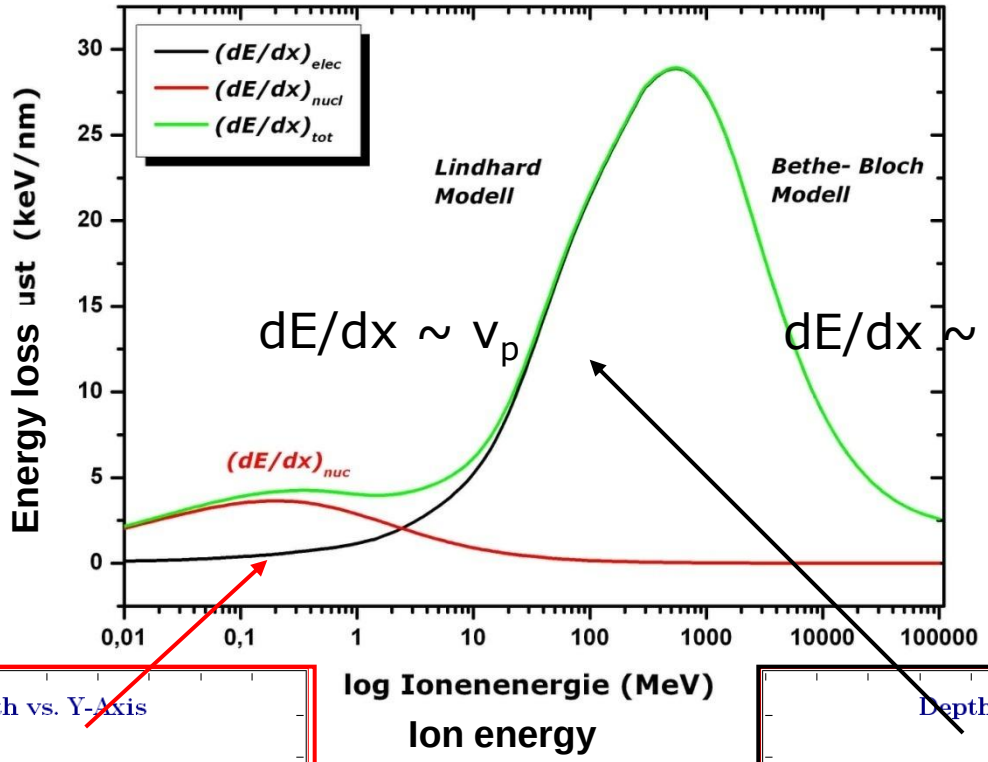
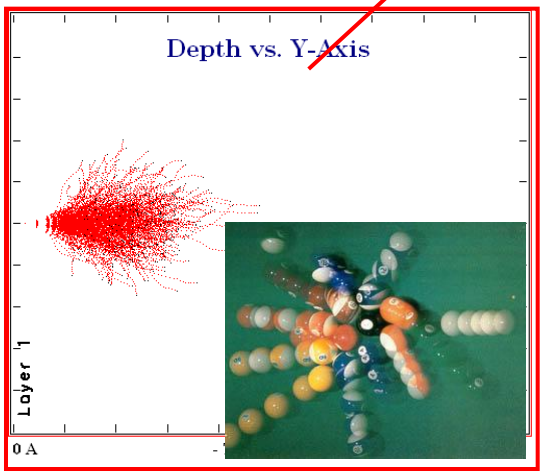
Silicon damage by electronic energy loss?

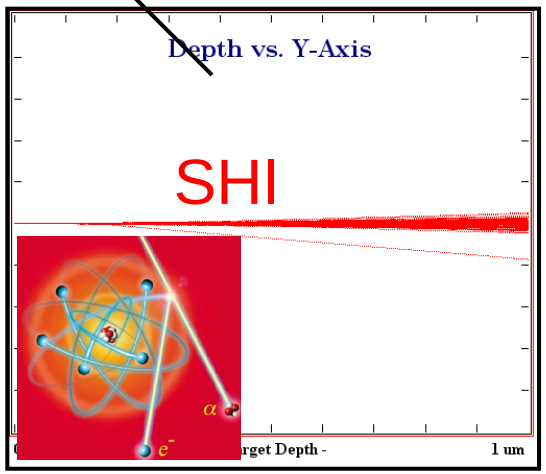
M. Schleberger

Energy loss in solids



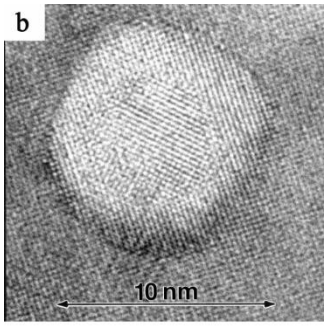
Electronic Excitation!

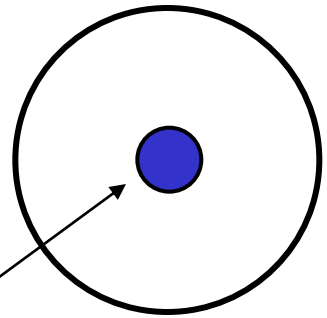




What kind of damage is induced by swift heavy ions?

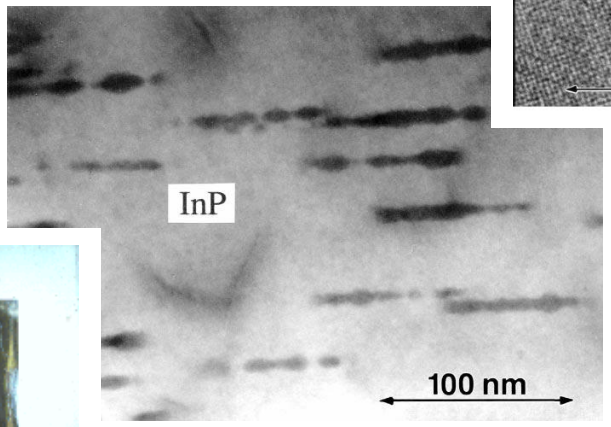
- Defects, Deformation
- Tracks

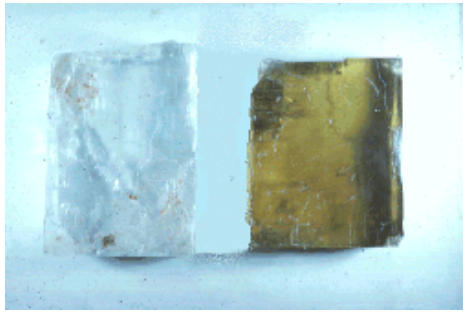




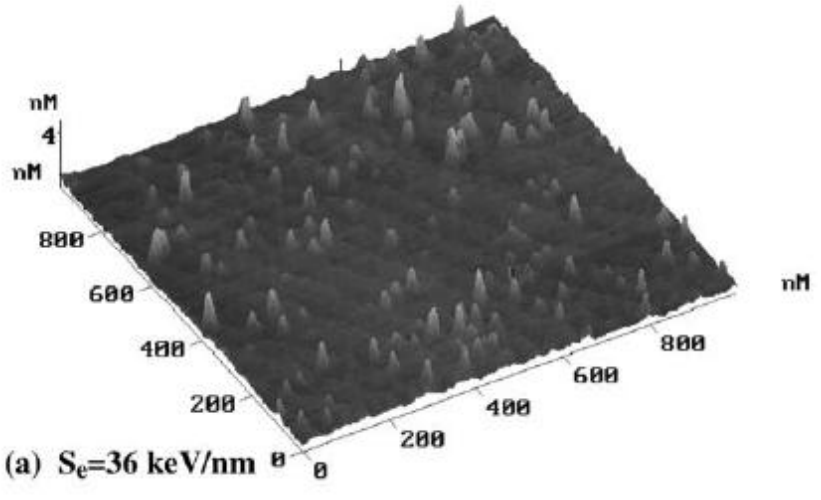
track core

Ø ~ 10 – 100 Å





- Surface damage („hillocks“ & „craters“)

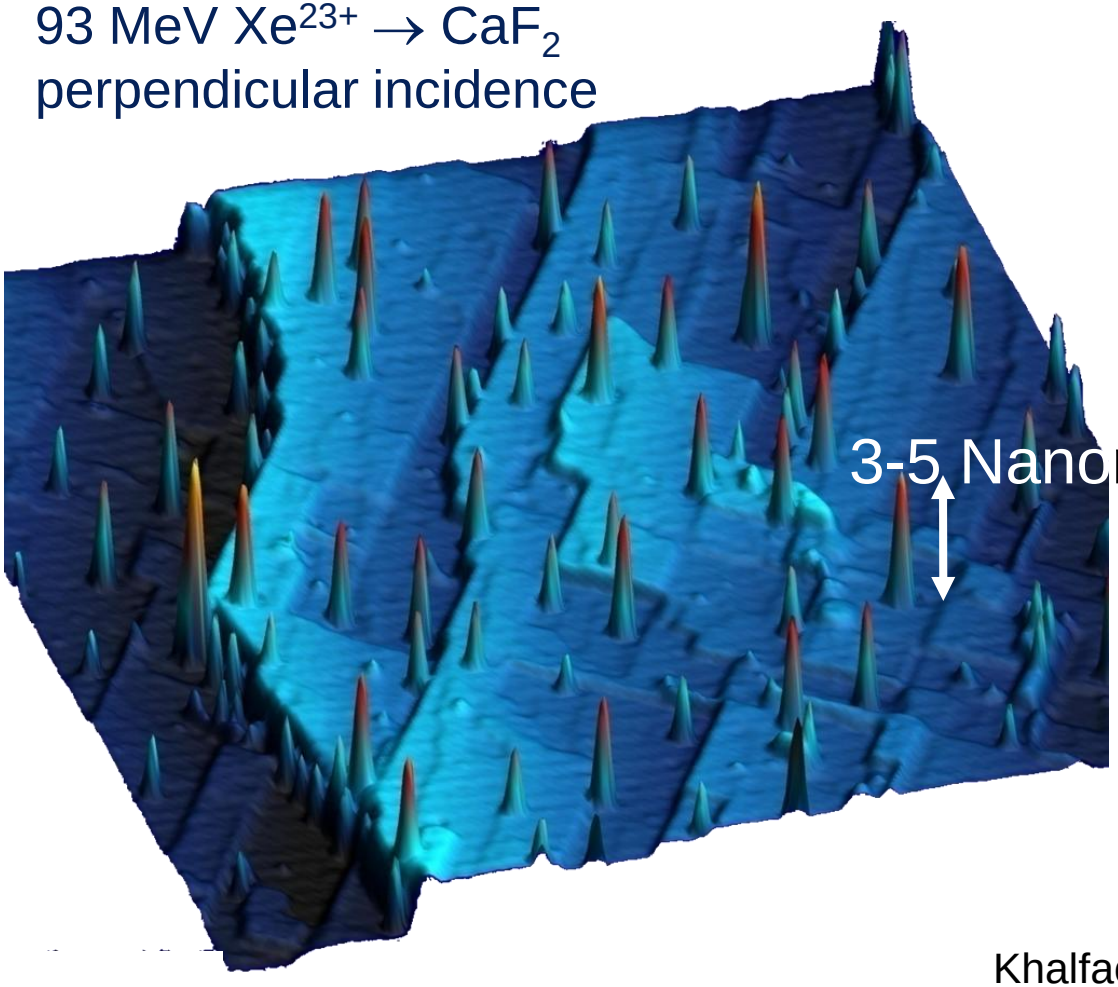


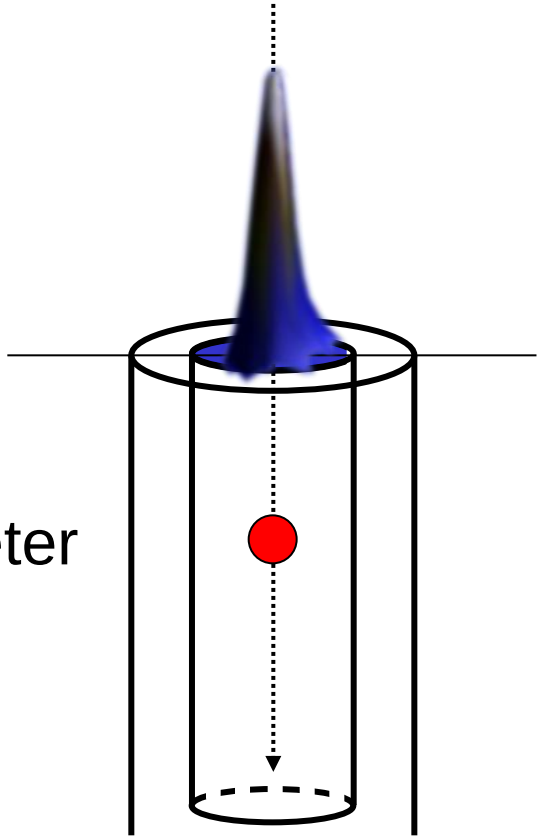
In what kind of materials can we induce damage by swift heavy ions?

- Depends on
  - stopping power
  - material (size & atomic packing & bonding)

Single SHI on insulators: Surface damage

AFM
93 MeV $Xe^{23+} \rightarrow CaF_2$
perpendicular incidence

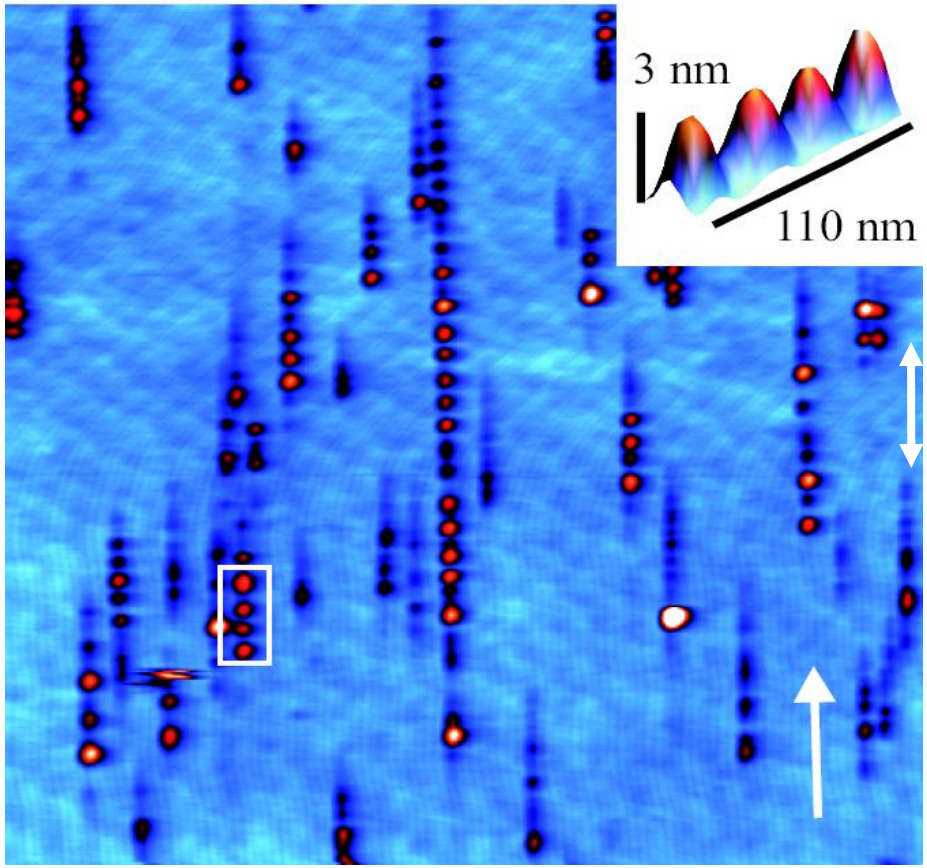


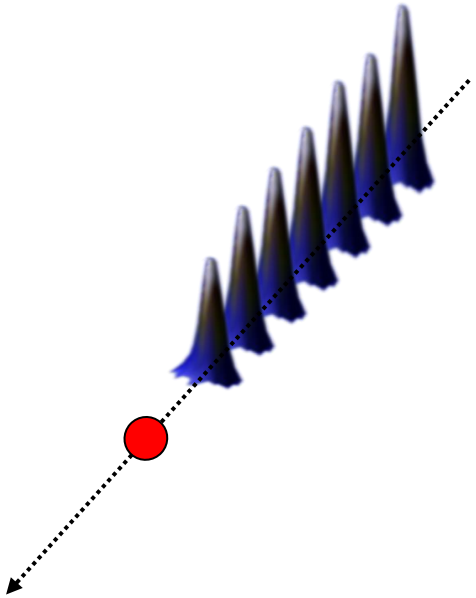


Khalfaoui, et al., NIMB 245 (2006) 246

Single SHI on insulators: Surface damage

AFM
93 MeV $Xe^{23+} \rightarrow SrTiO_3$
glancing incidence

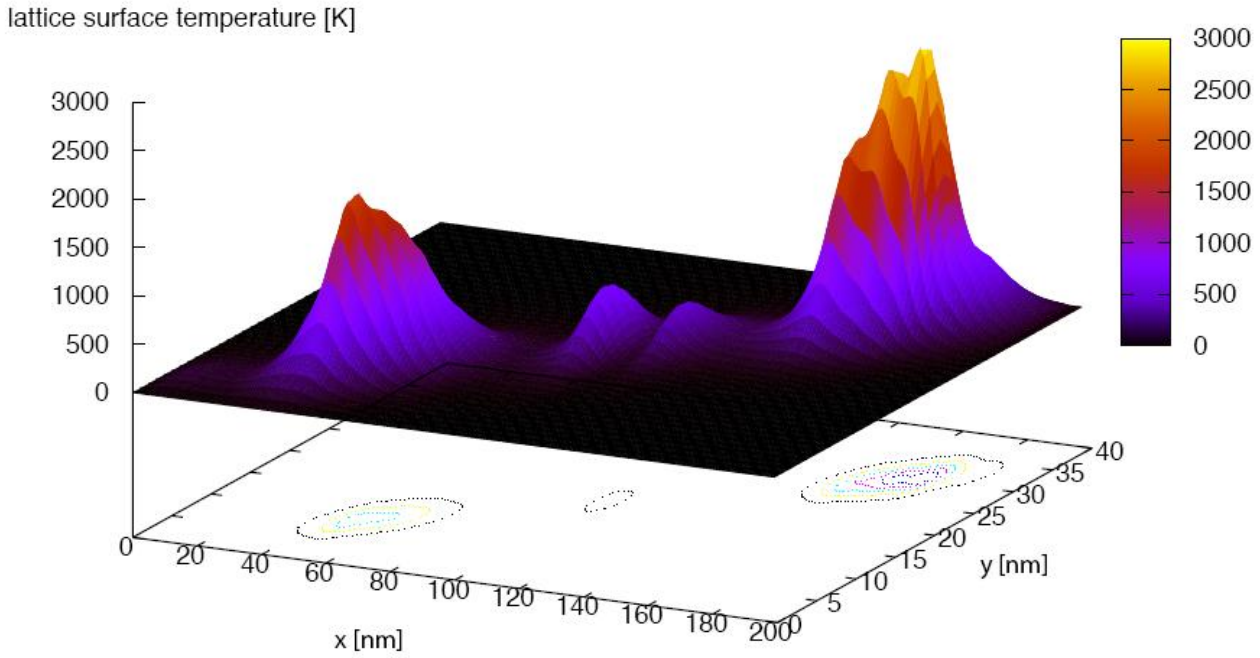




Akcöltekin, et al.,
Nature Nanotechn. (2007)

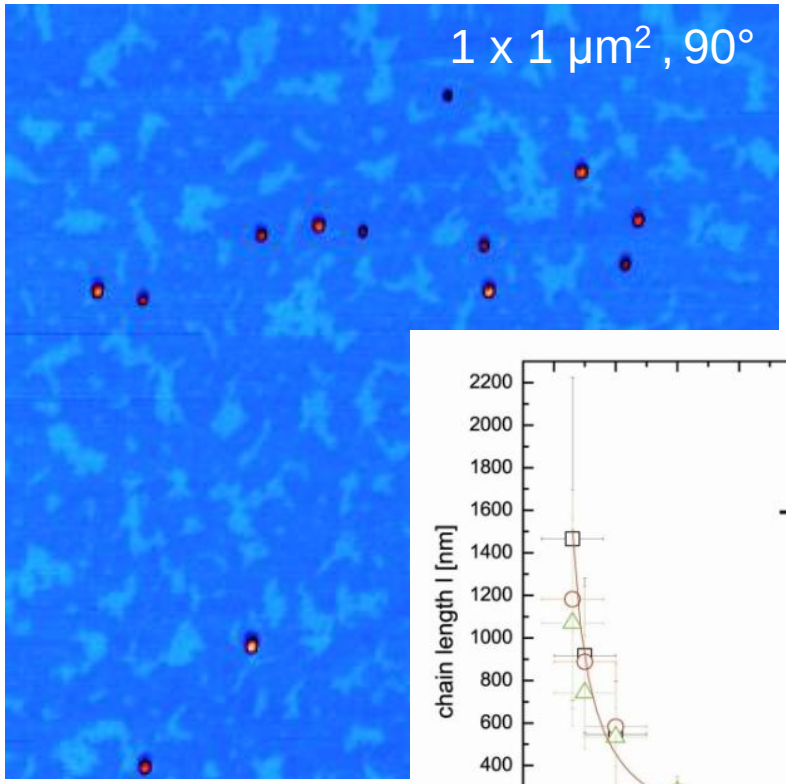
Single SHI on insulators: Surface damage

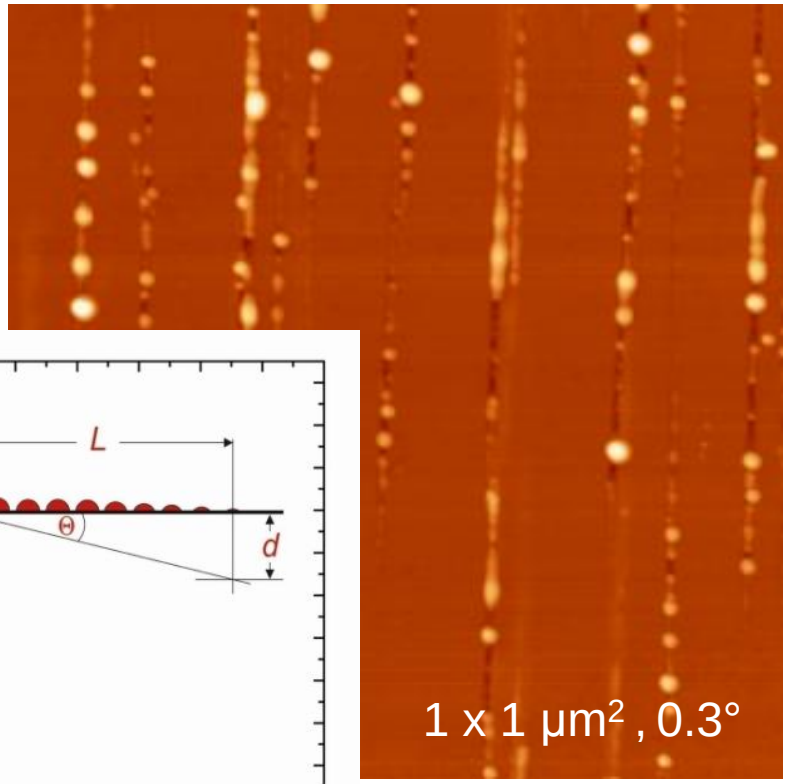
- Transient thermal spike
- Couloumb explosion

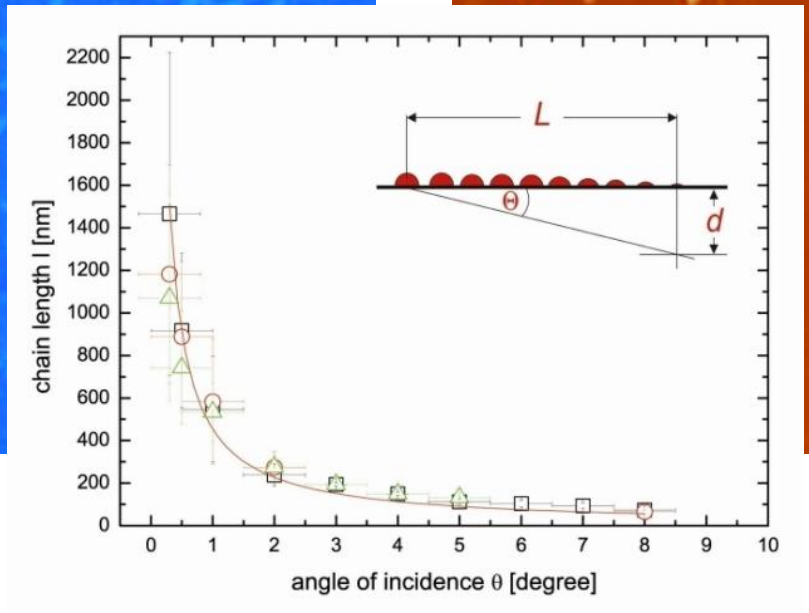


Osmani, et al., (2009)

SrF

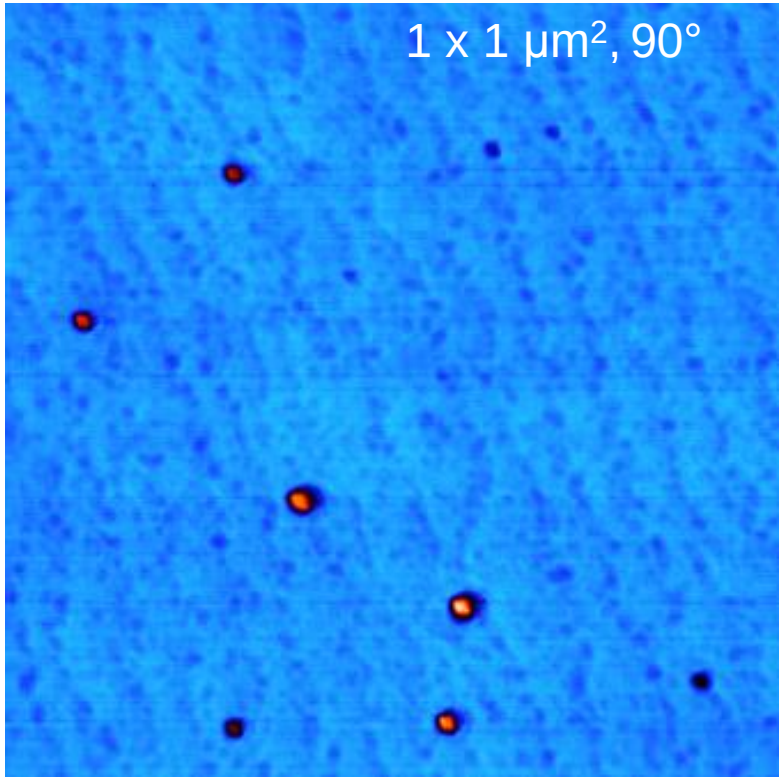

1 x 1 µm² , 90°

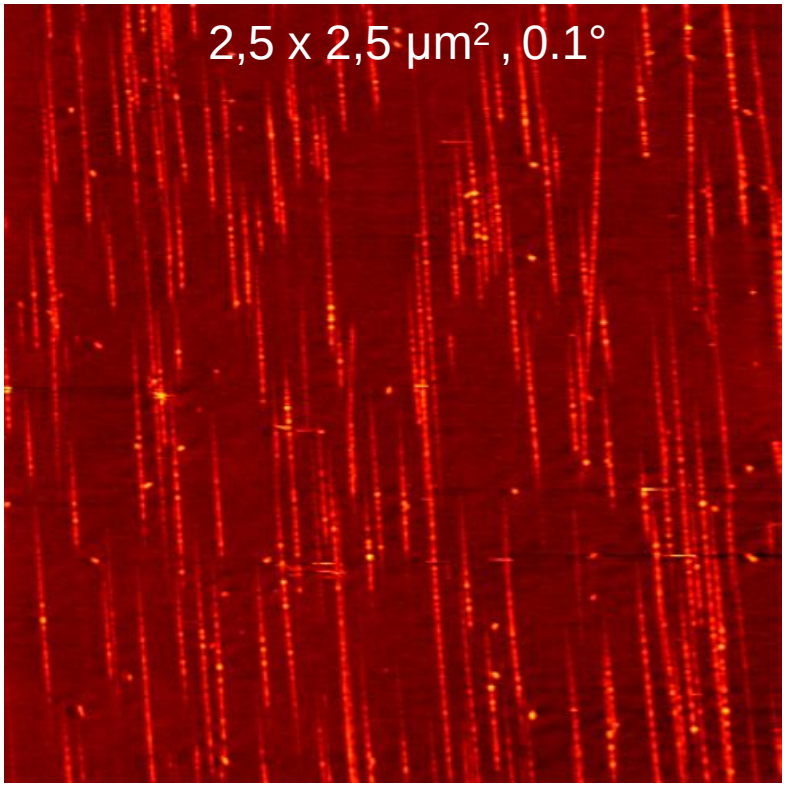

1 x 1 µm² , 0.3°


chain length l [nm]
angle of incidence θ [degree]
L
Θ
d
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
0
1
2
3
4
5
6
7
8
9
10

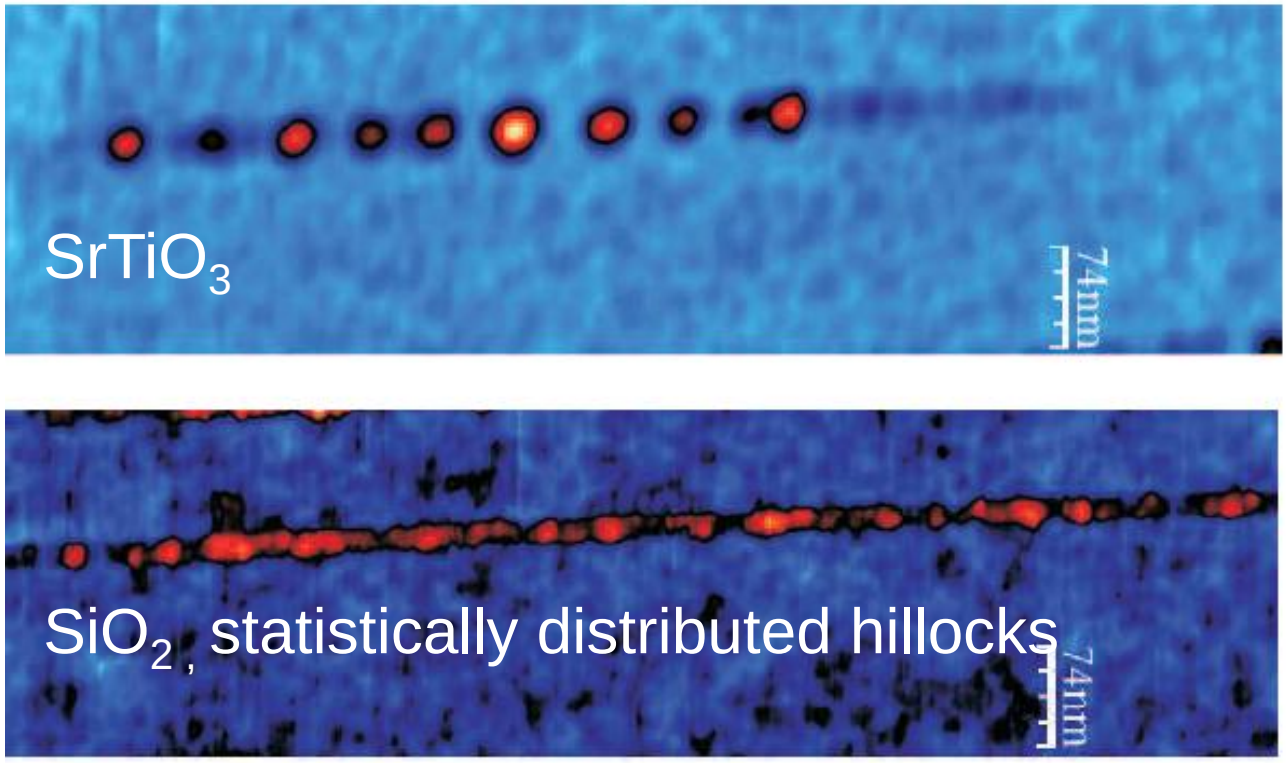
TiO_2

- Hillock chains on all kind of dielectrics





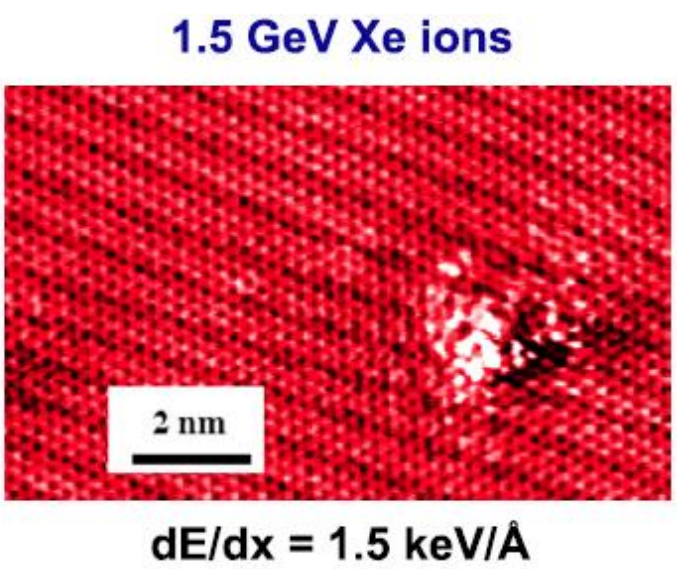
Crystalline vs. amorphous

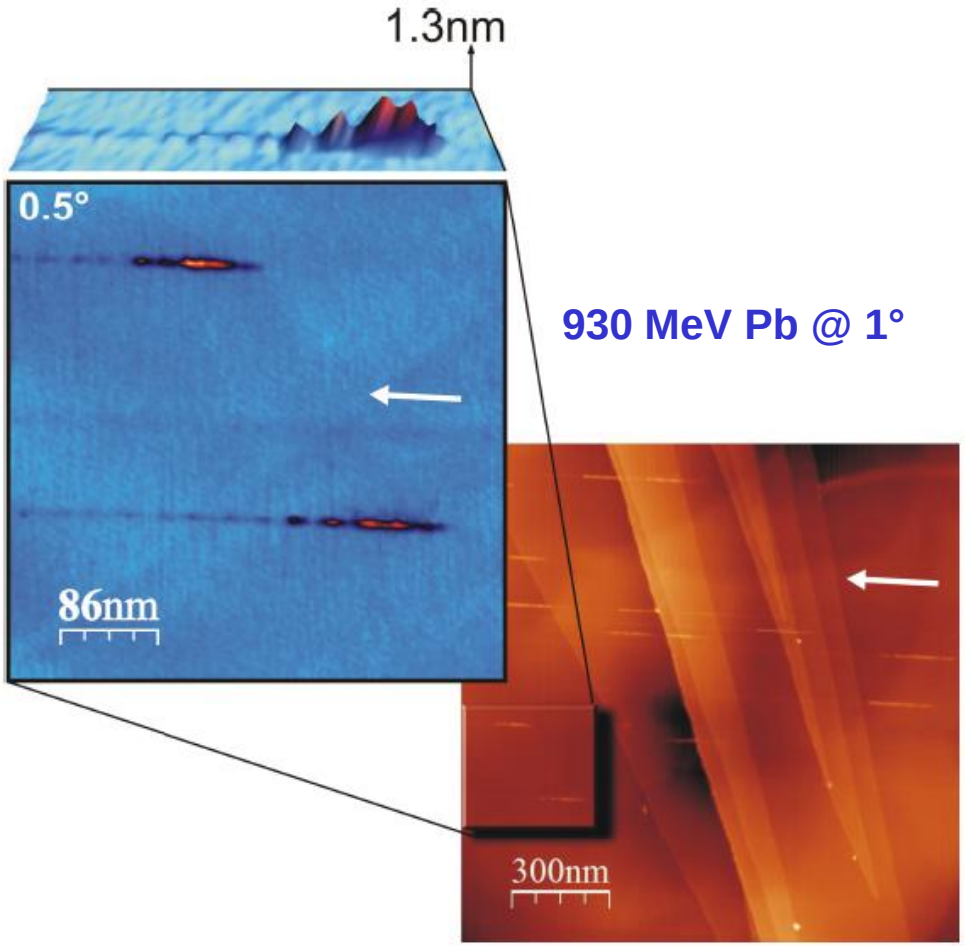


S. Akcöltekin et al., NIMB 267 (2009) 1386

Graphite

- tracks, hillocks and chains with SHI





J. Liu et al., PRB 64, 184115 (2001)
S. Akcöltekin et al., JVST B (2009)

Can we induce defects in silicon by single swift heavy ions?

- Densitiy and heat capacity & thermal spike

Crystal	$\rho c T_o$ J/cm^3	E_g eV	track[a] yes/no	$a(0)$ nm
InSb[p]	607	0.17	y	13.0±1.2
GaSb[p]	995	0.67	y	11.2±1.0
InAs[p]	1370	0.36	y	9.8±0.9
InP[p]	1677	1.27	y	7.95±0.72
Ge (Ref. 5)	1713	0.67	n	
GaAs[p]	2249	1.35	n	
Si (Ref. 3)	2890	1.1	n	

Szenes et al., PRB 65, 045206 (2002)

Can we induce defects in silicon by electronic exciation at all?

Experimental evidence up to now:

- Damage from nuclear collisions (el. resistance)
- No extended damage (DLTS)
- No tracks (TEM)

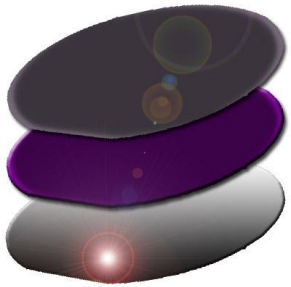
In what kind of materials can we induce damage by swift heavy ions?

- Rule of thumb

Dielectrics

Defects, tracks, hillocks, surface tracks, …

Semi-Conductors & -Metals



Defects, tracks, hillocks, surface tracks, …
Si, Ge, GaAs: Insensitive

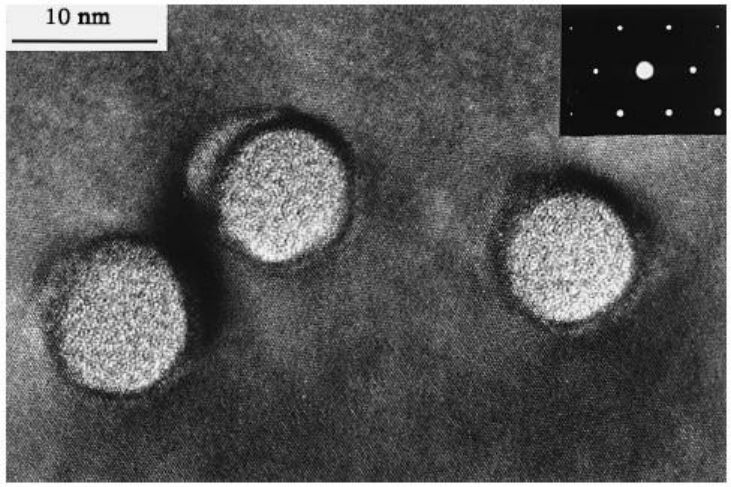
Metals

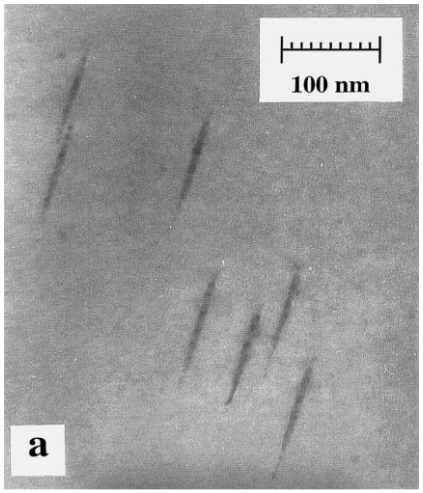
Transient defects & tracks higher threshold

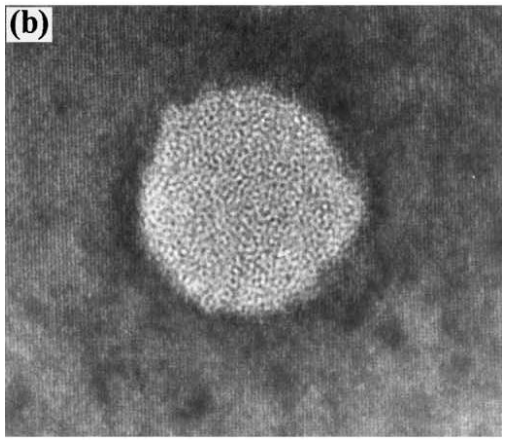
BUT …

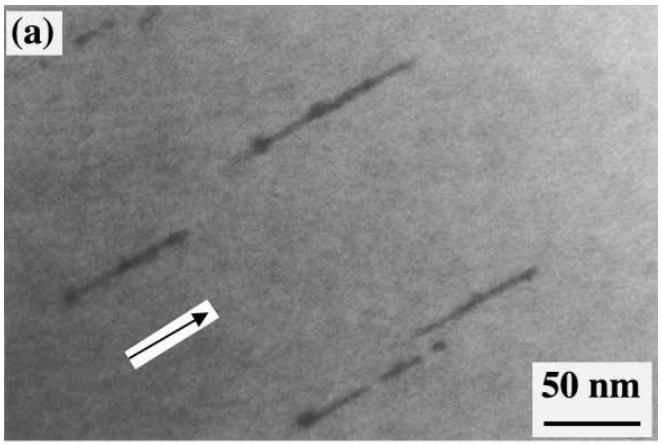
Si and Ge

- Tracks only after irradiation with C_{60}









Dunlop et al., PRB 64, 184115 (1998)
Colder et al., NIMB 174, 491 (2001)
Canut et al., NIMB 146, 296 (1998)

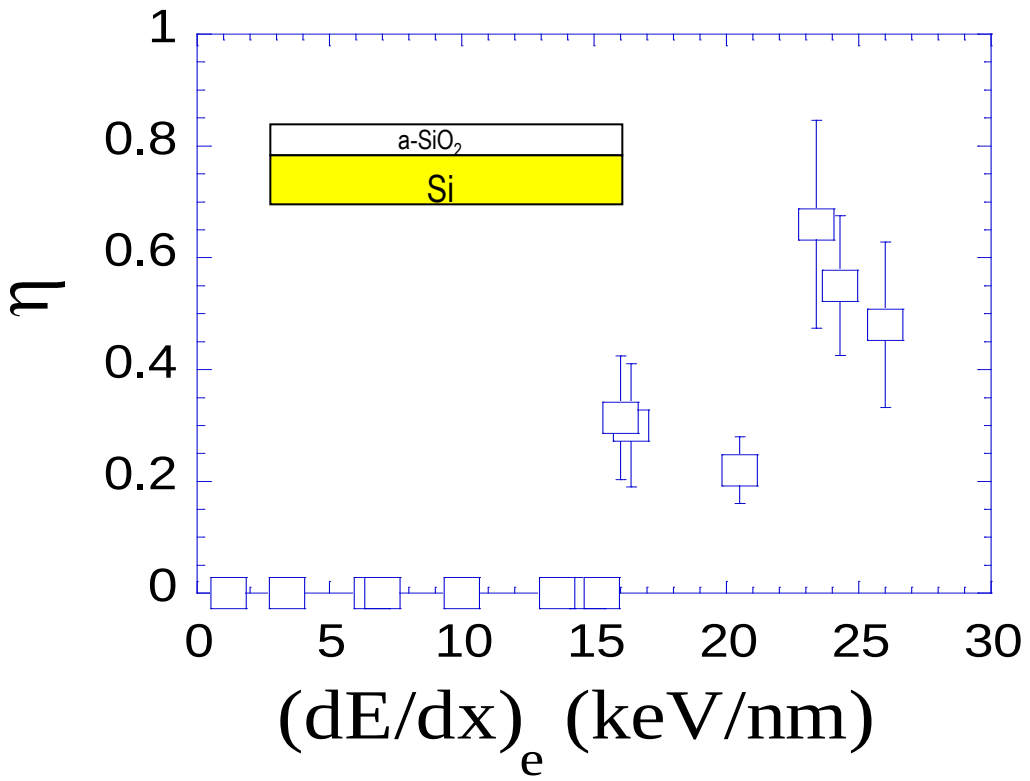
Can we induce defects in silicon by electronic exciation at all?

- Damage from nuclear collisions (el. resistance)
- No extended damage (DLTS)
- No tracks (TEM)

- Damage can be induced in small grains
- Damage can be induced with C_{60}
- Surface damage can be induced by slow highly charged ions
- Si/SiO_2 heterostructures show …

Irradiation of SiO_2/Si

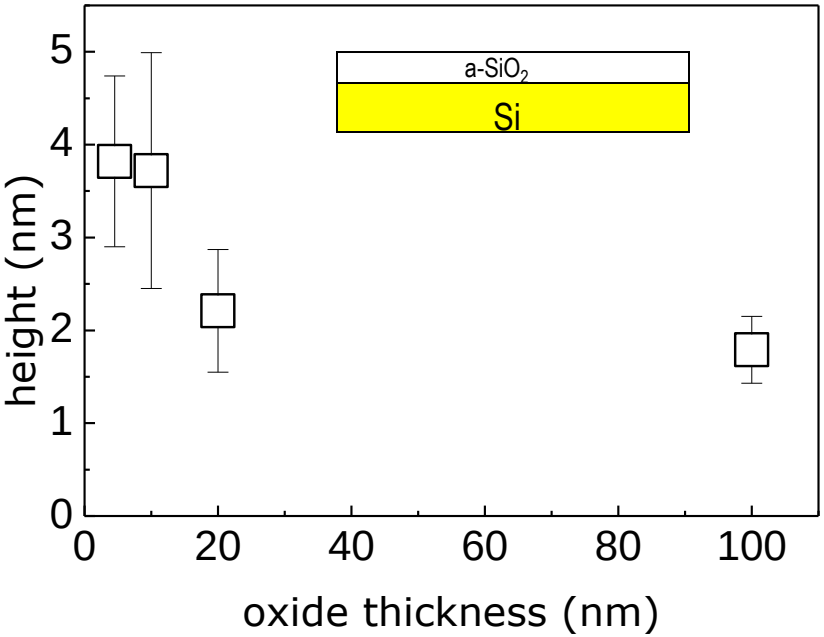
- Important for electronic devices
- Surface damage threshold: 16 keV/nm
- Structure creation efficiency < 1

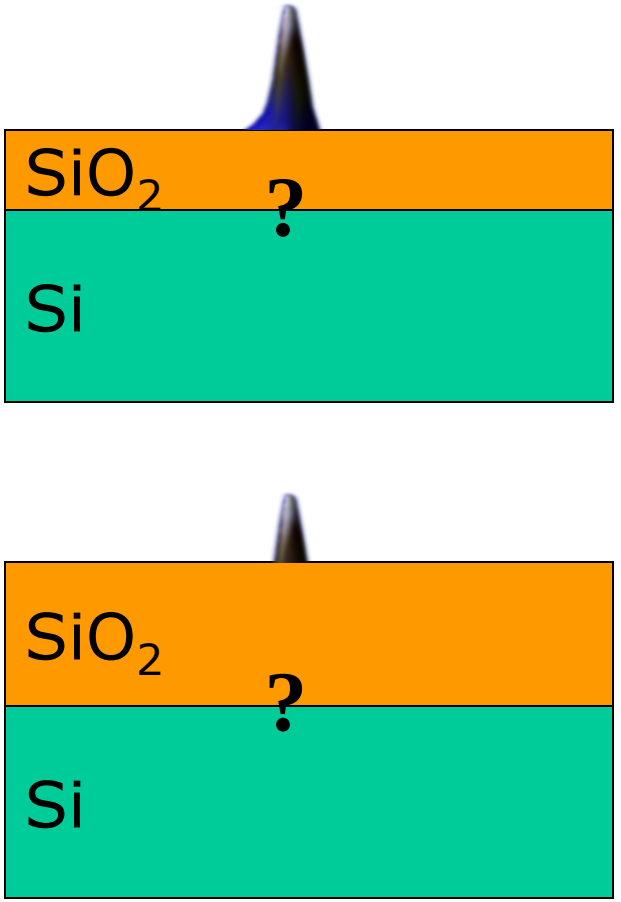


Rotaru, thesis (2005)

Irradiation of SiO_2/Si

- Pb: E = 2 MeV/u
- $(dE/dx)_e$ = 16 keV/nm



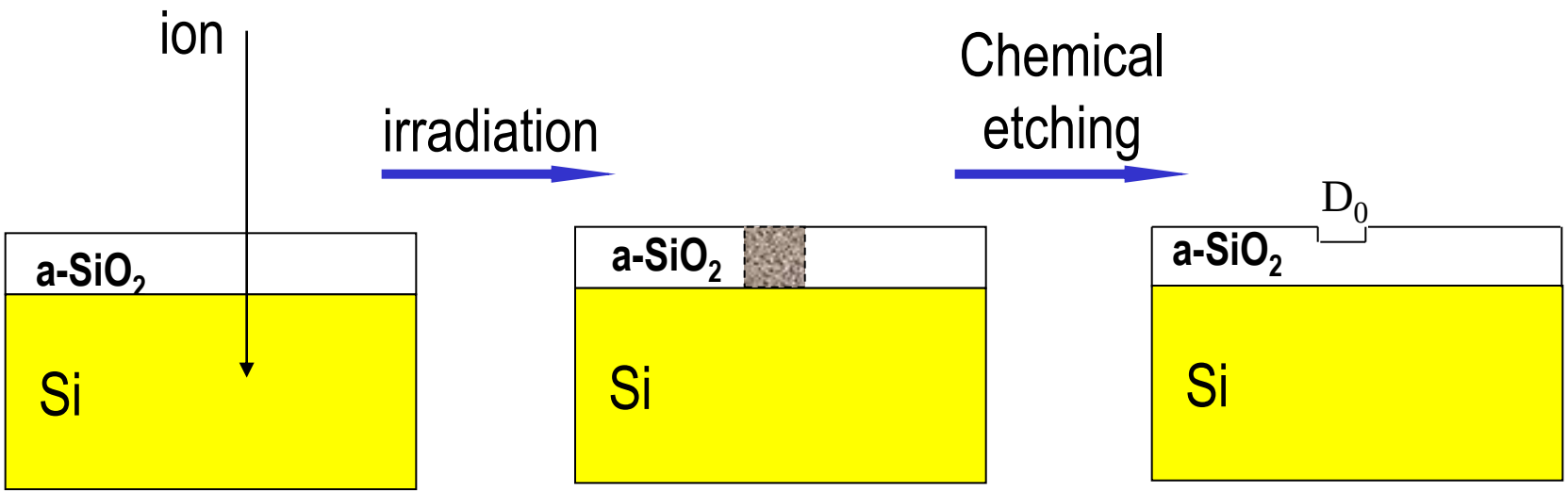


- Hillocks must come from Si or from the interface

Rotaru, thesis (2005)

Irradiation of SiO_2/Si

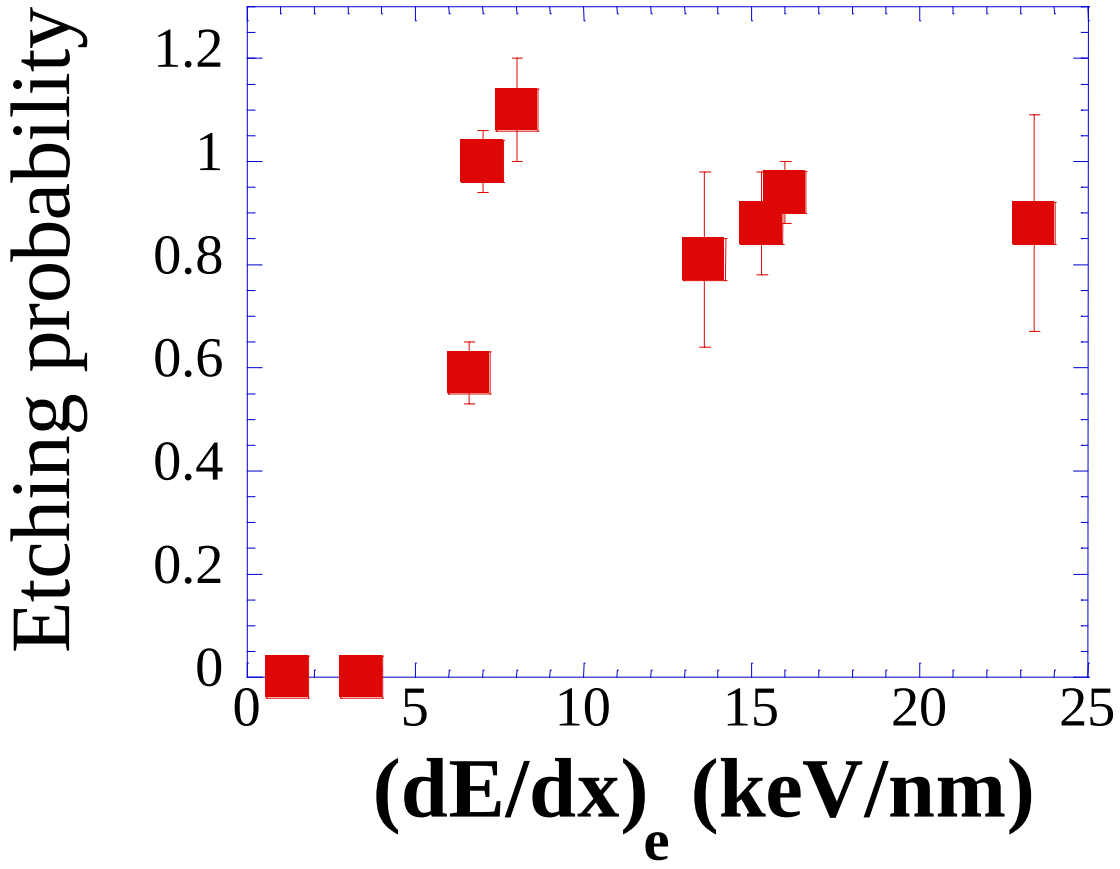
- Etched samples



Rotaru, thesis (2005)

Irradiation of SiO_2/Si

- Etched samples show threshold at 5 keV/nm

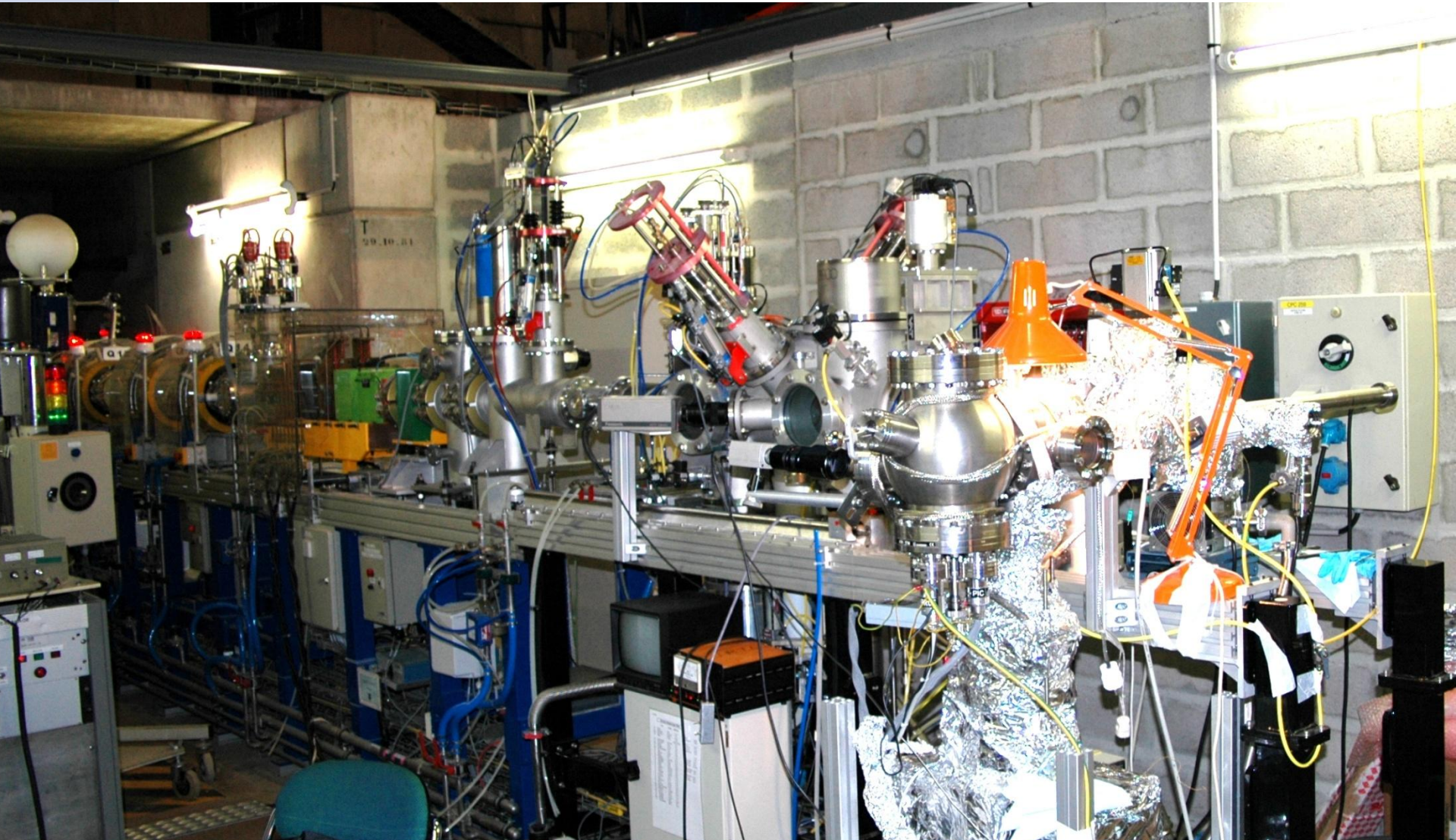


Is silicon damage possible by electronic excitation?

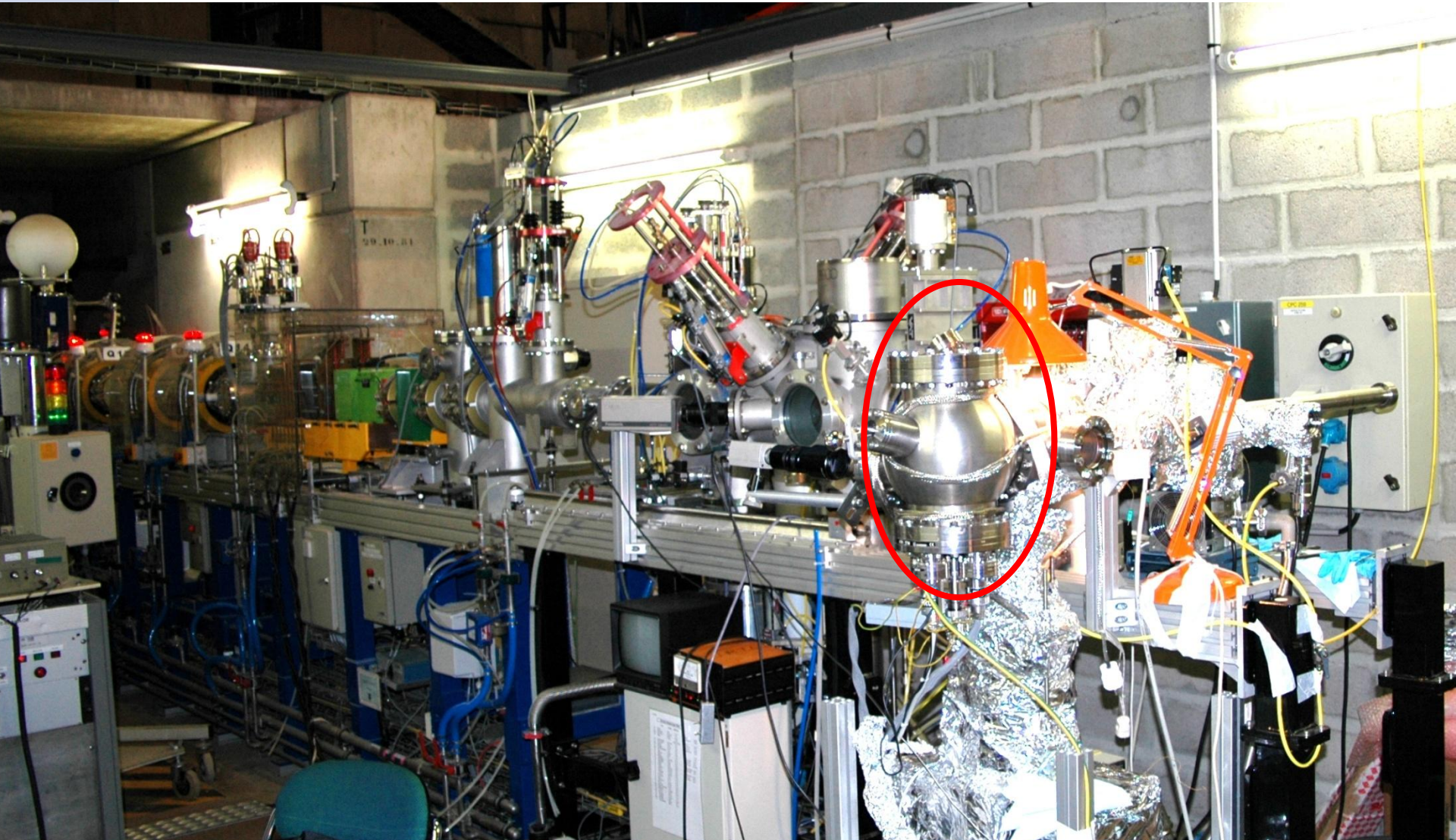
- No bulk tracks!
- Surface damage (hillocks or craters)?
- Surface tracks?

- New approach:
  Prepare Si(111)7x7 in-situ in UHV and check surface after irradiation without breaking the vacuum!

Experimental setup: UHV STM/AFM

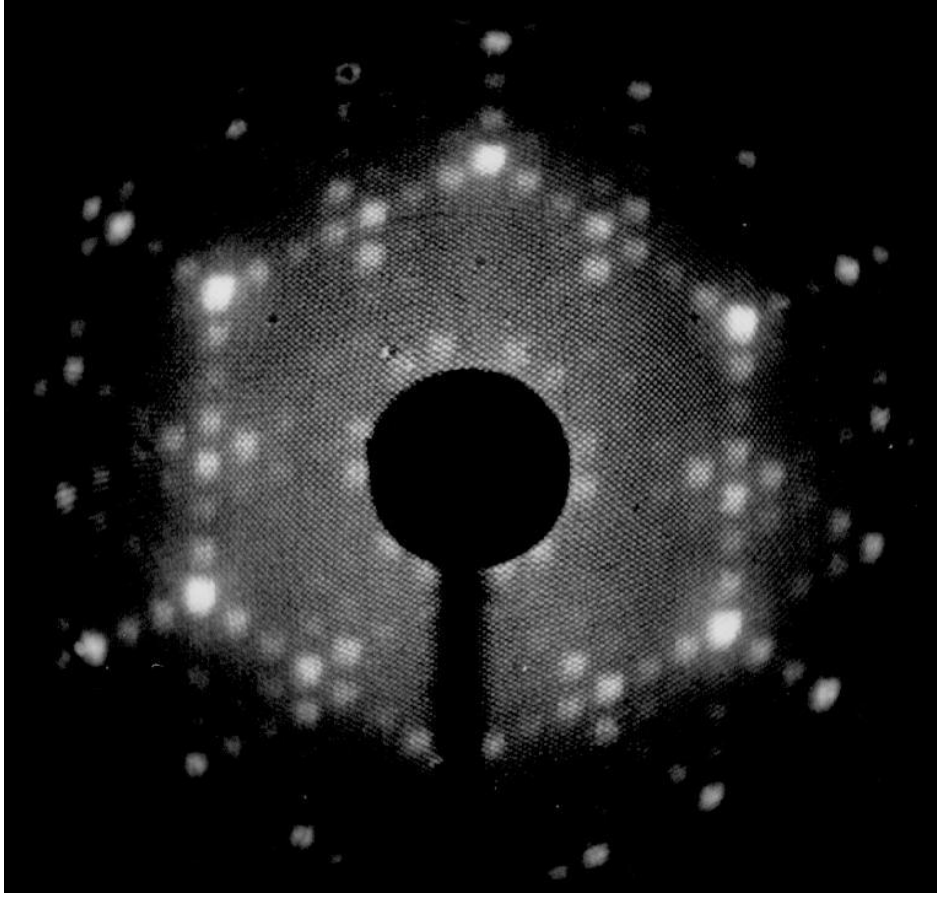


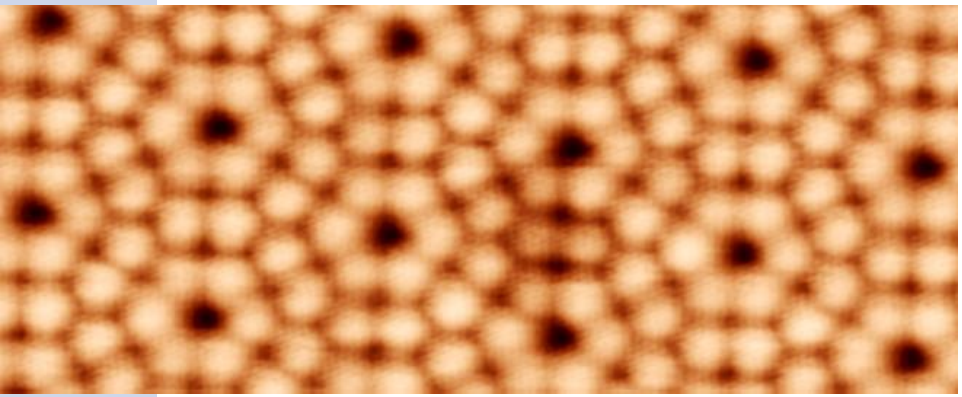
Experimental setup: UHV STM/AFM

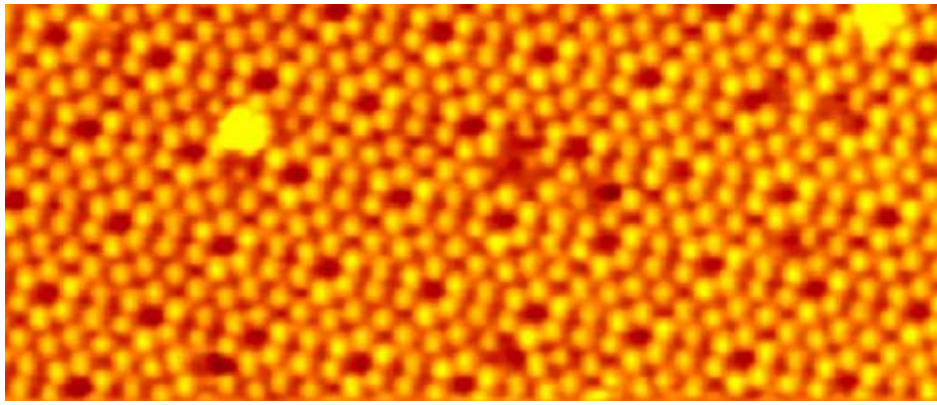


Experimental setup: STM/AFM/LEED

- In-situ AFM → Topography
- In-situ STM → Electronic states
- LEED → Long range order

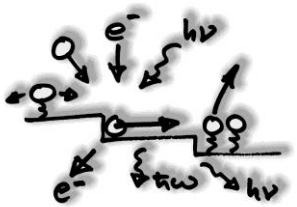






Funding & Collaborators:

SPIRIT



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