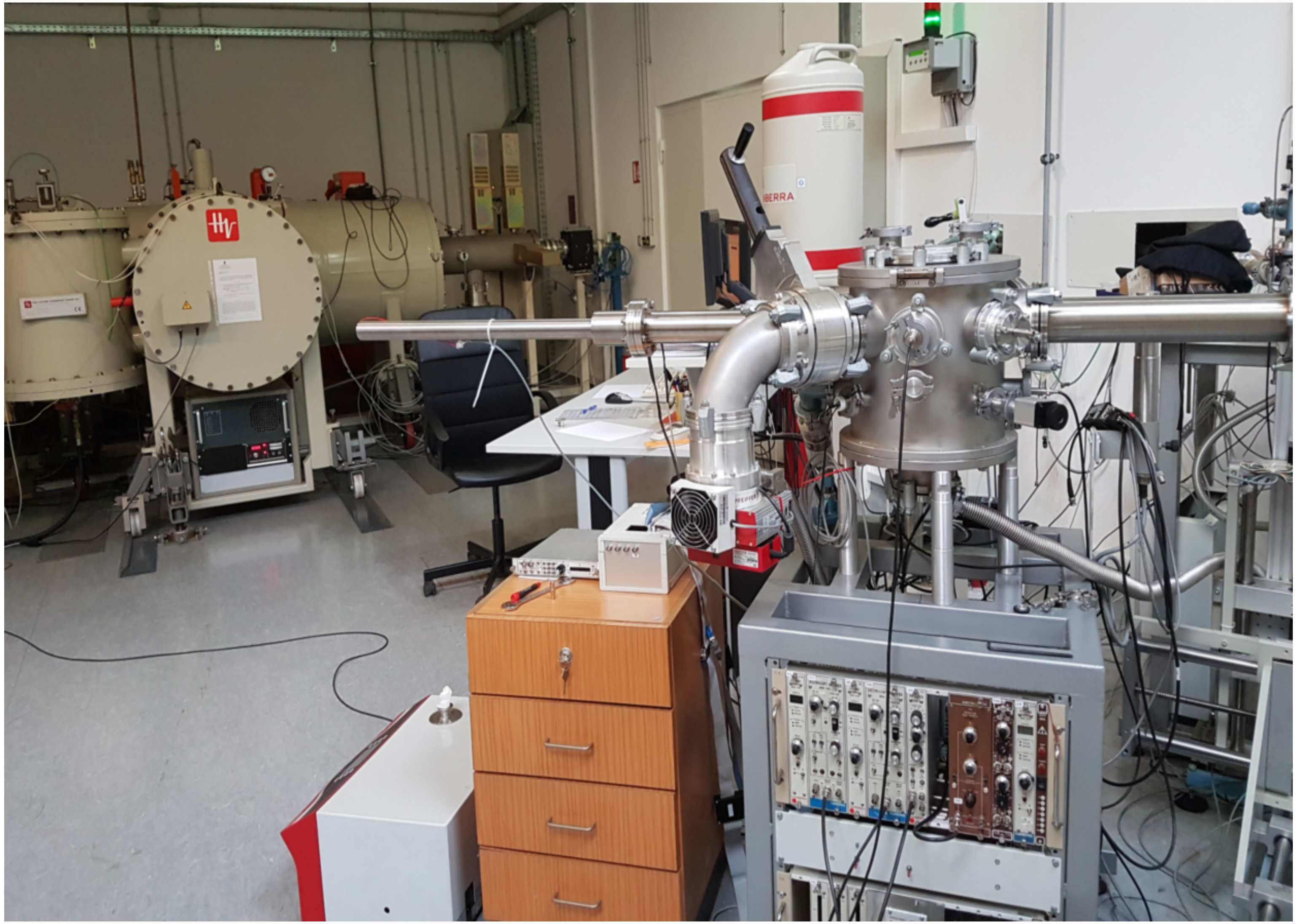
Samples Characterisation

- Rutherford backscattering spectroscopy

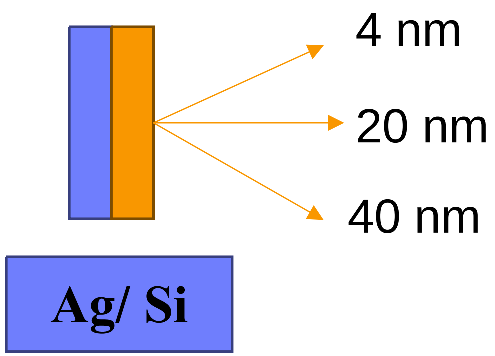
- ^{4}He 1MV Tandetron accelerator/ RBI

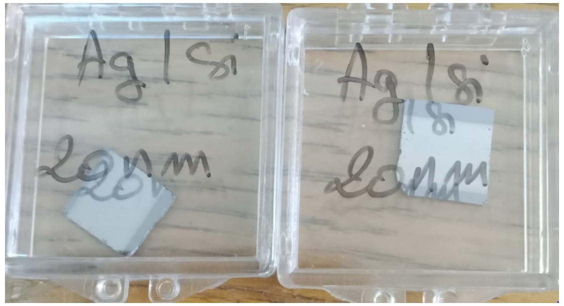


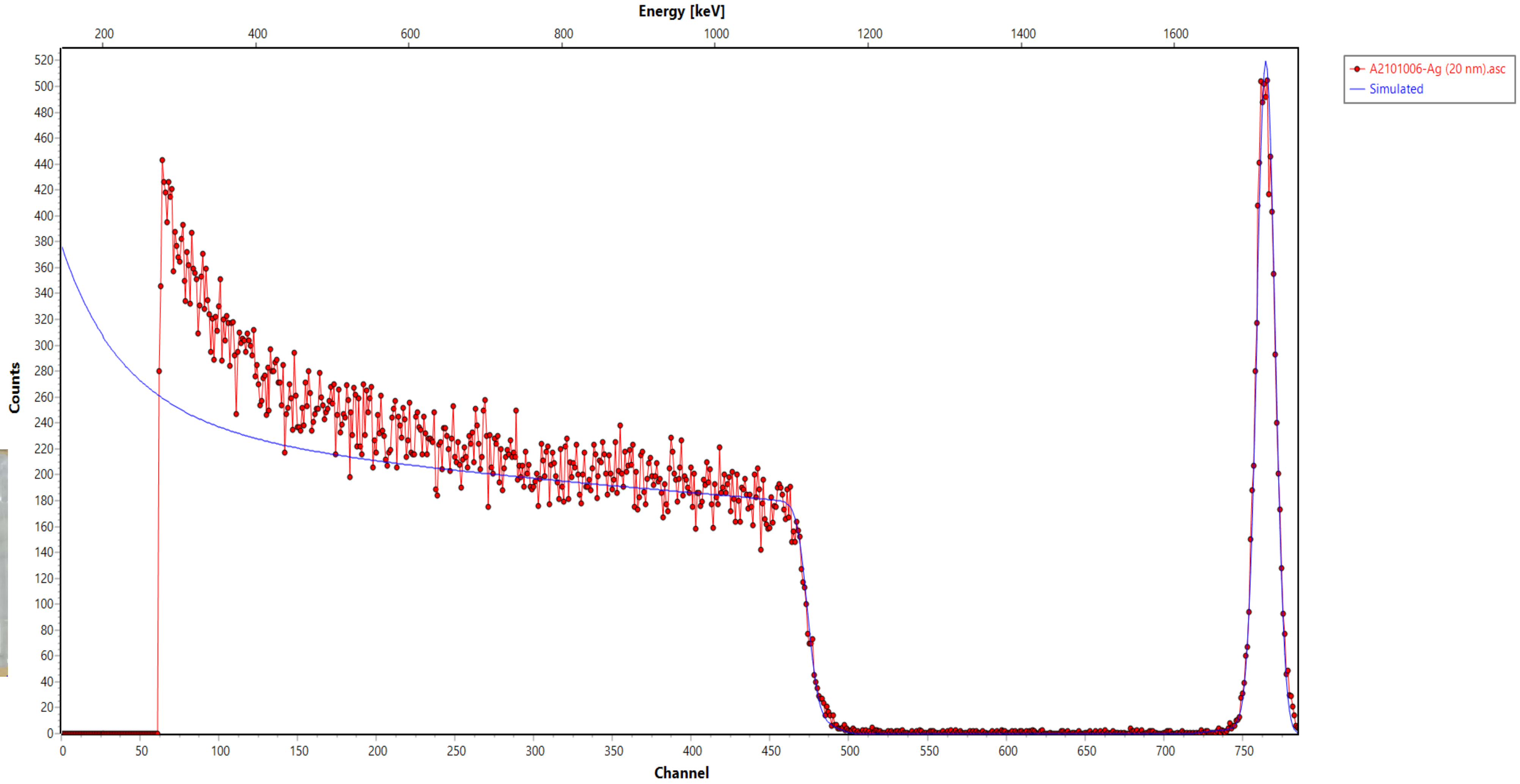


RBS results

1. Silver samples

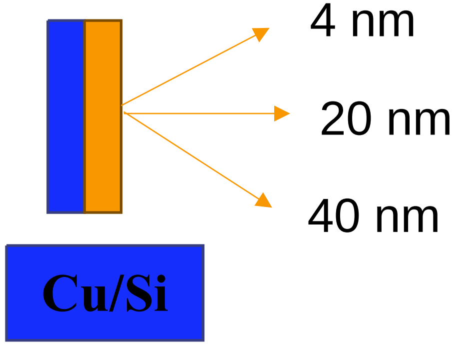


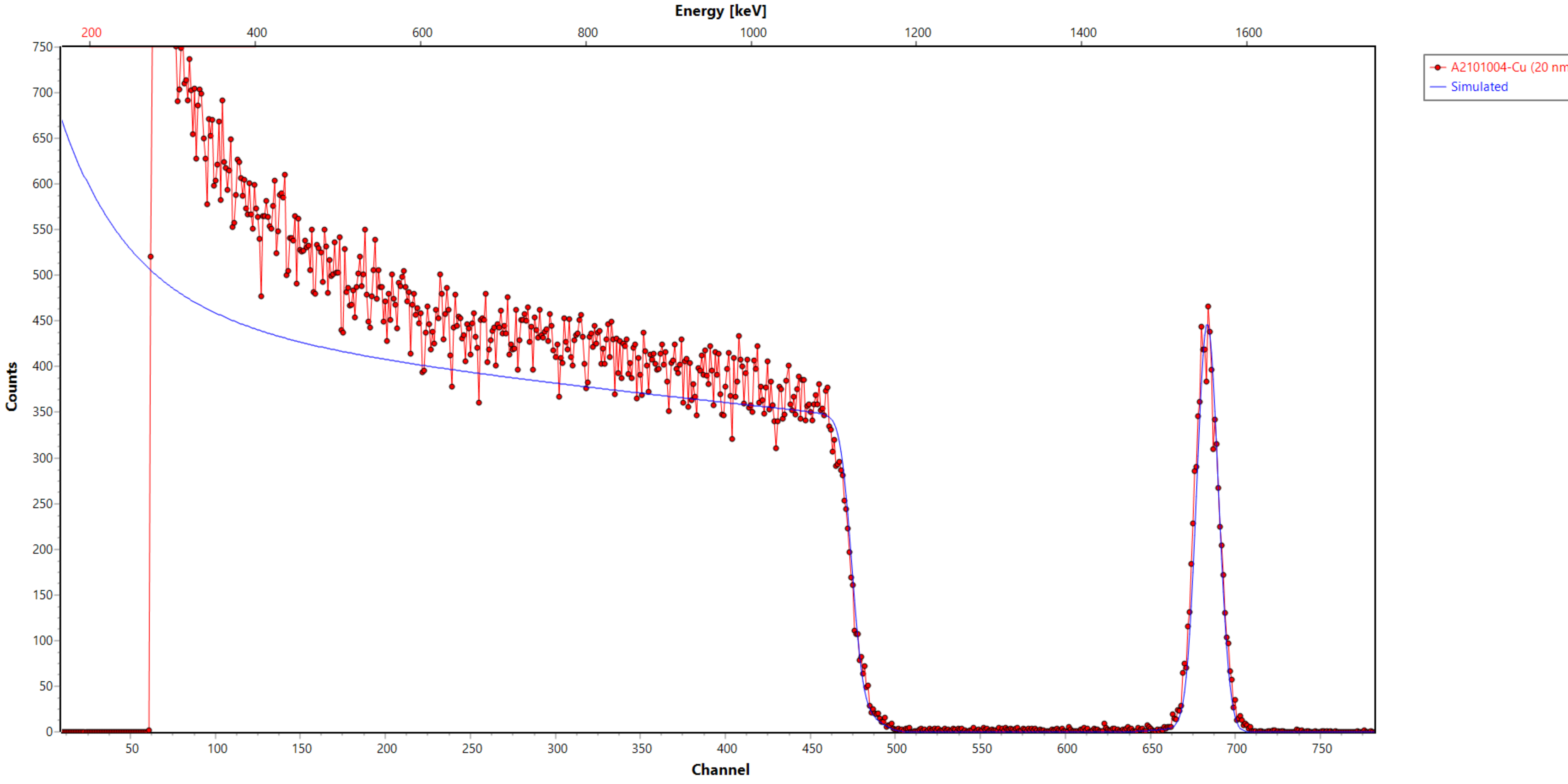




2. Copper samples

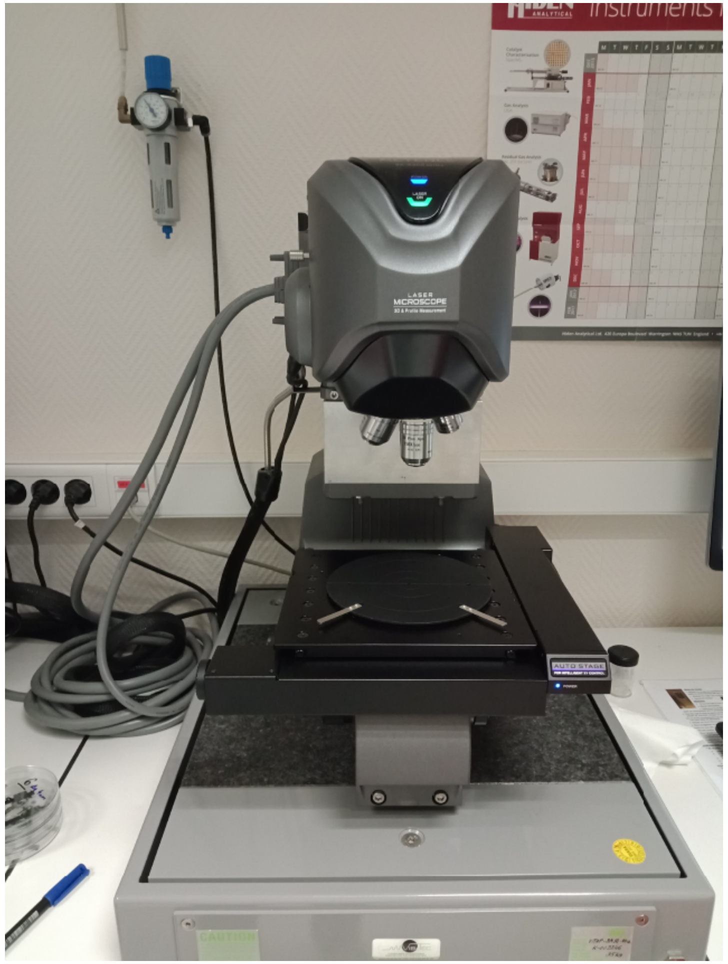
Deposit Thickness





Thickness tolerance < 5 %

Surface analyse using the Confocal



Confocal Microscope –IJCLab-Paris

- **Cu 20 nm**
- Objectif *10 Capture (size 1428µm*1071µm). → (a)
- Objectif*150 (Zoom in the center of the sample). → (b)

(a)

(b)

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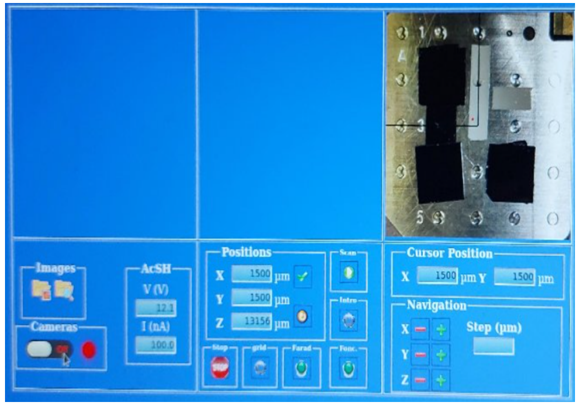
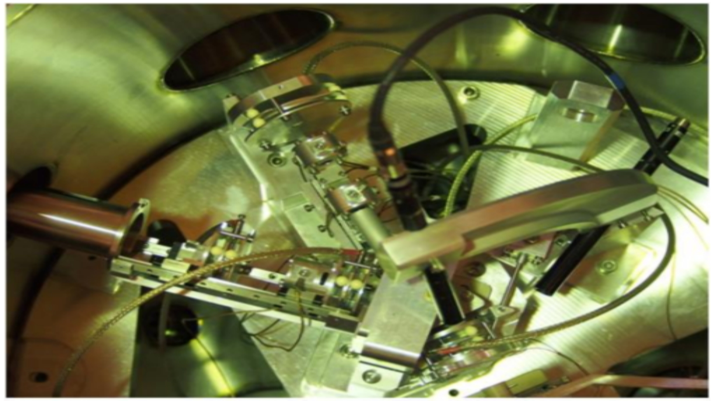
Andoromede facility

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis



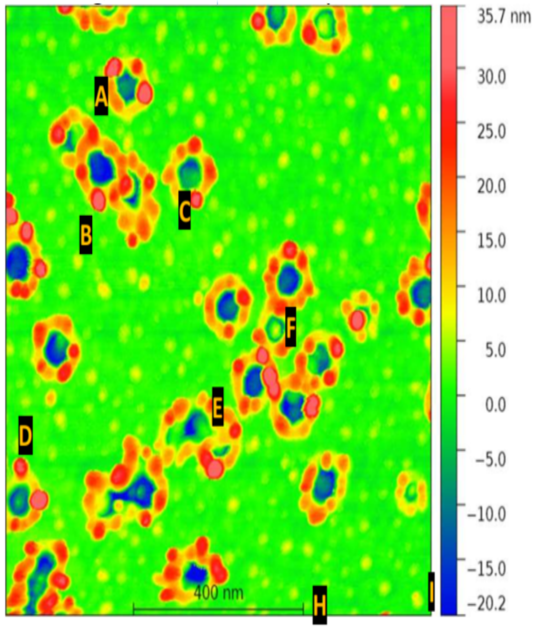


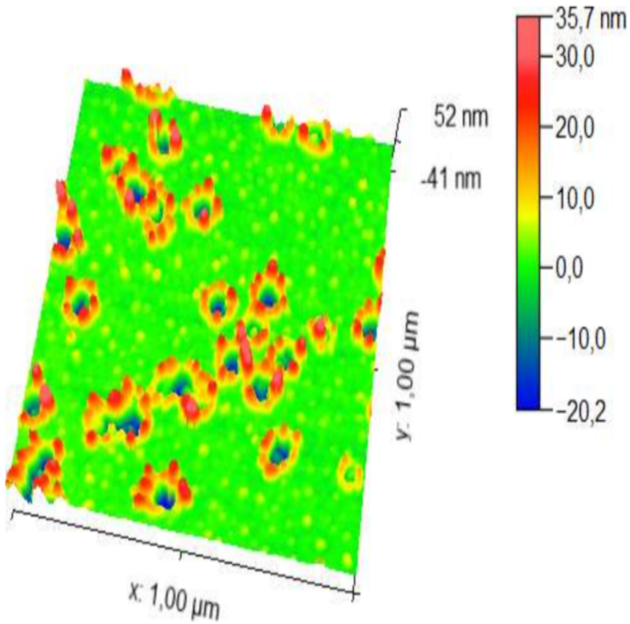
Irradiation using 12 MeV Au_{150}, Au_{400}, Au_{700}

Atomic Force Microscopy

- AFM Park NX 20 Parck Systems (Soleil synchrotron Paris-Saclay Univertsity)

- ✓ **Au_n→Au (4, 20 and 40 nm)**
- ✓ **Au_n→Ag (4, 20 and 40 nm)**
- ✓ **Au_n→Cu (4, 20 and 40 nm)**

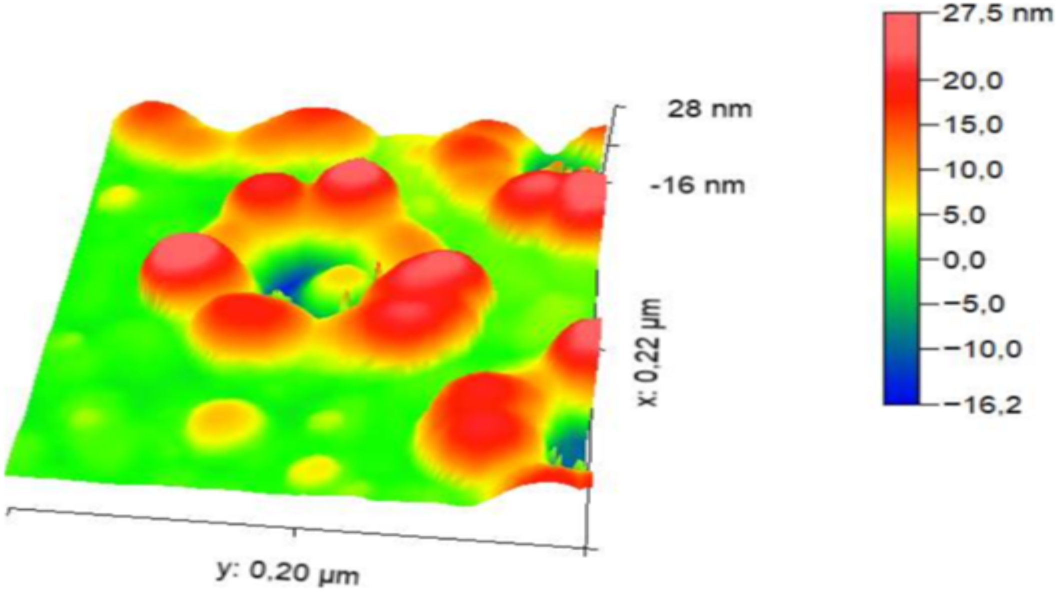


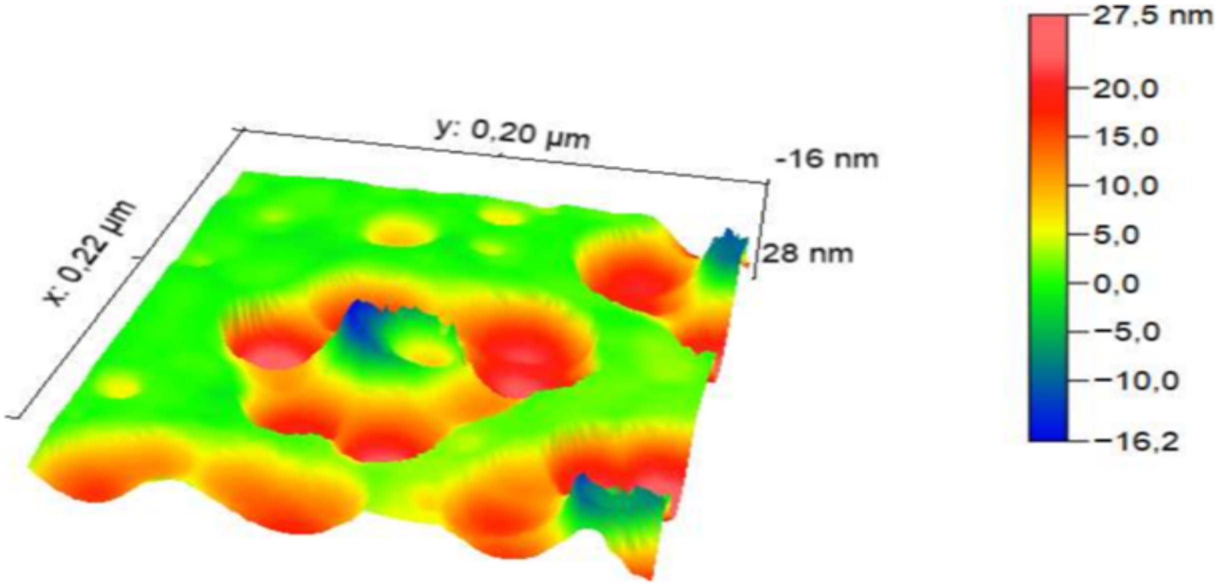


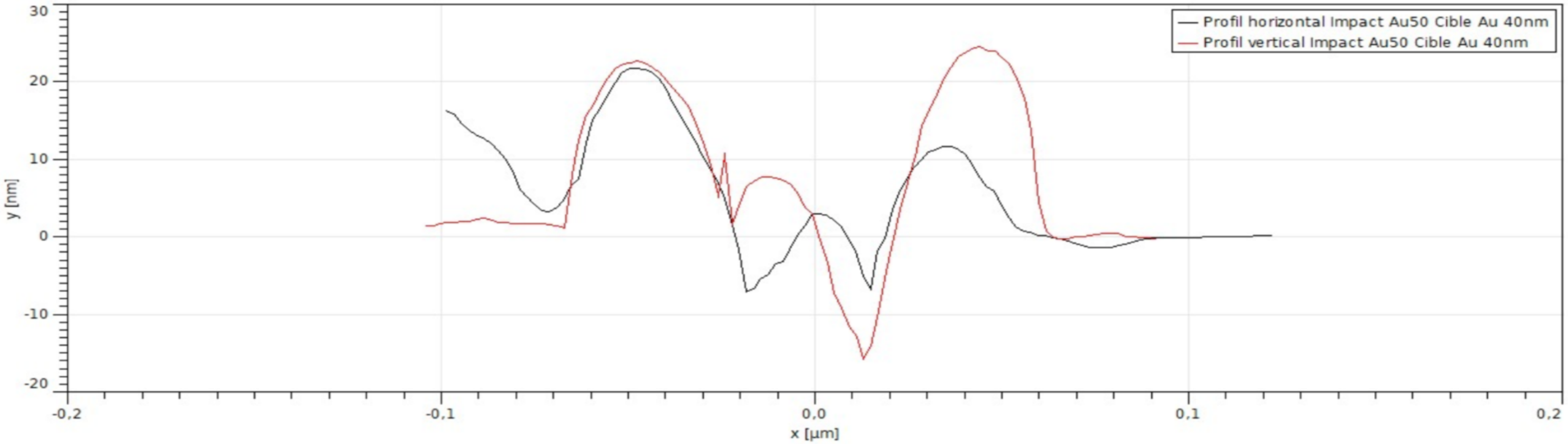
Characteristics of the available gold cluster beams

	Exit Accelerator	Center EVE chamber		
Ions	Energy (MeV)	Beam size (µm)	Intensity (pA)	Dose (ions/cm ^{2})
Au_{150}	6, 12	400	0.5	2.4±0.6 10^9
Au_{400}	6, 12	400	0.5	2.4±0.6 10^9
Au_{700}	6, 12	400	0.5	2.4±0.6 10^9

Individual impacts

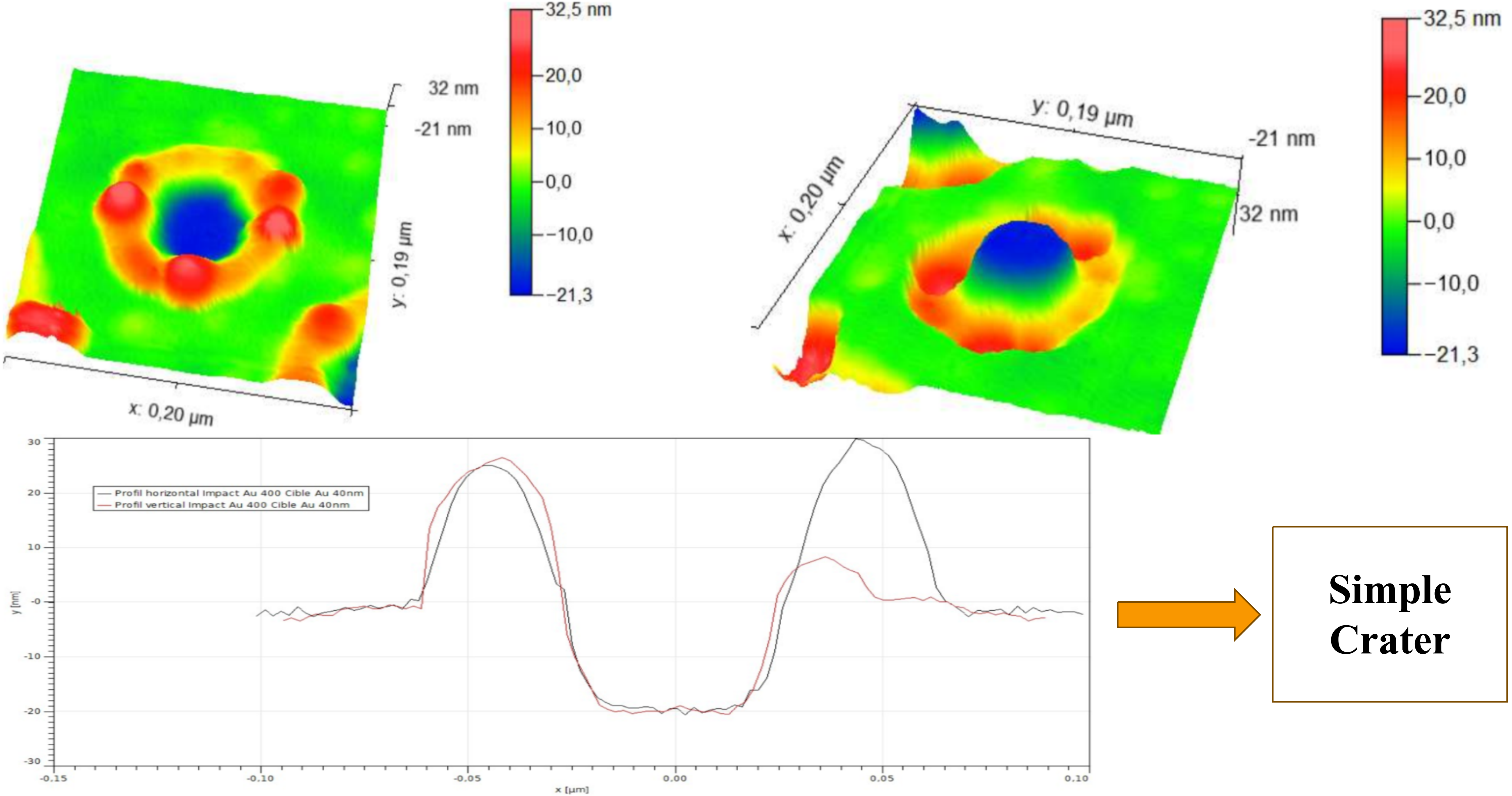






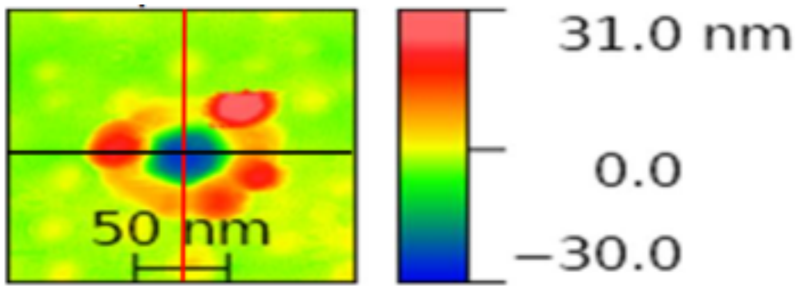
Complex Crater

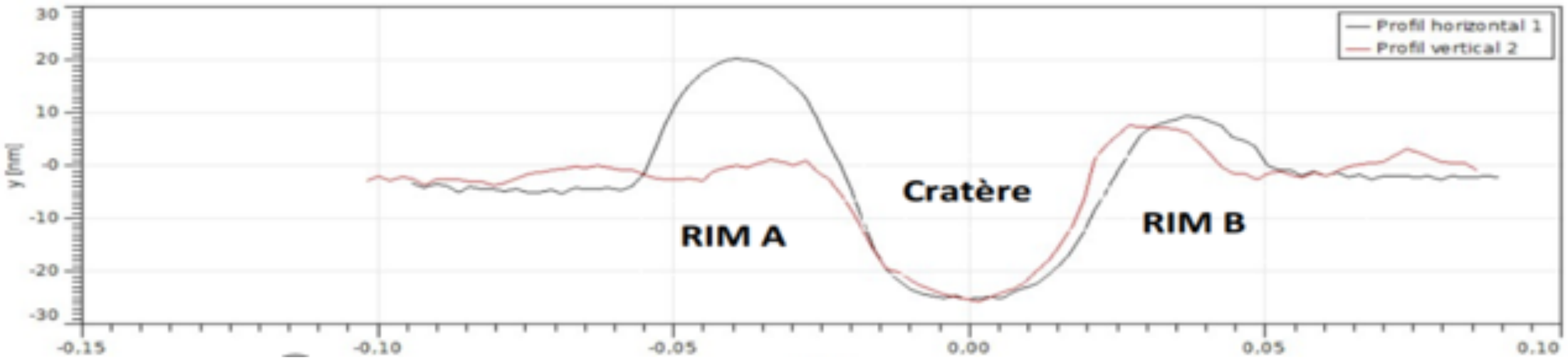
Hillocks

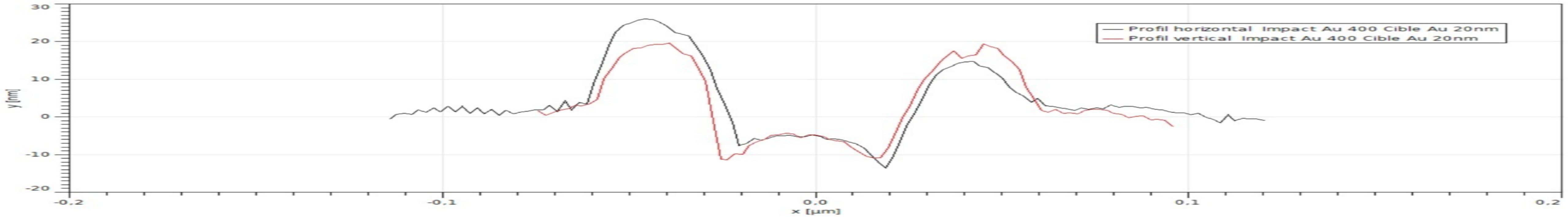


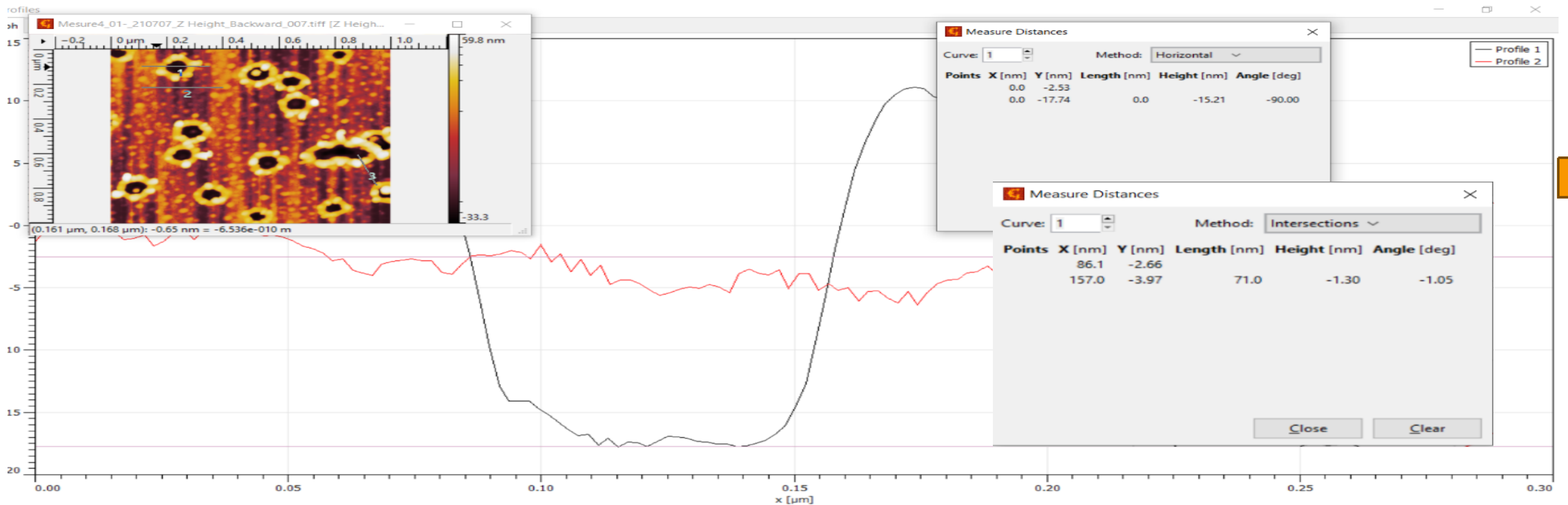
Simple Crater

Crater volume









- ✓ Crater depth
- ✓ Crater diameter

❑ Experimental crater volume

	Rim A		Rim B		Crater					
Trace	height max (nm)	width (nm)	height max (nm)	width (nm)	Depth (nm)	Diameter (nm)	Hillocks	Hilloks height (nm)	Radius (nm)	Crater Volume (nm^3)
A	14	36.6	26	39.6	18.22	58.8	Yes	13	29.4	/
B	10.8	28.5	17.7	34.6	18.5	62.5	Yes	3.3	31.25	/
C	14.8	35.9	6.5	22.6	19.84	55	No	/	27.5	47112.56
D	11	26.4	17.6	27	18.6	58	No	/	29	49117.764
E	3	21.3	9.2	28.4	22.7	44.4	No	/	22.2	35128.64952
F	27.6	34.6	9.25	25.4	19.4	51.1	No	/	25.55	39766.11709
G	9	26.3	19.8	37.4	20.15	45.5	No	/	22.75	32746.69694
H	10	46	13.4	27	21.4	58.2	No	/	29.1	56902.24476
I	15.9	31.7	20.2	34.1	20.6	64.5	Yes	25	32.25	/
				Mean	**20.34**	**52.03**			**26.01**	**43462**

❑ Theoretical crater volume

- **Angle 45°**
- **Energy 12 MeV**
- **Cluster size=400**

Spherical crater :

: free parameter of the model

Cylindrical crater :

,

where

- : velocity of particles behind the shock wave.
- cluster penetration velocity
- : rarefaction time
- : size dependence
- : free parameter of the model (may be considered as a free parameter to quantitatively describe any additional effect during the crater formation process).

Experimental volume

43462

Primary results

- ❑ Reproduce with a free parameter of the model **(=1 ± 0.1)** the experimental data of crater for the irradiations of gold targets.

Future work

- ❑ Study the other samples (silver and copper) → validation of the model.

Conclusions

- ❑ Under gold irradiation → Formation of simple and complex crater
- ❑ Experimental crater has cylindric shape with presence of Rims the crater surface
- ❑ Theoretical model gave a positive results concerning the irradiation of gold samples by gold clusters with different sizes (n=150, 400 and 700) on gold targets.
- ❑ For Confirmation of the **theoretical model validation** at high Energy (12 MeV), the analysis of the other samples is needed.

Acknowledgment

emir&a

Réseau national d'accélérateurs pour l'irradiation et l'analyse des molécules et matériaux

National network of accelerators for irradiation and analysis of molecules and materials, France.

Thank you for your attention