Exercises

Anisotropic material properties:

Correlation of
direct measurements
with texture based calculation

Karsten Kunze

karsten.kunze(at)scopem.ethz.ch

ETH Zürich, Switzerland

ETH zürich ScopeM

Mtex Demo & Exercises

E-Module Testing **=?** E-Module directional distribution **=** Elastic tensor from literature ***** Texture from
A. XTG (txt)
B. EBSD (OIM)

Materials Science & Engineering A 620 (2014) 213–222

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Texture, anisotropy in microstructure and mechanical properties of IN738LC alloy processed by selective laser melting (SLM)

Karsten Kunze [a,*], Thomas Etter [b], Jürgen Grässlin [c], Valery Shklover [c]

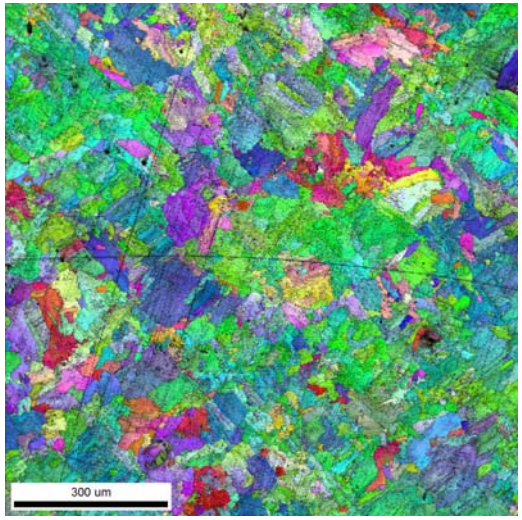
[a] Scientific Center of Optical and Electron Microscopy (ScopeM), ETH Zürich, CH-8093 Zürich, Switzerland
[b] ALSTOM (Switzerland) Ltd., CH-5401 Baden, Switzerland
[c] Laboratory of Crystallography, Department of Materials, ETH Zürich, CH-8093 Zürich, Switzerland

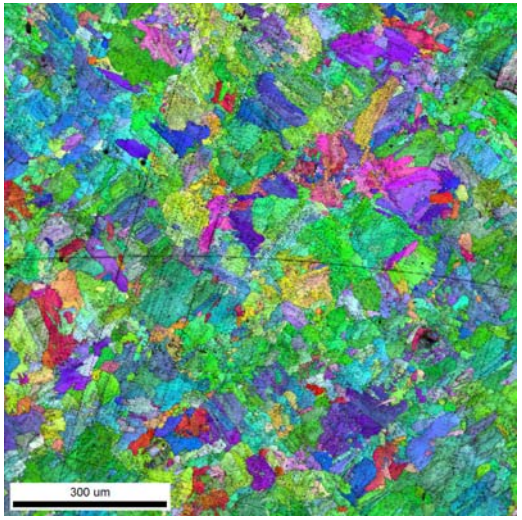
ETH zürich ScopeM

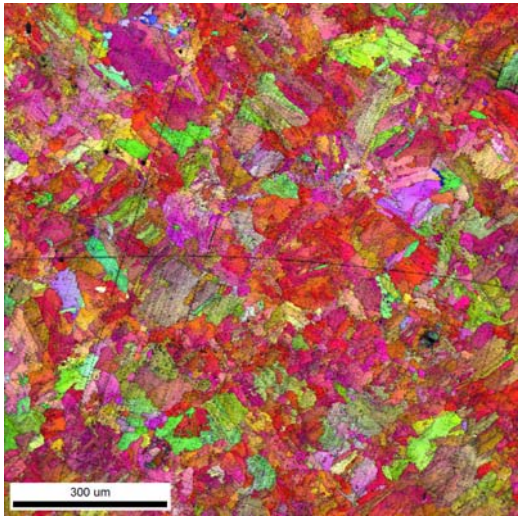
Ni-base superalloy

EBSD data

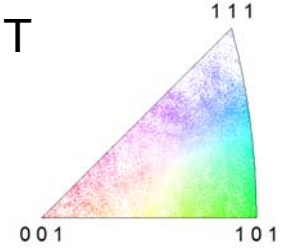
orientation maps

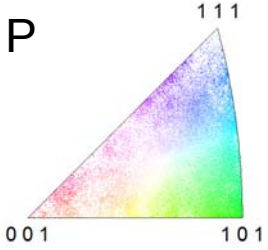


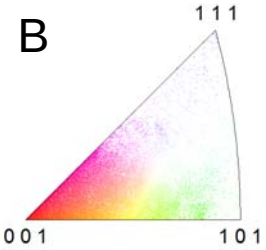




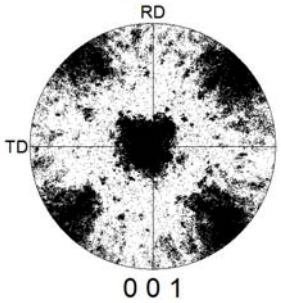
inverse pole figures

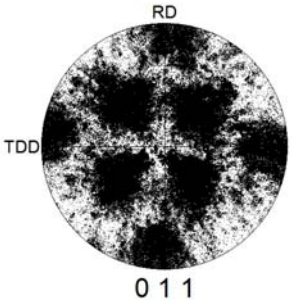


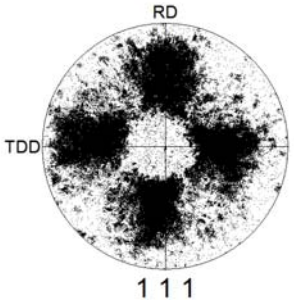


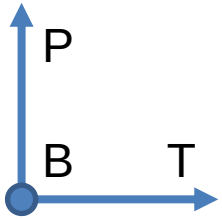


pole figures







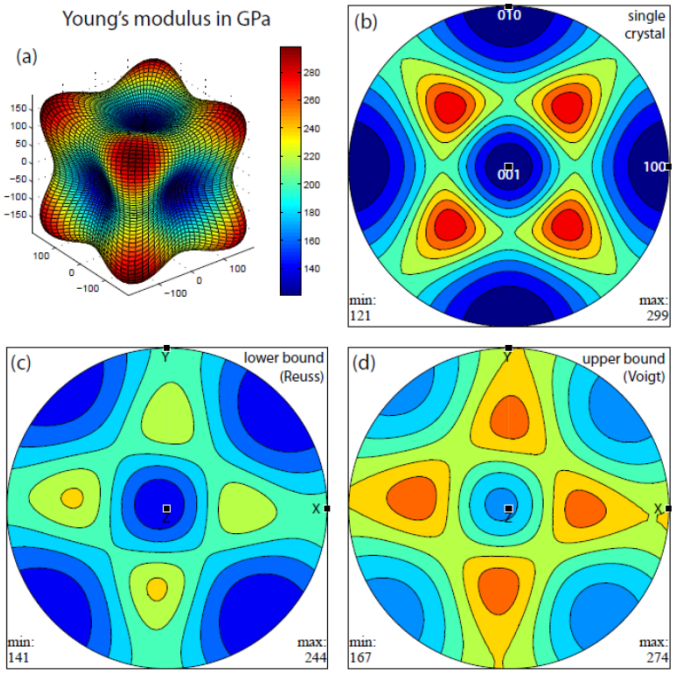


ETH zürich

ScopeM

Ni-base superalloy

Young's modulus



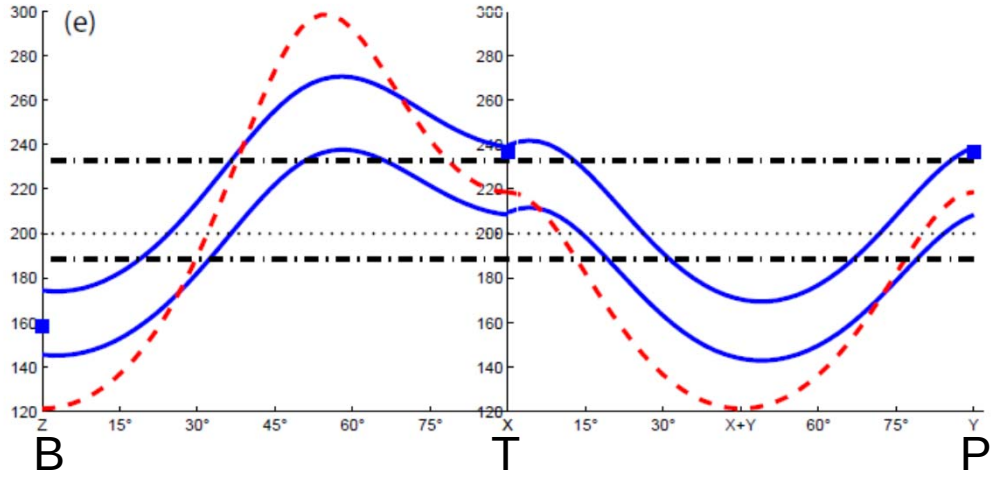
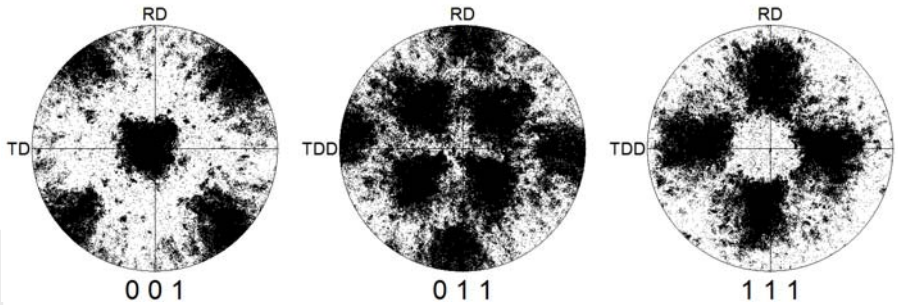
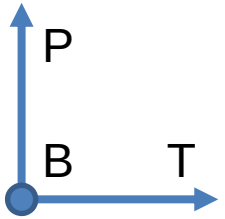


Fig. 10. Anisotropy in Young's modulus in SLM specimen. Same color legend applies from (a) to (d). (a) Single-crystal in three-dimensional visualization. (b) Single crystal in stereographic projection with respect to crystal axes. (c and d) Texture based lower/upper bound (Reuss and Voigt averages) in stereographic projection with respect to sample coordinates. (e) Profiles along great circles on the stereographic projections from *Z* via *X* to *Y* for lower and upper bounds (blue solid lines), for an infinitely sharp texture in the same principal orientation (red dashed line), for an isotropic material possessing uniform texture (black dash-dot lines). Measured values for SLM specimen (blue full squares) and isotropic reference value from database for cast material (black dotted line) are marked for comparison. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



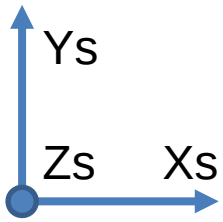


ETH zürich

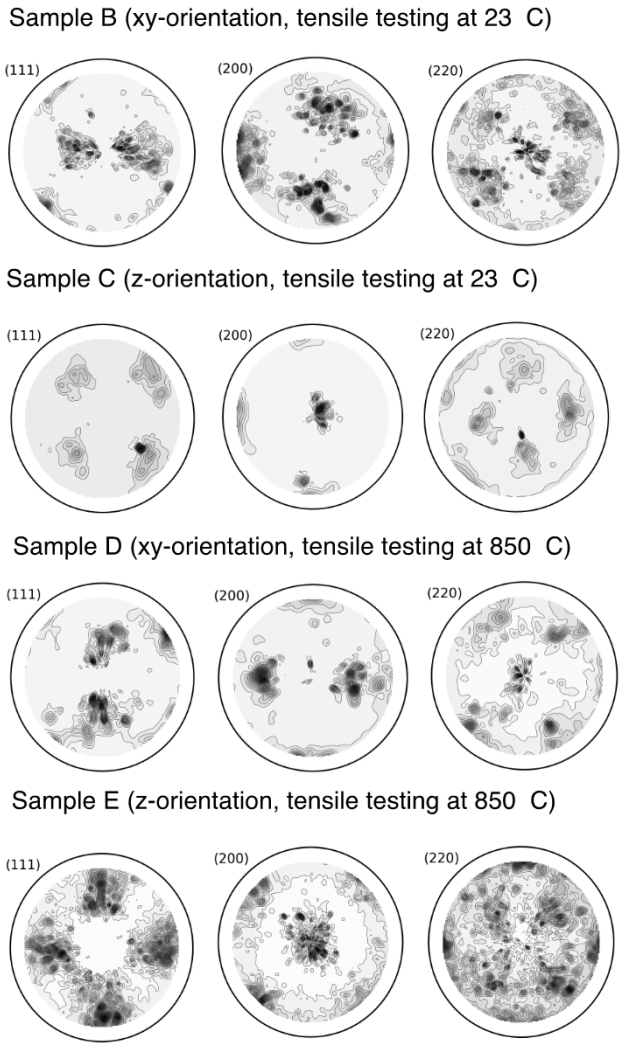
ScopeM

Input A – XTG

- Incomplete pole figures
- Corrected for background & defocussing
- Non-standard txt-file: azimuth polar intensity
- Diverse sample orientations with respect to process coordinate system



..\data_XTG\



No2_hkl.pan

No1_hkl.pan

No9_hkl.pan

No10_hkl.pan

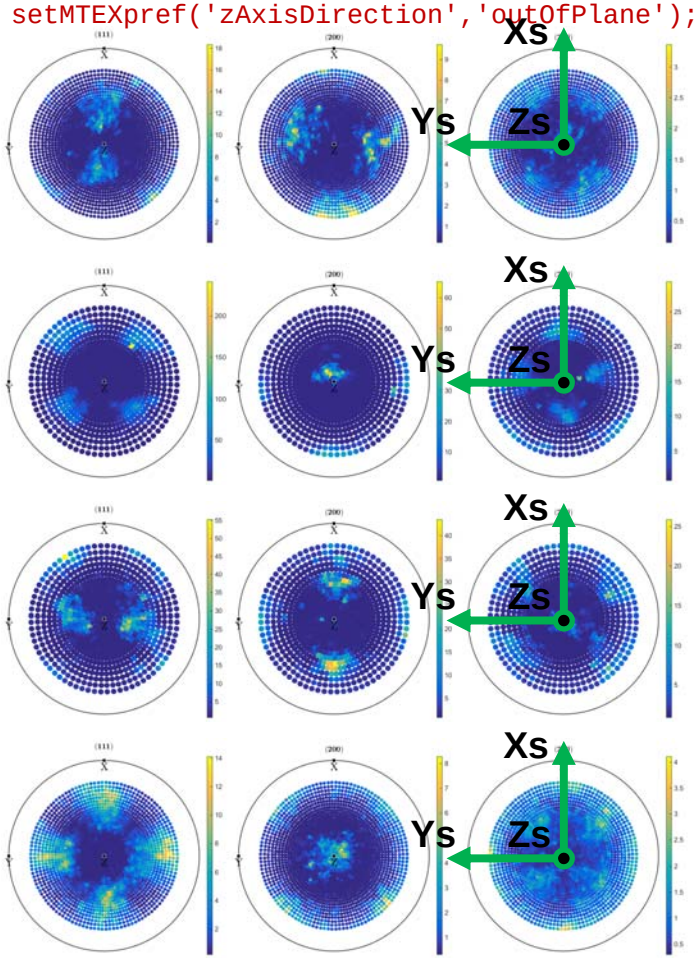
ETH zürich

ScopeM

Verify sample coordinate system

Analysis using

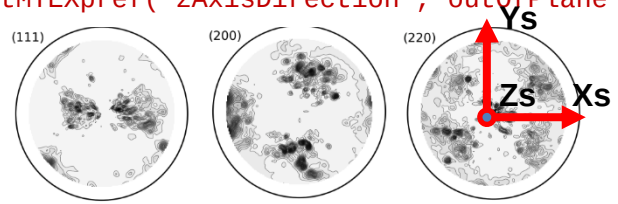
```
% plotting convention
setMTEXpref('xAxisDirection','north');
setMTEXpref('zAxisDirection','outOfPlane');
```



Raw data plotted using

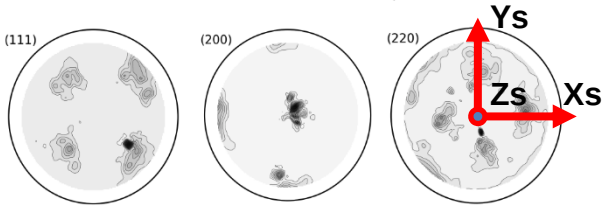
```
% plotting convention
setMTEXpref('xAxisDirection',east');
setMTEXpref('zAxisDirection','outOfPlane');
```

..\data_XTG\



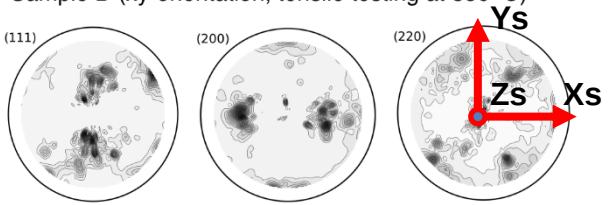
No2_hkl.pan

Sample C (z-orientation, tensile testing at 23 C)



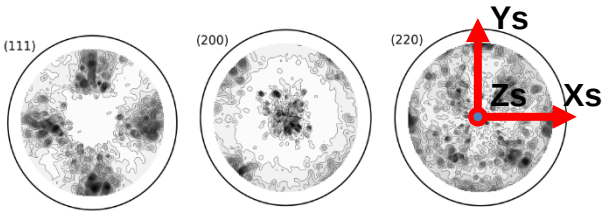
No1_hkl.pan

Sample D (xy-orientation, tensile testing at 850 C)



No9_hkl.pan

Sample E (z-orientation, tensile testing at 850 C)

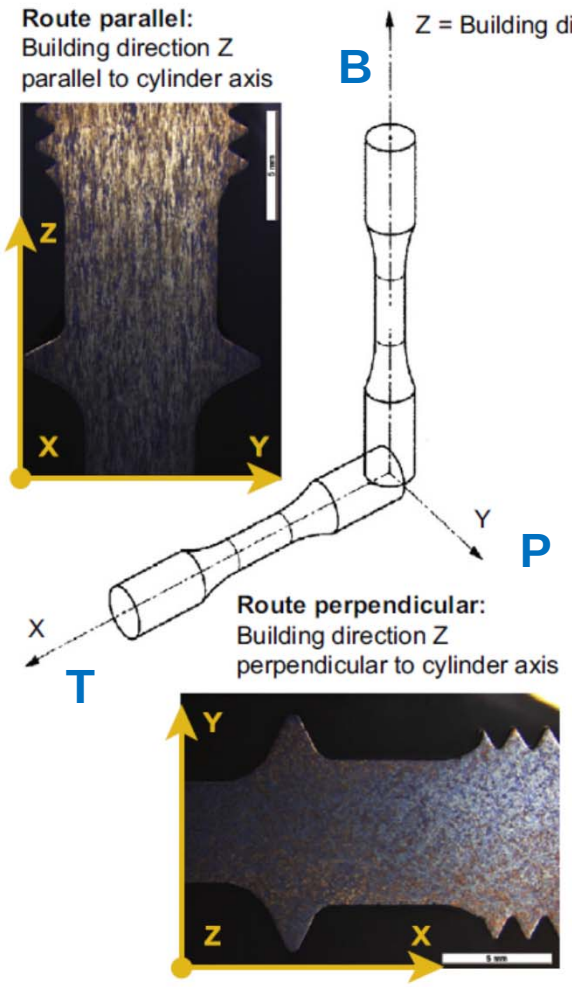


No10_hkl.pan

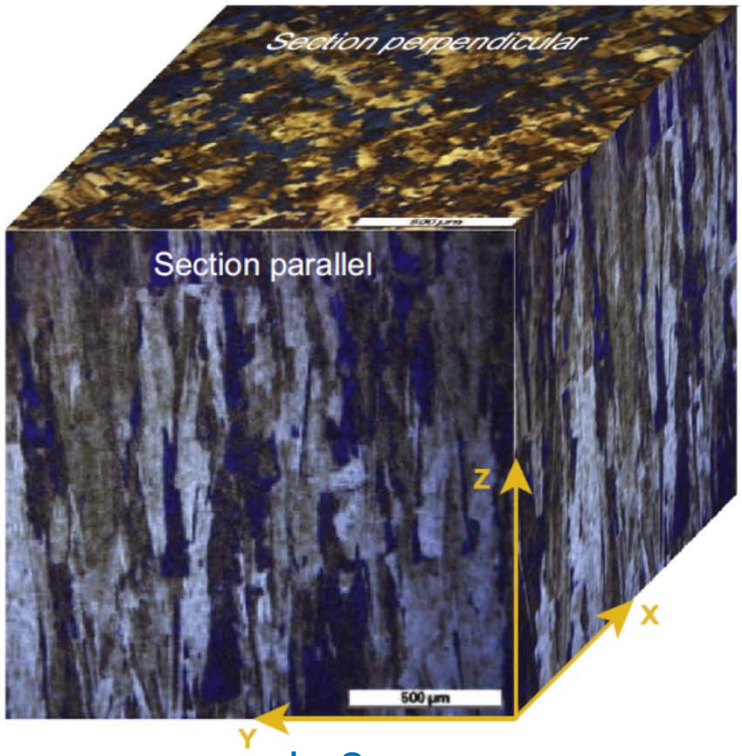
ETH zürich

ScopeM

SLM - Process coordinate system



sample 2s
sample 10



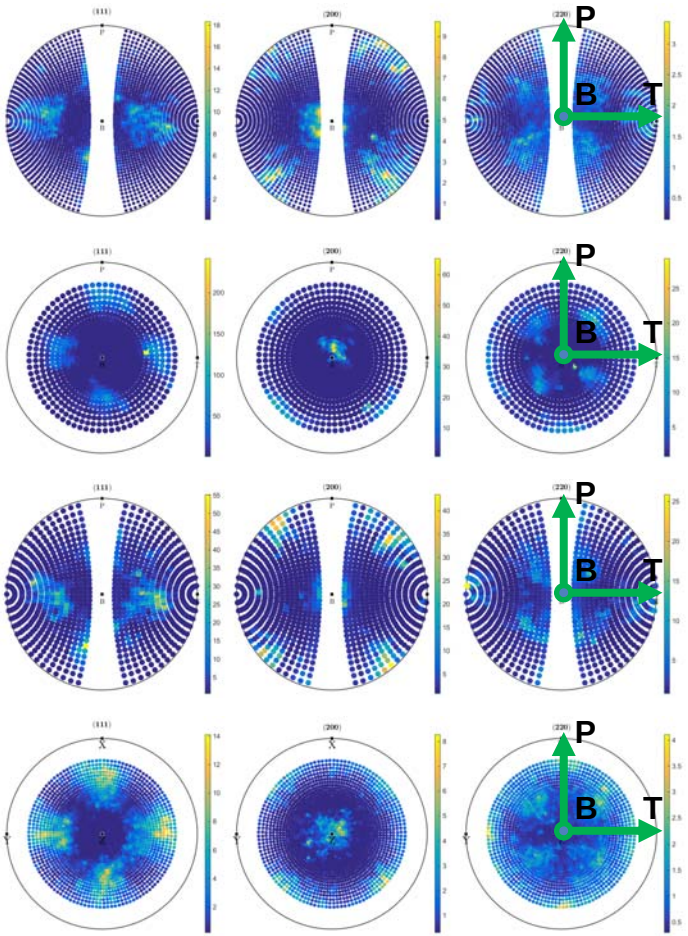
sample 2
sample 9

ETH zürich

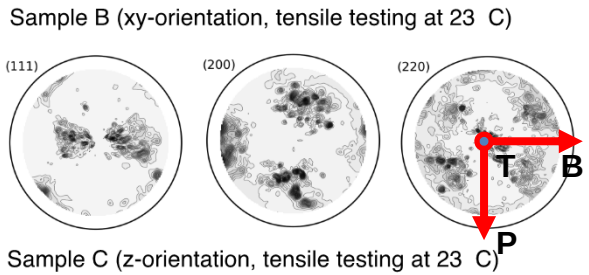
ScopeM

Rotate into process coordinate system

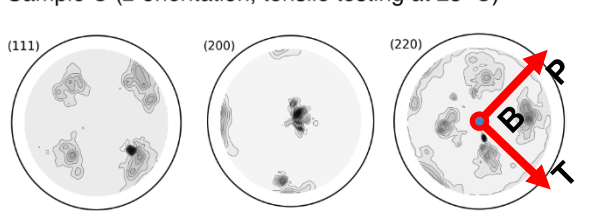
```
rot = rotation('Euler',0*degree,90*degree,90*degree)
pf_rot = rotate(pf,rot);
```



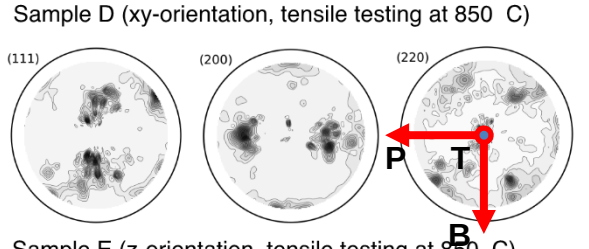
..\data_XTG\



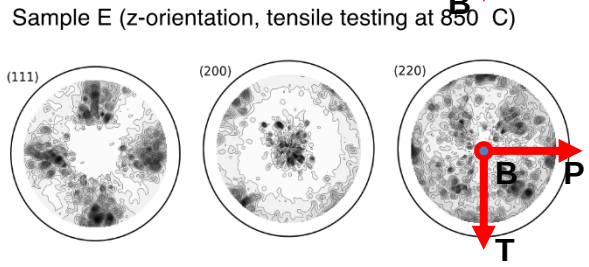
No_2_hkl.pan



No_1_hkl.pan



No_9_hkl.pan



No10_hkl.pan

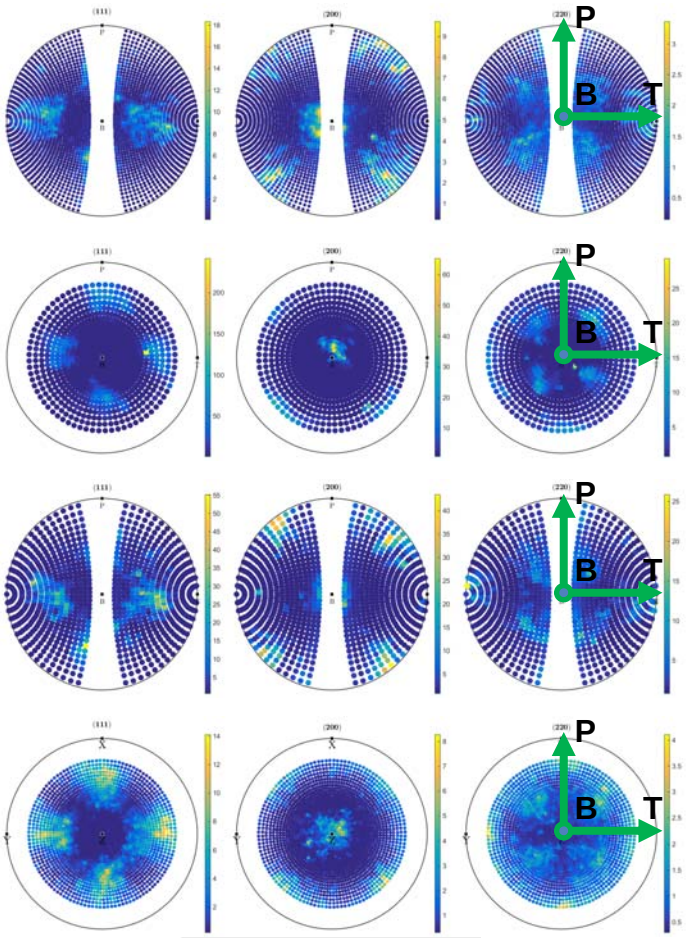
ETH zürich

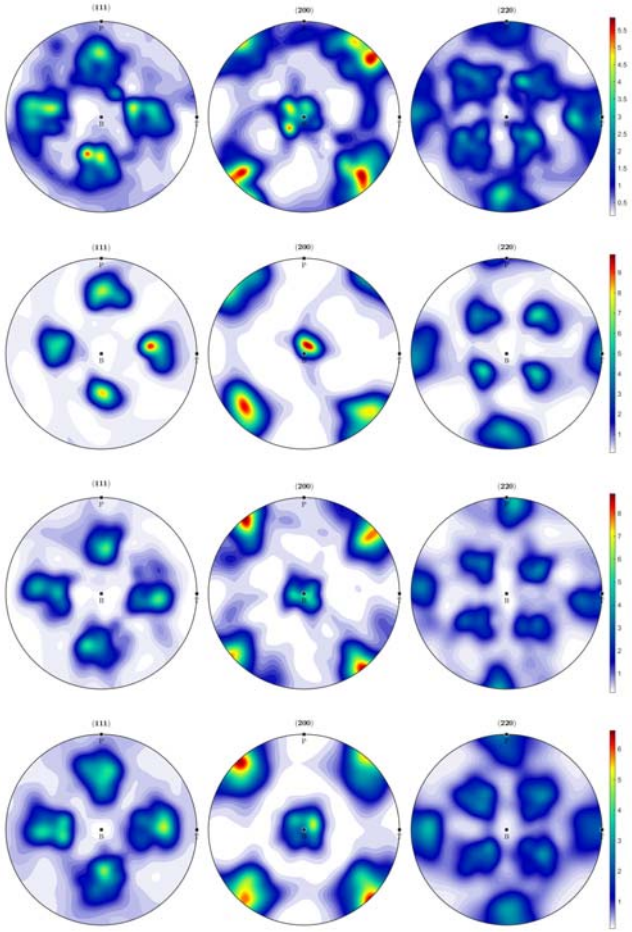
ScopeM

Calculate ODF & PDF

```
odf = calcODF(pf_rot)
plotPDF(odf,pf.h,'projection','stereo','antipodal')
```

..\data_XTG\





No_2_hkl.pan

No_1_hkl.pan

No_9_hkl.pan

No10_hkl.pan

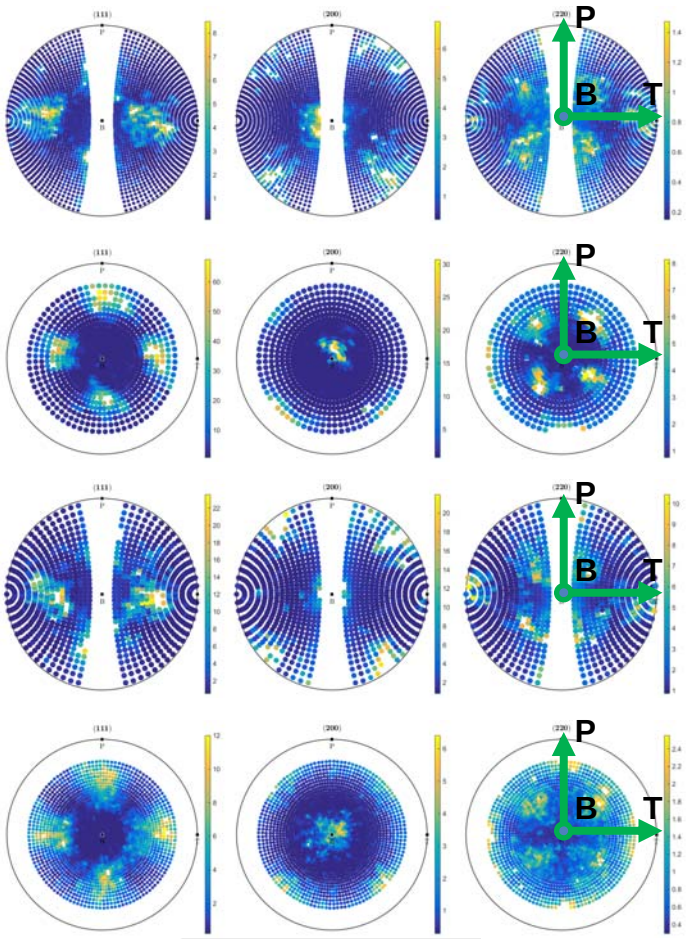
ETH zürich

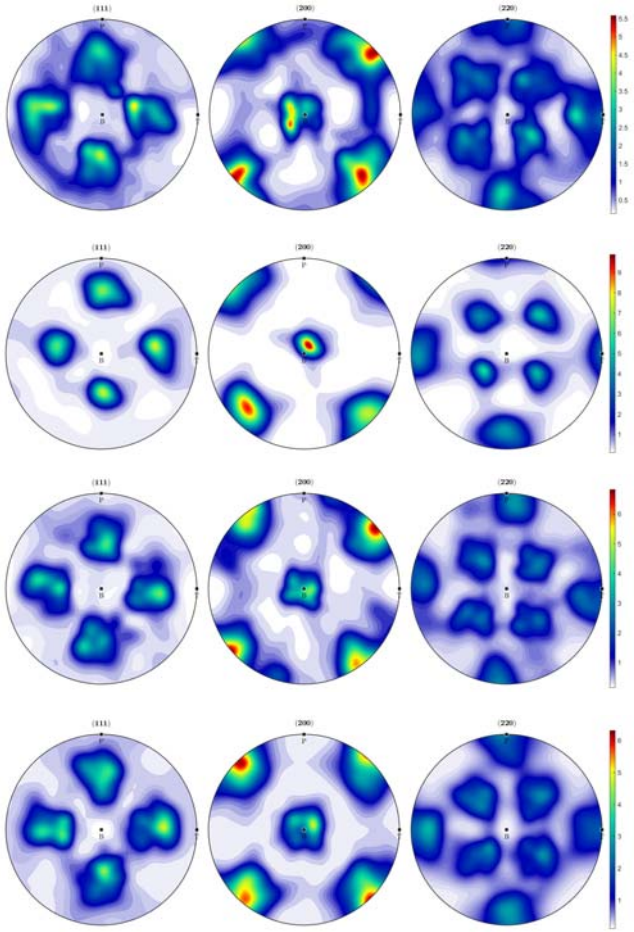
Scope M

Calculate ODF & PDF – outliers removed

```
pf_rot(pf_rot.isOutlier) = [];
```

..\data_XTG\





No_2_hkl.pan

No_1_hkl.pan

No_9_hkl.pan

No10_hkl.pan

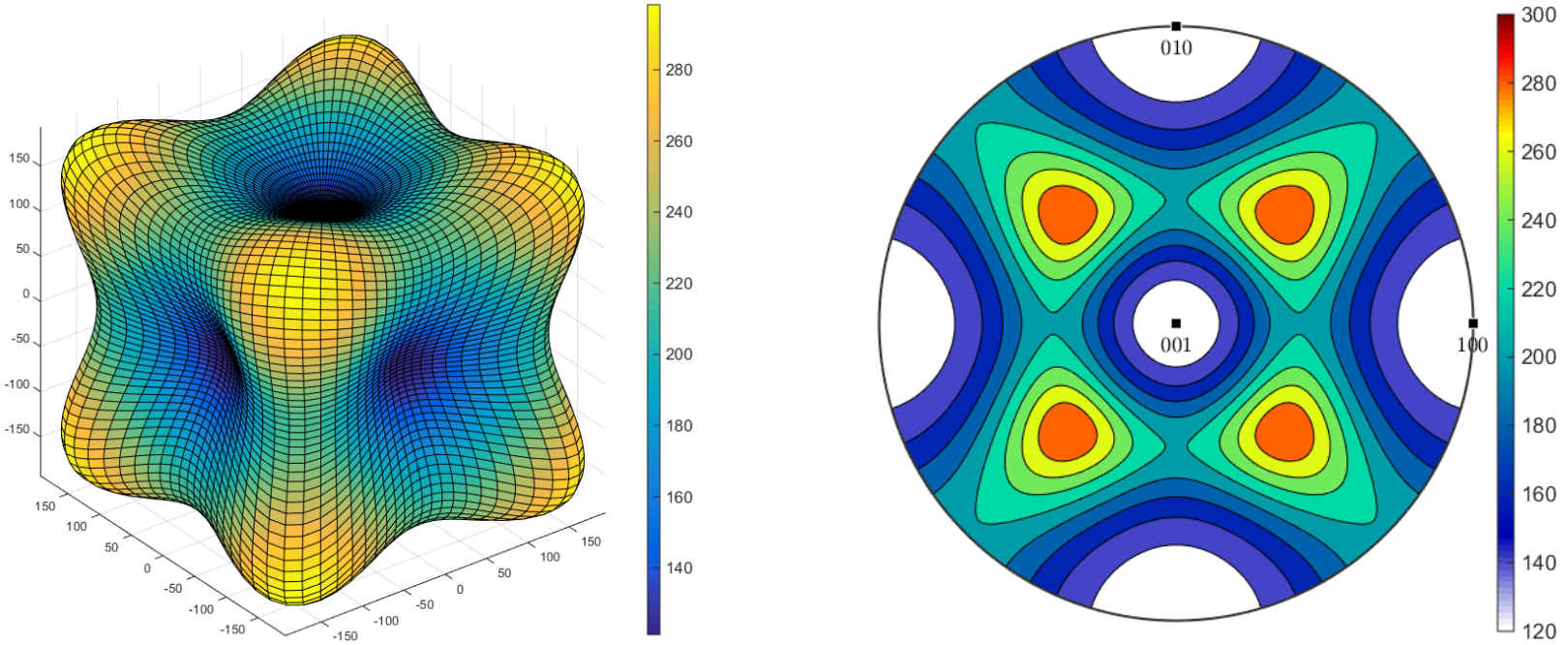
ETH zürich

Scope M

Youngs' modulus – IN738 single Xtal

$$E(x) = \left(S_{ijkl} x_i x_j x_k x_l\right)^{-1}$$

```
plot(C,'plotType','YoungsModulus','3d','complete');
```



c_{11} = 235.16 GPa
c_{12} = 147.67 GPa
c_{44} = 122.53 GPa

J.B. Han et al. (1995), Mater. Sci. Eng. A 191, 105–111

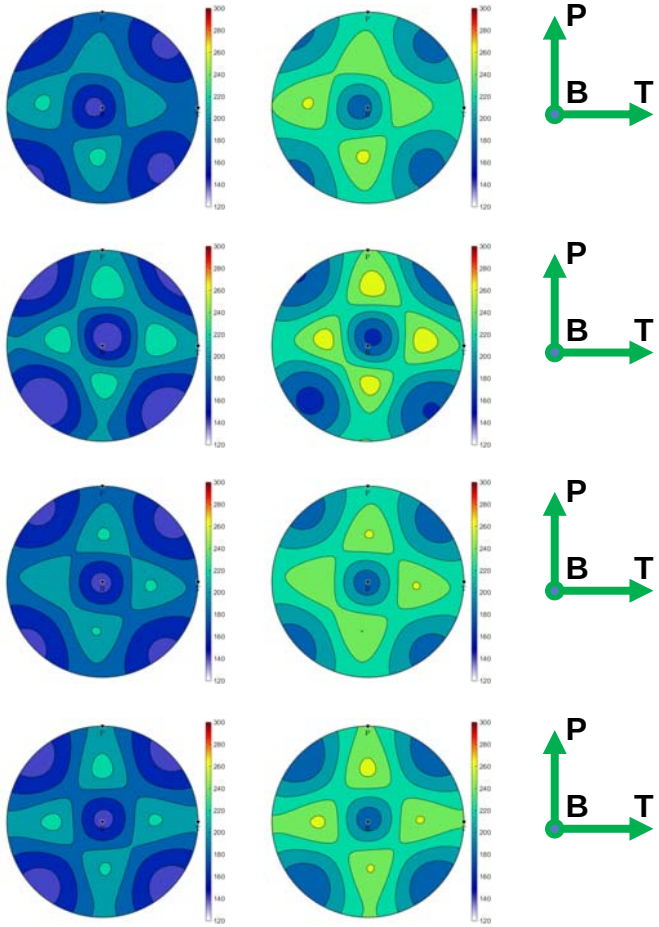
ETH zürich ScopeM

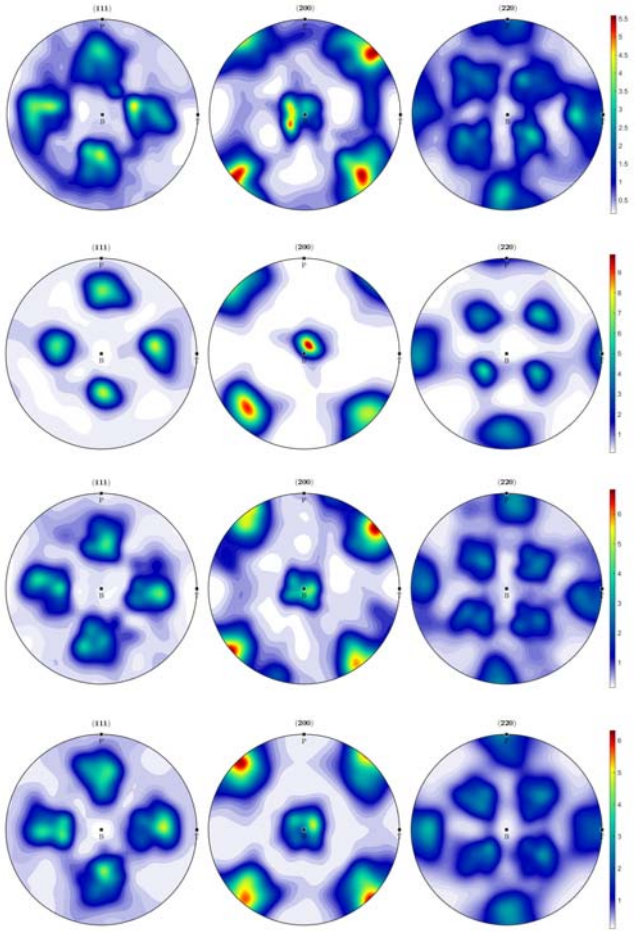
Calculate Young's modulus

Reuss (lower) Voigt (upper) bounds

```
[C_v,C_r,C_h] = calcTensor(odf,C)
```

..\data_XTG\





No_2_hkl.pan

No_1_hkl.pan

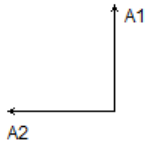
No_9_hkl.pan

No10_hkl.pan

ETH zürich

Scope M

Input B – EBSD .osc

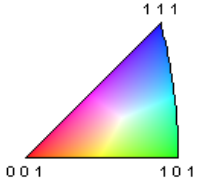


(Highlighted Points)/(Total Number of Points) = 0.000
(Highlighted Points)/(Number of Good Points) = 0.000
(Highlighted Points)/(Number of Partition Points) = 0.000

Gray Scale Map Type:<none>

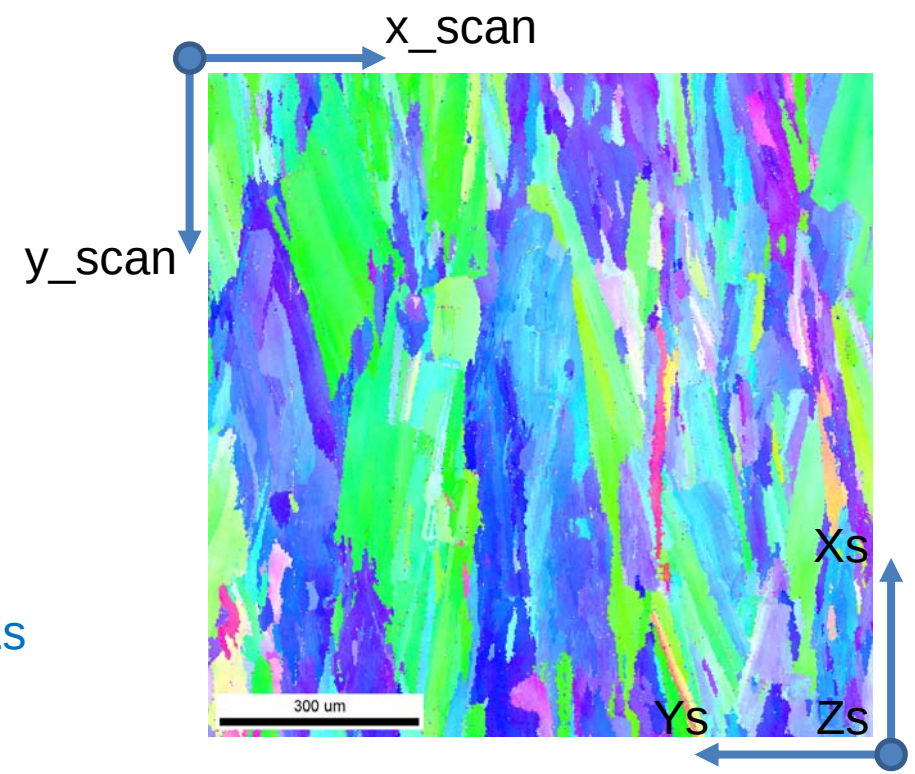
Color Coded Map Type: Inverse Pole Figure [001]

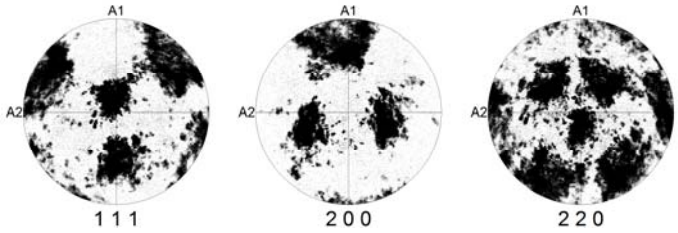
Nickel



Color LUT
with respect to Zs

Boundaries: <none>



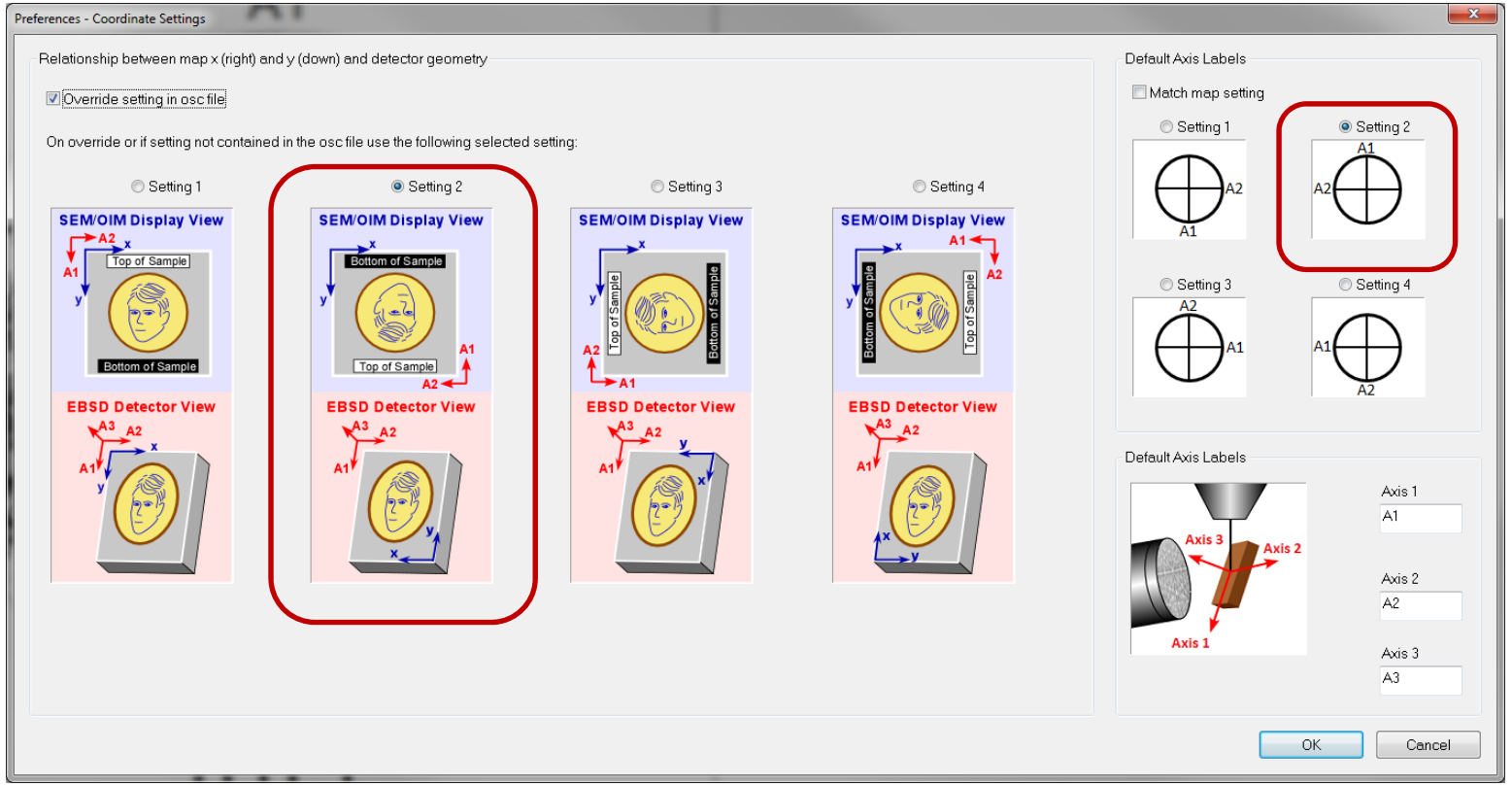


..\data_OIM\sample_2_scan1.osc

ETH zürich

ScopeM

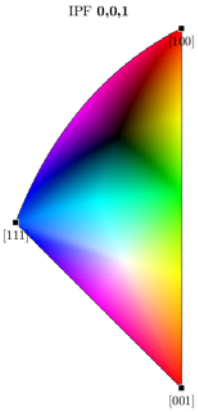
OIM – reference frames

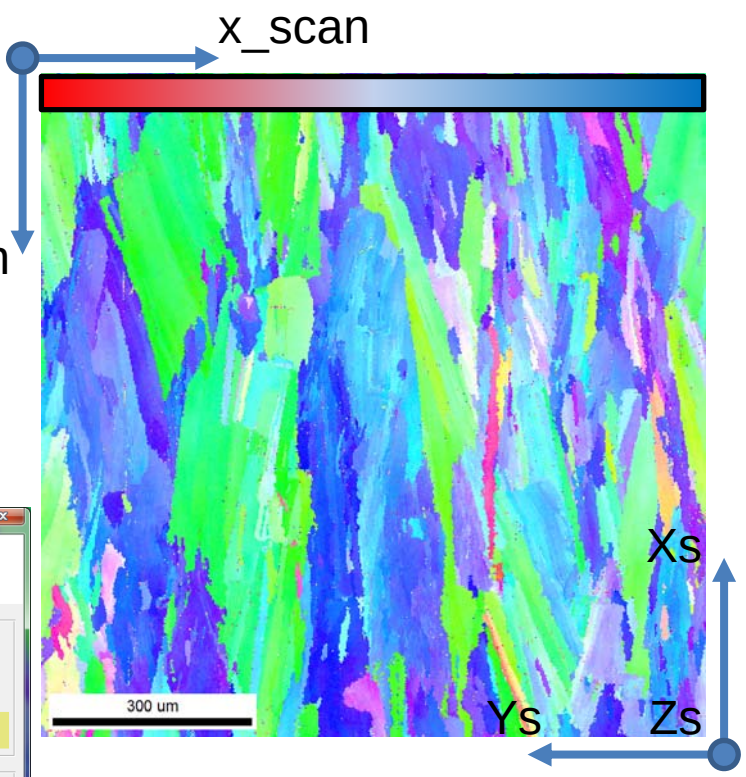


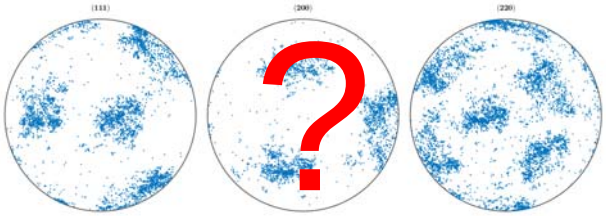
ETH zürich

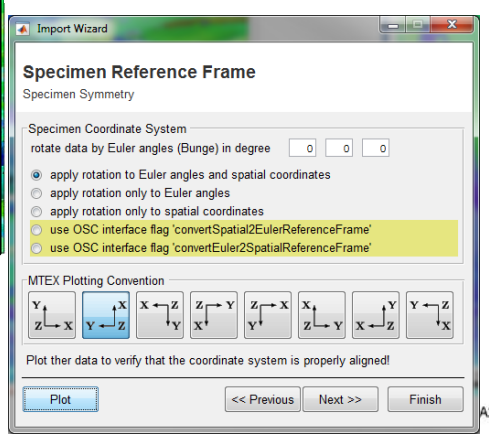
ScopeM

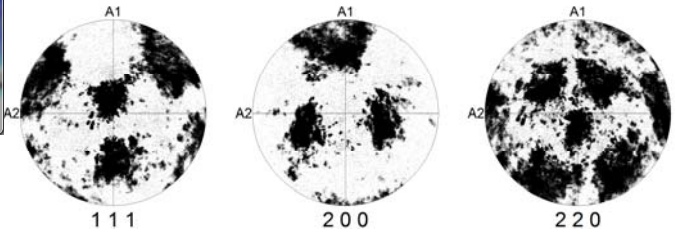
Input_Wizard I - ???









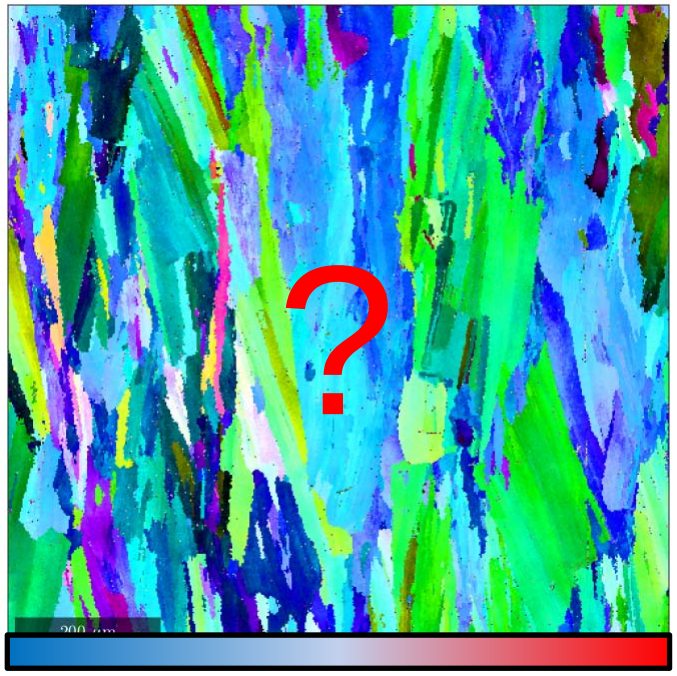


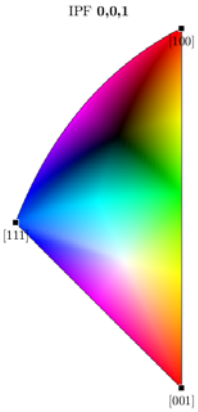
ETH zürich

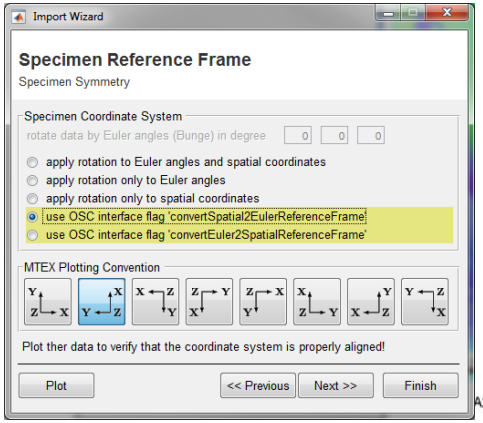
ScopeM

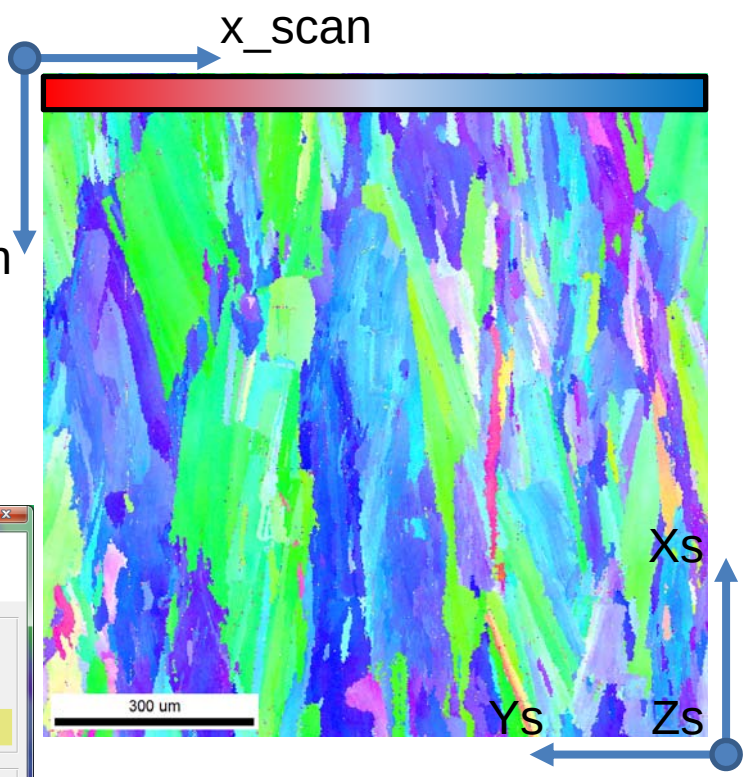
..\data_OIM\sample_2_scan1.osc

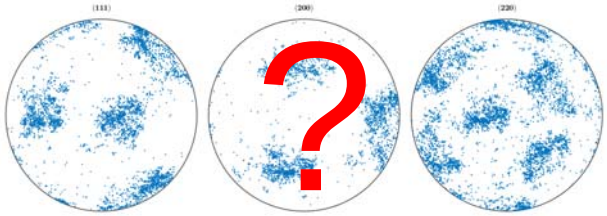
Input_Wizard II - ???

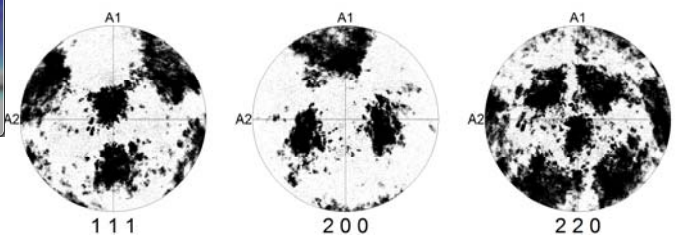










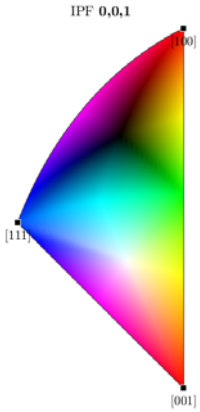


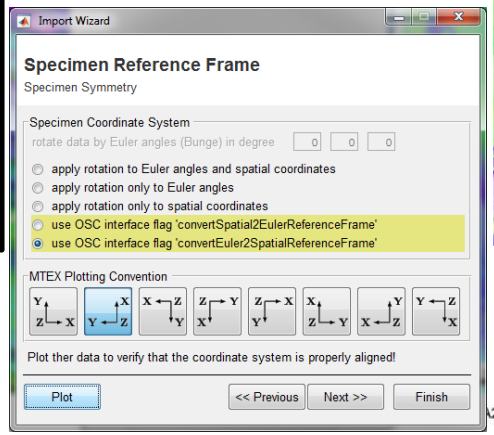
ETH zürich

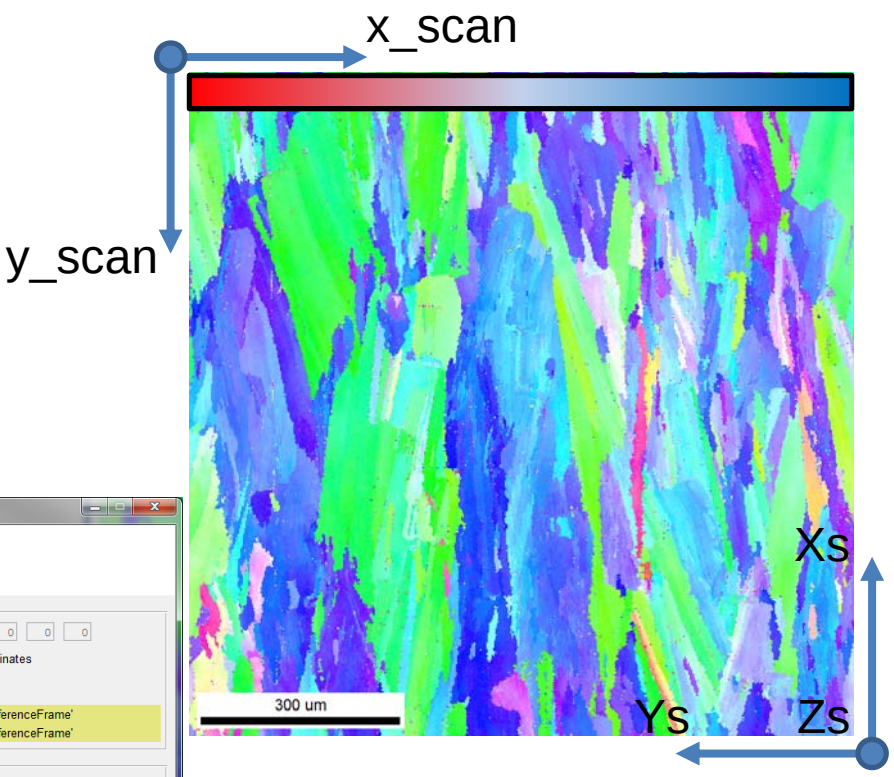
ScopeM

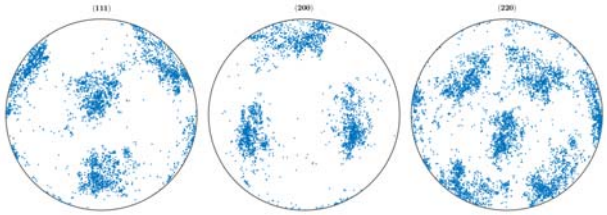
..\data_OIM\sample_2_scan1.osc

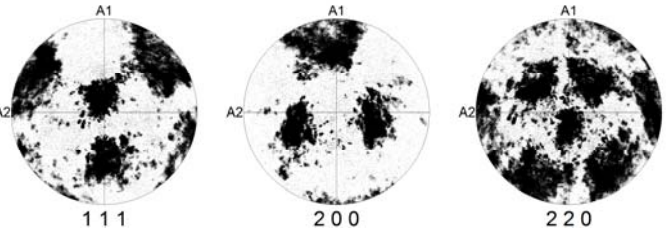
Input_Wizard III - ???







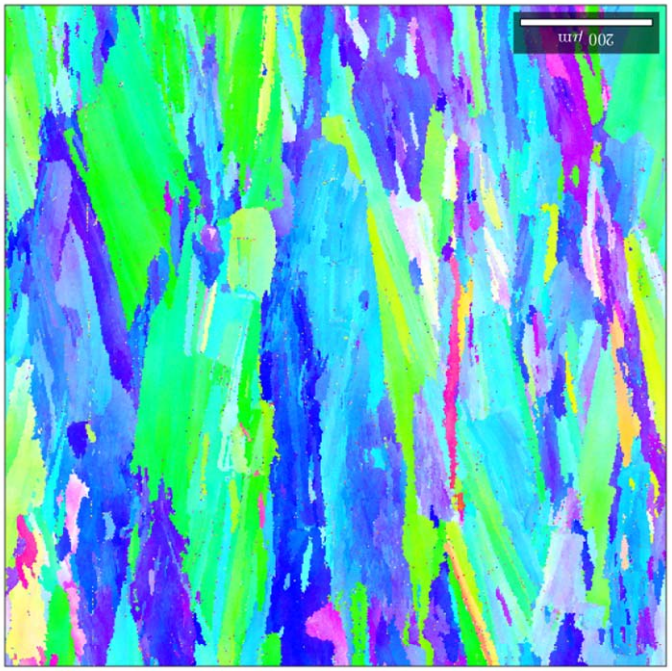


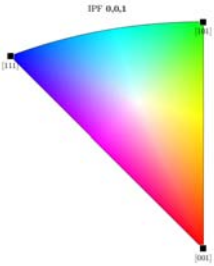


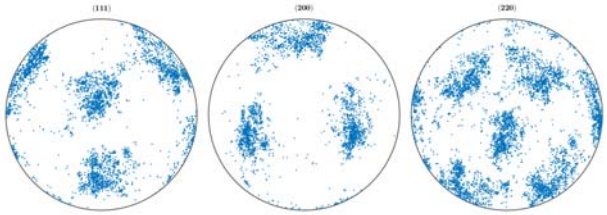
..\data_OIM\sample_2_scan1.osc

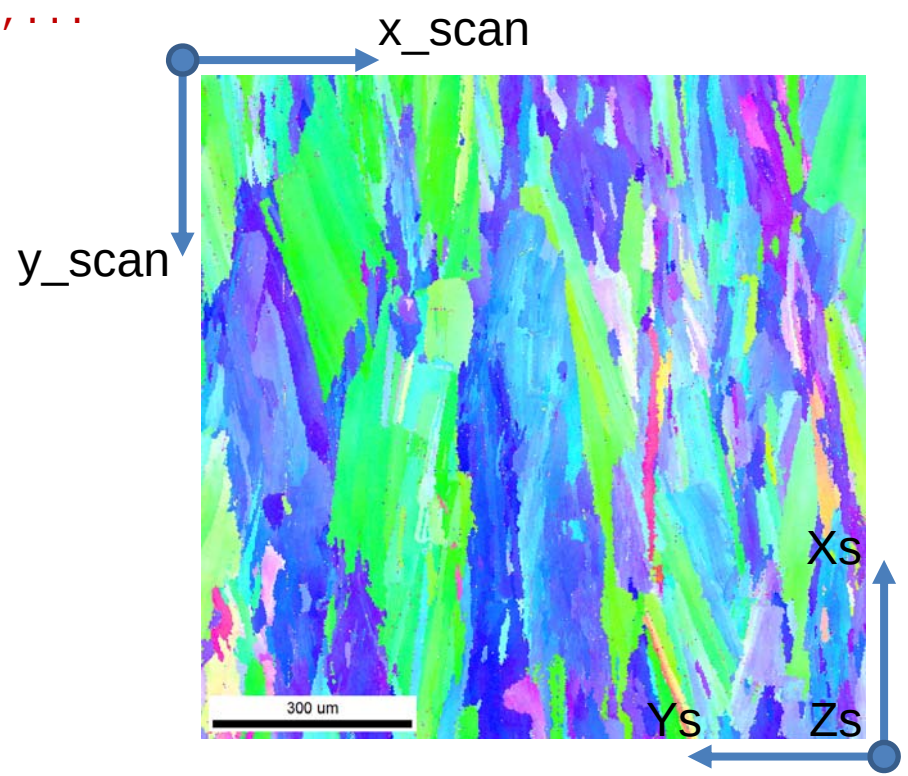
Input B – EBSD .osc

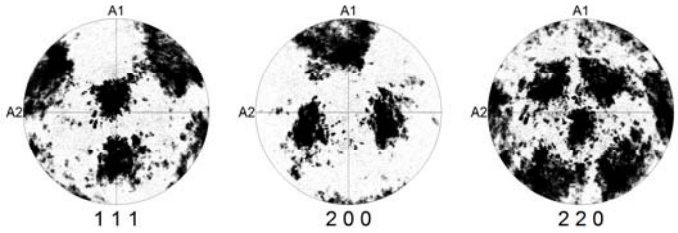
```
ebsd = loadEBSD(fname,CS,'interface','osc',...
  'convertSpatial2EulerReferenceFrame');
```







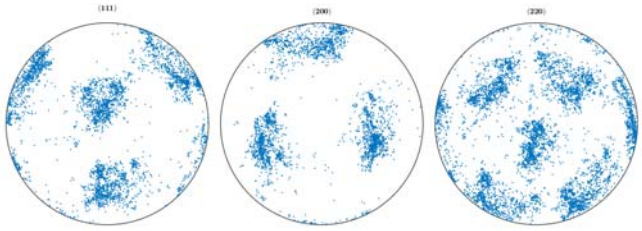




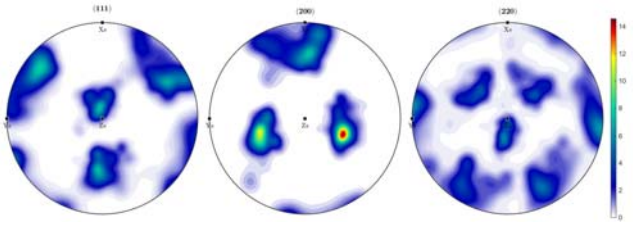
..\data_OIM\sample_2_scan1.osc

Calculate & rotate ODF, plot PDF

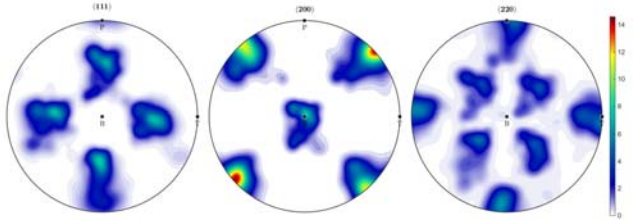
```
ebsd = loadEBSD(fname,CS,'interface','osc',...
  'convertSpatial2EulerReferenceFrame');
```



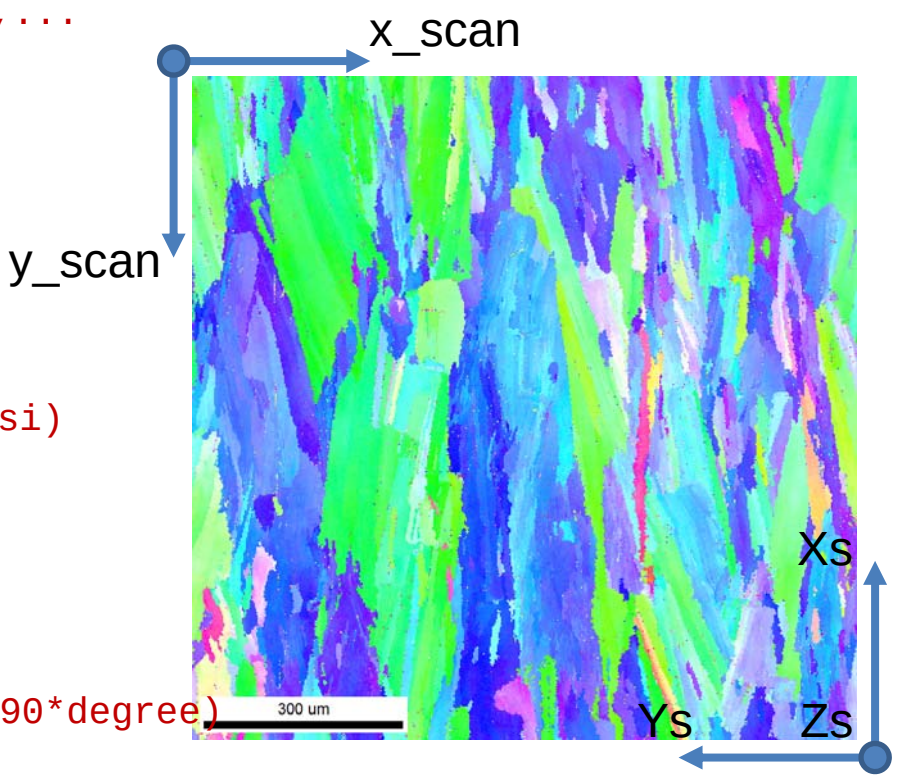

```
psi = deLaValeePoussinKernel(400);
odf = calcODF(ebsd.orientations,'kernel',psi)
```

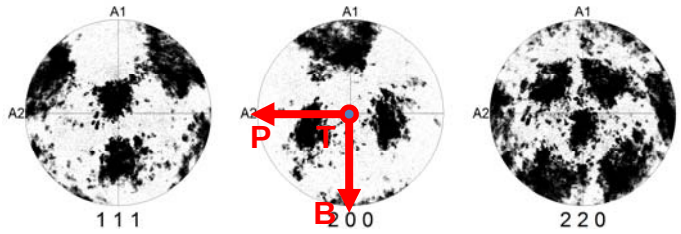



```
rot = rotation('Euler',0*degree,70*degree,90*degree)
odf_rot = rotate(odf,rot);
```



Preparation error corrected by rotation [20°,P]





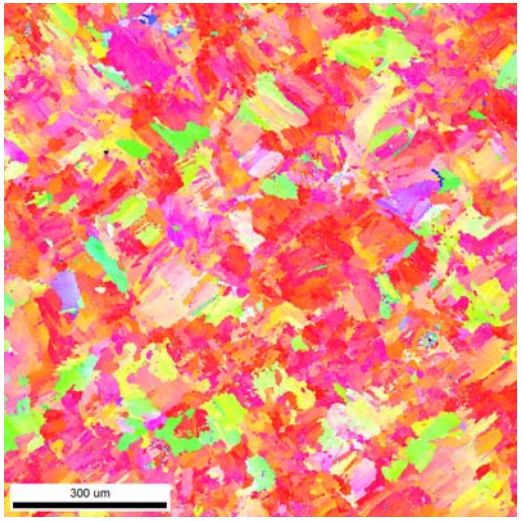
..\data_OIM\sample_2_scan1.osc

ETH zürich

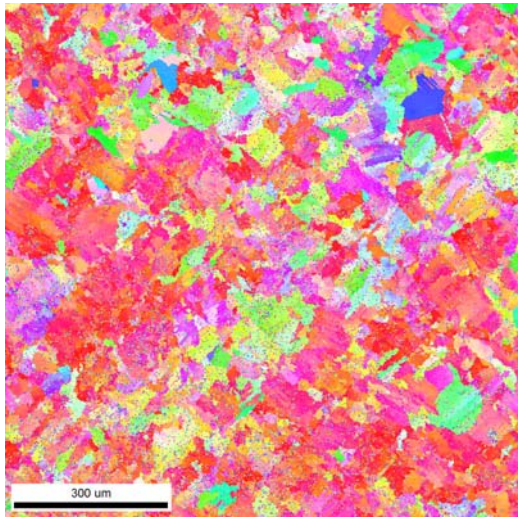
Scope M

Calculate & rotate ODF, plot PDF

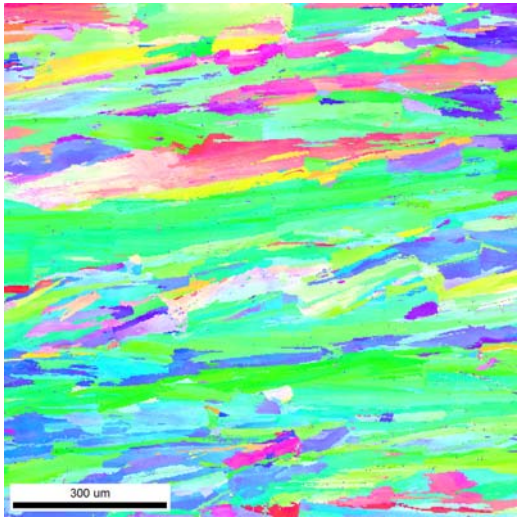
..\data_OIM\
sample10_scan3.osc

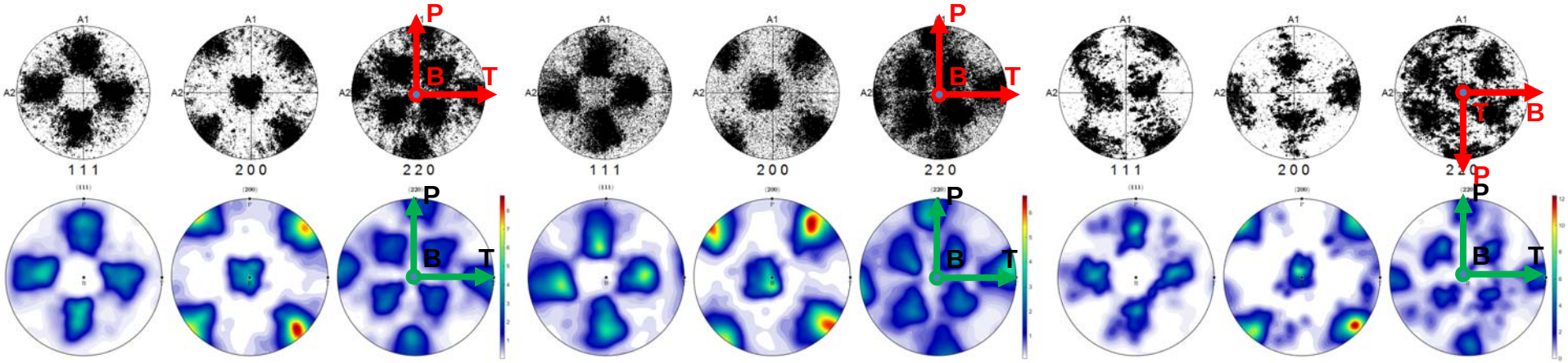


sample2s_scan3.osc



sample_9_scan2.osc

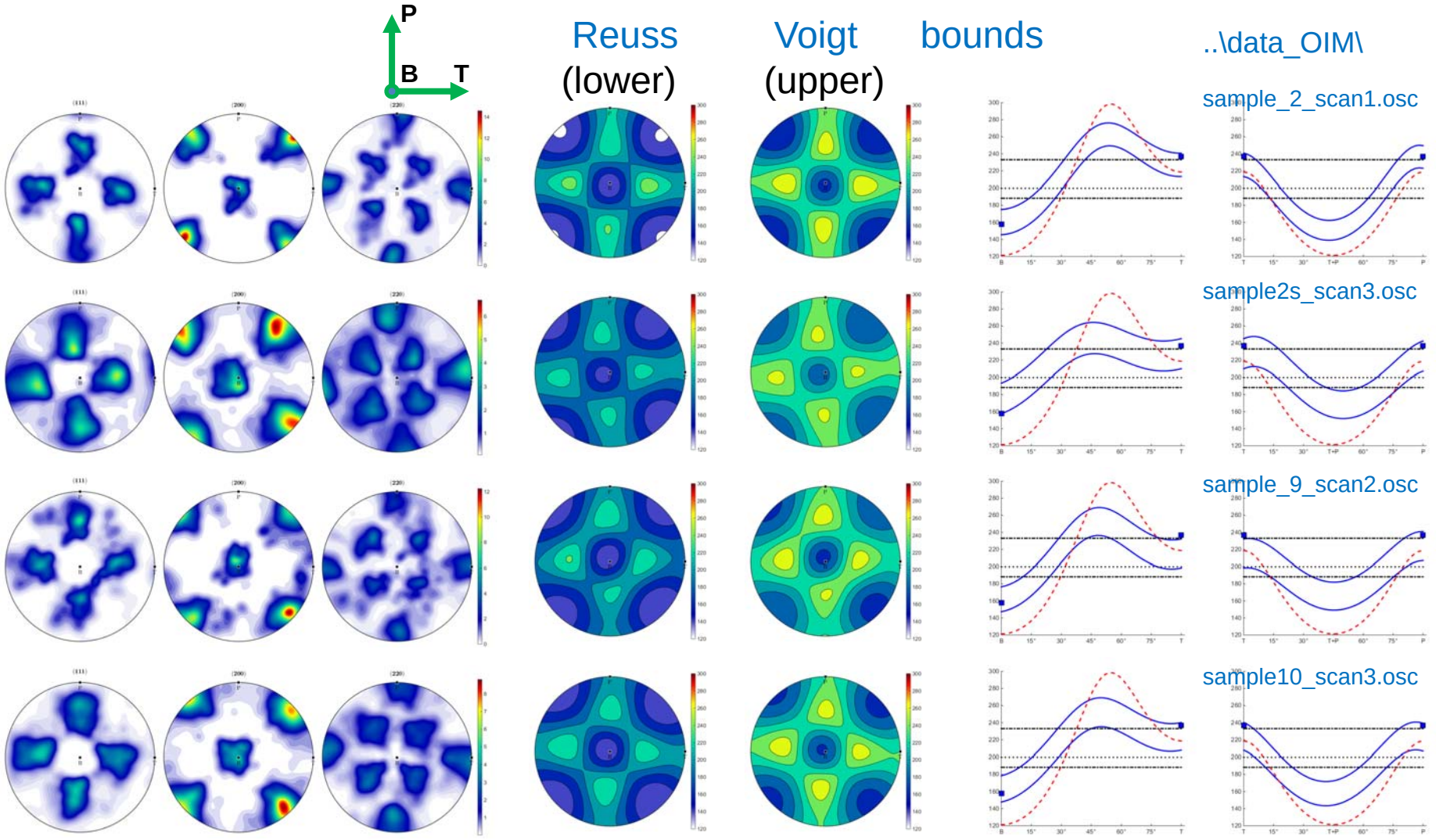




ETH zürich

ScopeM

Calculate Young's modulus



ETH zürich

ScopeM

Calculate Young's modulus

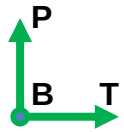
..\data_XTG\

No_2_hkl.pan

No_1_hkl.pan

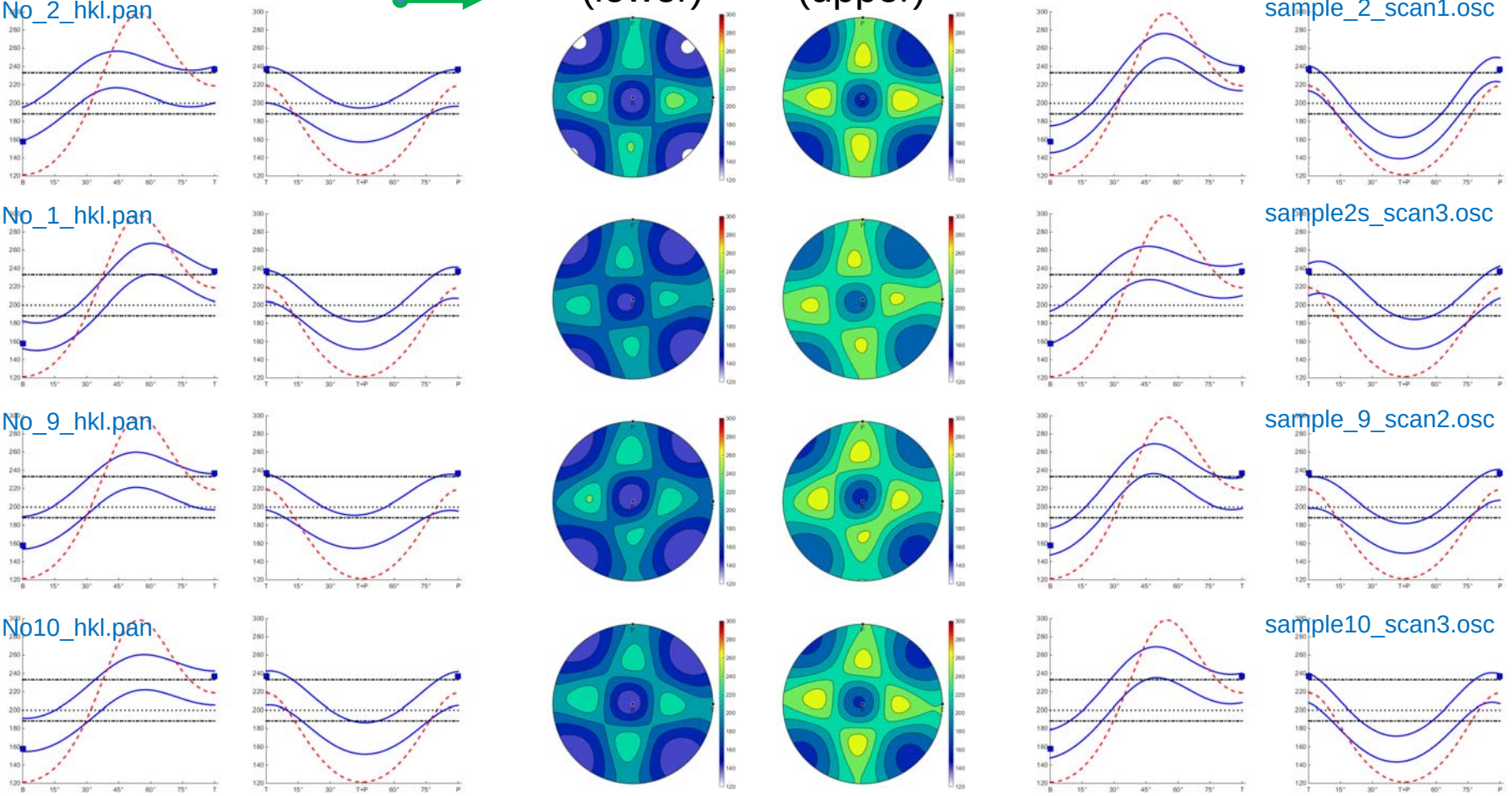
No_9_hkl.pan

No10_hkl.pan



Reuss (lower) bounds

Voigt (upper) bounds



..\data_OIM\

sample_2_scan1.osc

sample2s_scan3.osc

sample_9_scan2.osc

sample10_scan3.osc

ETH zürich

Scope M

What else could be done with the data ?

- ODF characteristics
  - entropy, texture index, components, uniform portion, …
- Texture statistics
  - Do the ODF (E-modules) differ significantly from each other?
  - Are the differences inherent, or just misalignments of the sample coordinate systems?
  - Would it be justified to take ODF averages?
- Mapping analysis
  - Grain size, shape, shape preferred orientation
  - Grain boundary characteristics, MDF
  - 3D parameters by stereology
  - Orientation spread, KAM, etc.
- Anisotropic properties
  - Refinements using 3D grain shape
  - Plastic properties

Thank you for your attention.

ETH zürich ScopeM