DAMASK: Düsseldorf Advanced MAterial Simulation **K**it for studying texture and plasticity in DP steels

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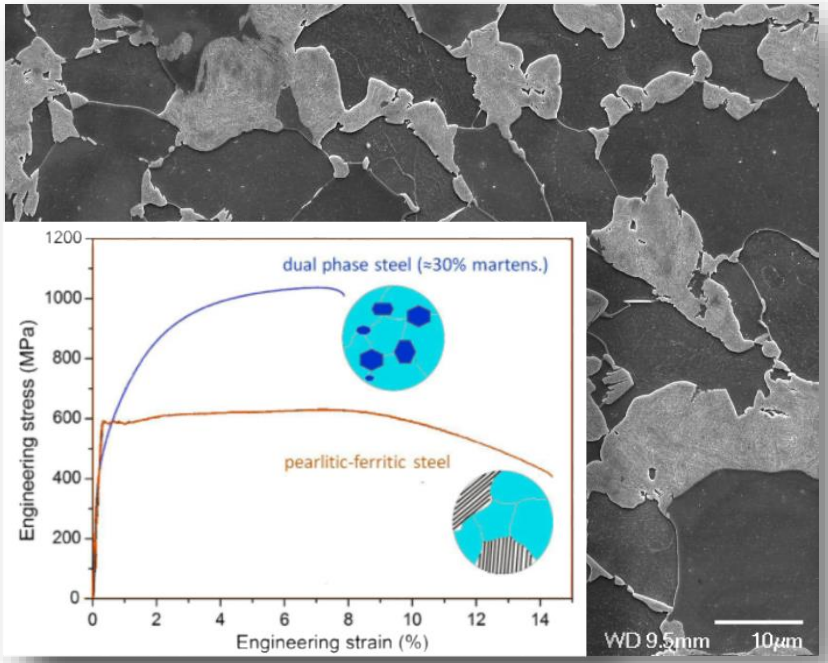
Max-Planck-Institut für Eisenforschung

Big thanks to
P. Eisenlohr, R. Lebensohn, B. Svendsen,
C. Zambaldi, C. Tasan, D. Ponge, T. Bieler, S. Zaefferer

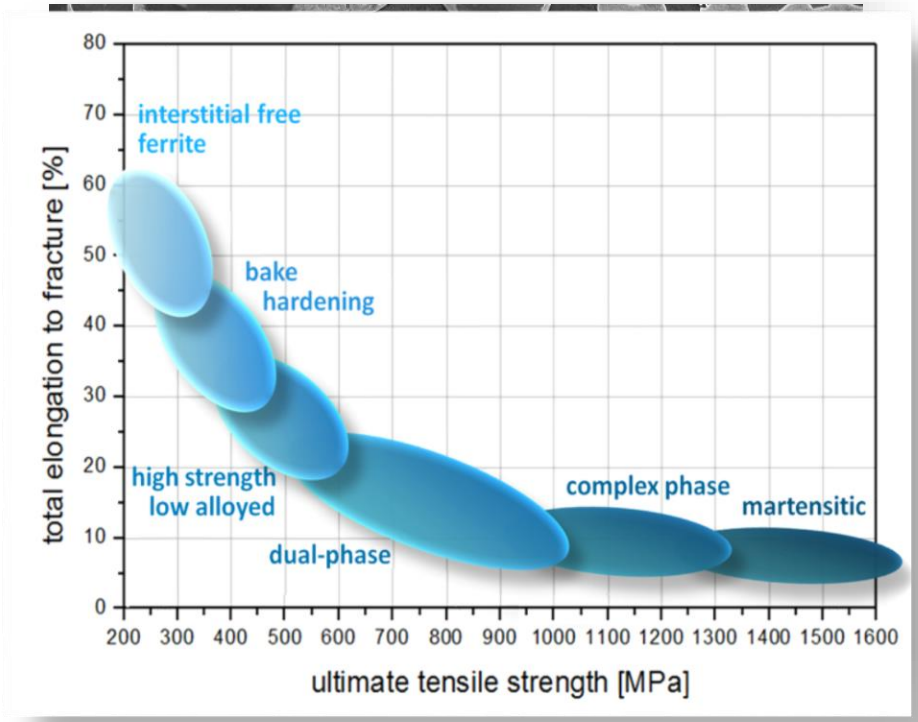
DP steels for auto applications



High UTS
Low yield strength
High stiffness
Sufficient ductility
Good formability
No Lüders strain
Tunable properties
Low cost

Increase in strength (e.g. more martensite) reduces ductility

DP steels for auto applications



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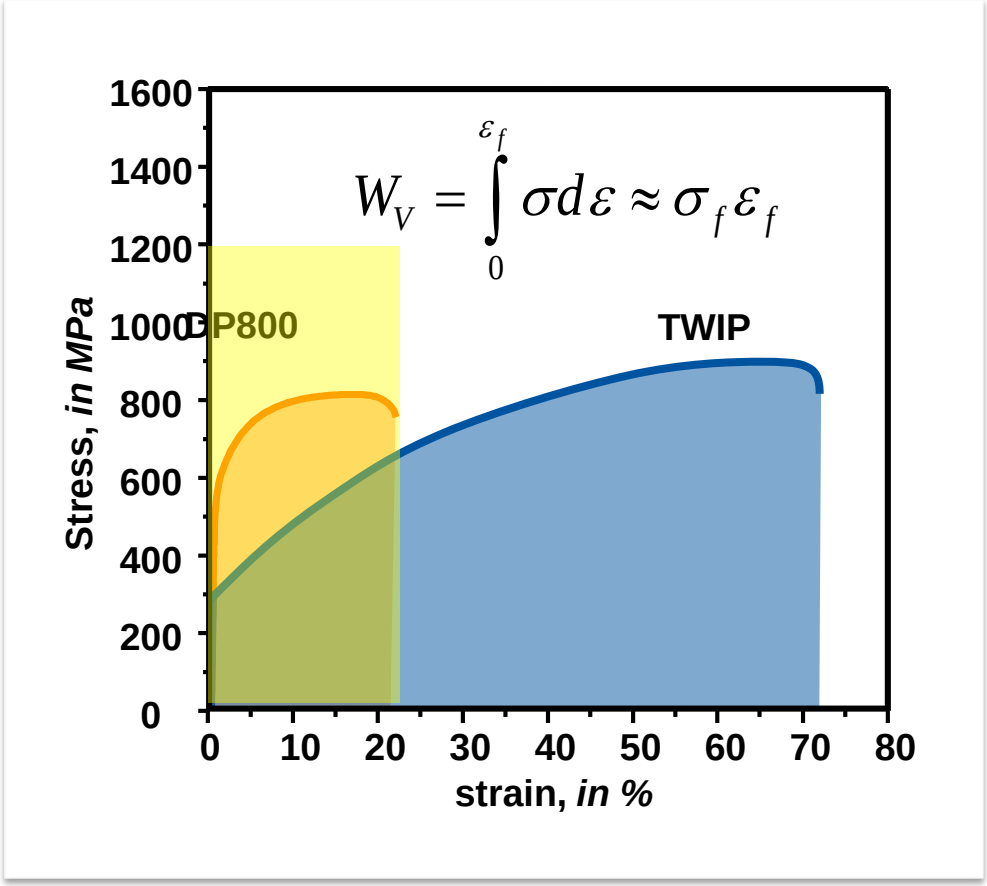
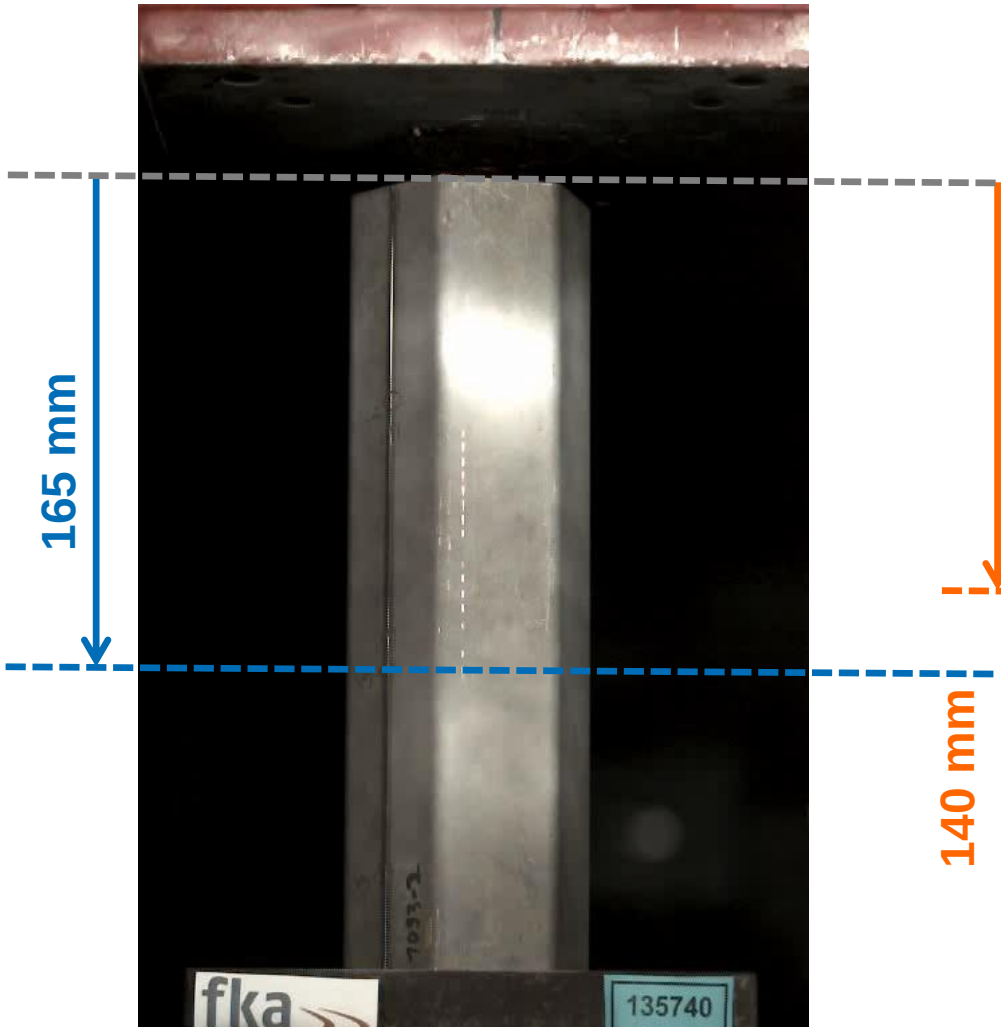
Strain rate 800/s: TWIP vs. DP800



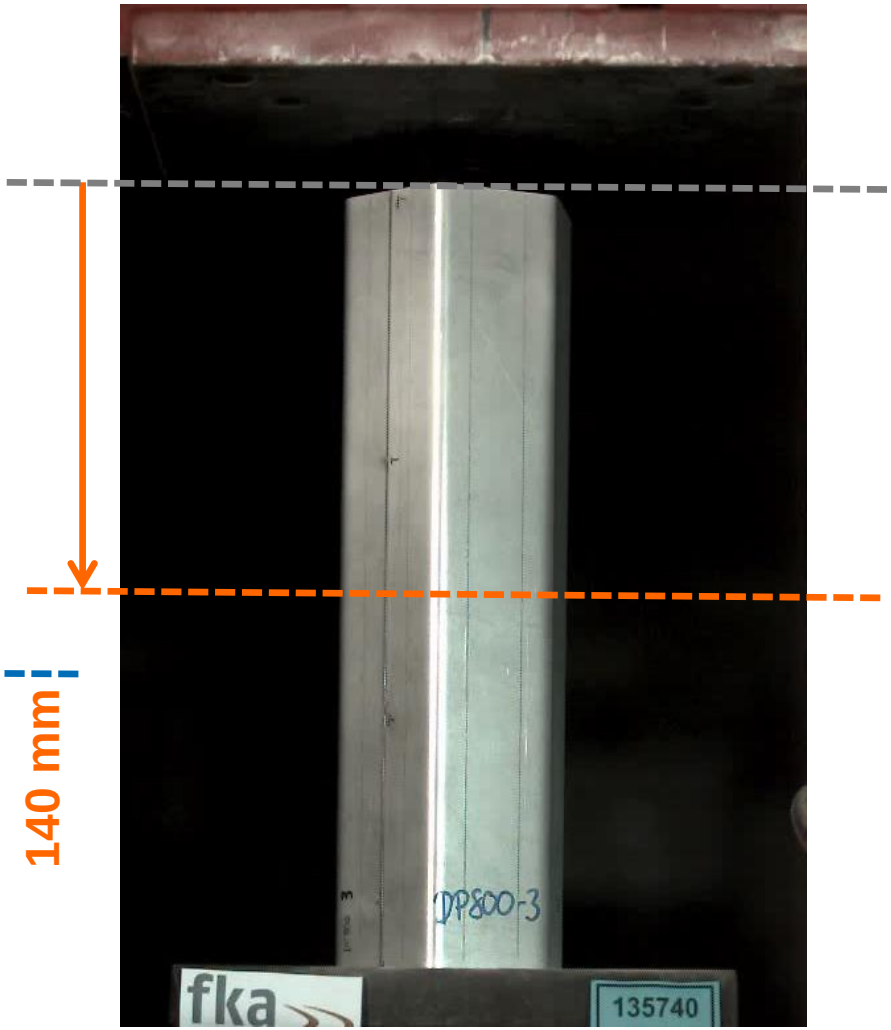
Energy absorption depends on material & design

Strain rate 800/s: TWIP vs. DP800

TWIP (X30Mn29)

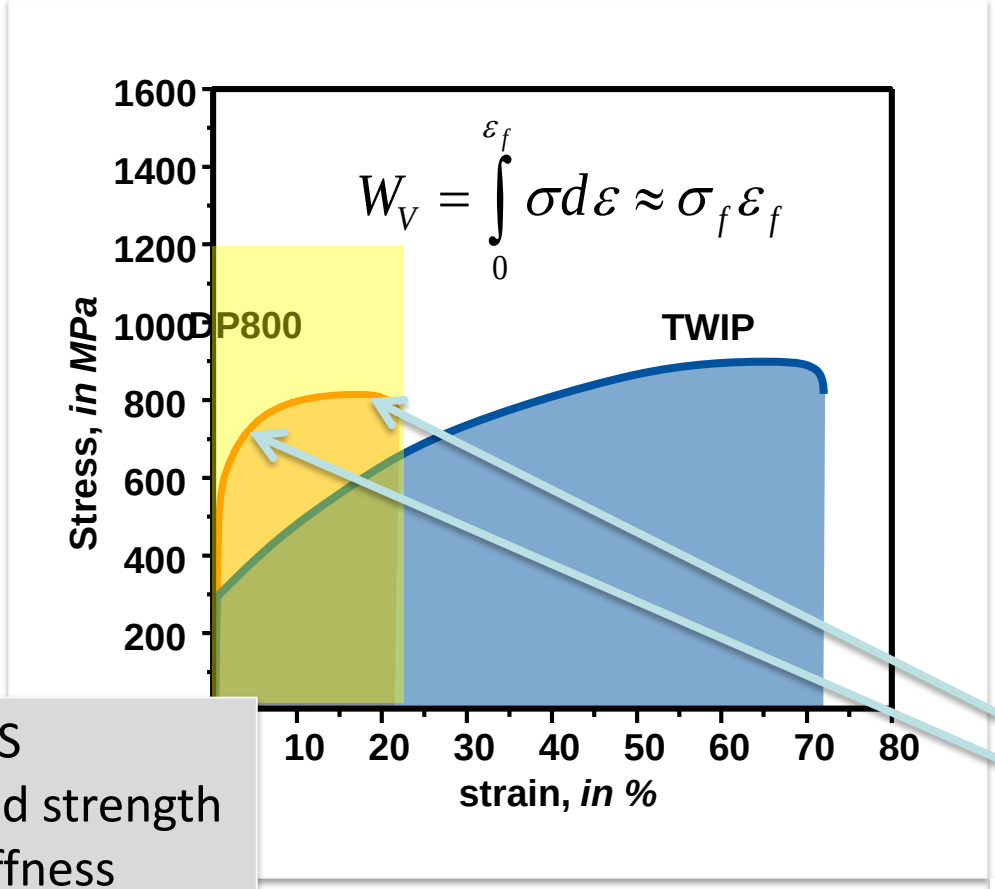


DP 800



Energy absorption depends on material & design

Strain rate 800/s: TWIP vs. DP800

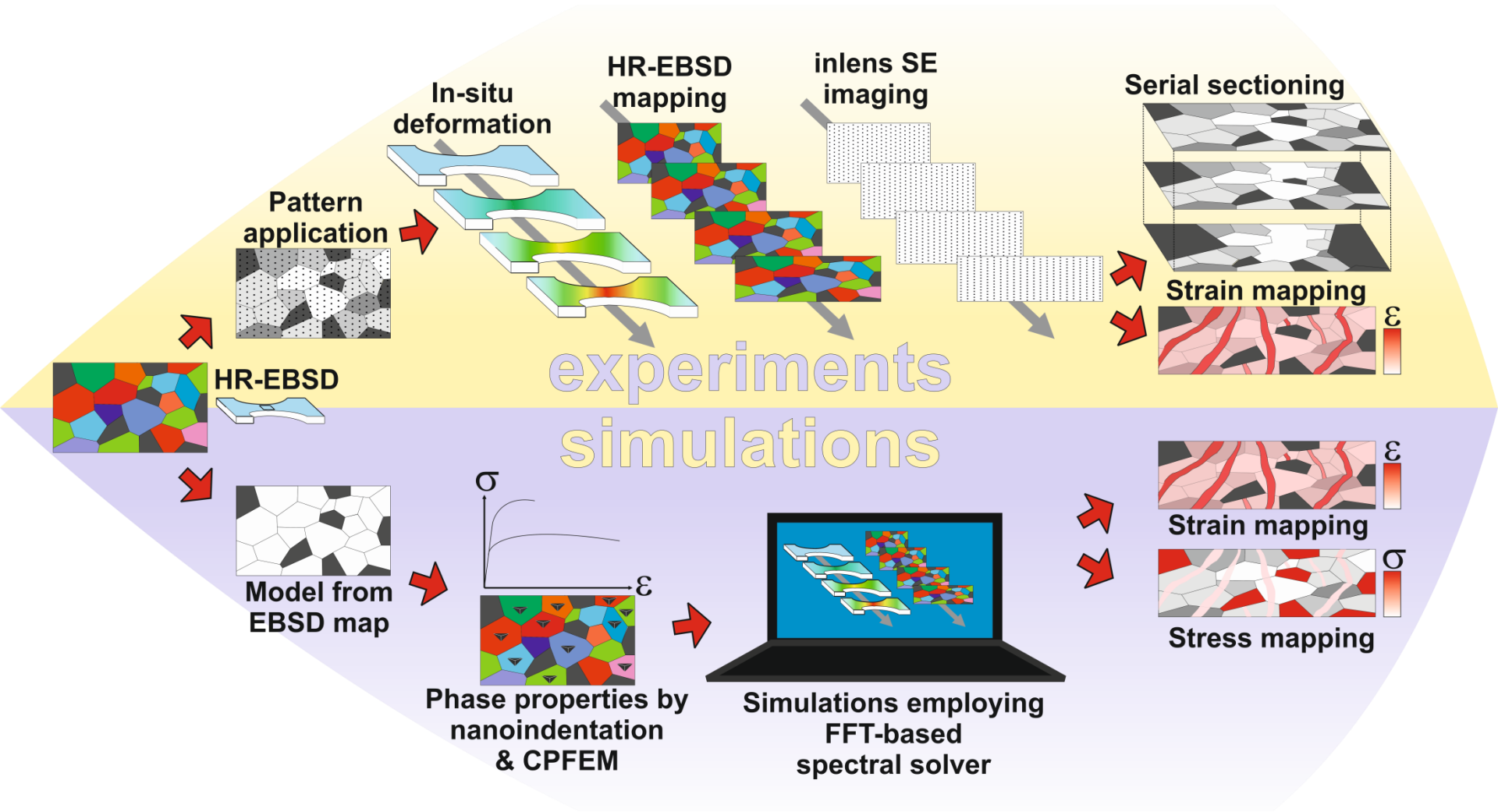


High UTS
Low yield strength
High stiffness
<u>Sufficient ductility</u>
Good formability
No Lüders strain
Tunable properties
Low cost

Loading points from buckling

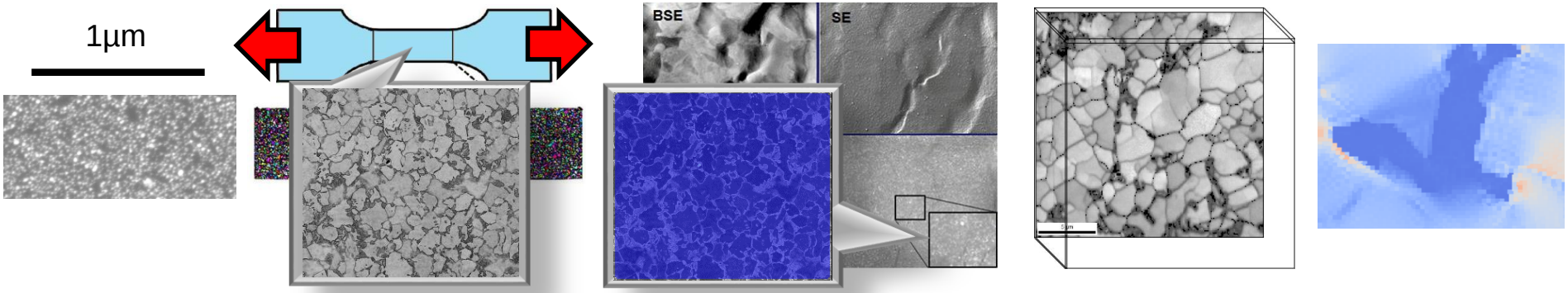
Energy absorption depends on material & design

ICME applied to DP steels

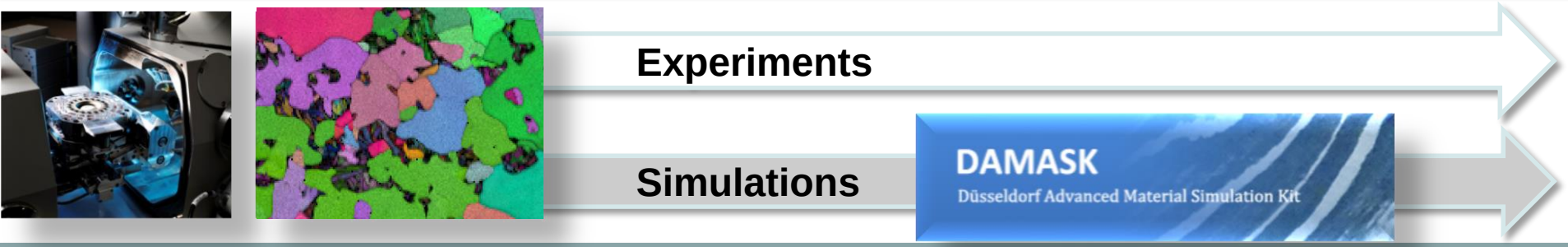


Diehl et al. Meccanica 51; JOM 69; Tasan et al. IJP 63; Tasan et al. IJP 63; Acta Mater. 81; Annual Rev Mater. Res. 45

ICME applied to DP steels

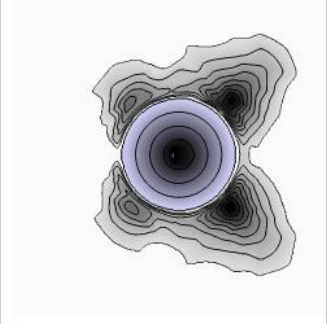


SiO_2 pattern | Deformation | Imaging & DIC | Sectioning | Strain map

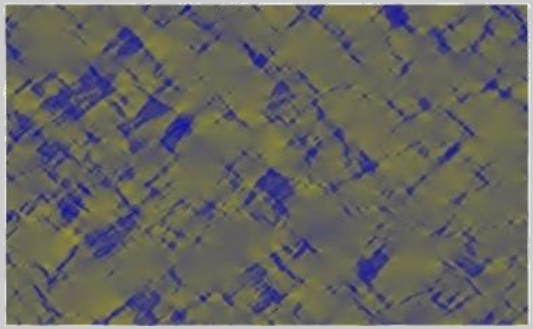


Digital model

Indents

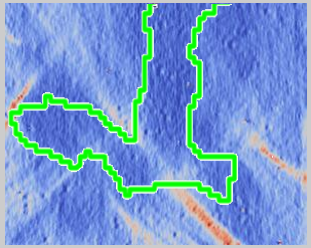


Spectral solver

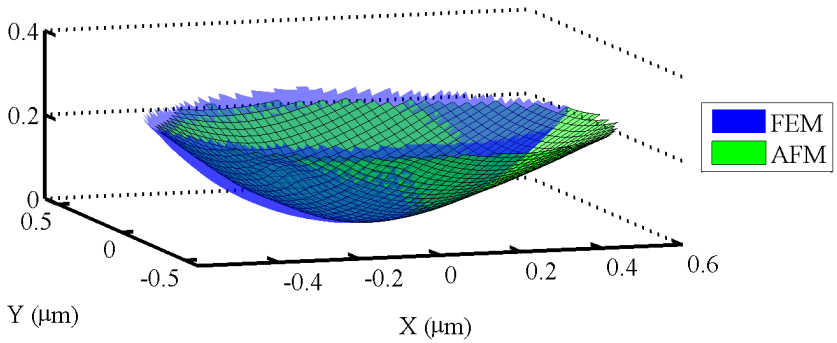


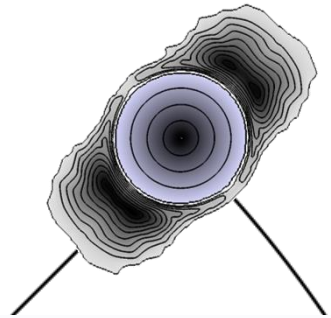
https://damask.mpie.de/

Strain map & stress map



Constitutive parameters: FEM & indents



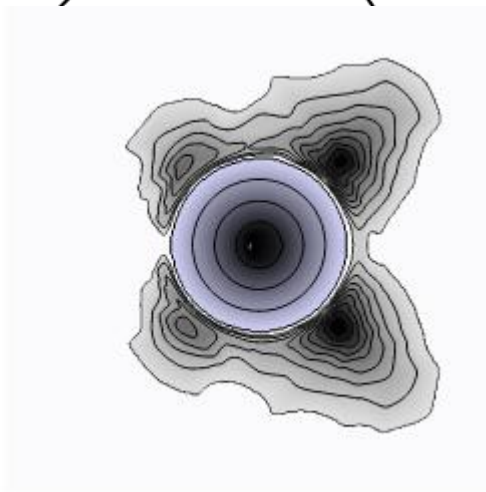


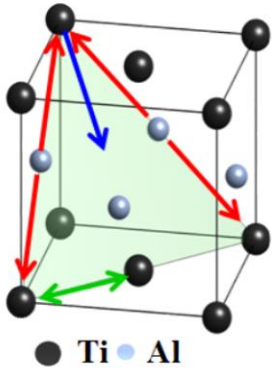
[110]

from 51 orientations
approx. resol. 9°

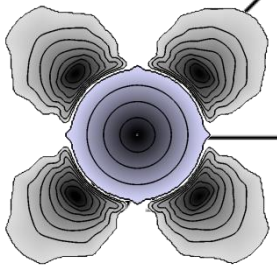
[111]

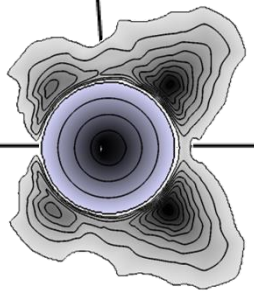
Pile-up inverse pole figure



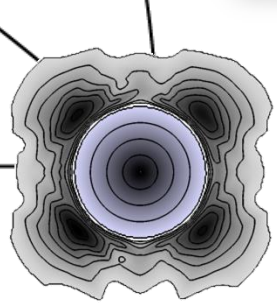


[001]





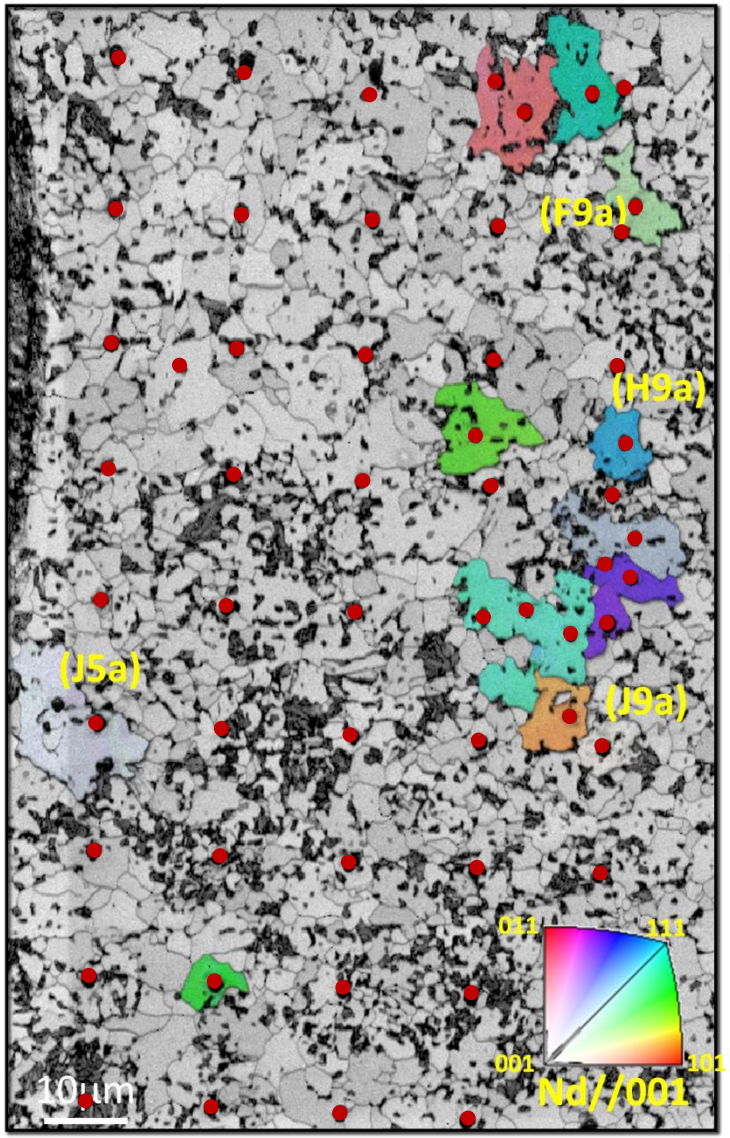
[101]

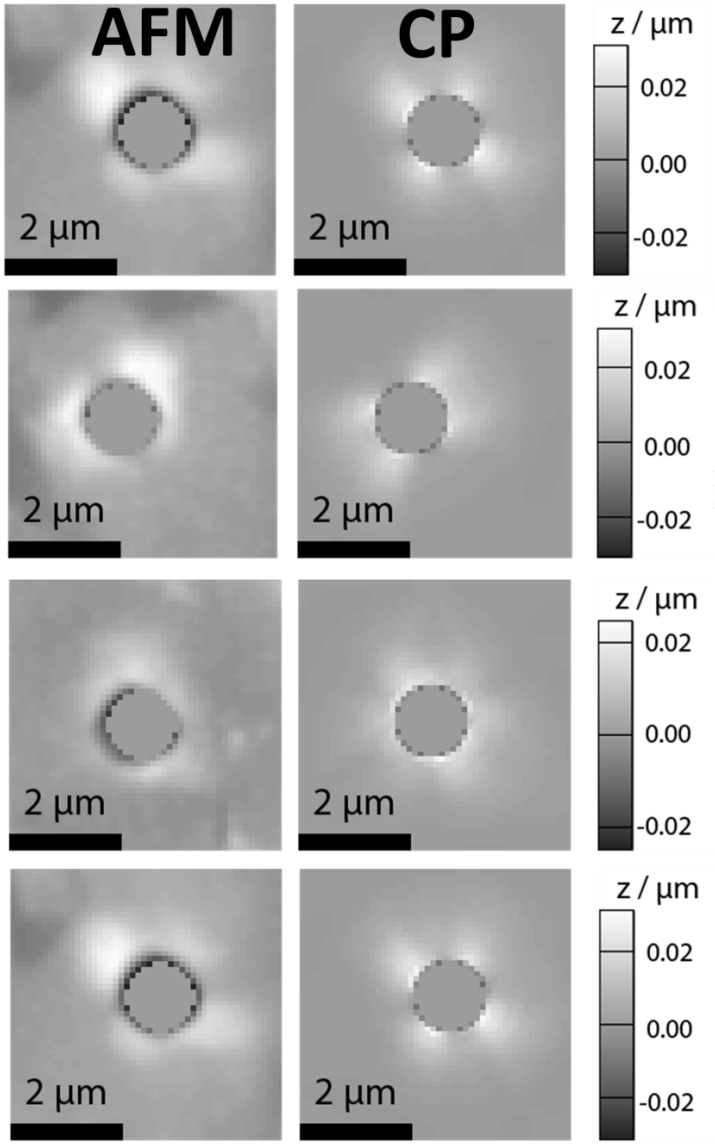


[100]

Cono-spherical <u>nanoindenter & AFM</u> or Fischerscope <u>microindenter & confocal</u>

Constitutive parameters: FEM & indents



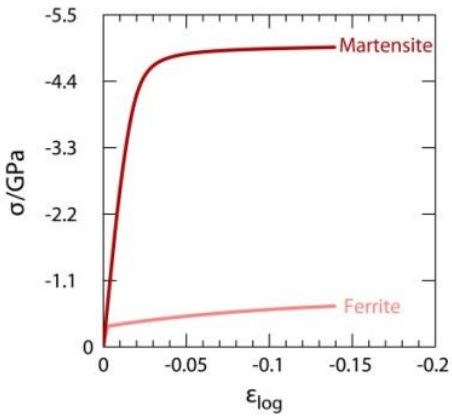


Indentation

-F-controlled

-Fmax= 4mN

-sphero-conical tip



Simulation

-{110} &{112} slip

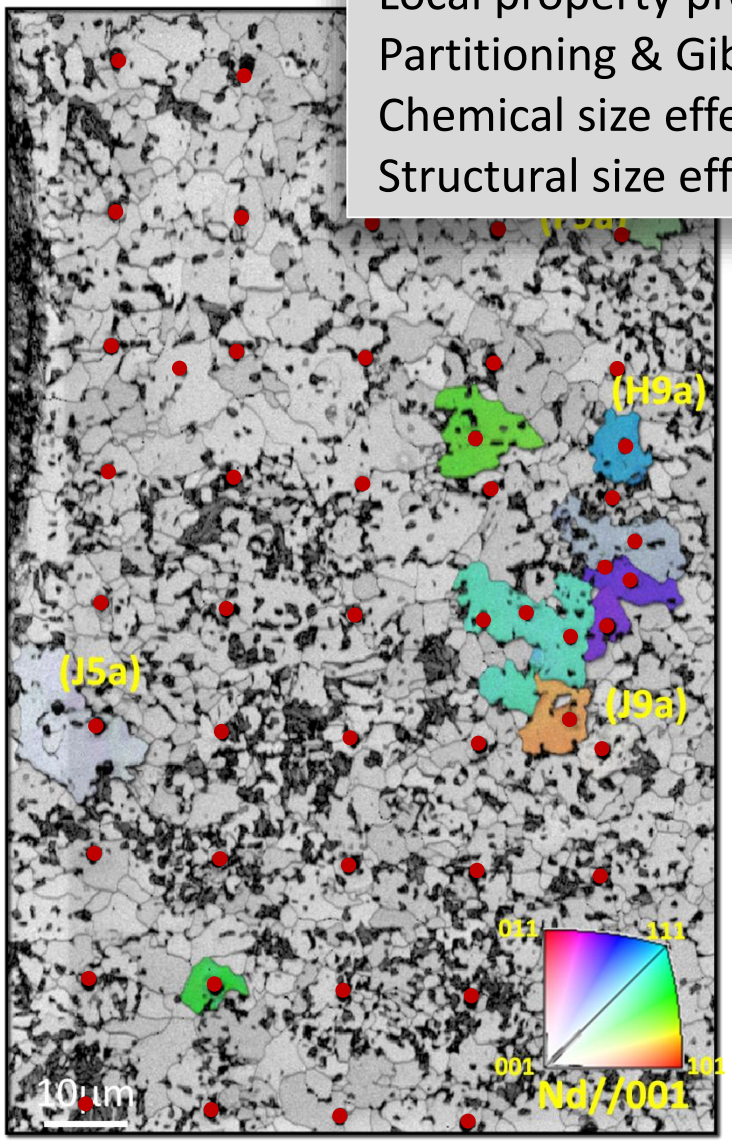
-Nelder-Mead opt.

-Pile-up geom.

-F-d curves

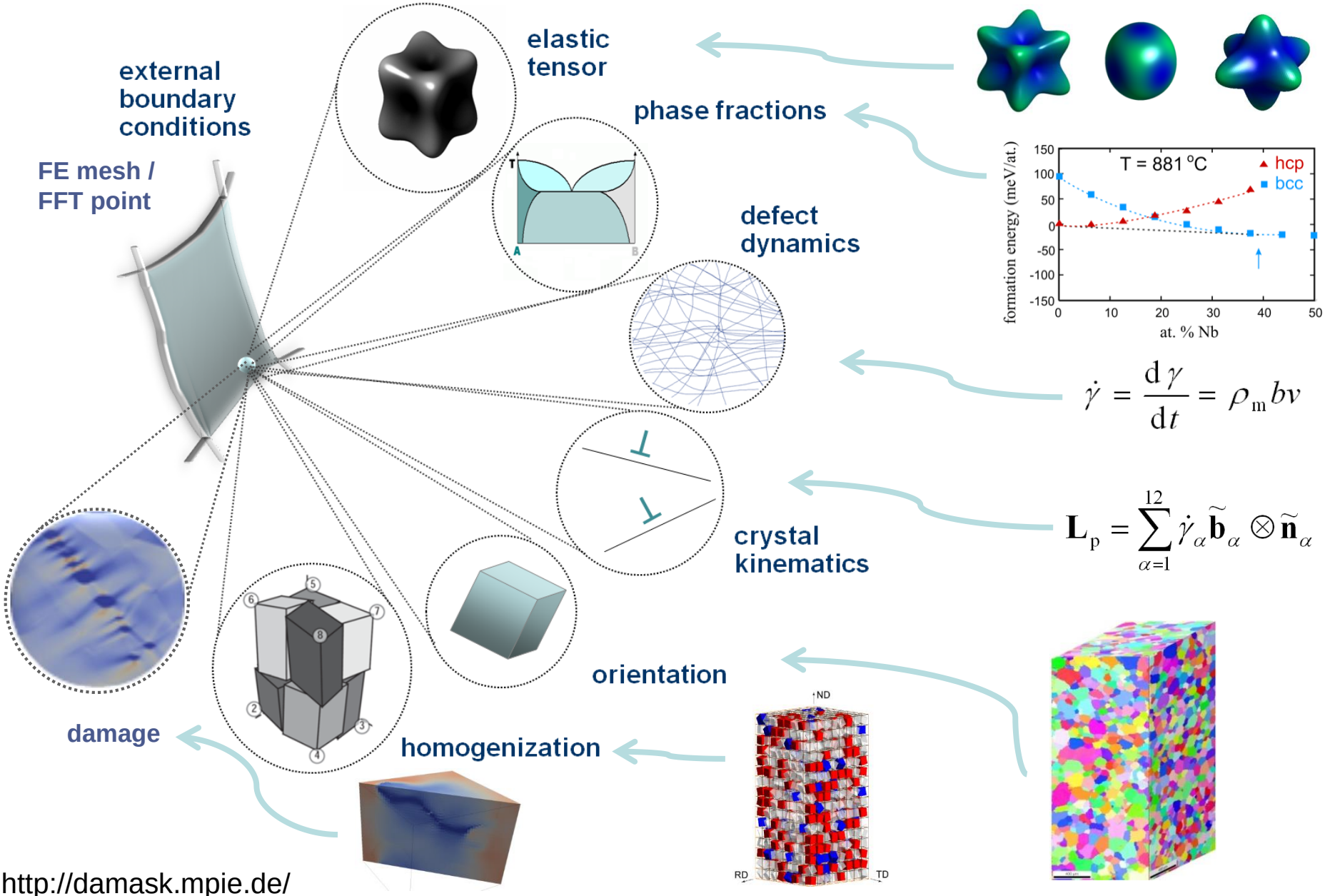
Constitutive parameters: FEM & indents

Local property probing for model parameter fitting:
Partitioning & Gibbs segregation in multiphase alloys
Chemical size effect
Structural size effect



Zambaldi et al. Acta Mater. 58 (2010) & J Mater. Res. 27 (2012) 356; 3516; Diehl et al. Meccanica 51; JOM 69; Tasan et al. IJP 63

DAMASK: Free multiphysics CP & PF



$$\dot{\gamma} = \frac{\mathrm{d}\gamma}{\mathrm{d}t} = \rho_{\mathrm{m}} b v$$

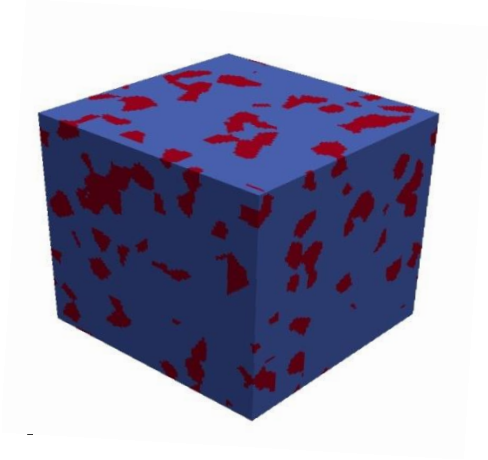
$$\mathbf{L}_{\mathrm{p}} = \sum_{\alpha=1}^{12} \dot{\gamma}_{\alpha} \tilde{\mathbf{b}}_{\alpha} \otimes \tilde{\mathbf{n}}_{\alpha}$$

http://damask.mpie.de/

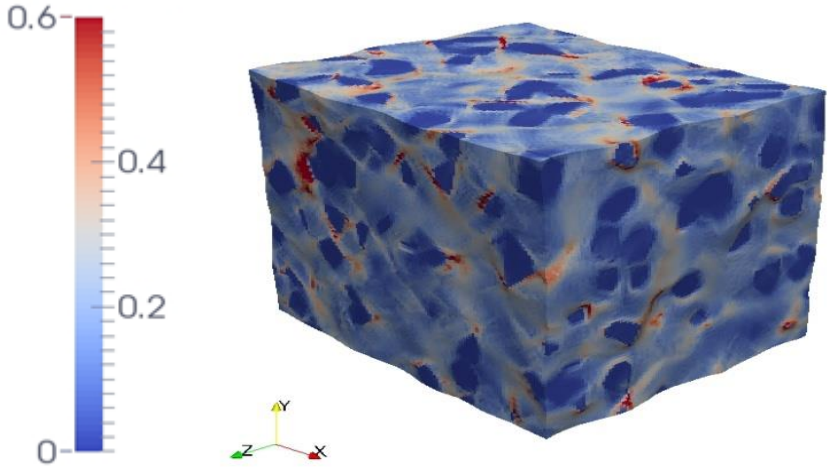
ICME applied to DP steels

Spectral solver, dual phase steel, 23% uni-axial deformation

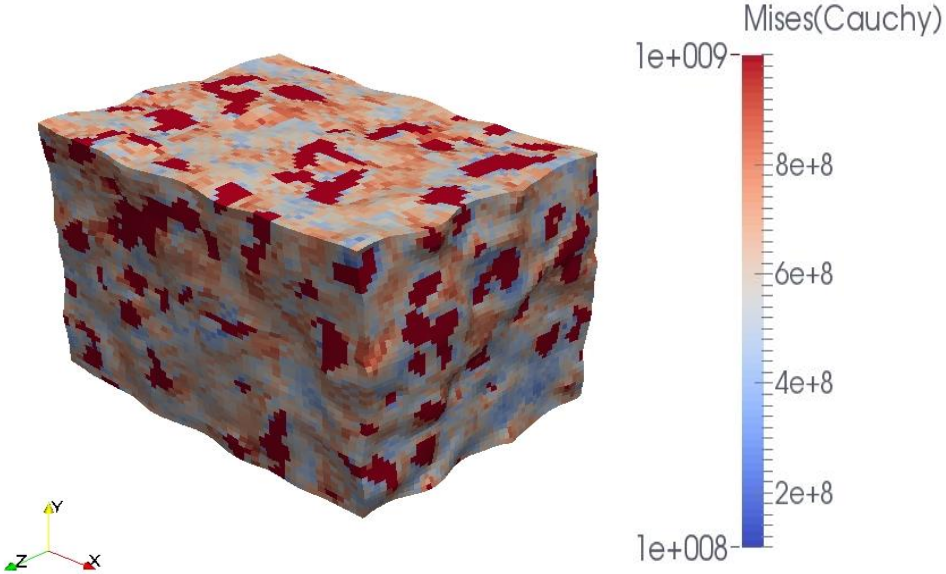
Microstructure input



Fourier grid



Strain distribution

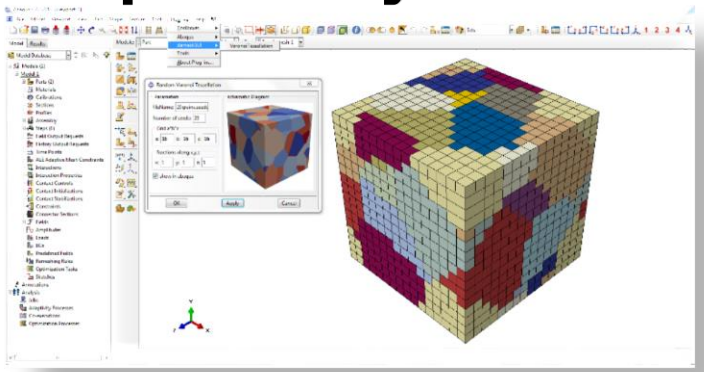


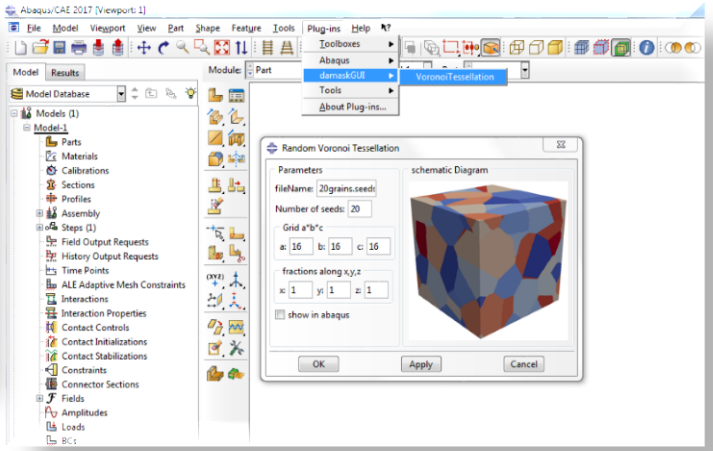
Stress distribution

Suquet, Moulineque, Khachaturian, Lebensohn, Eisenlohr, Roters, Shanthraj, Diehl,…

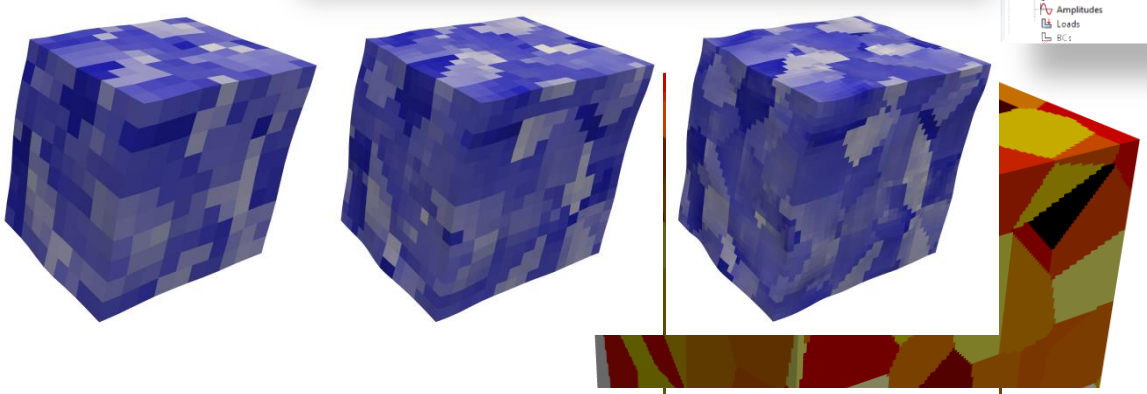
FFT polycrystal plasticity solver: fast in RVE

10^3





FEM

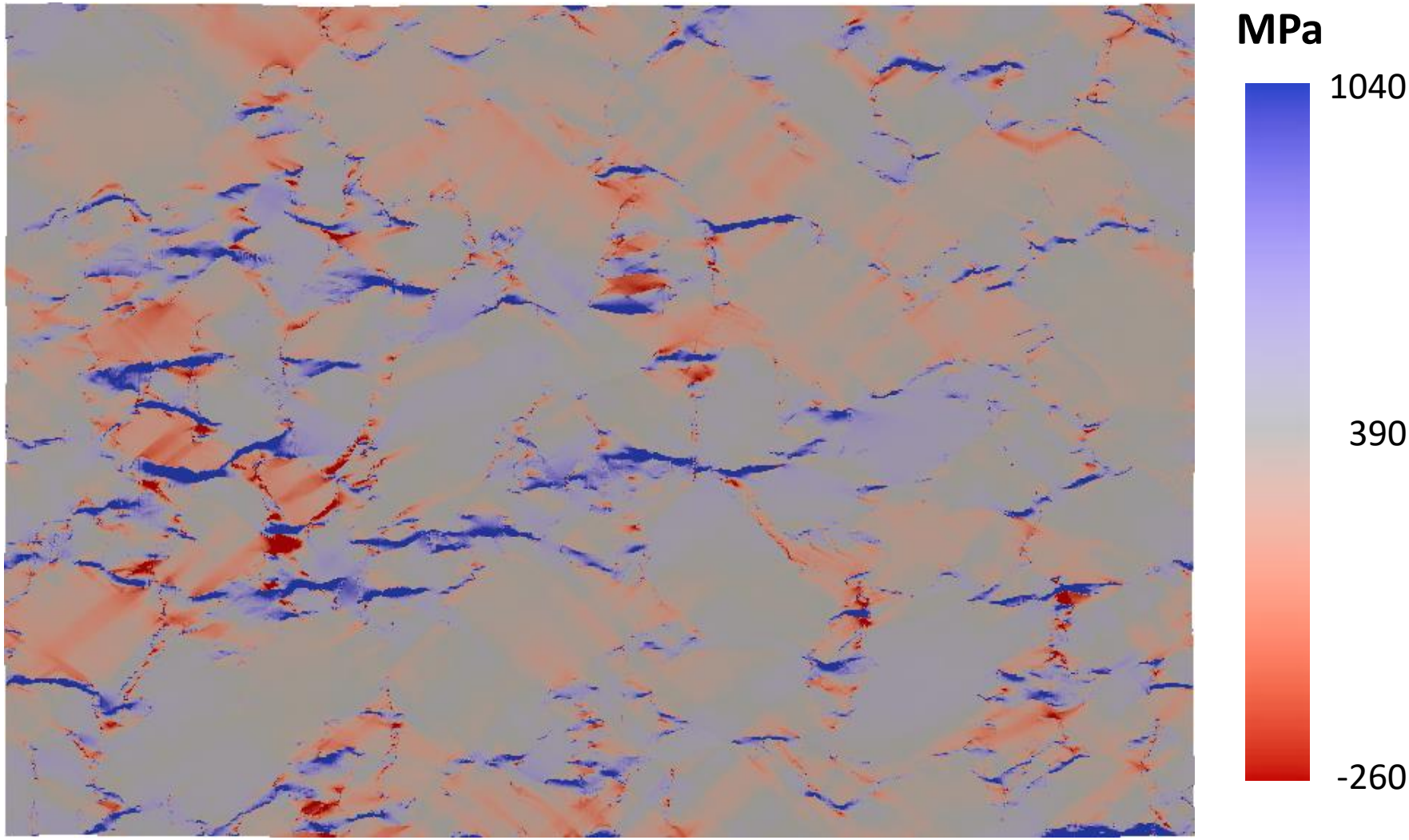


FFT

ICME applied to DP steels

Full-field microstructure simulation based on experimental EBSD

P_{11} @ $\bar{F}_{11} = 1.01$



Roters et al. Procedia IUTAM 3 (2012) 3; Diehl et al. Meccanica 51 (2016) 429; Diehl et al. JOM 69

ICME applied to DP steels

Full-field microstructure simulation based on experimental EBSD

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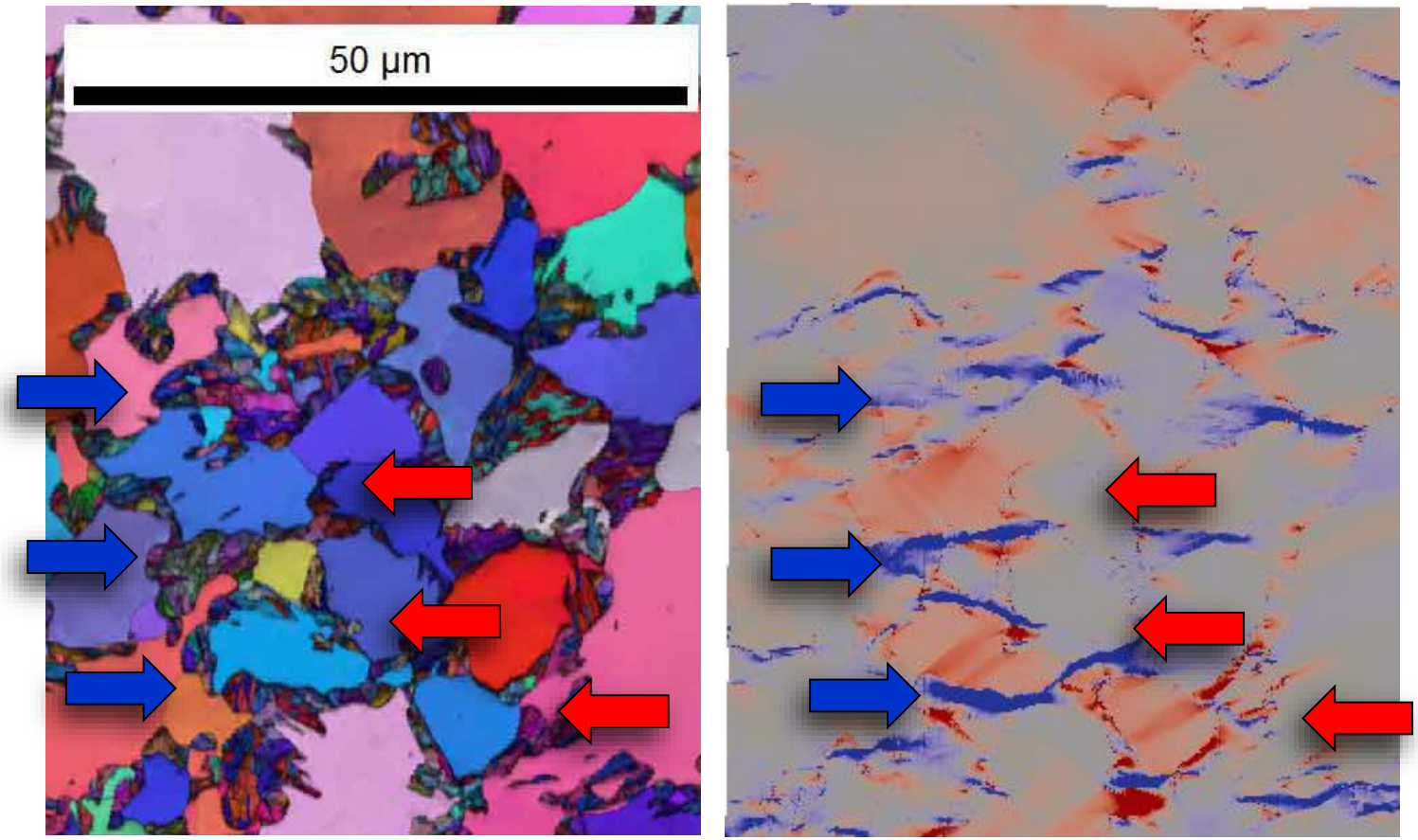
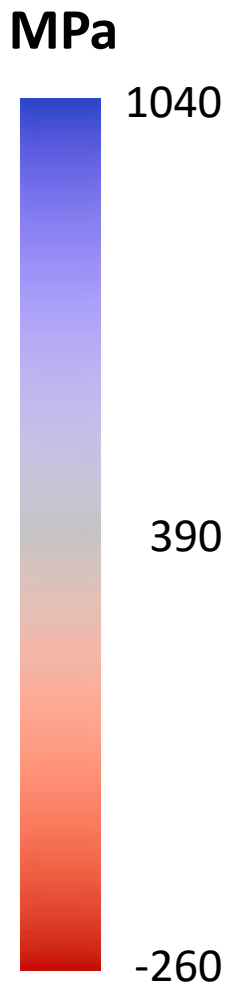
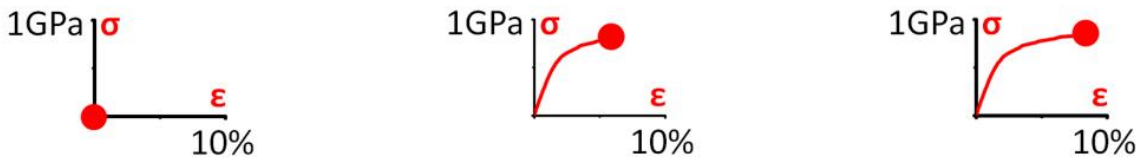




Roters et al. Procedia IUTAM 3 (2012) 3; Diehl et al. Meccanica 51 (2016) 429; Diehl et al. JOM 69

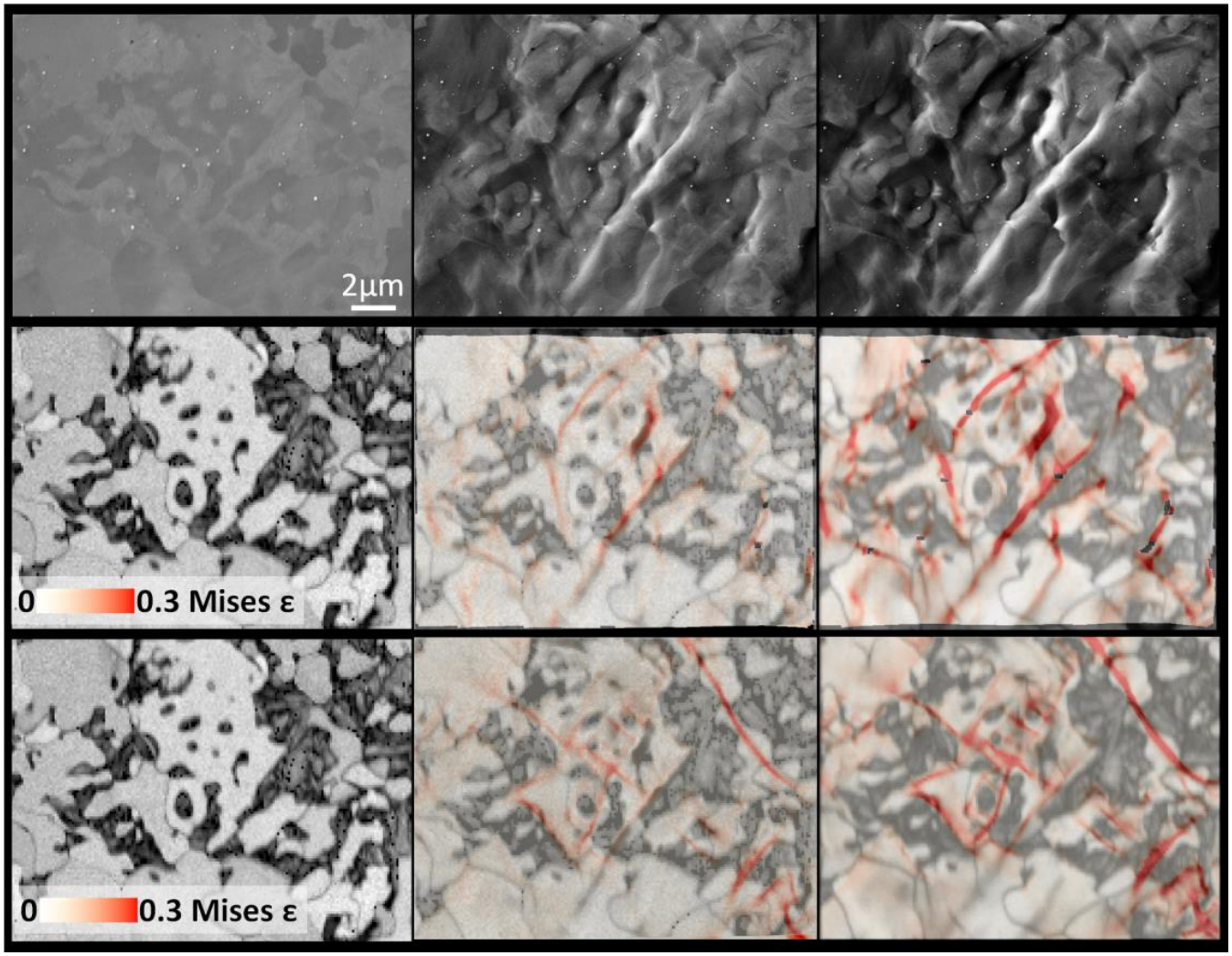
Experimental vs simulation



SE→

IQ+ DIC strain→

IQ + CP strain→



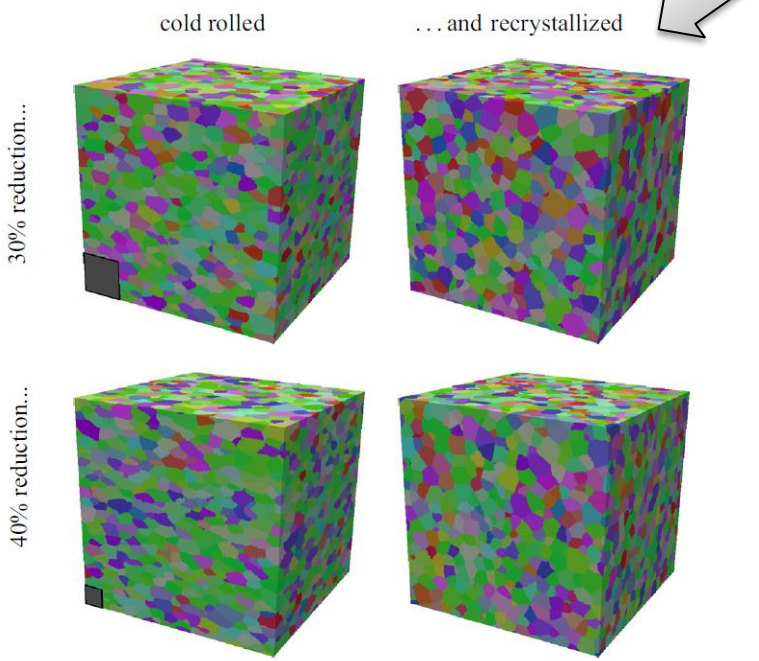
ICME applied to DP steels

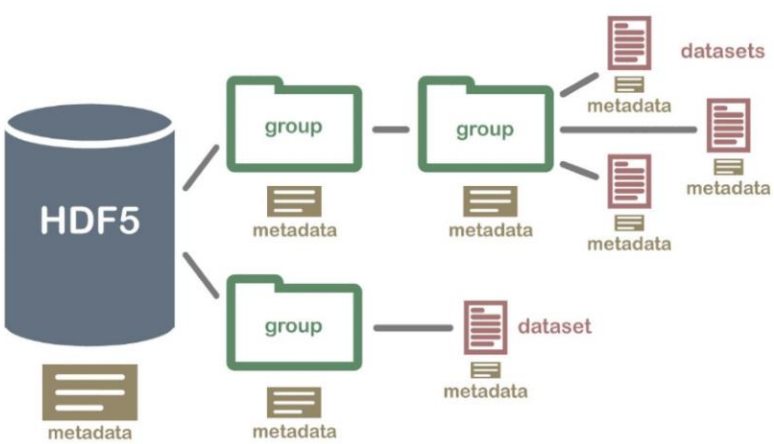
- Issue # 1:

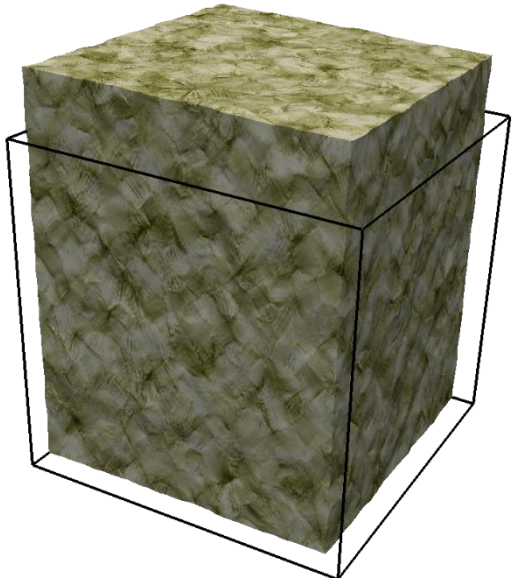
The world is 3D

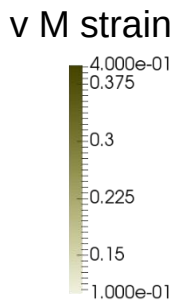
DAMASK & Dream3D: 3D coupling

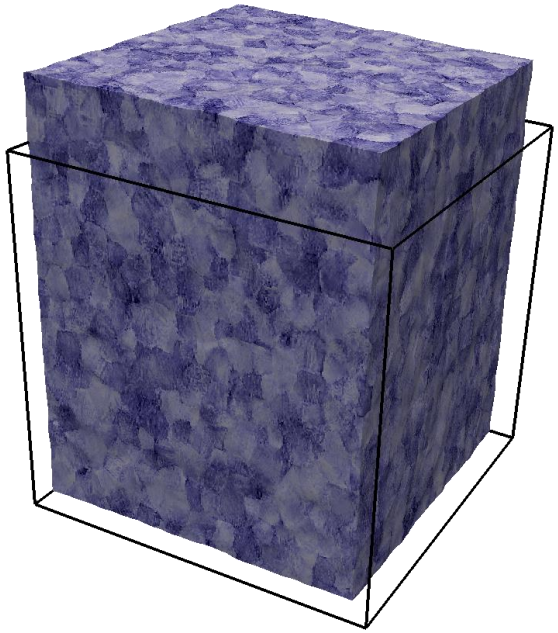
Synthetic RVEs

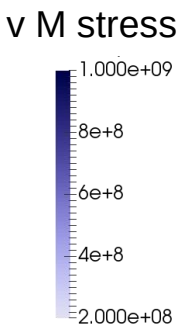






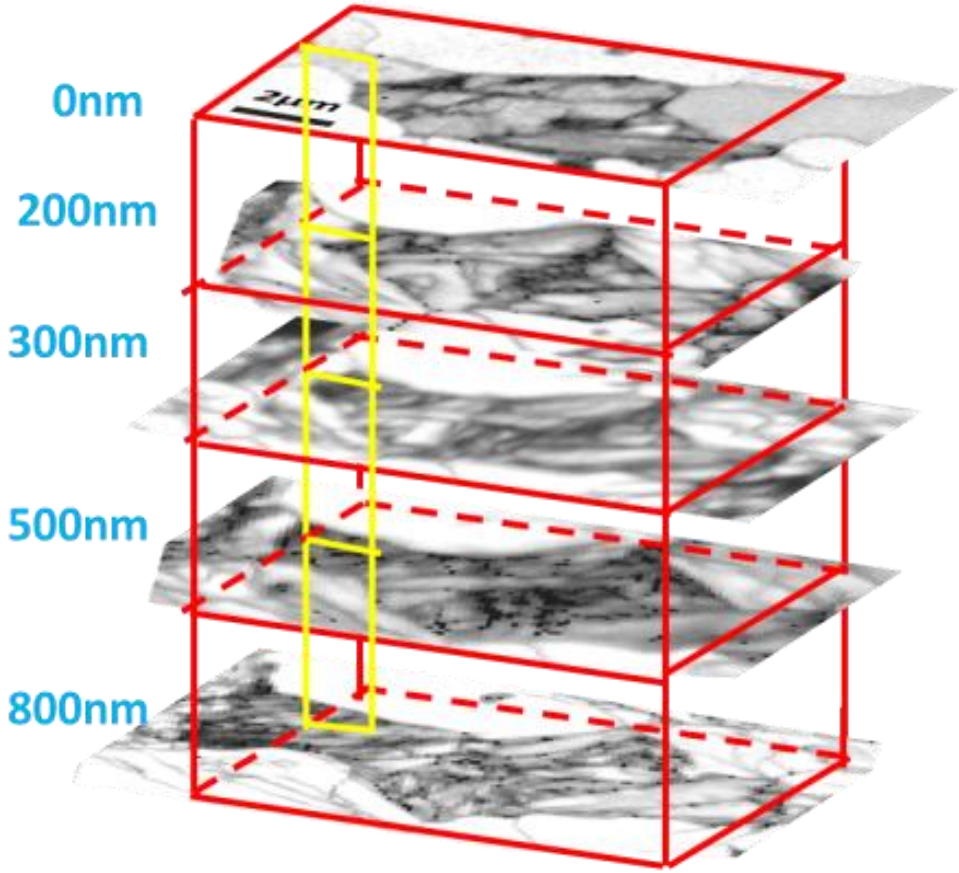




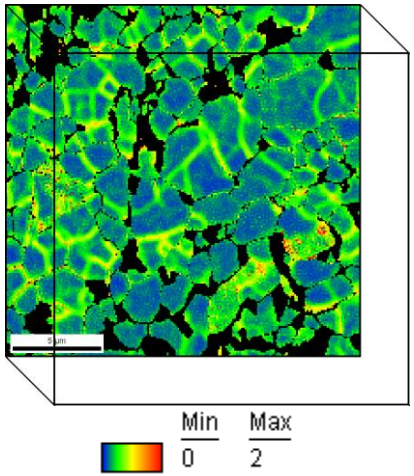


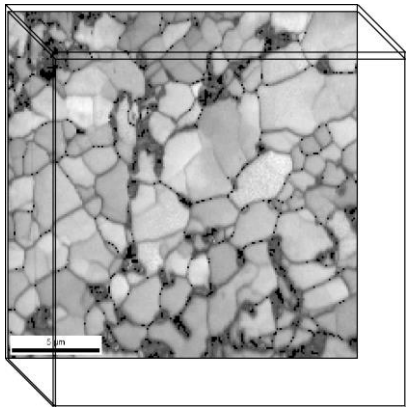
ICME applied to DP steels: 3D effects

Serial sectioning to reveal hidden martensite



3D EBSD: KAM

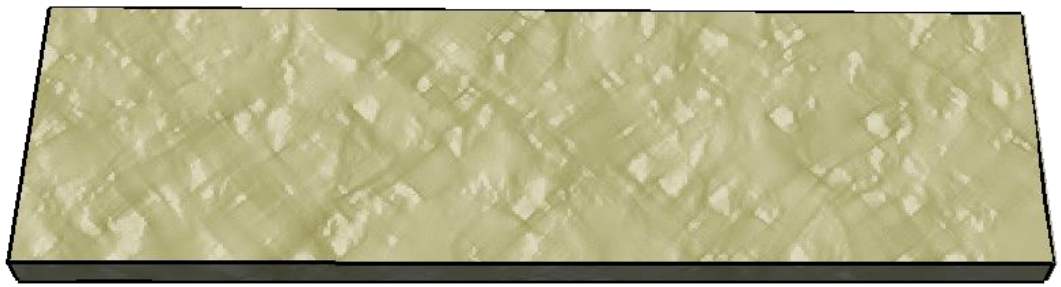




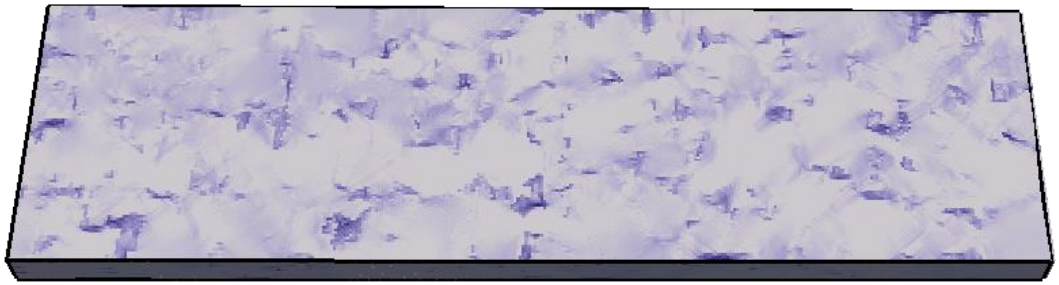
3D EBSD: Image Quality

Tasan et al. IJP 63; Konrad et al. Acta Mater 2006; 54: 1369; Zaefferer et al. Metall. Mater. Trans. A 39 (2008) 374

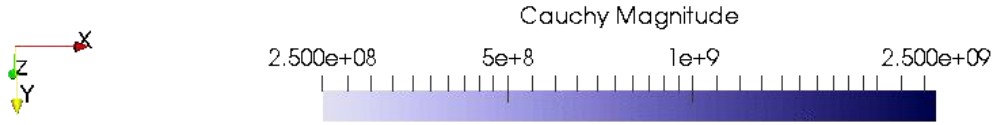
Serial sectioning; full field 3D simulation



v M strain



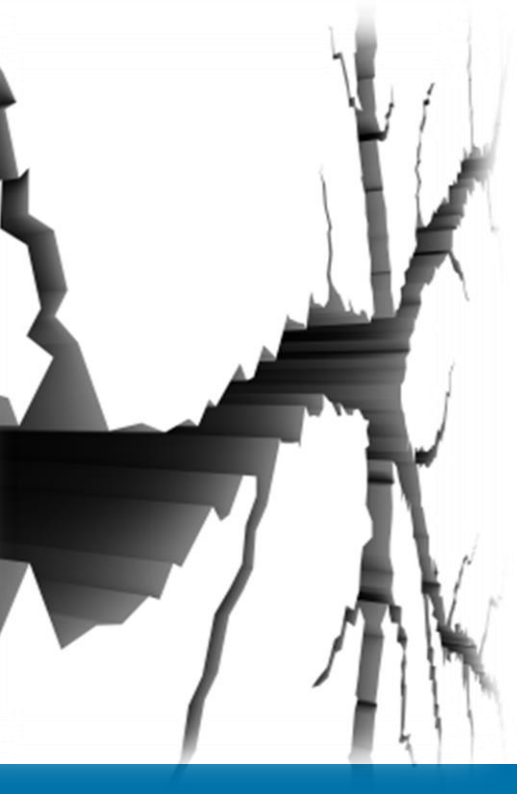
v M stress



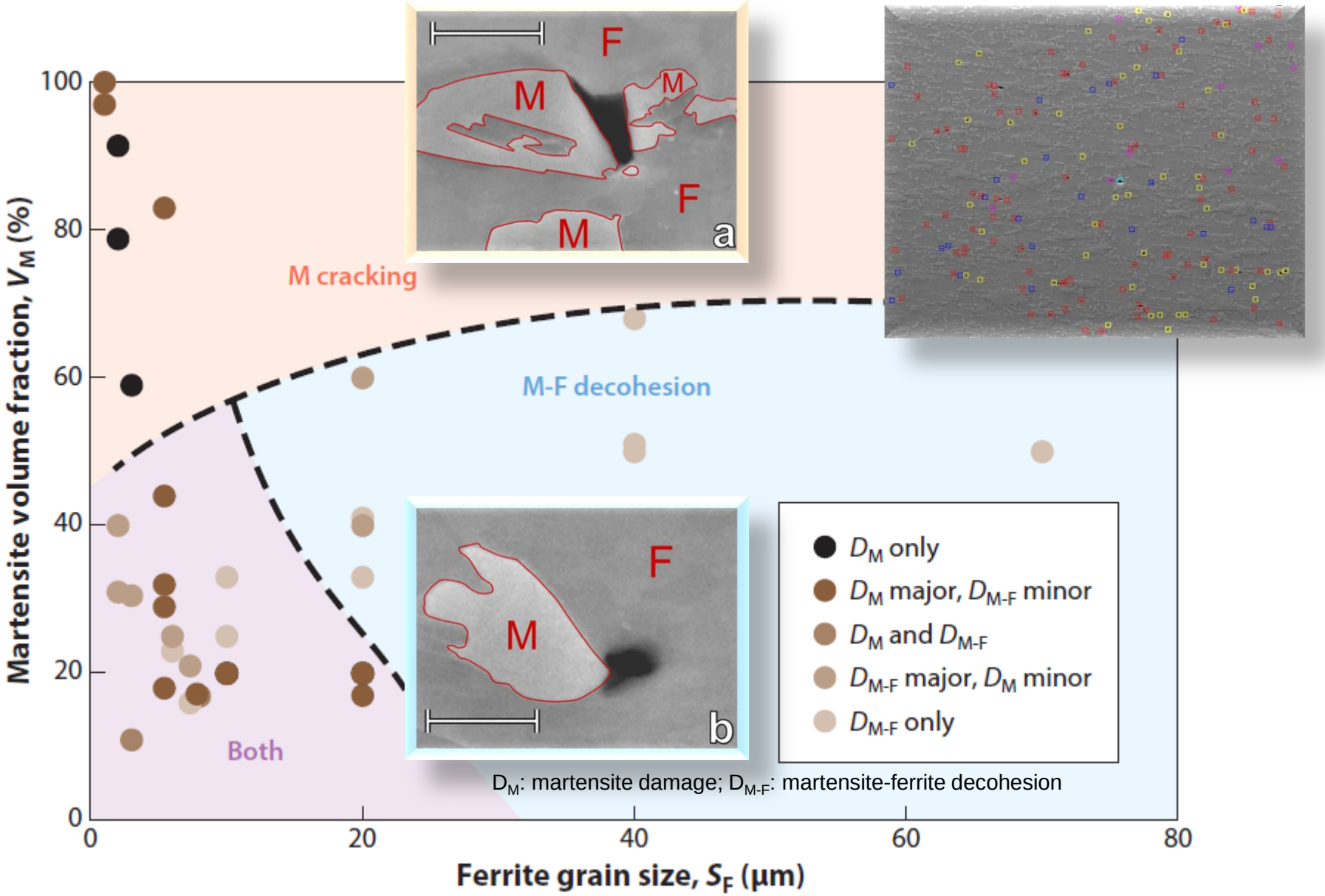
ICME applied to DP steels

- Issue # 2

Real DP steels contain micro-damage

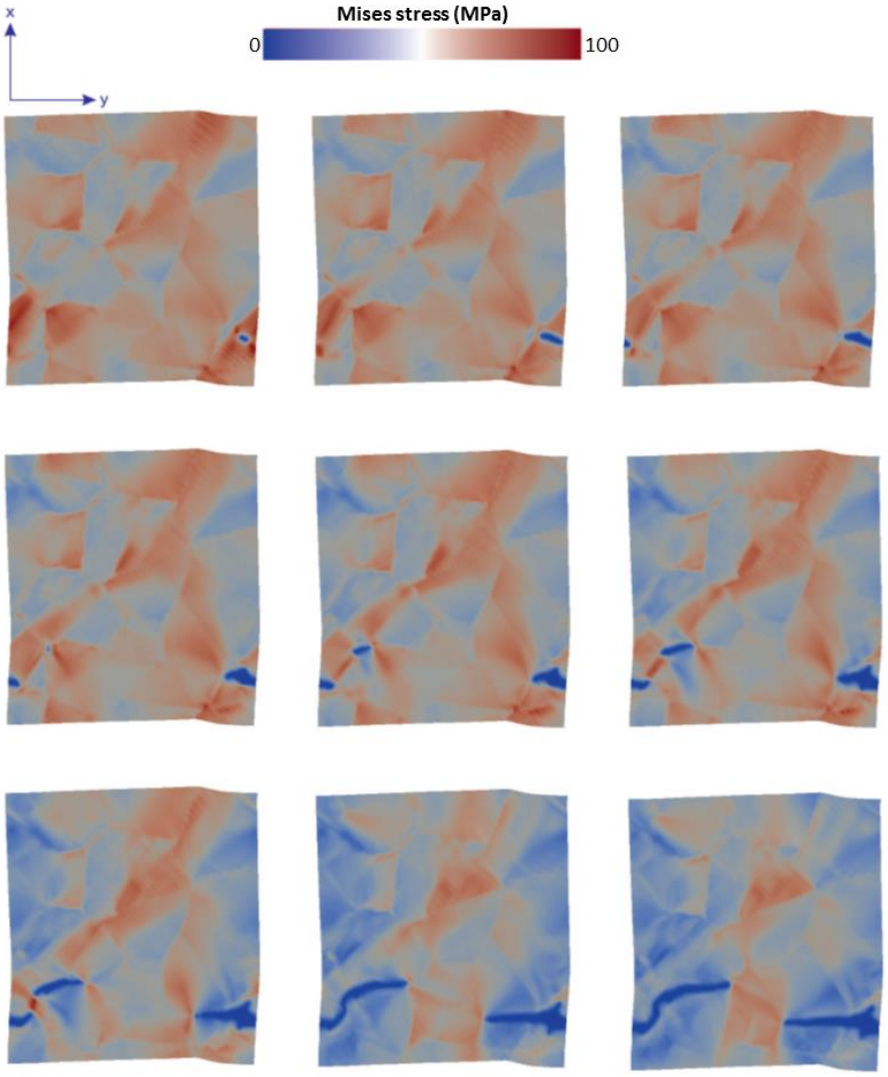


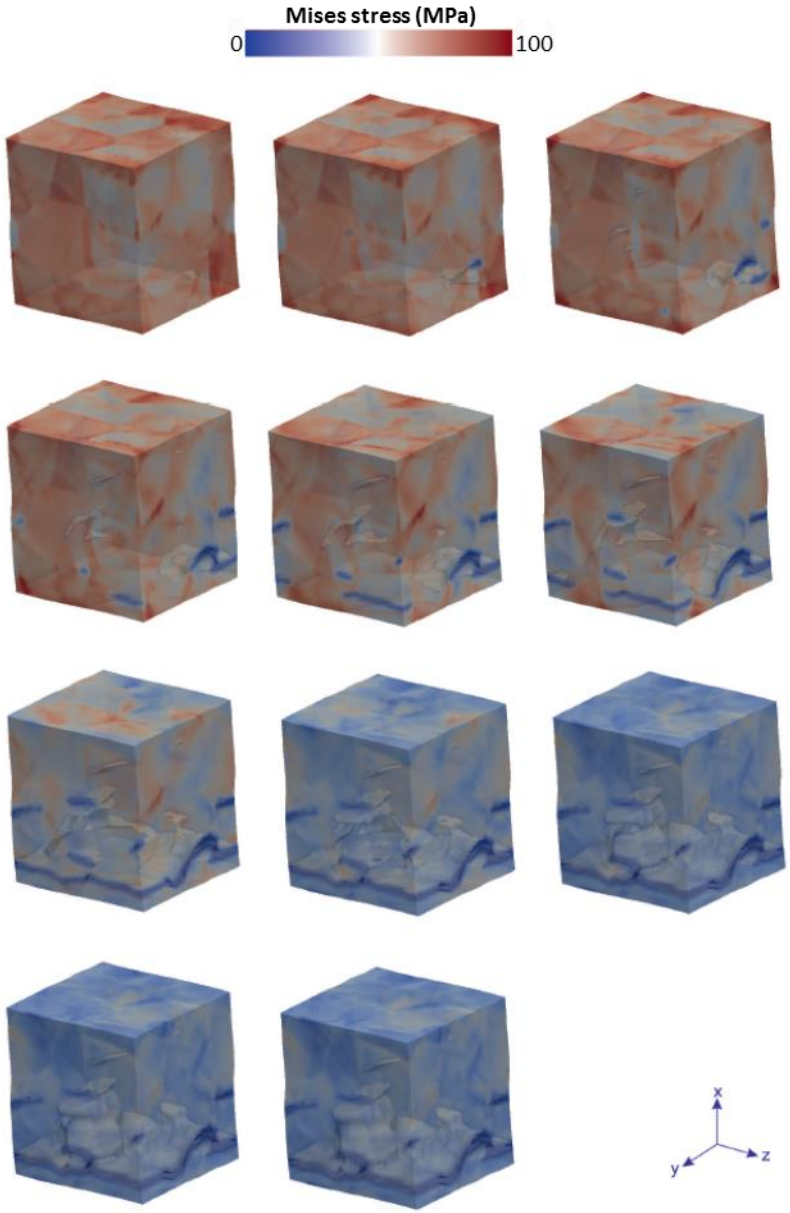
Damage in DP steels



D_M: martensite damage; $D_{M\text{-}F}$: martensite-ferrite decohesion

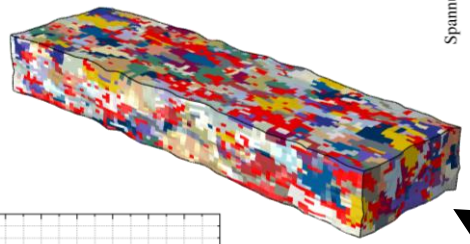
Damage modeling in DAMASK

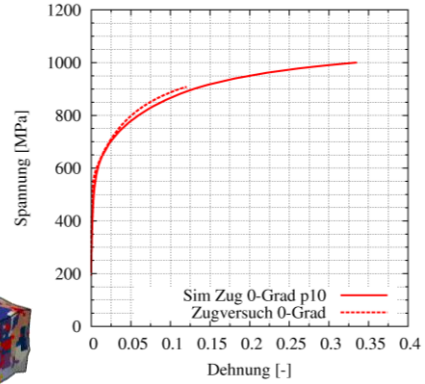




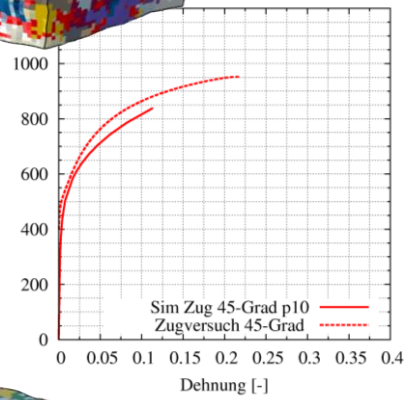
ICME applied to DP steels

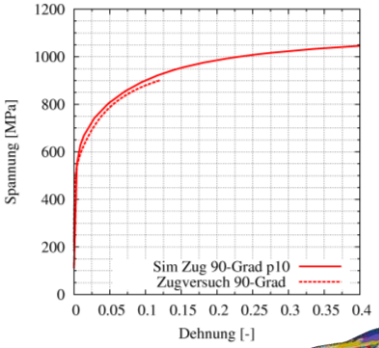
Tension 0° (RD)



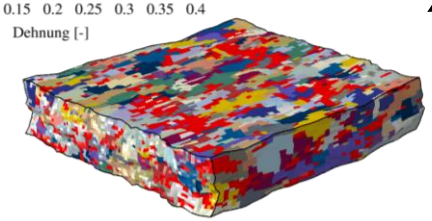


Tension 45°

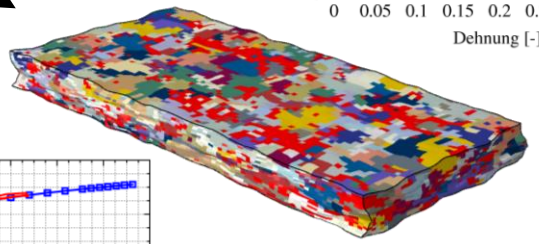




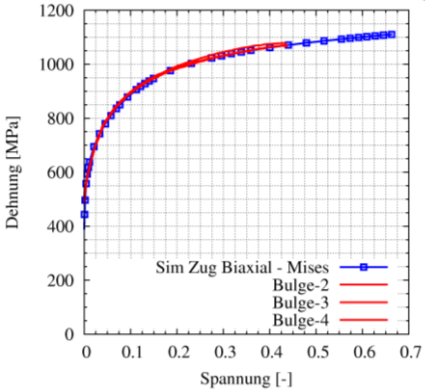
RVE



Tension 90°
(transvers direction)

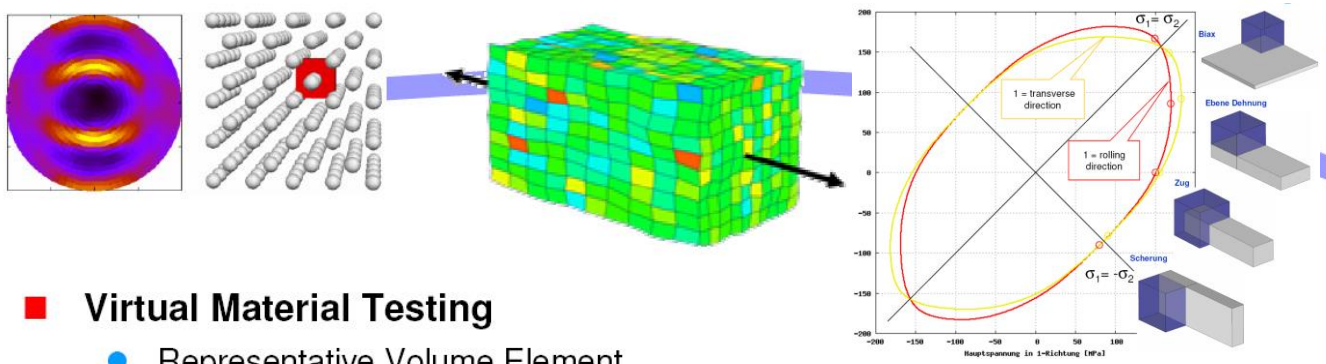


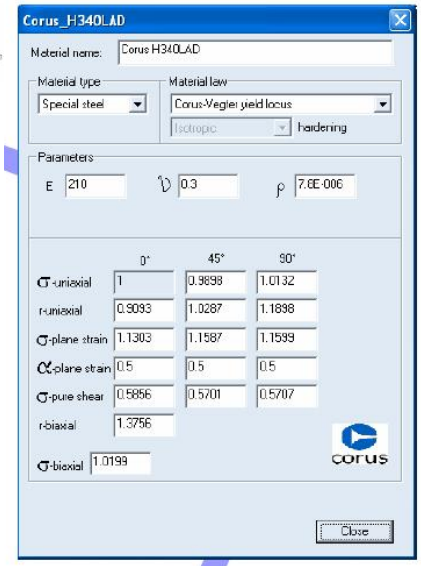
Tension biaxial



ICME applied to DP steels

From Crystal Plasticity to Deep Drawing





Vegter-Modell in PamStamp 2G

- **Virtual Material Testing**
  - Representative Volume Element
  - Virtual test program – extrapolation of calibration tests
  - Parameter fit of the macro material model
  - No performance loss compared to classical deep drawing simulation
  - Material behaviour limited to available models in commercial FE codes
  - Demonstrated by INPRO for (bcc) HSLA steel

http://DAMASK.mpie.de

Collaboration with Mercedes, Audi, BMW

DAMASK
Düsseldorf Advanced Material Simulation Kit
Freeware, GPL 3

Thank you for the attention

Crystal plasticity & phase field:
Mechanics, damage, phase transformation, diffusion,
recrystallization, hydrogen

> 20 years of development

> 55 man years expertise

> 50.000 lines of code

Pre- and post-processing

Blends with MSC.Marc and Abaqus

Standalone (FFT) spectral solver

Large user community

We train your students

http://DAMASK.mpie.de