Chemical gradients across martensite/austenite phase boundaries in precipitation hardened TRIP steel studied by atom probe tomography

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Overview

- Motivation and alloy design
- Atom probe tomography
- Mechanical properties and microstructure
- Mn partitioning and simulations
- Conclusions

Fe-Mn based maraging TRIP steel development

- **TRIP:** **deformation-stimulated transformation of unstable austenite into martensite and accommodation plasticity (e.g. Mn, Ni, low C)**

- **Maraging effect:** **hardening of heavily strained martensite via nano-sized (intermetallic) precipitates (Ni, Al, Ti, Mo)**

  (see also conventional Maraging steels)

What is **maraging-TRIP** ?

Quenched austenite: ductile low carbon martensite
Retained austenite (TRIP or TWIP)
Aging: austenite reversion (increase TRIP / TWIP volume)
Aging: controlled precipitation hardening

** TRIP: transformation-induced plasticity*
** Maraging: martensite aging*

Steel	C	Ni	Co	Mo	Ti	Al	Mn	Fe
Maraging	0.01	18	12	4	1.6	0.15	0.05	Balance
09MnPH	0.01	2	-	1	1.0	0.15	9	Balance
12MnPH	0.01	2	-	1	1.0	0.15	12	Balance
15MnPH	0.01	2	-	1	1.0	0.15	15	Balance

Low carbon: ductile martensite

Precipitation Hardenable

Mn (+Ni): austenite (TRIP)

Martensite aging after quenching at 450°C

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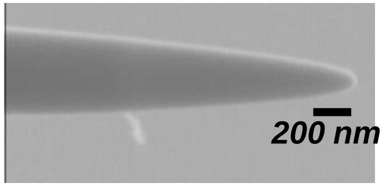

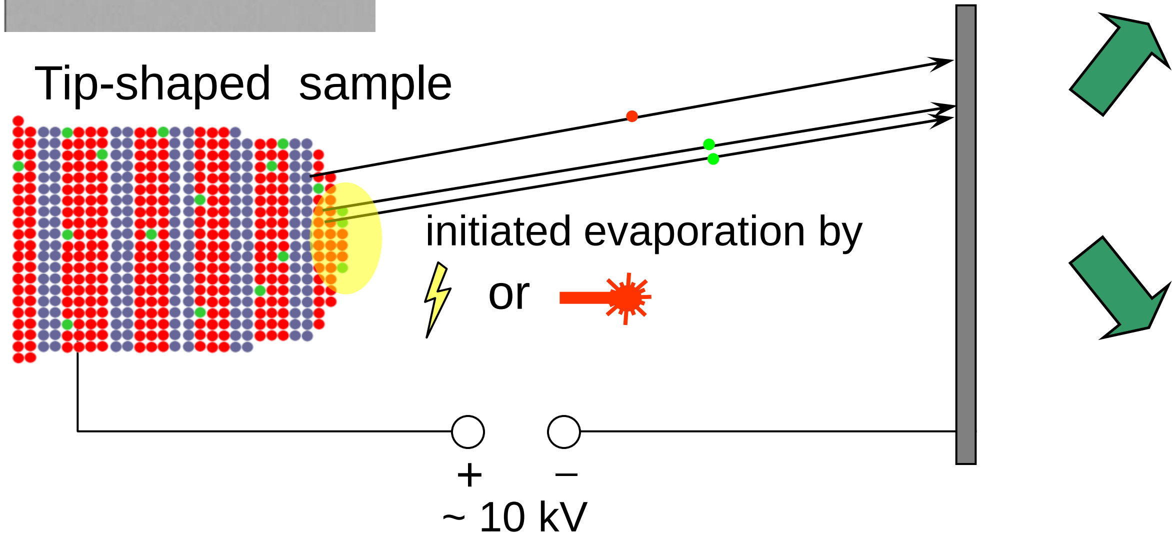

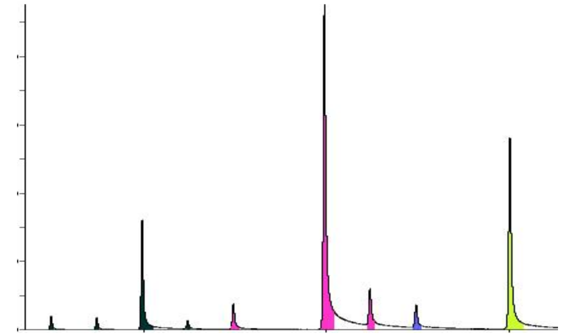

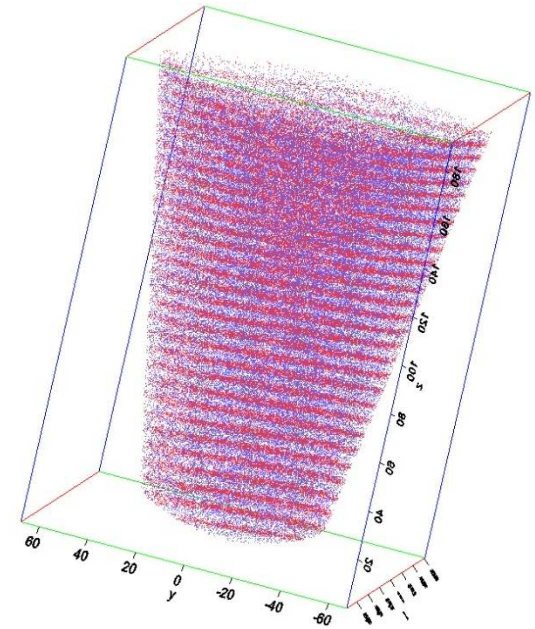

APT: Time of flight measurement
(chemical identification)
+
Ion projection microscopy
(determination of position)

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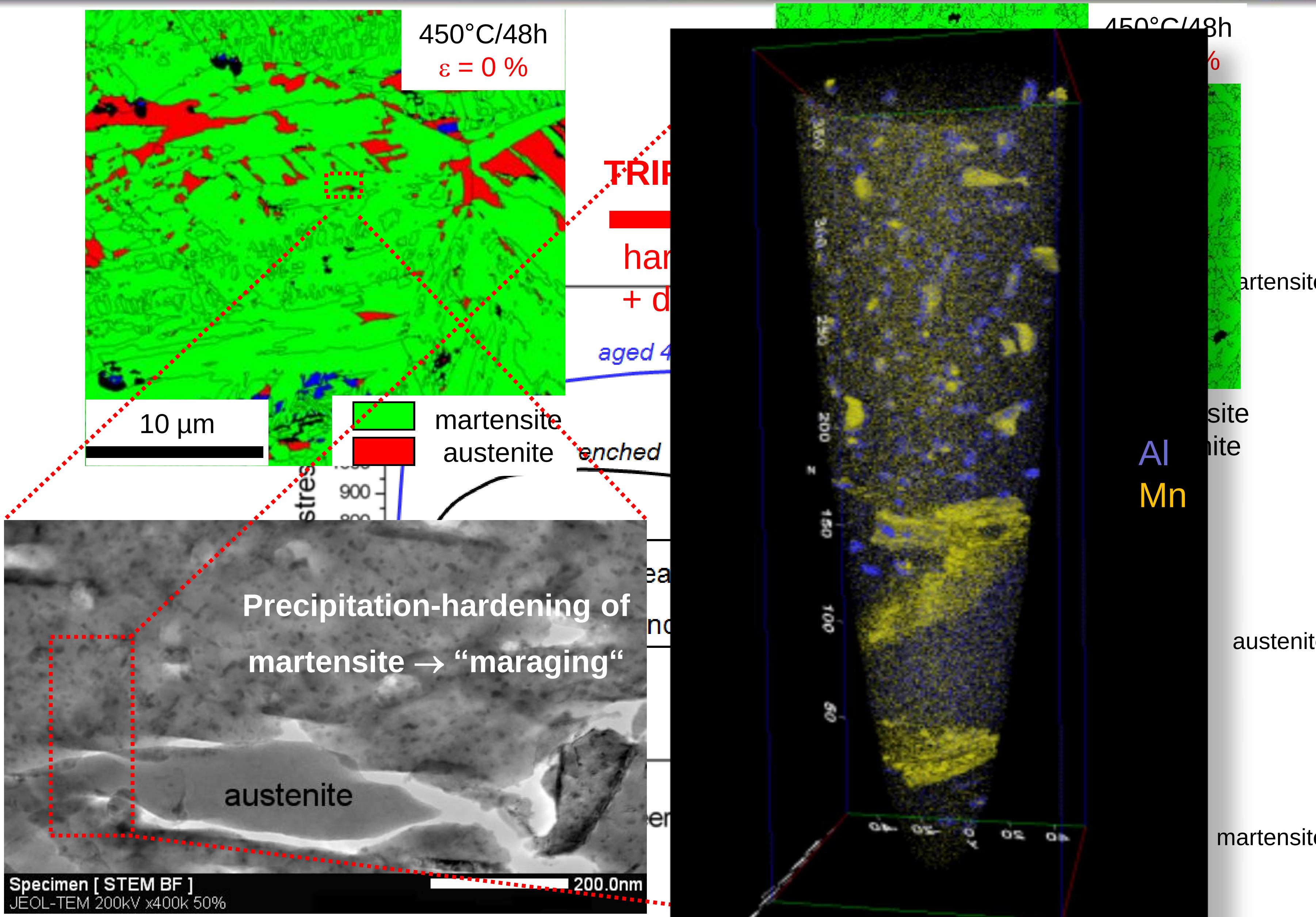
Hierarchy of maraging TRIP / TWIP steels



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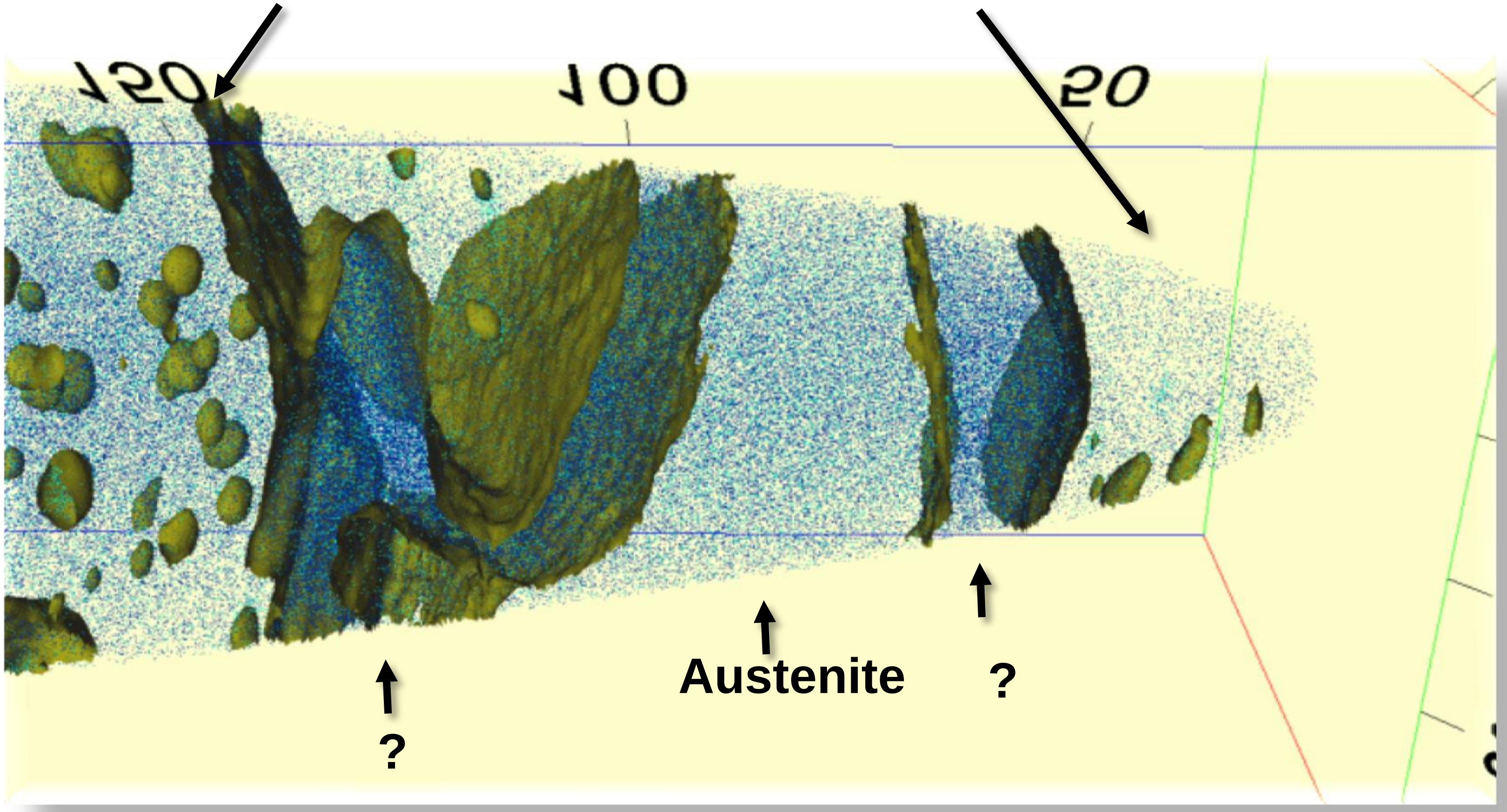
APT results: Atomic map (12MnPH aged 450°C/48h)

Martensite decorated by precipitations



Mn atoms
Ni atoms
Mn iso-concentration: 18 at.%

C	Ni	Mo	Ti	Al	Mn	Fe
0.01	2.0	1.0	1.0	0.15	12	bal.

70 million ions
Laser mode
(0.4nJ, 54K)

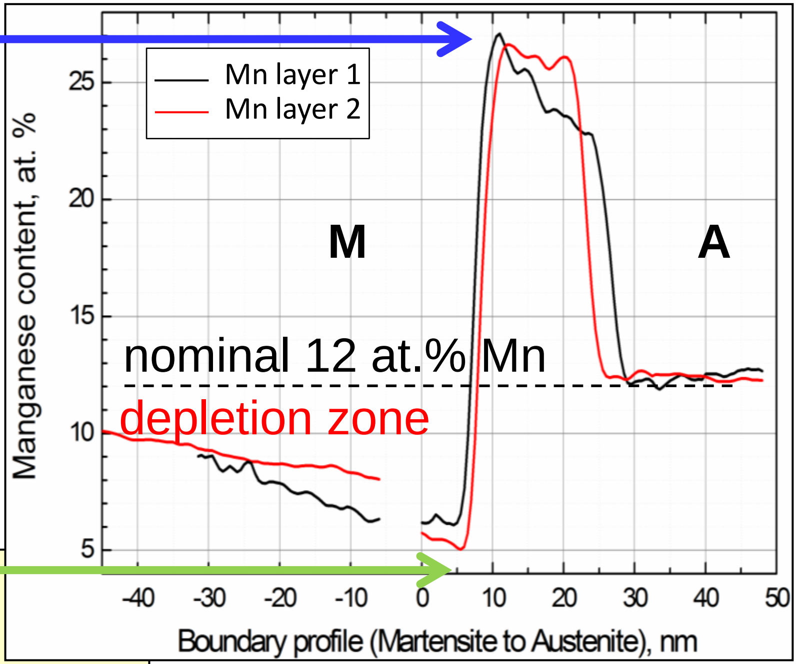
Aging-induced austenite reversion

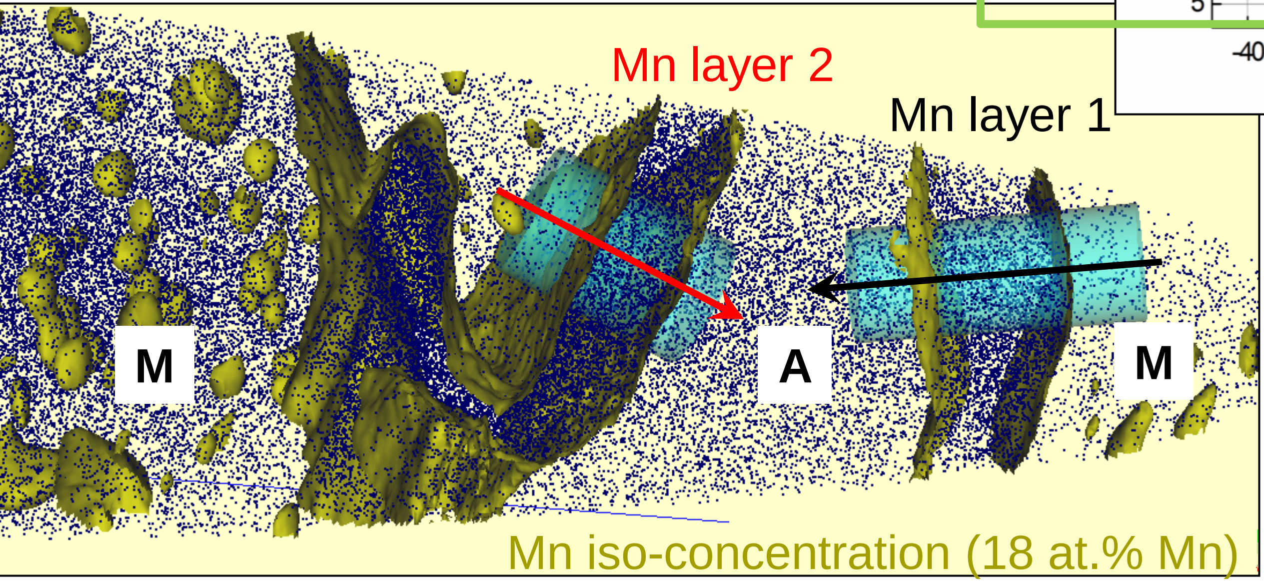
Thermo-Calc ⇒

equilibrium Mn-conc.:

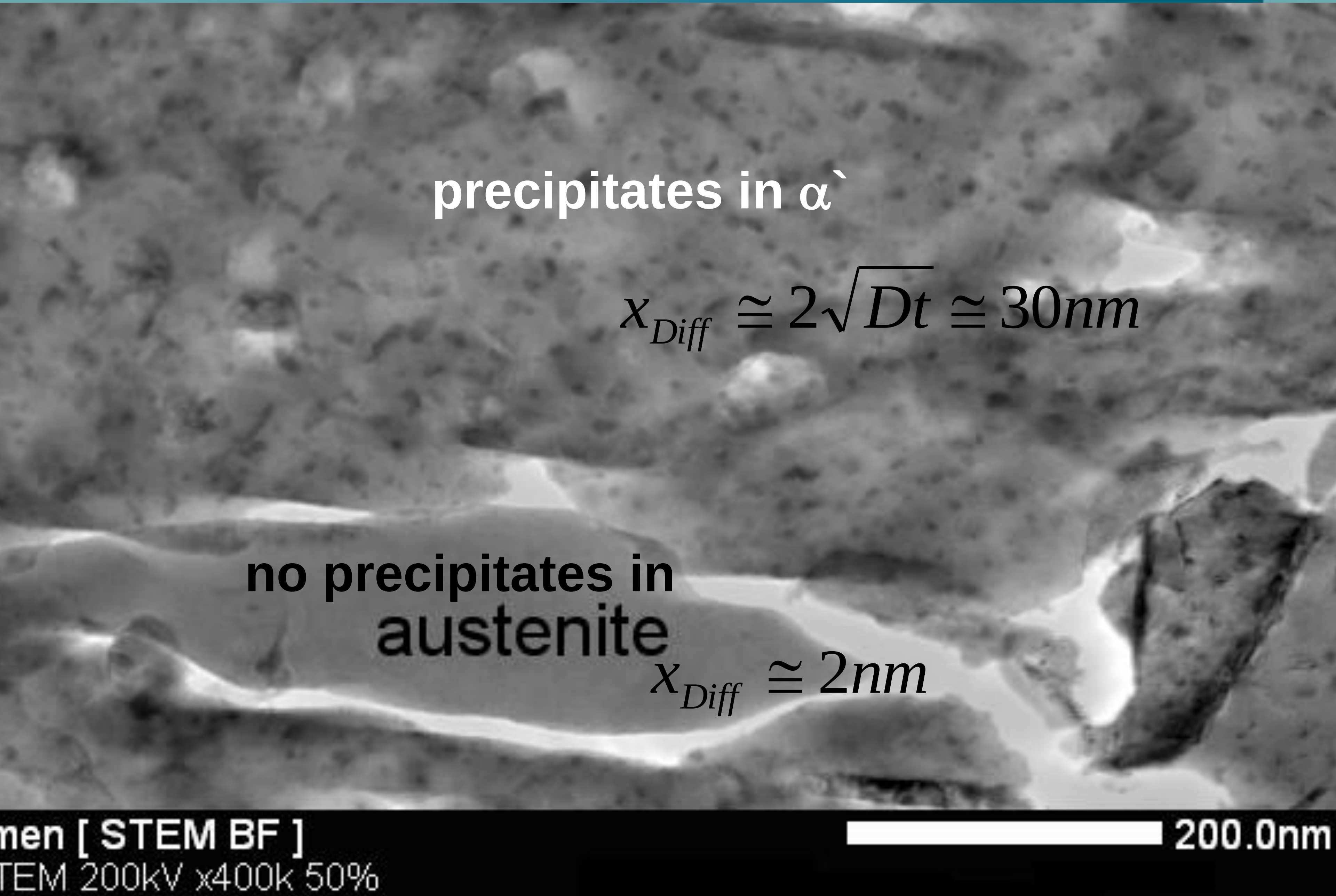
27 at. % Mn in austenite (A)

3 at. % Mn in ferrite (martensite) (M)





12MnPH after aging (48h 450°C)



precipitates in α`

$$x_{Diff} \cong 2\sqrt{Dt} \cong 30nm$$

no precipitates in austenite

$$x_{Diff} \cong 2nm$$

Aging-induced austenite reversion

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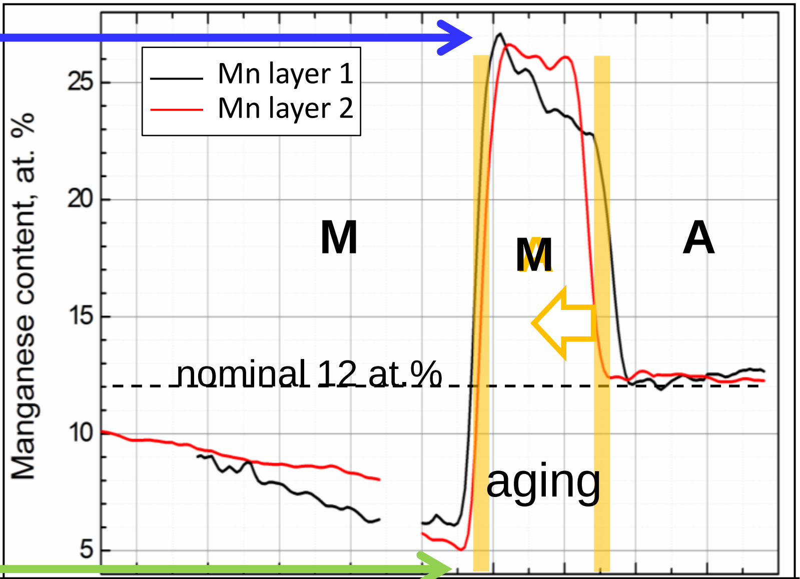
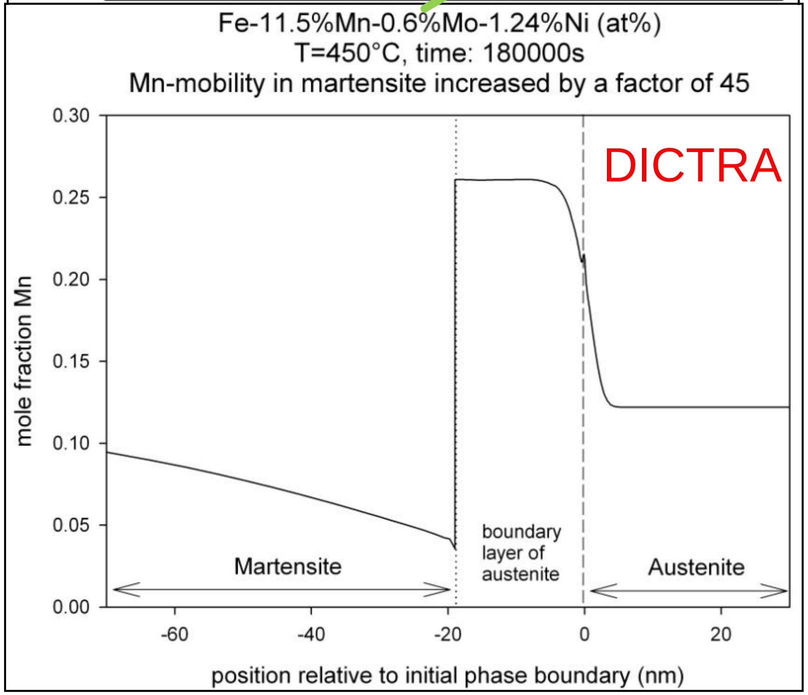
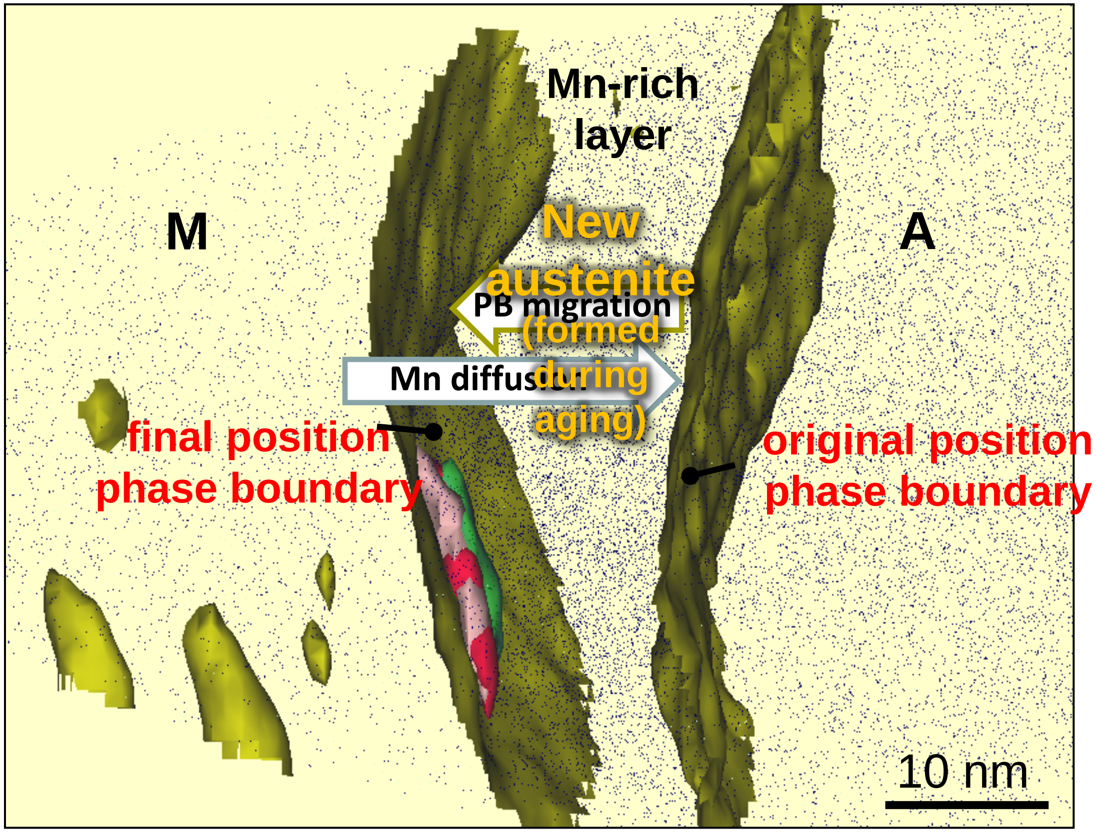




Excellent agreement between experiment & simulation !

Kinetic freezing and associated austenite reversion !

APT results and simulation: DICTRA/ThermoCalc



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Conclusions

- Maraging-TRIP as a new GPa steel design approach
- Unexpected simultaneous increase in strength and elongation
- Mn partitioning, predicted by ThermoCalc/DICTRA
- Austenite stability predicted using ab initio methods (see talk of T. Hickel)
- B2 and L21 nano-precipitates
- Next steps: lean composition, interstitials, alloy variants, equilibrium partitioning, nano-precipitates