

# Strain heterogeneities and local misorientations in deformed ice

## Digital image correlation, EBSD and full-field modelling

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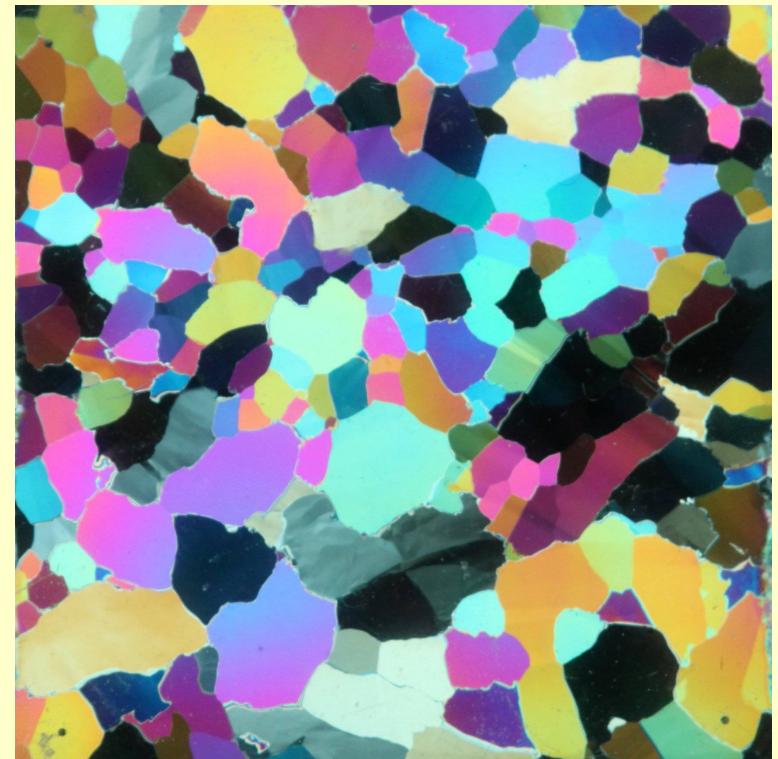
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(4) SYMME, Polytech, France

(5) LMA, CNRS, France



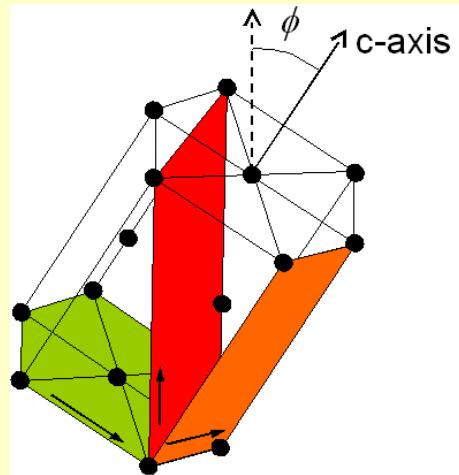
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# Ice: a highly anisotropic material

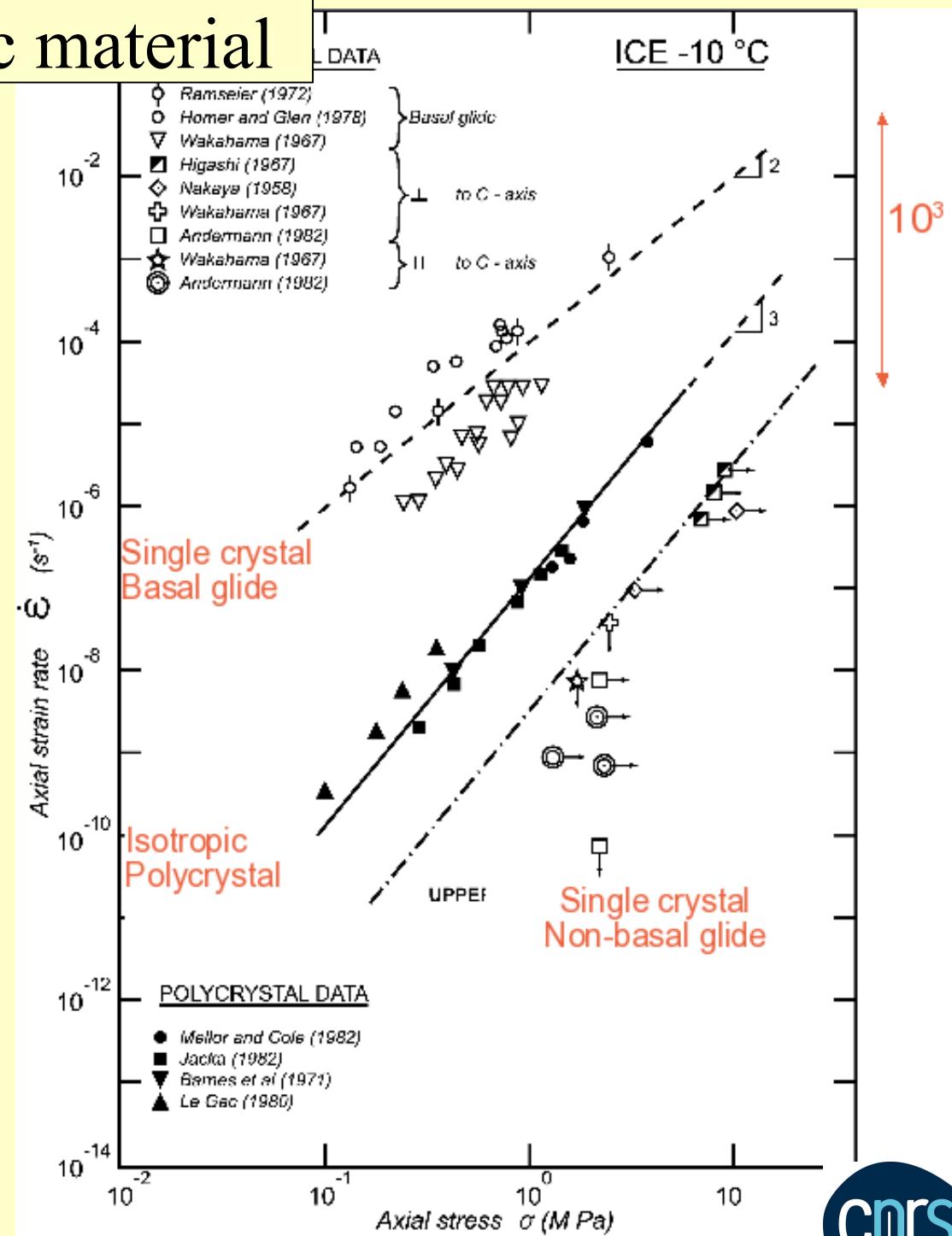


Easy glide on **basal planes**

Single crystal : large viscoplastic anisotropy



Polycrystal : strong strain heterogeneities



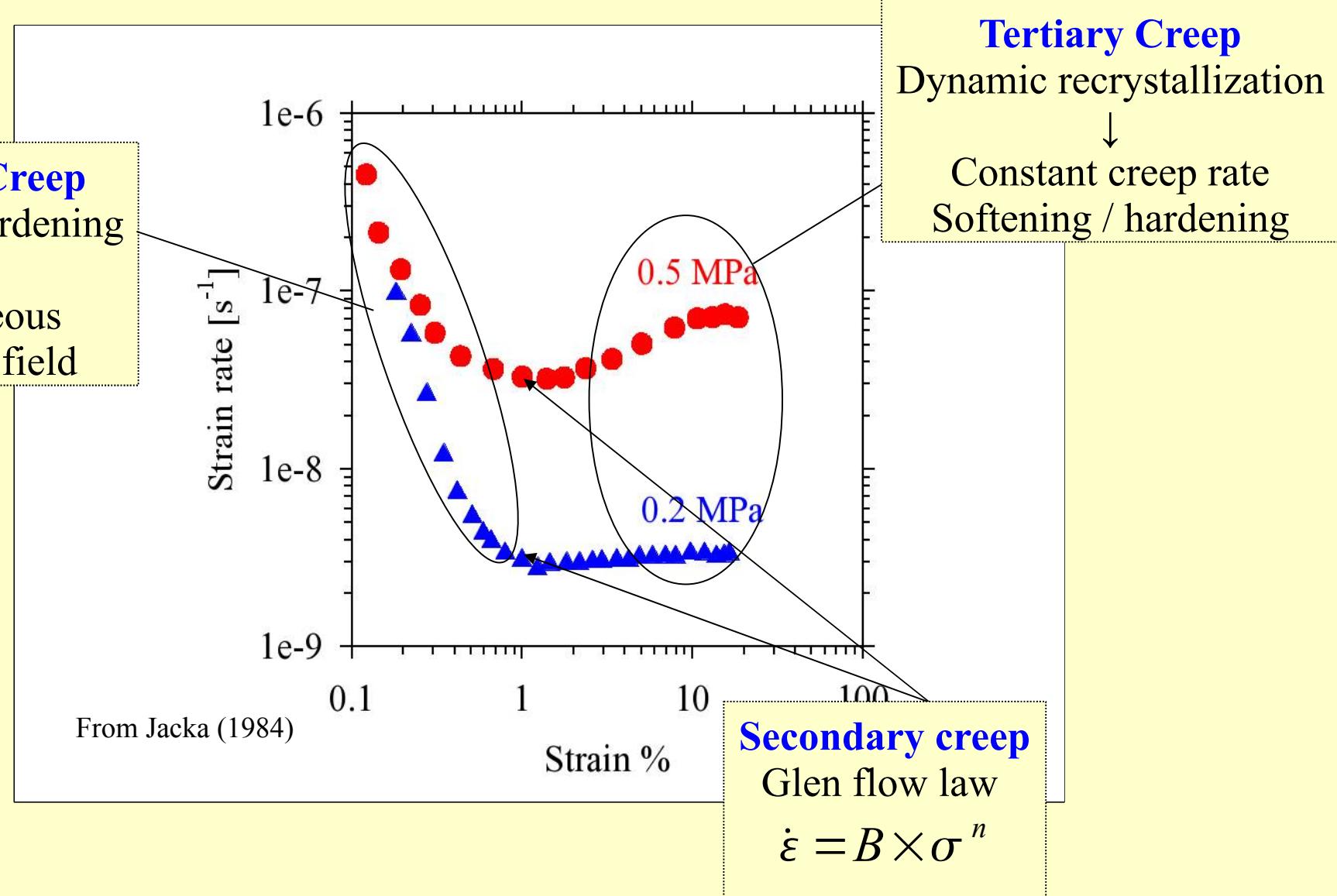
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# Polycrystal creep behaviour



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# Aim and tools

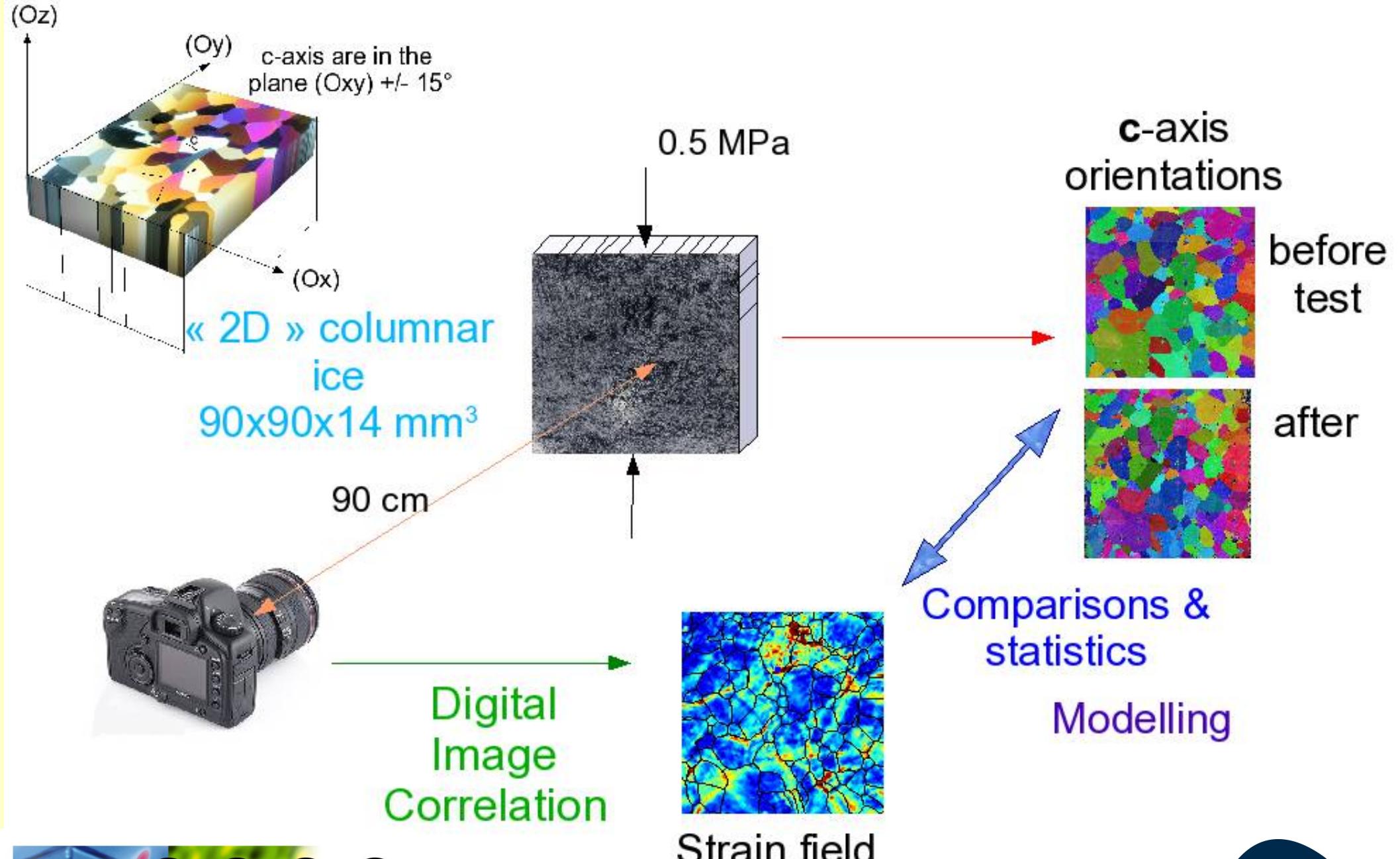
## To understand the development and role of strain heterogeneities (transient creep, recrystallization)

- Ice as a model for elasto-viscoplastic materials
- Cyclic and transient behaviour in natural ice bodies  
(ice sheets, glaciers, extraterrestrial ice cap...)

## Strain field measurements + Lattice misorientation characterization + Parametrization and modelling

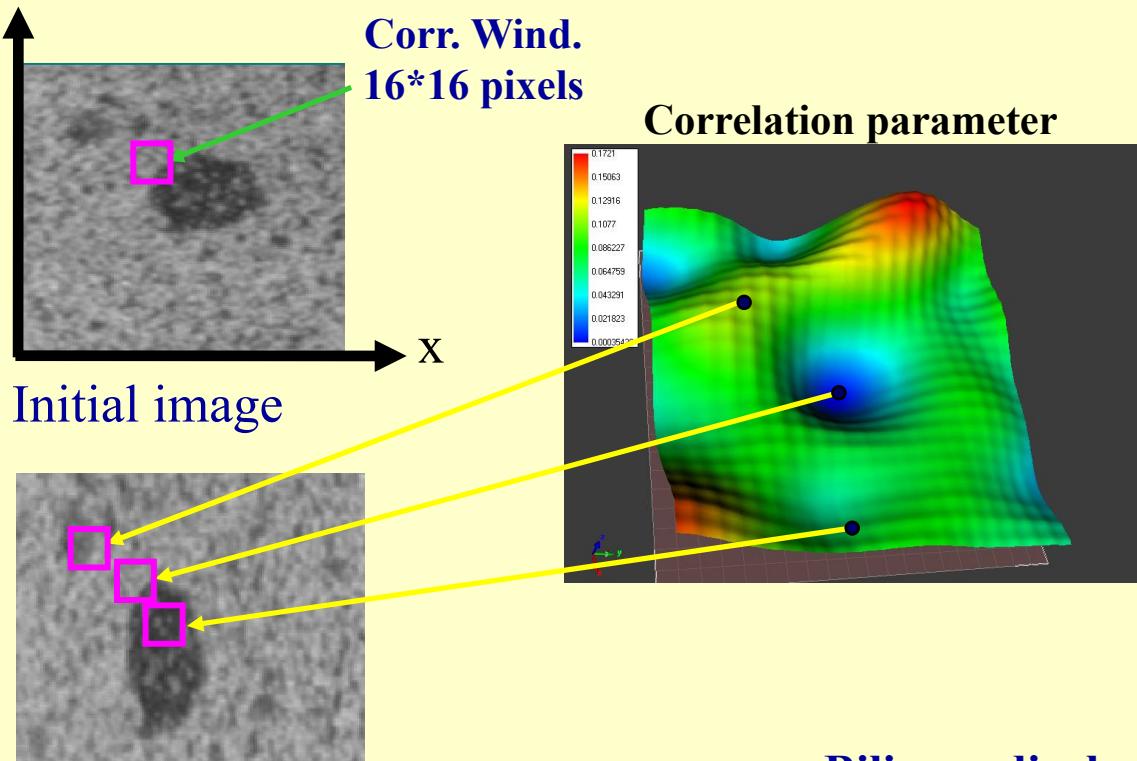
- Digital Image Correlation
- Automatic Ice Fabric Analyser, EBSD
- Full-Field approach

# Strain fields: Digital Image Correlation - 1

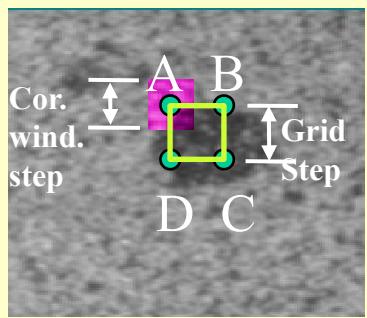


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# Strain fields: Digital Image Correlation - 2



Deformed image



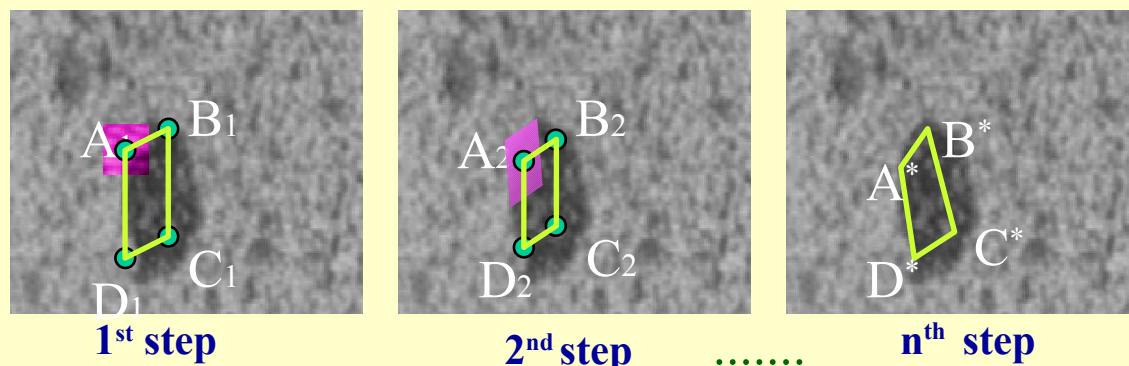
## Bilinear displacement field

$$U_x = a_x \cdot x + b_x \cdot y + c_x \cdot xy + d_x$$

$$U_y = a_y \cdot x + b_y \cdot y + c_y \cdot xy + d_y$$

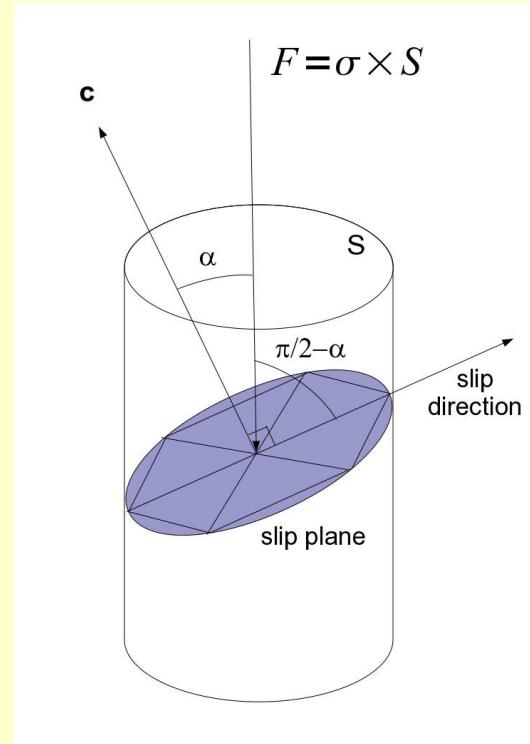
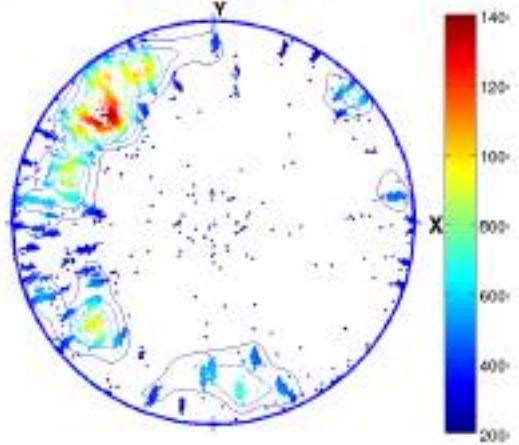
8 inconnues  $a_x, b_x, \dots, d_y$ ,

8 équations  $U_{x(A)}, U_{y(A)}, \dots, U_{x(D)}, U_{y(D)}$

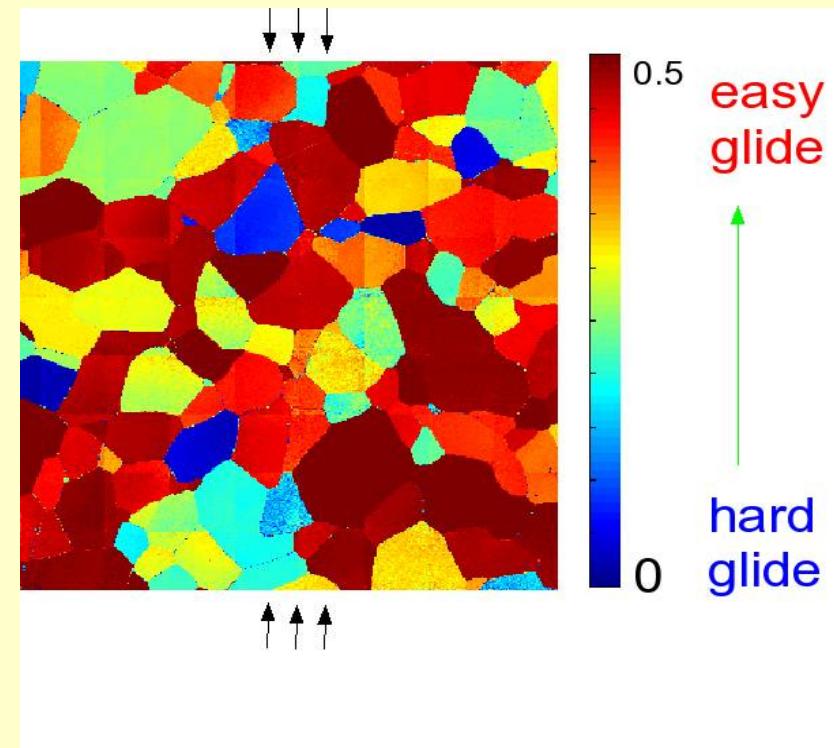


# Microstructure characterization

AITA 43  $\mu\text{m}$ , 1° to 3°



Schmid factor  
 $f(\alpha) = |\cos(\alpha)\sin(\alpha)|$



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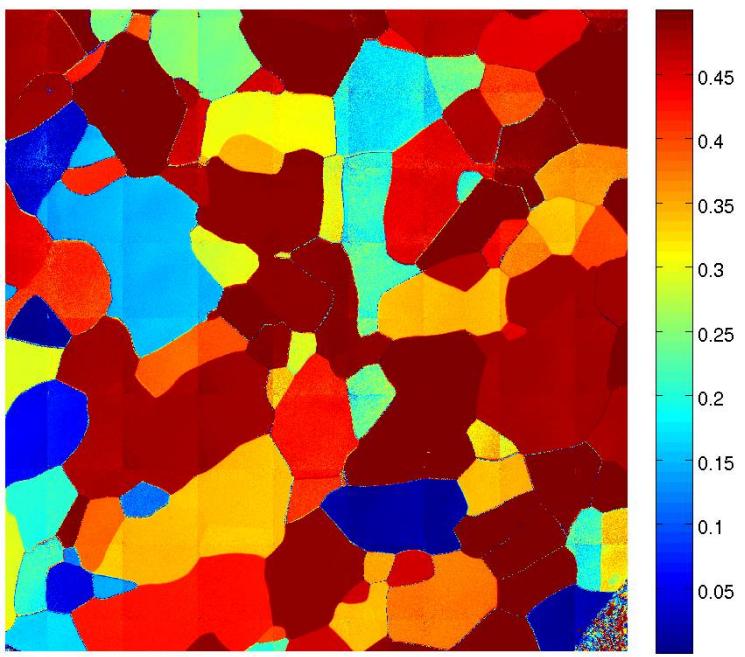
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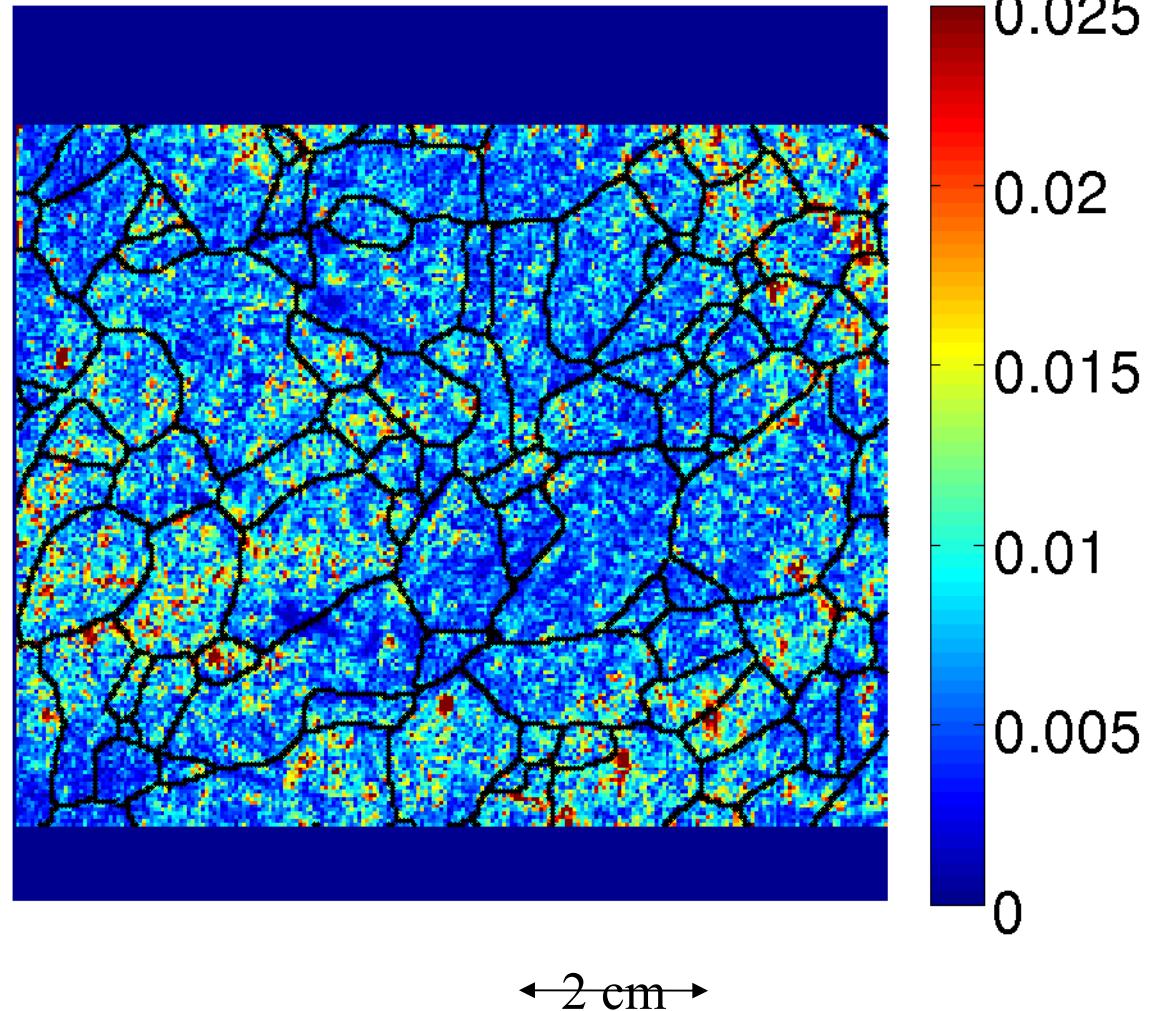
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# Strain fields: measurements

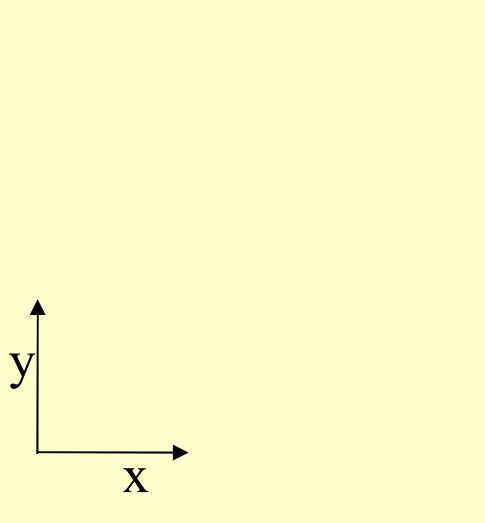
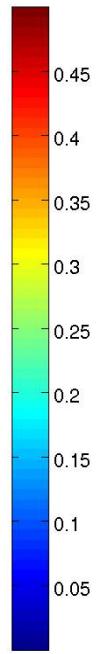
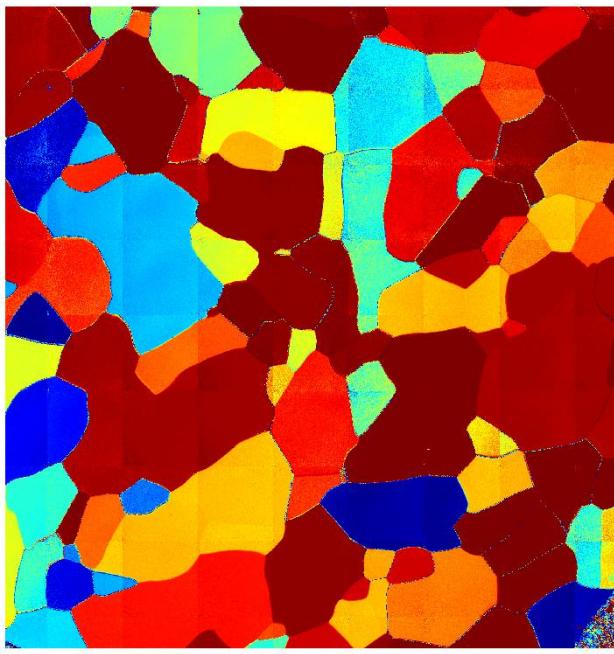
CREEP TEST to 1% strain



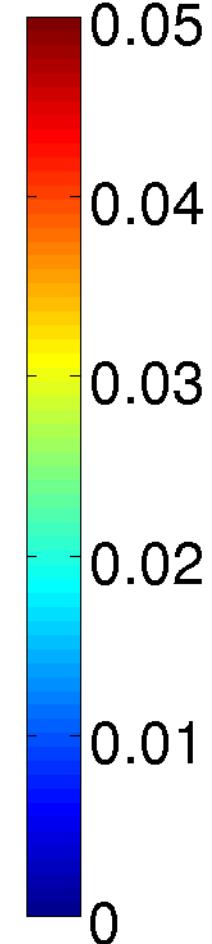
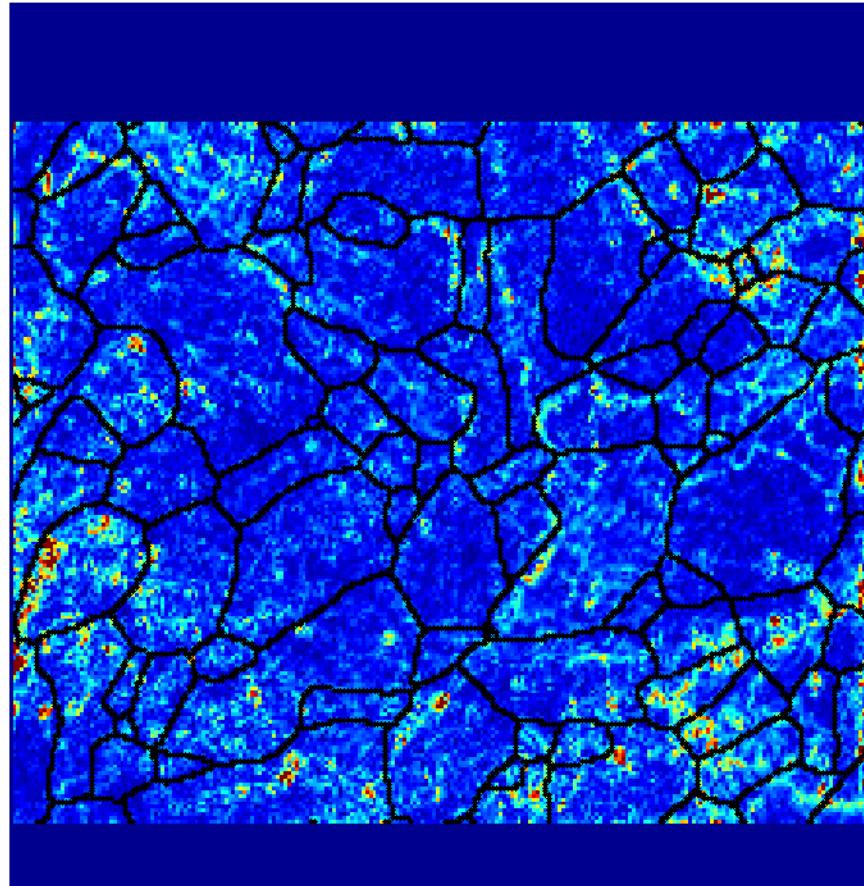
Equivalent strain( $\langle\epsilon_y\rangle=0.0013$ )



# Strain fields: measurements

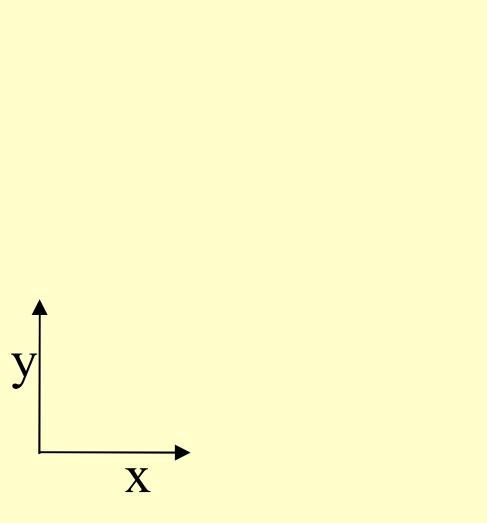
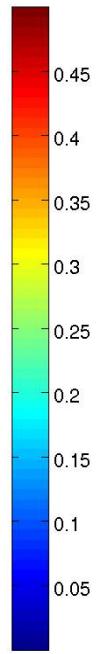


Equivalent strain( $\langle e_y \rangle = 0.0031$ )

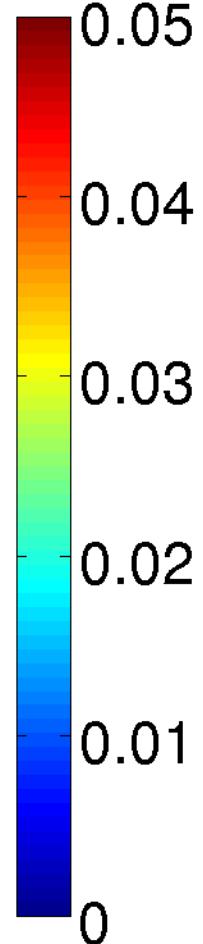
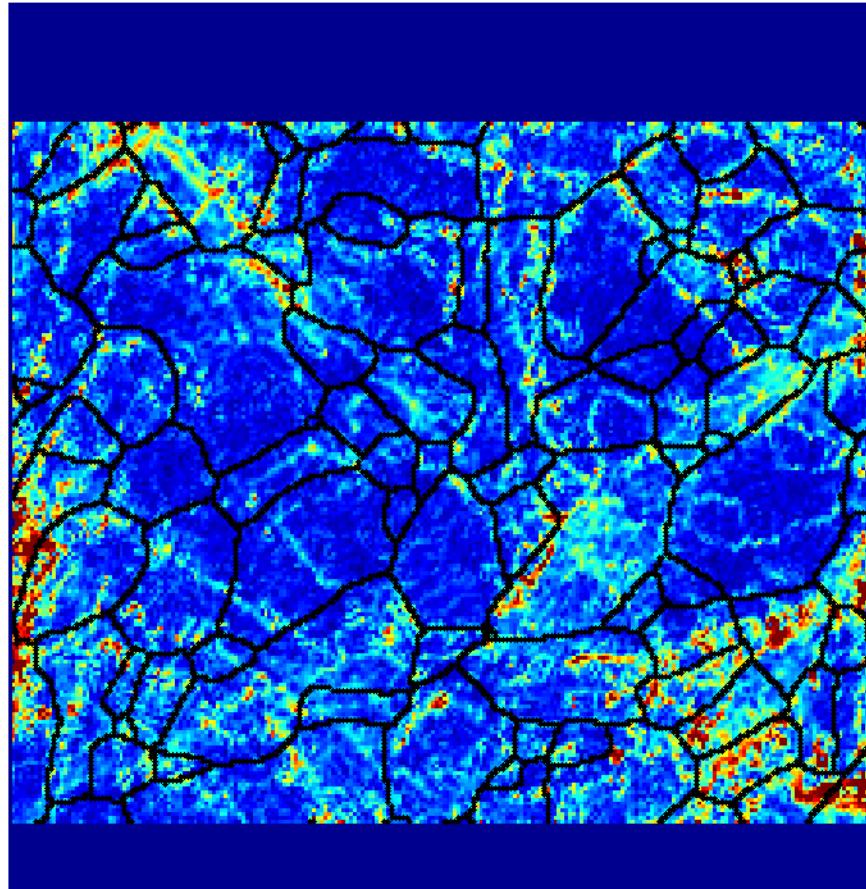


↔ 2 cm ↔

# Strain fields: measurements

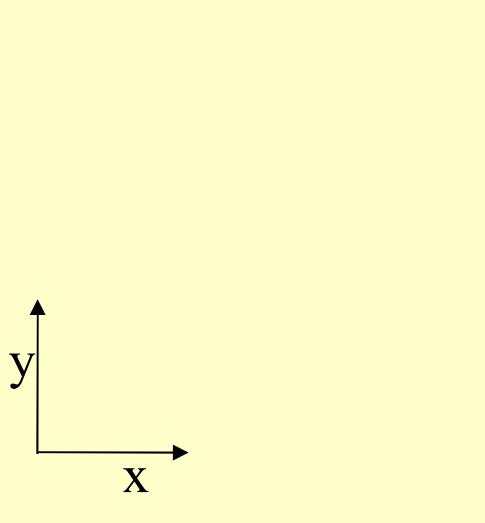
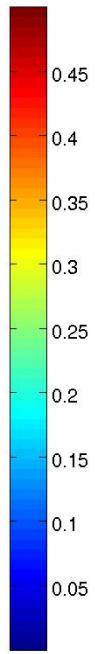


Equivalent strain( $\langle e_y \rangle = 0.0057$ )

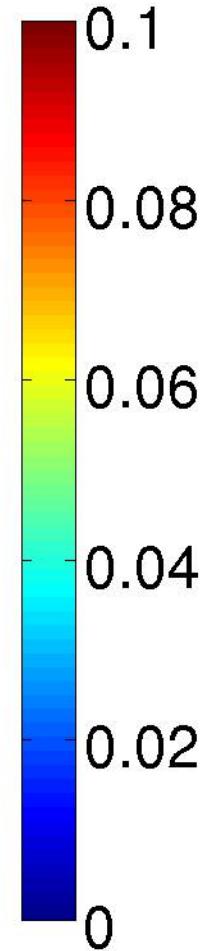
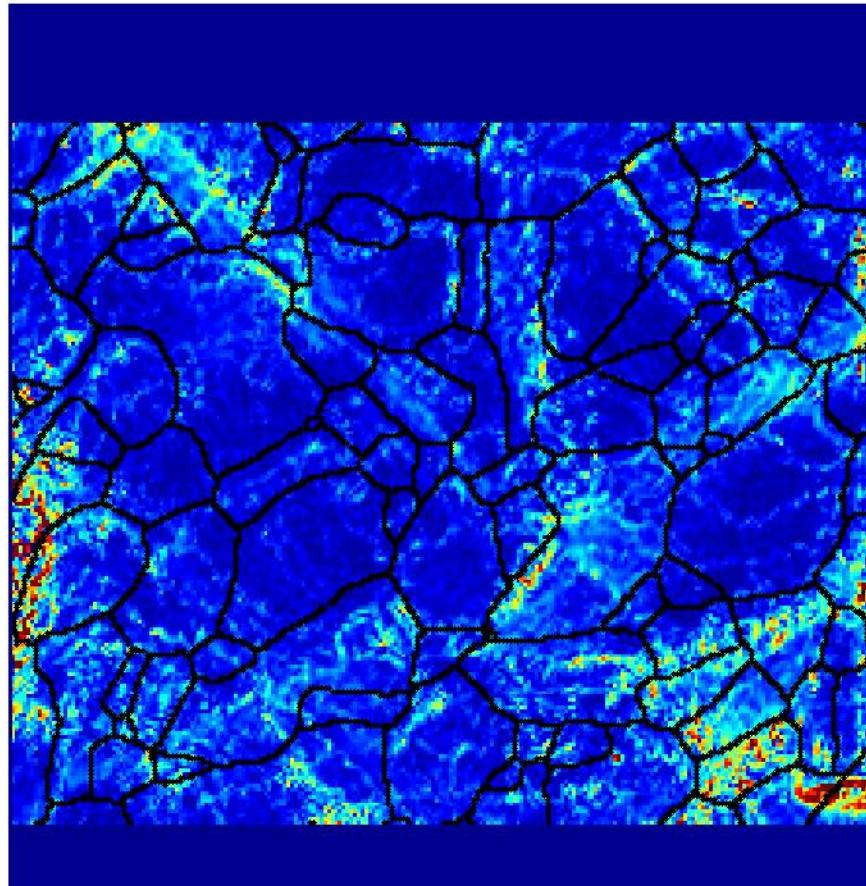


↔ 2 cm ↔

# Strain fields: measurements

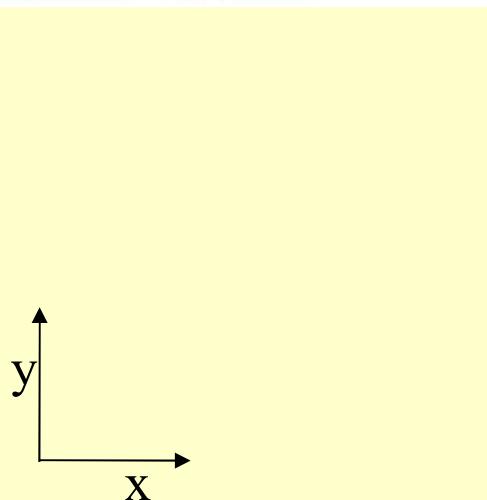
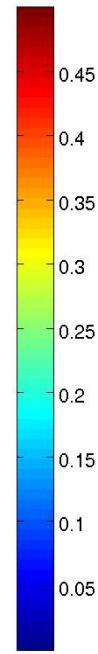
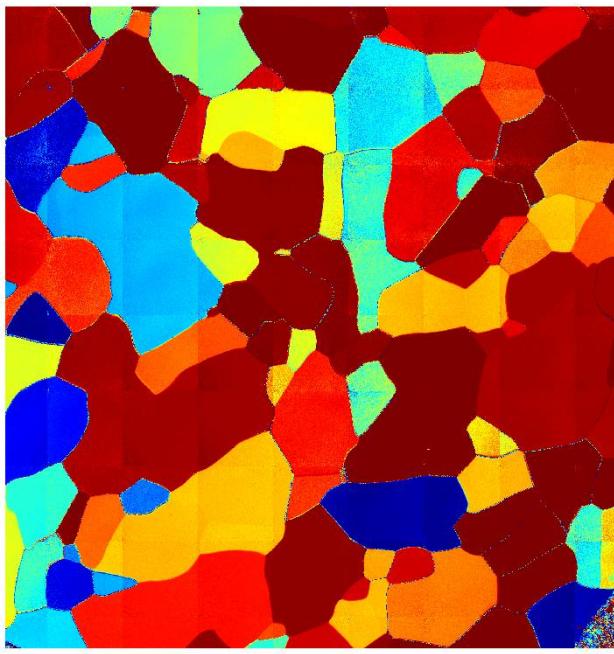


Equivalent strain( $\langle e_y \rangle = 0.0082$ )

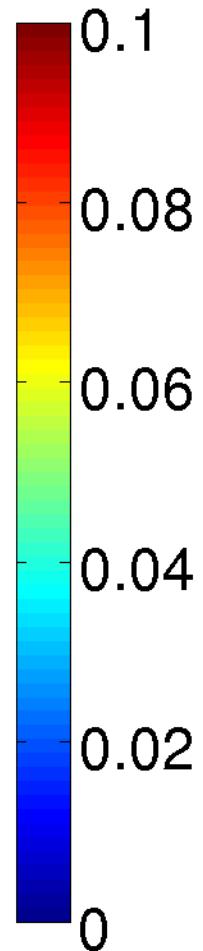
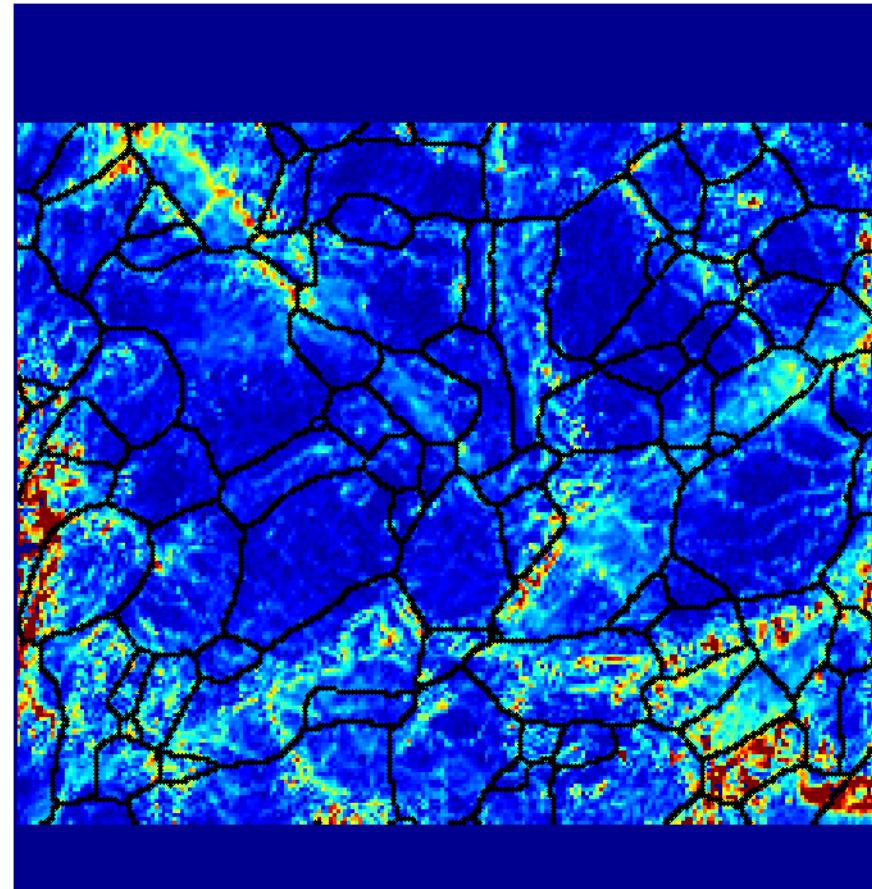


↔ 2 cm ↔

# Strain fields: measurements



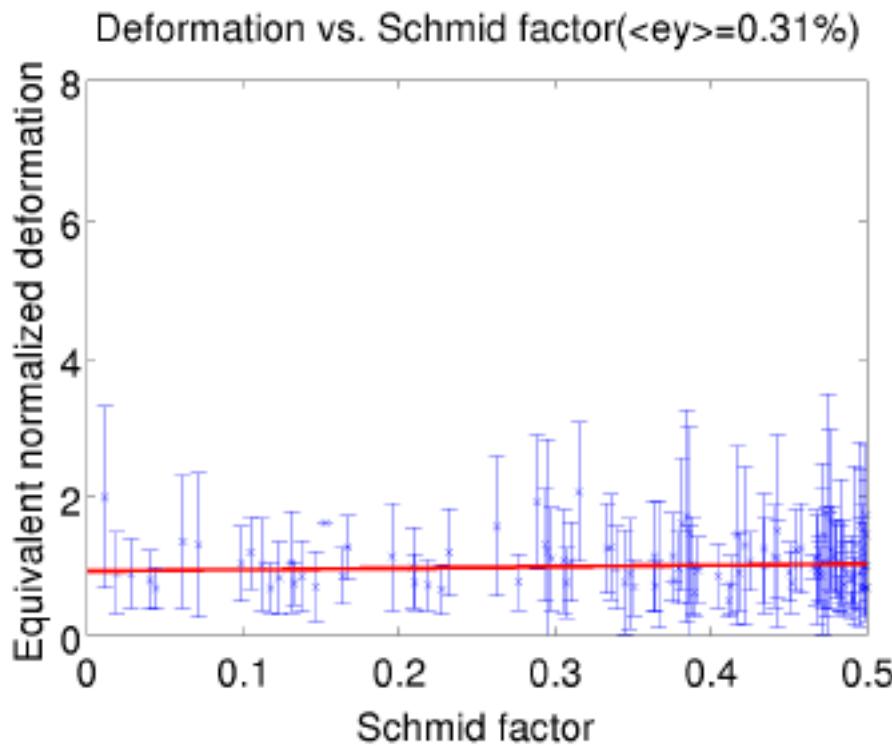
Equivalent strain( $\langle \epsilon_y \rangle = 0.0104$ )



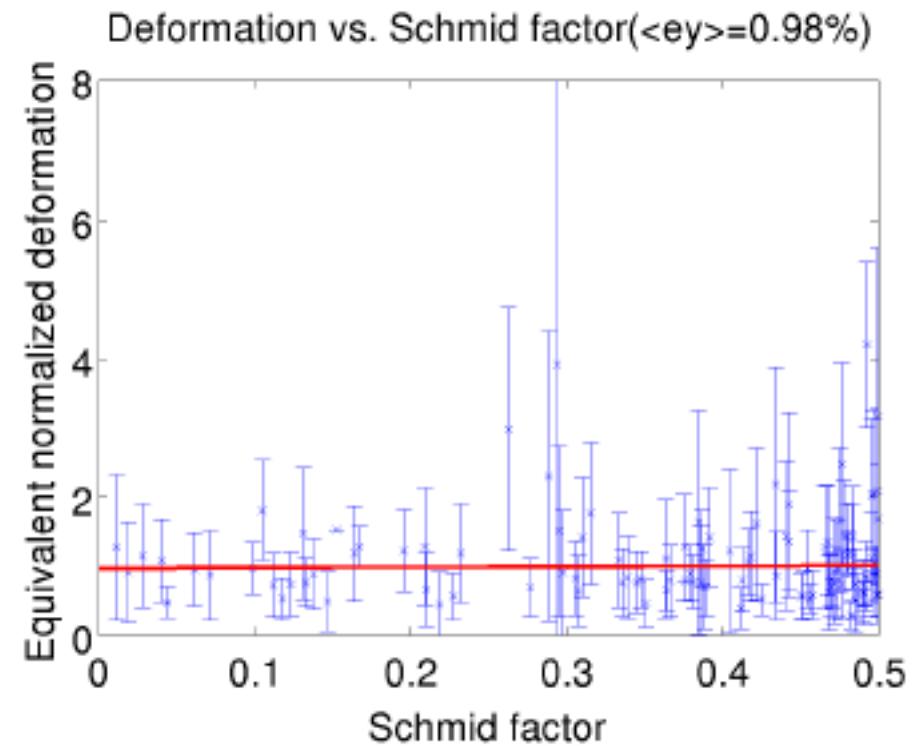
↔ 2 cm ↔

# Strain field heterogeneities: analyses

Mean deformation : 0.3 %



after 1 % deformation :



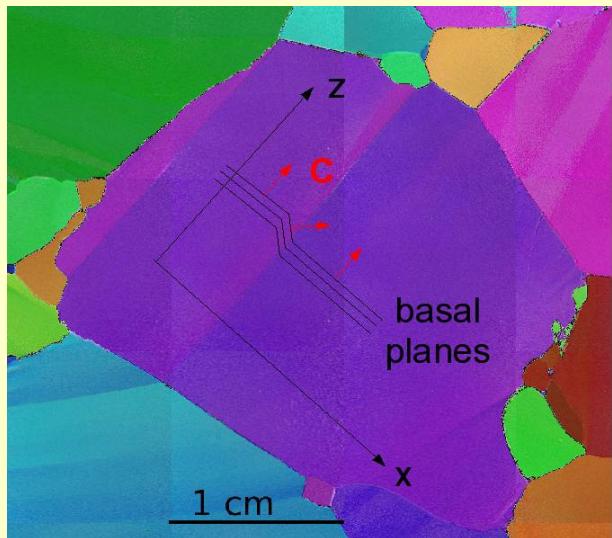
- Strong heterogeneities from the early stage of transient creep (< 0.2% strain)
- Local deformation **up to 10 times** the macroscopic one at secondary creep
- No obvious link between orientation and deformation level, at one sample scale



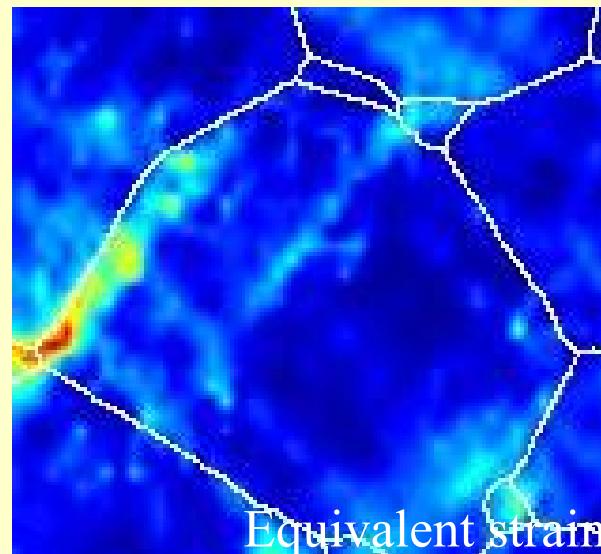
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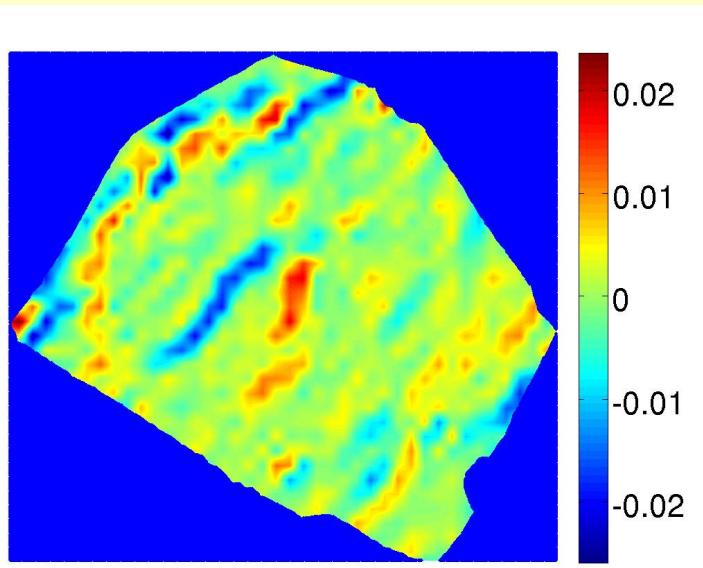
# Misorientations and strain fields: grain scale analyses



AITA c-axis orientation



Equivalent strain



Strain component  
along the c-axis

Strain “signature” of  
kink bands  
BUT  
misorientation  
resolution is too low



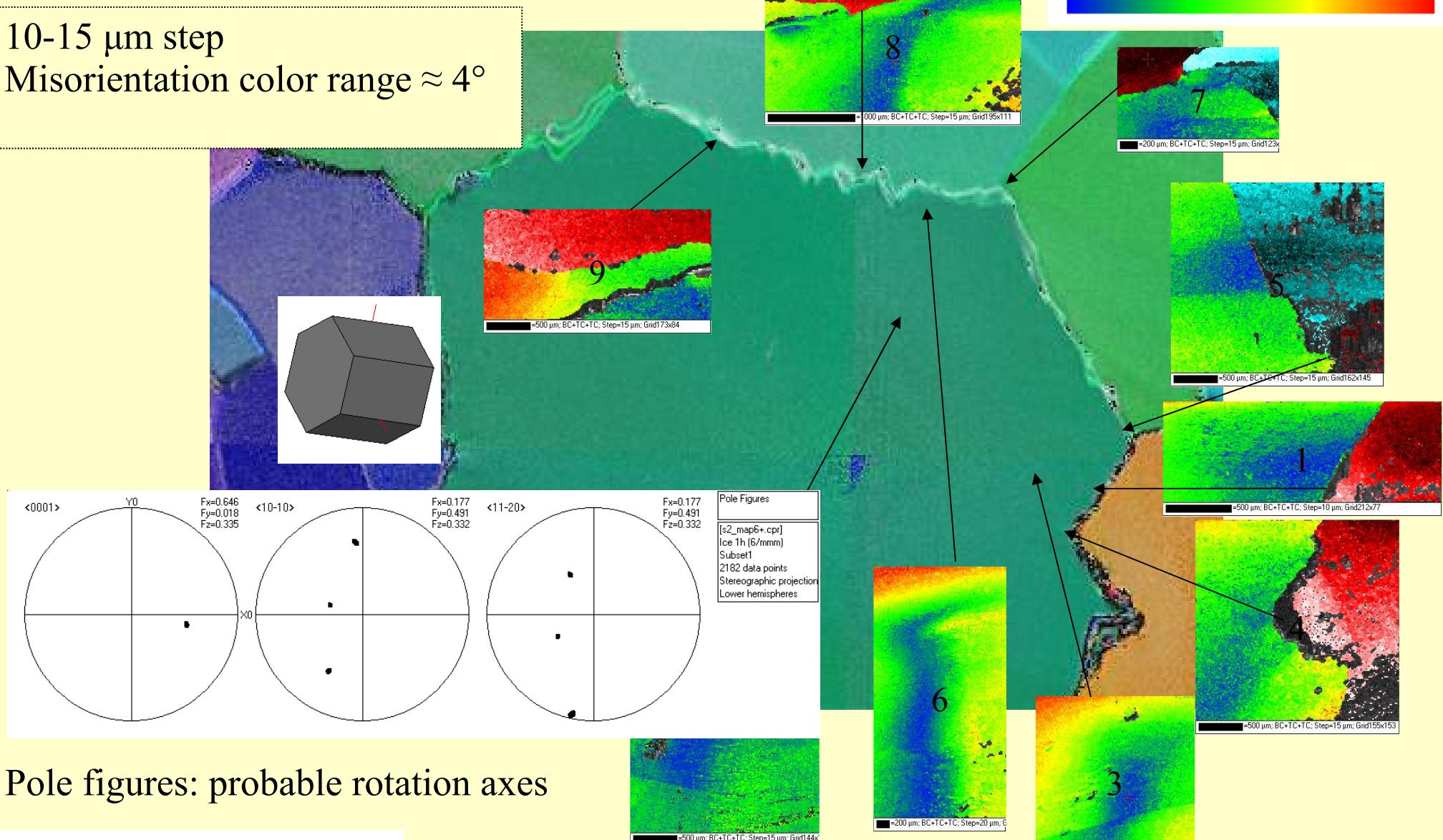
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# Misorientations: EBSD patterns

Stockholm University

10-15  $\mu\text{m}$  step  
Misorientation color range  $\approx 4^\circ$



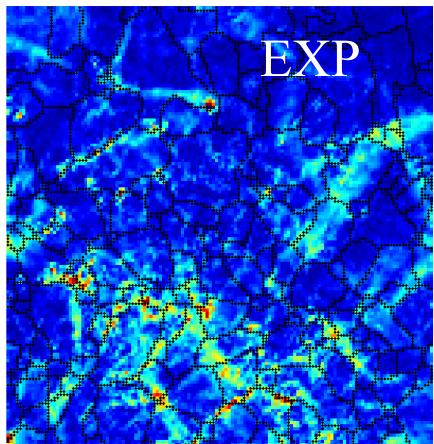
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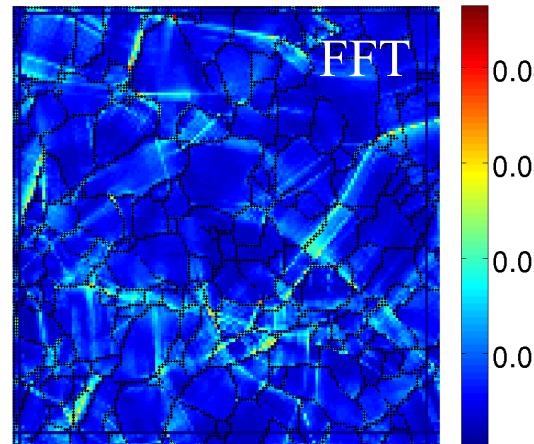


# Prediction of stress fields: FFT full-field modelling

Equivalent strain( $\langle e_y \rangle = 0.0078$ )



FFT equivalent strain( $\langle e_y \rangle = 0.0041$ )

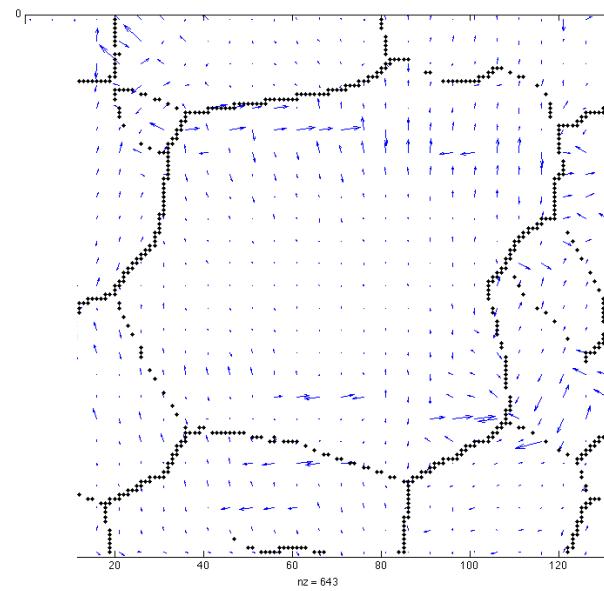
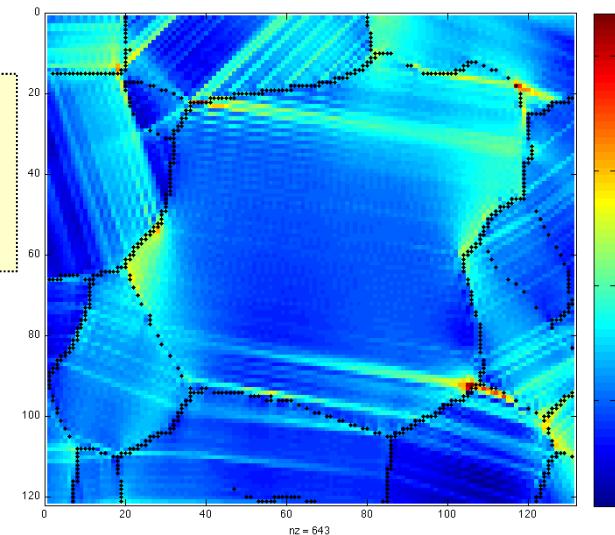


Under progress

**Elasto-viscoplastic formulation:**  
Strain evolution  
during transient creep

Good match for strain field prediction

Local stress map and direction



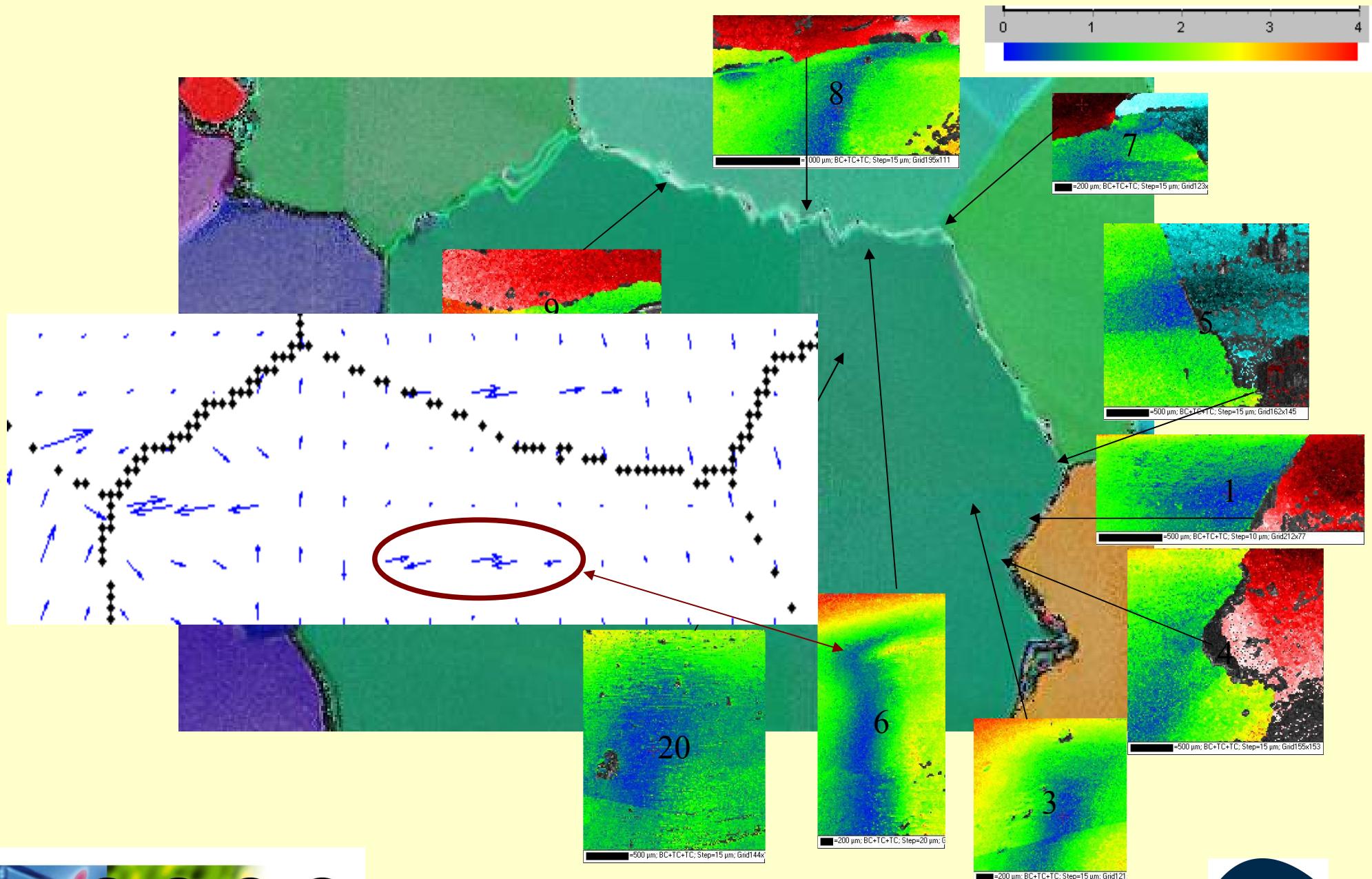
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# Misorientations and principal stress direction

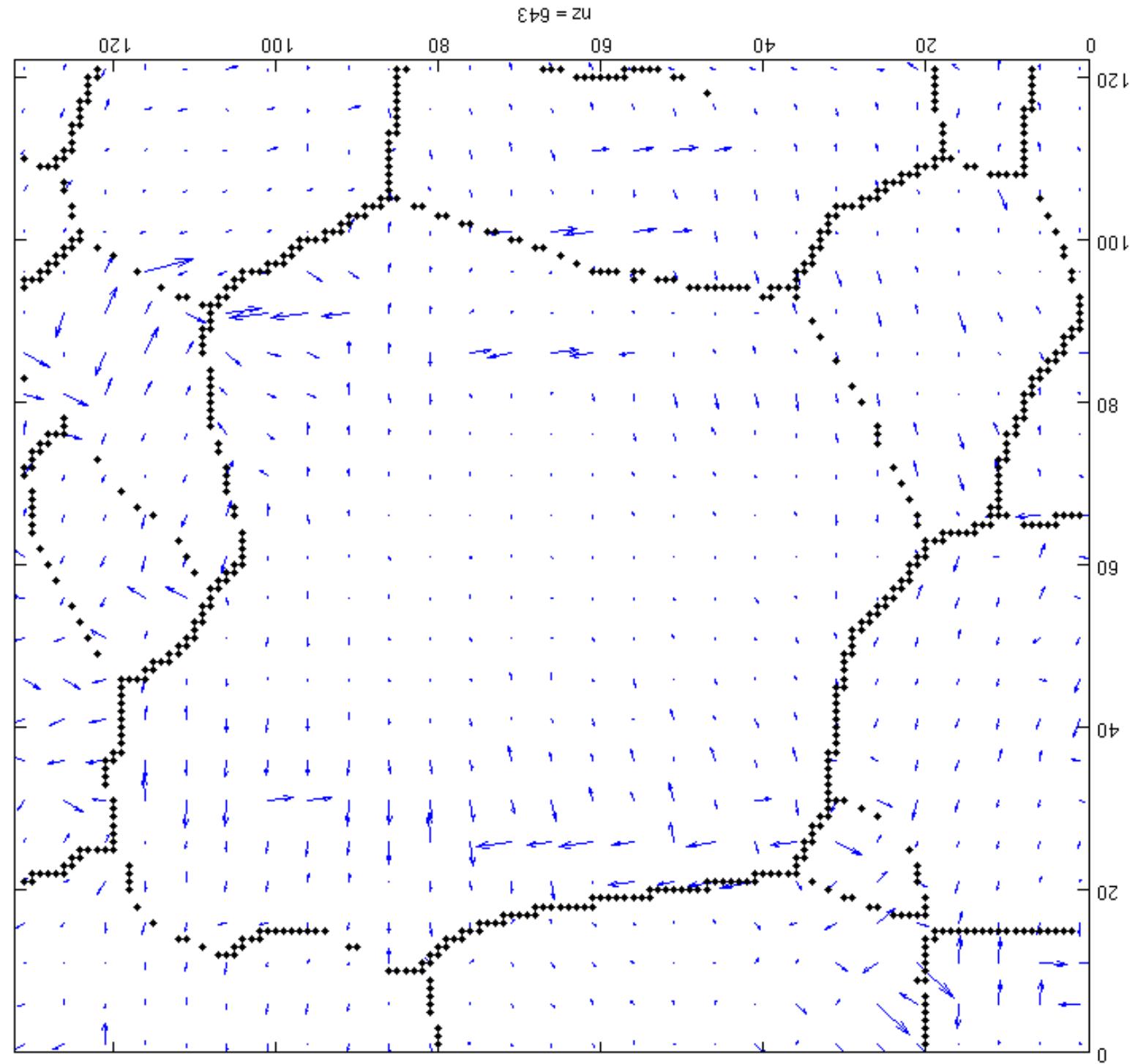


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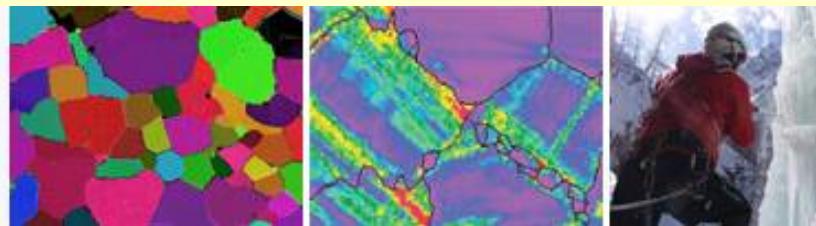
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# Micro-DICE

ESF research networking Programme on the Micro-Dynamics of Ice



## "Ice deformation; from the model material to ice in natural environments"



7-9 November 2011  
Grenoble, France.

A conference in honor of Paul Duval, emeritus researcher at LGGE, Laboratoire de Glaciologie et Geophysique de l'Environnement

<http://microdice.eu/activities/ice-deformation-from-the-model-material-to-polar-ice/>

