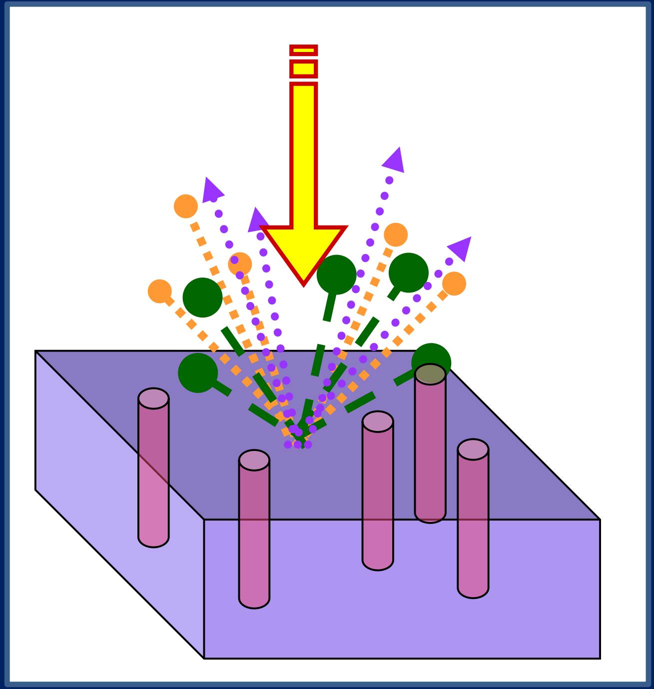
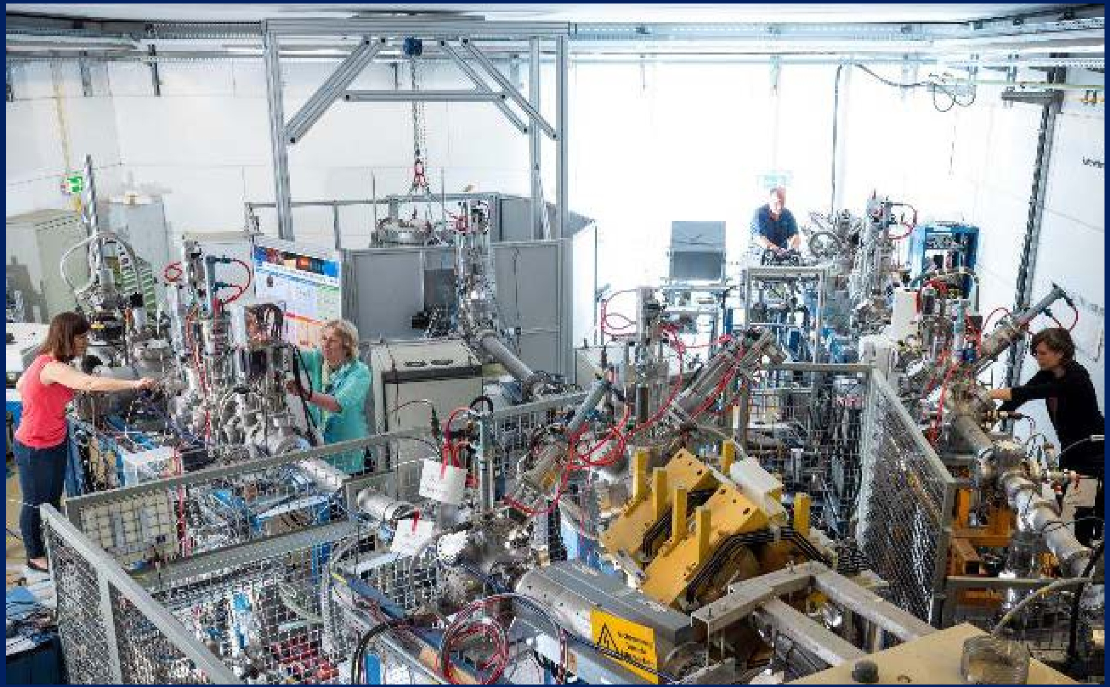
Material science with MeV-GeV heavy ions

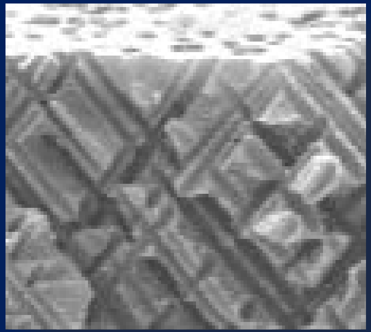
Basic interactions

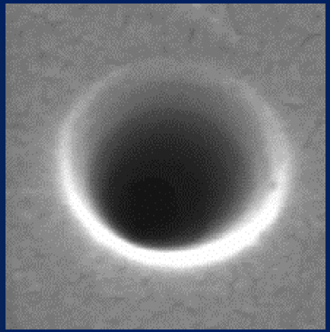
Facility & research topics

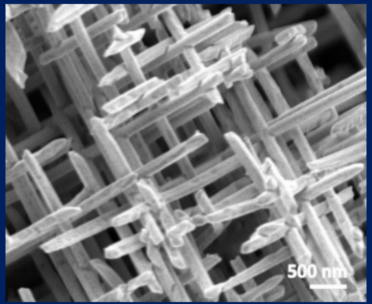
Nanotechnology & applications

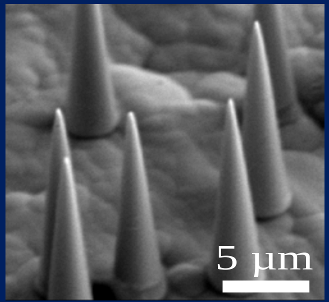




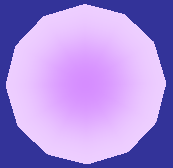






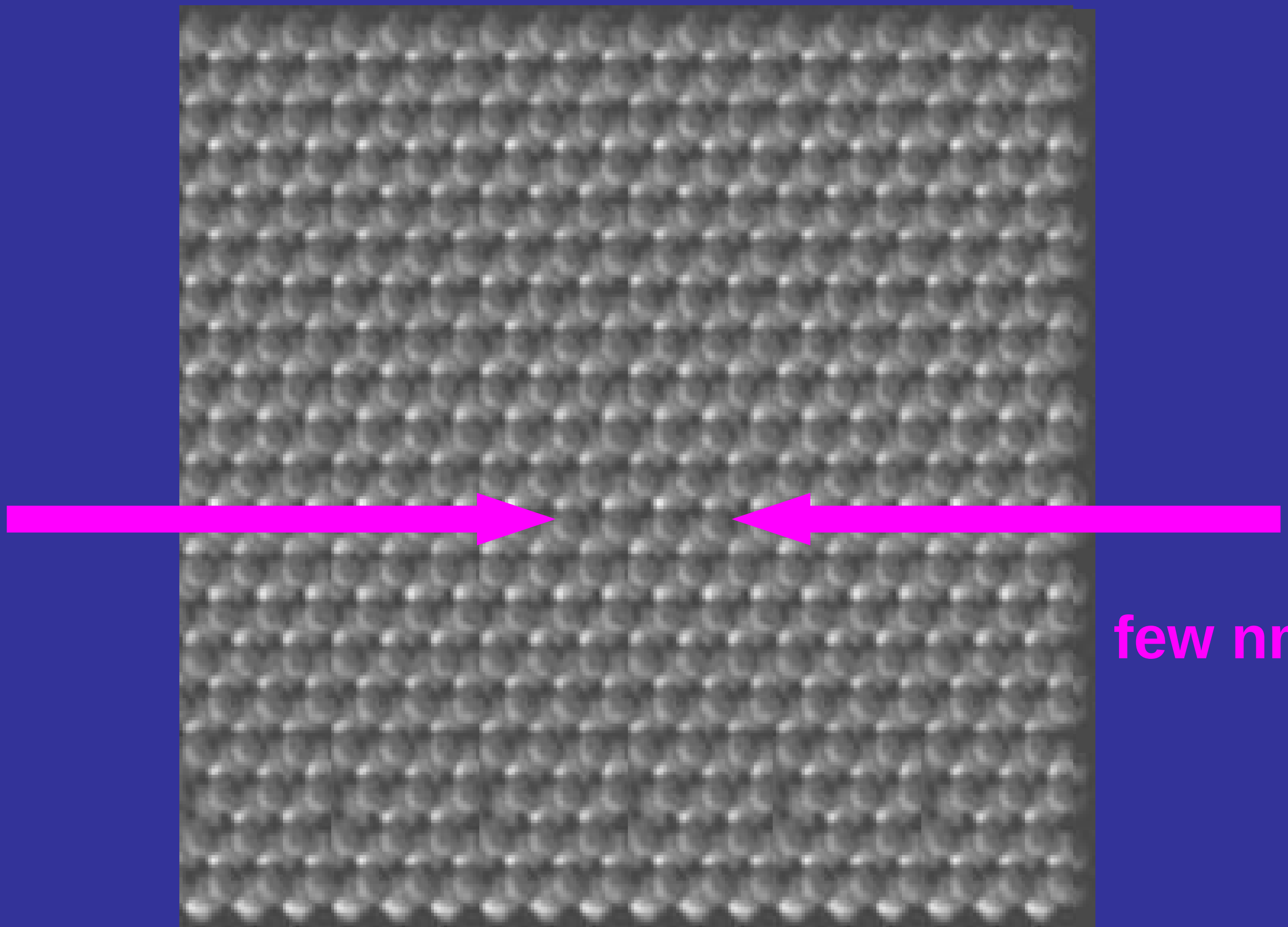


single heavy ion projectile



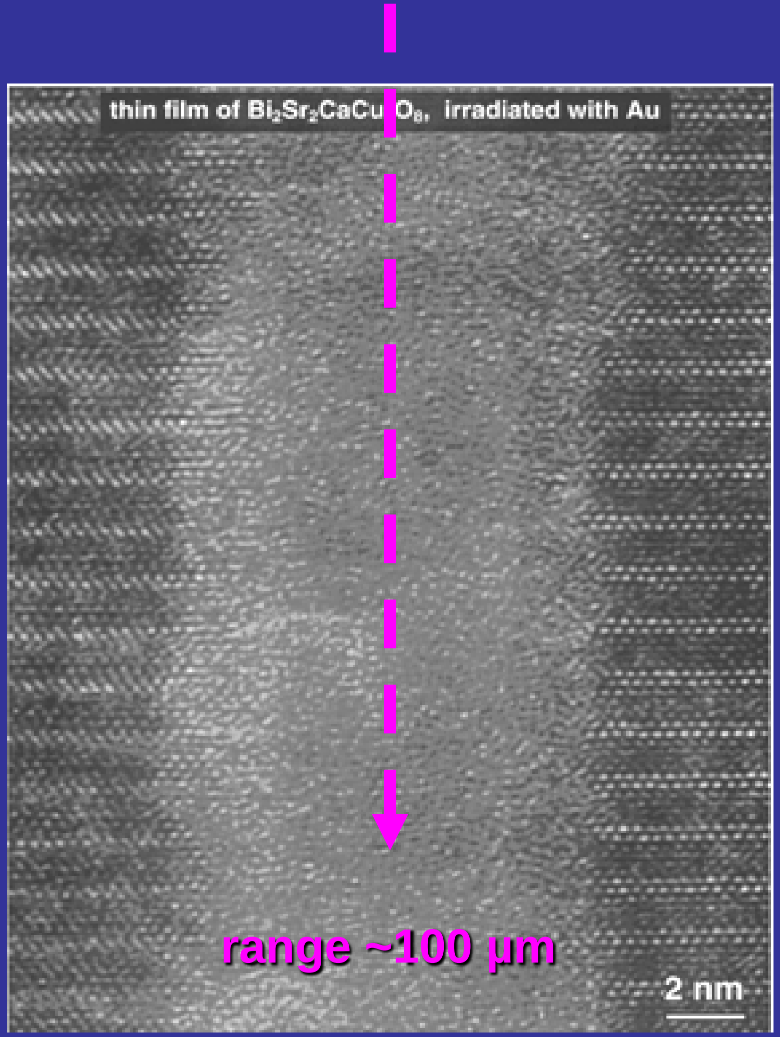
2 GeV heavy ion

v= 15% c



few nm

track formation mainly in insulators

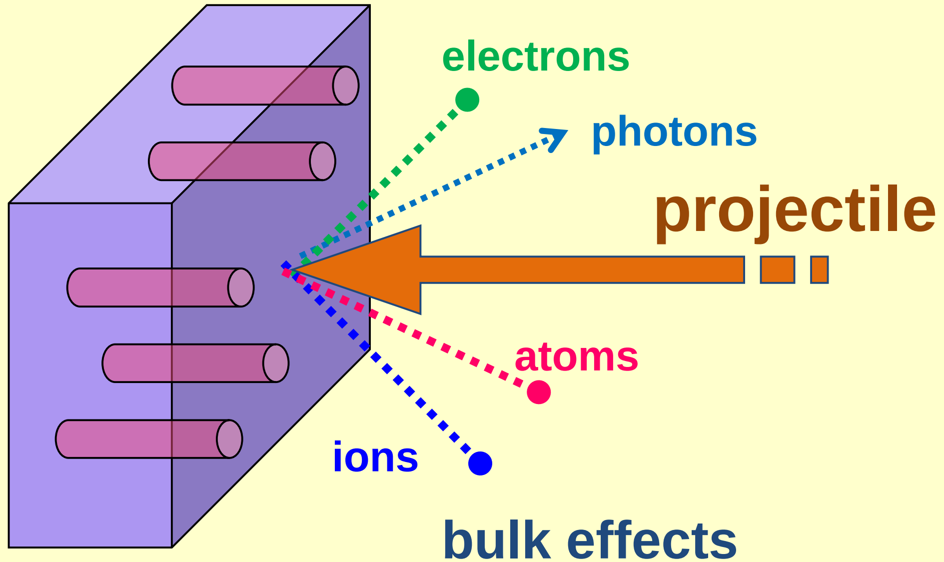


J. Wiesner, Physica C (1996)

Material science: topics and activities

surface effects

- emission of e^- and photons
- sputtering of ions & neutrals
- hillock or crater formation

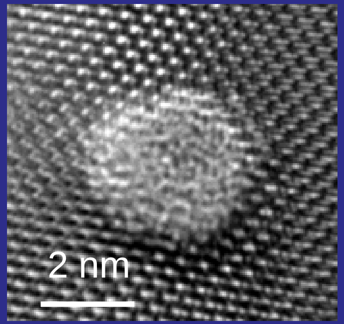


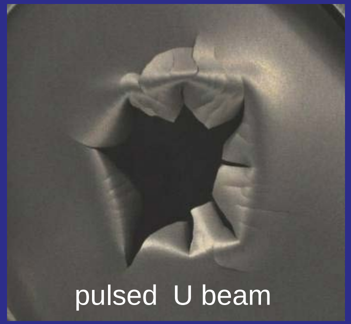
bulk effects

- structural changes
- defect formation
- swelling / stress

Radiation effects

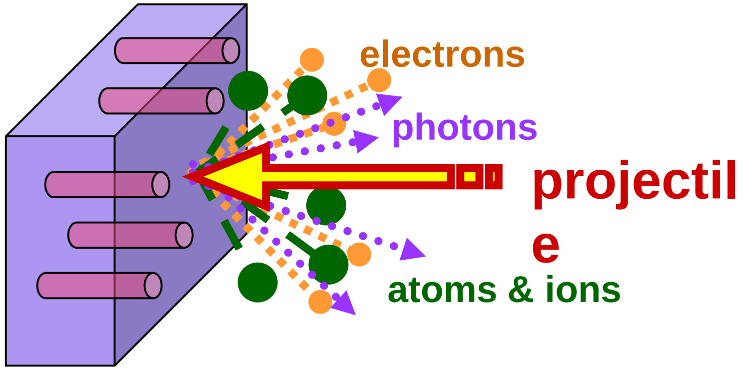
- track formation
- structural and other changes
- desorption and sputtering
- radiation hardness
- dose limits for functional materials





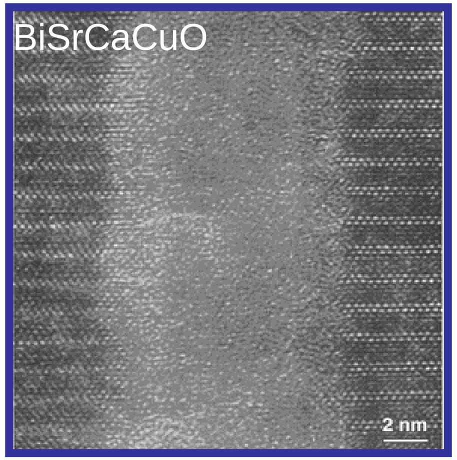
Materials science with swift heavy ions

destructive power



track formation & radiation damage

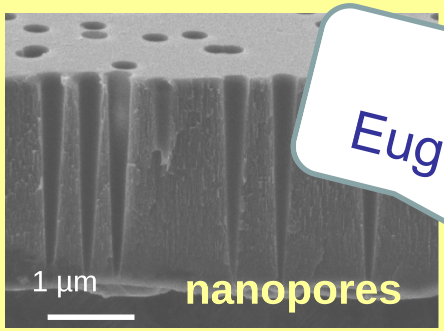
microscopic



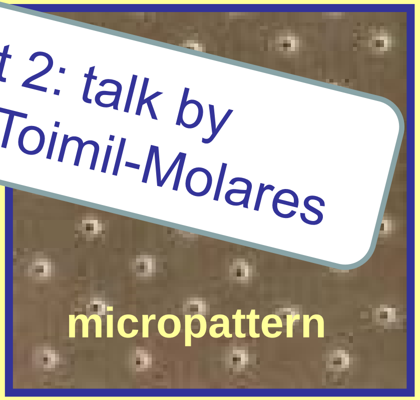
macroscopic

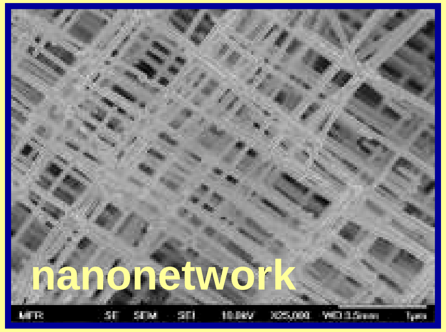
C. Trautmann, Micro- and Nanoengineering with Ion Tracks (2010)
DOI 10.1007/978-3-642-00623-4 30

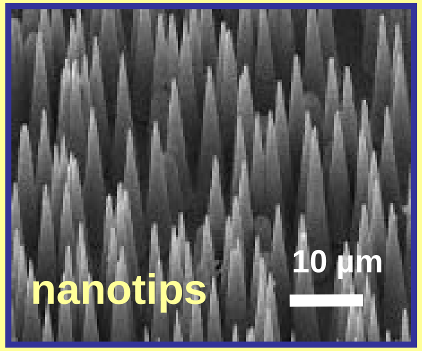
structuring tool

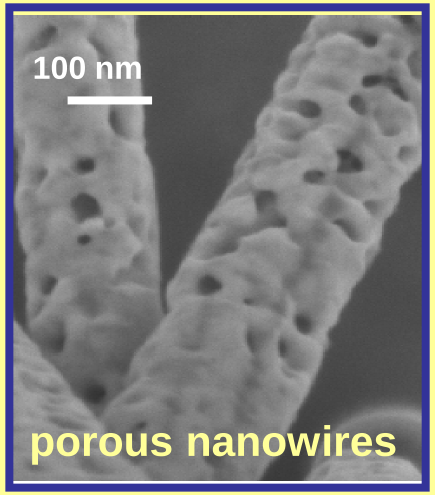


Part 2: talk by Eugenia Toimil-Molares



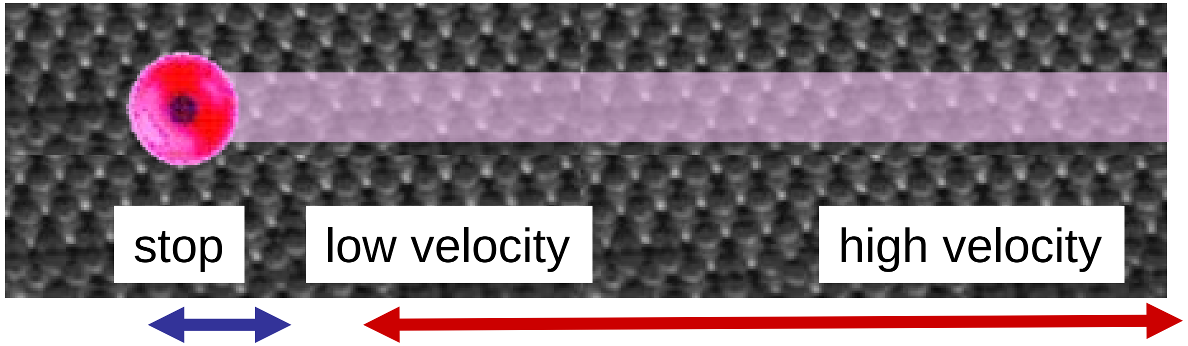






M.E. Toimil-Molares, Beilstein J. Nanotechnol 3 (2012) 860

Slowing down process of ions in solids



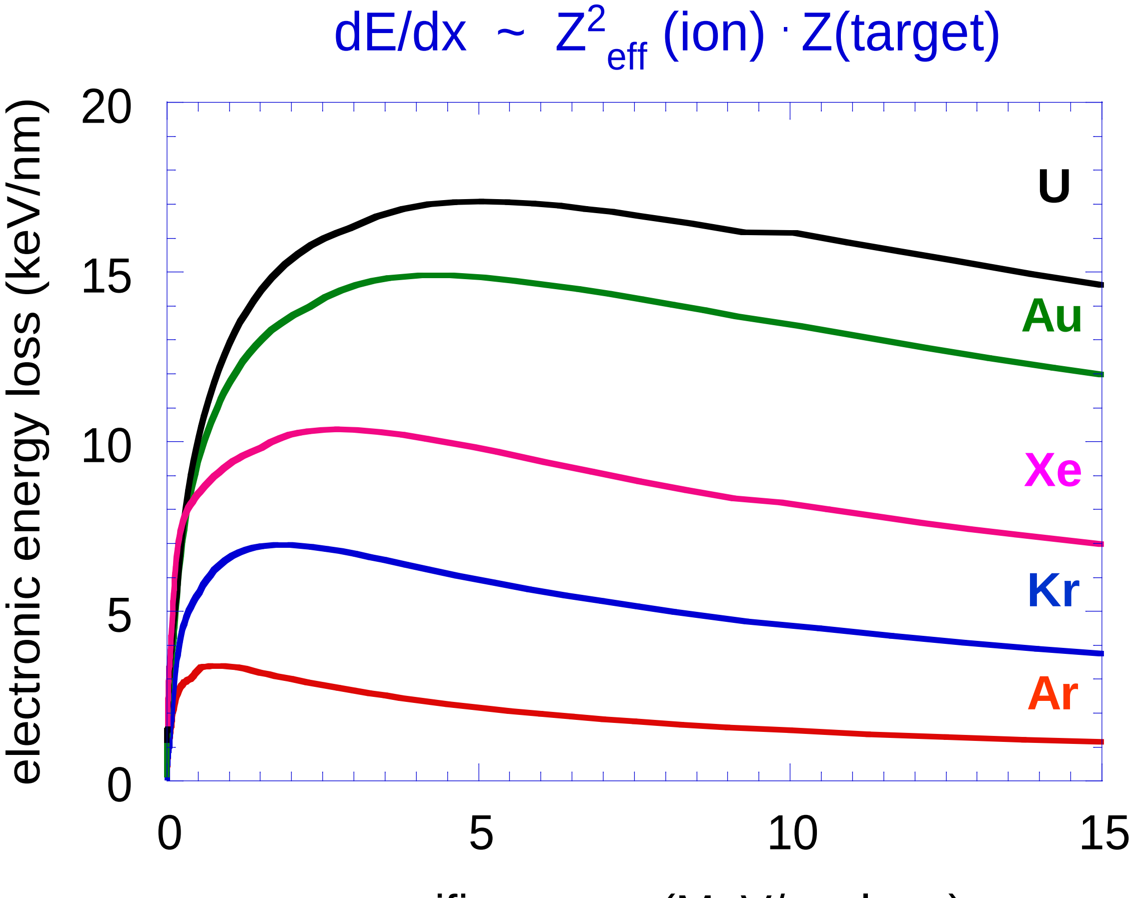
1 µm

99 µm

elastic collisions with atoms

collisions with electrons excitation and ionization

electron cascade

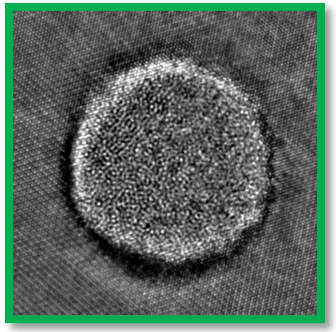


SRIM code

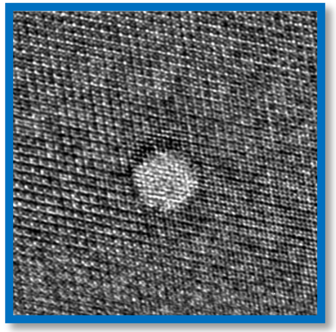
Slowing down process of ions in solids

ion track in pyrochlor $Gd_2Ti_2O_7$

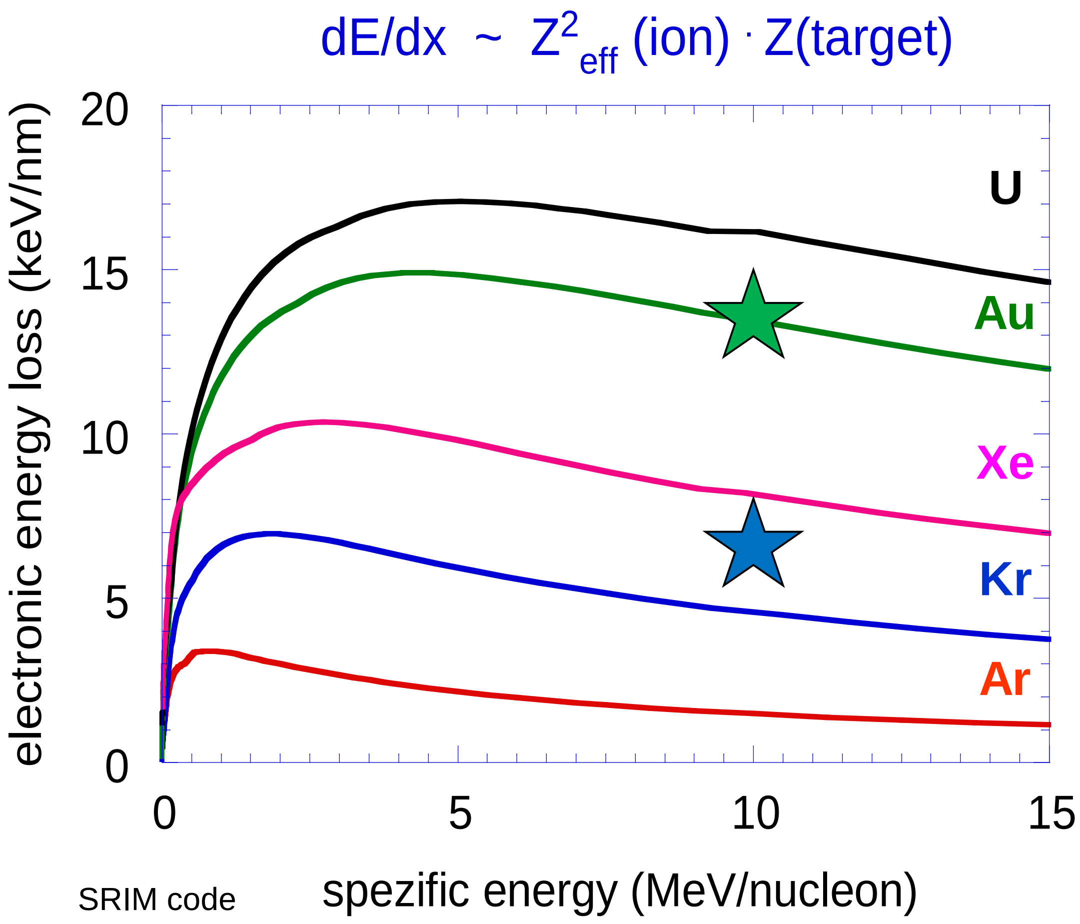
^{197}Au



^{101}Ru

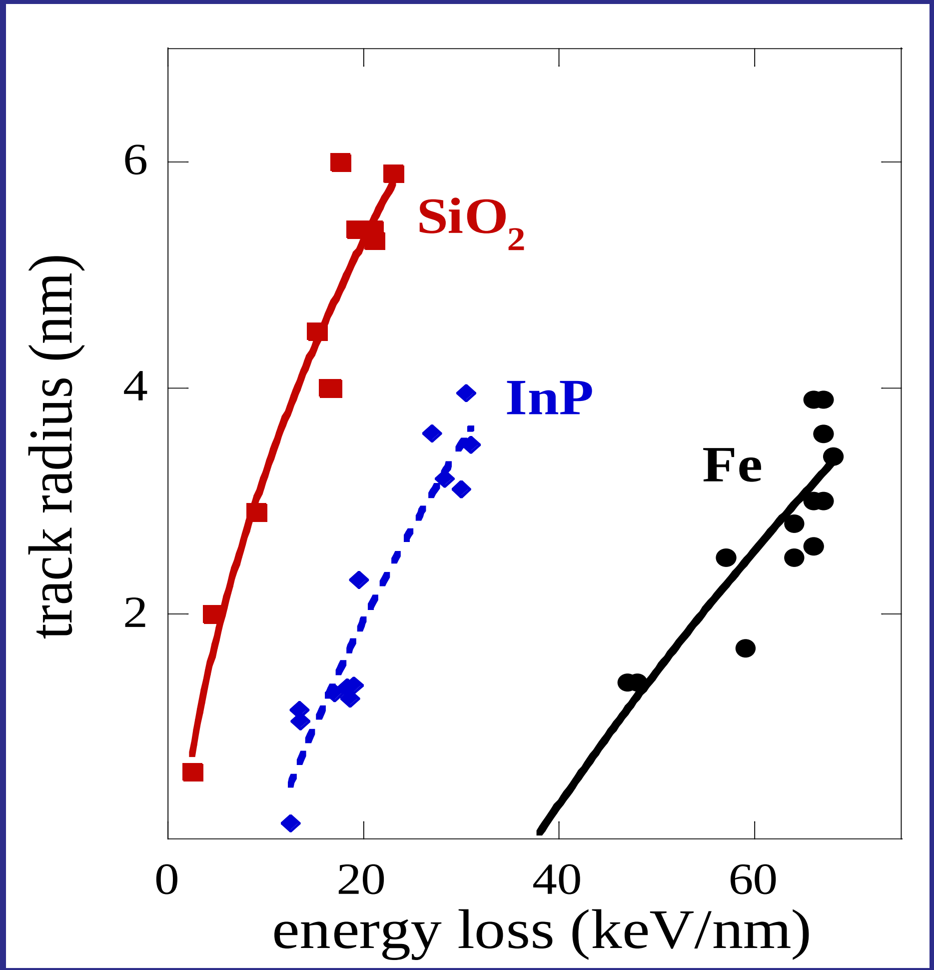


energy loss determines track size



by courtesy of M. Lang, Tennessee

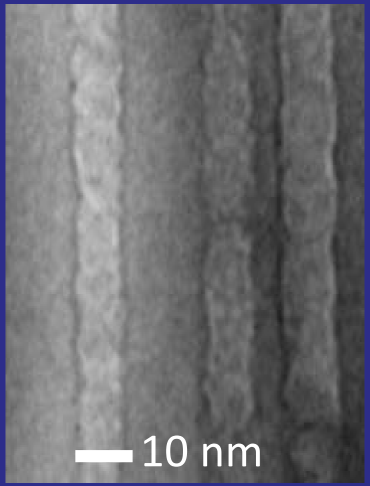
Characteristics of swift heavy ions (MeV-GeV)

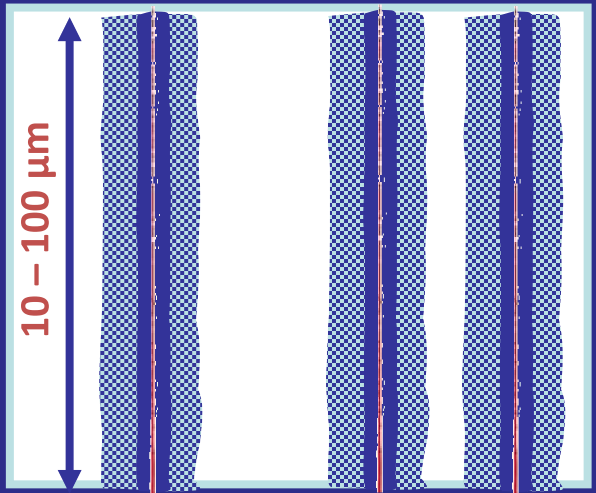


- each ion produces individual cylindrical track
- huge energy deposition (keV/nm)
- non-equilibrium conditions (fs, nm scale)
- transient processes (thermal spike, shockwave)
- localized phase changes (amorphous, defects)
- track formation requires critical energy loss
- track formation is material dependent

Sensitivity:

insulators > semiconductors > metals

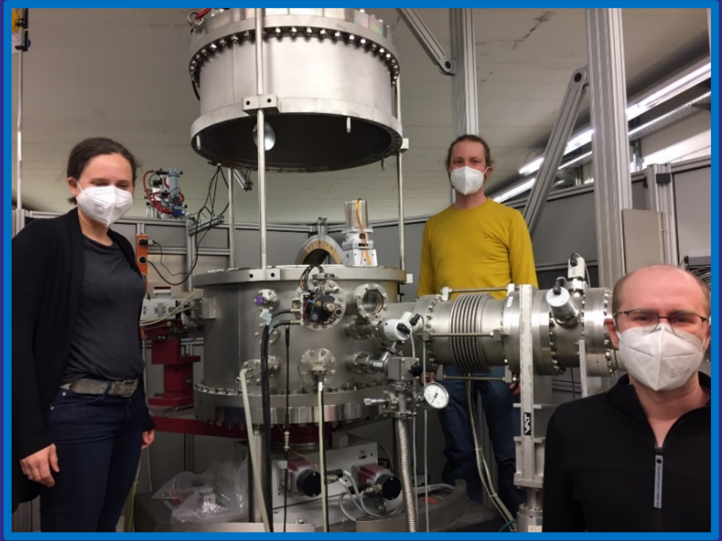




User platform for Material Science

Technical requirements

- different ion species
- broad energy range
- broad fluence regime
- exposure of large samples (few cm^2)
- adjustable temperature conditions

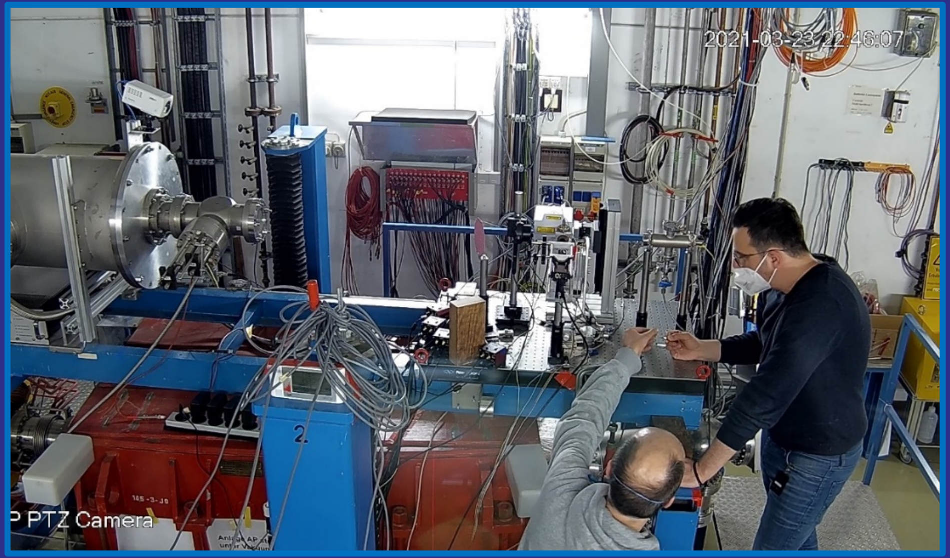


important

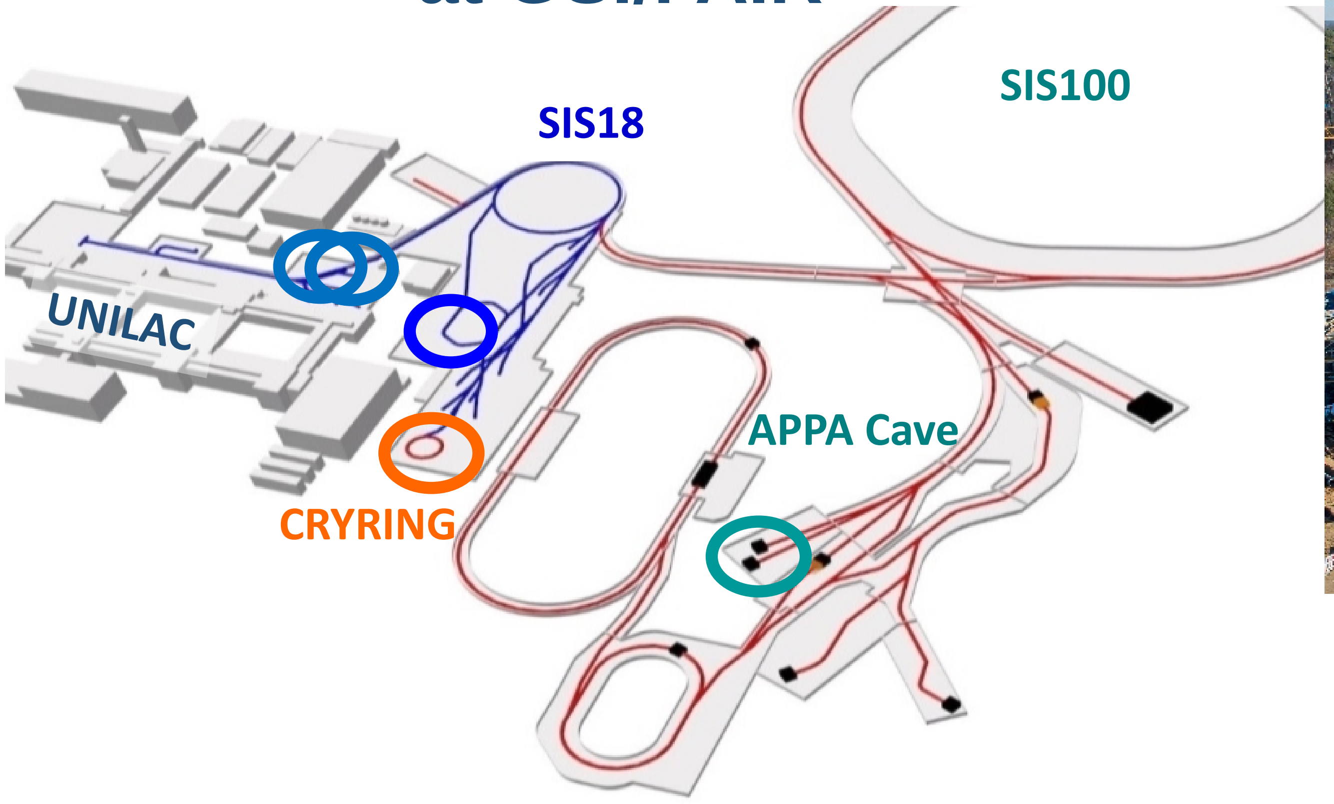
Dedicated beamlines

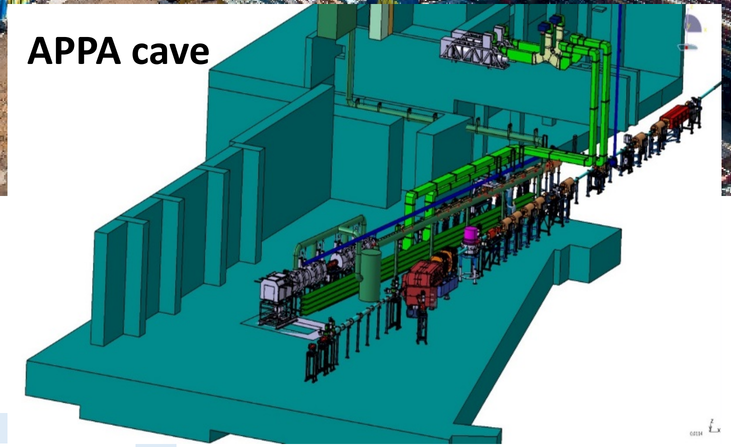
Flexibility to adjust to users needs

In-situ and online characterization



User platform for Material Science at GSI/FAIR



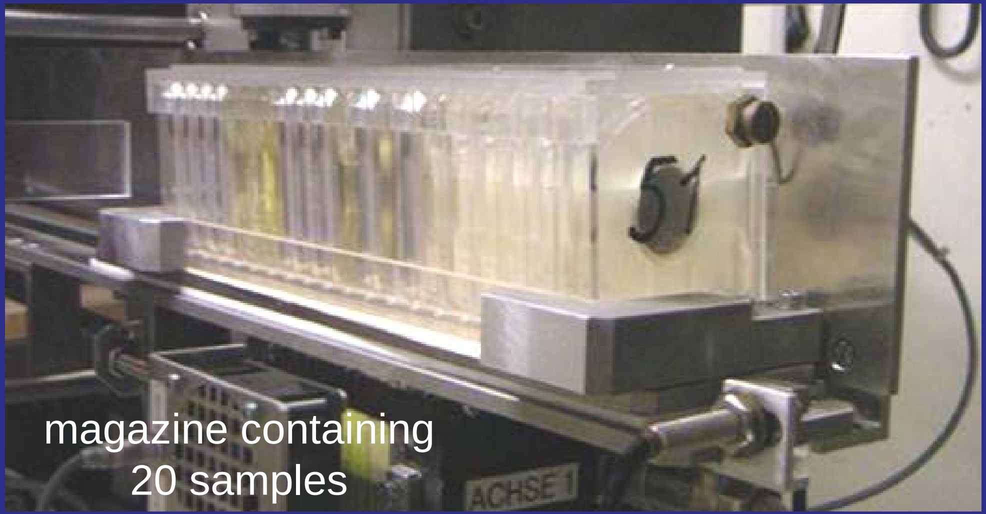


UNILAC 3-11 MeV/u	SIS-18 80-1000 MeV/u	CRYRING 0.3-14 MeV/u	SIS-100 0.1–10 GeV/u
M-Branch beamline X0 microprobe	Cave A GSI high energy cave	MAT station low energy highest charge states	APPA Cave FAIR high energy cave
		beam >2021	beam >2025

APPA
- atomic physics
- plasma physics
- biophysics
- material science

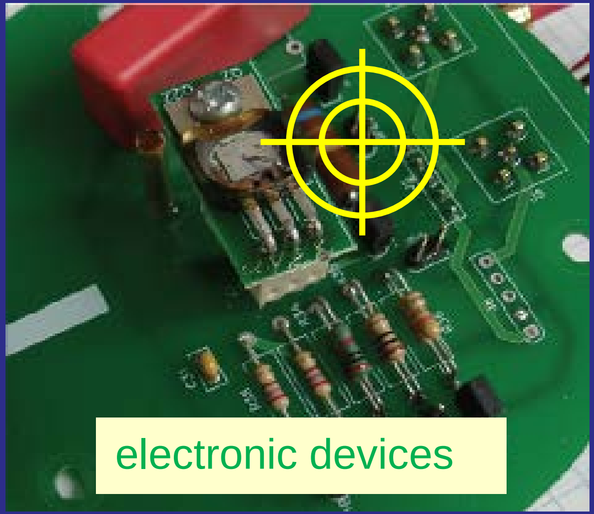
User operation for very diverse user community
(material science, nanoscience, chemistry, biology, geology, mineralogy,...)

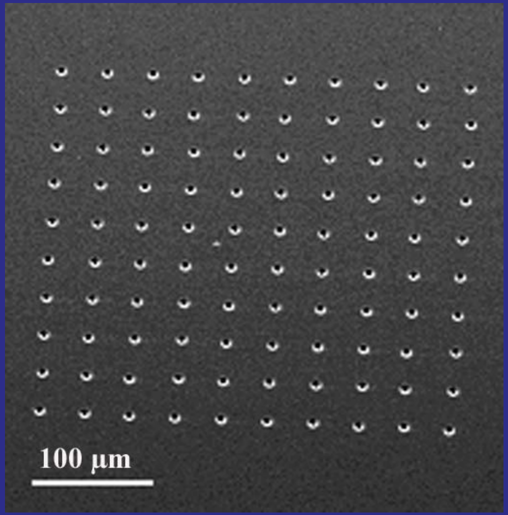
sample exchange system for efficient remote-control operation

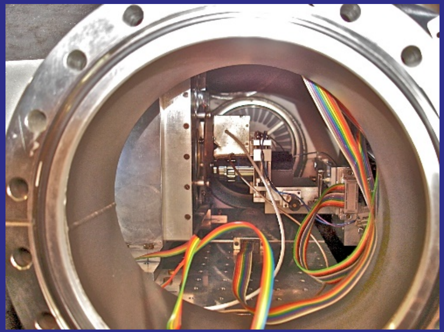


sample holder 5 x 5 cm^2

targeting with single ions at microprobe







energy range: 3-11 MeV/u

targeting precision ~ 1µm

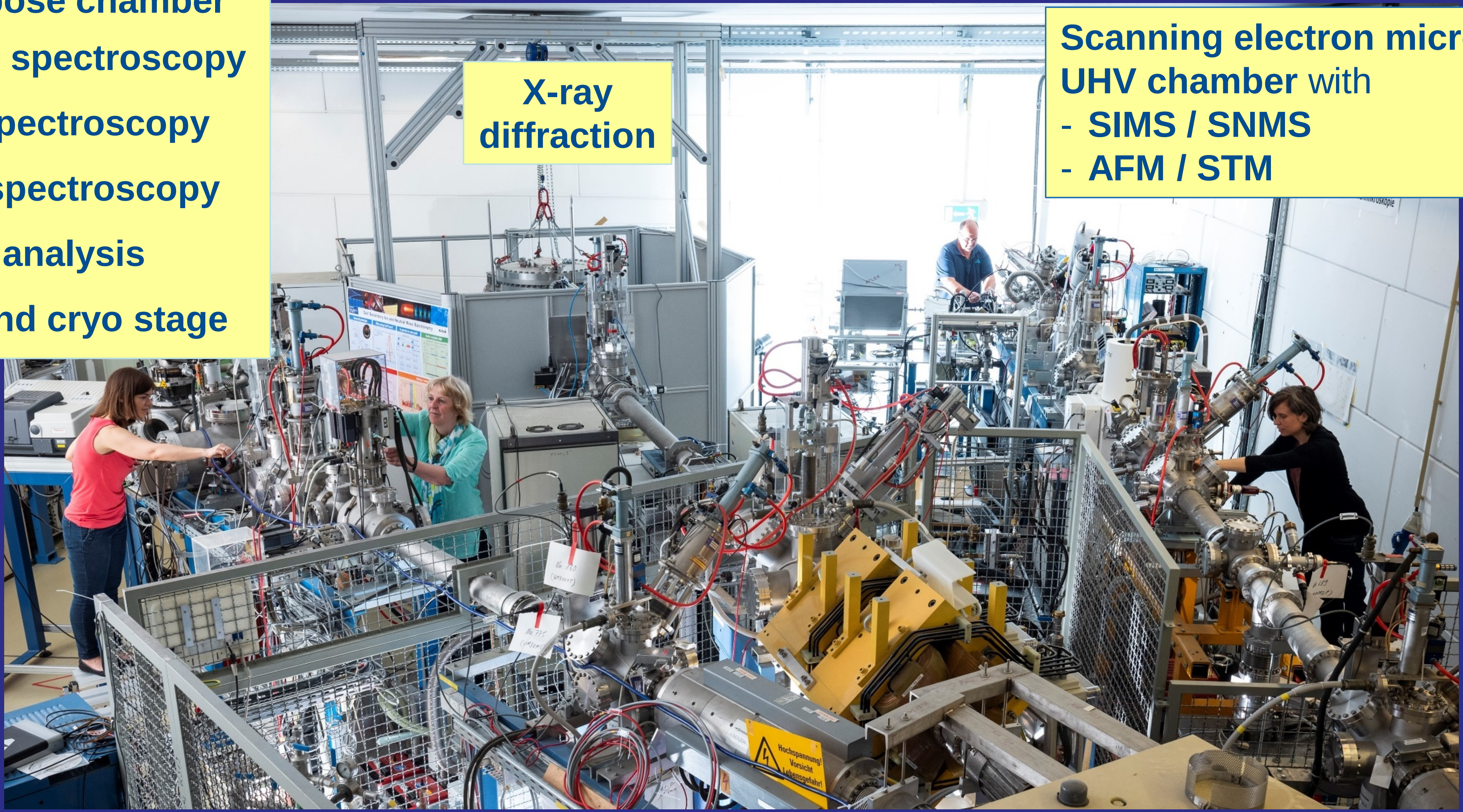
Irradiation combined with in-situ analysis

M-branch at UNILAC (3.6 – 11.4 MeV/u)

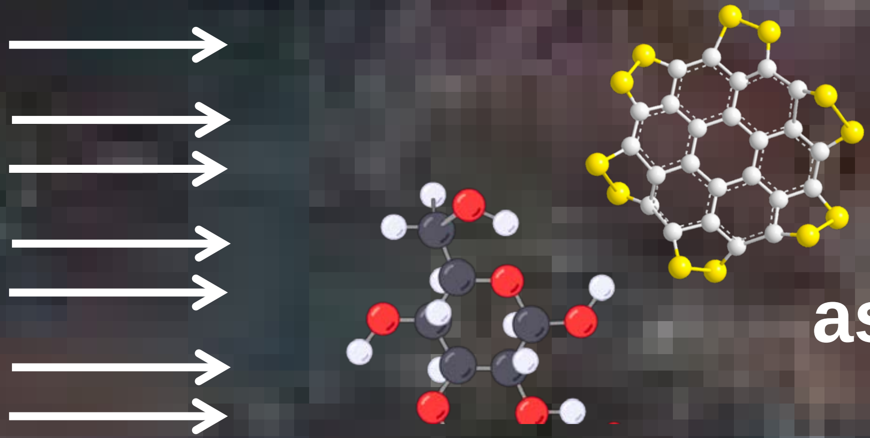
Multi-purpose chamber
- **infra-red spectroscopy**
- **UV-vis spectroscopy**
- **Raman spectroscopy**
- **rest gas analysis**
- **high T and cryo stage**

X-ray diffraction

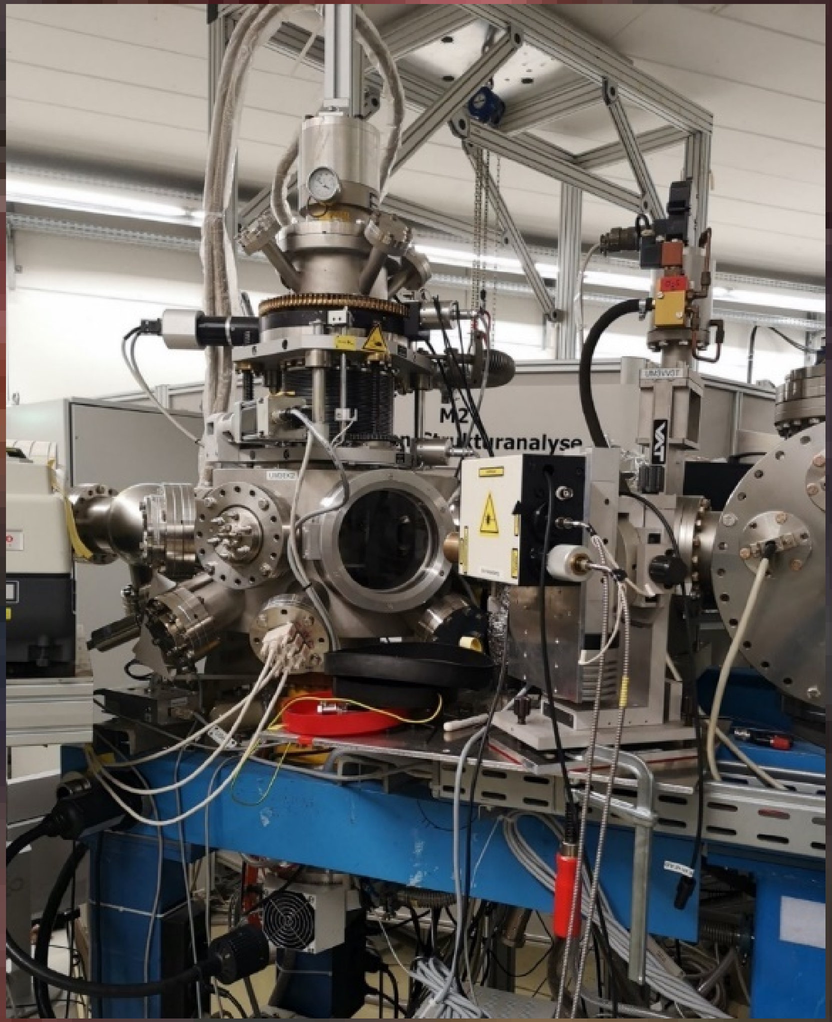
Scanning electron microscopy
UHV chamber with
- **SIMS / SNMS**
- **AFM / STM**



Simulation of cosmic radiation



astrochemistry

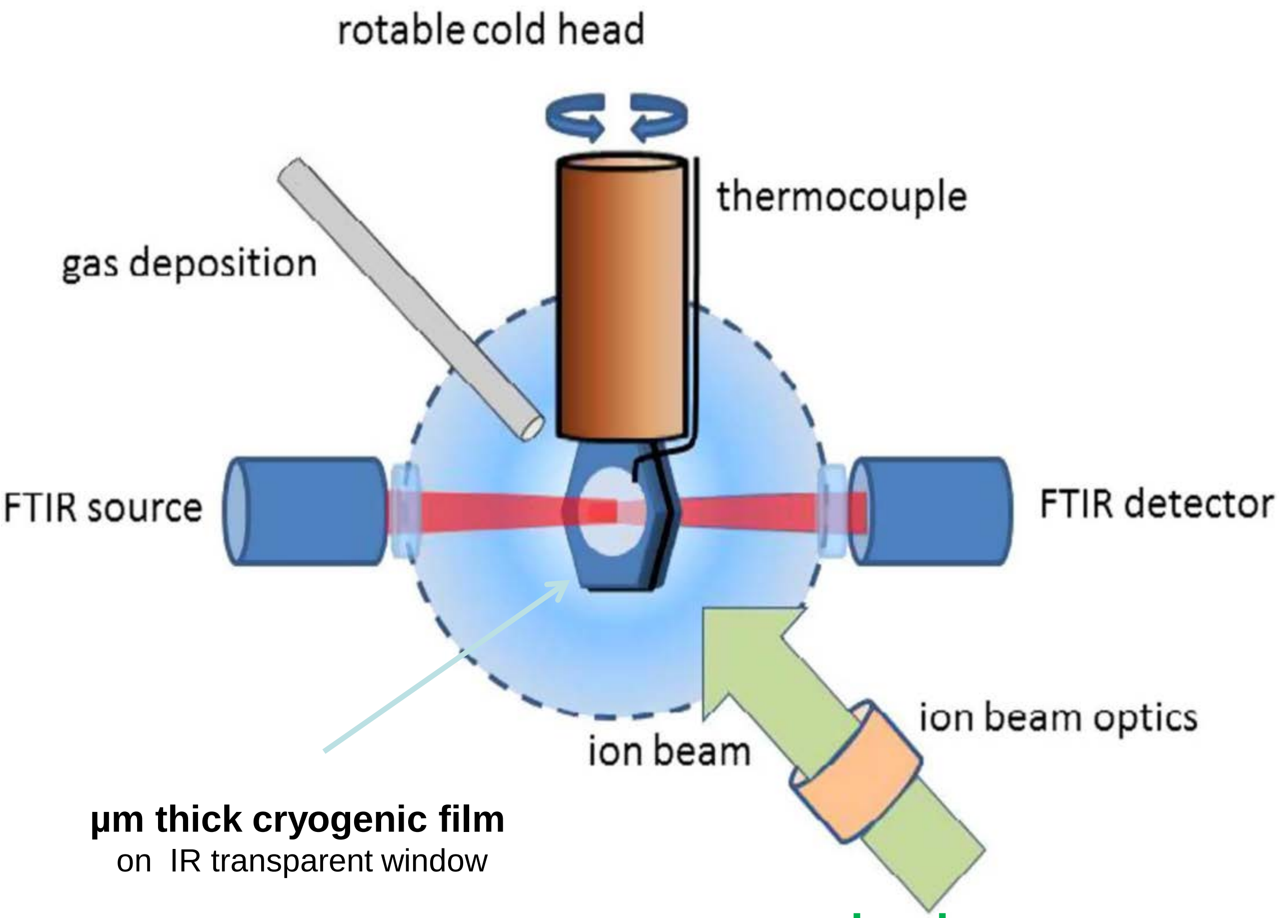


Radiation leads to:

- **fragmentation and radiolysis**
- **formation of new molecules**
- **desorption/sputtering**
- **structural changes / amorphization**

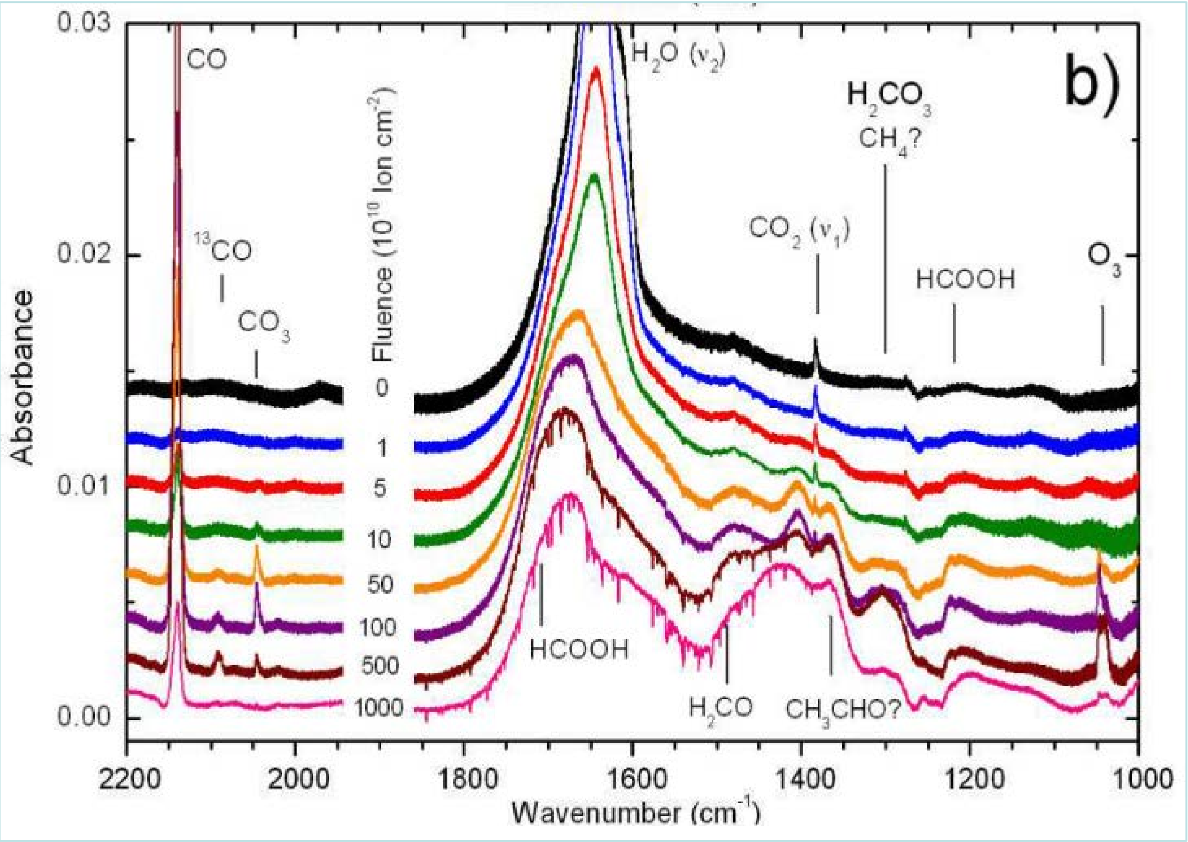
Simulation of cosmic radiation processes

Irradiation of cryogenic surfaces & in situ infrared-spectroscopy



µm thick cryogenic film
on IR transparent window

ion beam

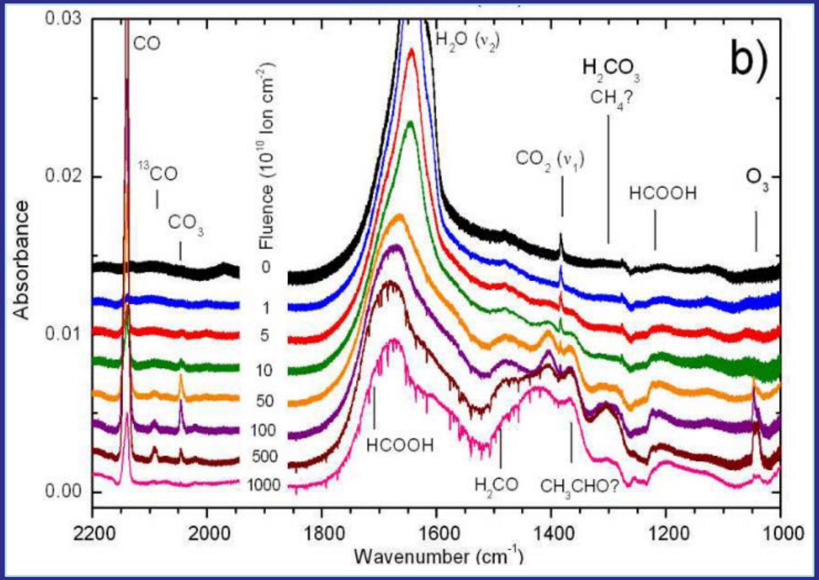


in-situ infrared spectra for large fluence range

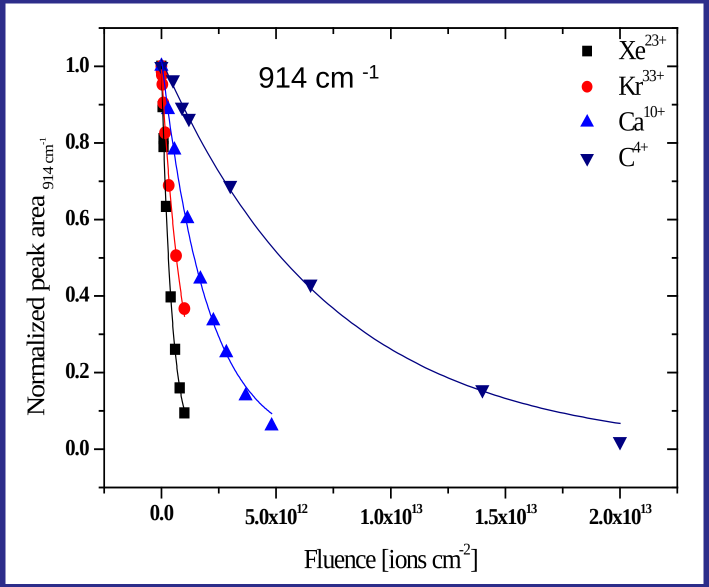
collaboration: H. Rothard et al., CIMAP/GANIL

In situ infra-red analysis and damage cross section

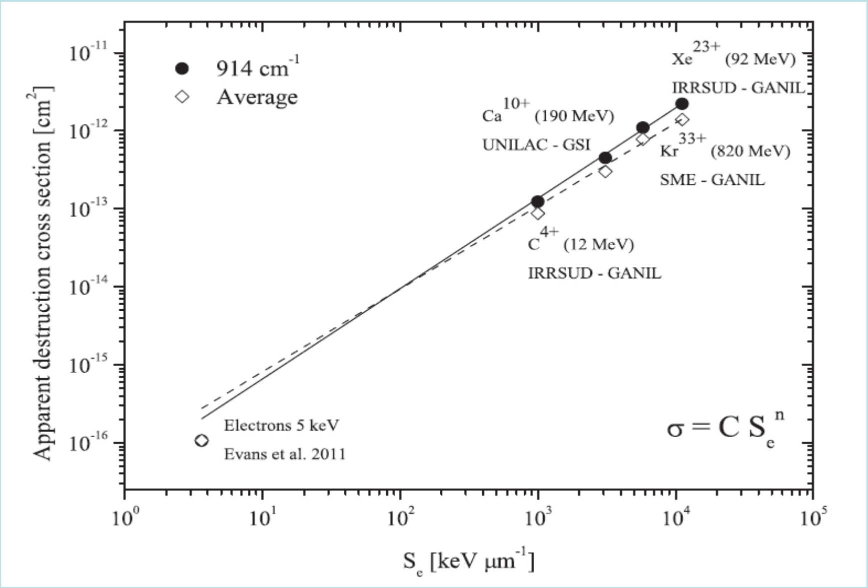
record spectra for large fluence range



analyze specific bands versus fluence, deduce damage cross section



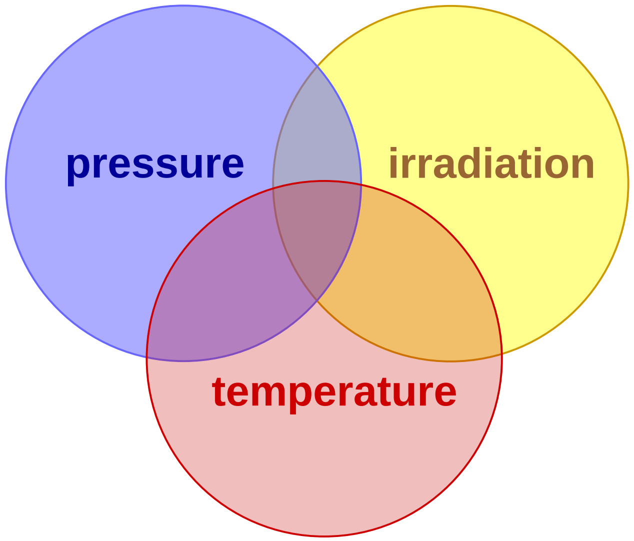
analyze damage cross section versus energy loss, develop scaling law



- **Comparison with telescope observations in space**
- **Input to astrochemical models**

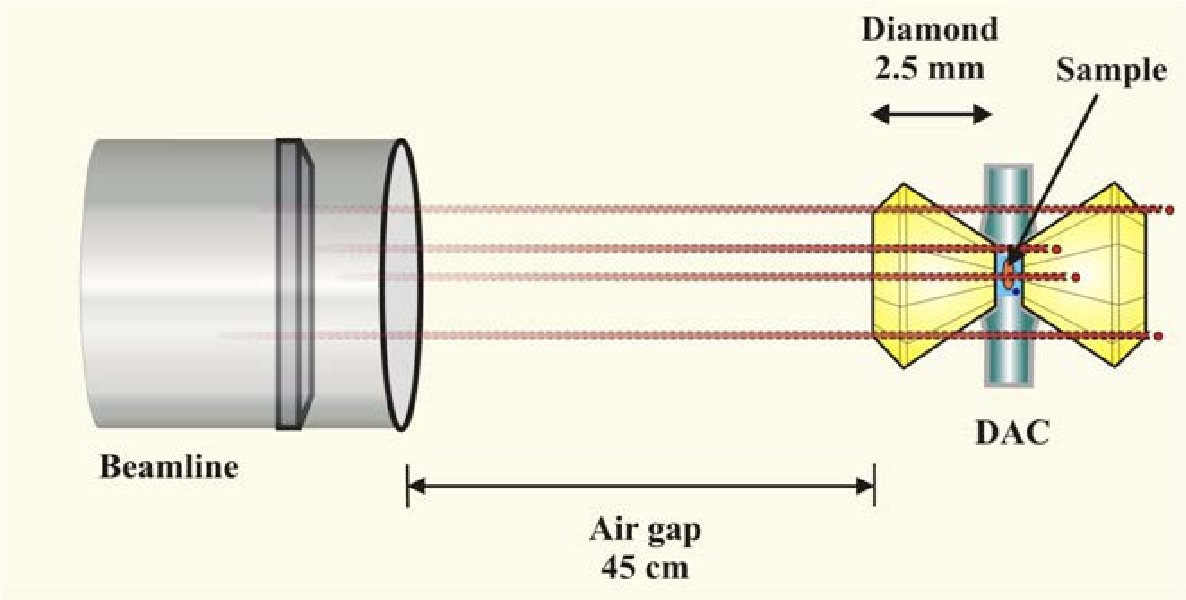
Rothard et al, J.Phys.B 50 (2017)

Materials under multiple extreme conditions



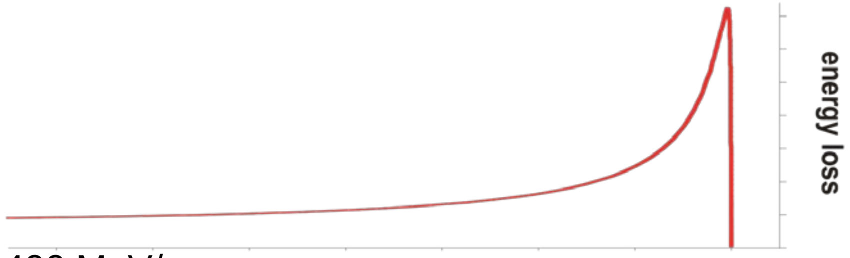
relativistic ions

e.g., Au, Pb, U

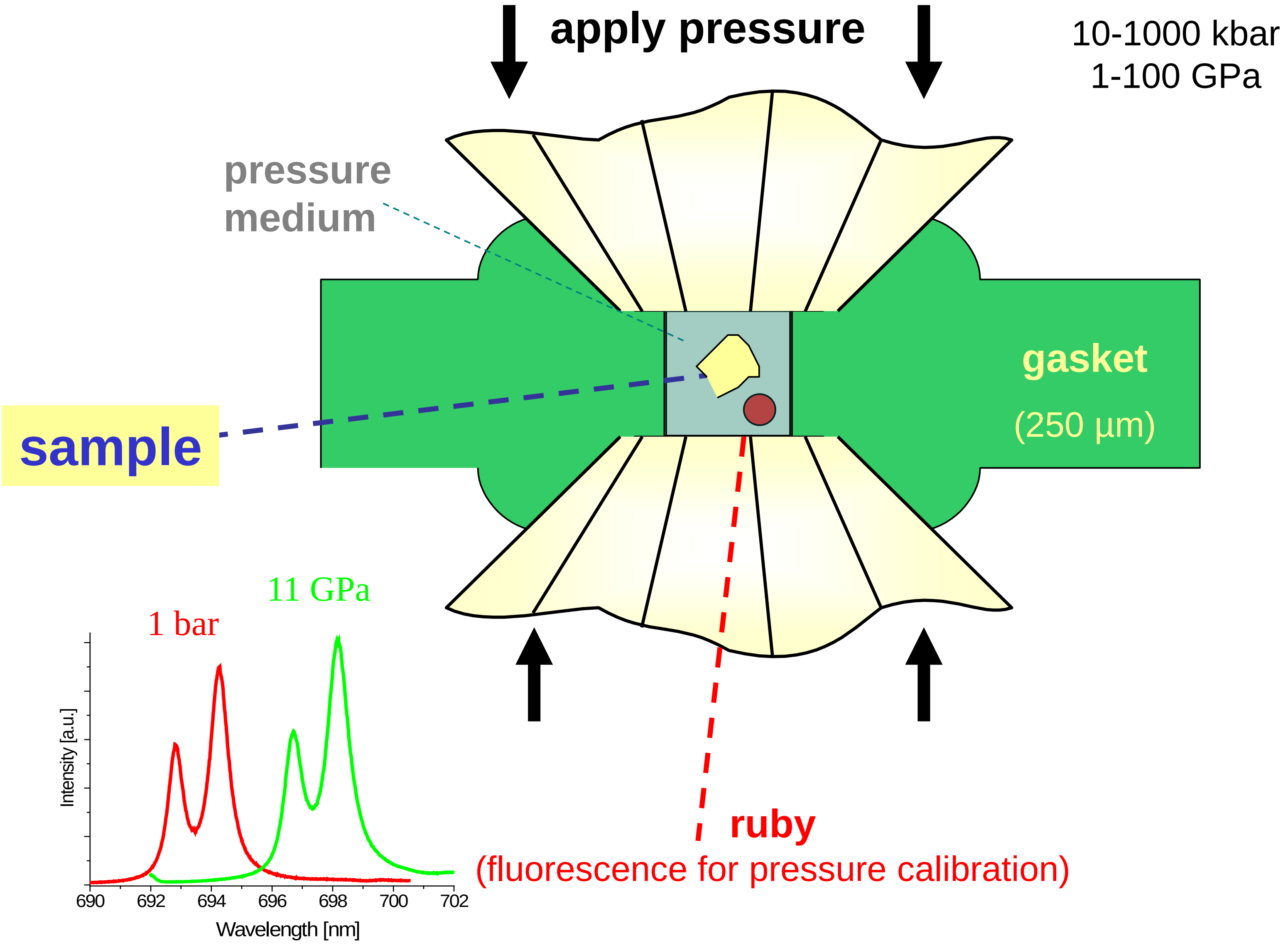


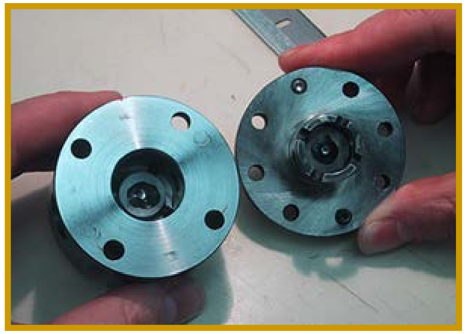
Motivation

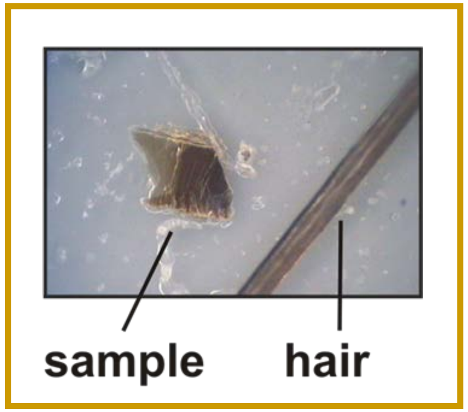
- access to complex phase diagram
- recover high-pressure phases
- geosciences: minerals within Earth’s interior



Diamond anvil cell (DAC)

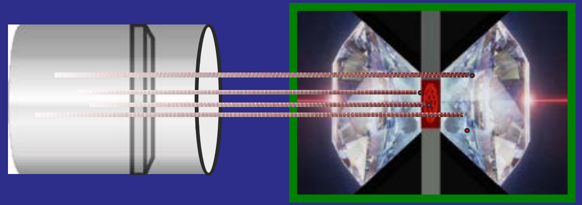


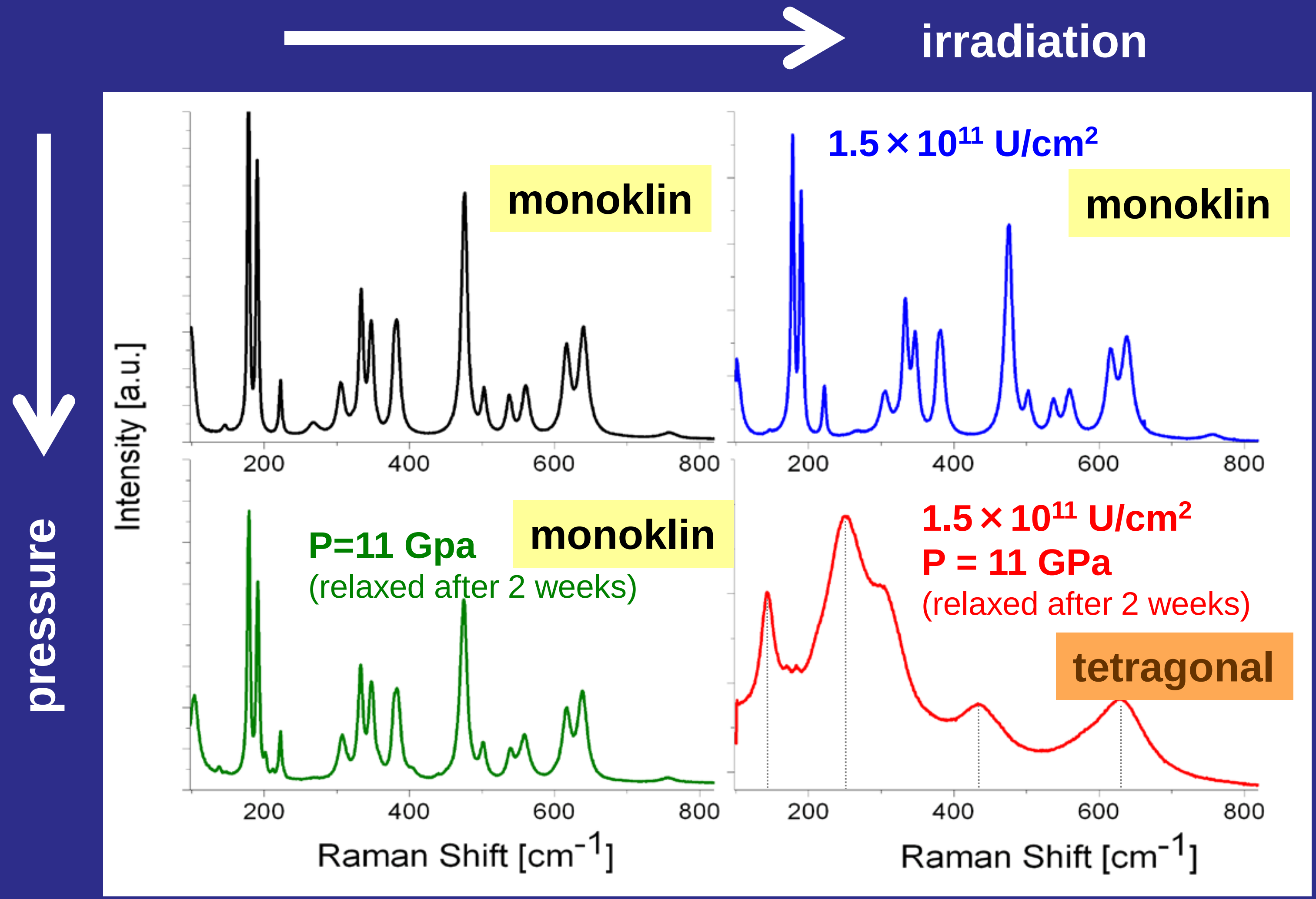




Ion irradiation under high pressure

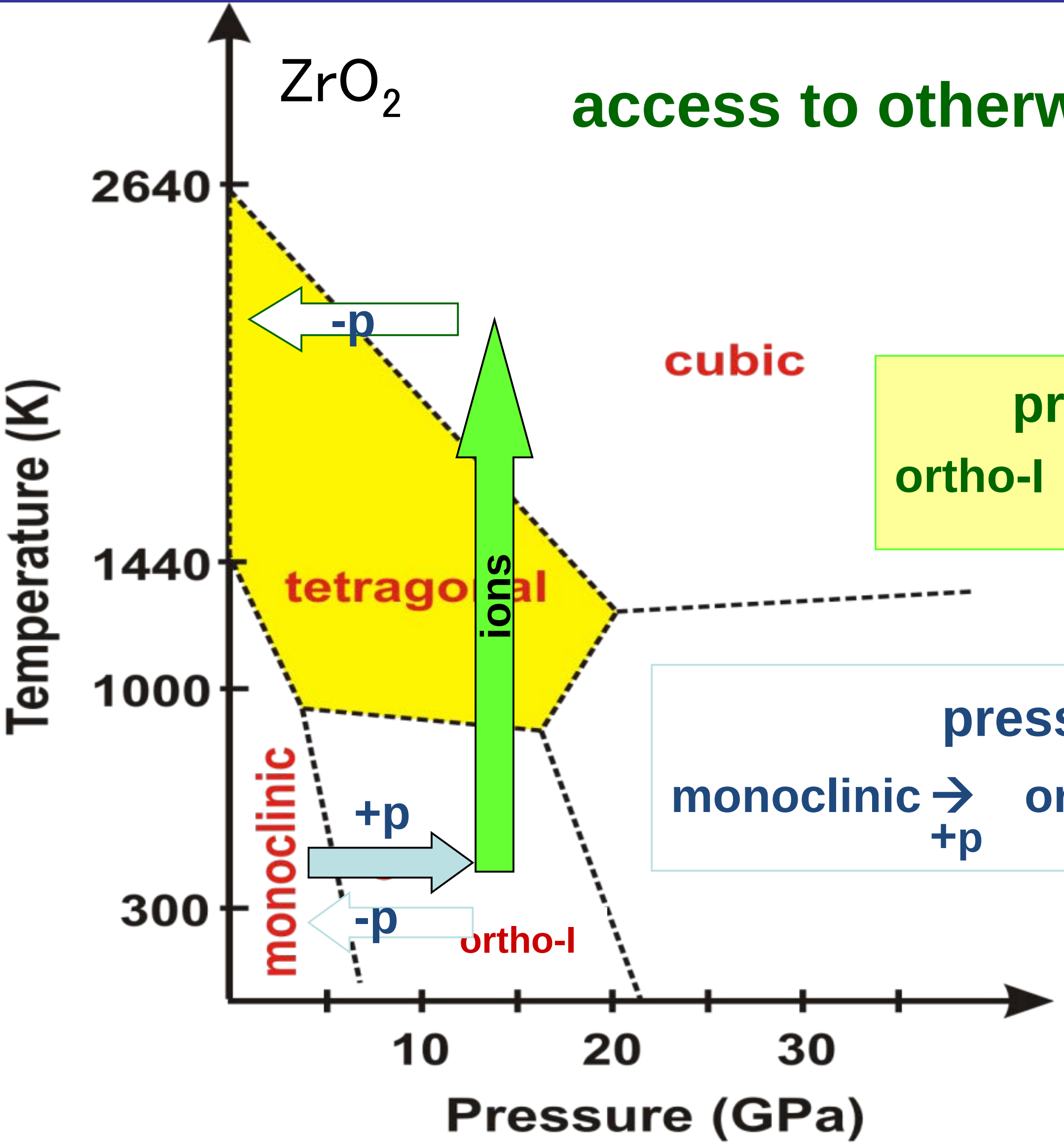
Zirconium dioxid ZrO_2





B. Schuster et al.,
https://doi.org/10.1016/j.nimb.2009.02.046

Phase transition under irradiation & pressure



access to otherwise unquenchable phases

pressure & irradiation

ortho-I → (+p) cubic → (-p) tetragonal

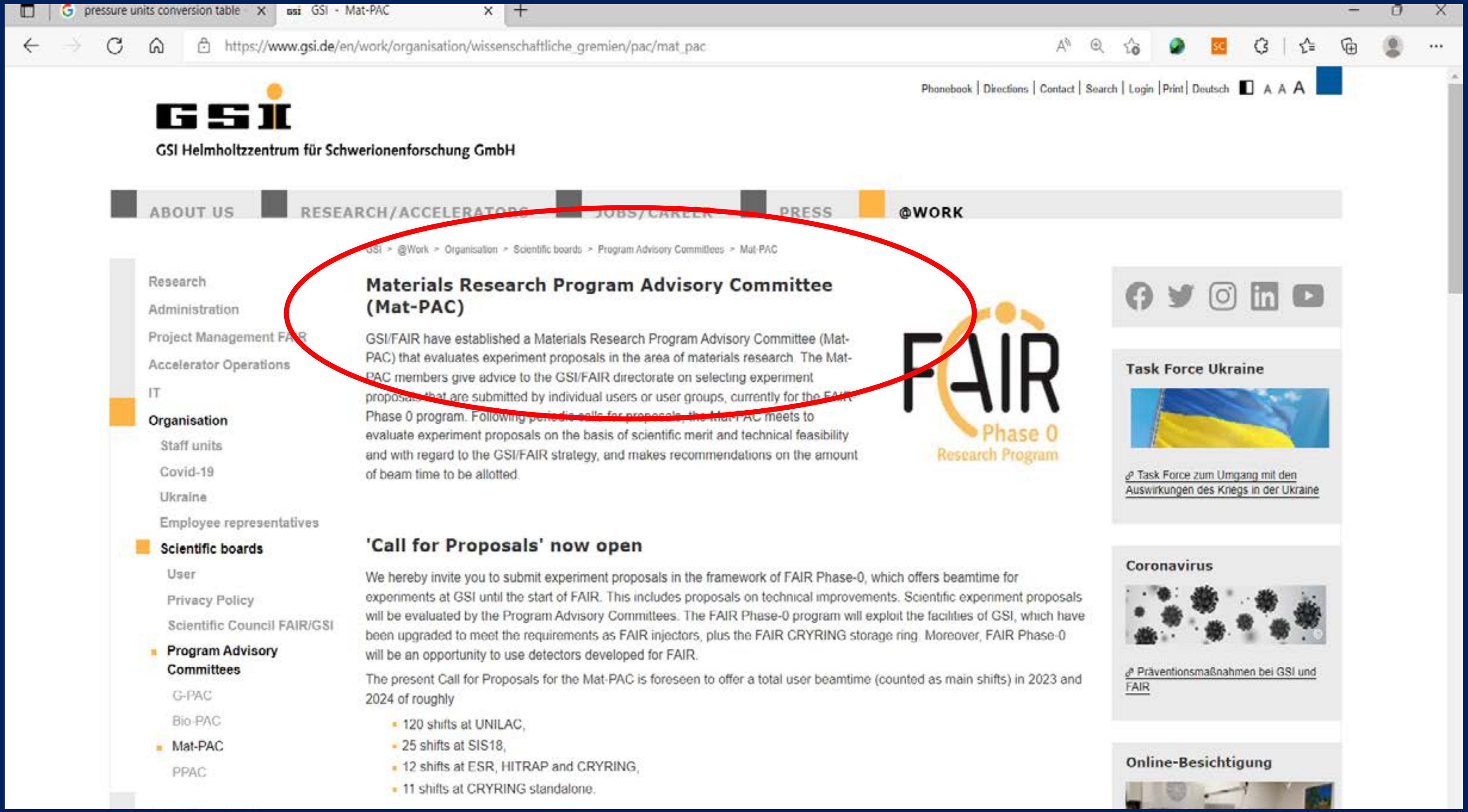
pressure alone

monoclinic → (+p) ortho-I → (-p) monoclinic

Material science with MeV-GeV heavy ions

Call for MAT proposals for beamtime 2023 and 2024

deadline June 30, 2022



UNILAC <11 MeV/u	SIS18 80-1000 MeV/u
X0 Autosampler	Cave A Irradiation Cave
Microprobe Single Ion Control	
M-Branch On-line Analysis	Cryring 0.3-14 MeV/u
	Cryring MAT target station

contact: c.trautmann@gsi.de