



UNIVERSITÉ
CAEN
NORMANDIE

CiMap

MATERIAL SCIENCE AT CIMAP-GANIL FACILITY

Platform for welcoming interdisciplinary researches at GANIL, CIRIL
Research center on Ions, Materials and Photonic, CIMAP

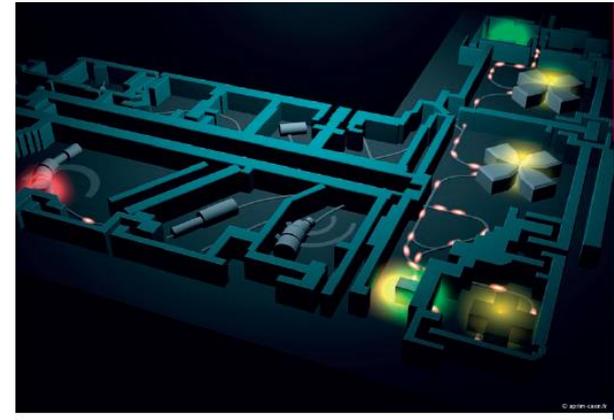
Ciril CiMap

GANIL
laboratoire commun CEA/DSM *spiral2* CNRS/IN2P3

Dr Clara GRYGIEL
IRRSUD beamline coordinator
MADIR group
CIMAP
grygiel@ganil.fr



GANIL campus



GANIL + SPIRAL1

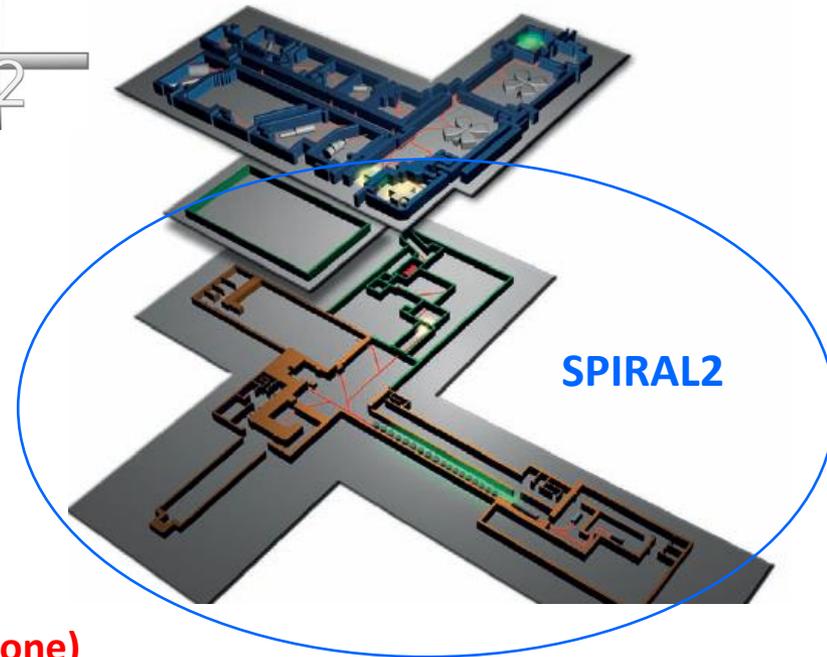


1983: First experiment
 ➤ 38 years of running

Users: 600 physicists (50% foreigners)

Beam: 5600 hours per year (normal)
 + 1000 to 2000 hours in parallel (SME)
 + 1000 hours in parallel (IRRSUD)
 + 2000 hours in parallel
 (ion sources ARIBE)

Total: about 10000 hours per year (normal one)



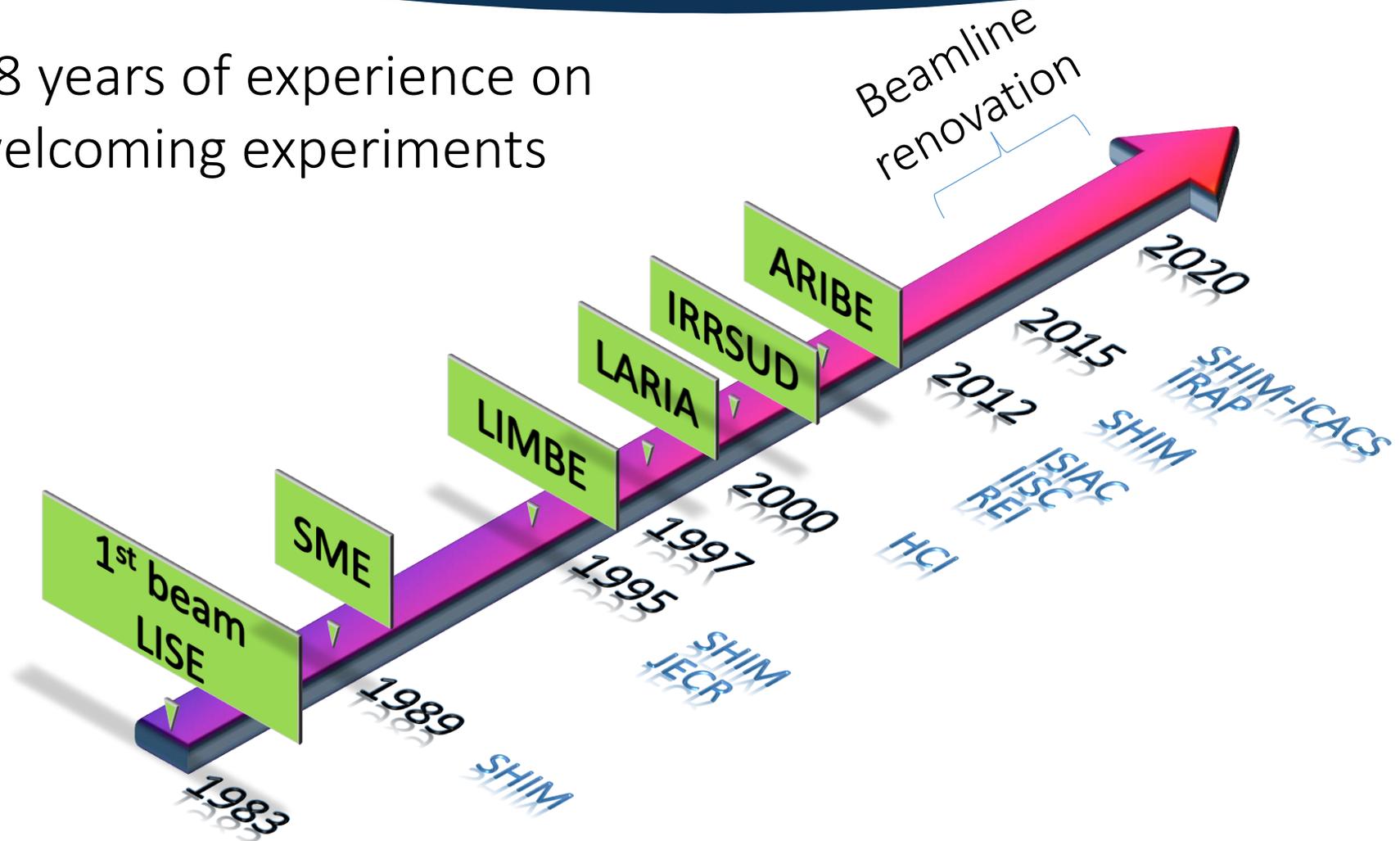
SPIRAL2

Average numbers

CIRIL PLATFORM'S HISTORY

Platform for welcoming interdisciplinary researches at GANIL

38 years of experience on welcoming experiments



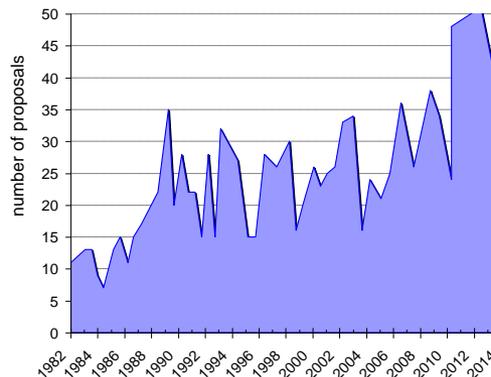
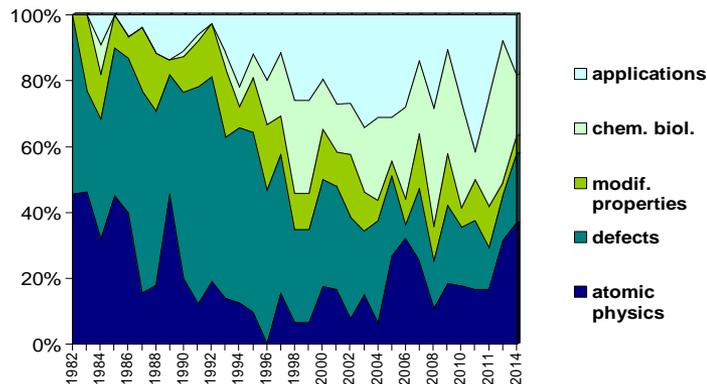
a “local contact structure”
for helping the use of the GANIL beams
in interdisciplinary research



Run the beam lines and equipments
Develop new equipments

Manage the proposal selection process iPAC

Schedule of interdisciplinary beam time (iPAC, RADIATE, EMIR&A)



RESEARCH CENTER ON IONS, MATERIALS AND PHOTONIC, *CIMAP*

<http://cimap.ensicaen.fr/>

CIRIL : local contact structure at GANIL facility

MADIR: Materials , Defects, Irradiation

AMA: Atoms, Molecules, Clusters

ARIA: Radiobiology group

SIMUL: Numerical simulation and theory

+ 3 groups on materials and photonics

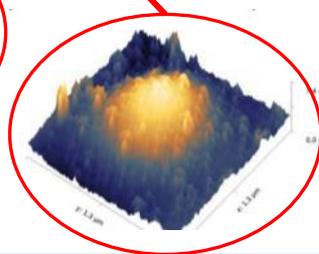
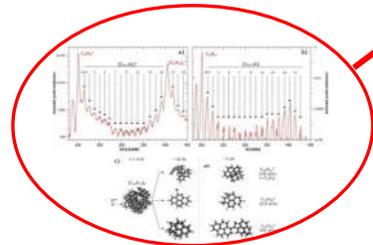
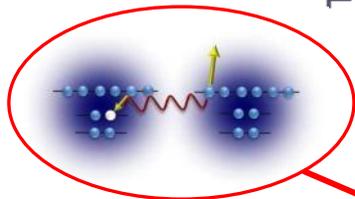
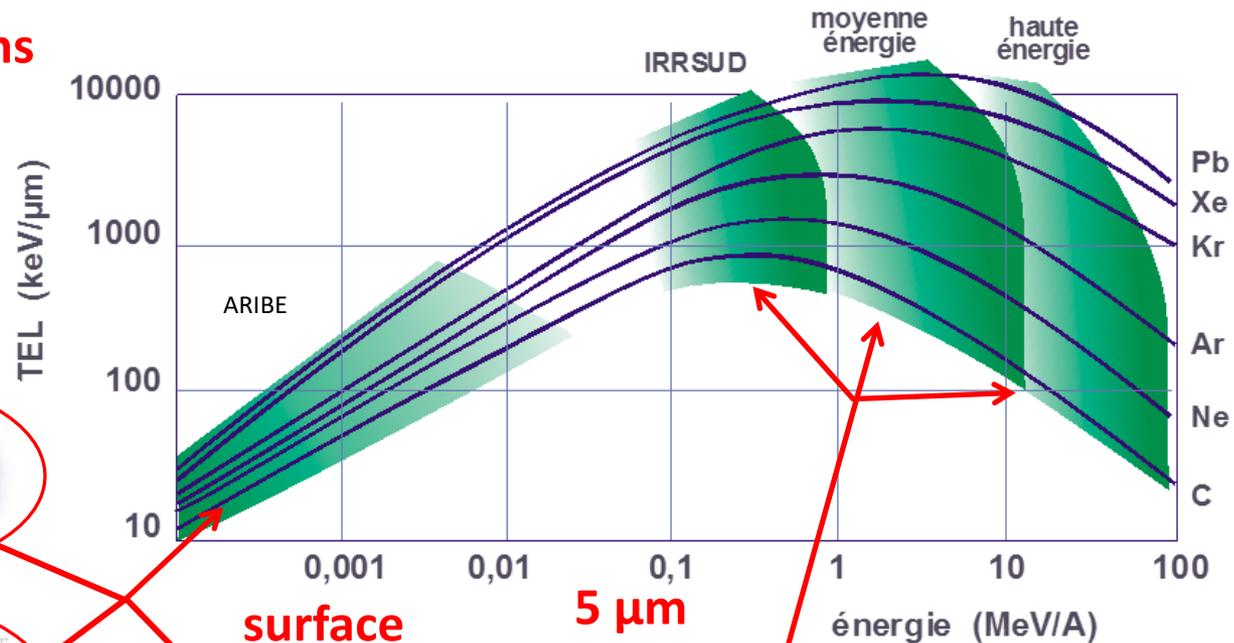


INTERDISCIPLINARY PHYSICS AT GANIL

ENERGY RANGE

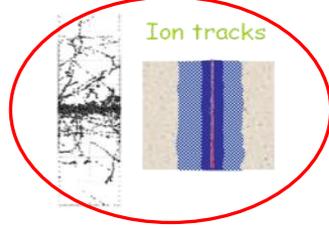
Highly charged ions
Potential energy

Swift heavy ions
Electronic excitations



surface

5 μm
> 10¹⁵ cm⁻²

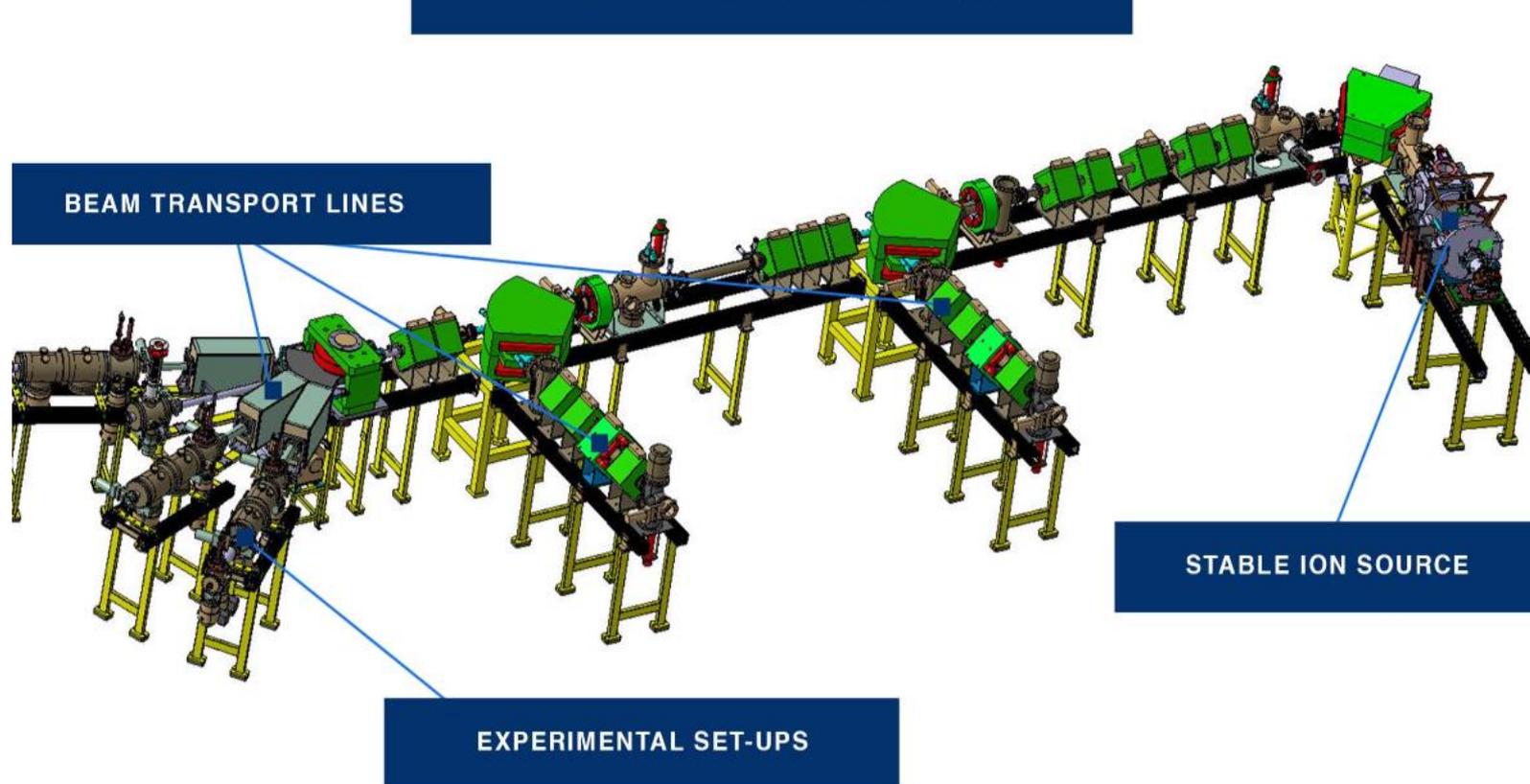


100 μm

1500 μm
10¹³ cm⁻²

LOW ENERGY BEAM FACILITY : ARIBE

at very low energy set-ups in which the ions interact with matter at the atomic scale.

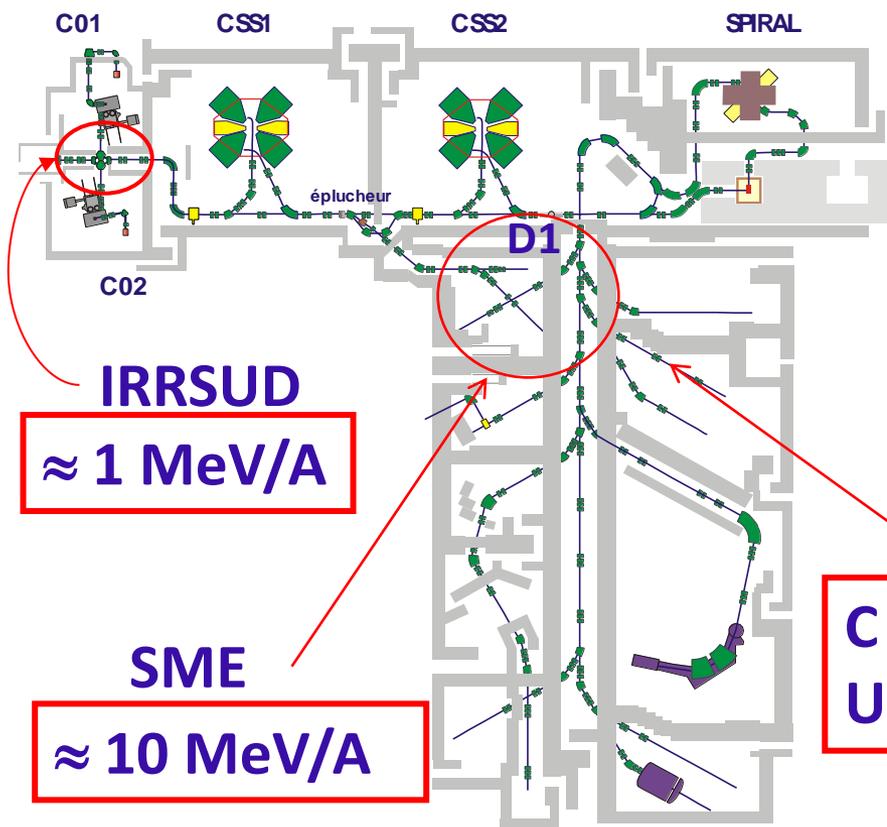


From He^+ to Xe^{31+} ; 20 kV

Credit: C. Feierstein, CIMAP

HIGHER ENERGIES

Heavy ions at higher energies (from C to U)



flux up to $10^{10} \text{ ions.cm}^{-2}.\text{s}^{-1}$

Rp to some hundred microns

Continuous measurement of flux

Beam sweeping up to 30cm^2

SOME NUMBERS

SRIM

$^{36}\text{Ar}^{10+}$
0,98 MeV/A
35 MeV



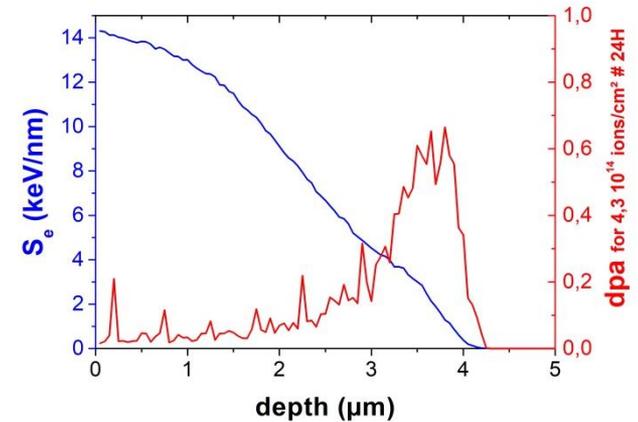
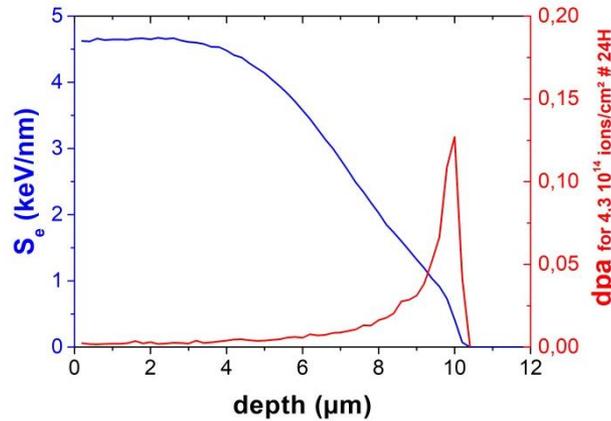
average flux, RT: $5^e9 \text{ ions/cm}^2.s$ at IRRSUD
In 24H : fluence $4,3^e14 \text{ ions/cm}^2$
(Rastered beam on 25cm^2)

C 1,8g/cc

Rp	10,4 μm
Se	4,61 keV/nm
Sn	0,0079 keV/nm
ENSP surface	584

W 19,35g/cc

Rp	4,2 μm
Se	14,24 keV/nm
Sn	0,0417 keV/nm
ENSP surface	341



SOME NUMBERS

SRIM

C 1,8g/cc

W 19,35g/cc

$^{36}\text{Ar}^{10+}$
0,98 MeV/A
35 MeV



average flux, RT: 5^e9 ions/cm².s
In 24H : fluence $4,3^e14$ ions/cm² at IRRSUD
(Rastered beam on 25cm²)



$^{129}\text{Xe}^{23+}$
0,7 MeV/A
92 MeV

Rp	10,4 μm
Se	4,61 keV/nm
Sn	0,0079 keV/nm
ENSP surface	584

Rp	4,2 μm
Se	14,24 keV/nm
Sn	0,0417 keV/nm
ENSP surface	341

Rp	13,09 μm
Se	12,15 keV/nm
Sn	0,077 keV/nm
ENSP surface	158

Rp	4,8 μm
Se	35 keV/nm
Sn	0,45 keV/nm
ENSP surface	78

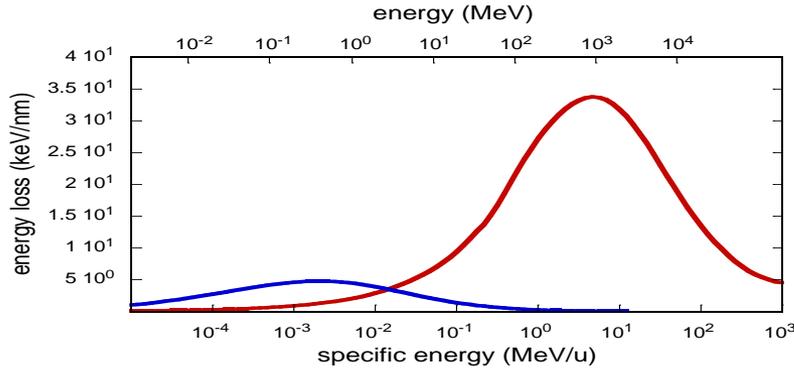
ME: average flux, RT: 1^e9 ions/cm².s in 24H : max fluence $8,6e13$ ions/cm²

HE: average flux, RT: 5^e8 ions/cm².s in 24H : max fluence $4,3e13$ ions/cm²

MATERIAL DAMAGING VS ENERGY LOSSES: GANIL CASE

Nuclear energy losses

Electronic Energy losses



GANIL ions: high energy ions

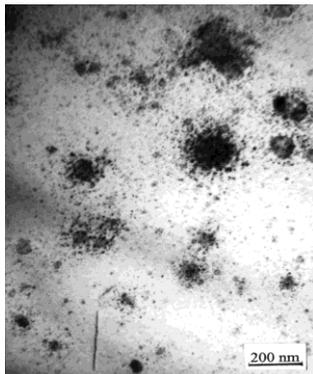
Energy losses by electronic excitations

Fast process: $10^{-17}\text{sec} \leq t \leq 10^{-10}\text{sec}$

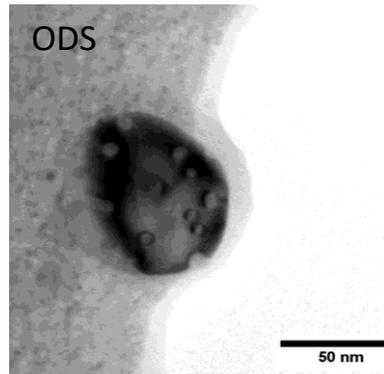
Key parameter: **Electronic stopping power**
(dE/dx)_e or S_e

Anisotropic effect

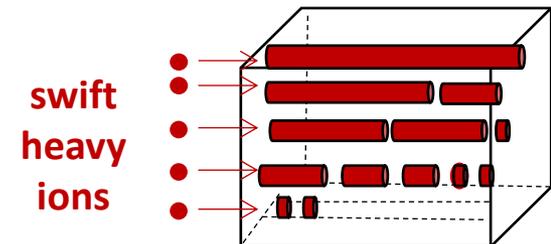
⇒ latent track formation



Elastic collisions



Electronic interactions

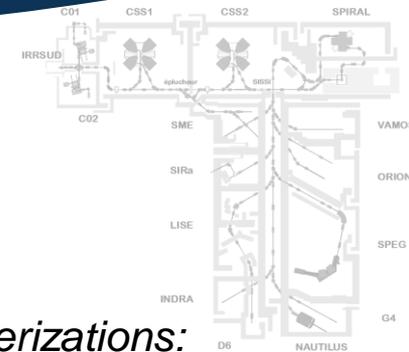


Monnet et al, J. Nucl. Mater 424 (2012) 12

IN-BEAM CONDITIONS

Ions: C to U *multicharged*

Energy: keV up to 0.3 – 100 MeV/A



Online setups for material characterizations:

Beam scanning

Temperature
8 - 1300K

Incidence
90° - 0°

Gas partial pressure

+ Nuclear materials

XRD

ALIX IRRSUD

Absorption spectro

FTIR
UV-Vis



CASIMIR 15-300K
CESIR RT
DETAIL up to 1400K

Emission spectro

SPORT IRRSUD Time-solved 8-300K

Gas release

FTIR
Mass spectroscopy

Sputtering

TOF or catchers
AODO (X-Y TOF SIMS in situ LEED Auger)

External user setups

ex: *MiniMecaSiC* (CEA-DEN) or Raman (Orléans)

GAS RELEASE



GRAL

FTIR absorption of the gas mixture
Small hydrocarbons (up to 3 Carbons)

→ Track creation at high stopping power in organic compounds

Picq et al, NIM B 151 - 76 (1999)



CIGAL

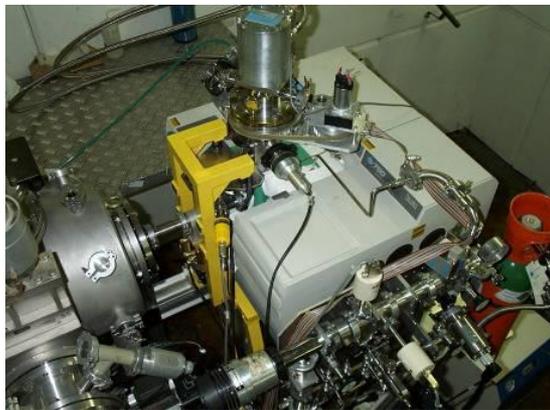
mass spectrometry
 H_2 formation, O_2 consumption, CO, CO_2

→ Gas production during nuclear waste storage of organic compounds contaminated with actinides as Pu (gloves, ...)

Dely et al, NIM B 236 - 145 (2005)

ABSORPTION SPECTROSCOPY

Vibrational spectroscopy: **FTIR**, $8000 - 400 \text{ cm}^{-1}$ Electronic spectroscopy: **UV-vis** $200 - 900 \text{ nm}$



CASIMIR

15 K - 300 K

- Nitrides
- Polymers, fundamental mechanisms
- Effects in solids relevant to astrophysics and astrochemistry

Sall et al, EPL 102- 26002 (2013)

Balanzat et al, NIM B 105 - 1 (1995)

Pilling et al, Astronom & Astrophys 509 – A87 (2010)



CESIR

Room temperature

Melot et al, NIM B 208 - 345 (2003)



DETAIL

High temperature & FTIR
Up to $1100 \text{ }^\circ\text{C}$

CHESOI

Special low volume chamber for rare gas atmospheres ($^{18}\text{O}_2$)

EMISSION SPECTROSCOPY

SPORT

Iono luminescence

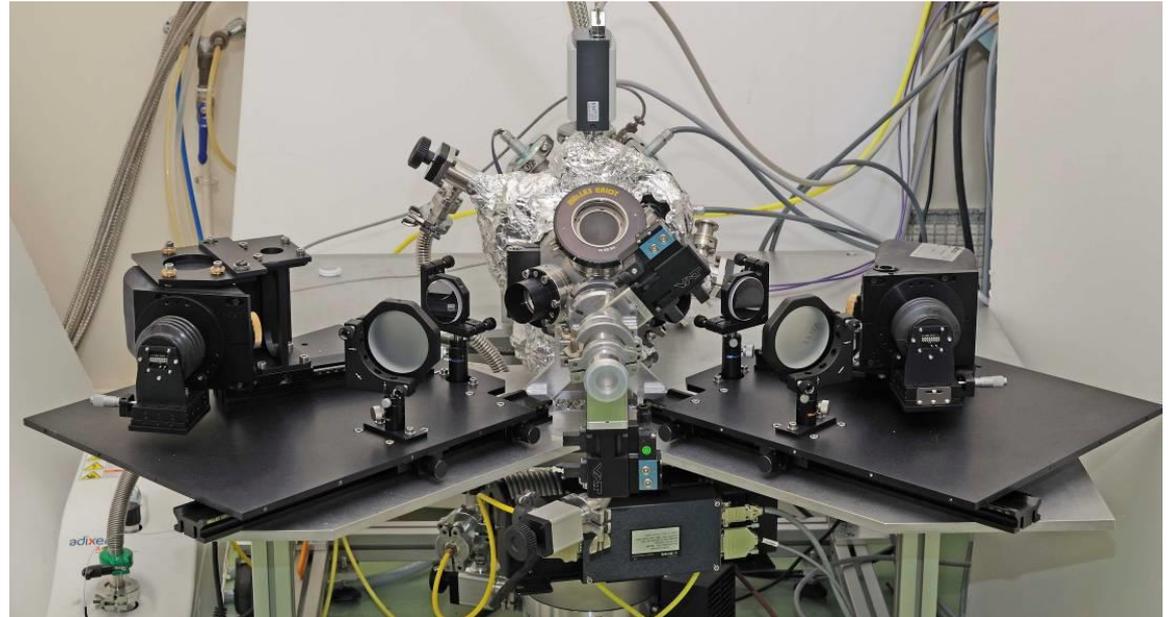
UV-Vis 200 - 800 nm

400 ps resolution

Single ion - n photons

8 K - 300 K

≈ UHV $1 \cdot 10^{-9}$ mbar



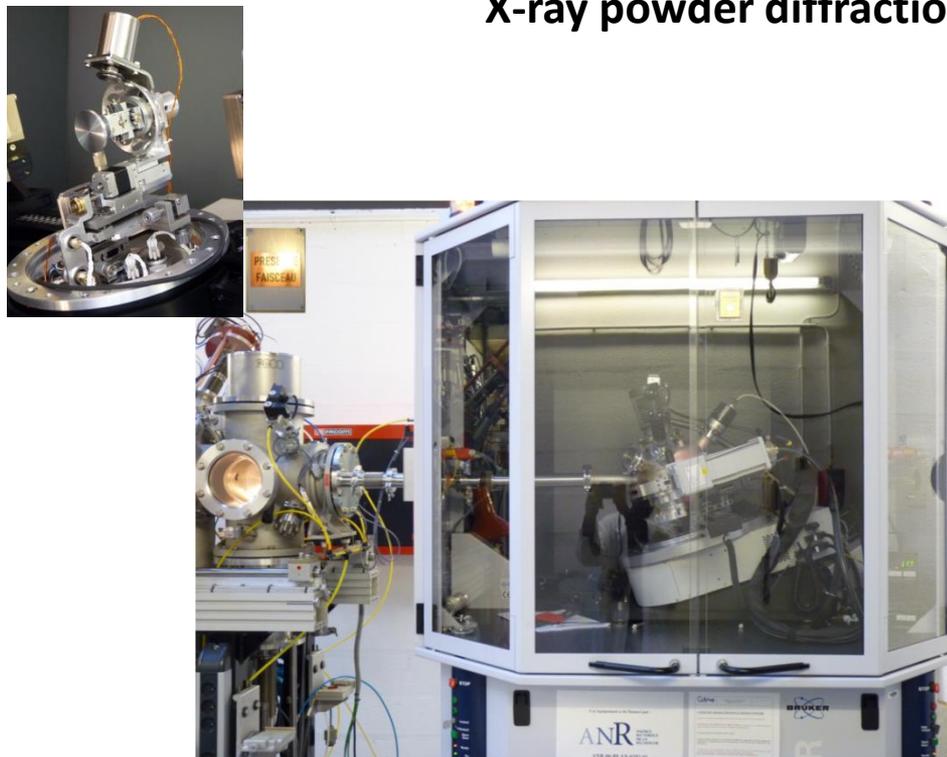
→ *Radiation-induced luminescence ageing of a fast plastic scintillator (BC-400)*

(Important scintillator for hadrontherapy)

Gardes et al, NIM B 297 – 39 (2013)

STRUCTURAL - MICROSTRUCTURAL ANALYSES

X-ray powder diffraction



“ALIX” setup

Only on IRRSUD

grazing incidence diffraction
simultaneous or sequential

→ Phase transition & structural modifications

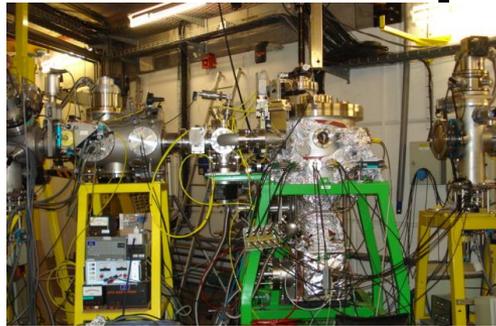
→ Kinetics studies

Grygiel et al, RSI 83-013902 (2012)
Sattonnay et al, Acta Mat (2013)
Grygiel et al, Acta Mat 140, 157 (2017)

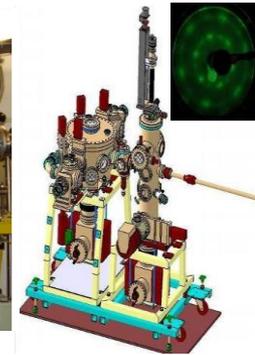
CHEXPIR, on ME not anymore available

SPUTTERING

High energy



Low energy



AODO
(X-Y TOF SIMS)

UHV
In-situ LEED - Auger

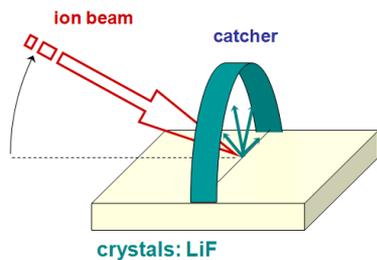
Hijazi et al, NIM B 269 – 1003 (2011)

Time of flight

charged particles

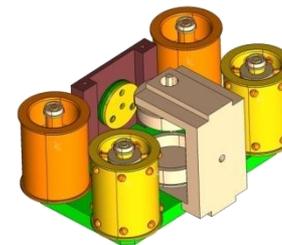
Catcher

neutrals



Ex-situ analysis by RBS, ERDA, ...

Toulemonde et al, NIM B 212 – 346 (2013)



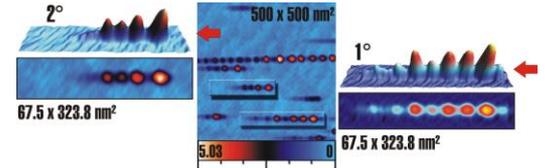
In-situ Auger

Salou et al, RSI 84-095115 (2013)

USER'S INSTRUMENTATION



In-situ UHV AFM



→ Creation of multiple nanodots by single ions, foldings on 2D

Akcoeltek et al, Nature Nanotech 2 - 290 (2007)

H Lebius, M Schleberger Nature Nanotech 2, 290(2007), New J Phys 10-053007(2008)

E Gruber et al, J. Phys.: Condens. Matter 28, 405001 (2016); 30, 285001 (2018)

Collab Prof M. Schleberger, Uni. Duisburg-Essen, Germany

In-situ traction on SiC fibers

Jankowiak et al, NIM B (2013)



PIE TECHNIQUES

- High Resolution X-Ray Diffraction
- Transmission/Scanning Electron Microscopy and FIB
- Atom Probe Microscopy
- Raman spectroscopy
- Resistivity measurements at RT
- and many others...



Equipments for material synthesis are also available :

- Uniaxial press
- Classical furnace with $T_{max} \approx 1200^{\circ}\text{C}$
- atmosphere controlled furnace with $T_{max} \approx 1600^{\circ}\text{C}$ with primary vacuum or N_2 or Ar
- Chemistry laboratory for polymer synthesis
- and many others....

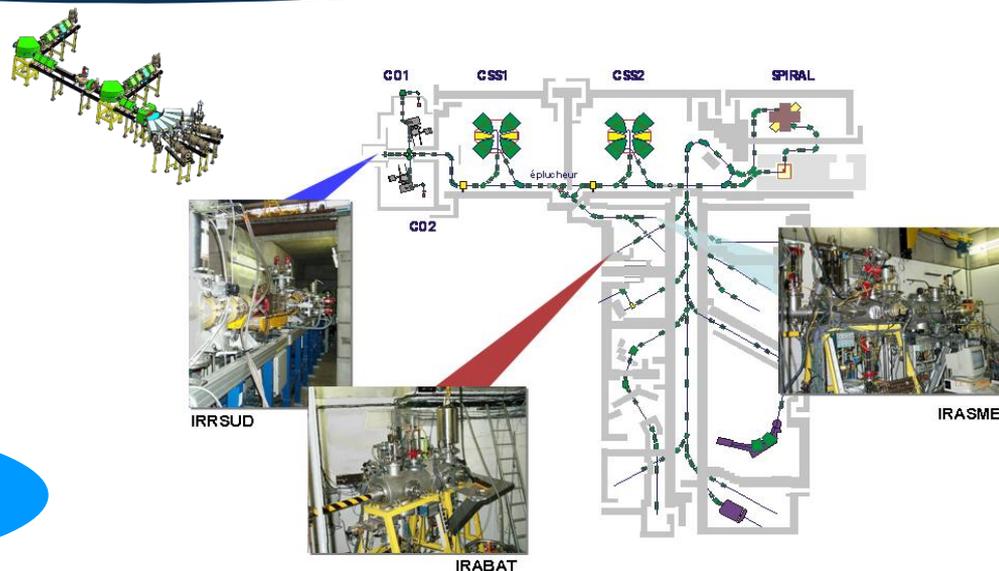
SUMMARY OF CIMAP-GANIL TOOLS

**Ion beams from eV to GeV
Carbon to Uranium**

Broad range of flux

from 8K up to 1500K

ion/target incidence down to 0,2°



Online characterizations: gaz release analysis, ToF, absorption and emission spectroscopy, XRD, AFM, resistivity....always in progress

Ex-situ characterizations: AFM, Raman, TEM, XRD

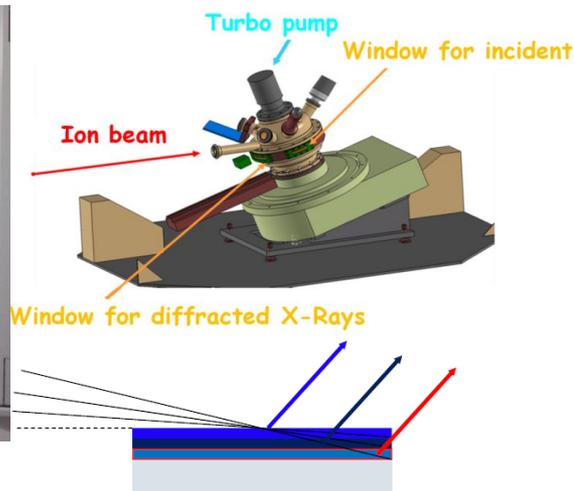


HIGHLIGHT ON MATERIALS : IN-SITU & EX-SITU

In-situ ALIX X-Ray Diffractometer



IRRSUD beamline



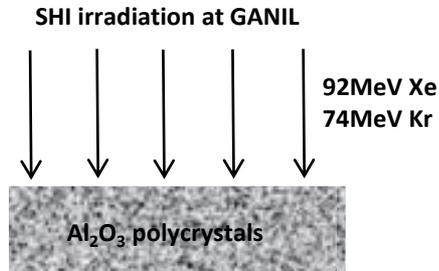
- Vacuum and RT
- theta-theta geometry (# polycrystals)
- Classical or grazing diffraction

Ex-situ DISCO X-Ray Diffractometer



- Post-irr experiments only
- High resolution geometry
- In-plane geometry
- 2D detector

IN-SITU XRD ON AL2O3 POLYCRYSTALS



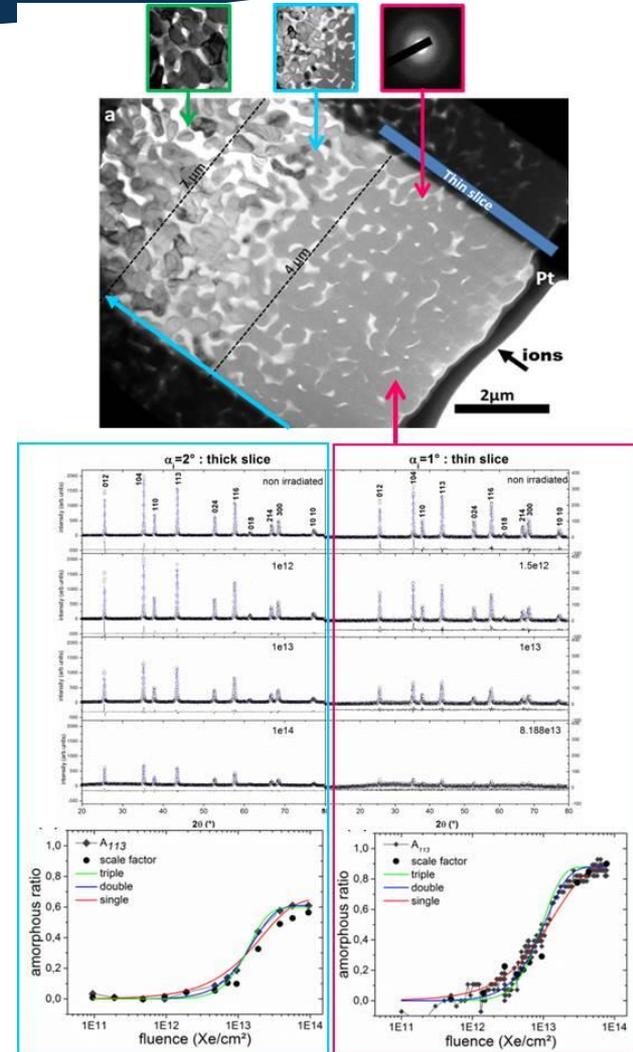
In-situ XRD
In-situ optical absorption
Ex-situ TEM

$S_e > S_{eth}$ Amorphization from surface by ion overlapping

S_n Coloured centres (oxygen vacancies F⁺)

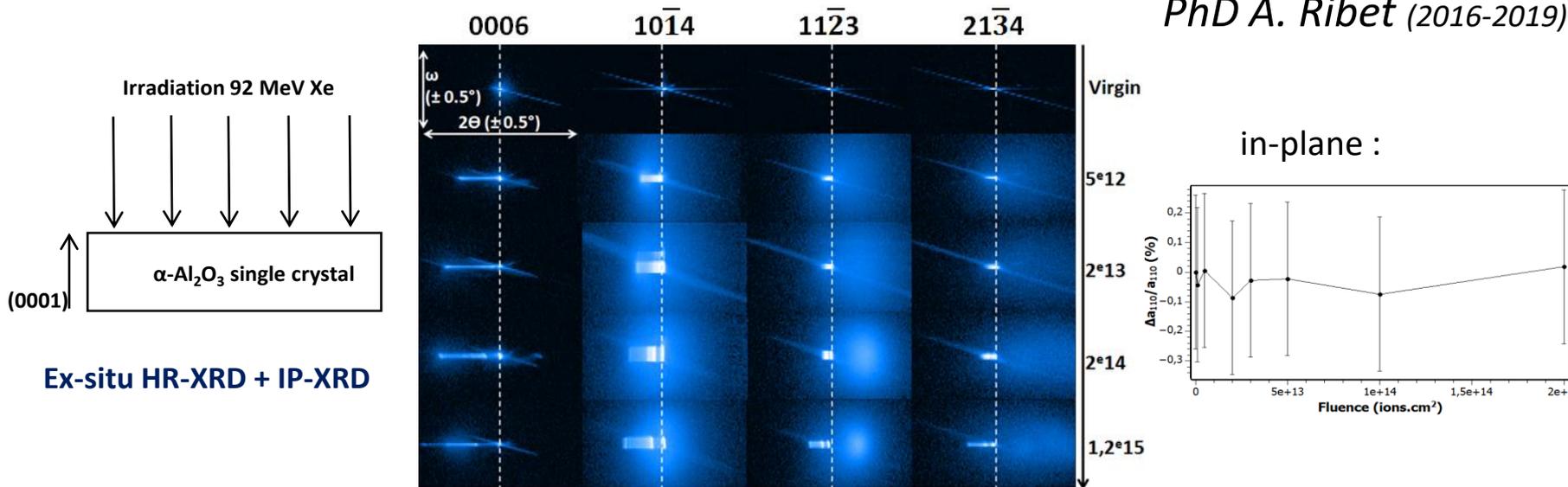
$S_e + S_n$ Swelling of crystalline unit-cell

Grygiel et al, *Acta Materialia* **140**, 157-167 (2017)



EX-SITU XRD ON (0001)-AL₂O₃ CRYSTALS

PhD A. Ribet (2016-2019)

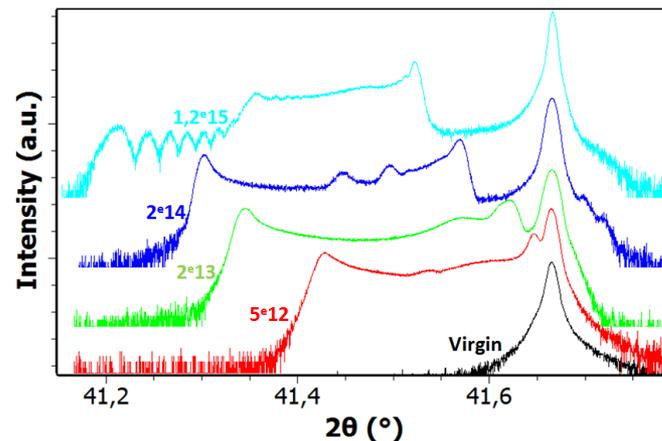


Anisotropic strain

Only out-of-plane in c , none in-plane in a

No relaxation on 8 μm of projected range

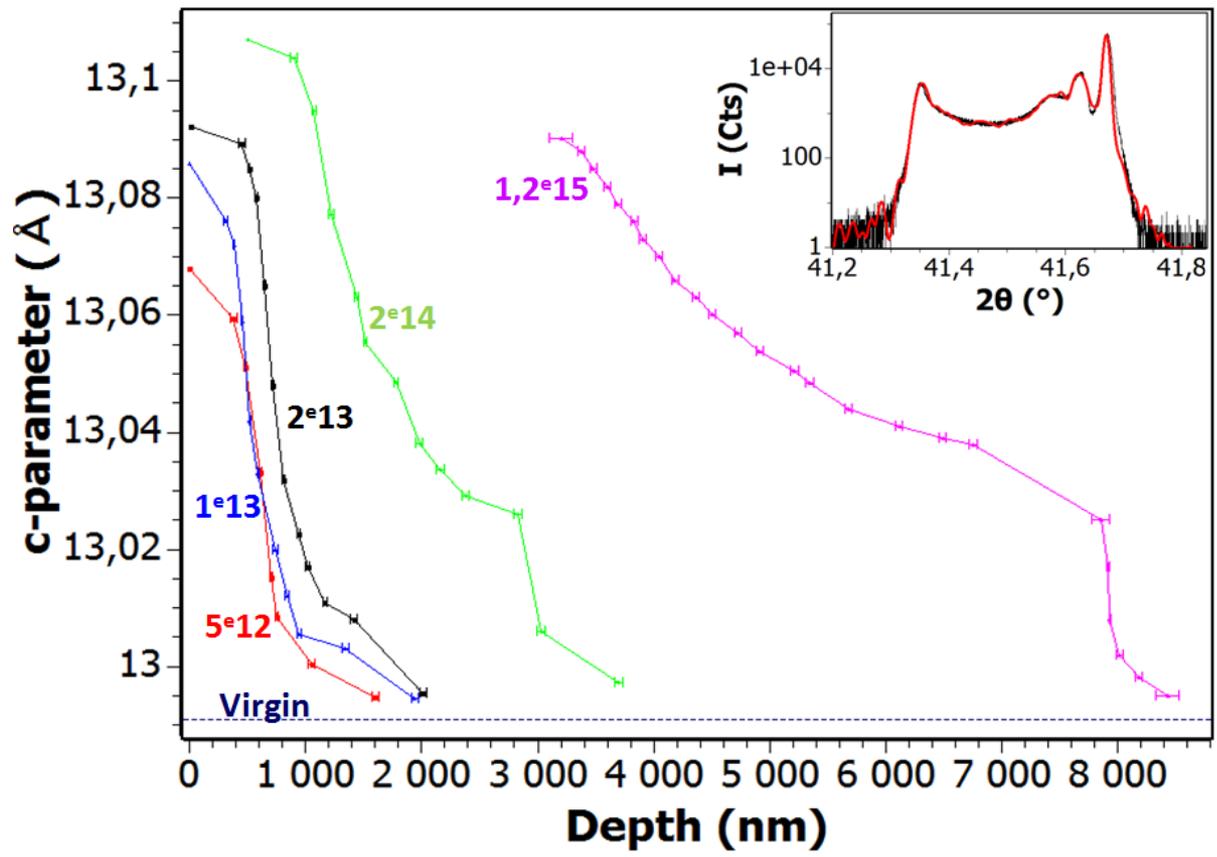
Single impact kinetics on strain



Ribet et al, NIM B 445, 41 (2019)

DAMAGE DEPTH PROFILE

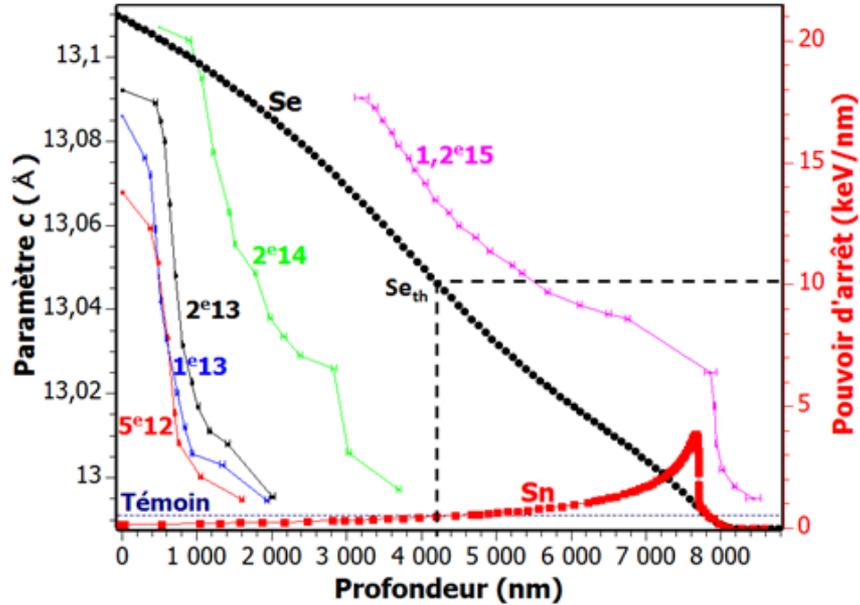
(0001)-Al₂O₃ by 92MeV Xe



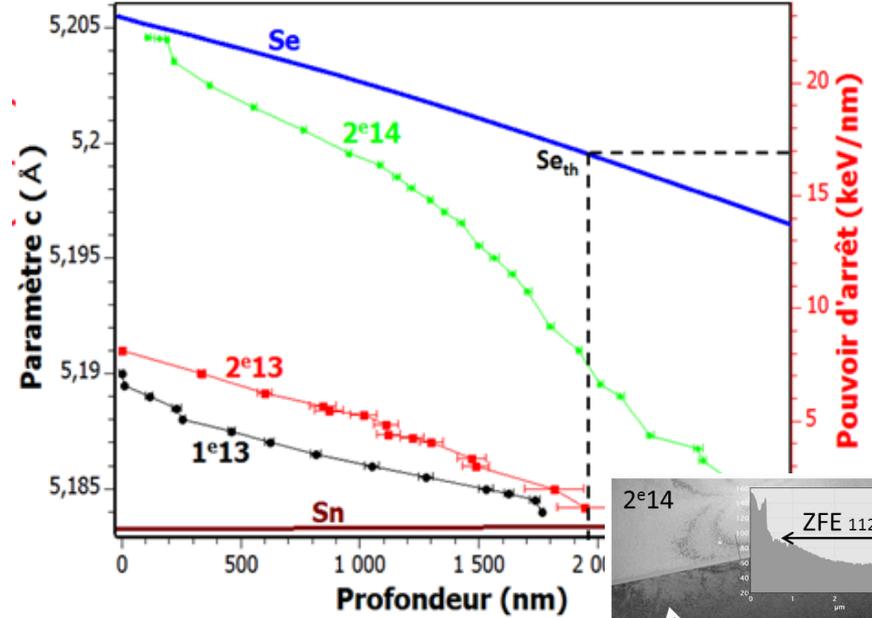
Ribet et al, NIM B 445, 41 (2019)

DAMAGING - COMPARISON

(0001)- Al₂O₃



(0001)-GaN

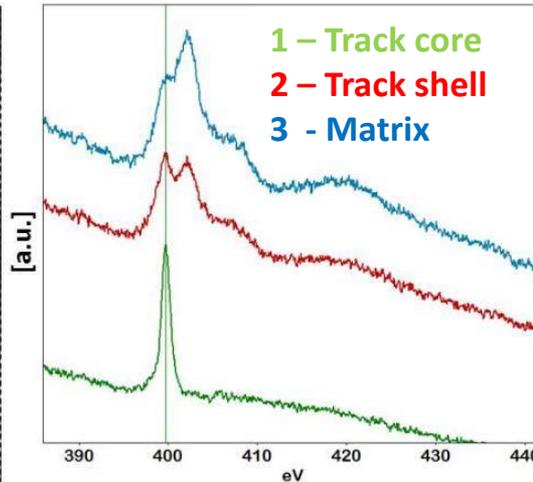
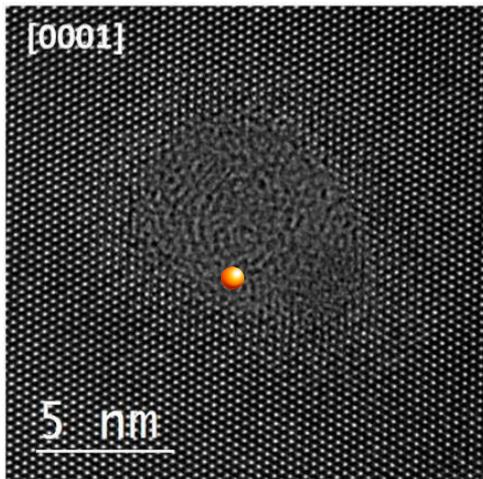
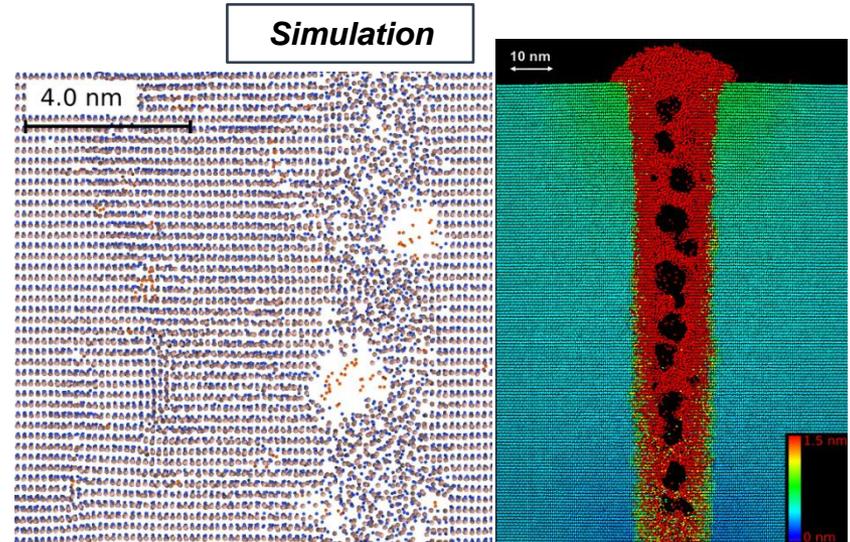
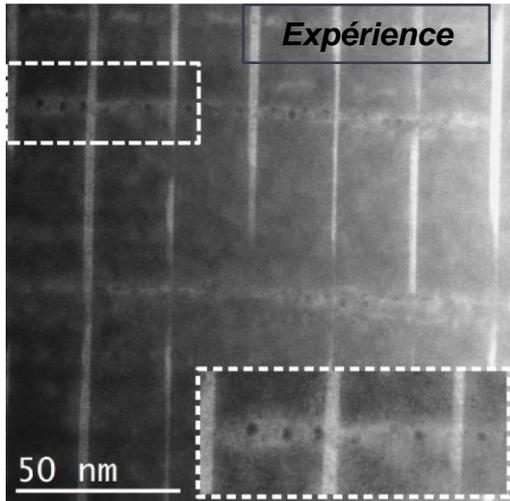


→ Al₂O₃ damaging from surface, GaN along the trajectory

Ribet et al, NIM B 445, 41 (2019), PhD thesis A. Ribet (2019)

FROM PROFILE TO TRACK STRUCTURE

Track structures: GaN, InGaN



Collaboration:

University of Helsinki, Finland
IST Lisbon, Portugal



Formation of N₂ bubbles inside tracks

Recrystallization by track overlap

Sequeira et al, Comm Phys 4, 51 (2021)

Mattei et al, Materialia 15 - 100987 (2021)

CiMap

CIMAP-GANIL FACILITY

4 Beam lines/4 Energy ranges

- Access through call for proposals (iPAC, EMIR&A or RADIATE)
- Accepted proposals: beamtime during 3 years in backlog
- 2022: 4/5 months of beamtime
- Beamline renovation work: IRRSUD 2022, ME 2023, HE 2024

- Beamtime free for scientific collaborations
- PIE: various costs depending on techniques (mainly for MEB/FIB/TEM)

CIRIL-CIMAP PLATFORM STAFF

Scientific Leader:

J. Rangama

Technical Leader:

F. Ropars

+

Coordination:

C. Grygiel: IRRSUD

P. Rousseau: ARIBE

A. Méry: SME-HE

+

Experimental area

manager:

T. Madi : D1 et IRRSUD

C. Feierstein: ARIBE

+

Technical staff:

T. Been

F. Dardy

Y. Doublet

J-M. Ramillon

F. Ropars

A. Sineau

Administration:

S. Colineaux

L. Debaermaker

Scientific staff:

A. Benyagoub

P. Boduch

A. Cassimi

J-Y Chesnel

F. Chevalier

A. Domaracka

E. Gardes

C. Grygiel

S. Haghdoost

H. Lebius

A. Mery

I. Monnet

Y. Ngonu

J-C. Pouilly

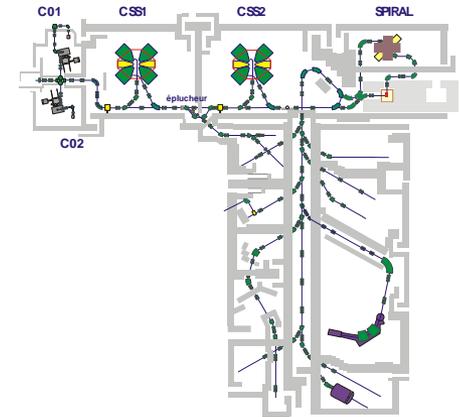
J. Rangama

H. Rothard

P. Rousseau

M. Sall

V. Vizcaino



Thank you for your attention

+ Strong support of GANIL's technical staff

<http://cimap.ensicaen.fr/>

CiMap