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# HR-EBSD based Characterization of Dislocations in Additive Manufactured 316L Stainless Steel

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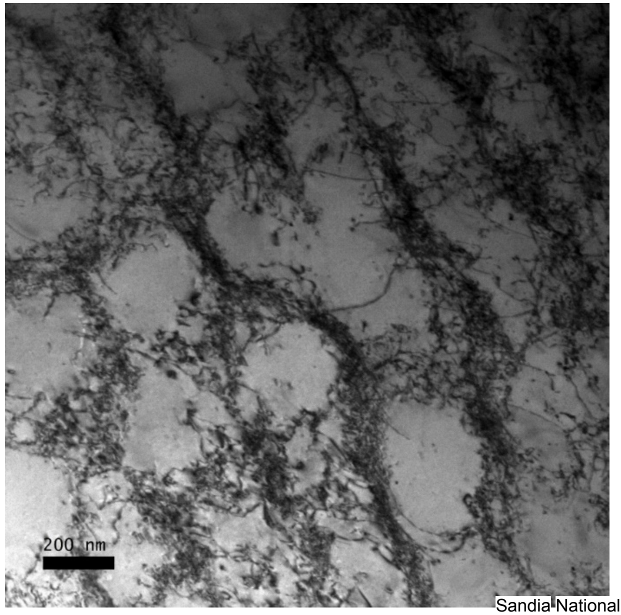


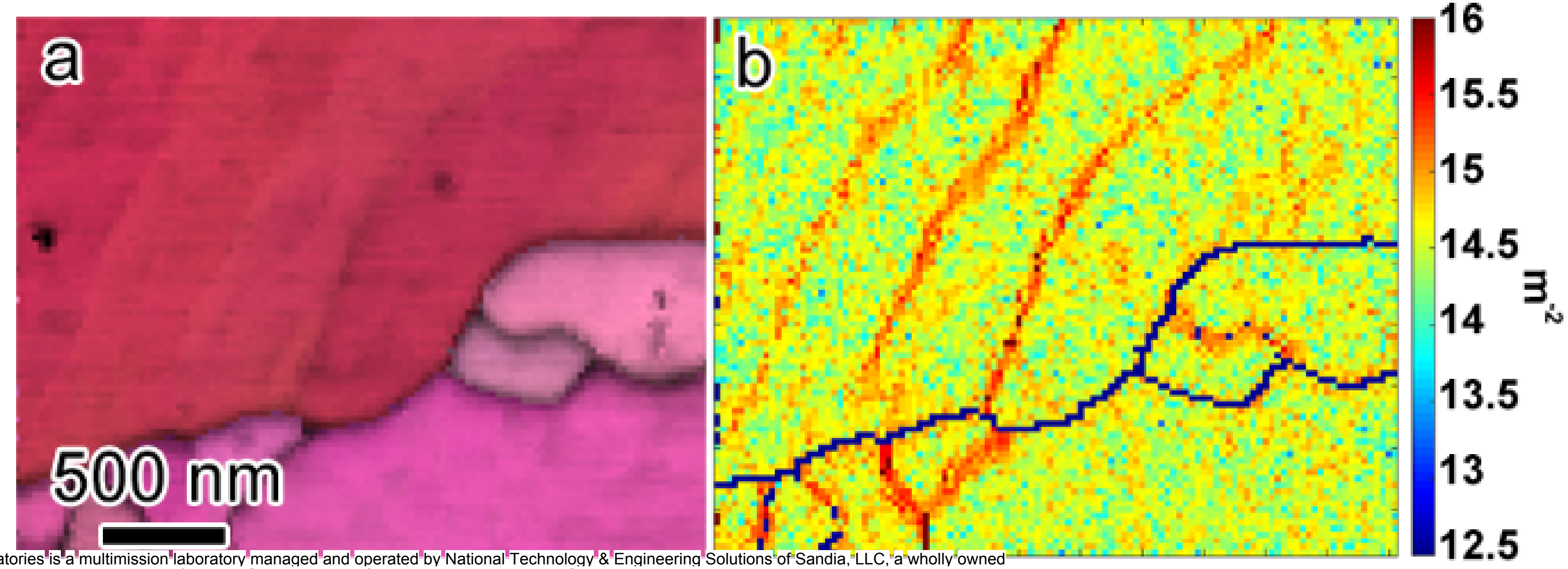


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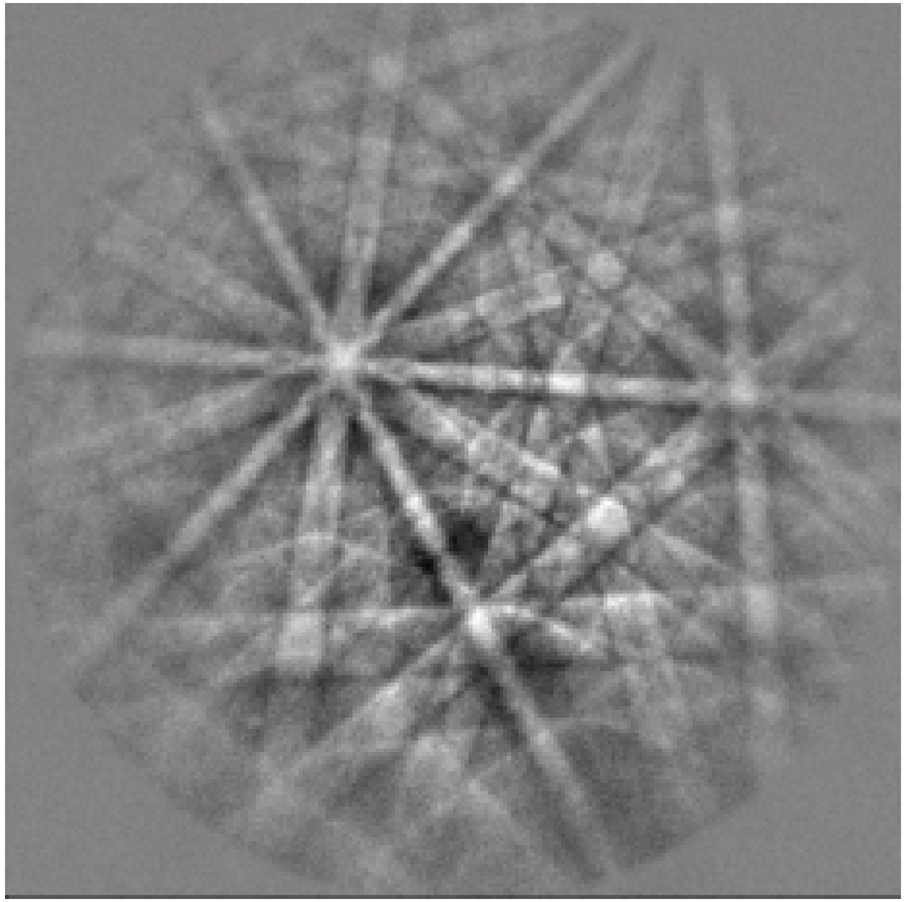
# EBSD



Pattern indexing rates now exceed 1,000 fps

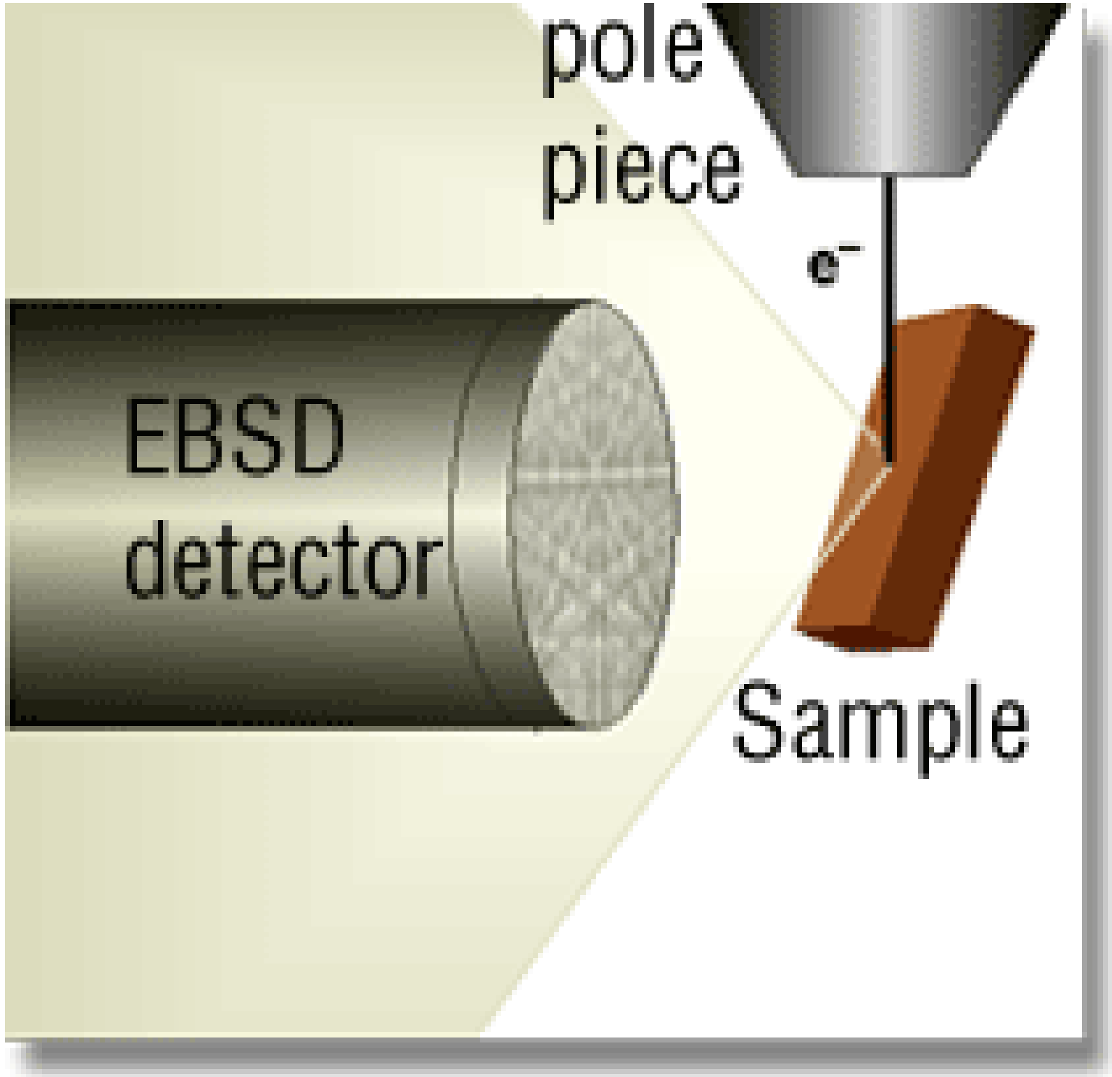
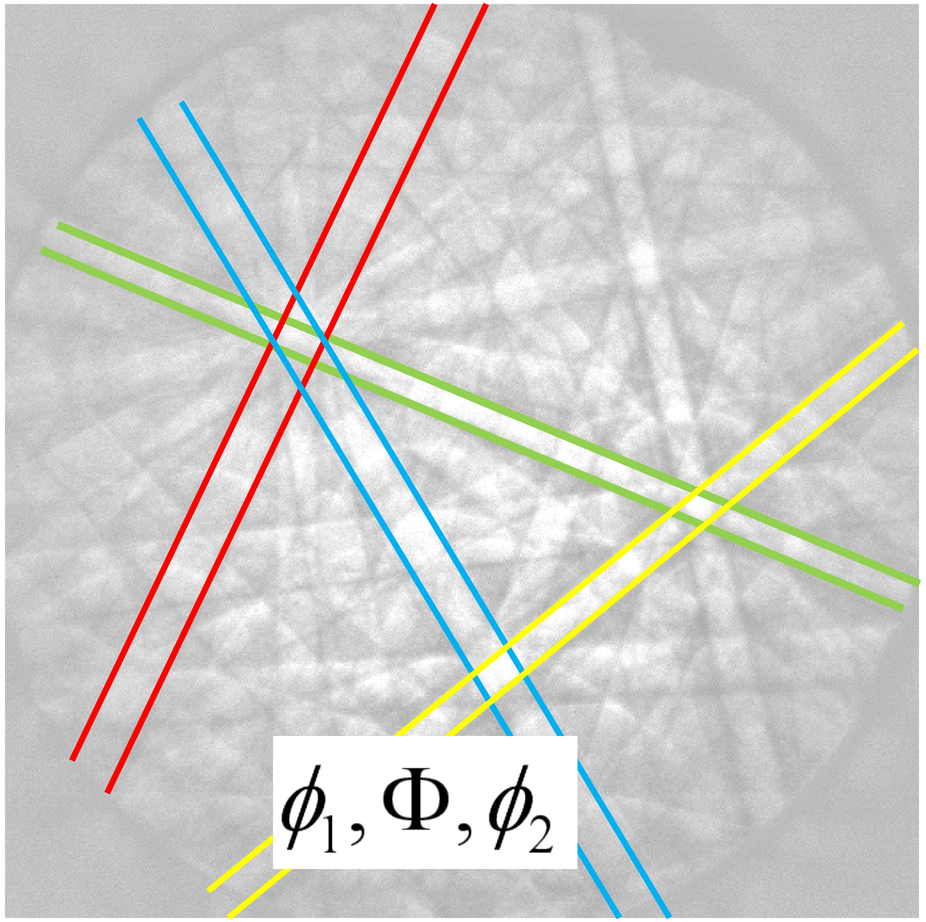


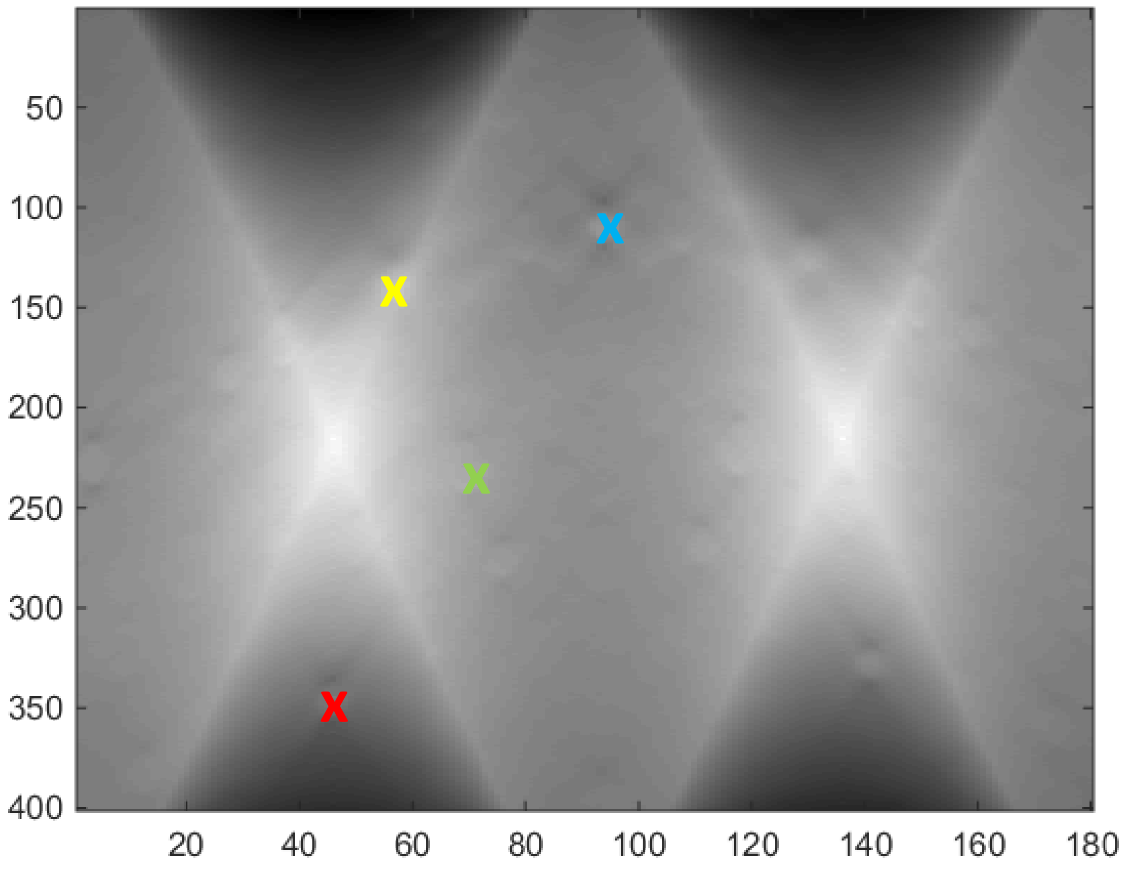

*Image courtesy of EDAX/TSL*

# Hough-based analysis

$$r = x\cos\theta + y\sin\theta$$

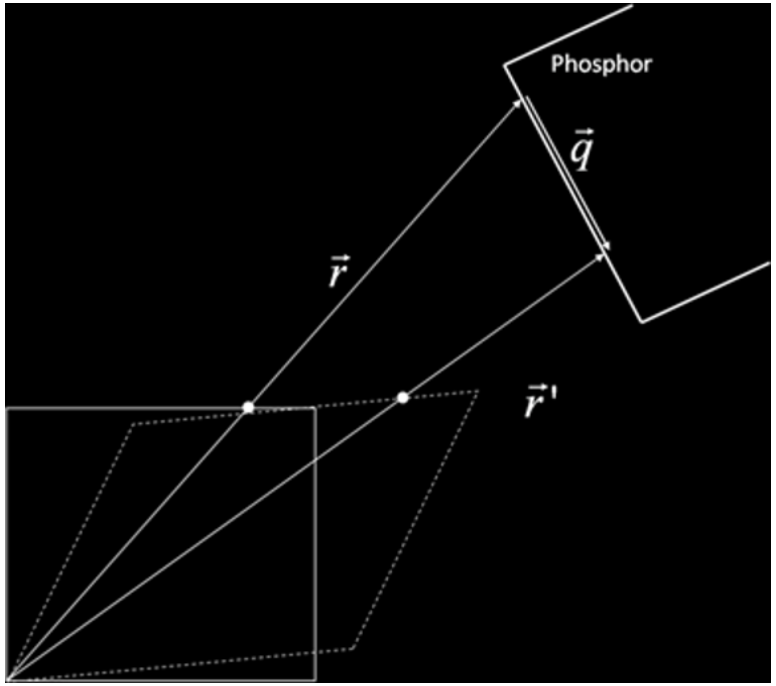



Diffraction space



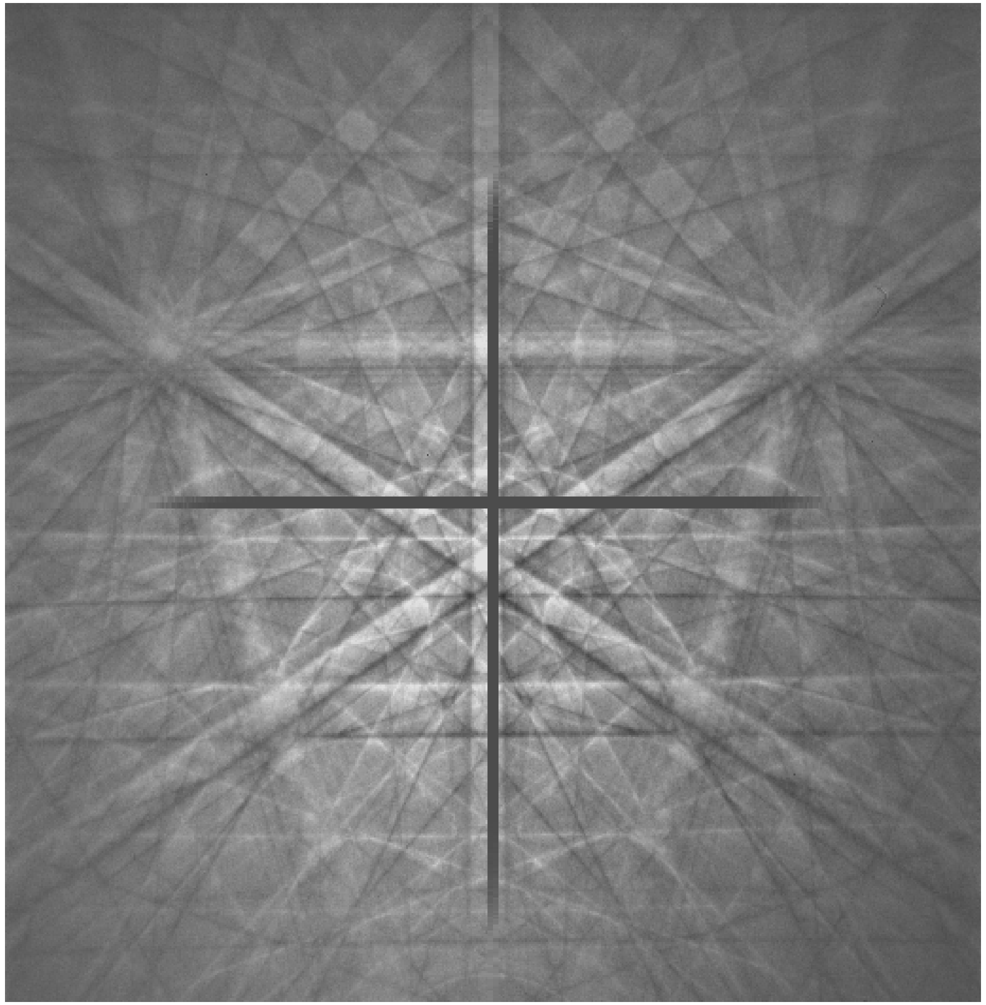

Hough space

# High angular resolution EBSD




$$\frac{\vec{q}}{\lambda} = \vec{w} - (\vec{w}\cdot\hat{r}')\hat{r}' + \frac{\vec{q}\cdot\hat{r}'}{\lambda}\hat{r}'$$

$$\lambda = \frac{z^*}{\hat{r}^{pc}\cdot\hat{r}} \qquad \vec{w} = D\hat{r}$$



$\varepsilon_{11}$

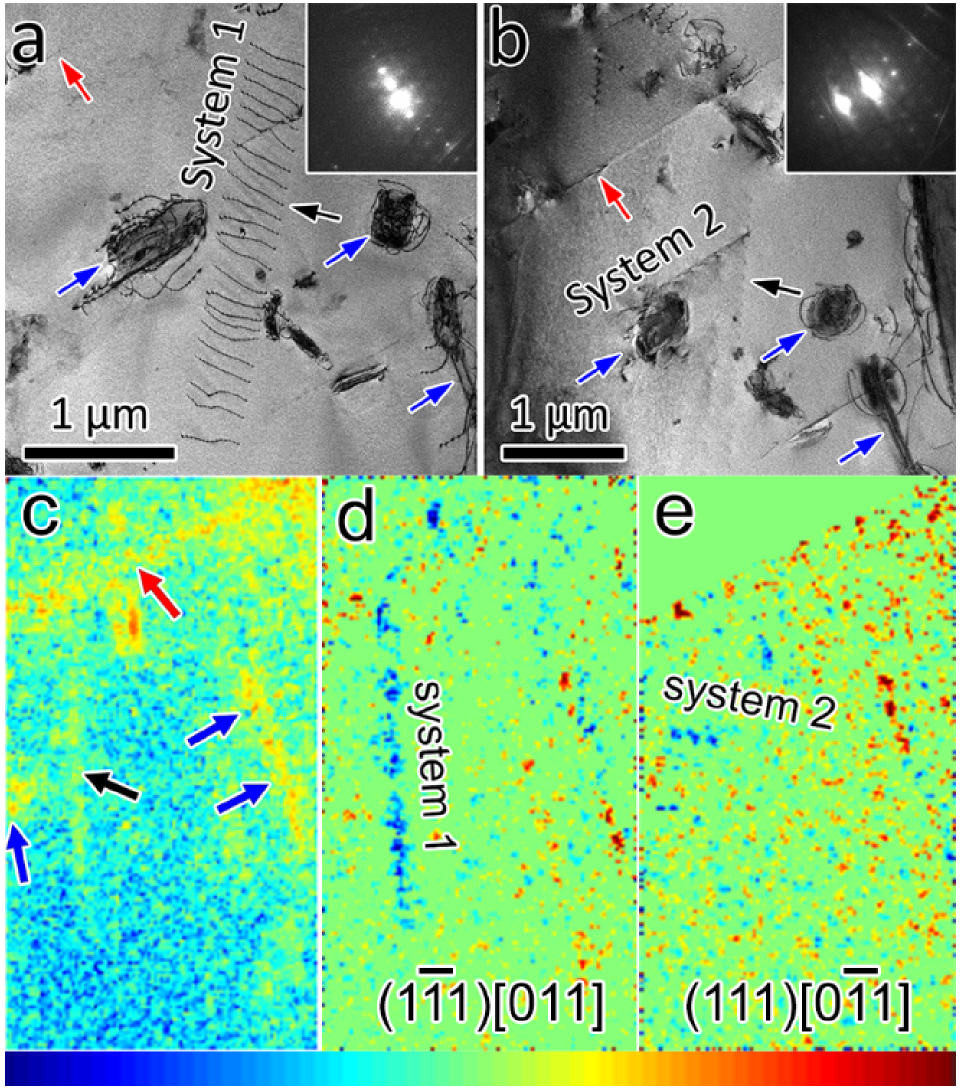
$D$ can be decomposed into strain and rotation components


*A. Wilkinson, D. Randman. Philosophical Magazine, 90: 9, 1159 — 1177*

*J. Kacher, C. Landon, B.L. Adams, D. Fullwood. Ultramicroscopy 109 (2009) pp. 1148–1156*

# Approaching single dislocation resolution

- GND density can be related to EBSD and HREBSD based misorientation measurements via the Nye Tensor
- With assumptions about noisiest components, can approach single-dislocation resolution



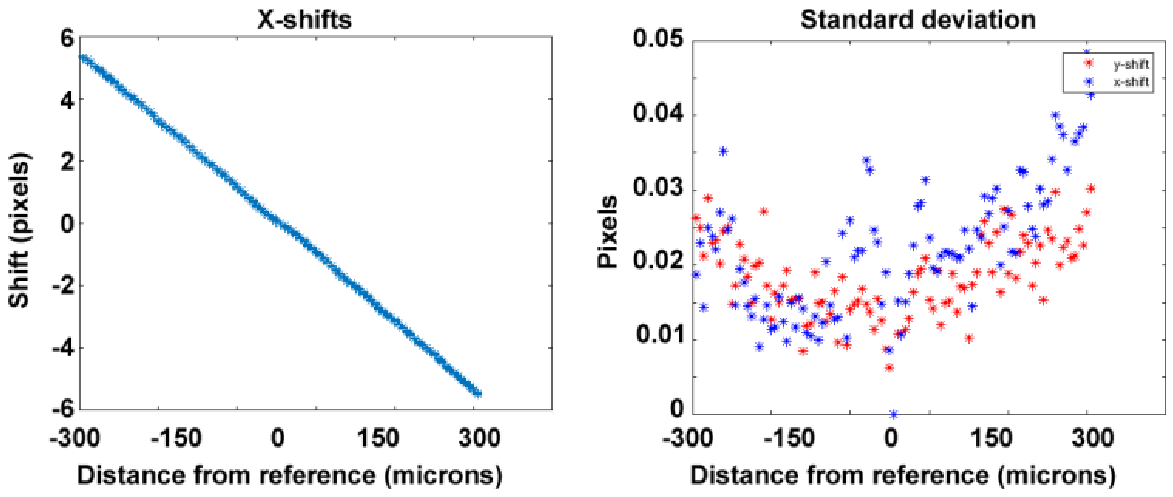

**Curvature:** $$\kappa_{ij} = \frac{\partial \theta_i}{\partial x_j}$$

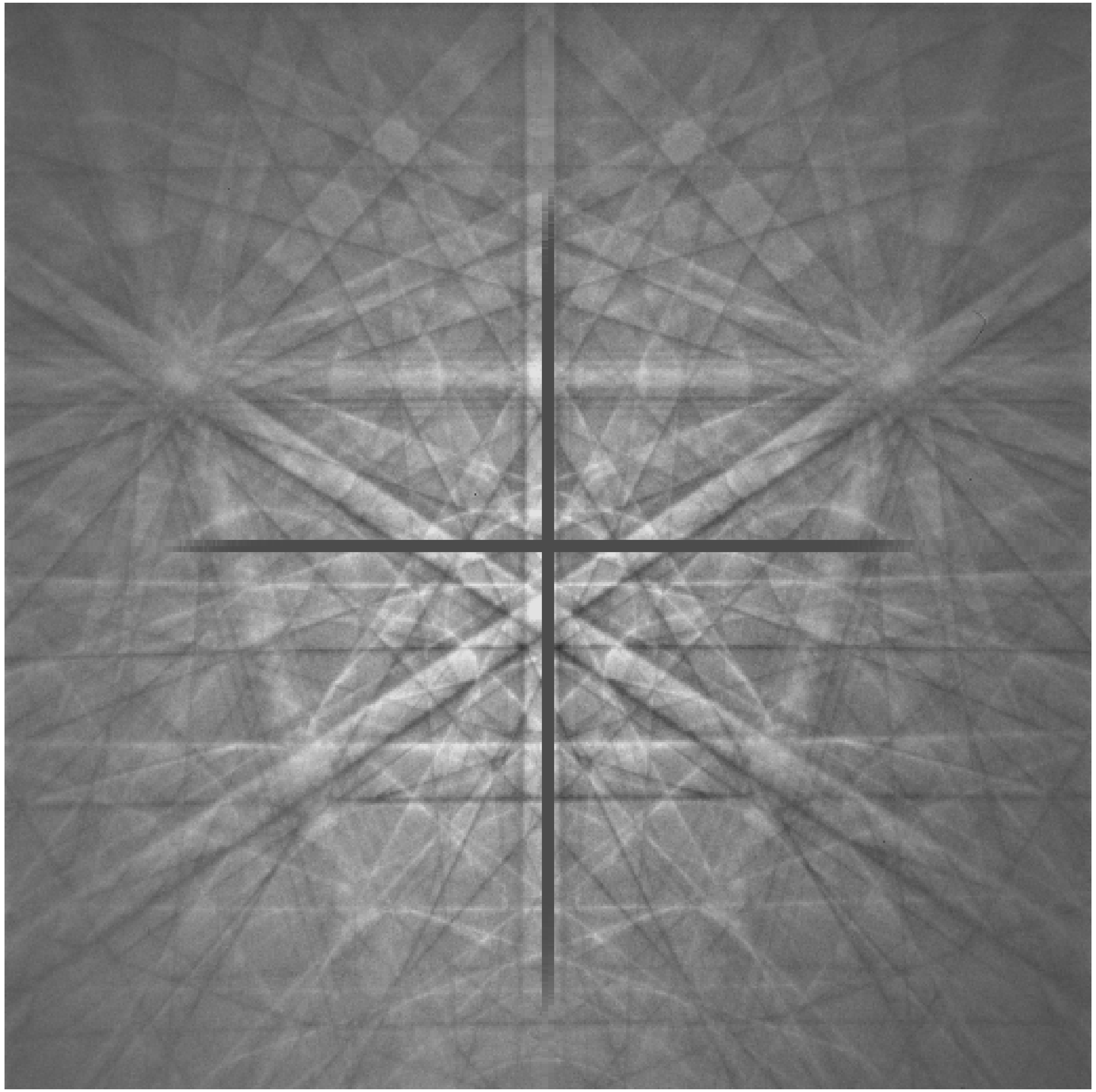
**Nye Tensor:** $$\alpha_{ij} = \sum_N b_i l_j \rho^N$$

**Relationship:** $$\kappa_{ij} = -\alpha_{ij} + \tfrac{1}{2}\delta_{ij}\alpha_{kk} - e_{ilk}\varepsilon^e_{jk,l}$$

*Ruggles, T,... J. Kacher, Ultramicroscopy, 2020*

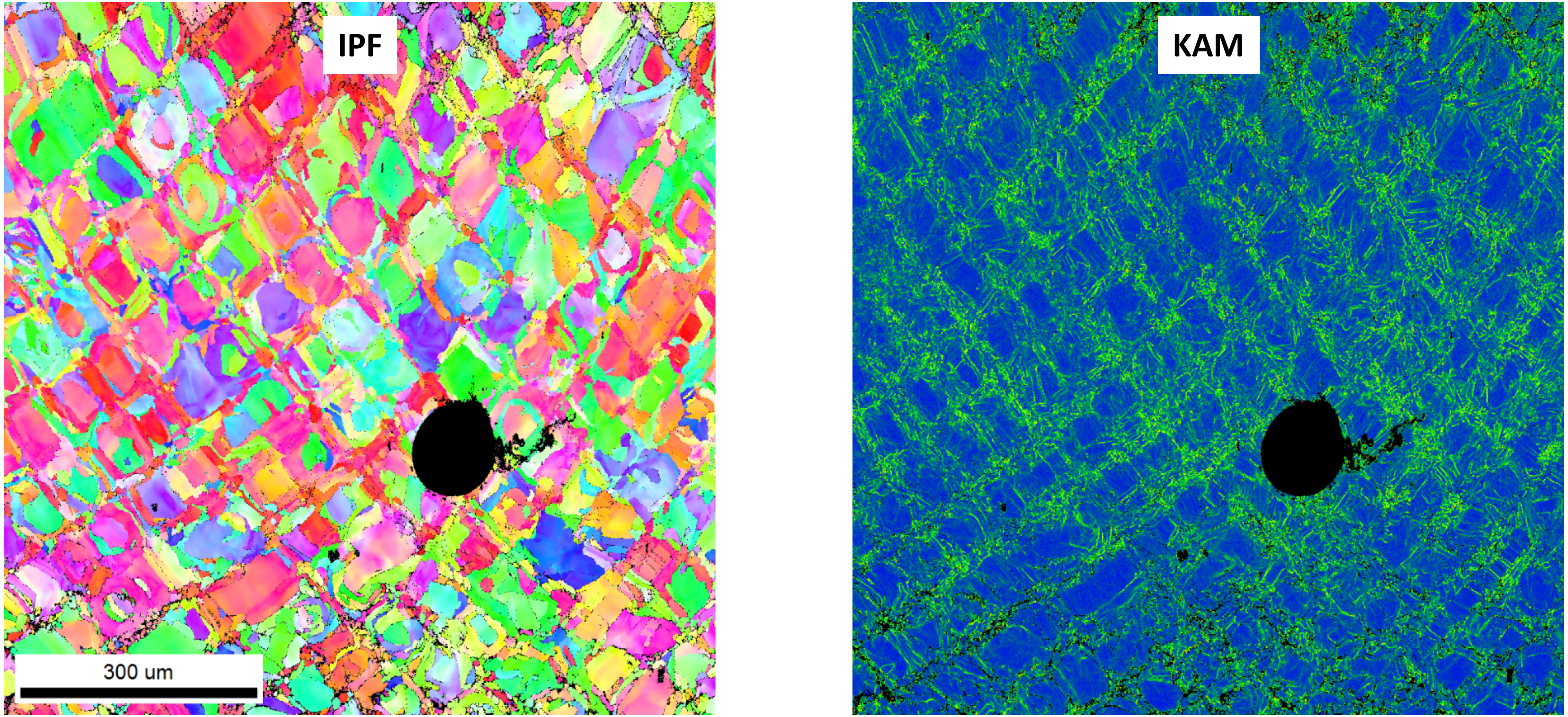
# Direct electron detection for EBSD



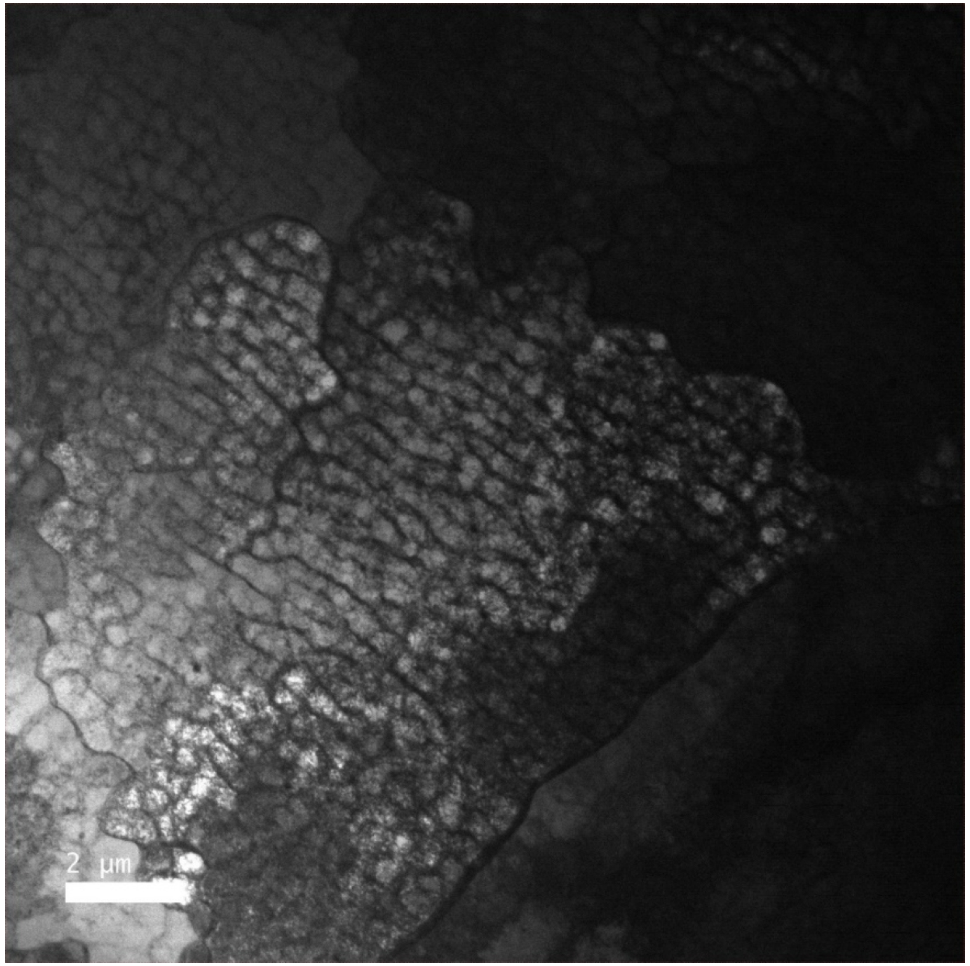
- Direct electron detectors bypass conversion from electrons to photons, increasing detection sensitivity
- Pattern shift experiments show that feature tracking is precise to ~1/30$^{th}$ of a pixel
- Precision is maintained over patterns collected hundreds of microns apart

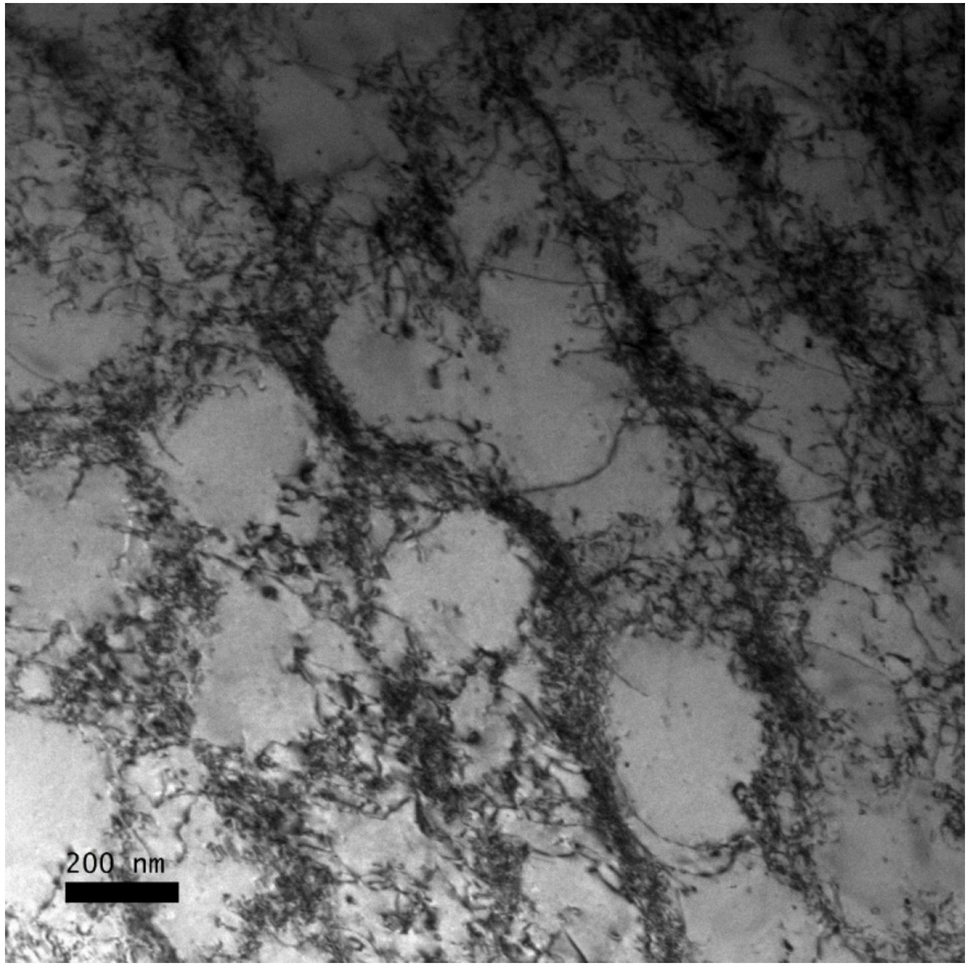
# Microstructure of AM steel




Microstructure of AM steel composed of thatched structure, with melt tracks visible as refined-grain regions

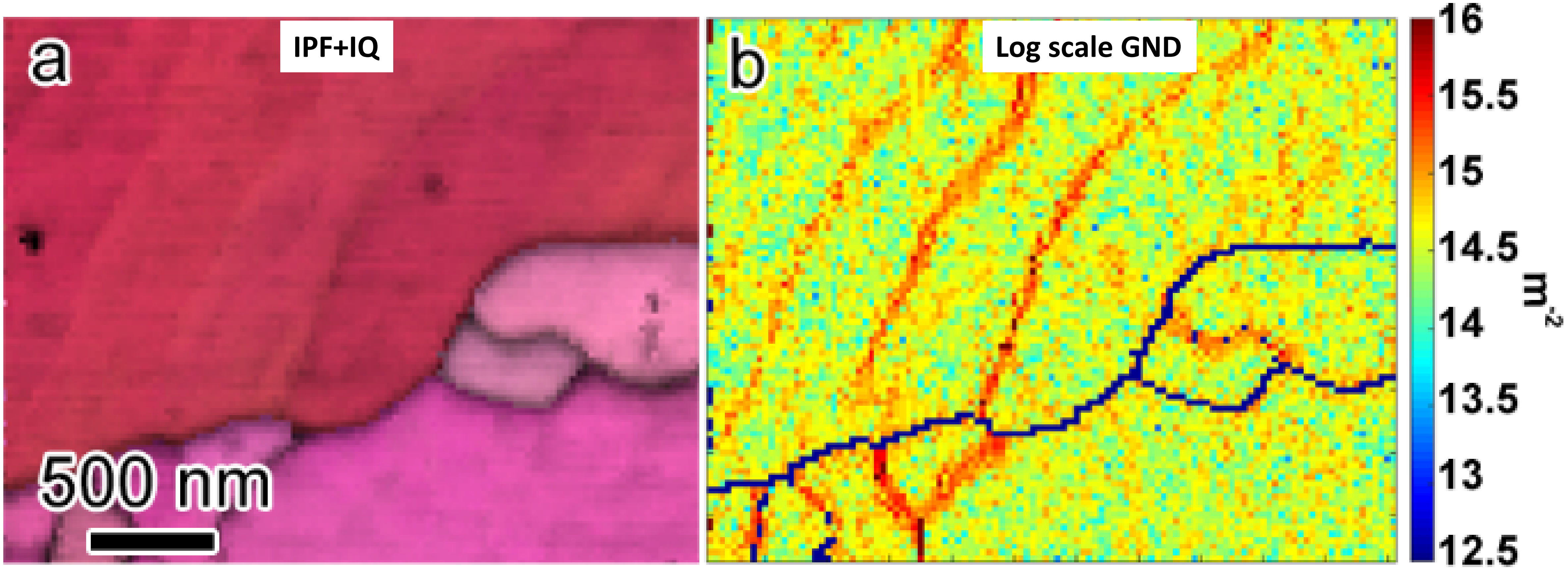
# Defect structures in AM steels




- TEM analysis shows that structure is composed of dense dislocation networks
- These dislocation cell-like structures have been shown to increase both the strength and ductility of the printed parts

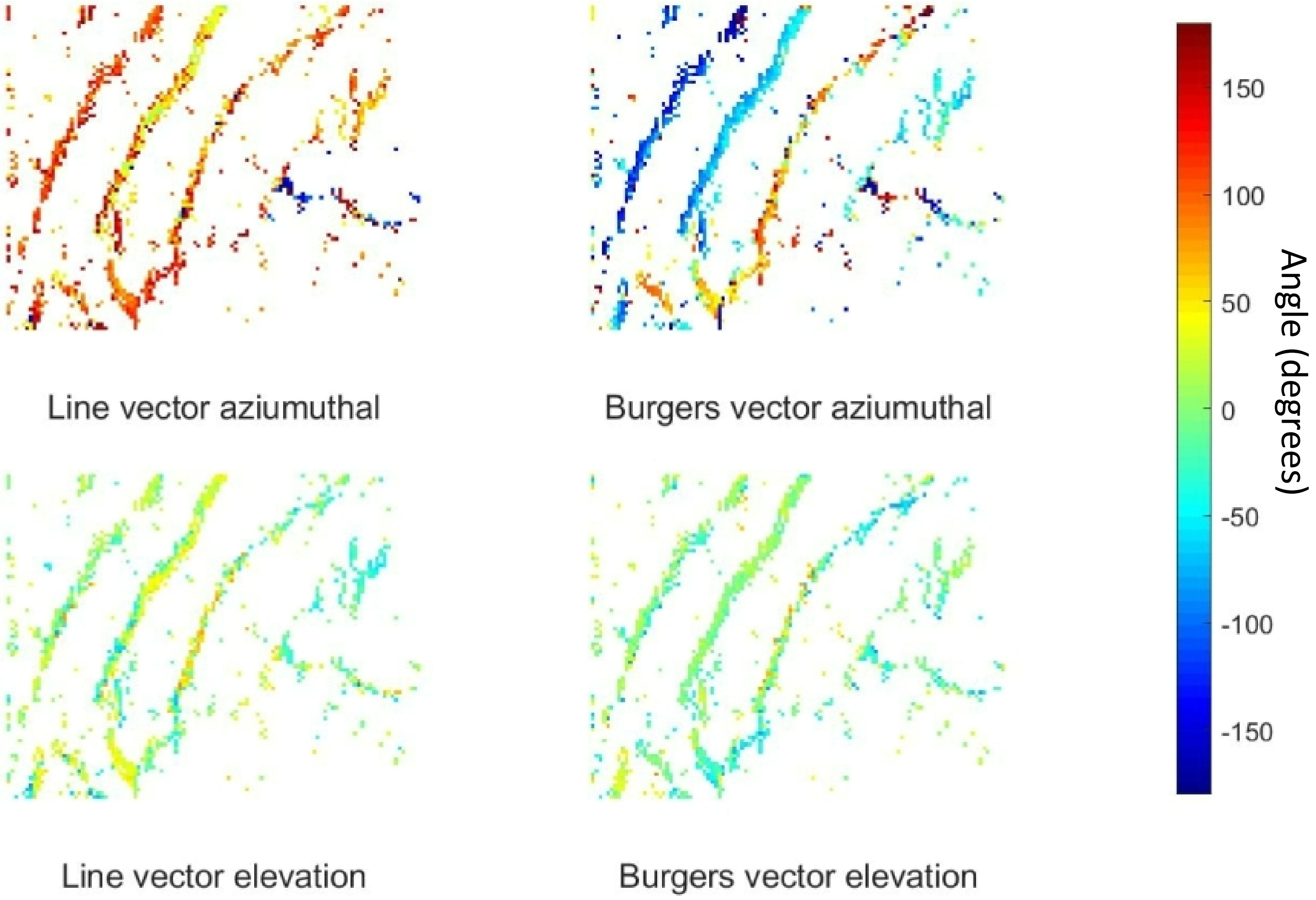
# Characterizing the area




- Small region selected for HR-EBSD analysis using Clarity camera
- Dislocation structures clearly visible through Nye-tensor analysis
- Cells align with <001> direction

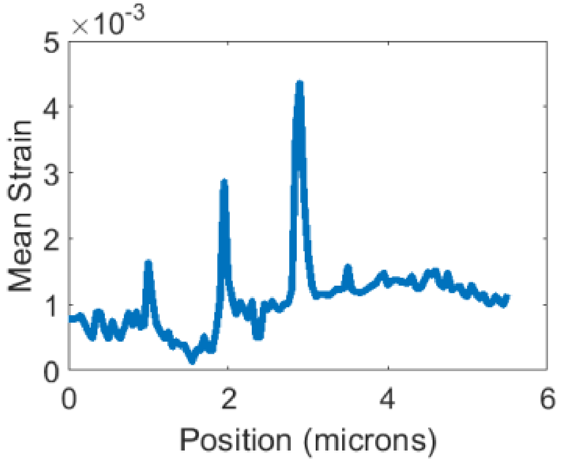
# Characterizing the dislocation structures

- Small length scale assumption used to assign on Burgers vector type to each point in scan (Ruggles, T, Deitz, J, t al., 2020)
- Pictured are the measured Burgers vector direction and dislocation line vector direction given in the reference frame of the sample.
- From left to right, the three dislocation boundaries have a dominant Burgers vector of [-1 -1 0], [1 -1 0] and a mixture of [1 1 0] and [0 1 -1]

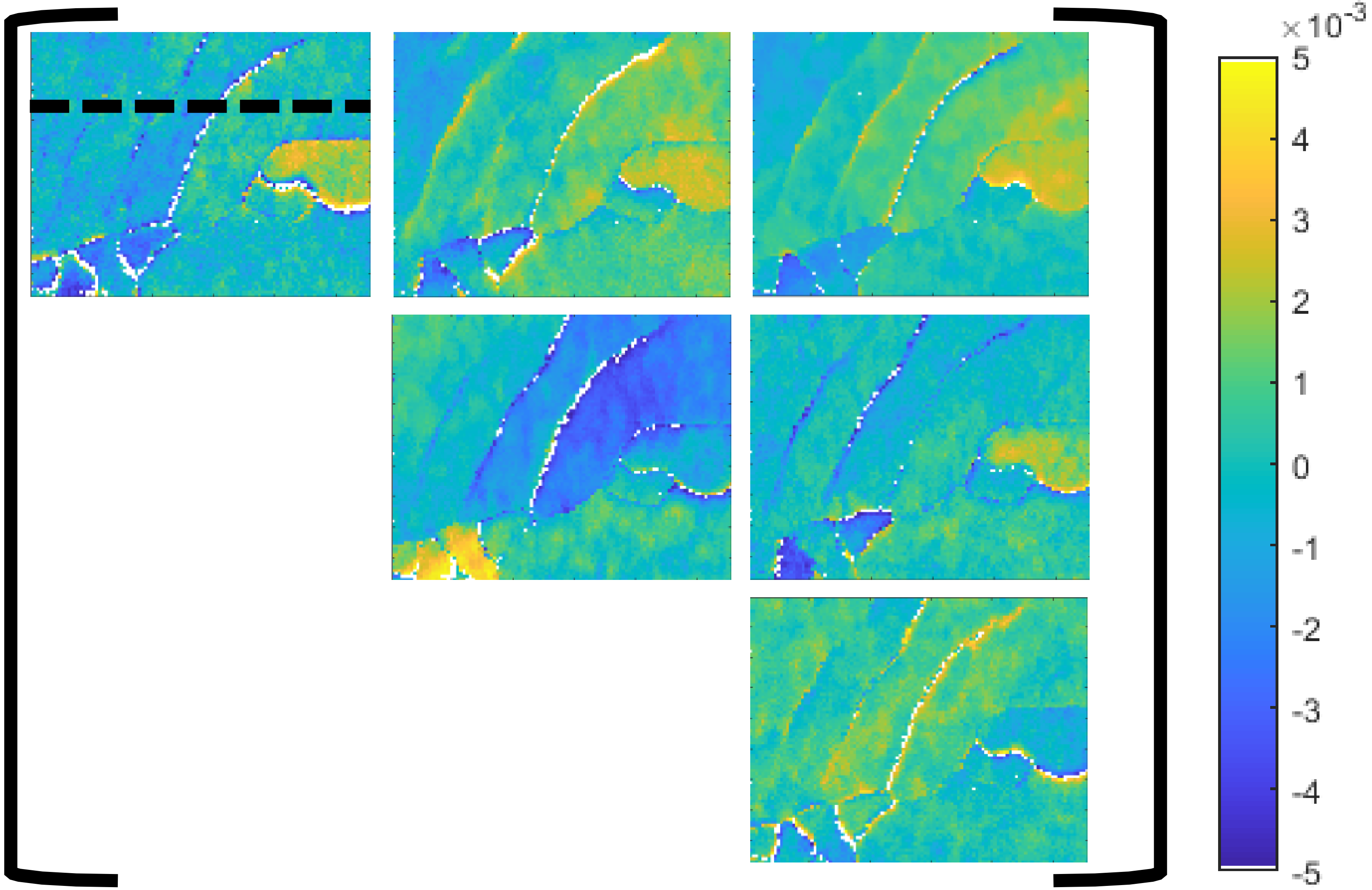


# Characterizing the retained strains

- By applying a traction free boundary condition, all 6 independent components of elastic strain gradient tensor available
- Strain analysis shows high elastic strains near dislocation boundaries

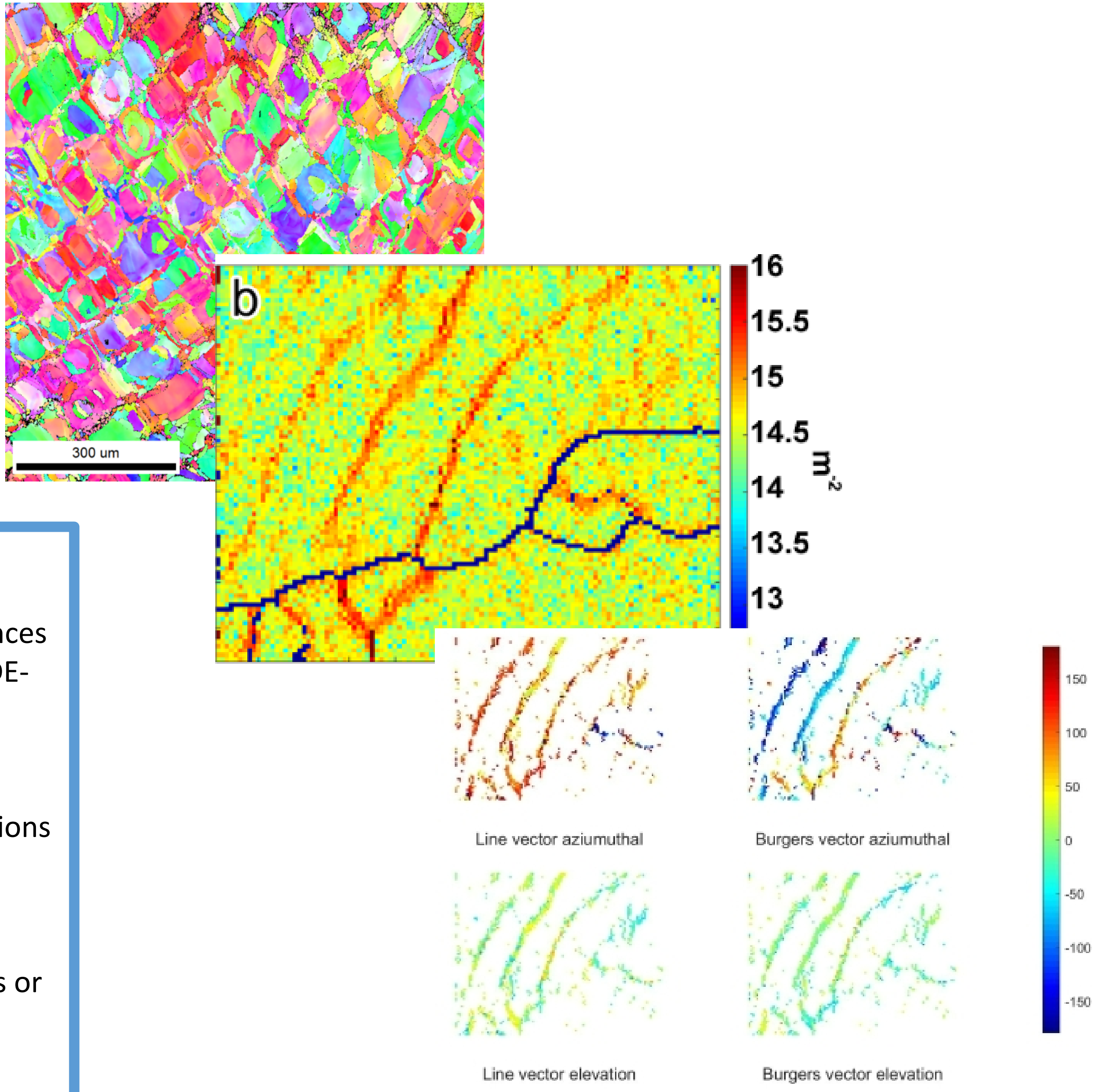



Mean strain along dashed line



# Conclusion

- High-angular resolution EBSD provides direct access to the GND state of AM materials
- Rapid analysis and quantitative data is attractive avenue for future couplings with computational analysis





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