Ion beam analysis of materials with MeV beams at the Ruhr University Bochum

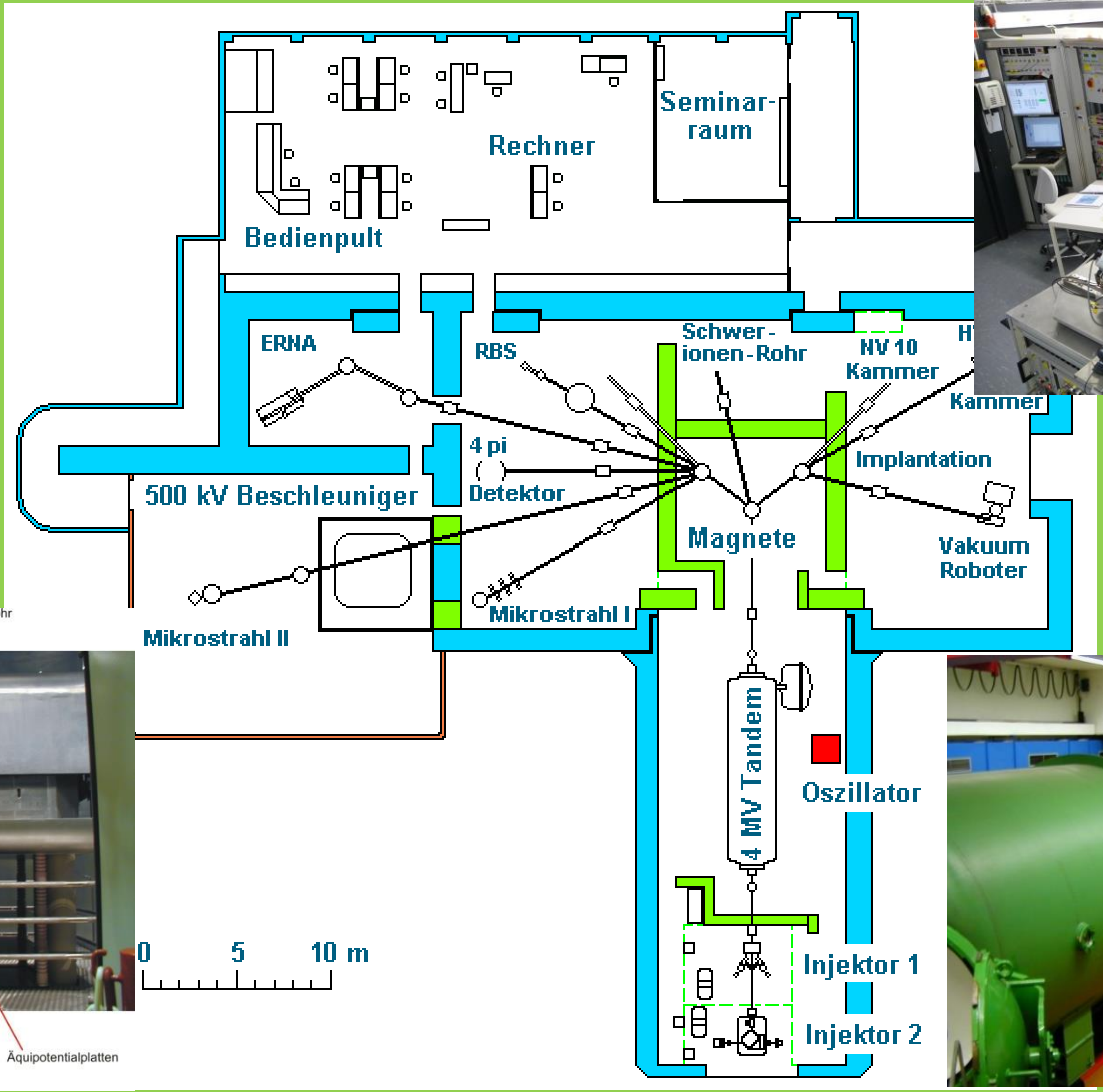
RUBION
Zentrale Einrichtung für Ionenstrahlen und Radionuklide

Ruhr-Uni-Bochum

Contribution to the ISOLDE workshop, Dec, 4th 2017, Hans-Werner Becker

Accelerators in Bochum

Ion Beams from a few keV up to some 20 MeV



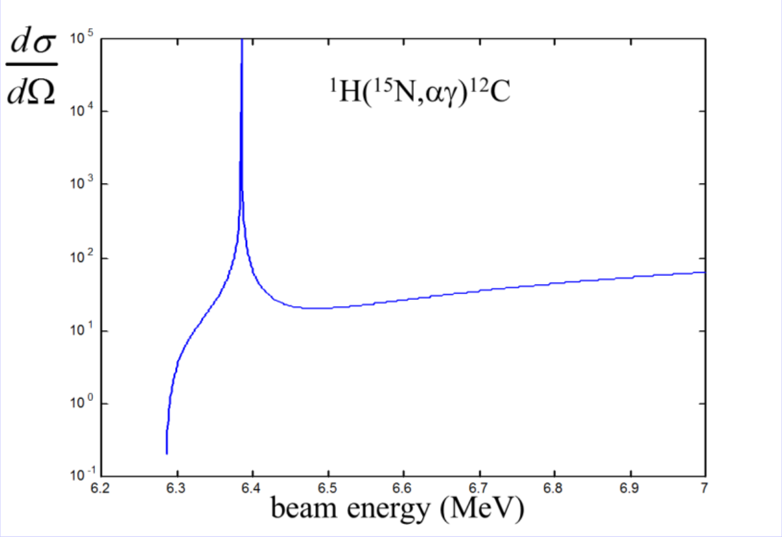
Depth profiling
with
Nuclear Resonance Reaction Analysis

Motivation:

–**Detection of light elements (in particular Hydrogen)**

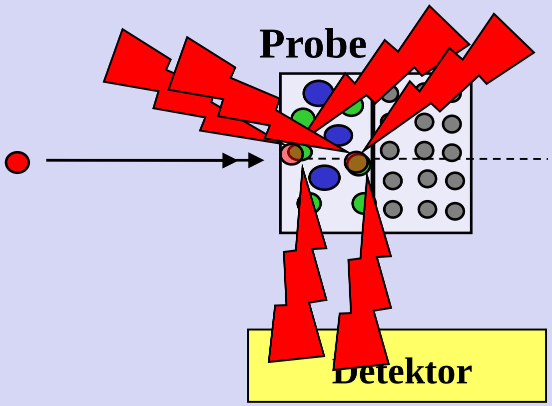
–**isotopic tracing**

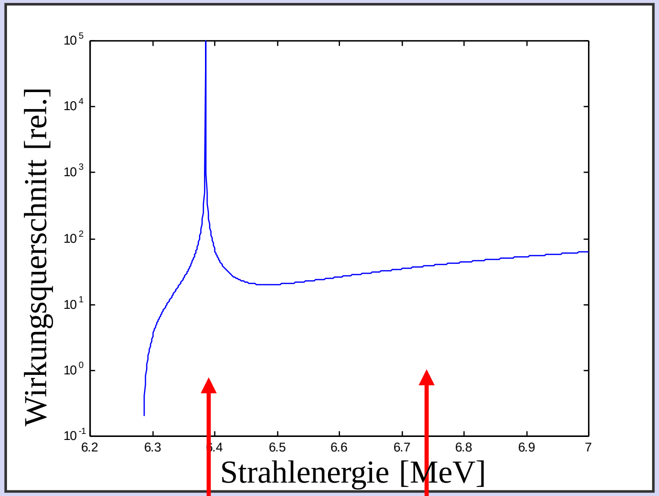
Example:
Hydrogen depth profiling
with an ^{15}N beam



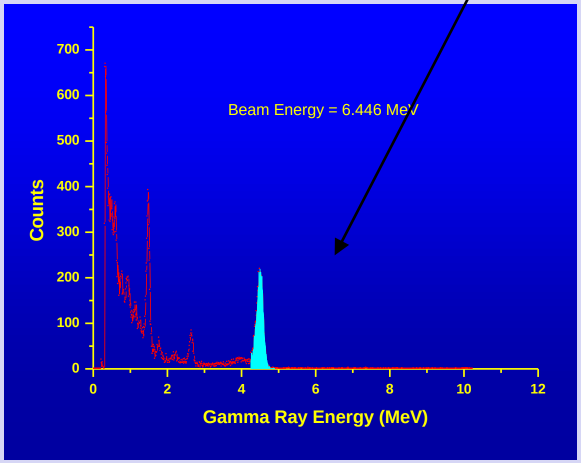
Nukleare **R**eaktions **A**nalyse (NRA) am Beispiel $^{15}N(p,\alpha\ \gamma)^{12}C$

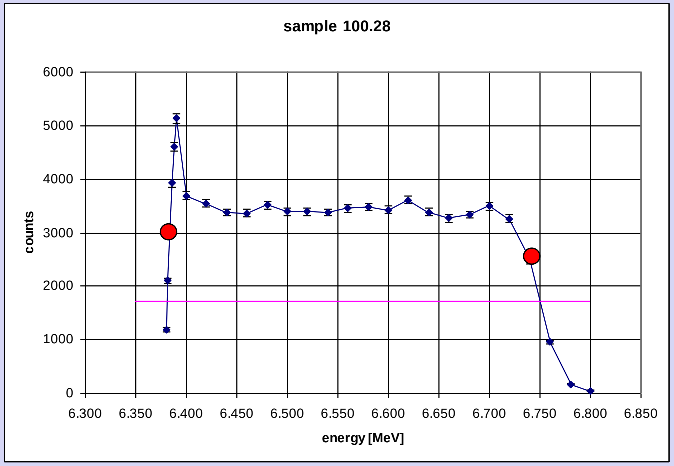
$E \geq E_R$





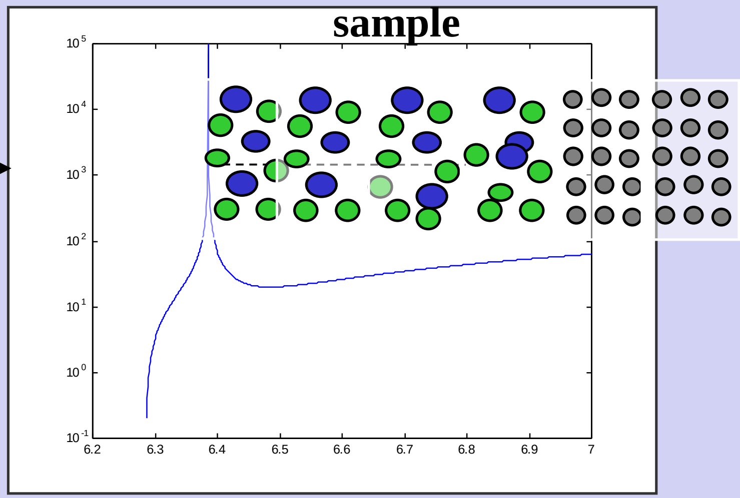
$E = E_R$ $E > E_R$



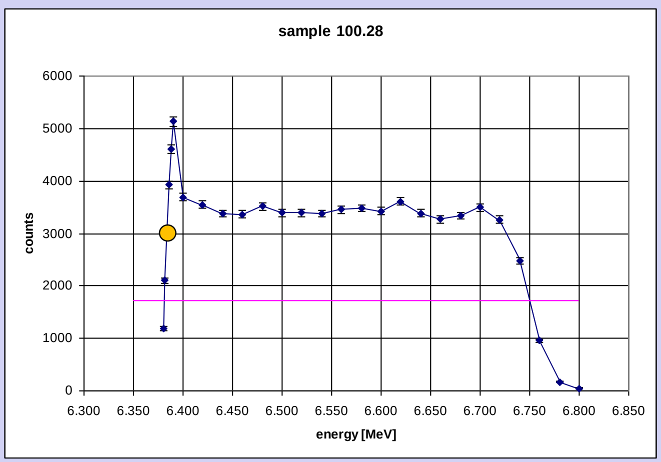


Wasserstoff in Silizium
Ringversuch Bundesanstalt für Materialforschung

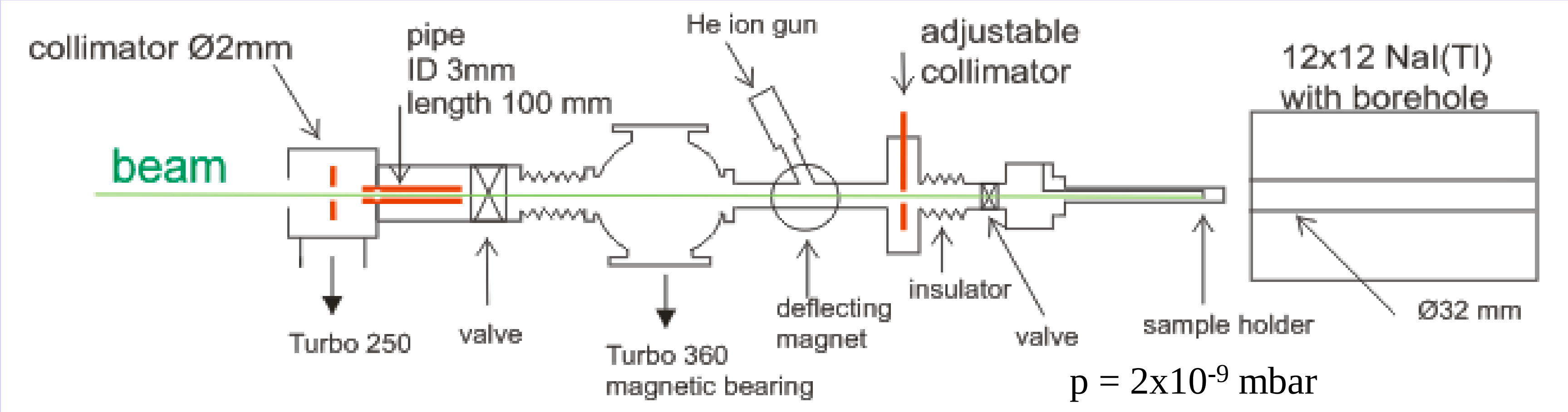
beam

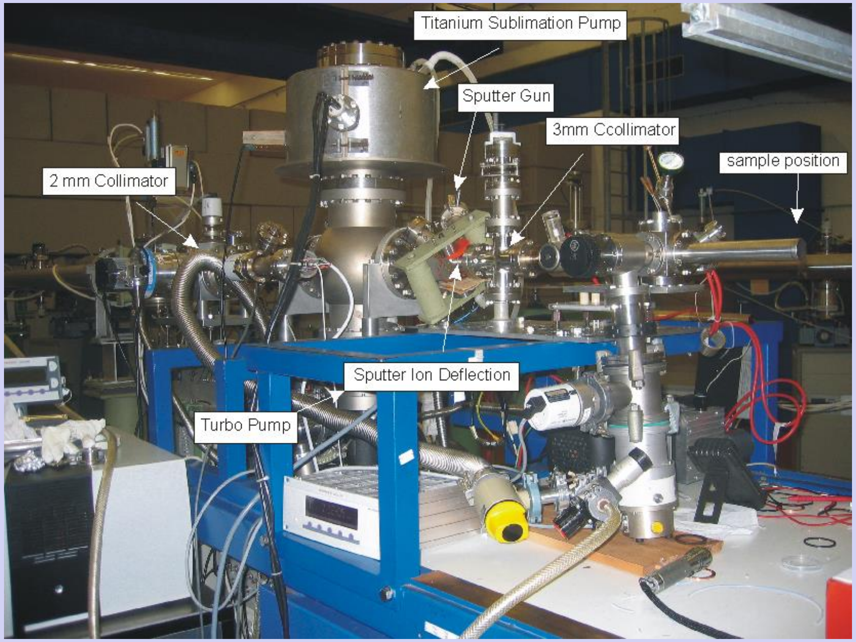


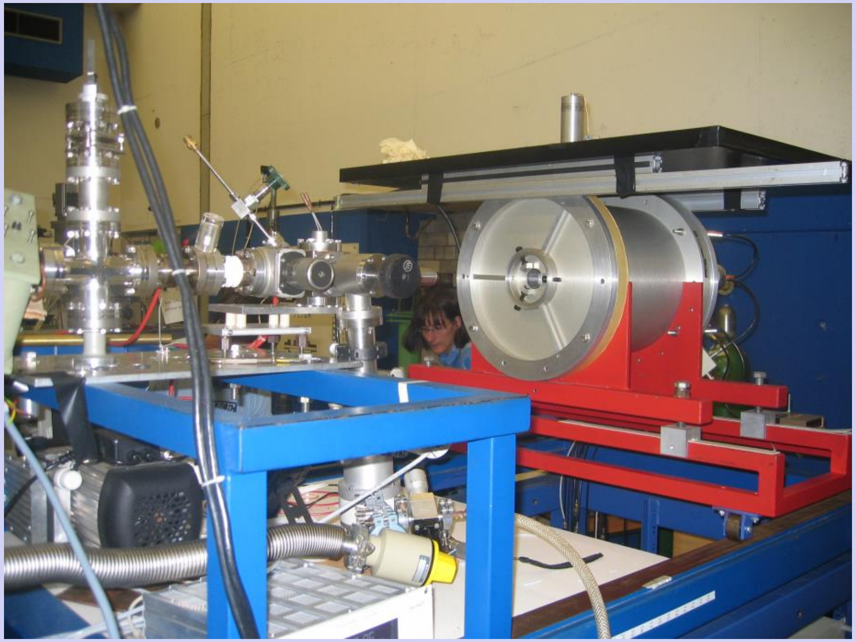
Depth resolution: a few nm



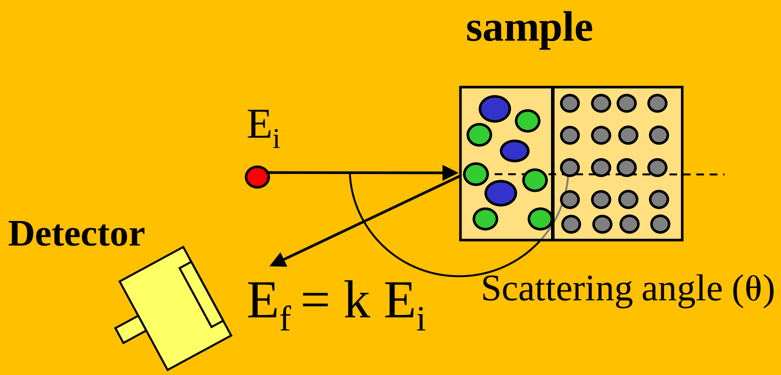
The set-up in Bochum







Rutherford **B**ackscattering **S**pectroscopy

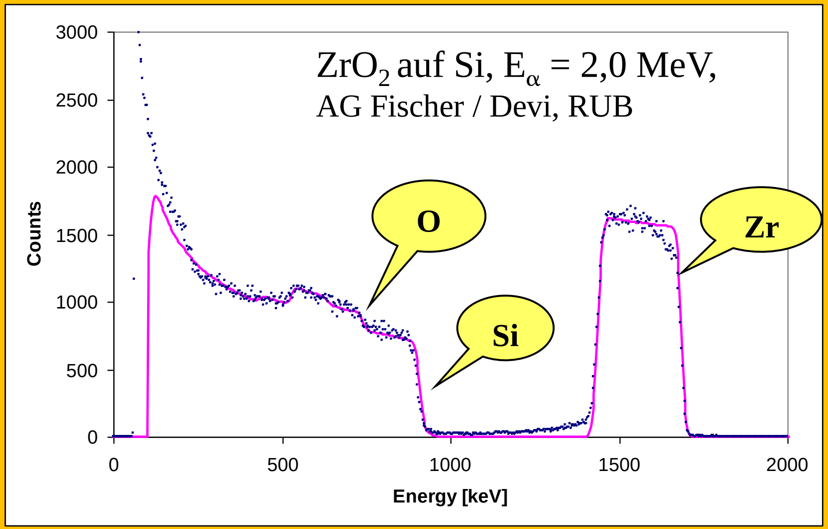


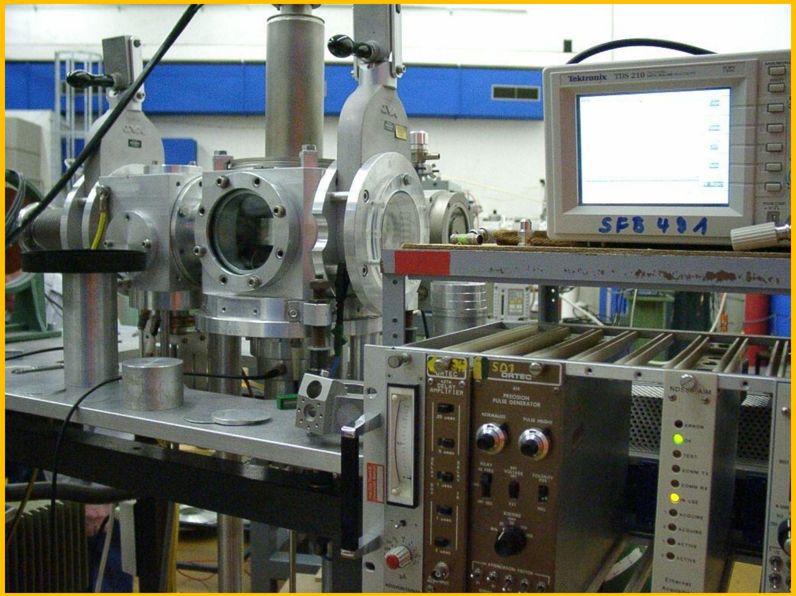
Probability for scattering:

$$\frac{d\sigma}{d\Omega} \propto \left[\frac{Z_{Ion} Z_{Probe}}{E_{Ion}}\right]^2$$

Energy of scattered particle:

$$k = \left[\frac{\sqrt{M_{Probe}^2 - M_{Ion}^2 (\sin\theta)^2} + M_{Ion}\cos(\theta)}{M_{Ion} + M_{Probe}}\right]^2$$





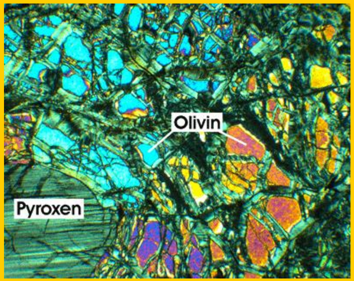
energy scale →

mass scale →

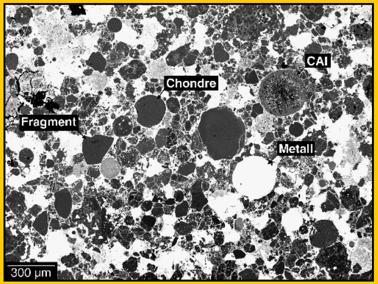
depth scale ←

Study of Diffusion in Minerals – why?

1. Diffusion is observed in samples
e.g. from subduction zones

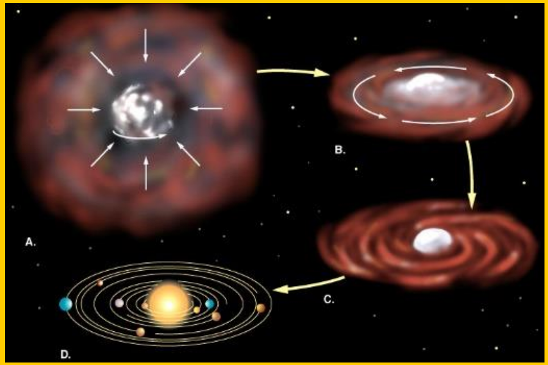


or meteorites…



…and one can learn something about processes in the interior of the Earth

or during the origin of the solar system

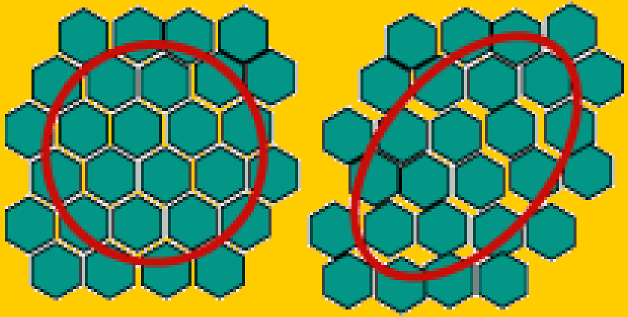


(time- temperature- and pressure scales)

when diffusion parameters are known!

Study of Diffusion in Minerals – why?

2. There is a close connection between diffusion and creep



mechanical properties ⟷ microscopic properties

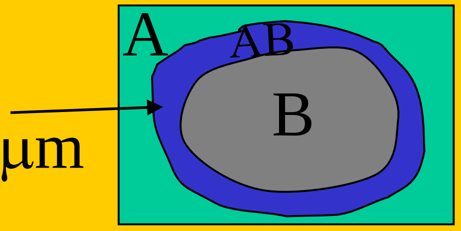
and it all depends on defects in crystals !

Measurement of diffusion processes in the laboratory

Nature

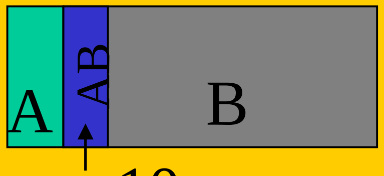
Timescale

100 µm



100000 years

Experiment



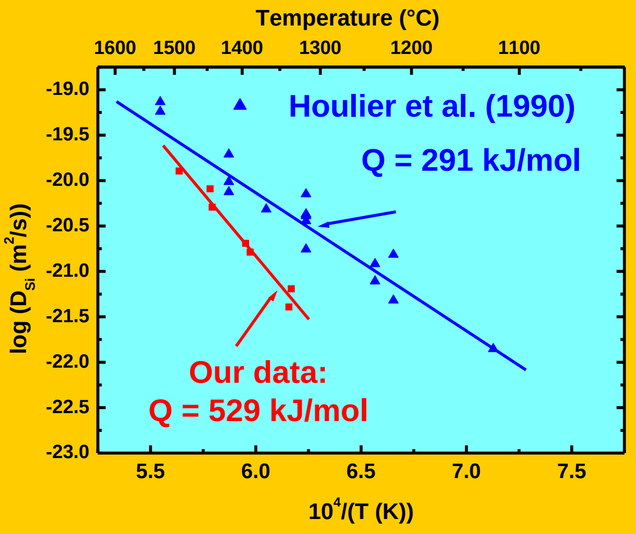
10 nm

~ 8 days

Temperature scale

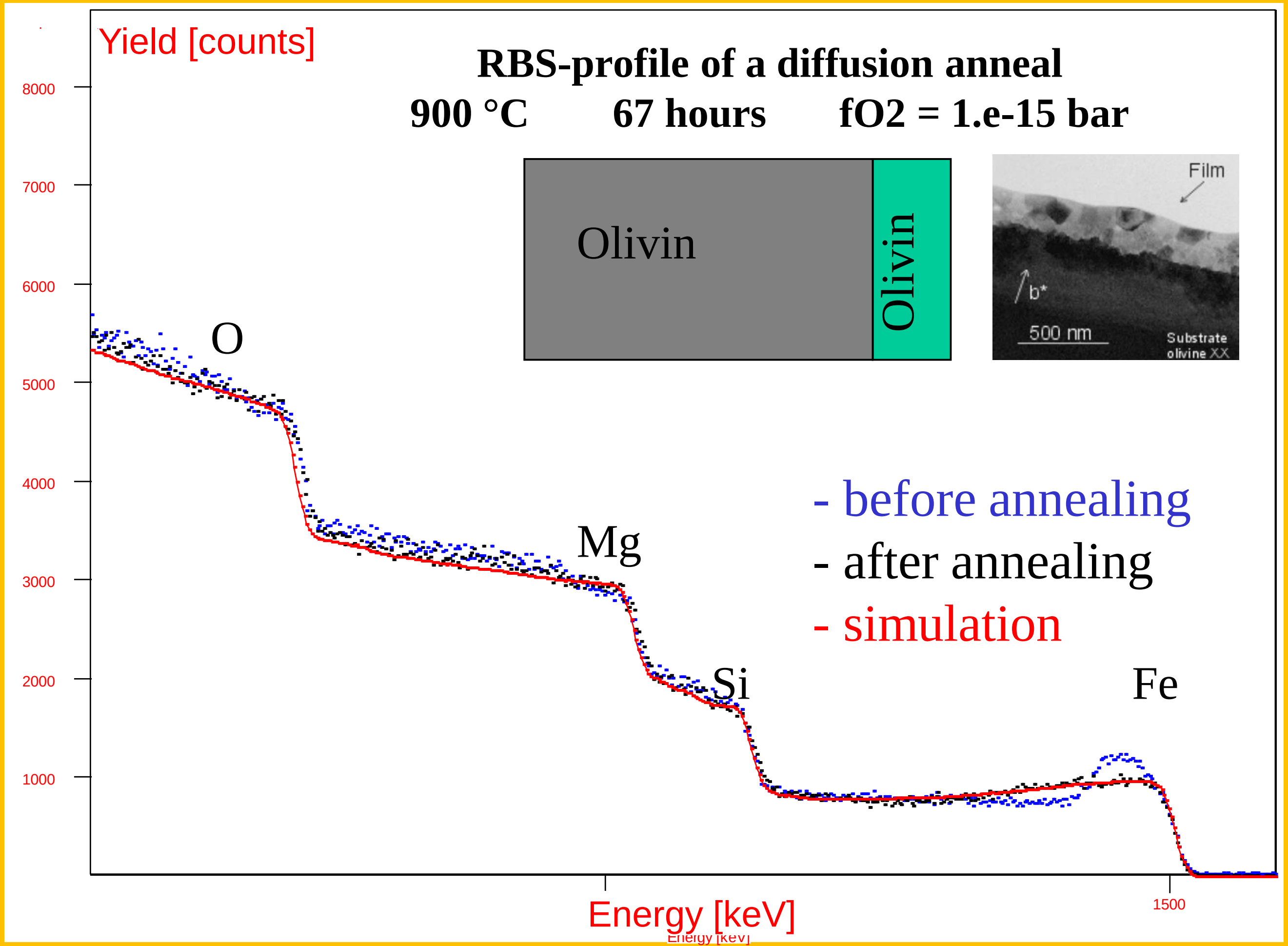
$$D = D_0 \cdot \exp\left(-\frac{Q}{kT}\right)$$

Q = activation energy



Example: Fe-Mg diffusion in olivine:

Fayalite	Olivine:	Forsterite
Fe_2SiO_4	$(Fe_x,Mg_{1-x})_2SiO_4$	Mg_2SiO_4



It would be very interesting for the understanding of diffusion studies to know more about amount and type of defects

↓

PAC ?

There is only very little literature about PAC studies in minerals

e.g. Miami University Oxford, Ohio 2005

H. Jaeger, M. P. Rambo, R. E. Klueg, S. McBride…

Our first challenge is now to understand what we can learn from PAC results „finding a common language between geoscientists and PAC people“

e.g. the investigations of zircon ($ZrSiO_4$)

Thesis McBride 2005

Measurement fitted with the perturbation function…

$$G_2(t) \doteq s_{20}(\eta) + \sum_{i=1}^{3} s_{2i}(\eta) \cos\big(g_i(\eta)\nu_Q t\big) \exp\big(-g_i(\eta)\delta t\big)$$

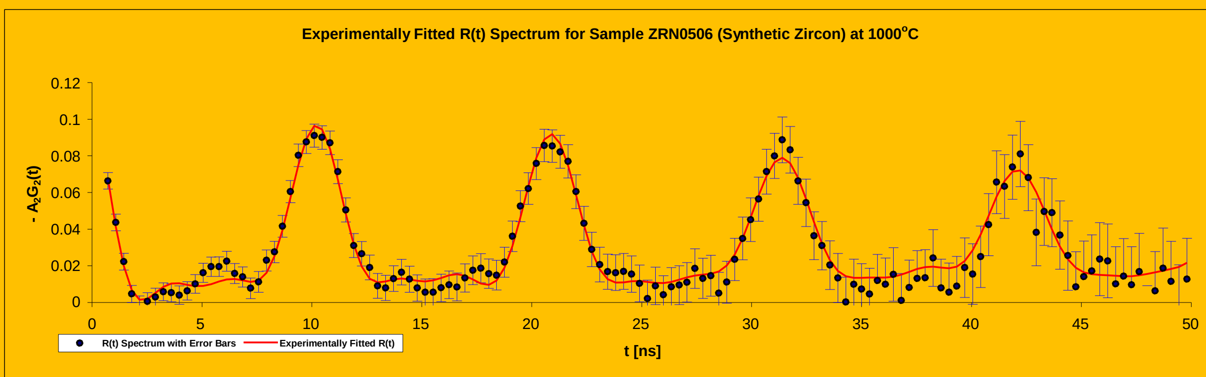


Figure G.1- Experimentally Fitted R(t) Spectrum for Sample ZN0506 (Synthetic Zircon) at 1000 Degrees

…to deduce
the EFG parameters:

η (asymmetry parameter)
ν_Q (quadrupole frequency)
δ (damping parameter)

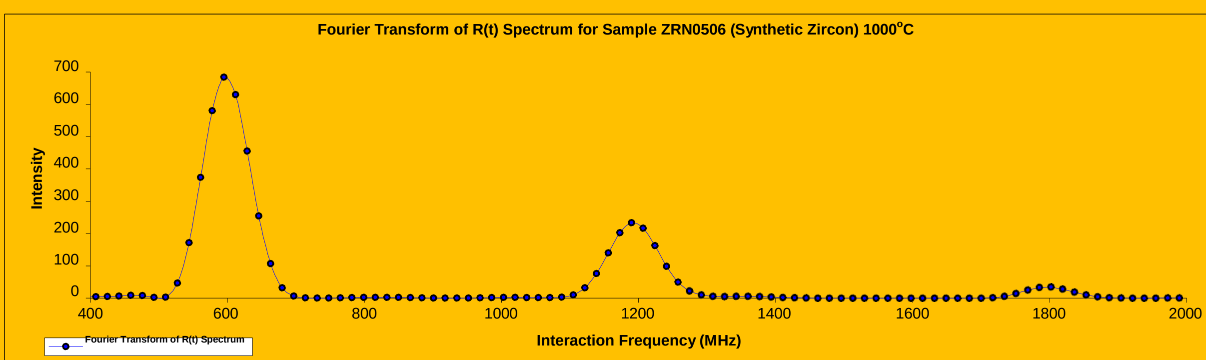


Figure G.2- Experimentally Fitted Fourier Transform Spectrum for Sample ZRN0506 (Synthetic Zircon) at 1000 Degrees

The EFG parameters

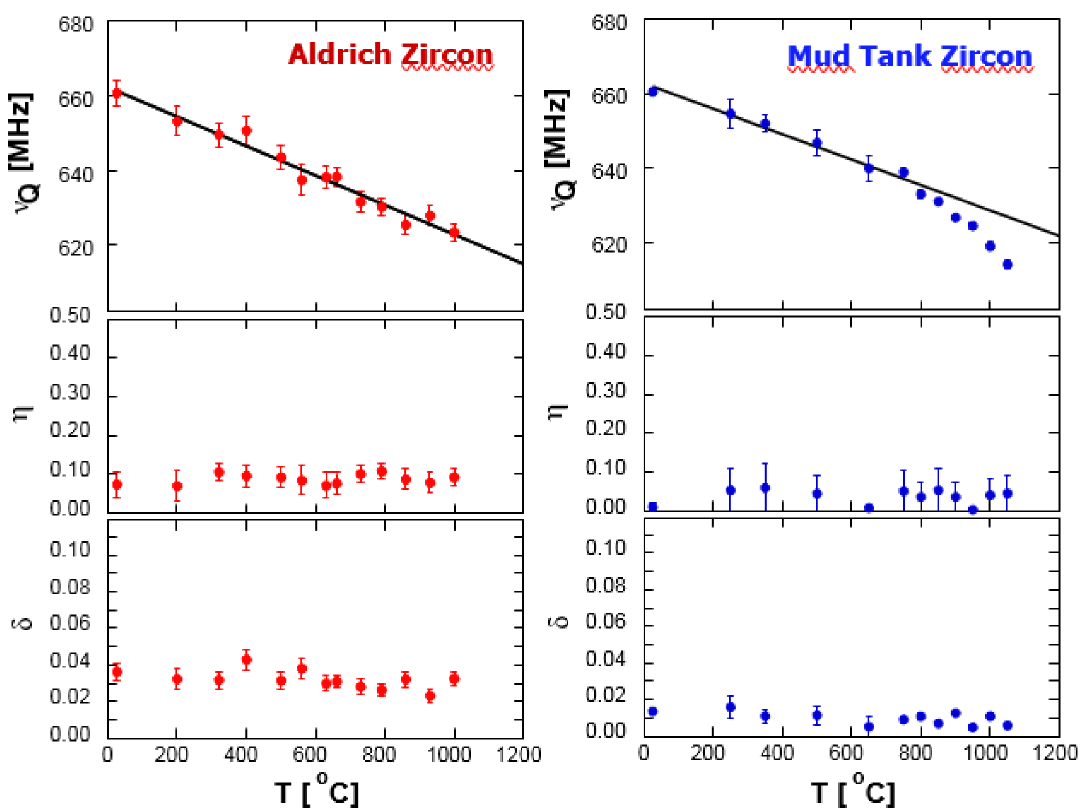


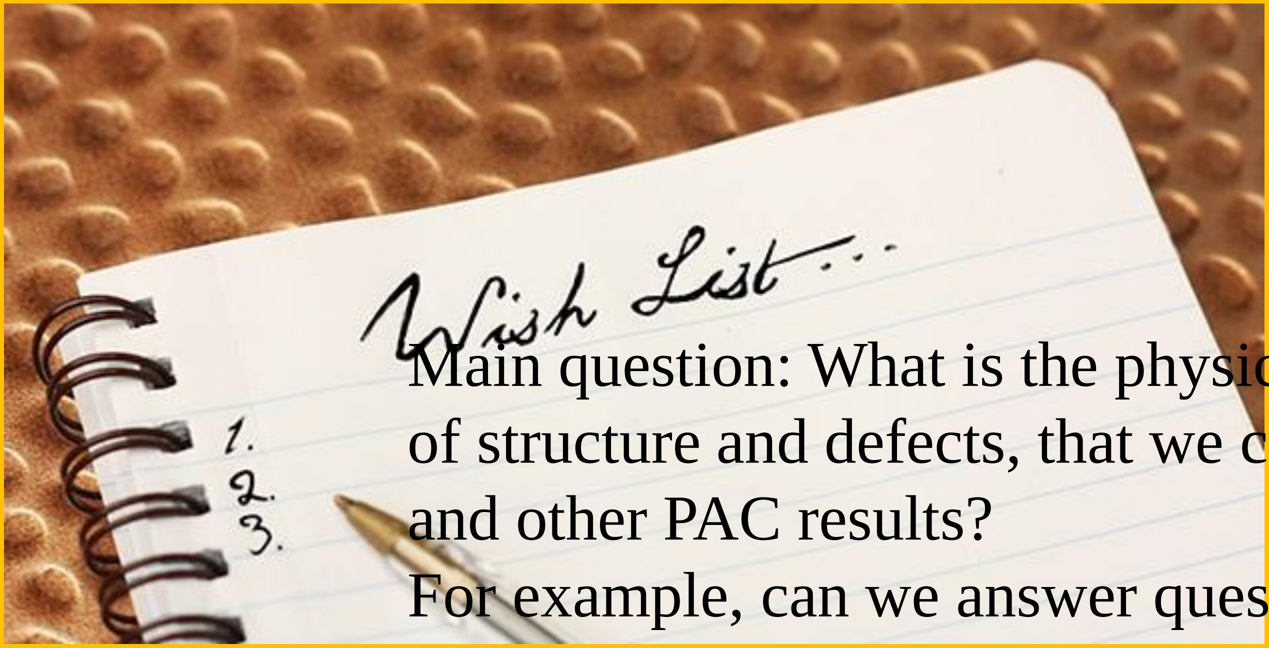
Figure 7.3 - EFG Parameters for Commercial and Natural Zircon Sample- The data was collected on runs that were made from room temperature up to 1000°C. Note the phase change occurs at roughly 700°C for the natural zircon while the commercially obtained zircon exhibits no phase change.

Change in slope of temperature dependence
 > displacive phase transition ?

η = 0 no radiation damage
η > 0 radiation damage
and impurities ?

what to learn from
the damping parameter

Thesis S. P. McBride 2005



from the geoscientist

Main question: What is the physical picture, in terms of structure and defects, that we can learn from these and other PAC results?

For example, can we answer questions such as:

What is the concentration of a certain kind of defect at a given condition e.g. T, P,…

What is the geometry of the atoms around the defect site?

How much energy is required to form a certain kind of defect?

What are the different kinds of defects that are present in a crystal, and in what concentrations?

etc. etc.

… is needed