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Direct observation of bulk and surface effects caused by SHI impacts

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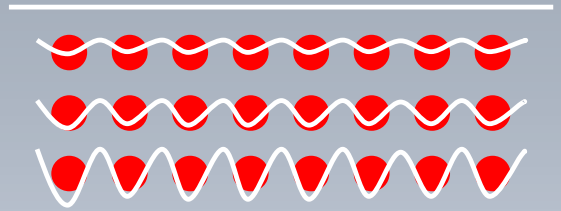
Centre for High Resolution Transmission Electron Microscopy
Gamtoos Mouth
Blue Horizon Bay
Clarendon Marine
NEWTON PARK
WALMER
Port Elizabeth International Airport
20 Dec 2:00pm
M15
M12
M9
M7
M18
© 2015 Google

- Double Cs corrected JEOL ARM 200F
  - TEM resolution 110 pm (65 pm)
  - HAADF STEM resolution 80 pm (65 pm)
  - Gatan GIF Quantum EELS spectrometer
  - Large area EDS detector (Oxford) (simultaneous EDS – EELS)
- JEOL 2100
  - EDS
  - EELS
- FEI Helios Dual beam (TEM specimen prep)
- JEOL 7001F
  - EDS, WDS, EBSD, TKD

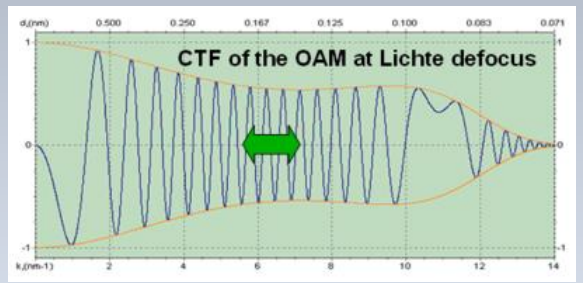
TEM: Only technique with sufficient spatial resolution for single track investigation

Only if you are careful!

- Projection, projection, projection… z ≈ 300 – 1000 times lateral resolution!
- Low statistics
- Extremely sensitive to specimen preparation (artefacts?)
- Difficult to produce high quality foils less than ~30 nm in thickness

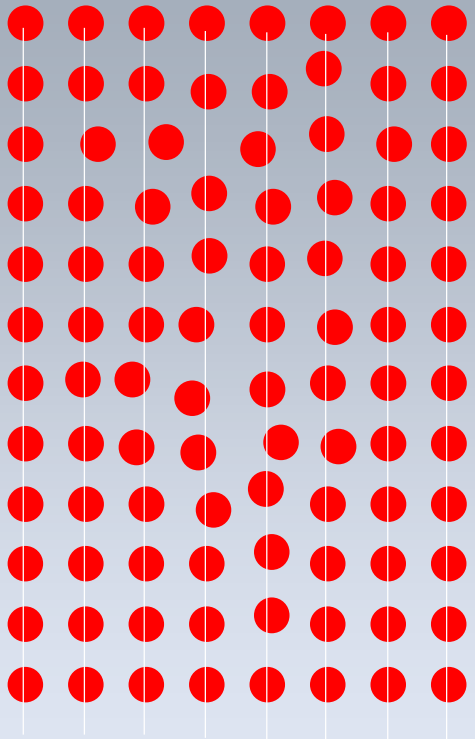


Periodic crystal



Black magic

Detector

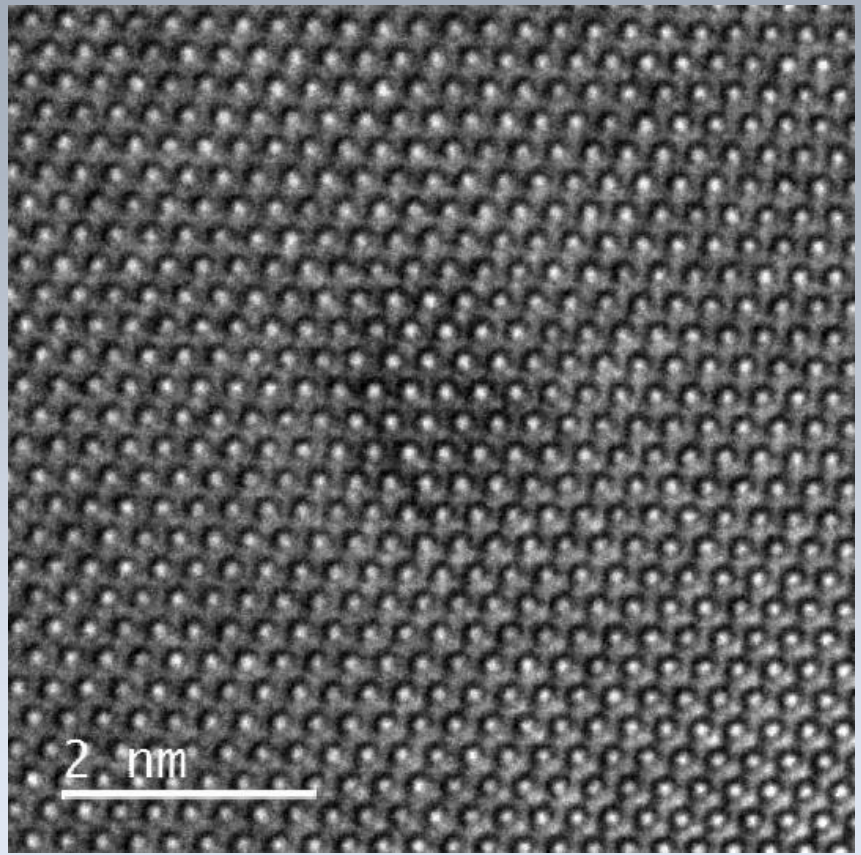


~ 30x – 100x

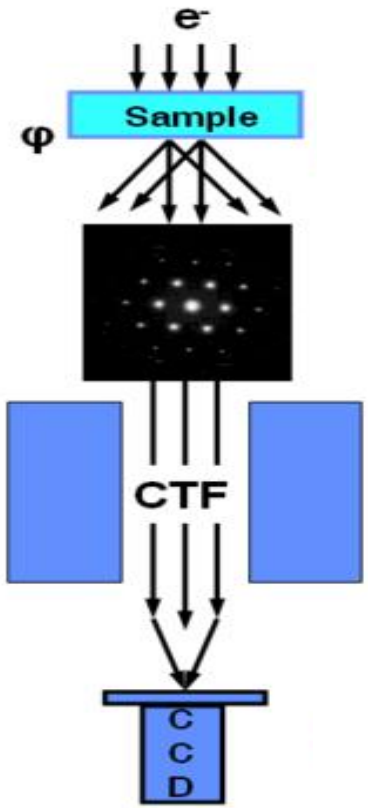
Typical x-section FIB lamella ($1x10^{11}$ cm^{-2})

10 um

Through focal series (1 nm step)

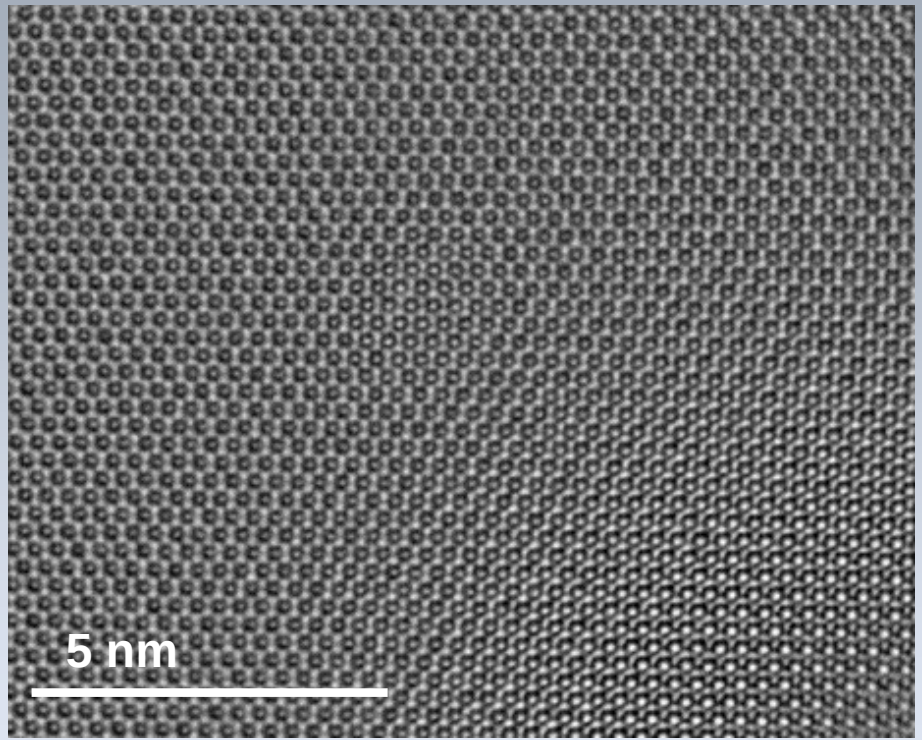


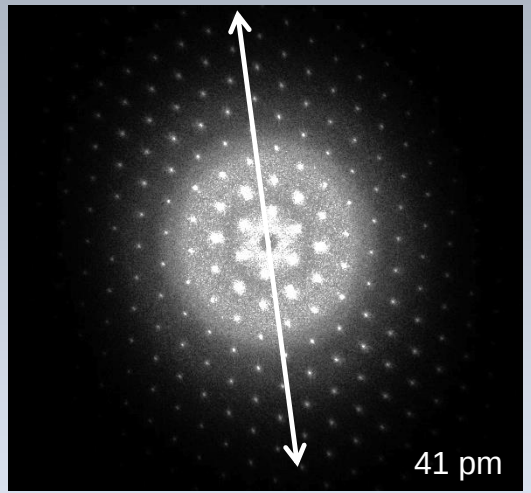
Reconstructing exit electron wave

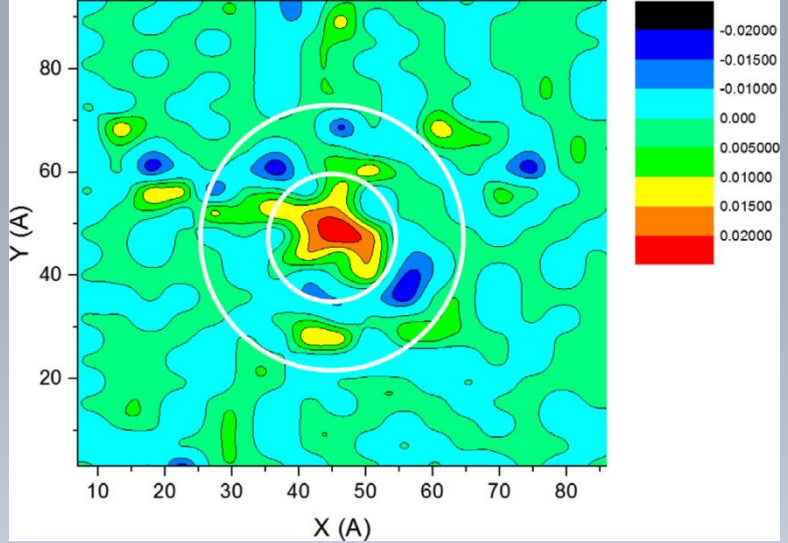


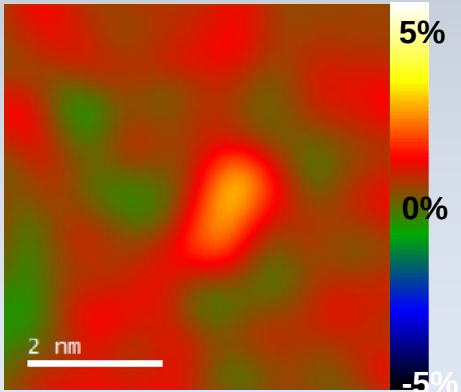
W.M.J. Coene, A. Thust, M. Op de Beeck, D. Van Dyck, Ultramicroscopy 64 (1996) 109
A. Thust, W.M.J. Coene, M. Op de Beeck, D. Van Dyck. Ultramicroscopy 64 (1996) 211

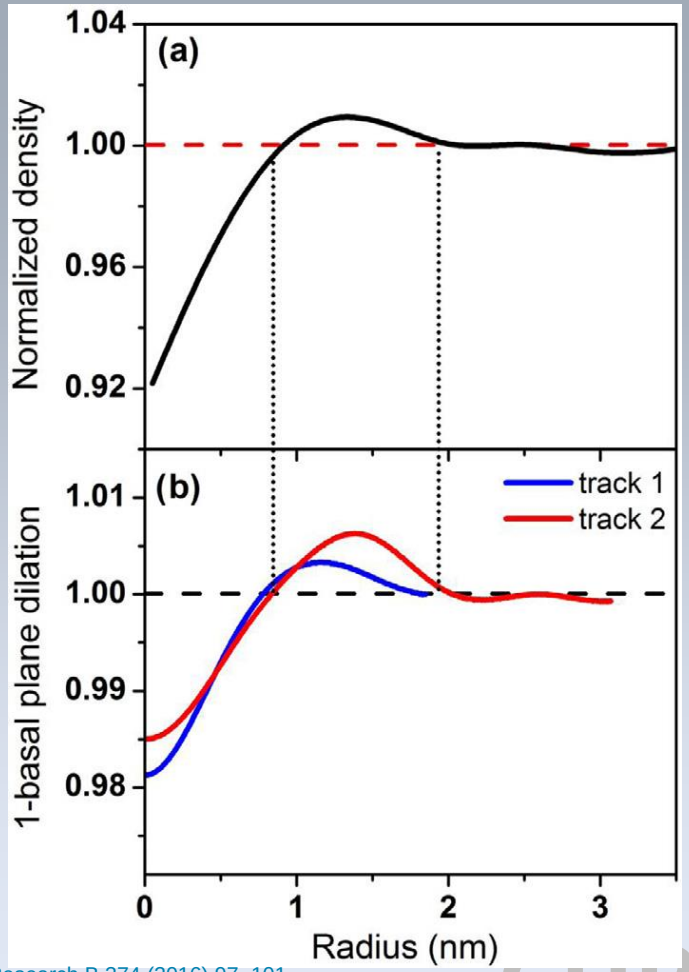
Reconstructed electron exit wave (phase)



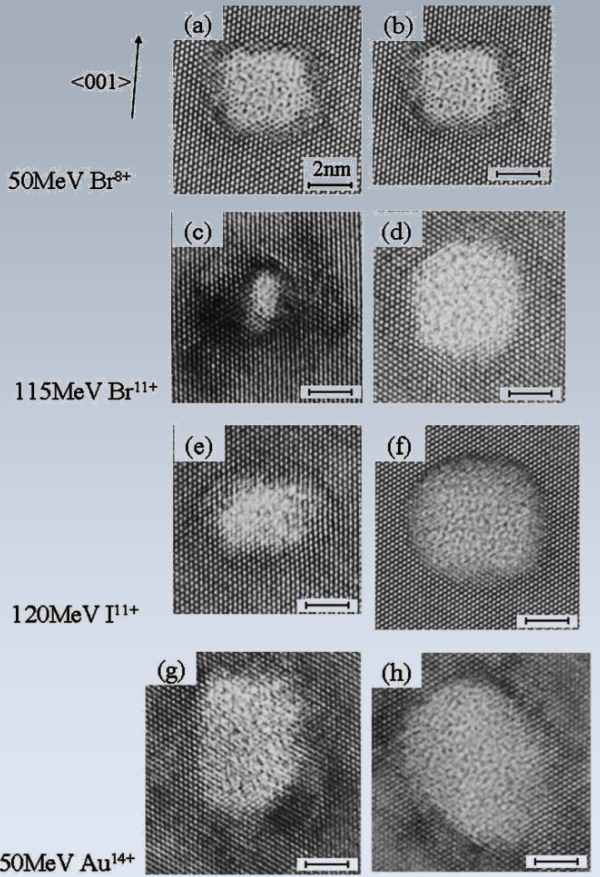



Y (A)
X (A)
-0.02000
-0.01500
-0.01000
0.000
0.005000
0.01000
0.01500
0.02000


5%
0%
-5%
2 nm

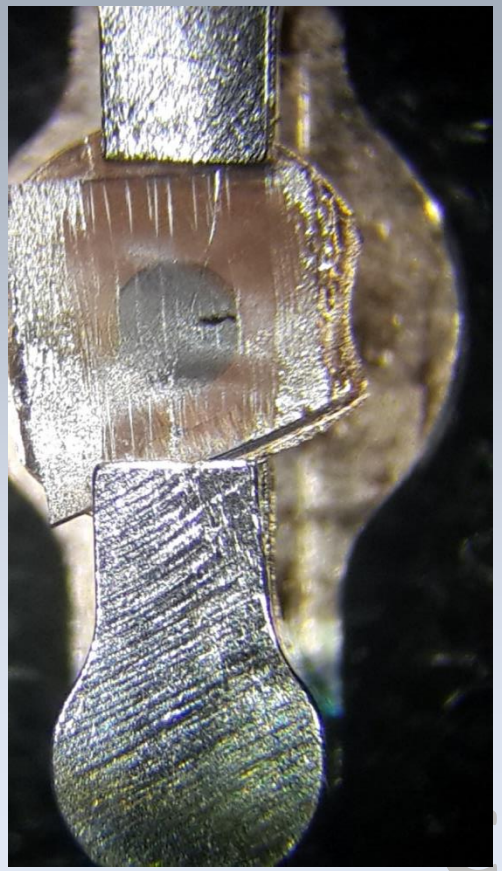

(a)
Normalized density
(b)
1-basal plane dilation
track 1
track 2
Radius (nm)

Latent tracks in rutile

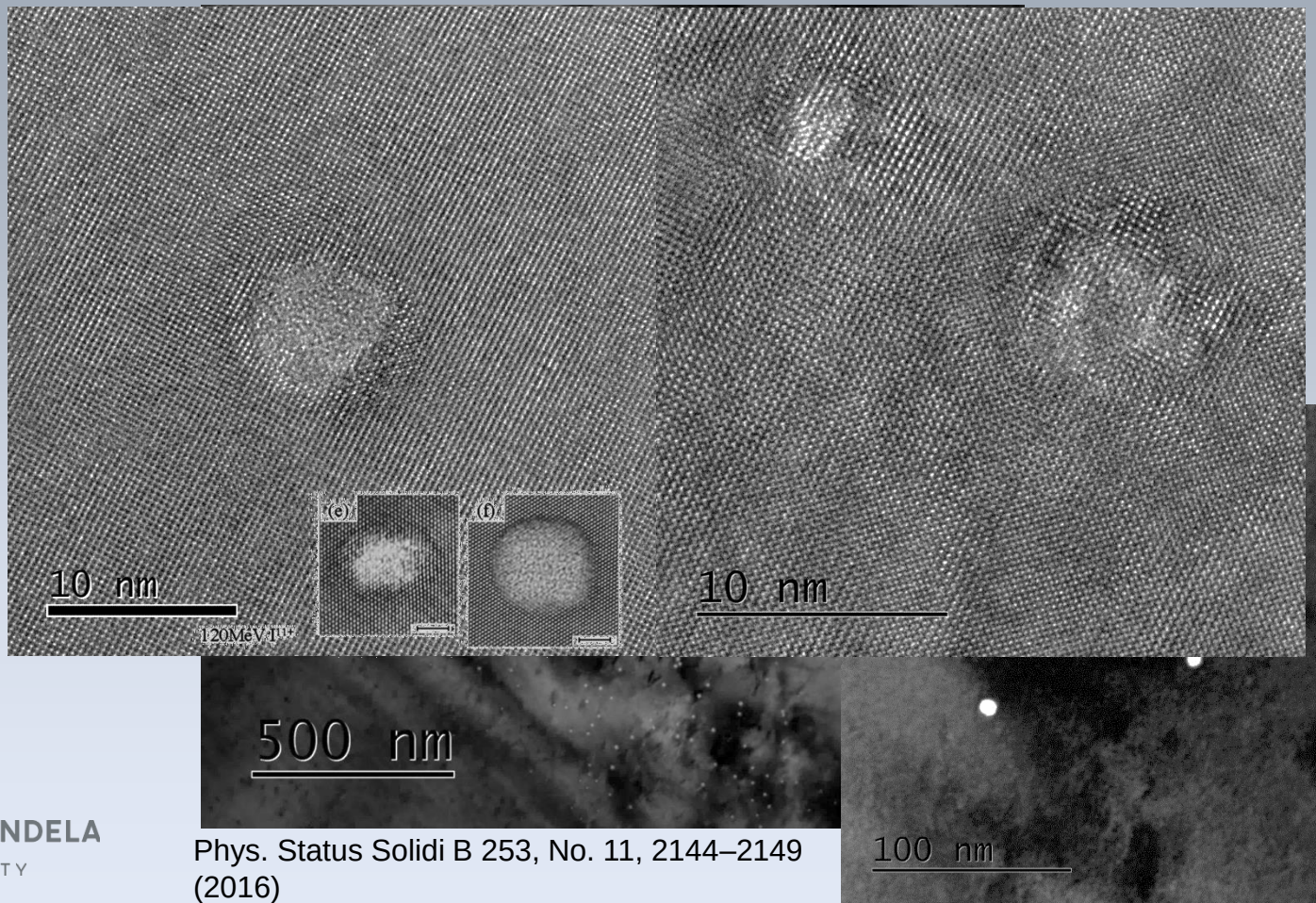


J. Appl. Phys. 100, 044308 (2006)

Pre-thinned $2x10^{10}$ Xe 167 MeV



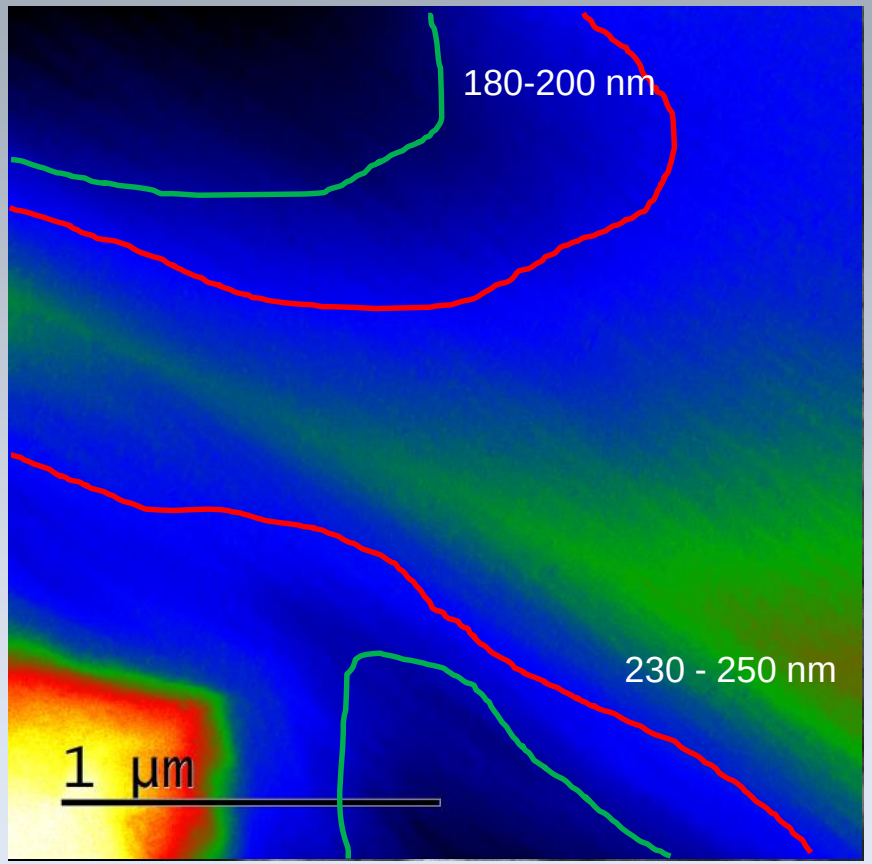
Pre-thinned $2x10^{10}$ Xe 167 MeV



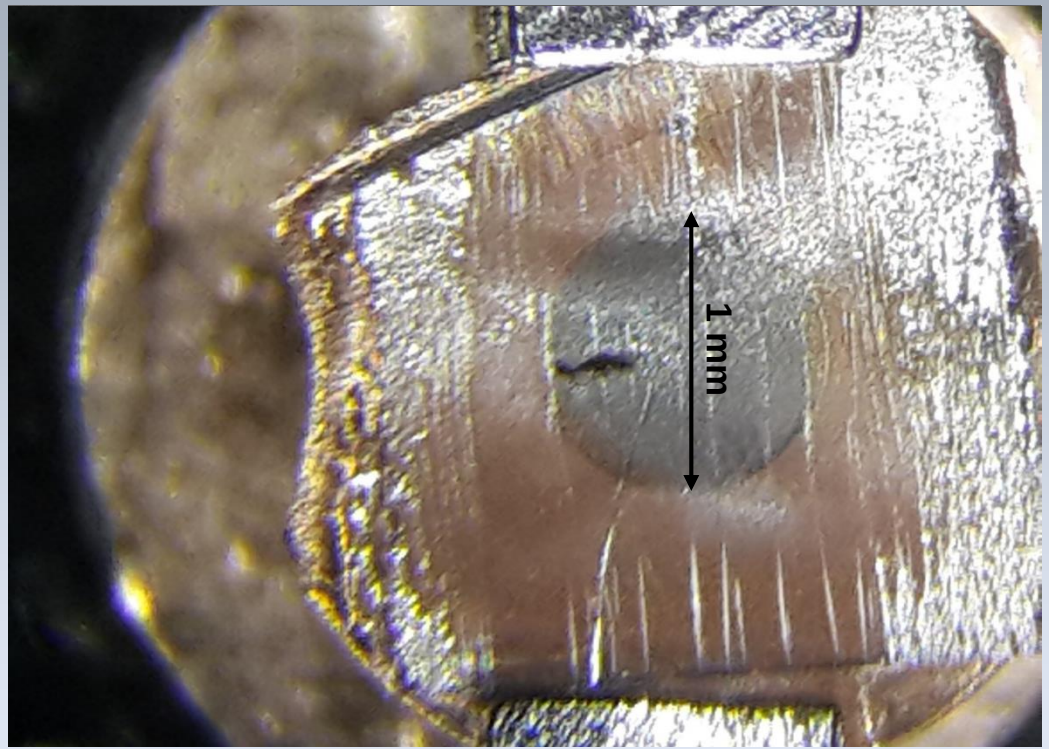
Phys. Status Solidi B 253, No. 11, 2144–2149 (2016)

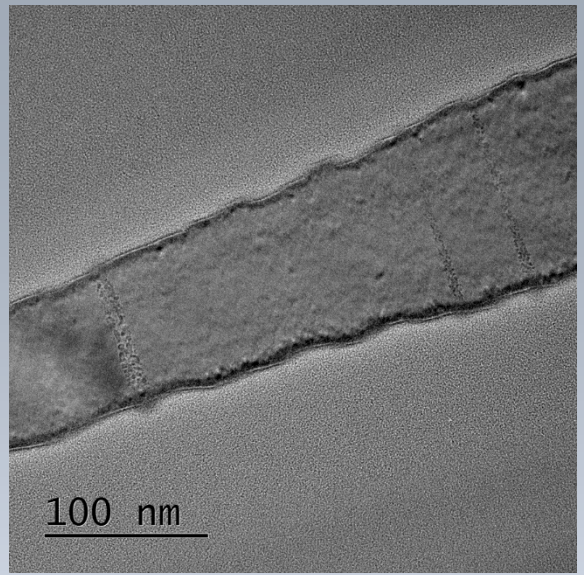
TEM

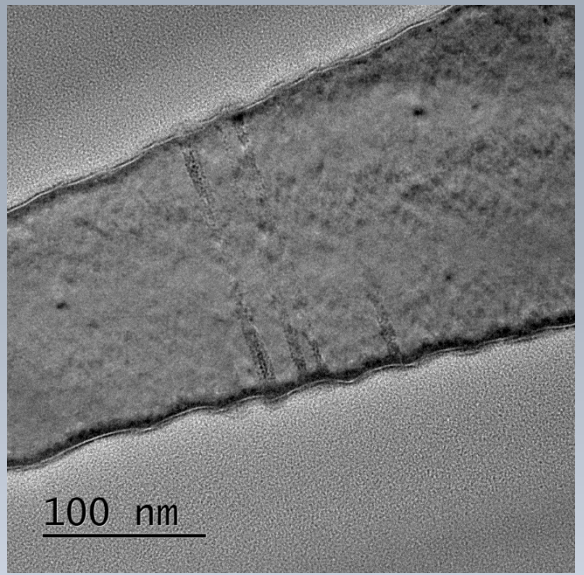
Thickness dependent amorphization

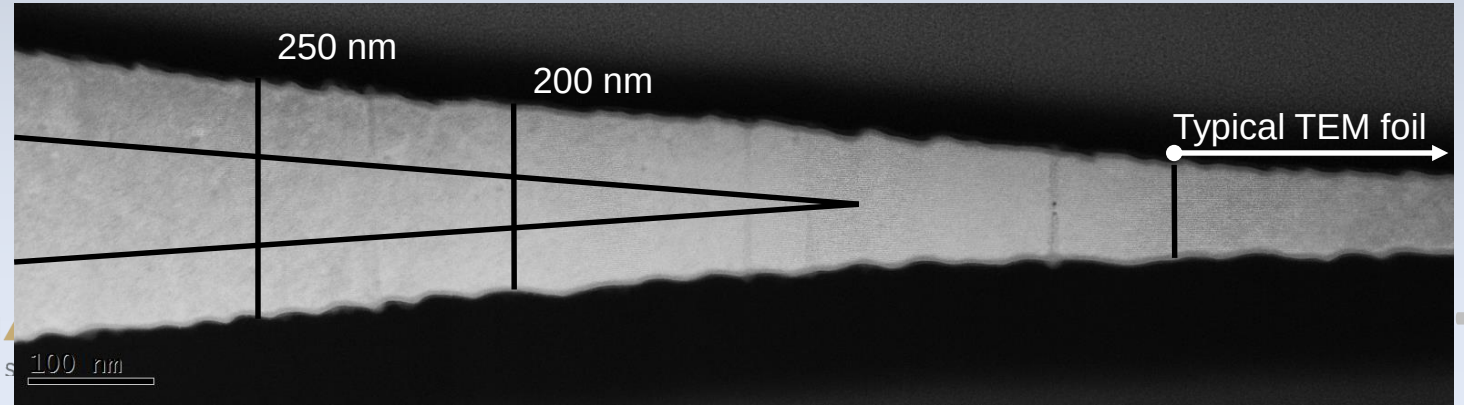


Pre-thinned $2x10^{10}$ Xe 167 MeV X-section

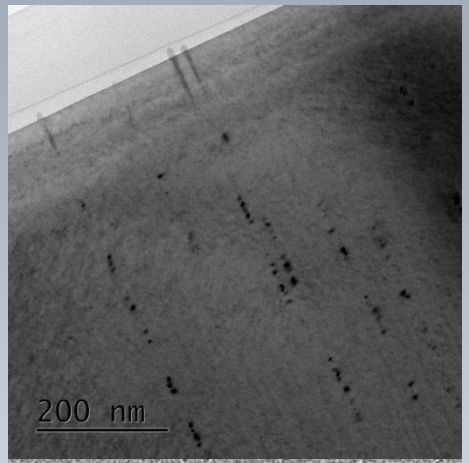


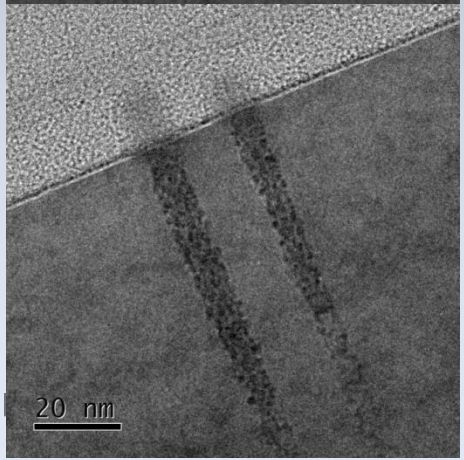

100 nm

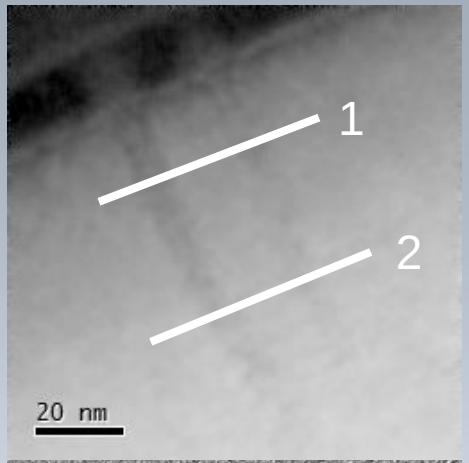

100 nm

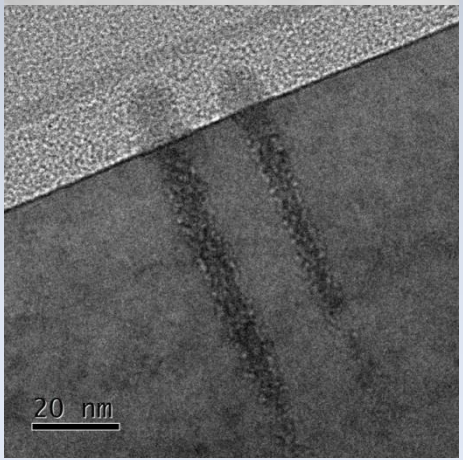

250 nm
200 nm
Typical TEM foil
100 nm

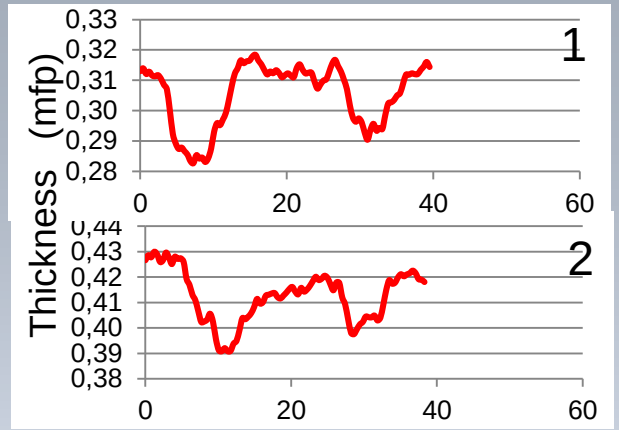
Near surface damage enhancement





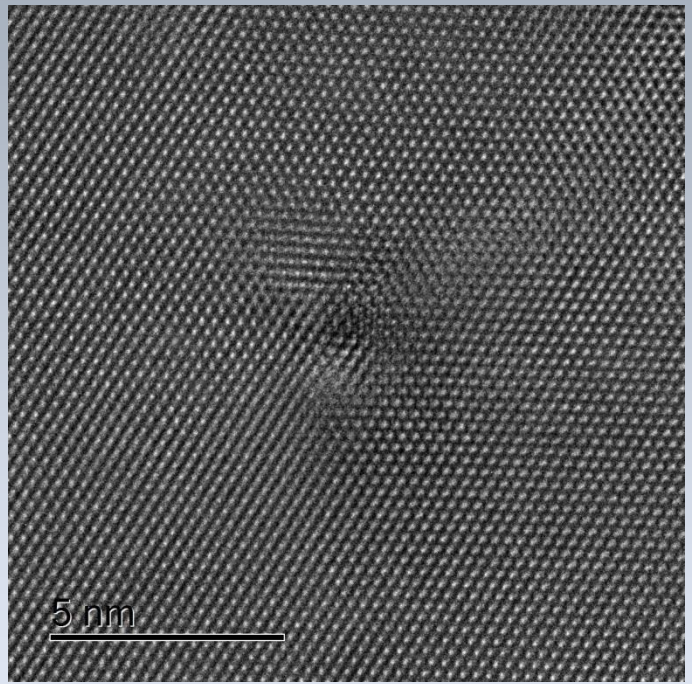




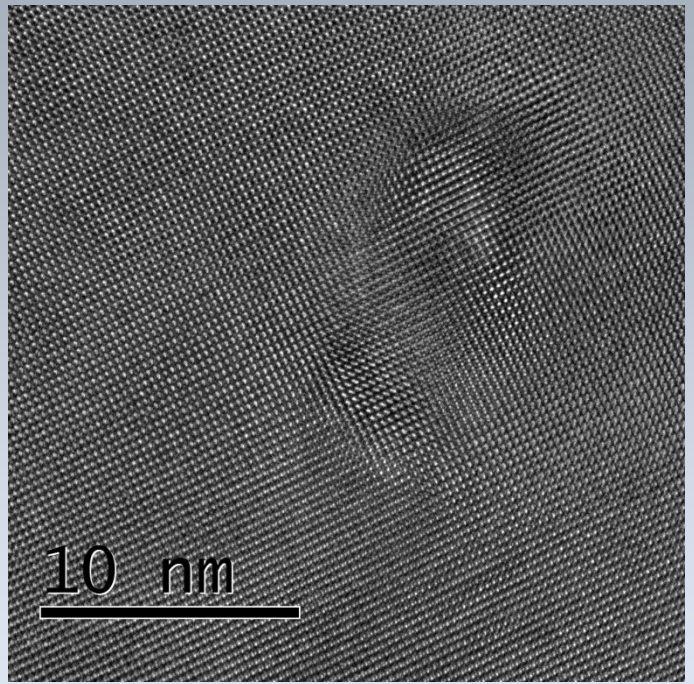


Defective crystalline tracks

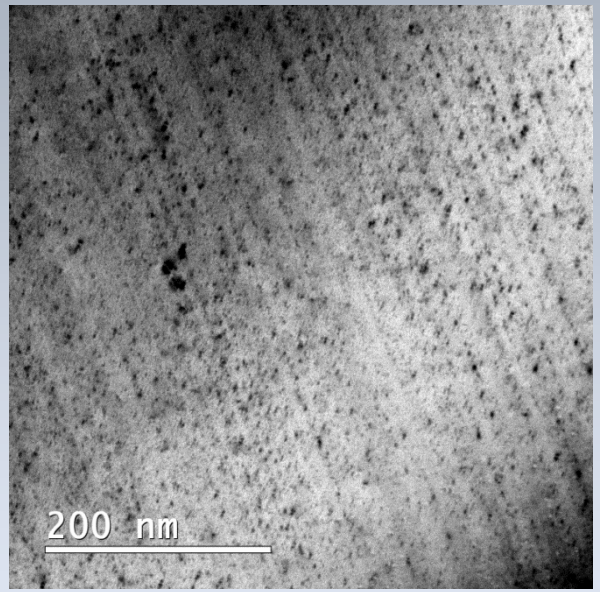
Al_2O_3

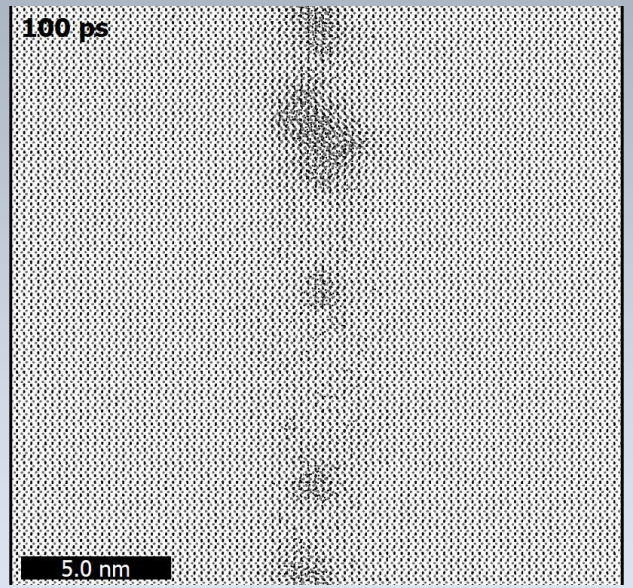


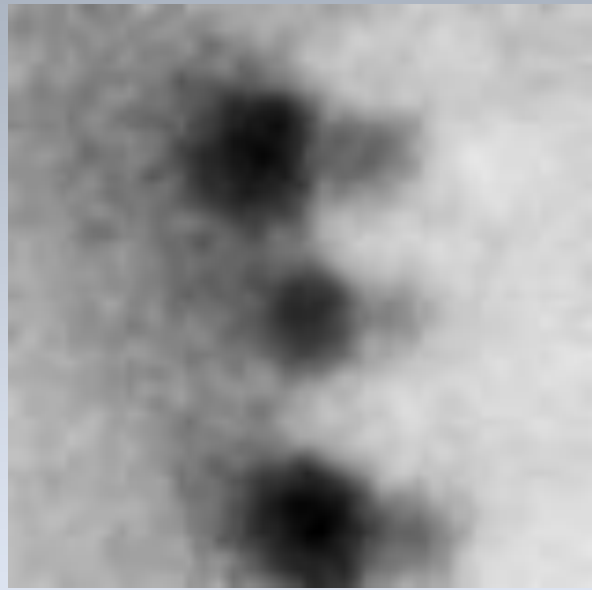
TiO_2



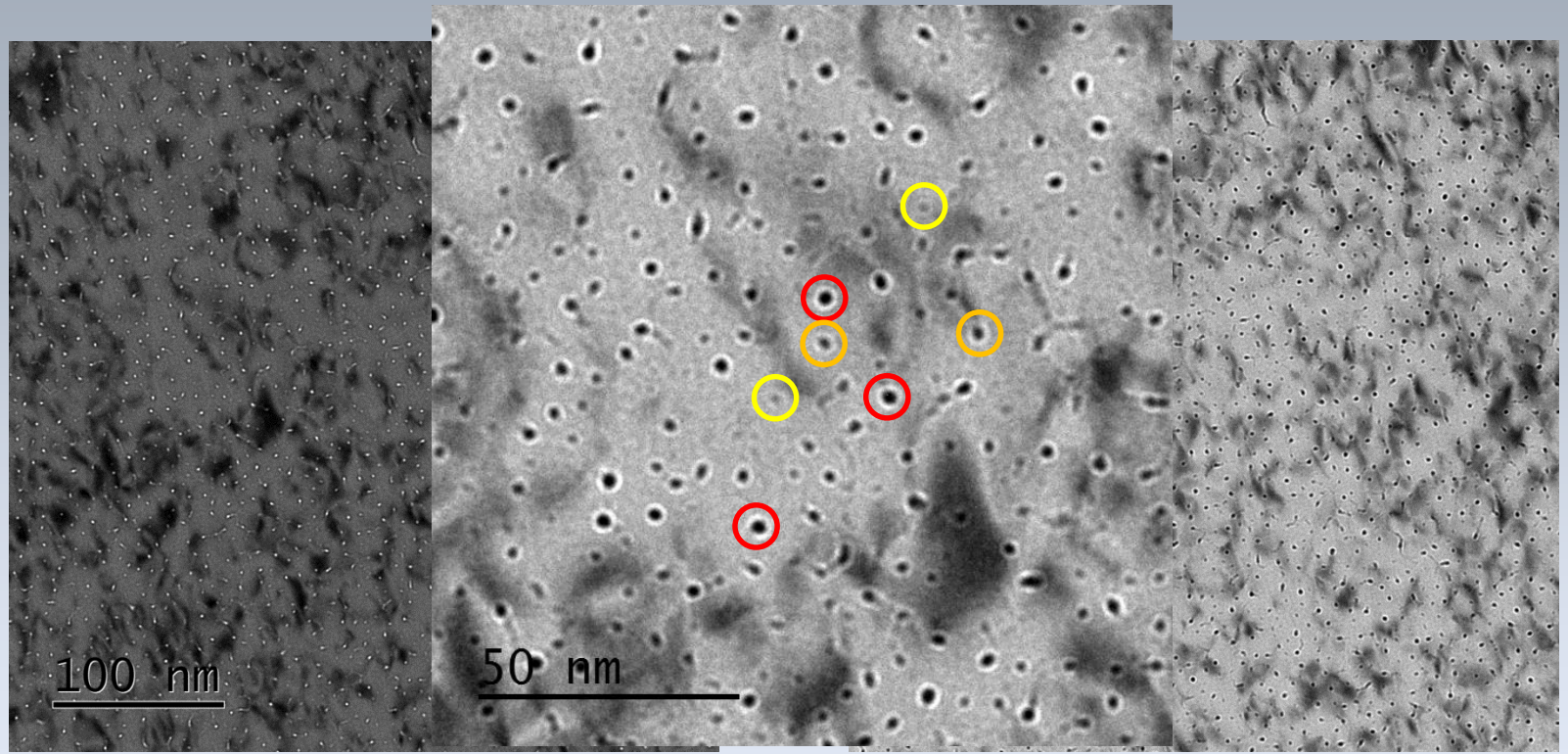
Al_2O_3



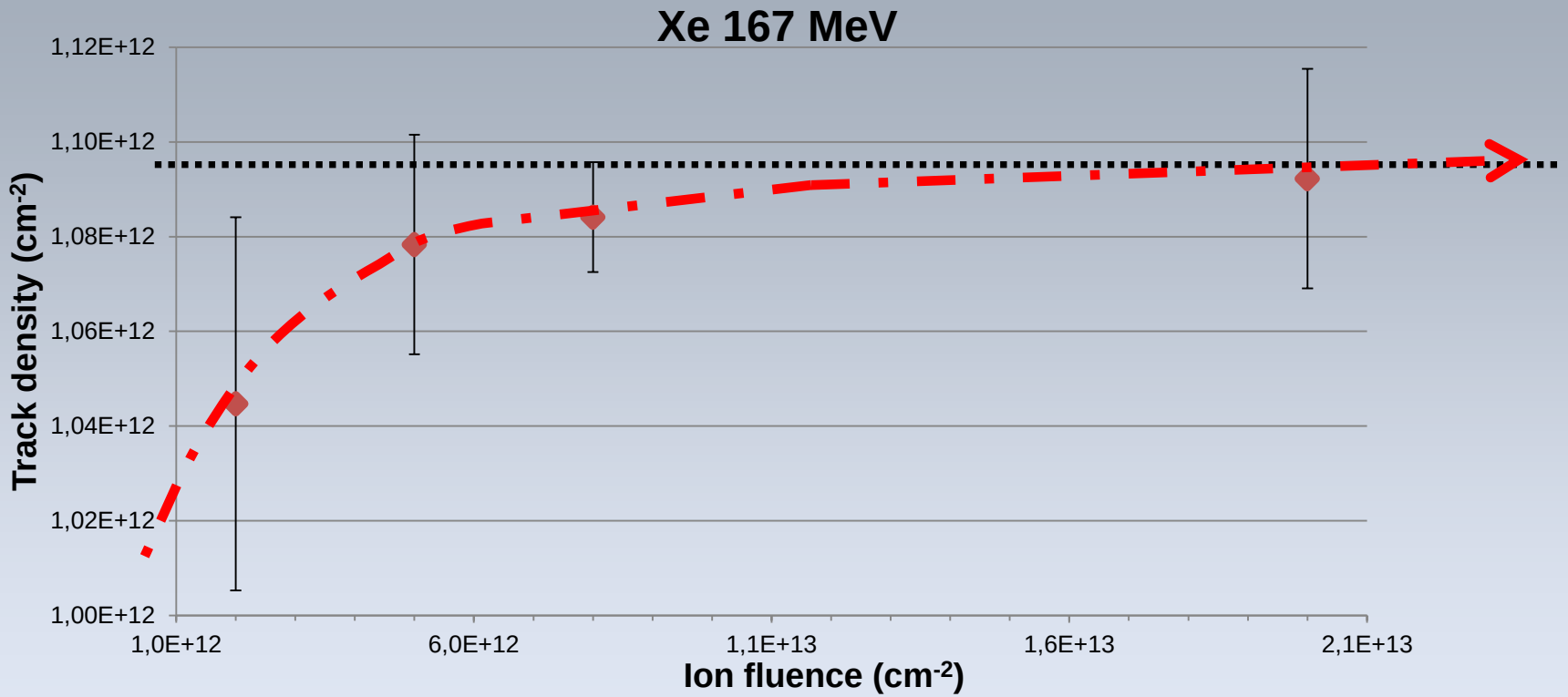




167 MeV Xe in Al_2O_3 ($2x10^{12}/cm^2$)



Saturated track density in Al_2O_3



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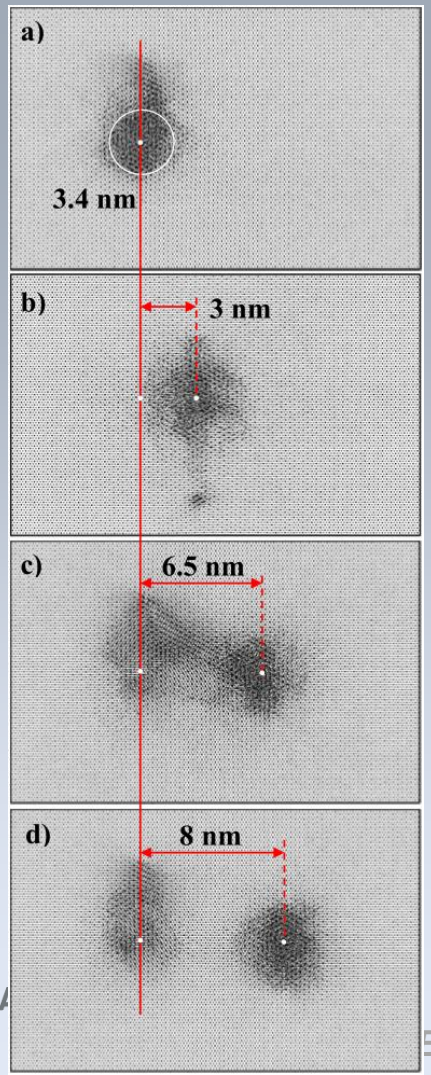
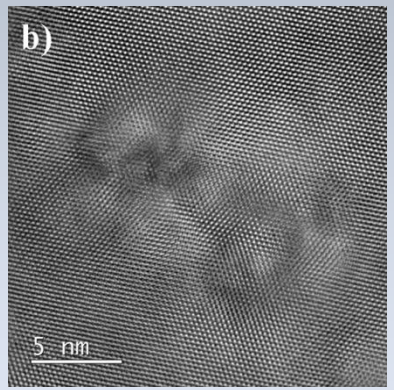
O'Connell *et al.* Nucl. Inst. Meth. B 374 (2016) 97–101

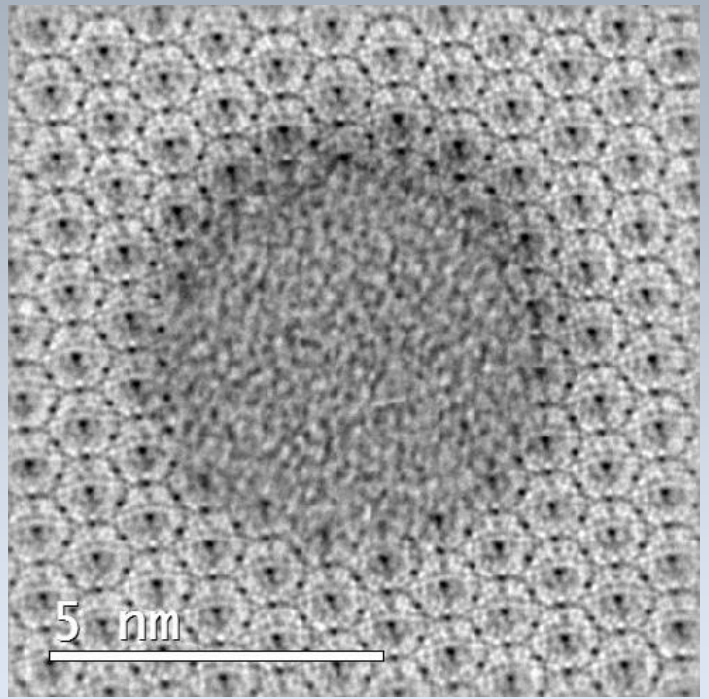
CHRTEM

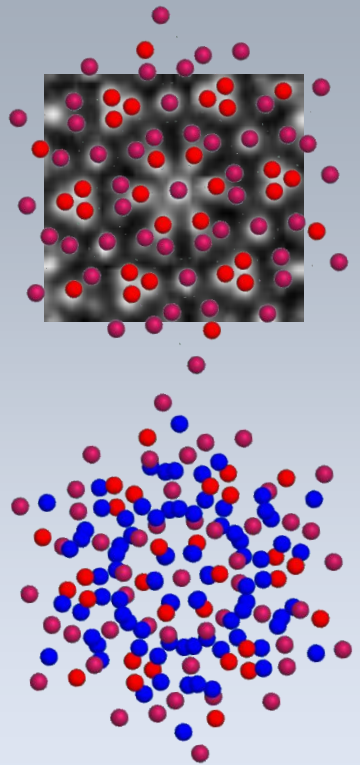




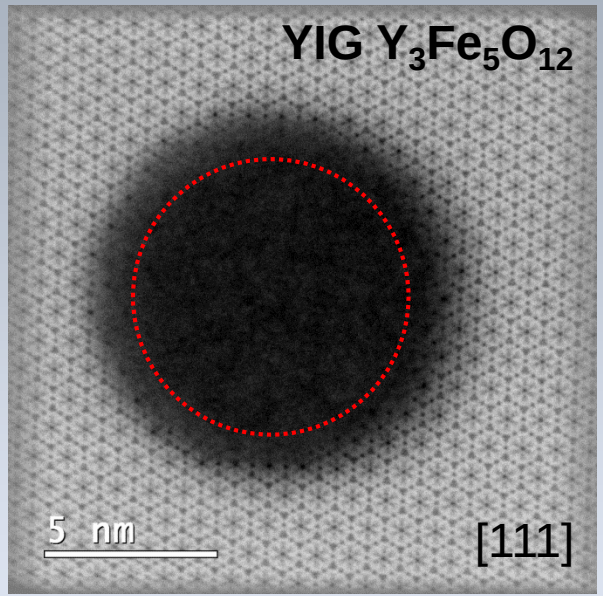
Nuclear Inst. and Methods in Physics Research B 435 (2018) 121–125

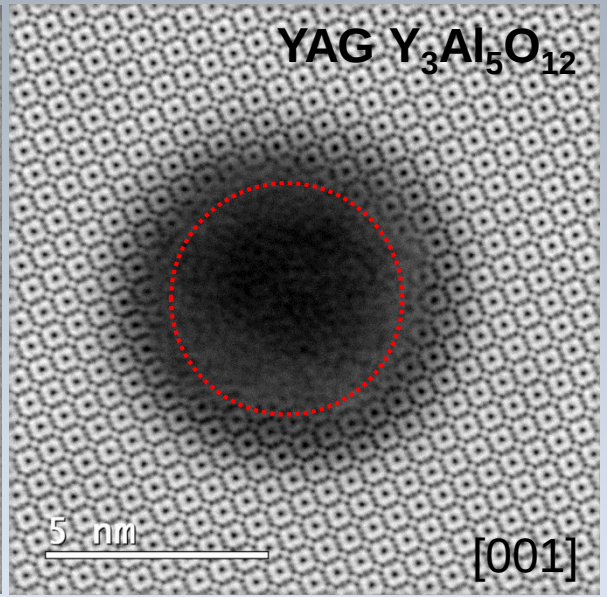
STEM

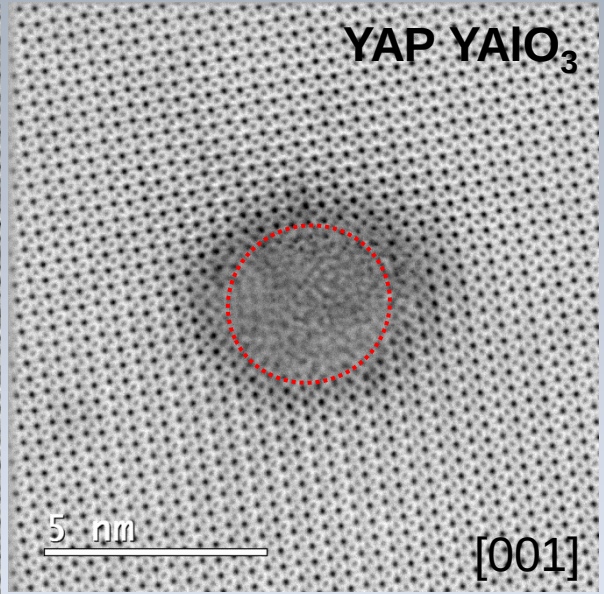




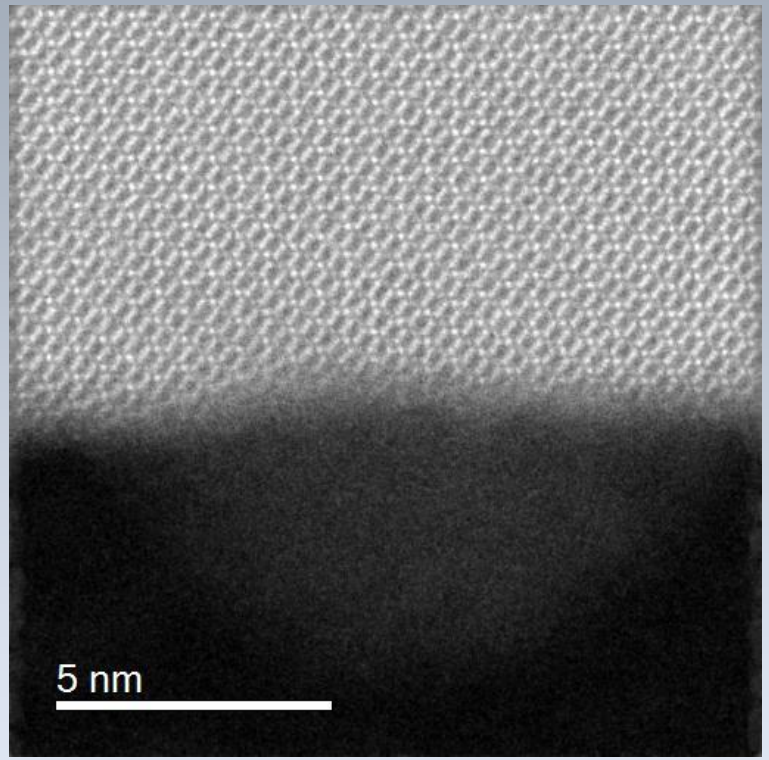
HRSTEM ABF micrographs of 167 MeV Xe ion tracks in amorphizable materials

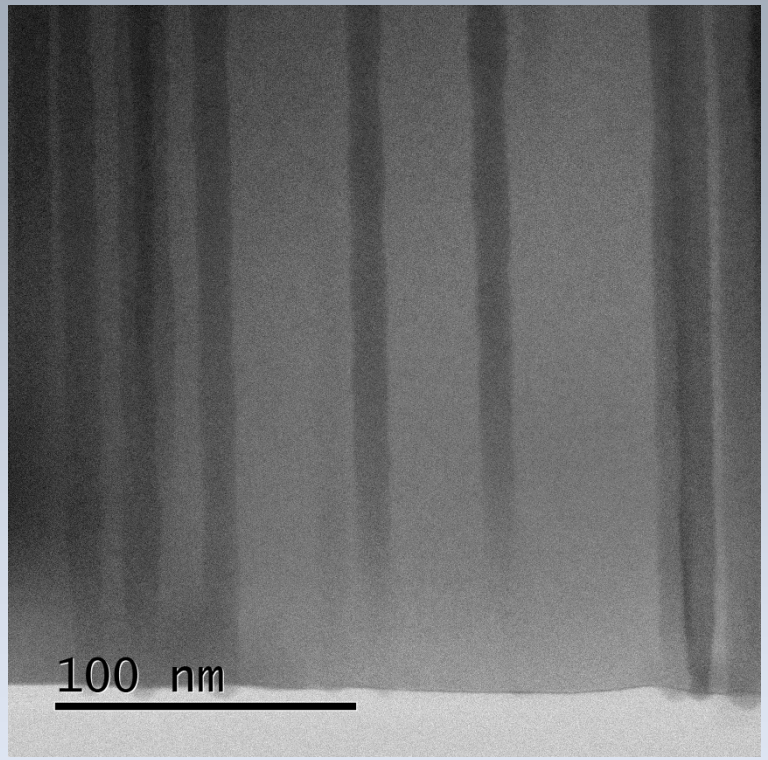




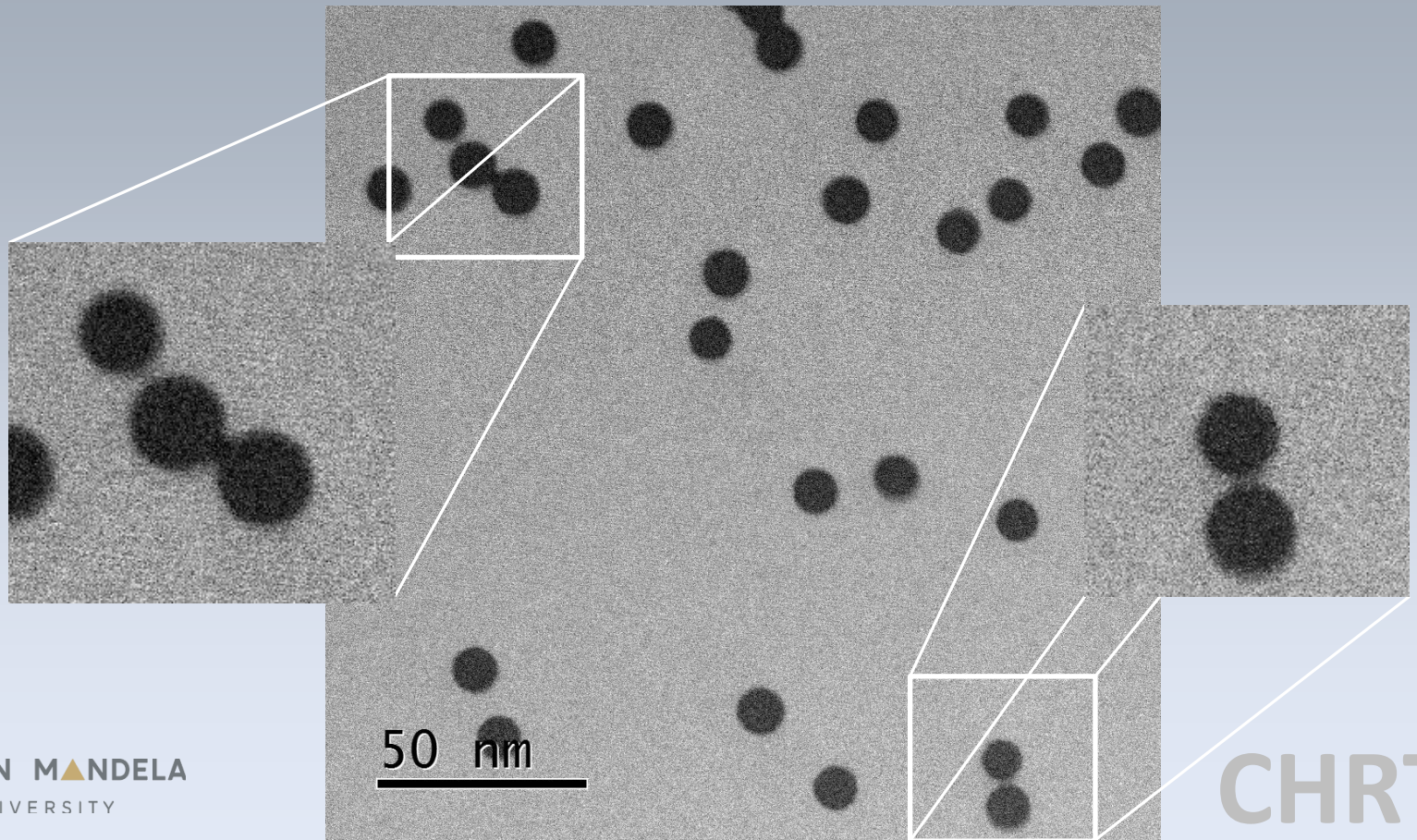


220 MeV Xe ion tracks in YIG





Track interaction in YIG



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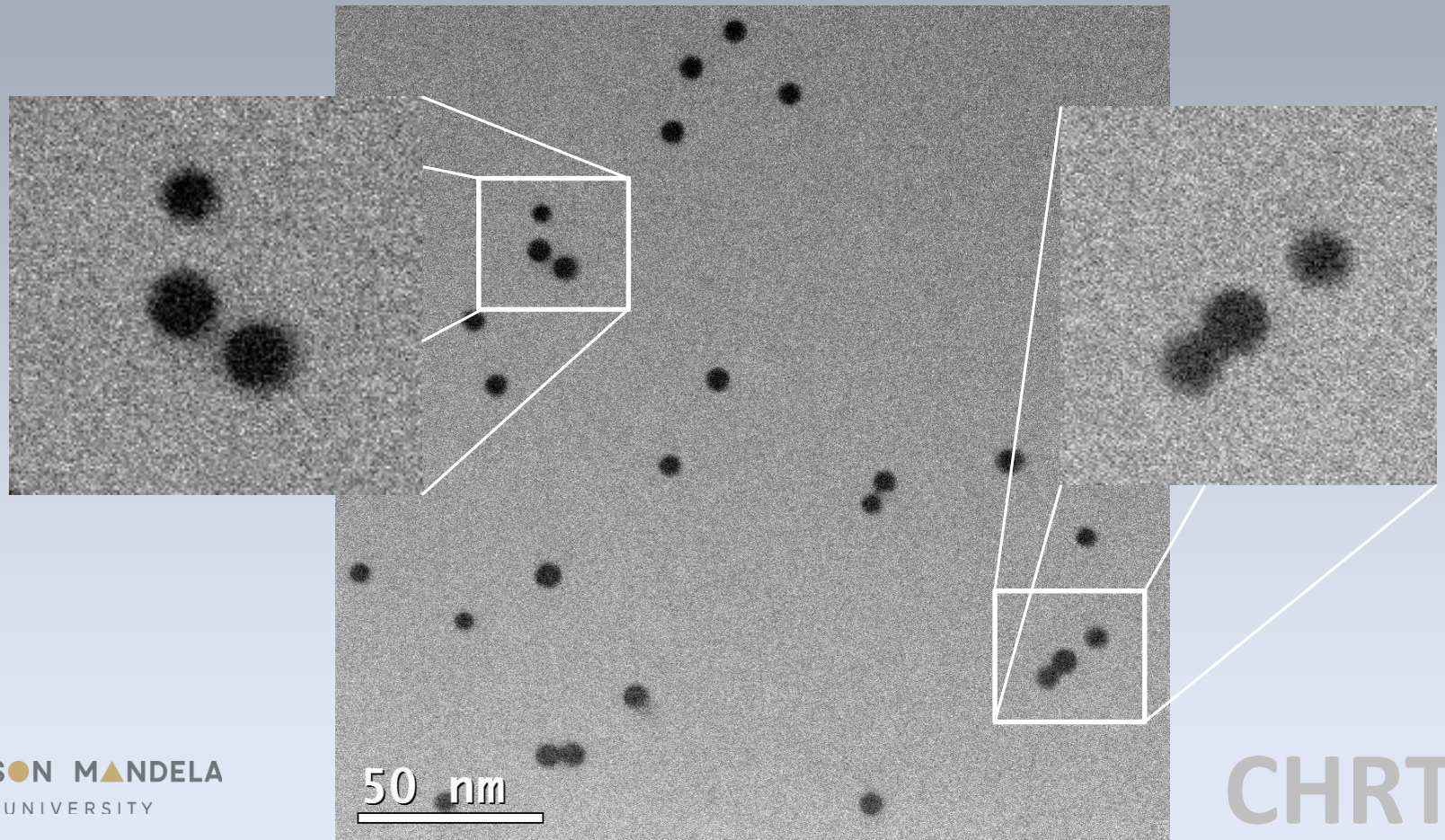
CHRTEM

Track interaction in YAG



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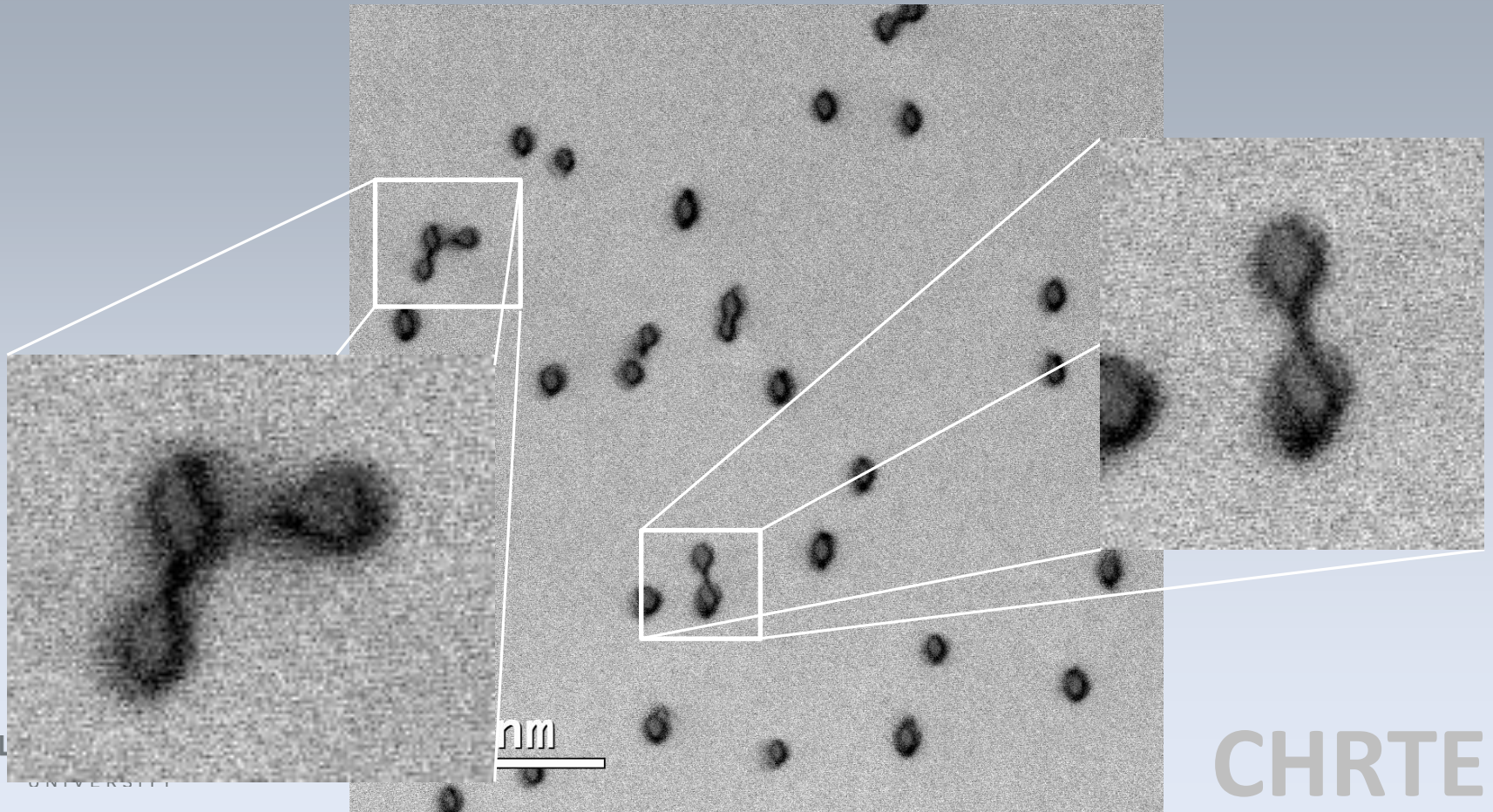
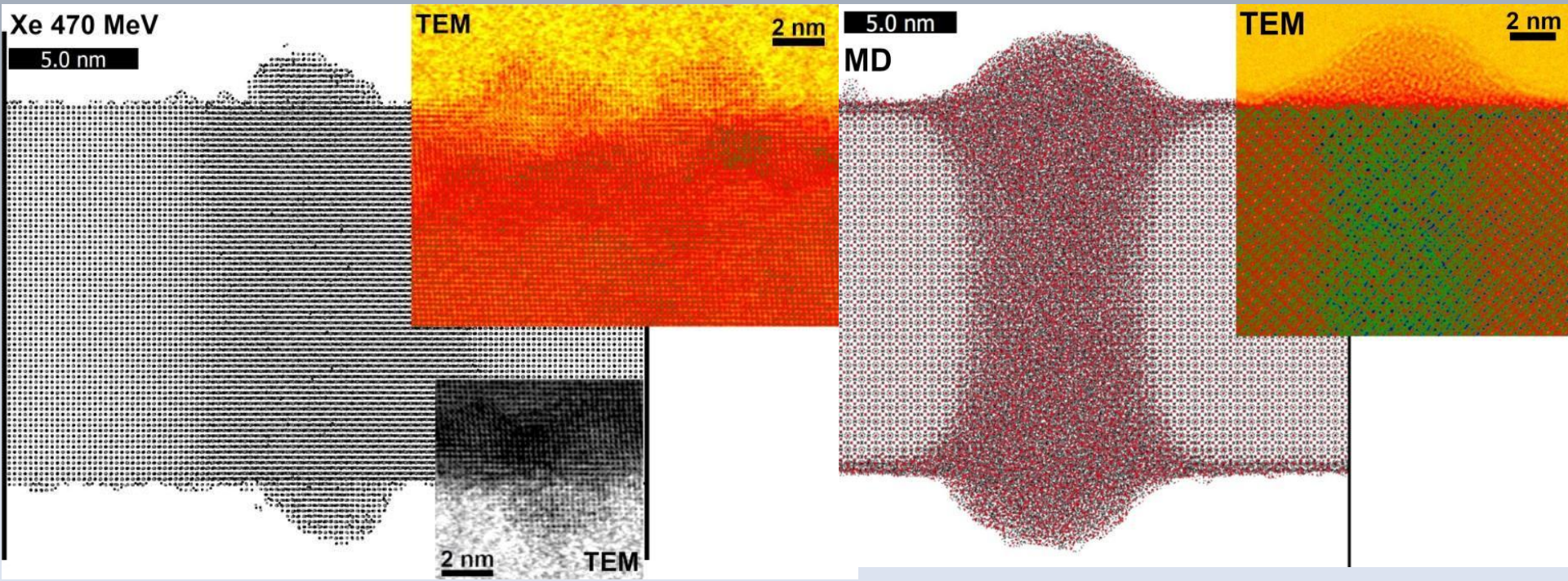
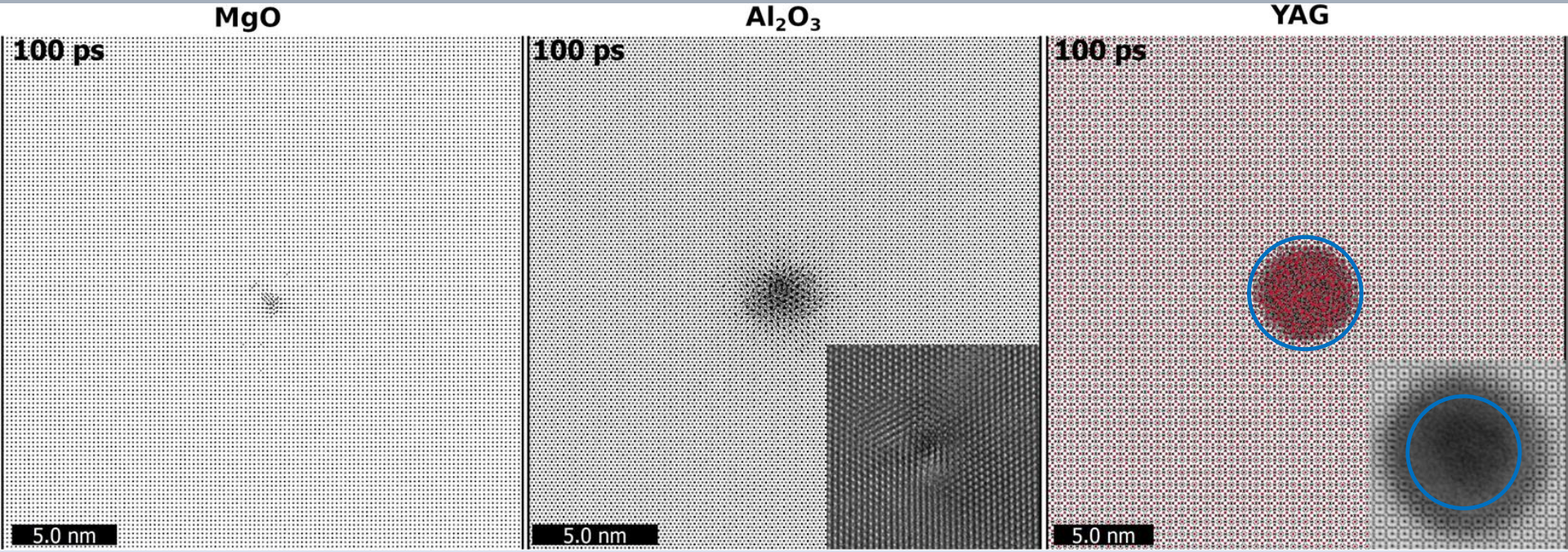
CHRTEM

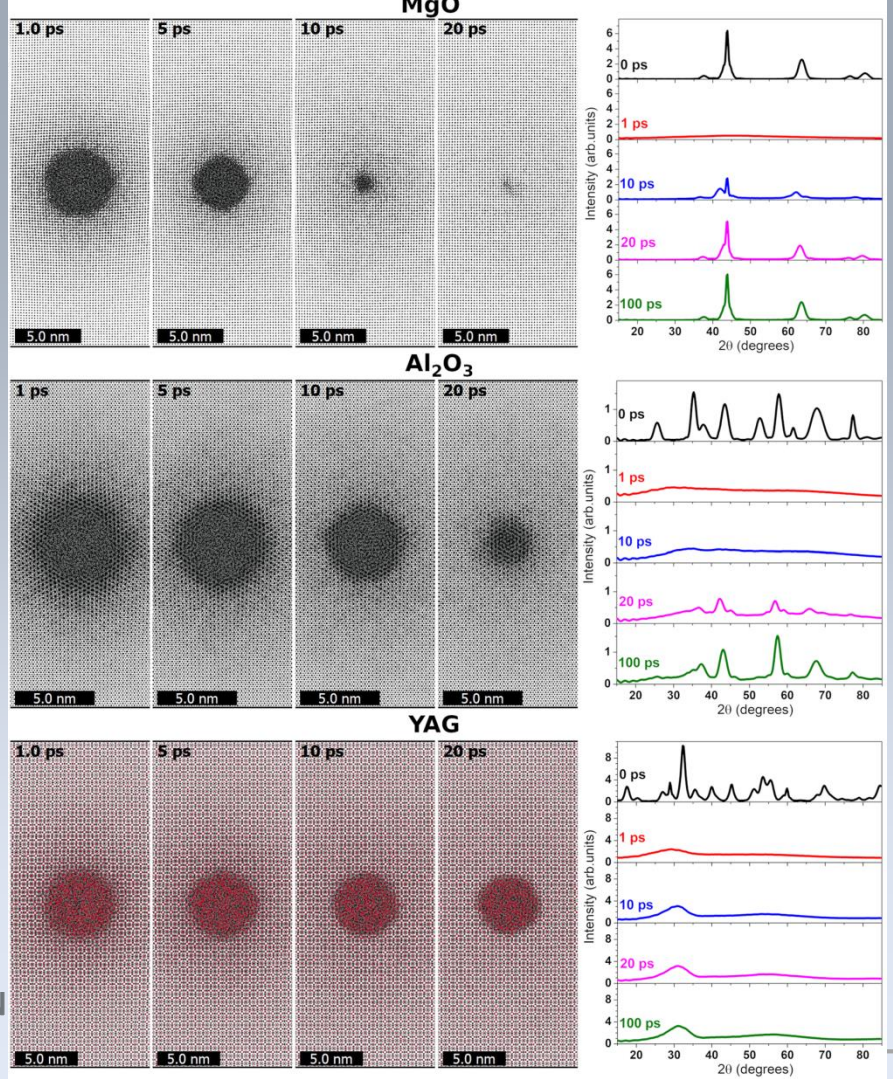
Track interaction in YAP

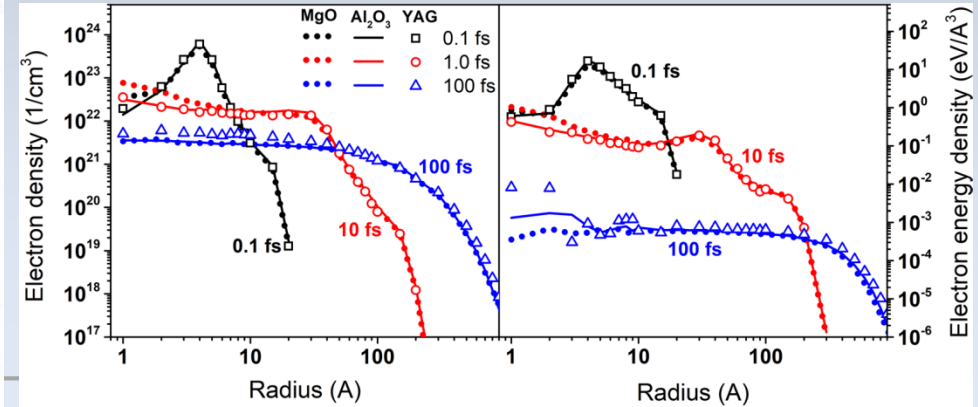



Xe 470 MeV
5.0 nm
TEM
2 nm
2 nm
TEM
5.0 nm
MD
TEM
2 nm

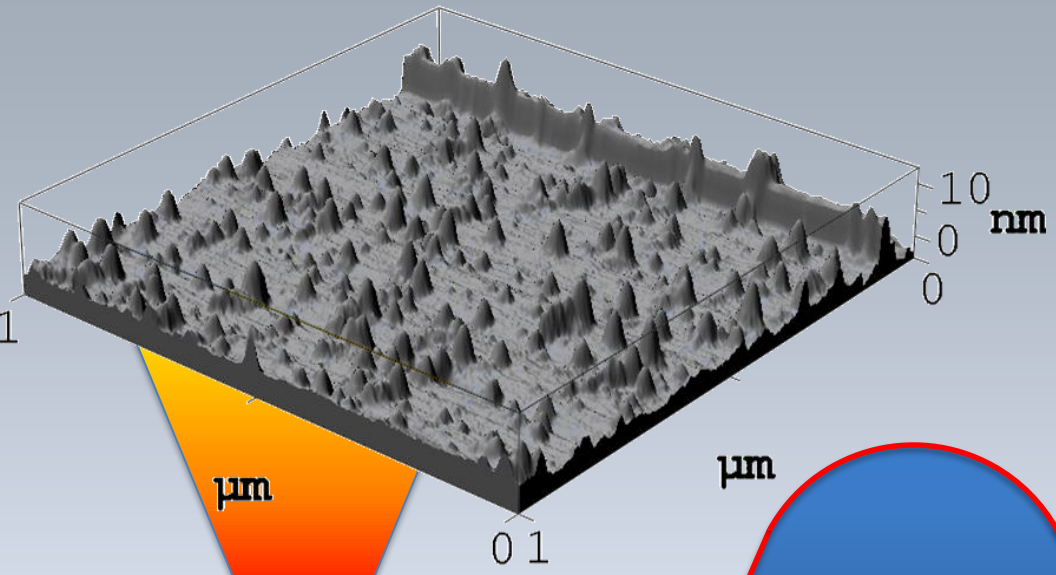


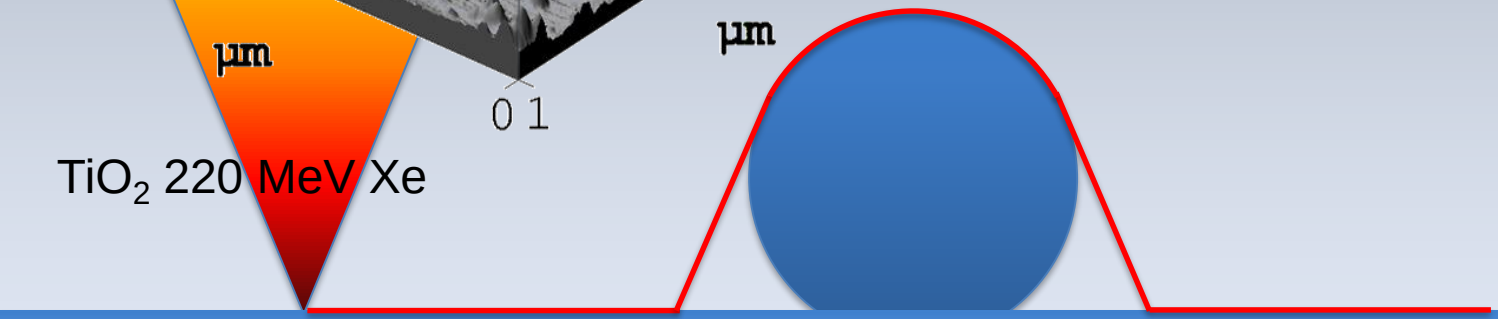
Scientific Reports **volume 9**, Article number: 3837 (2019)


MgO
1.0 ps
5 ps
10 ps
20 ps
5.0 nm
0 ps
1 ps
10 ps
20 ps
100 ps
Intensity (arb.units)
2θ (degrees)
Al2O3
YAG


MgO
Al2O3
YAG
0.1 fs
1.0 fs
100 fs
Electron density (1/cm3)
Electron energy density (eV/A3)
Radius (A)

AFM view of a surface hillock

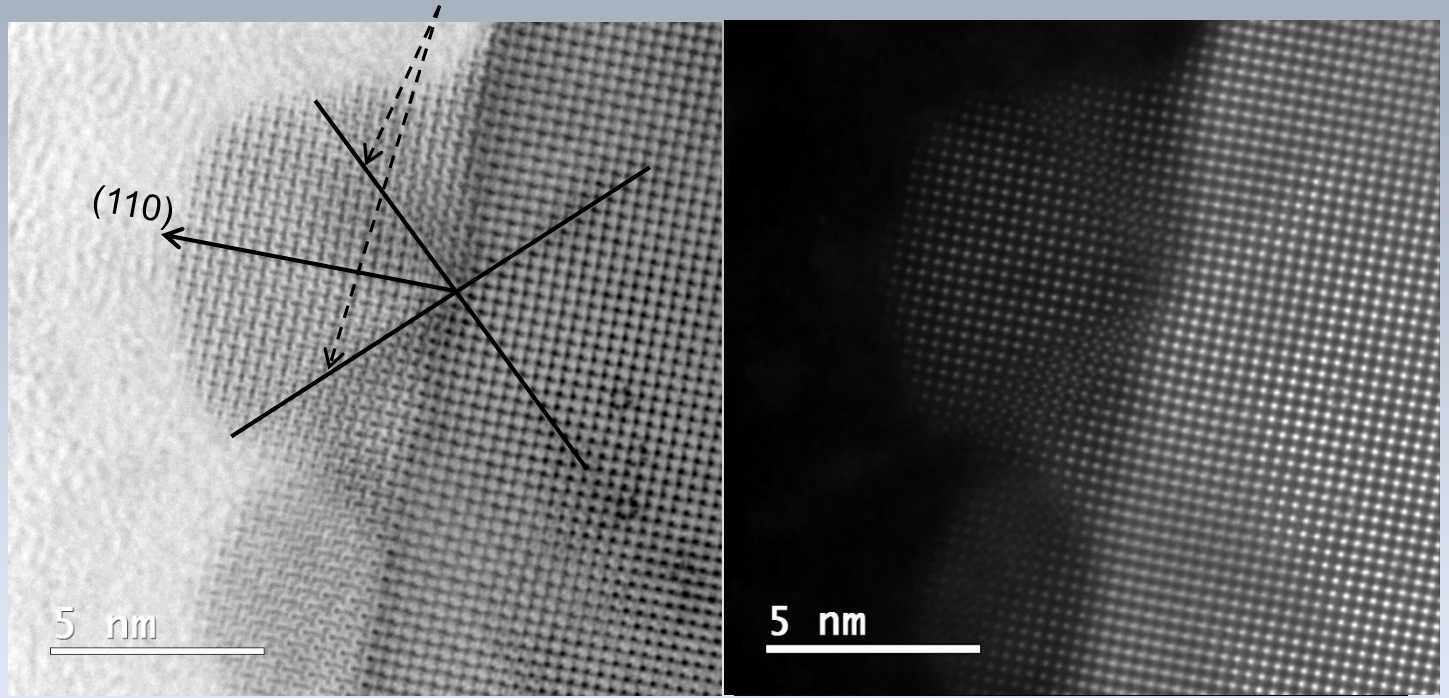




TiO_2 220 MeV Xe

220 MeV Xe 700 °C

Slip {110} & **{101}**



Seeing is believing!

Unless you’re seeing artefacts…