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In-situ nano-mechanical tests in the light of μLaue diffraction

Thomas Cornelius
Aix-Marseille Université, thomas.cornelius@im2np.fr

Cedric Leclere
Aix-Marseille Université

Zhe Ren
Aix-Marseille Université

Anton Davydok
Aix-Marseille Université

Olivier Thomas
Aix-Marseille Université

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[1] B. Wu, A. Heidelberg, J.J. Boland, Nature Materials 4 (2005) 525 [2] G. Richter, K. Hillerich, D.S. Gianola, R. Mönig, O. Kraft, C.A. Volkert, Nano Lett. 9 (2009) 3048 [3] F. Östlund, et al., Adv. Funct. Mat. 19 (2009) 2439 [4] Z. Ren et al., J. Synchrotron Radiat. 21 (2014) 1128 [5] C. Leclere et al., J. Appl. Cryst. 48 (2015) 291 [6] C. Kirchlechner et al., Acta Materialia 60 (2012) 1252 [7] R. Maaß, S. van Petegem, C.N. Borca, H. van Swygenhoven, Mater. Sci. Eng. A 524 (2009) 40

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Albufeira, Portugal
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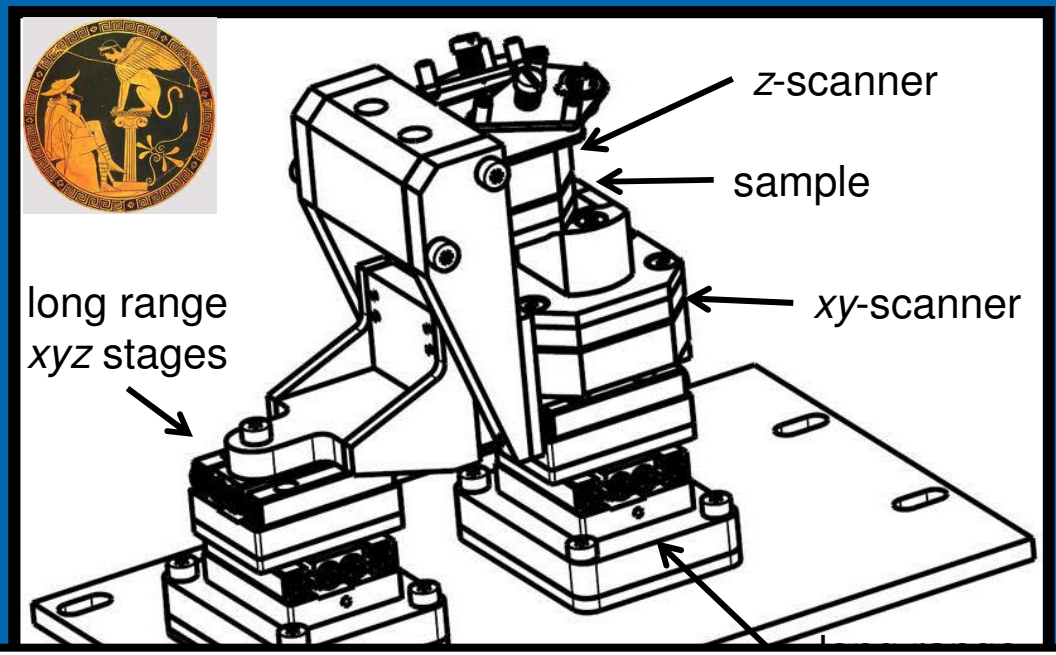
In situ three-points bending tests of Au nanowires in the light of μLaue diffraction

T.W. Cornelius,
Z. Ren, C. Leclere, A. Davydok, O. Thomas
Aix-Marseille Université, CNRS, IM2NP UMR 7334, Marseille, France
J.-S. Micha, O. Robach
BM32 beamline, ESRF, Grenoble, France
G. Richter
MPI for Intelligent Systems, Stuttgart, Germany

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR
ANR

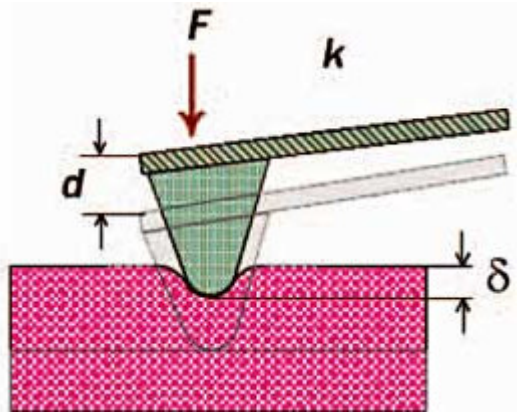
SFINX

Scanning Force microscope for In situ Nanofocused X-ray diffraction

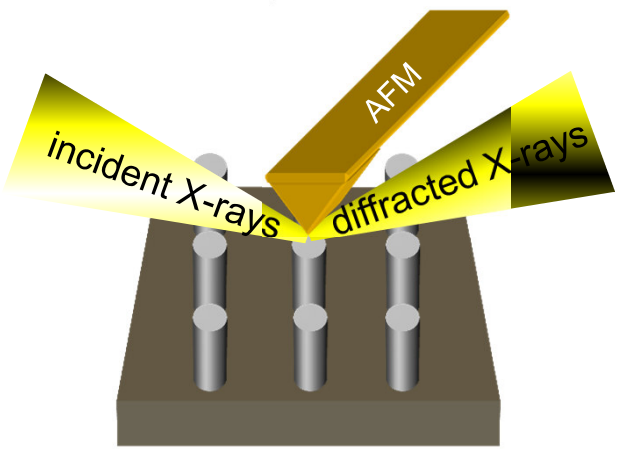


Z. Ren et al.,
J. Synchrotron Radiat.
21 (2014) 1128

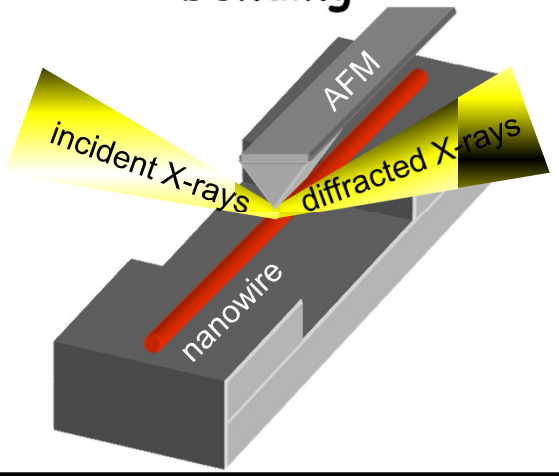
indentation



compression

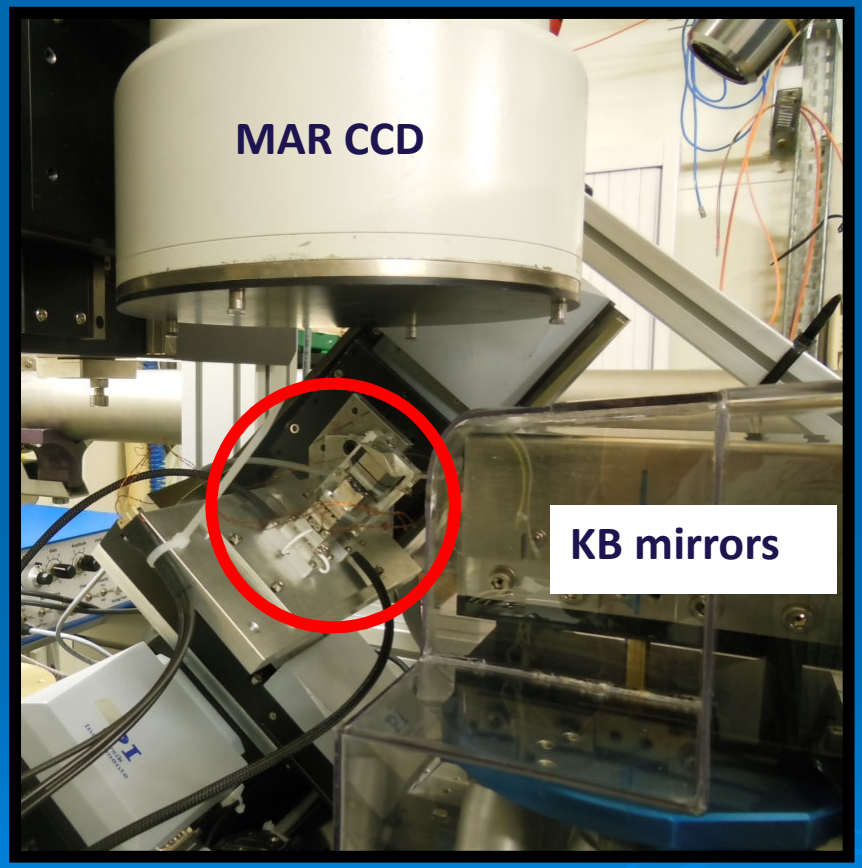


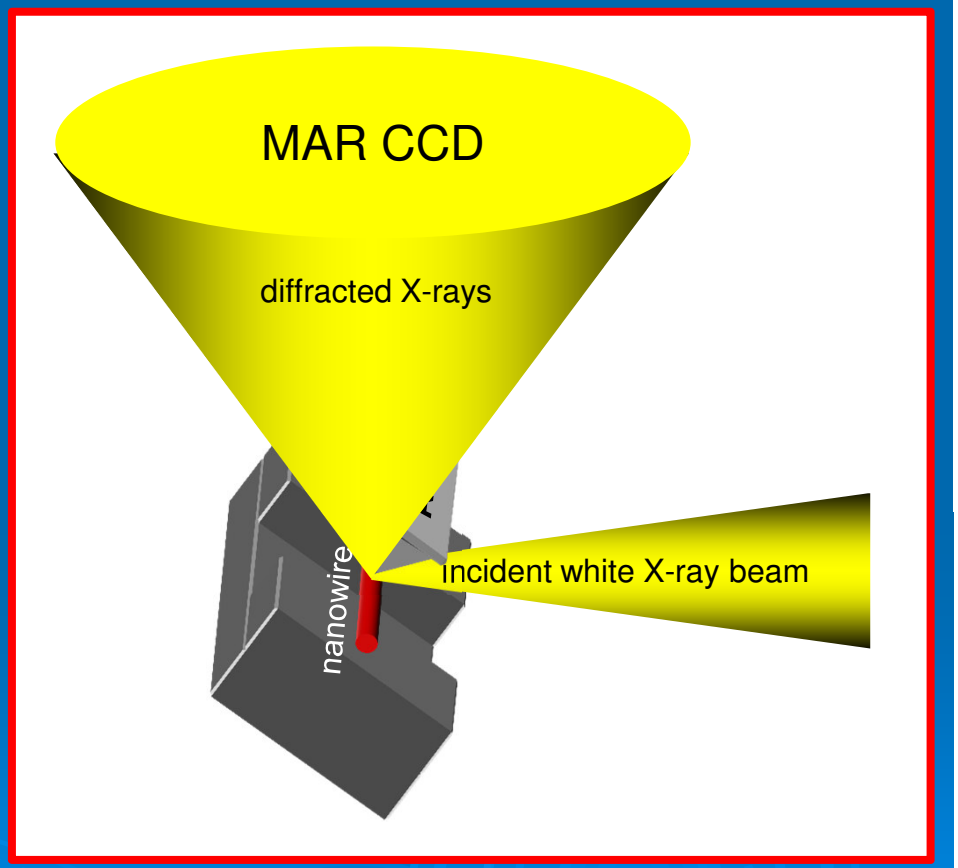
bending



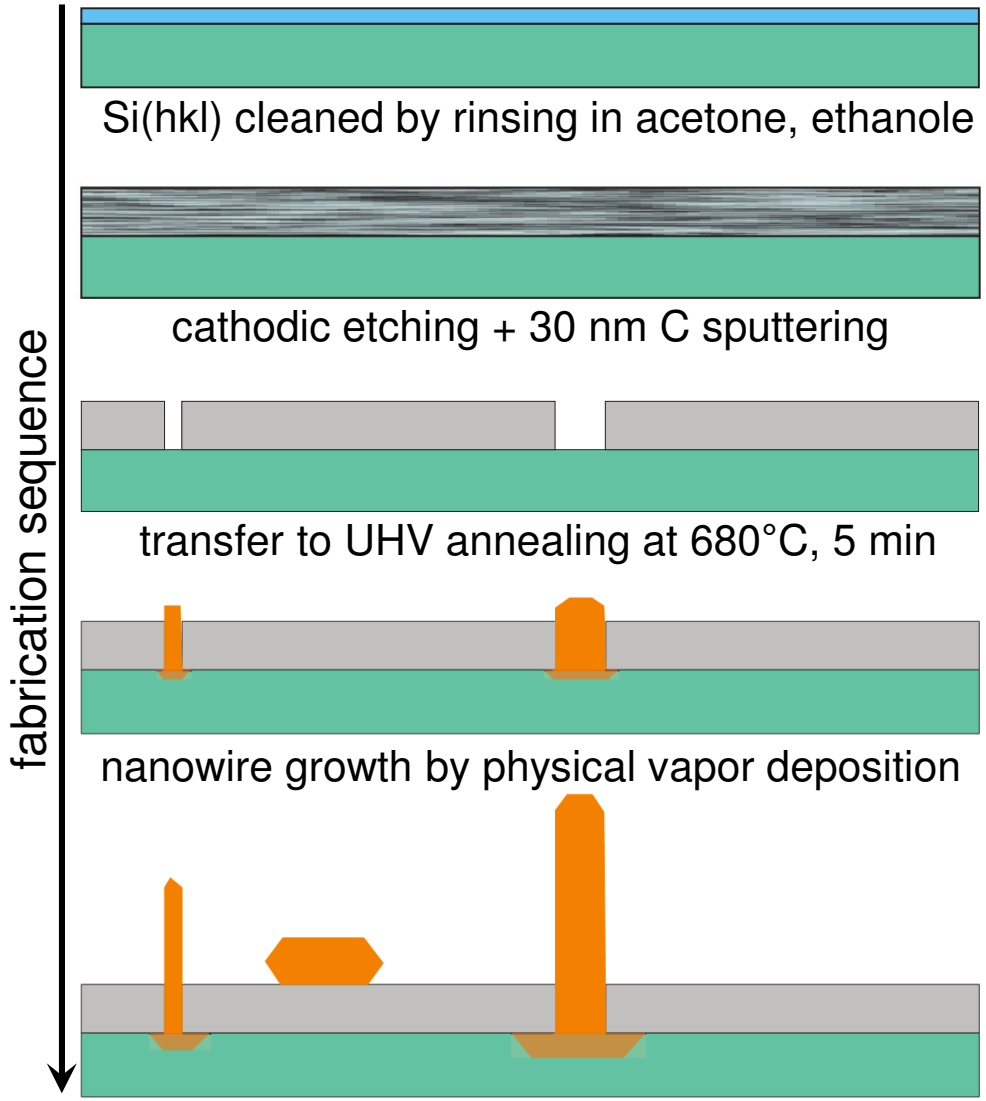
in situ µLaue diffraction

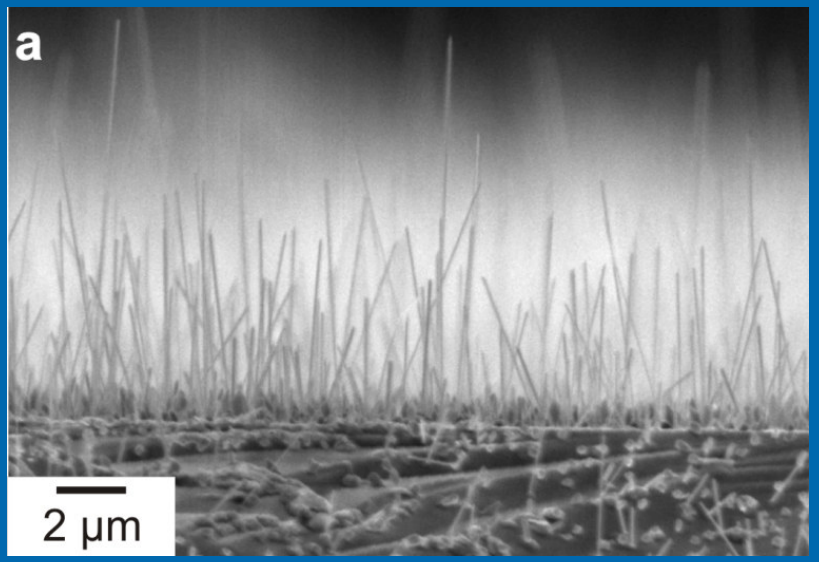
setup at BM32 @ ESRF

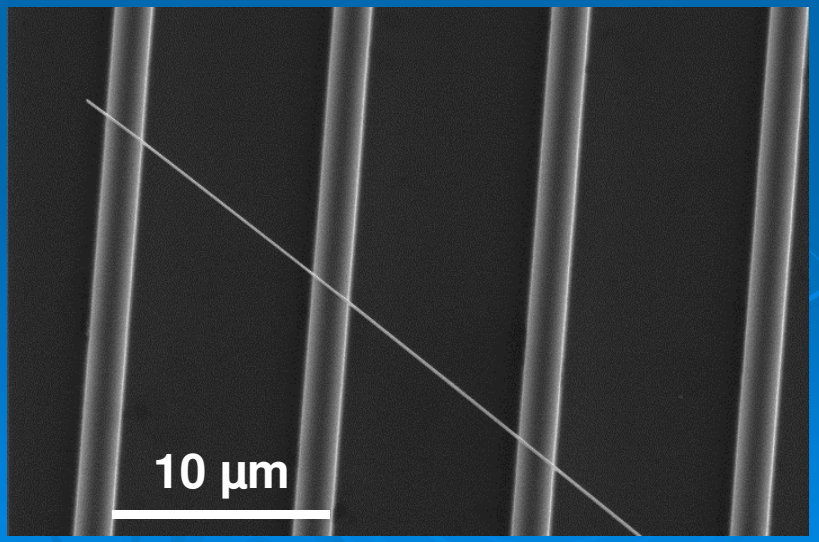




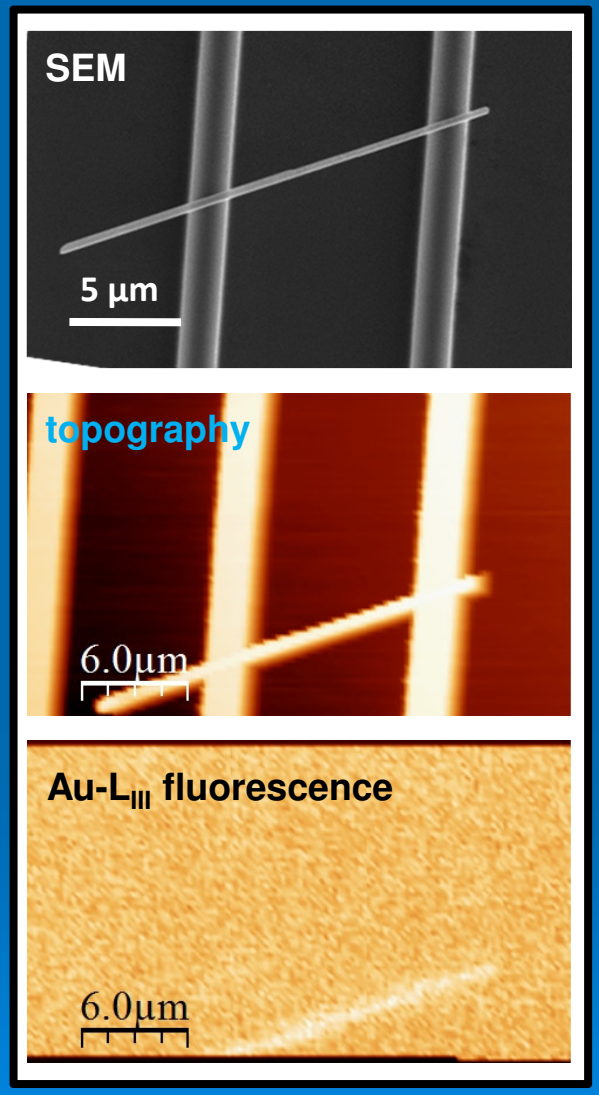
Au nanowires

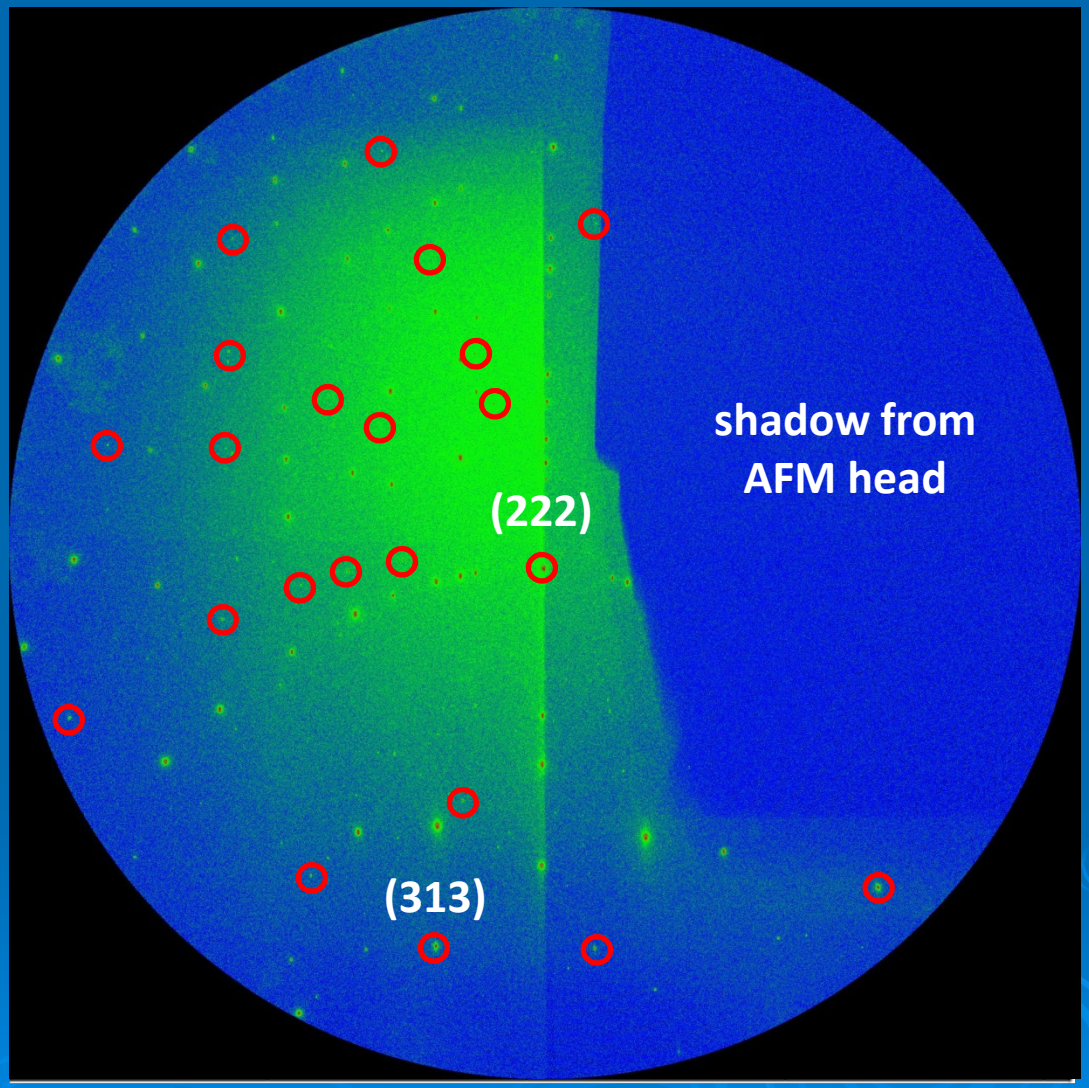






μLaue diffraction

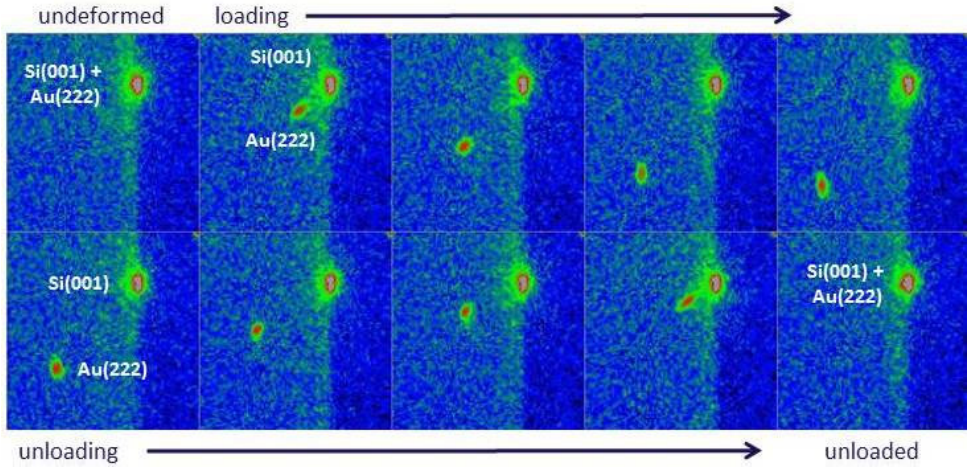




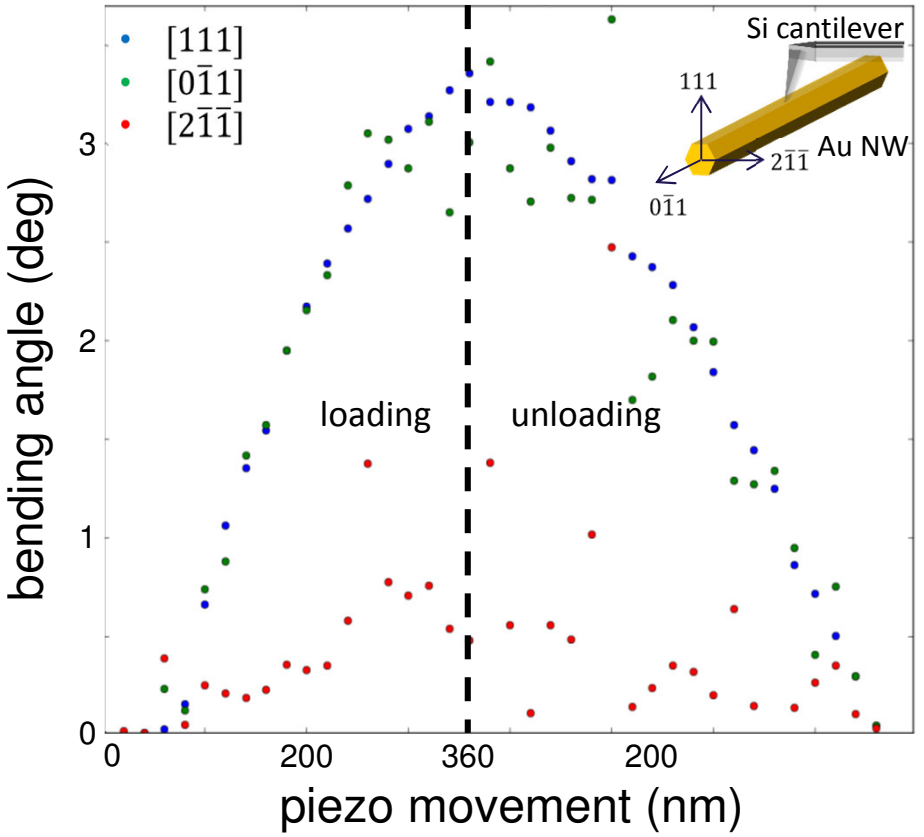
red circles indicate Laue spots from Au nanowire

C. Leclere, T.W. Cornelius et al., J. Appl. Cryst. 48 (2015) 291 – 296

nanowire bending



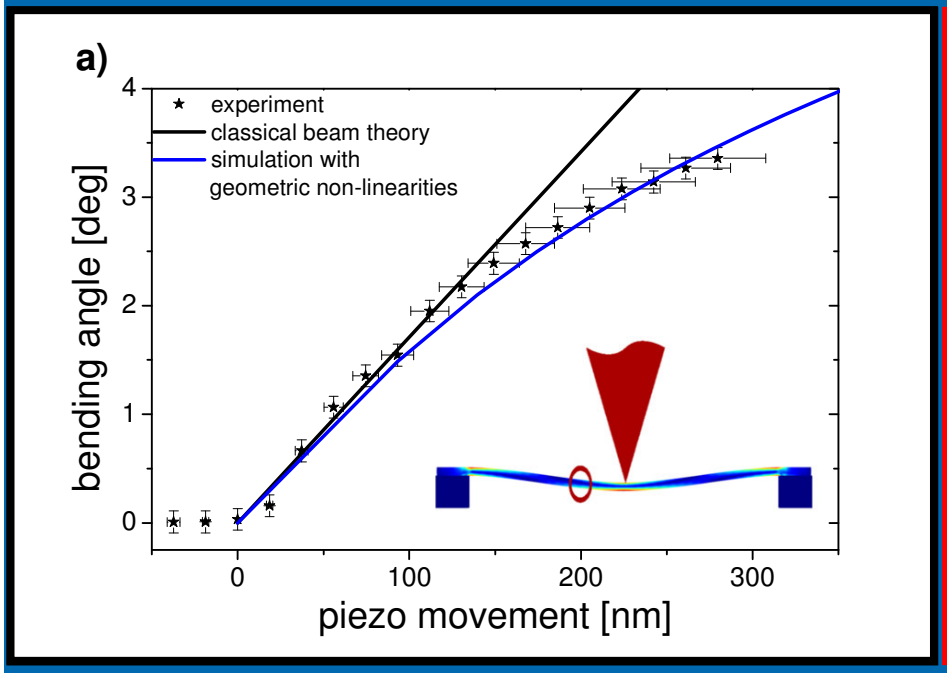
- **UB matrix computed from position and displacement of Laue spots**
- **calculation of crystal orientation – bending + rotation**

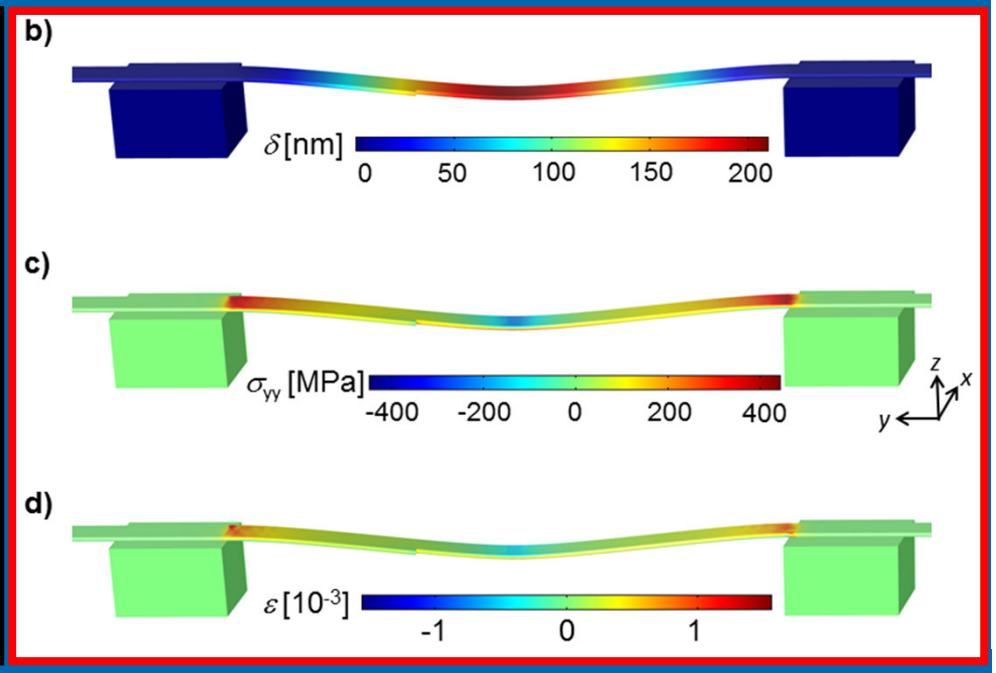


bending angle β increases up to 3.5° for [111] and [0-11] direction, while for [2-11] $\beta < 1°$
$\Rightarrow$ force not perfectly vertical but finite lateral force exist due to cantilever deflection

C. Leclere, T.W. Cornelius et al., J. Appl. Cryst. 48 (2015) 291 – 296

FEM simulation



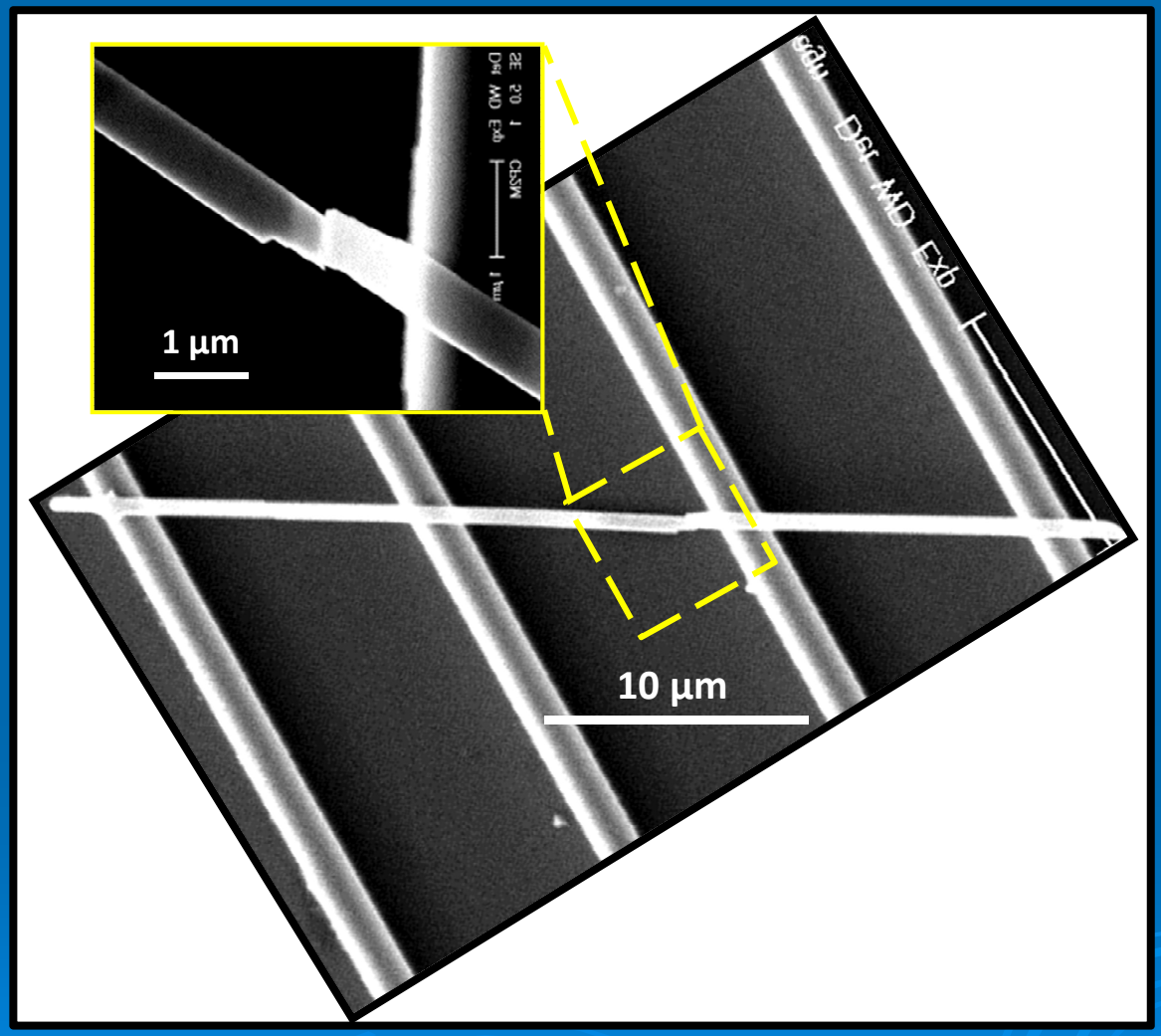


experiment well described by FEM simulations

- **bulk elastic constants**
- **geometric non-linearities due to strain inhomogeneity**
- **σ_{max} > 450 Mpa >> bulk yield strength**
- **max. theoretical shear stress for Au $\tau_{max} = G/2\pi$ ~ 4.8 GPa**

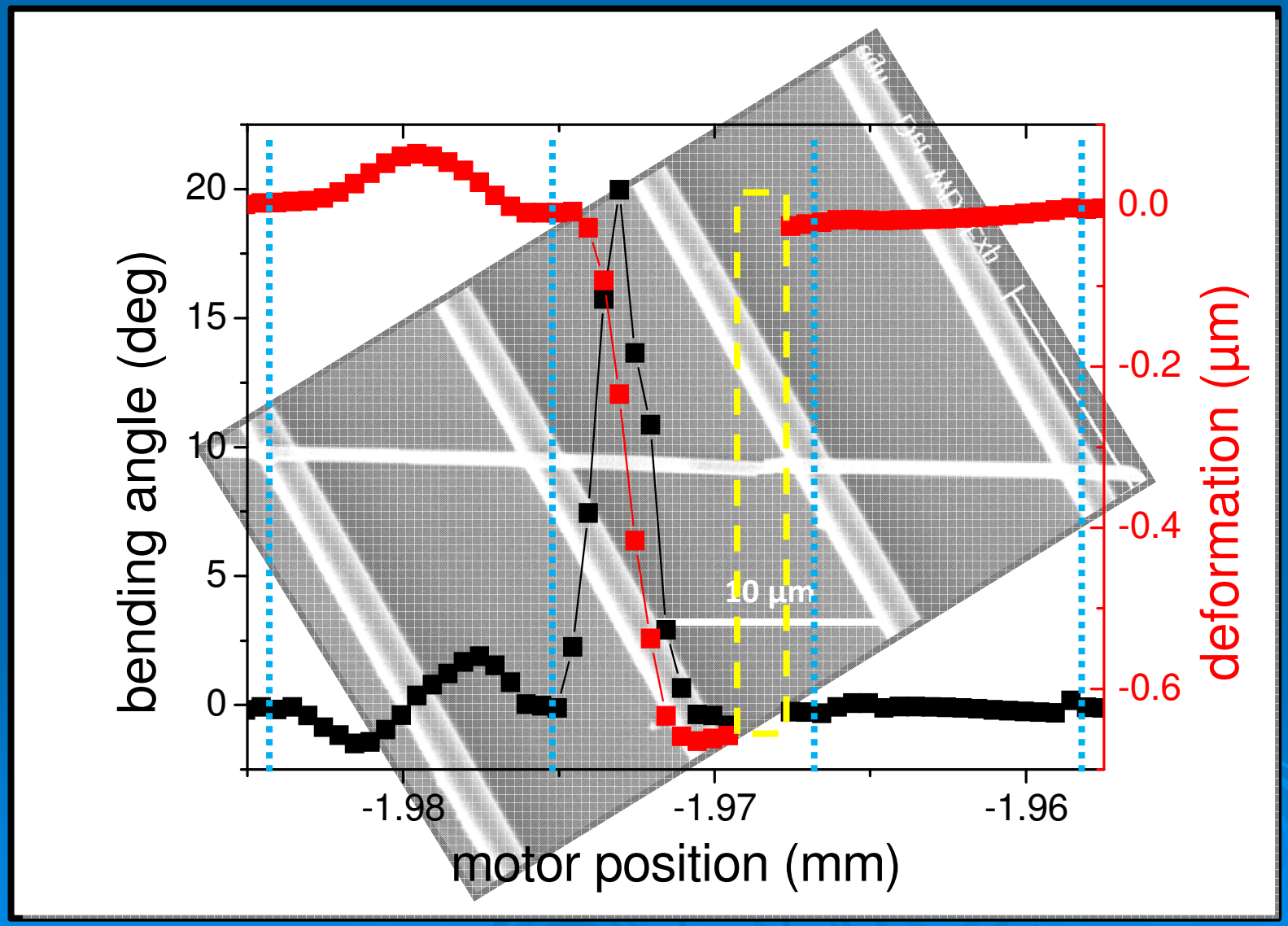
C. Leclere, T.W. Cornelius et al., J. Appl. Cryst. 48 (2015) 291 – 296

plasticity



- Au nanowires plastically deformed using AFM
- *Ex situ* scans with µLaue diffraction along nanowire

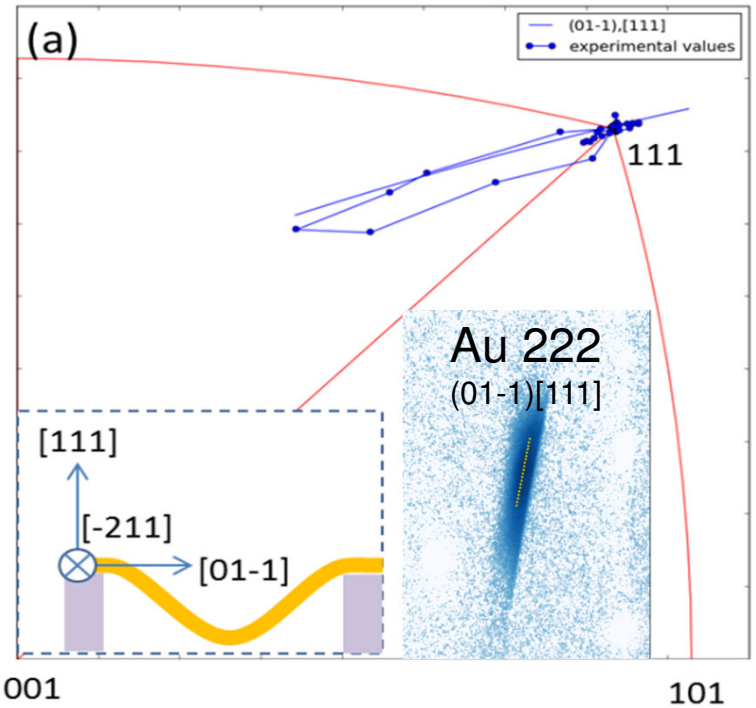
plasticity


bending angle (deg)
20
15
10
5
0
-1.98
-1.97
-1.96
motor position (mm)
0.0
-0.2
-0.4
-0.6
deformation (µm)
10 µm

identifying slip systems

experiment

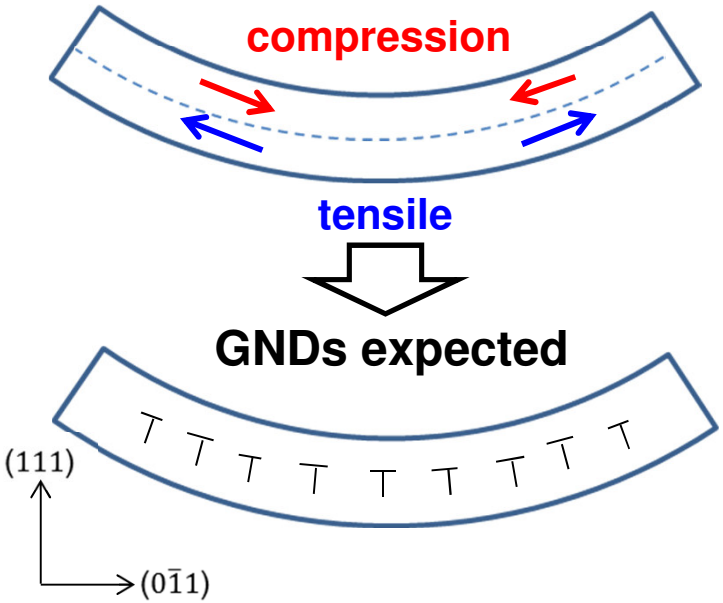
inverse pole figure



- ❑ mainly activated slip system: (0-11),[111]
- ❑ slight deviation observed
  ⇒ second slip system
- ❑ calulated geometry
  ⇒ clamped boundary conditions

theory

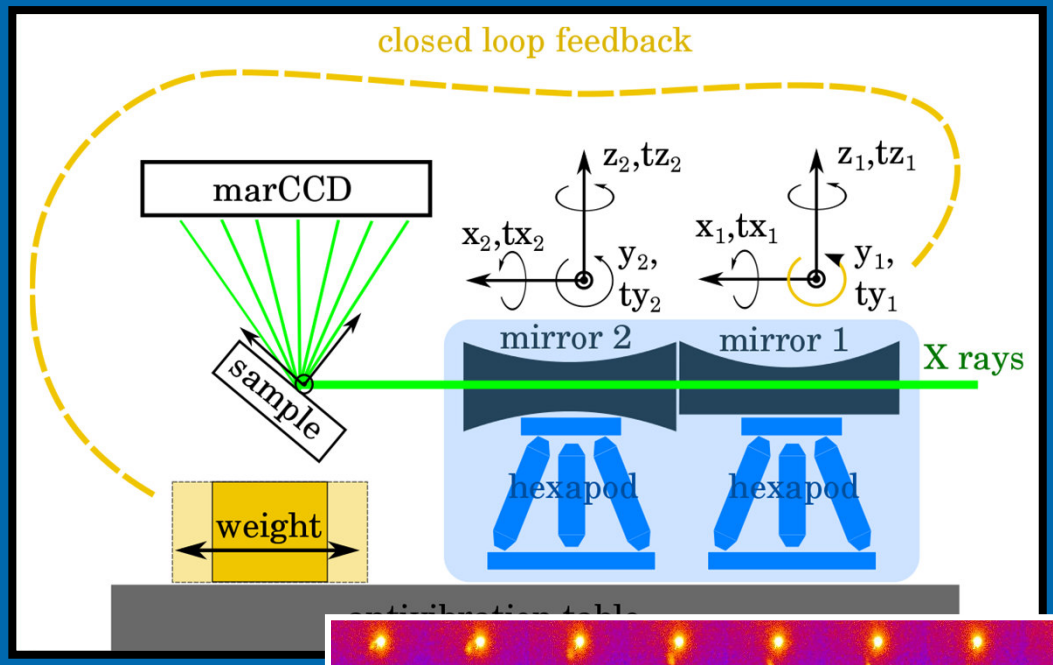
Stress distribution

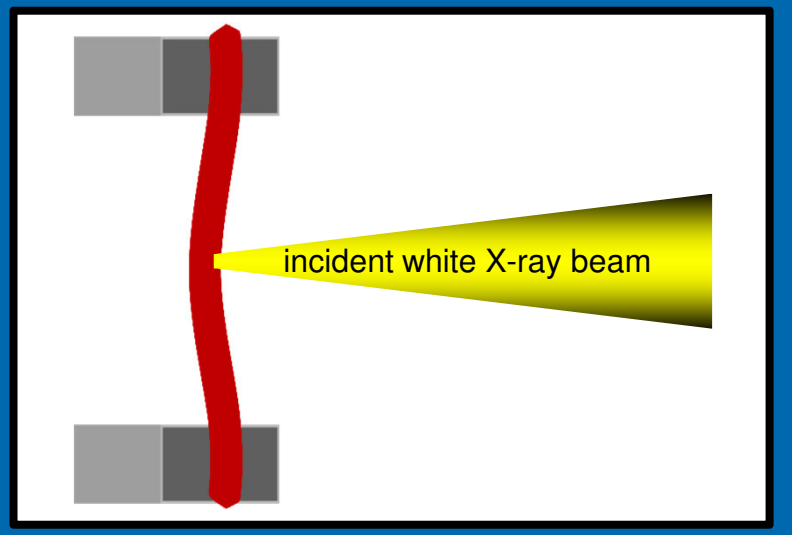


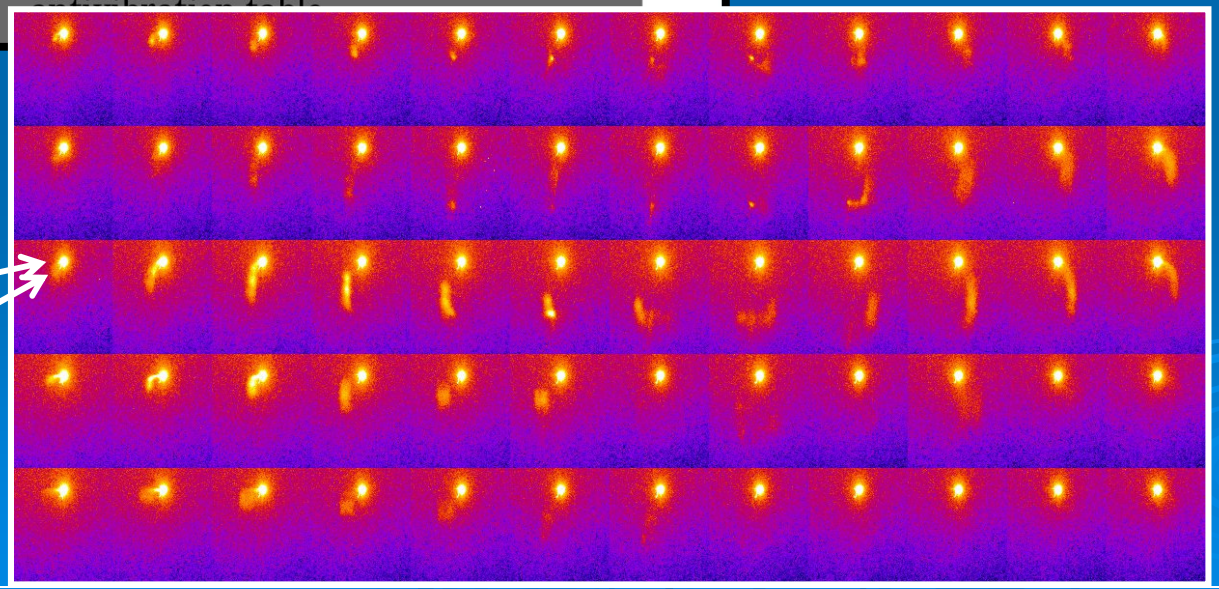
- ❑ expected slip system: (0-11),[111]
- ❑ dislocation stored for compatible deformation of crystal (GNDs)

N. Fleck et al., Acta Metall. Mater. 42 (1994) 475-487

in situ KB scan

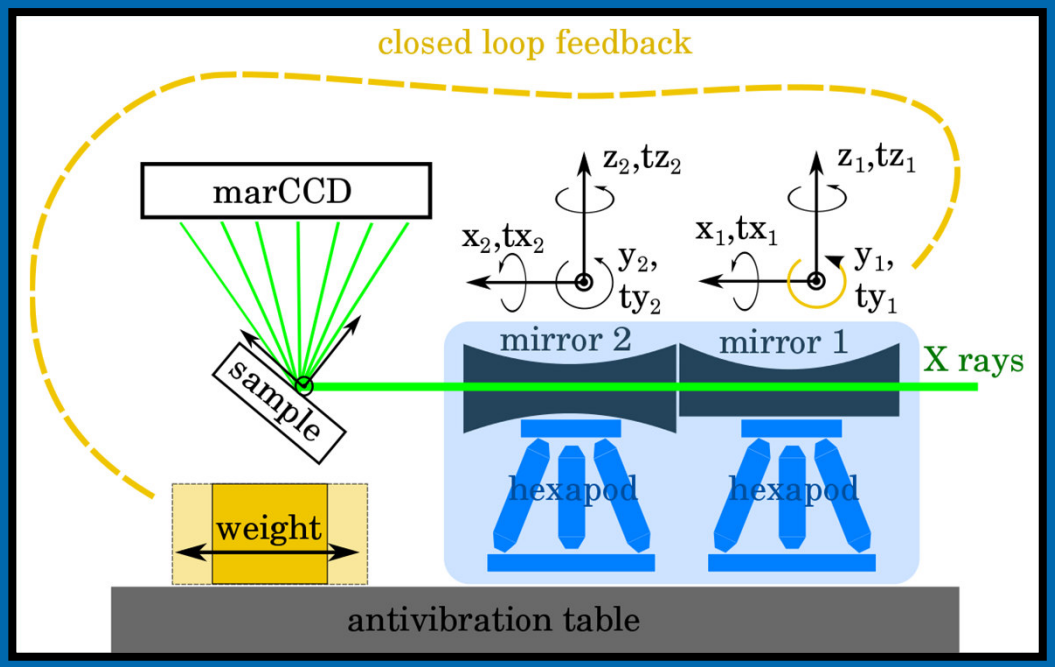


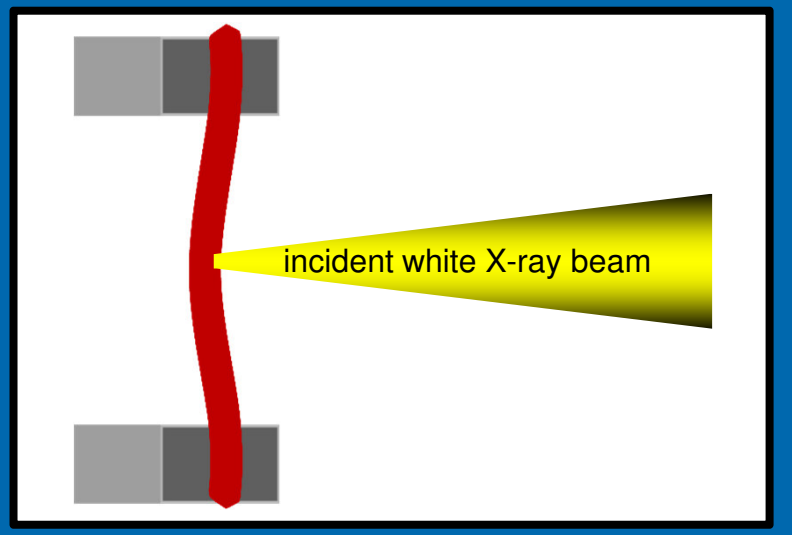


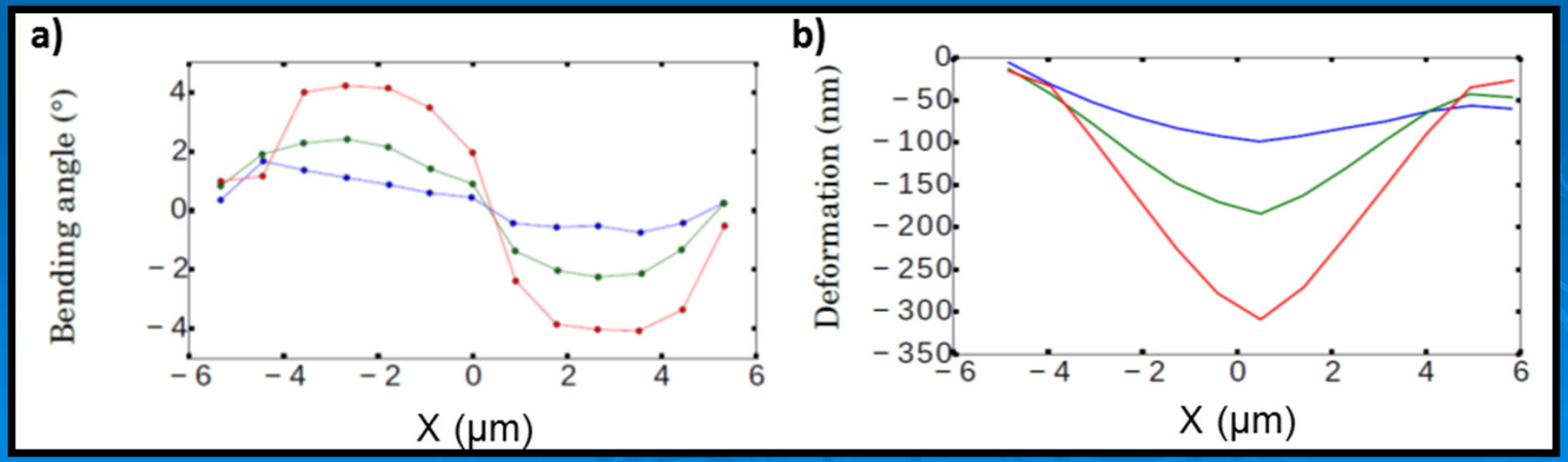


C. Leclere et al., in preparation

in situ KB scan

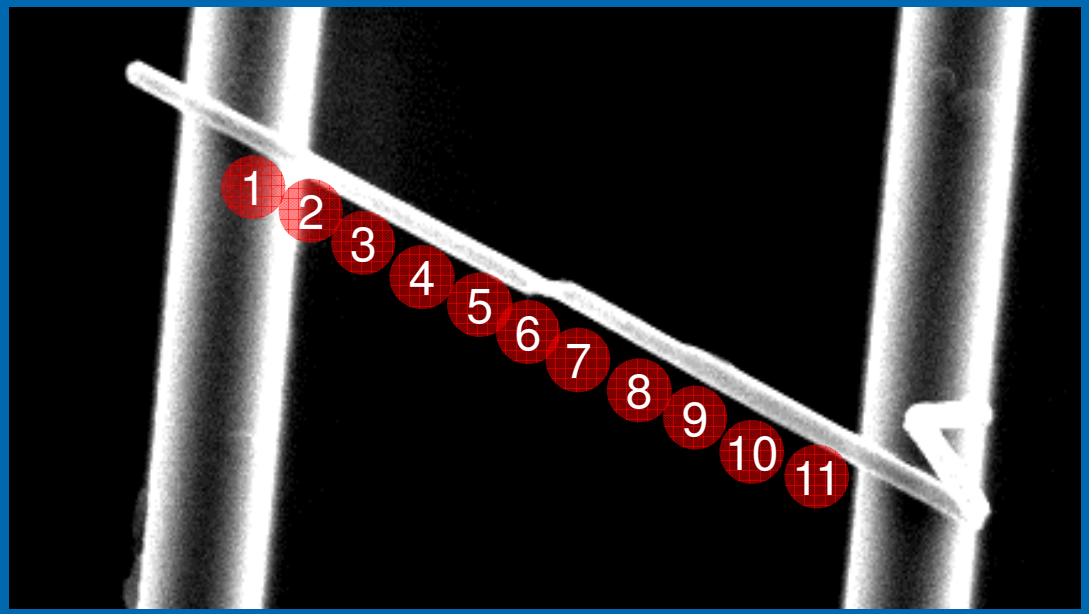


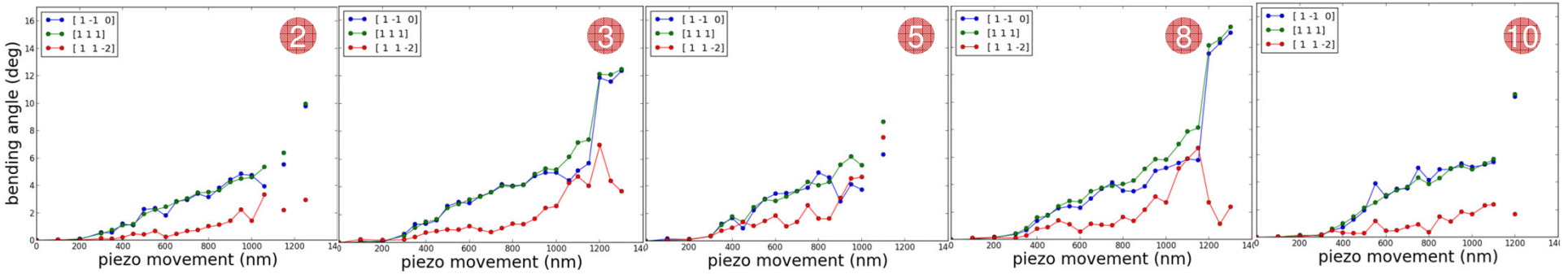




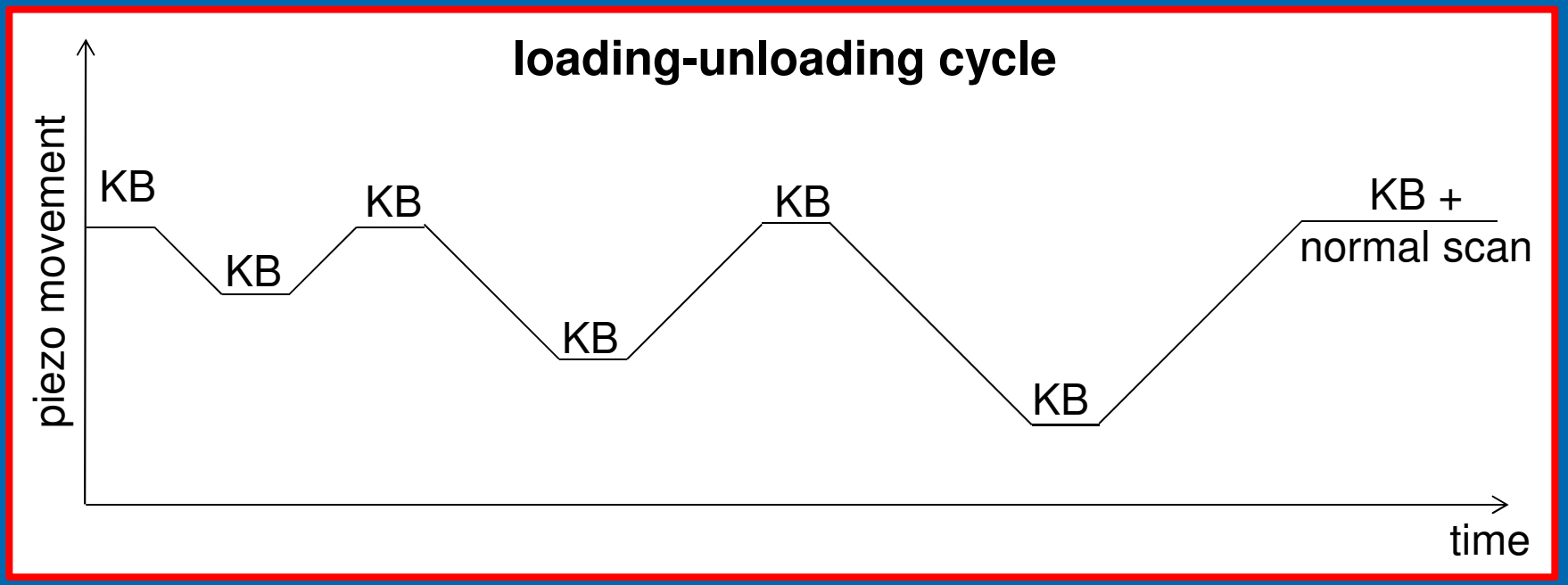
C. Leclere et al., in preparation

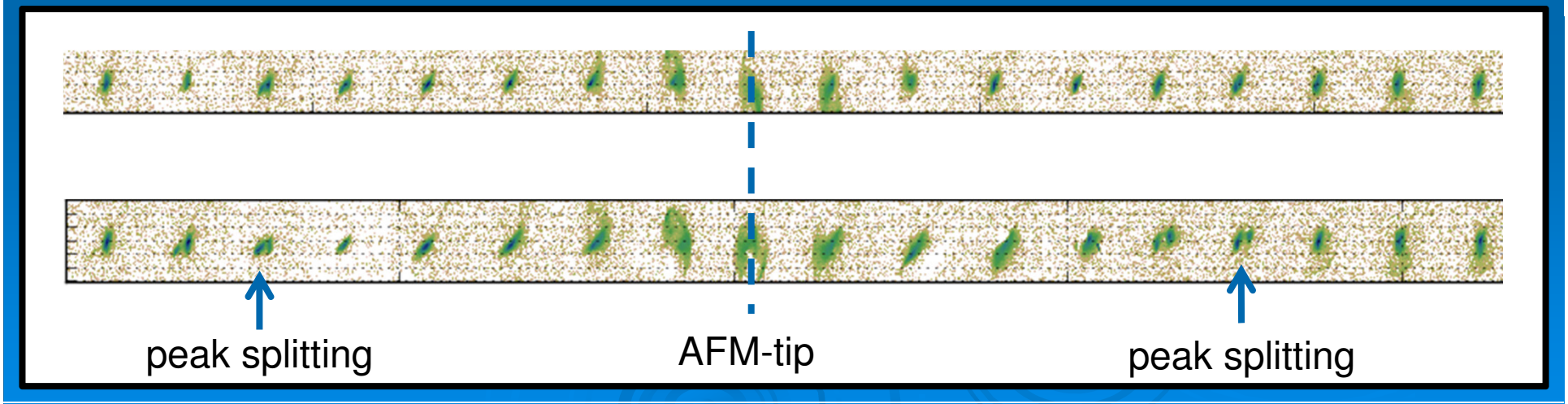
in situ KB scan



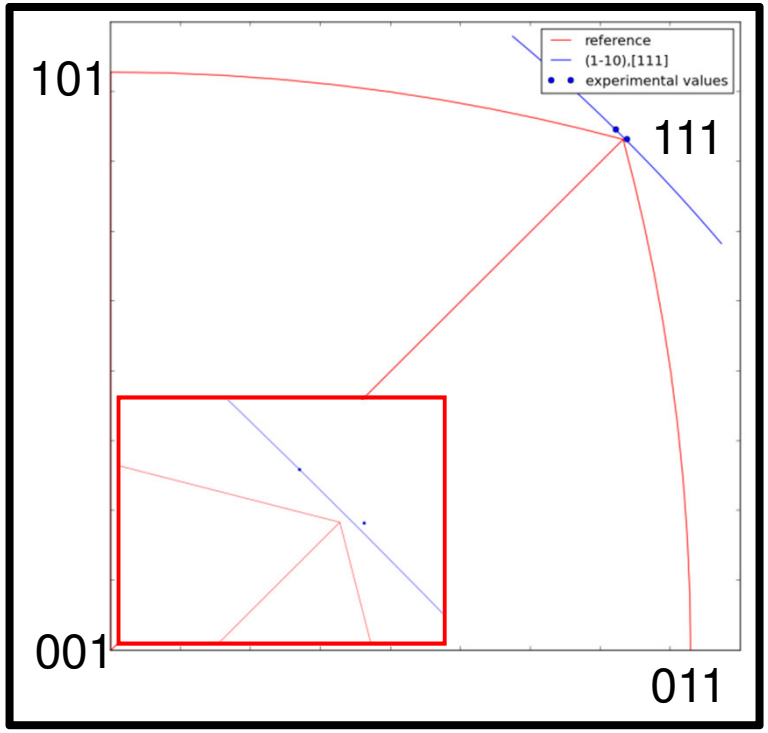


in situ plasticity





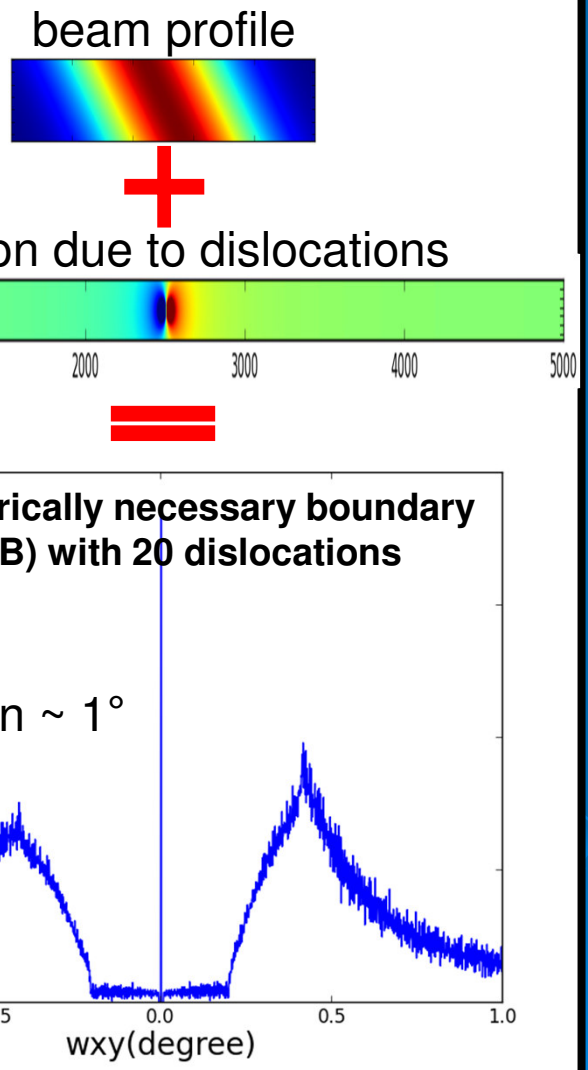
dislocations



bending angles:
(11-2)=0.13⁰, (1-10)=1.05⁰, (111)=0.93⁰

inverse pole figure indicates single slip oriented

Calculations based on:
F. Hofmann et al., *Nature Comm. 4, 2774 (2013)*



facilitates « counting » number of dislocations

conclusions

Scanning force microscope for in situ nanofocused XRD

- ✓ Combination with μLaue diffraction
- ✓ In-situ imaging
- ✓ Elastic bending of NWs
- ✓ Plastic deformation of NWs

***In situ* studies**

- ✓ Elastic properties of NWs
- ✓ Defining activated slip system
- ✓ « counting » number of dislocations

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General Meeting

on the Mechanics of Nano-objects

Marseille, November 5-6, 2015

Organizing Committee : Olivier Thomas, Cathy Paitel (IM2NP Marseille)

Registration deadline: October 11th, 2015


! Thanks for your attention !