NUCLEAR PHYSICS INSTITUTE

THE CZECH ACADEMY OF SCIENCES

PUBLIC RESEARCH INSTITUTION

NEUTRON DIFFRACTION

JAN ŠAROUN

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Neutron diffraction experiments at NPI

Part of the NPI-CANAM infrastructure

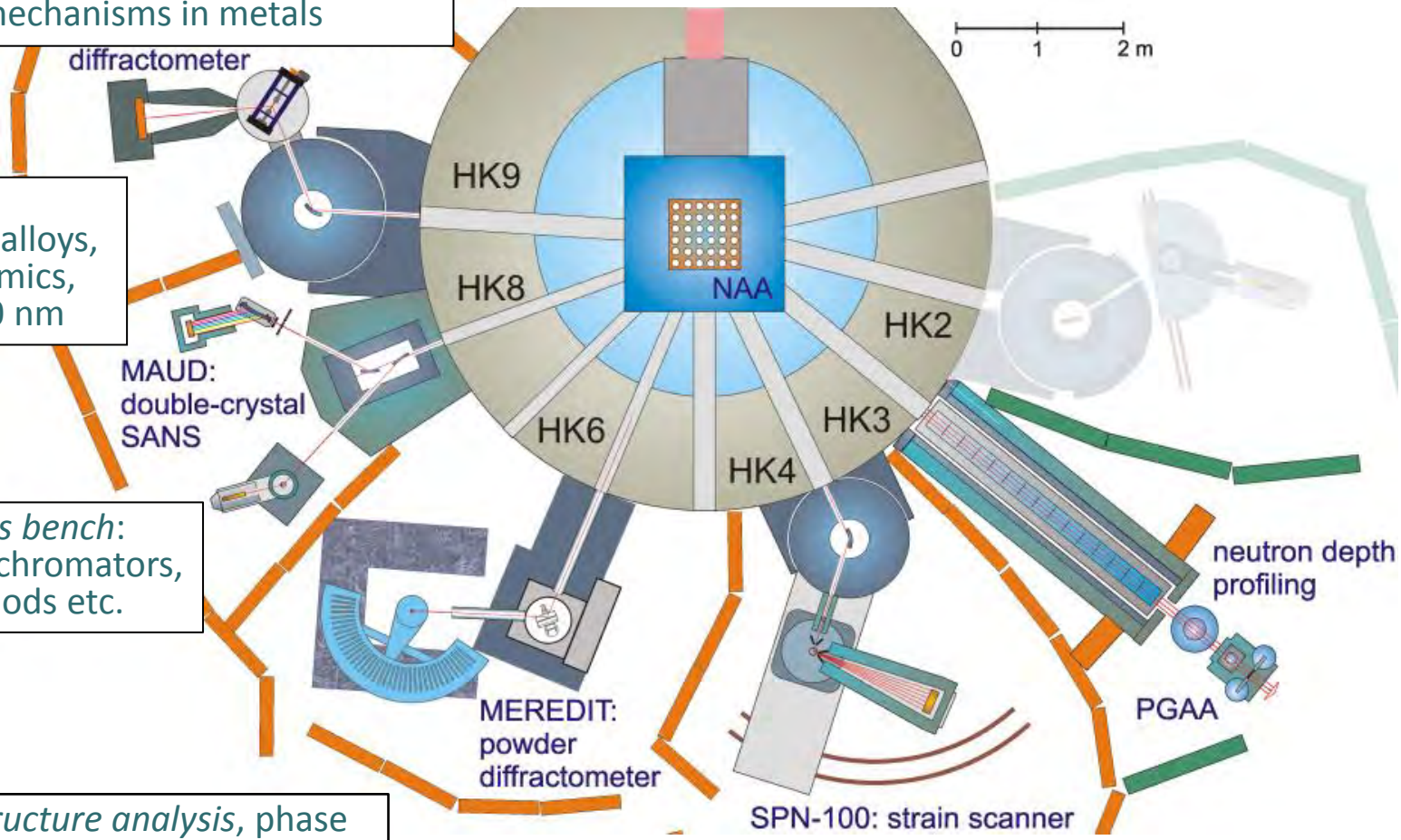
lattice strains in metals under *thermo-mechanical loading*, studies of deformation mechanisms in metals

microstructure: precipitation in alloys, porosity in ceramics, scale: 50 – 2000 nm

neutron optics bench: testing monochromators, imaging methods etc.

structure analysis, phase transitions in-situ (4 K < T < 1300 K)

Neutron beams at the reactor LVR15 (RC Řež)



mapping of residual strains (e.g. in welds)

European Spallation Source (ESS)

5 MW spallation neutron source in Lund, Sweden

Features:

- 2 GeV, 14 Hz linac
- peak power 125 MW
- 4t rotating W target
- high-brightness bi-spectral moderator (H_2O + para-H_2)
- 22 neutron beamlines
- 16 operational by 2025

Czech in-kind contribution

The NPI ND team participates in the design and construction of

Beamline for **E**uropean Materials **E**ngineering **R**esearch (BEER)

Joint project of

Nuclear Physics Institute, v.v.i.
Czech Academy of Sciences

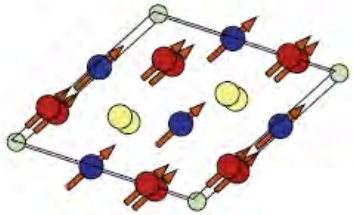
and

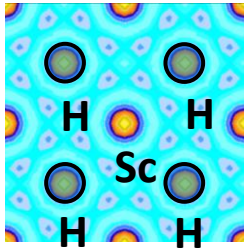
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Material research with neutrons

Structure analysis

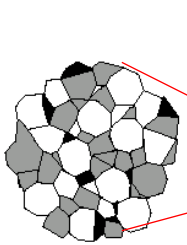
positions of light atoms
magnetic structure





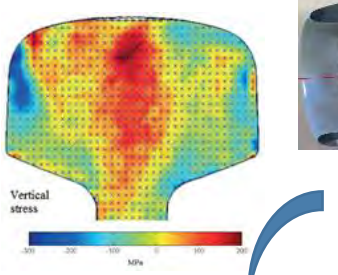
Deformation mechanisms

lattice strains: response to external load, plastic deformation, phase transformation, twining, ...



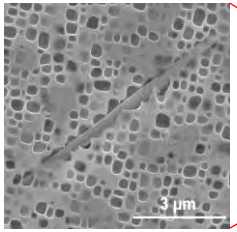
Residual stresses

affect structural integrity
accumulate during manufacturing and use
welding, rolling, mechanical and thermal load, cycling



Microstructure

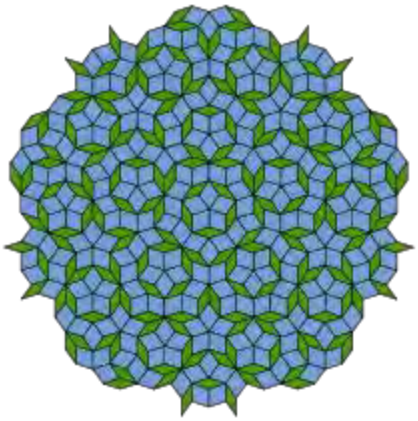
phase transitions: evolution of precipitates
nanovoids, texture, fatigue cracks



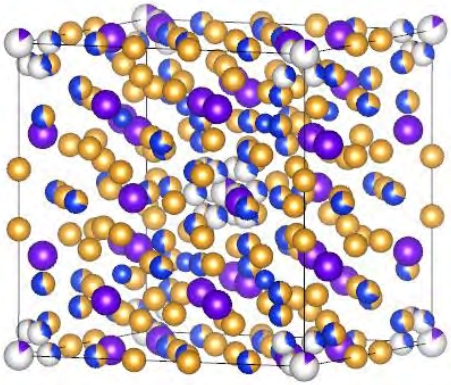
1. Quasicrystal approximants

quasicrystal:

- symmetric
- aperiodic



Tb-Au-Si

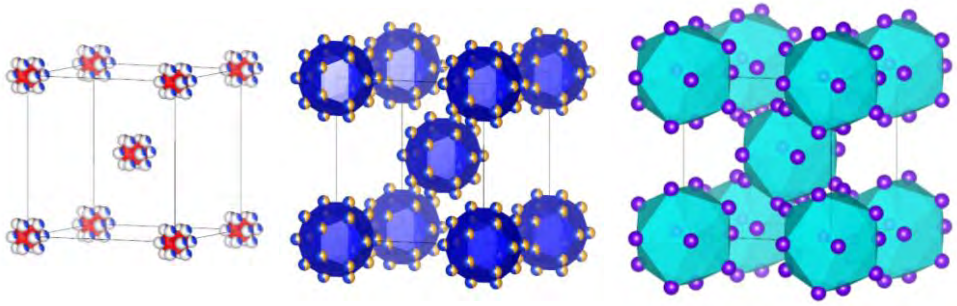


quasicrystal approximant:

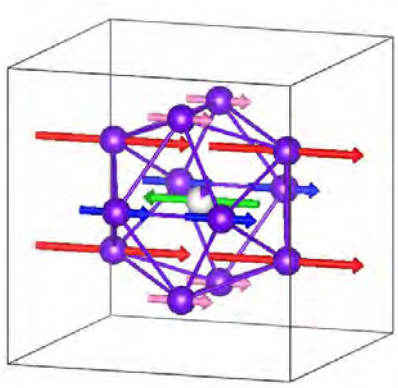
- regular crystal with a complex unit cell
- composition similar to a real QC
- contains motives with QA symmetry

coordination spheres:

1st 2nd 3rd



Ferrimagnetic-like ordering of magnetic moments in TbAuSi

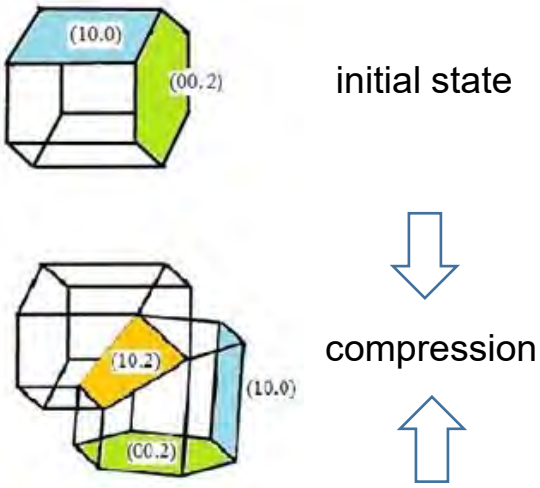


1st determination of magnetic structure in a quasicrystal approximant was done at NPI

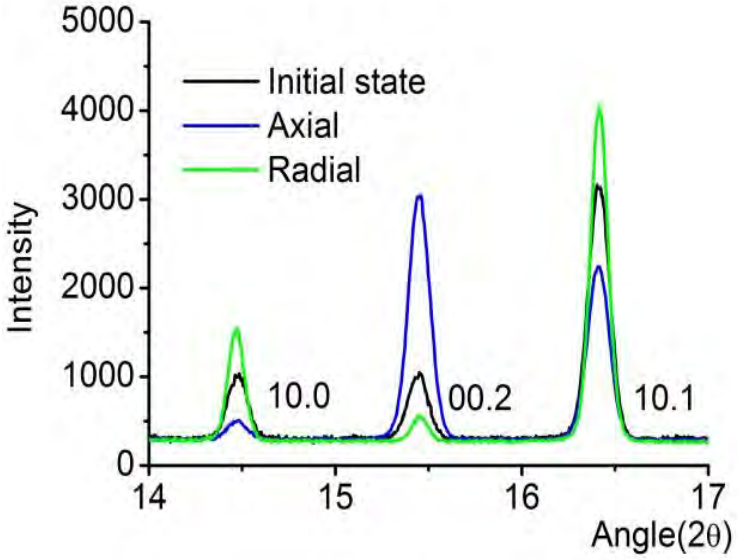
G. Gebresenbut, M. S. Andersson, P. Beran, P. Manuel, P. Nordblad, M. Sahlberg and C. P. Gomez, *J. Phys.: Condens. Matter* 26 (2014) 322202.

2. Deformation mechanisms of Mg alloys and composites

Twinning in Mg alloys



Neutron diffraction (ND):
Change in the **volume of the twinned grains** can be derived from variation of peak intensities



Volume of twinned grains changes by
1) **creation of new twins**, especially at initial stage of deformation
2) **growth** of twinned grains at later stages

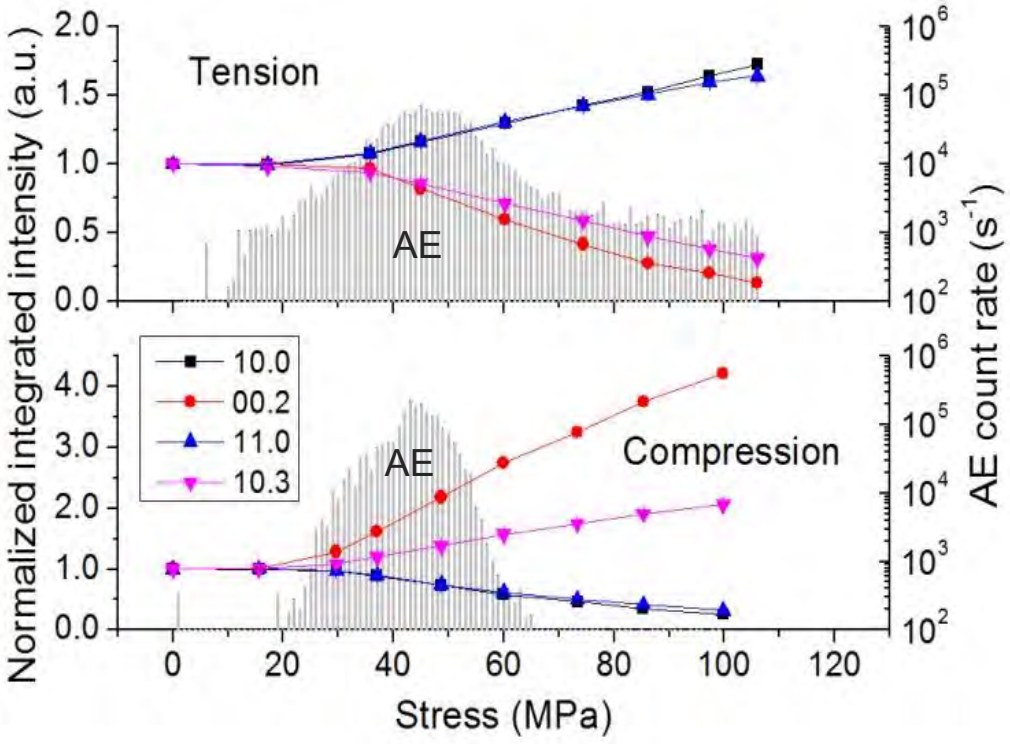
Cannot be distinguished by neutron diffraction alone

2. Deformation mechanisms of Mg alloys and composites

Acoustic emission (AE) :

Creation of new twins is accompanied by sound effects
=> recording of AE during deformation reveals the **number of twinned grains**

Combination of
acoustic emission
+
neutron diffraction

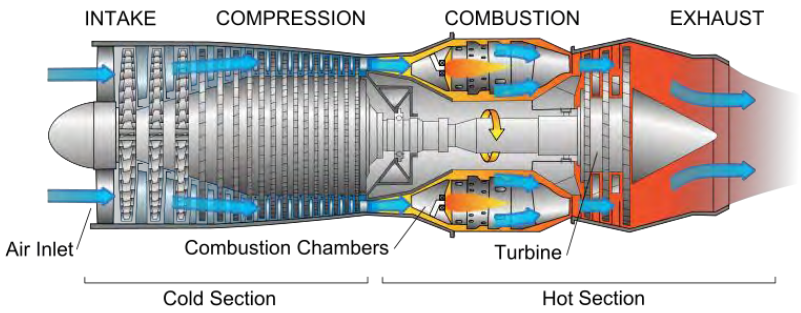


Collaboration with MFF UK:

- J. Čapek, G. Farkas, J. Pilch, K. Máthis, *Materials Science & Engineering* A 627 (2015) 333–335.
- J. Čapek, K. Mathis, B. Clausen, J. Straska, P. Beran, and P. Lukáš, *Materials Science and Engineering A - Structural materials* 602 (2014) 25–32.

3. Stability of Co-Re alloys at HT

Applications: aircraft, energy industry (gas turbine)



efficiency $\eta_{th} \leq 1 - \frac{T_C}{T_H}$

Requires:

- high T_H
- strength, oxidation resistance

turbine blade

Current limits:

Ni base superalloys: $T_H \approx 1100$ °C

Co-Re base alloys: new candidate for HT applications, melting T > 1540 °C

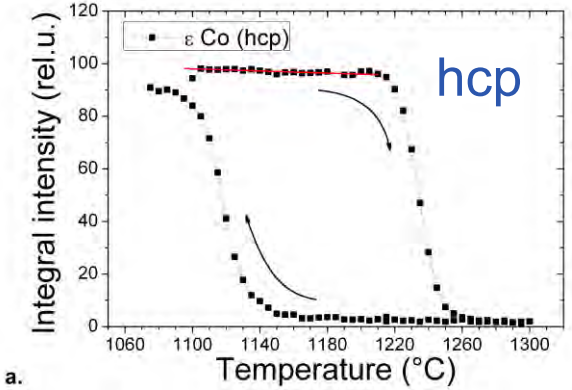
⇨ **search for strengthening precipitates, which are stable at HT**

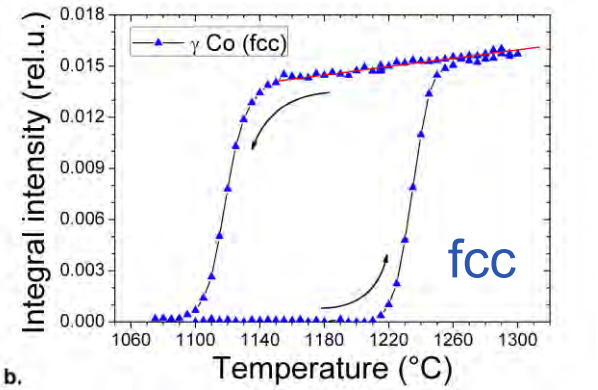
Collaboration with TU Braunschweig/TU Munich

- D. Mukherji, P. Strunz, R. Gilles, M. Hofmann, F. Schmitz, J. Rösler. *Materials Letters* 64 (2010) 2608-2611.
- D. Mukherji, R. Gilles, L. Karge, P. Strunz, P. Beran, H. Eckerlebe, A. Stark, L. Szentmiklosi, Z. Mácsik, G. Schumacher, I. Zizak, M. Hofmann, M. Hoelzel and J. Rösler, *J. Appl. Cryst.* 47 (2014) 1417-1430.

3. Stability of Co-Re alloys at HT

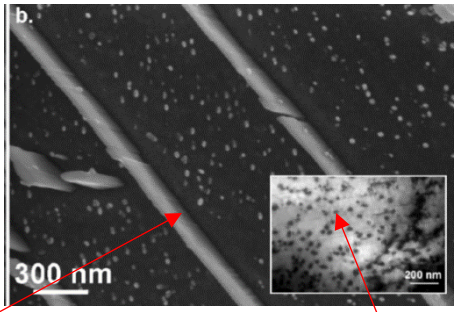
Neutron Diffraction (ND)
hysteresis in Co phase transformations at HT

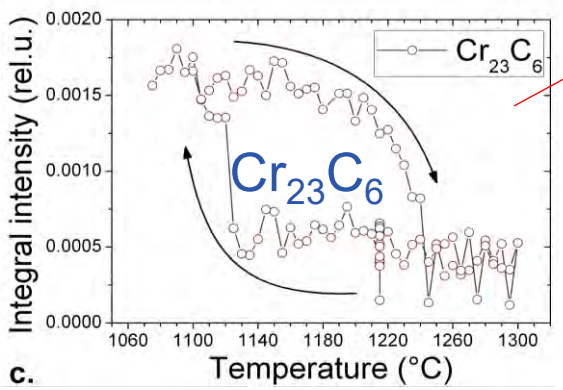


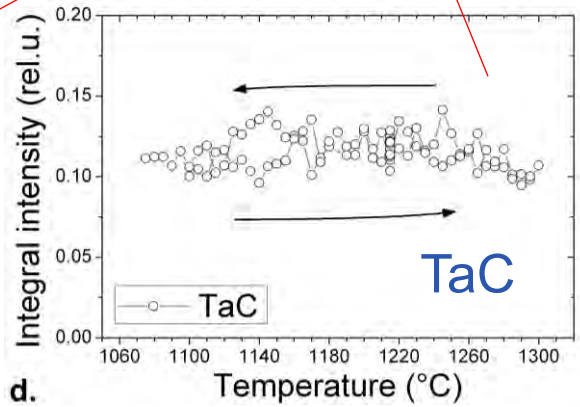


... linked to microstructure

Small-Angle Neutron Scattering (SANS)
HT microstructural stability







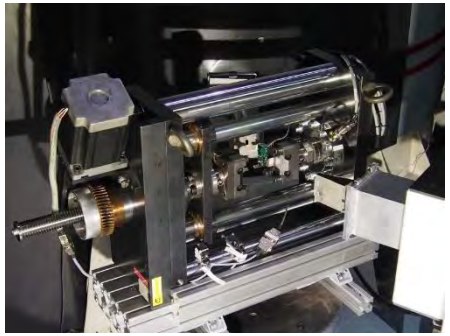
TaC found to be a promising candidate for HT strengthening

Thank you for your attention

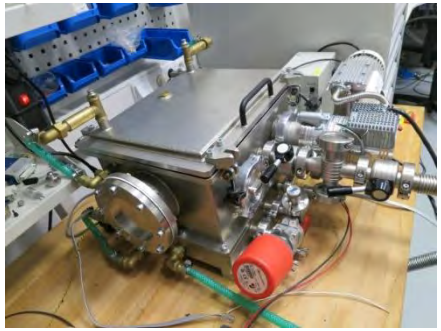
EXPERIMENTAL BASE

Sample environment for in-situ experiments with neutrons

20 kN deformation rig with current heating

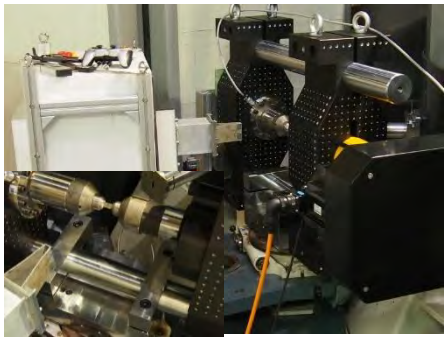


vacuum furnaces for SANS



vacuum furnace for powder diffraction

60 kN deformation rig with vacuum furnace



robotic arm for sample positioning

closed-cycle cryostat