High Entropy Shape Memory Alloys (HESMA)
–
Alloy Compositions, Processing and Microstructures

David Piorunek, Jan Frenzel, Gunther Eggeler

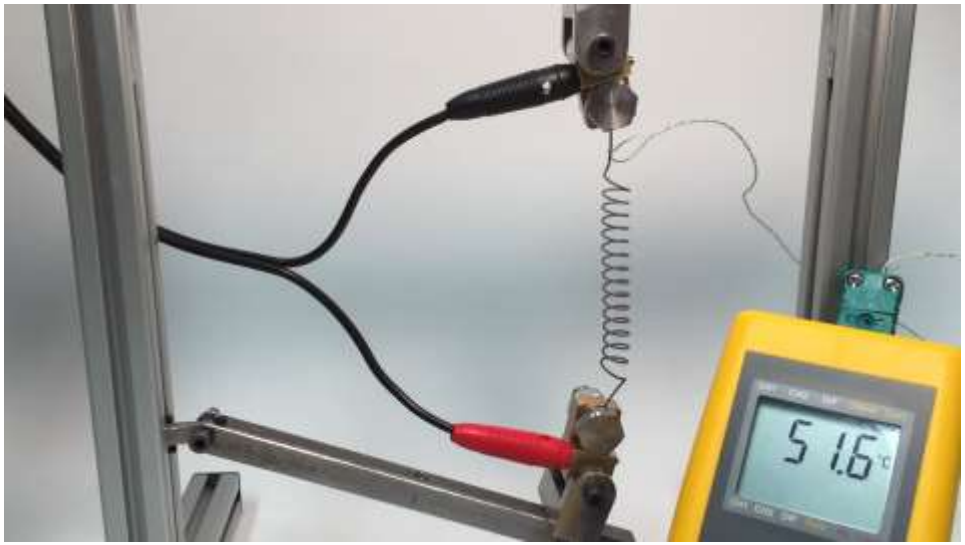
RUHR-UNIVERSITÄT BOCHUM
LWW Lehrstuhl Werkstoffwissenschaft
materials science and engineering

EG 101/32-1

Outline

- Shape memory alloys & martensitic transformation
- High entropy shape memory alloys
- Project and work programme
- Interactions in SPP

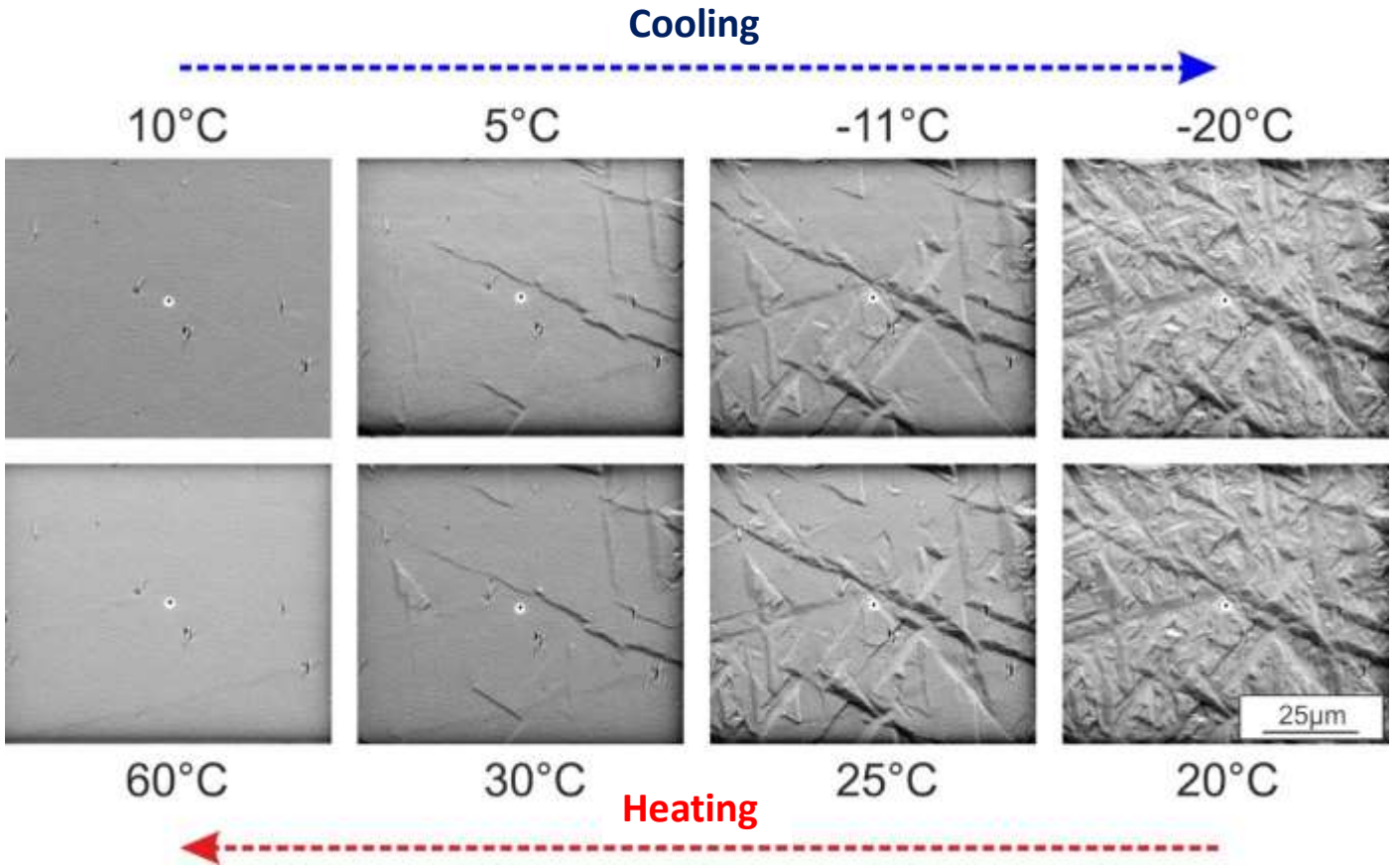
Shape memory alloys (SMAs)



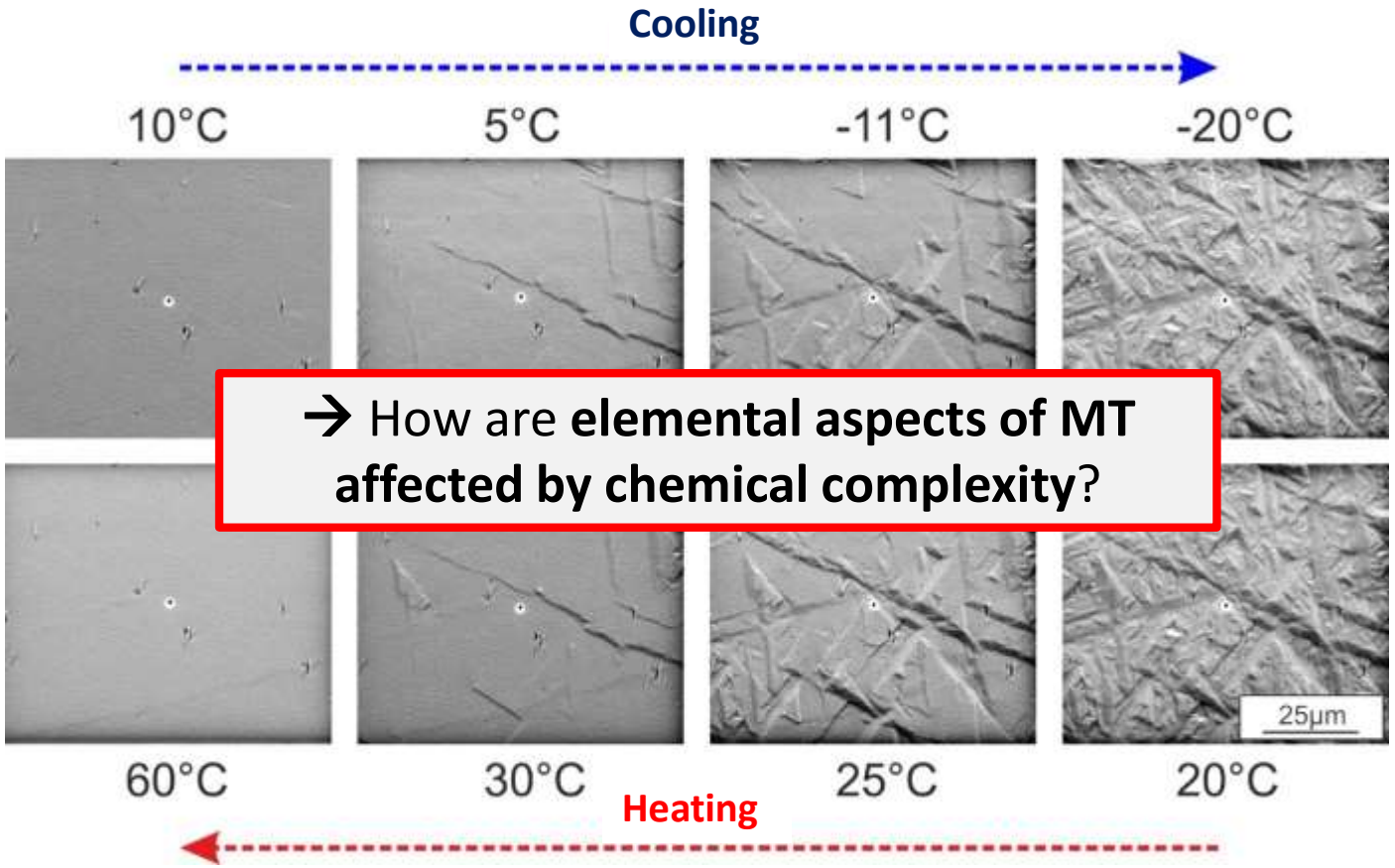
SMA spring actuator

- Shape recovery
- Two types of SM effects
  - Thermal memory
  - Mechanical memory
- Effects rely on reversible martensitic transformation (MT)
- Effects are governed by phase transformation temperatures (PTT)

Martensitic transformation

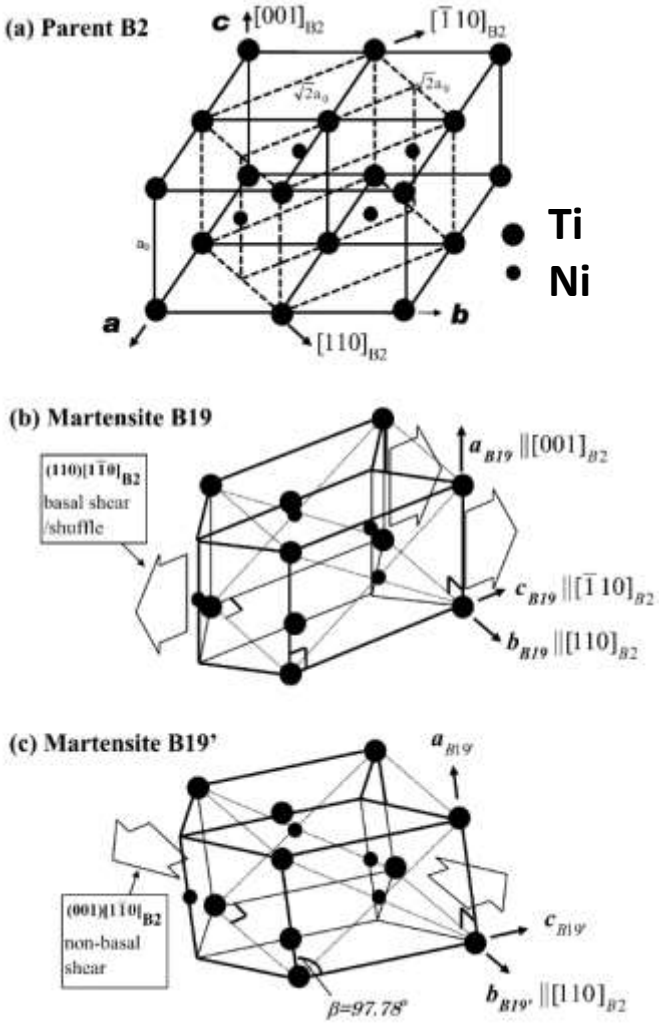


Martensitic transformation



→ How are **elemental aspects of MT affected by chemical complexity**?

Martensitic transformation in Ni-Ti



B2

(β, austenite, ordered BCC - CsCl)

basal shear ⇩

B19

(α^+/ α^- , martensite, orthorhombic)

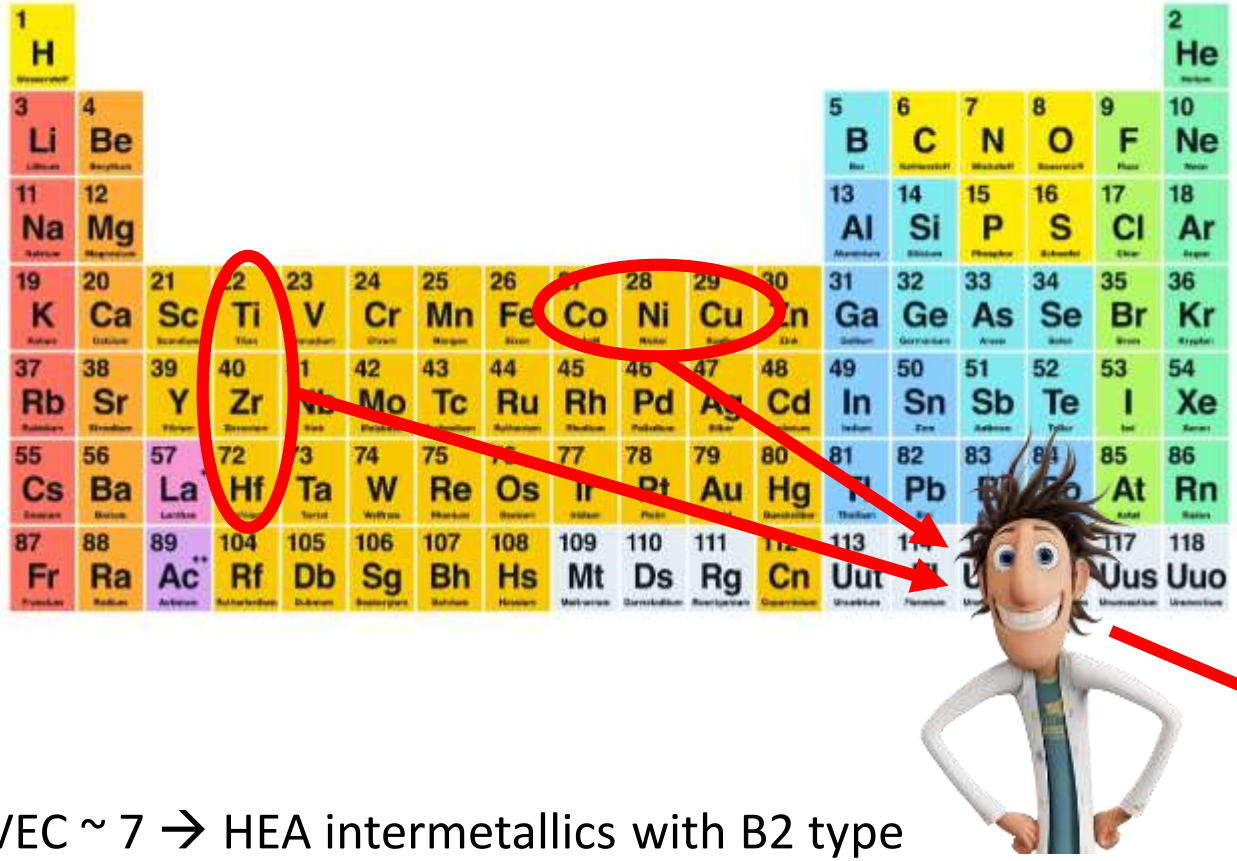
non basal shear ⇩

B19'

(α'^+/ α'^- martensite, monoclinic)

Transformation from B2 to B19'
(Otsuka & Ren, Progr. Mater. Sci. 50, 2005)

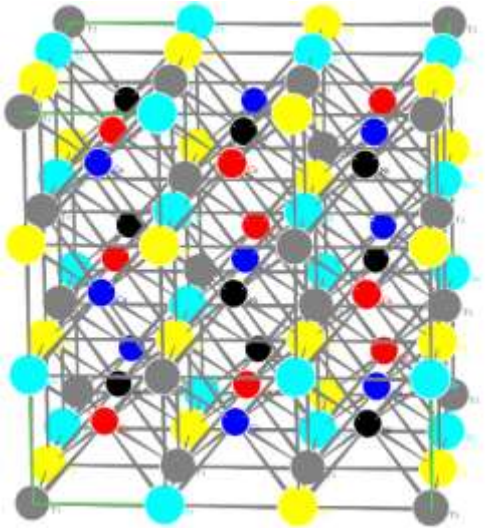
High entropy shape memory alloys



VEC ~ 7 → HEA intermetallics with B2 type

Crystal structure of HESMAs

- XRD and DFT by Firstov et al. (2015)
- $Ti_9Zr_9Hf_9Ni_9Cu_9Co_9$-Unit cell
  - Ti-sublattice-sites occupied by Ti, Hf, Zr
  - Ni-sublattice-sites occupied by Ni, Cu, Co

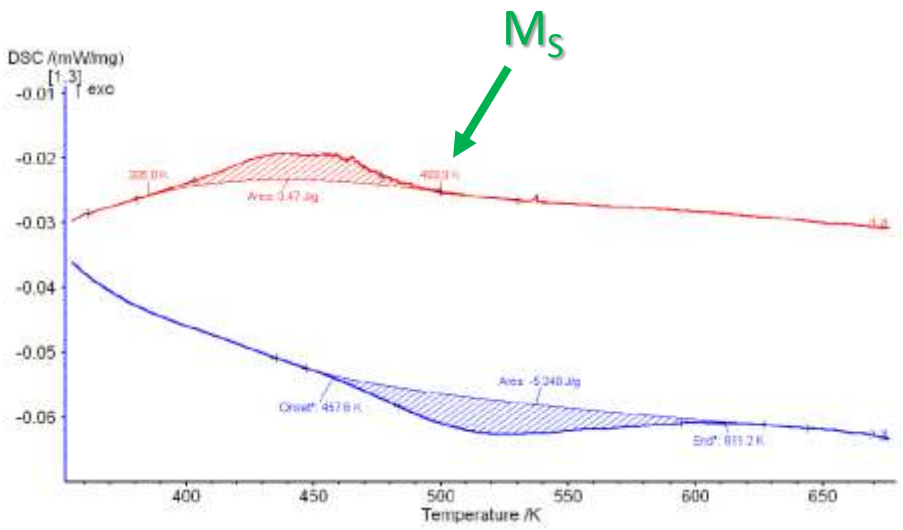


B2-related triclinic P1 phase of HESMA
(Firstov et al., Matec. Web Conf. 33, 2015)

- Unlike to B2, slightly triclinic
  - Lattice distortion
- Higher configurational entropy than in binary NiTi
  - Ordered solid solution HEA

Phase transformation behavior of HESMAs

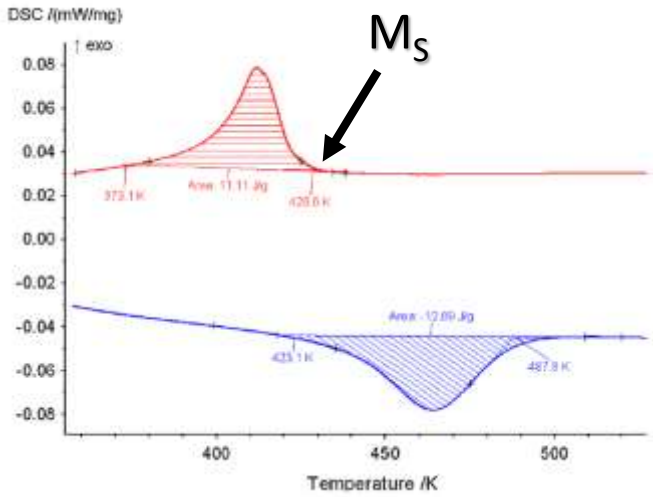
$Ti_{16.667}Zr_{16.667}Hf_{16.667}Ni_{25}Cu_{25}$



(Firstov et al., Matec. Web Conf. 33, 2015)

M_S = 500 K / 217 °C

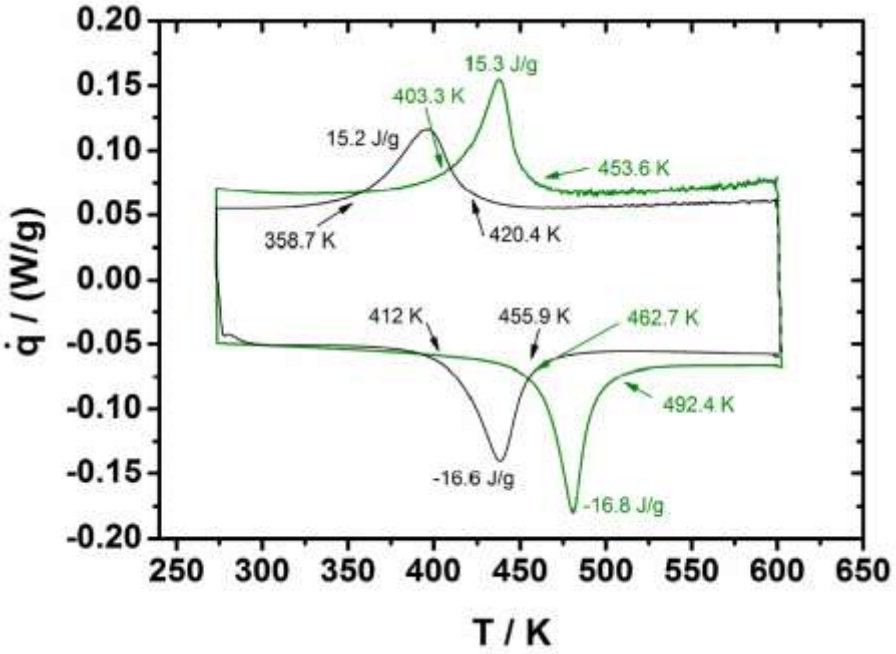
$Ti_{16,667}Zr_{16,667}Hf_{16,667}Ni_{25}Cu_{15}Co_{10}$



(Firstov et al., Sha. Mem. and Superelas., 2015)

M_S = 430 K / 157 °C

HESMAs made in Bochum



$Ti_{16.667}Zr_{16.667}Hf_{16.667}Ni_{25}Cu_{25}$

→ M_S = 454 K / 181 °C

$Ti_{16.667}Zr_{16.667}Hf_{16.667}Ni_{25}Cu_{15}Co_{10}$

→ M_S = 403 K / 130 °C

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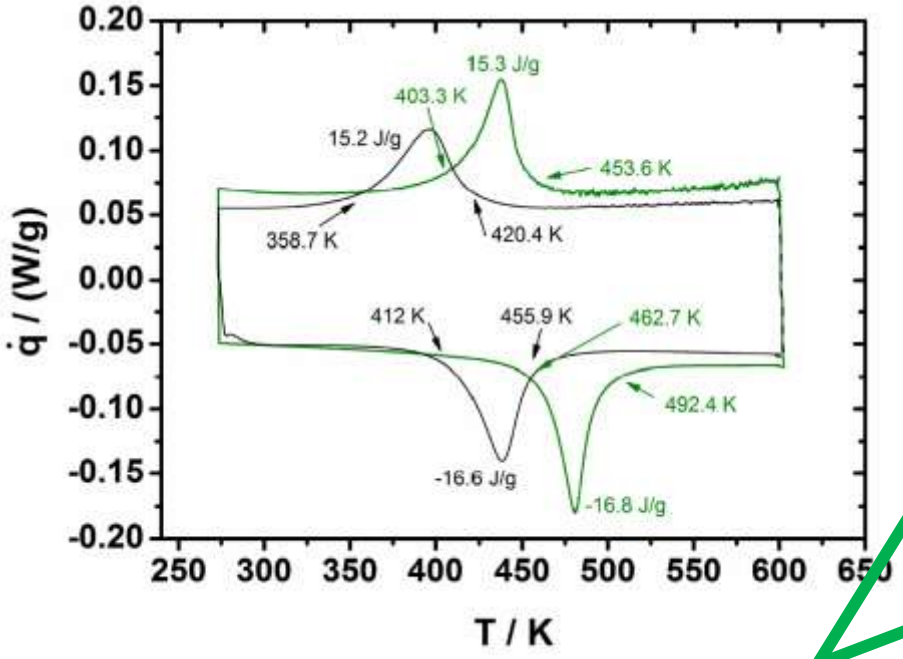

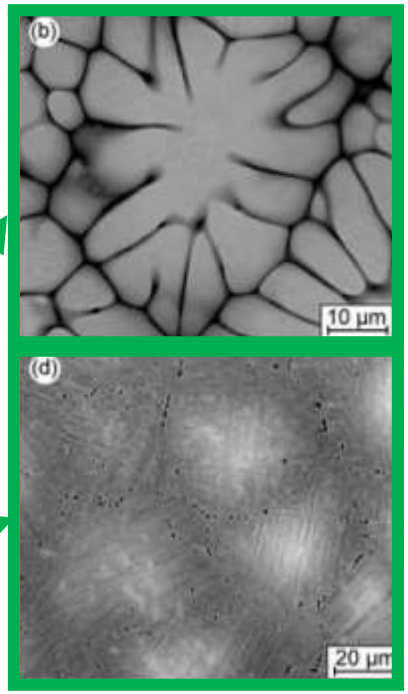

As-cast

900 °C / 72 h

$Ti_{16.667}\ Zr_{16.667}\ Hf_{16.667}\ Ni_{25}\ Cu_{25}$

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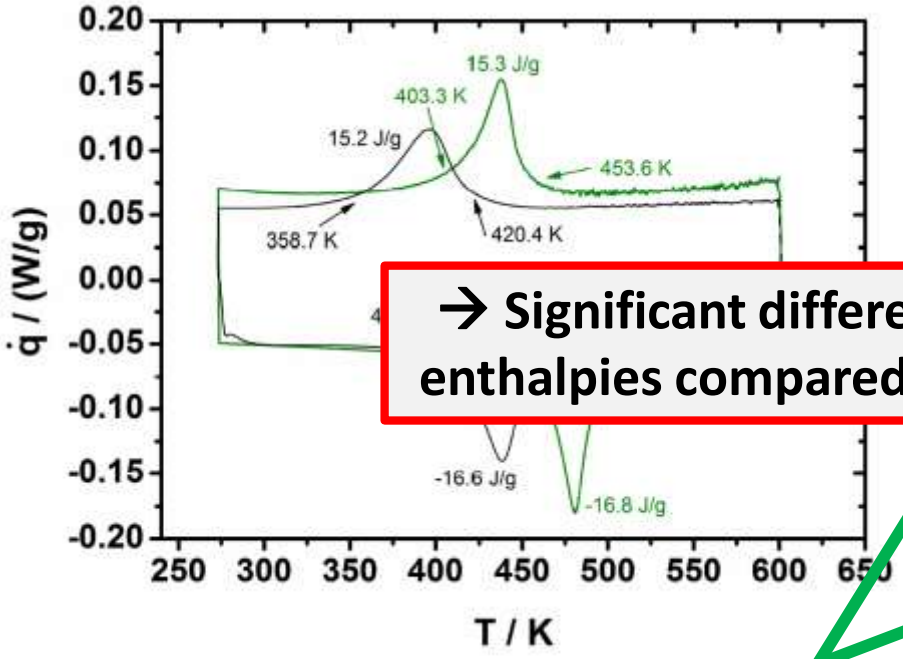
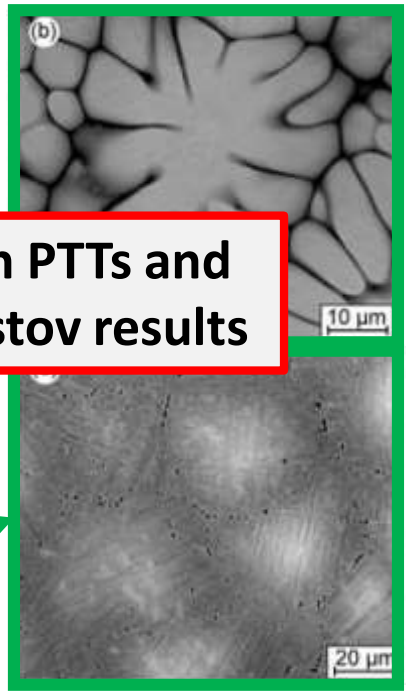


→ **Significant differences in PTTs and enthalpies compared to Firstov results**



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Project and work programme

Microstructure-Functional Behavior-Relationships in High Entropy Shape Memory Alloys

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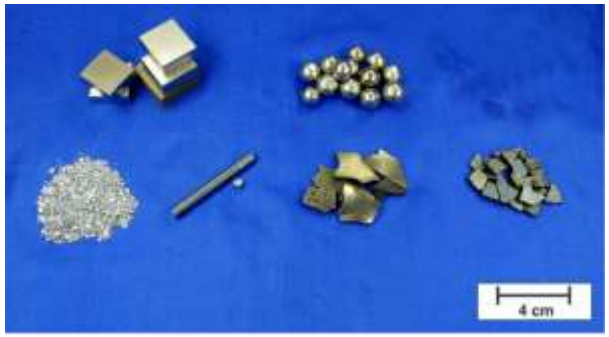
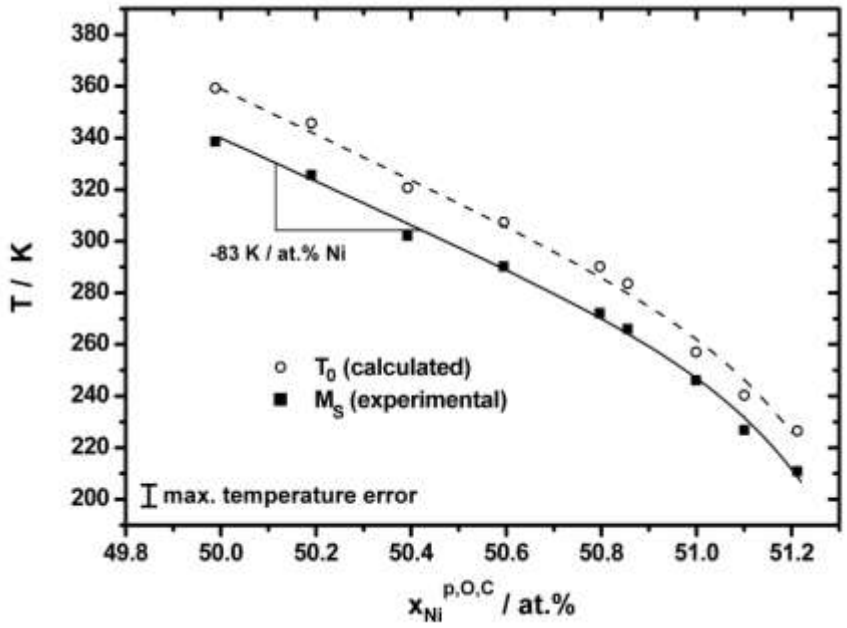
- Ingot metallurgy and compositional screening
- Characterization of martensitic transformation
- Phase stability and atomic mobilities
- Thermo-mechanical processing and heat treatment

- Basic mechanical properties
- Thermo-mechanical fatigue testing to assess functional fatigue resistance
- Identification of functional degradation mechanisms
- Structural fatigue



Processing of HESMAs

Alloy composition and PTTs



(Frenzel et al., Acta Mat. 58, 2010)

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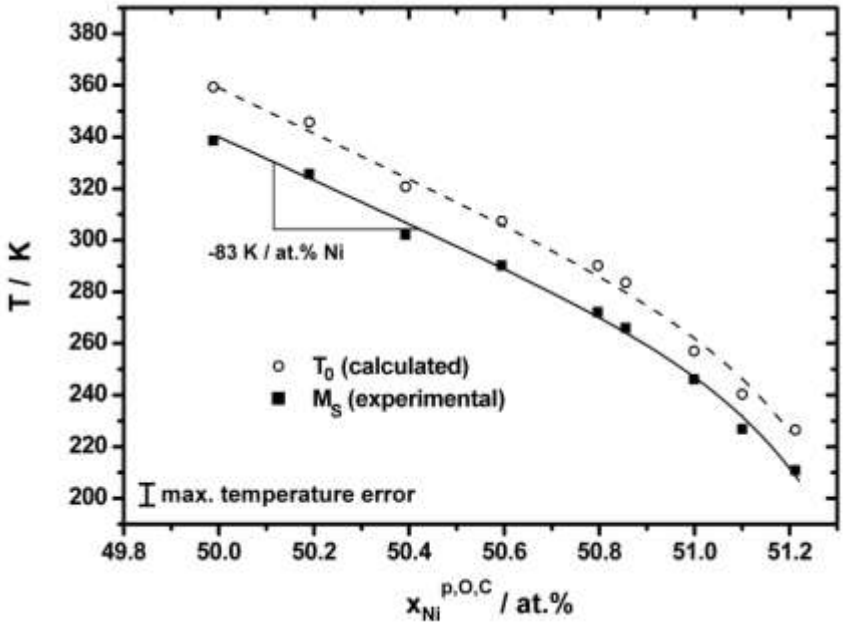
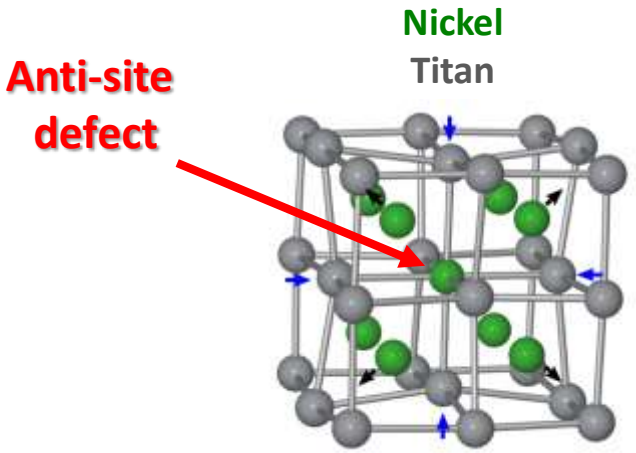


(Frenzel et al., Acta Mat. 58, 2010)



(Frenzel et al., Acta Mat. 90, 2015)

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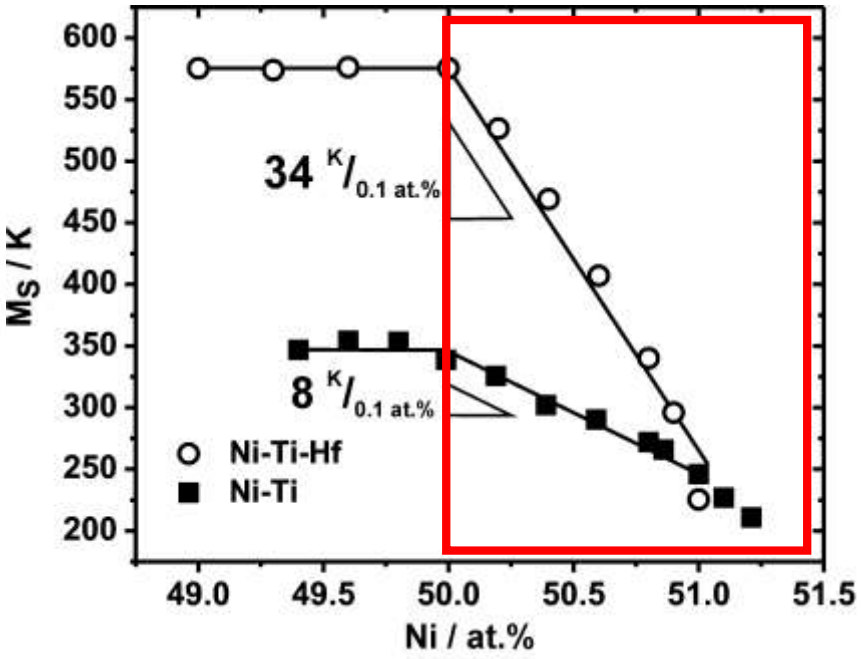

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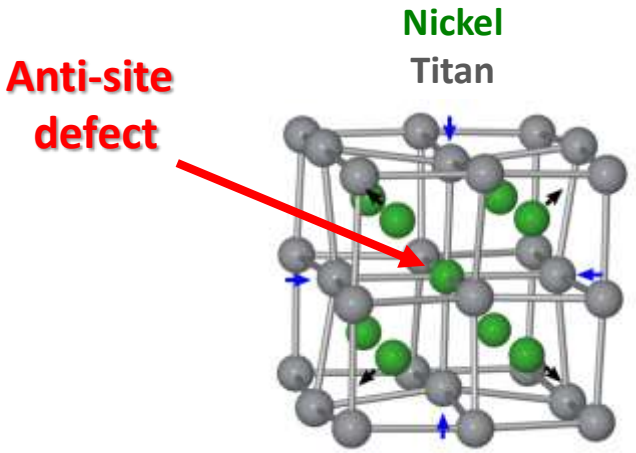
(preliminary work)



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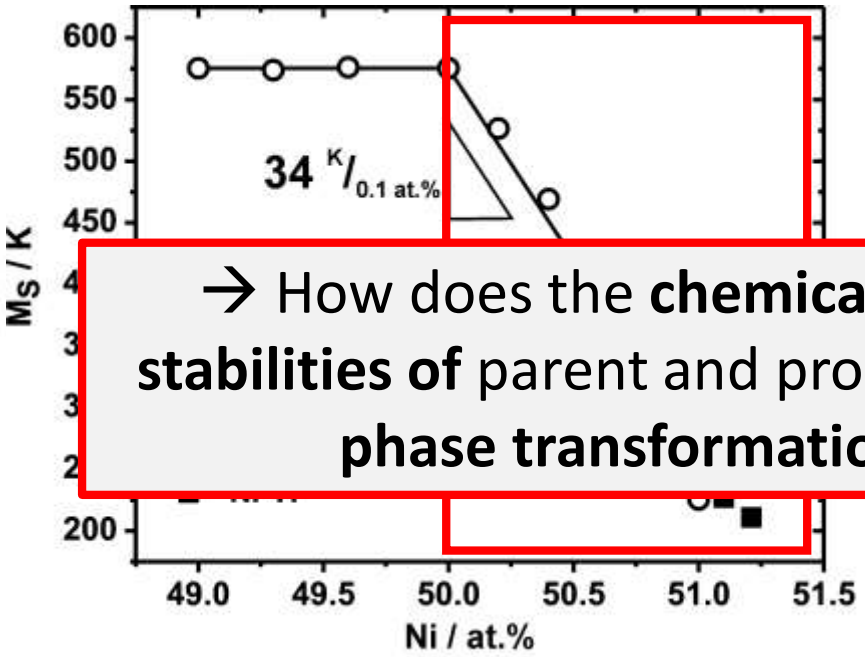

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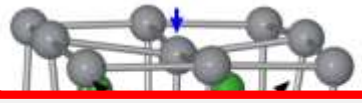
Anti-site defect

Nickel

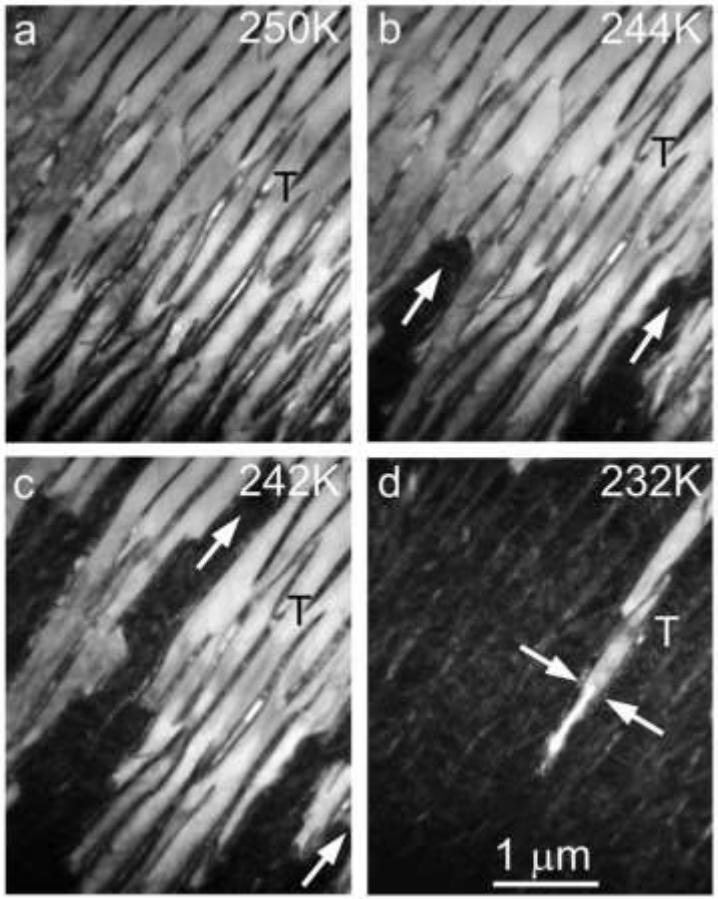
Titan



→ How does the **chemical complexity affect** the **stabilities of** parent and product **phases** and thus the **phase transformation temperatures**?

(Frenzel et al., Acta Mat. 90, 2015)

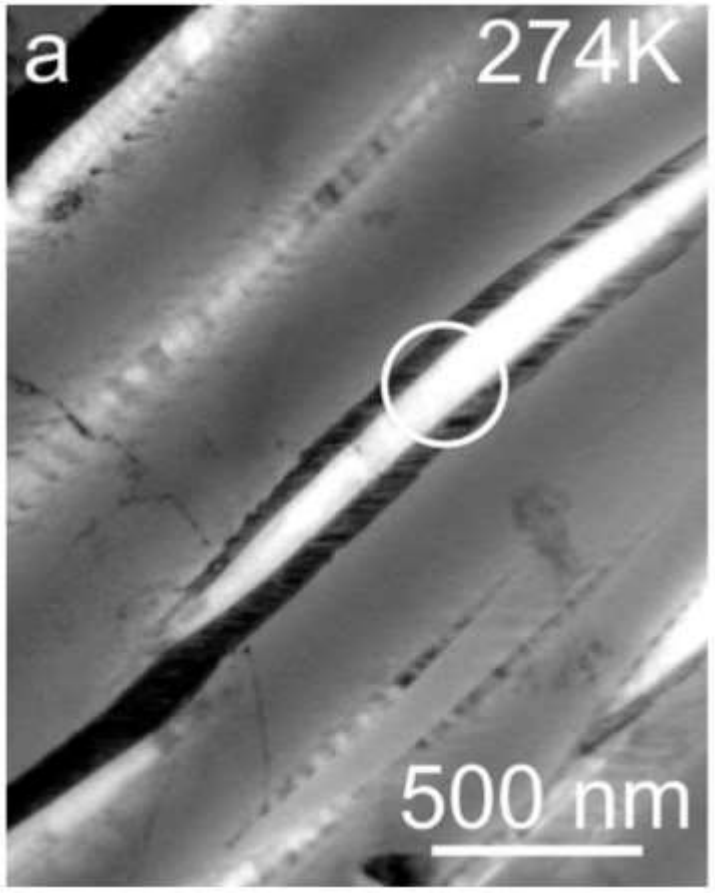
Aging and phase stability



(Michutta et al., Acta Mat. 33, 2015)

- Elementary MT processes depend strongly on microstructure and phase stability
- Aging → Ni_4Ti_3 precipitates
- Multi-step MTs (B2 → R → B19')

Aging and phase stability



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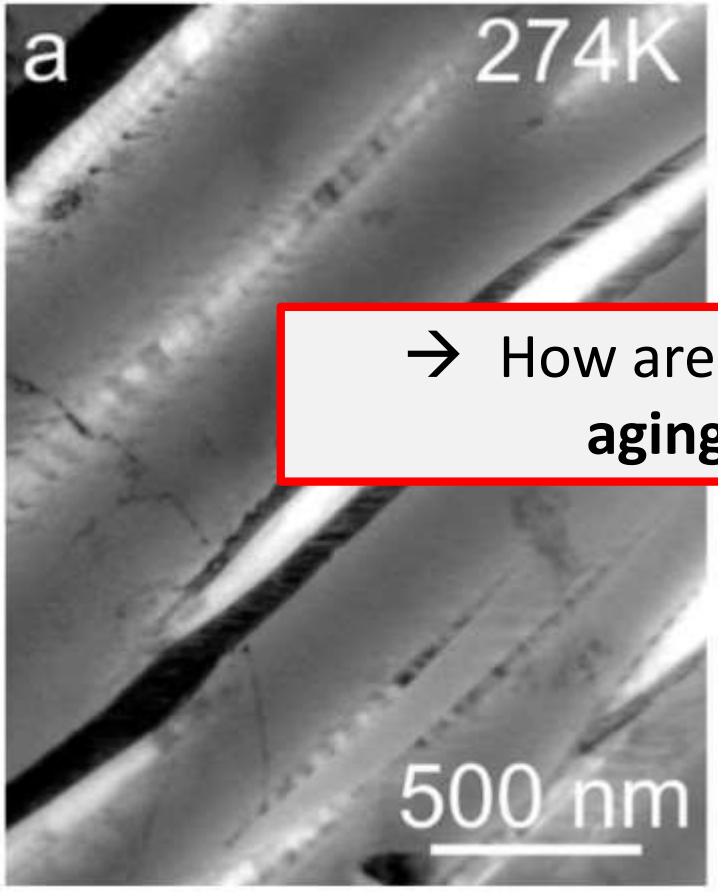
- **B19' nucleation** not only determined by **large-scale** (Δc) but also **small-scale heterogeneities**

Aging and phase stability



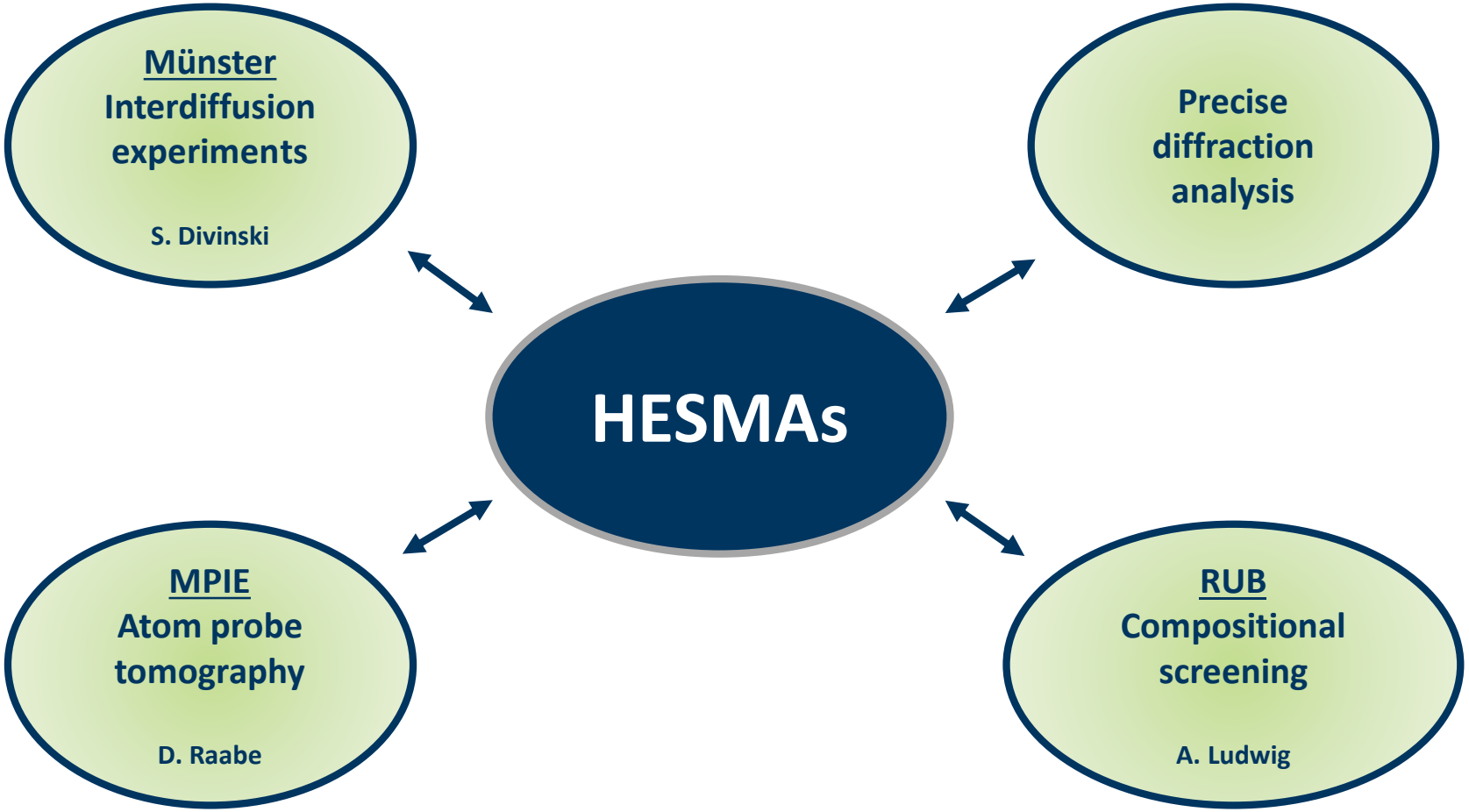
(Michutta et al., Acta Mat. 33, 2015)

- Elementary MT processes depend strongly on microstructure and phase stability

→ How are HESMAs affected by **aging treatments**?

- **B19' nucleation** not only determined by **large-scale** (Δc) but also **small-scale heterogeneities**

Interactions in SPP



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Thank you for your attention!