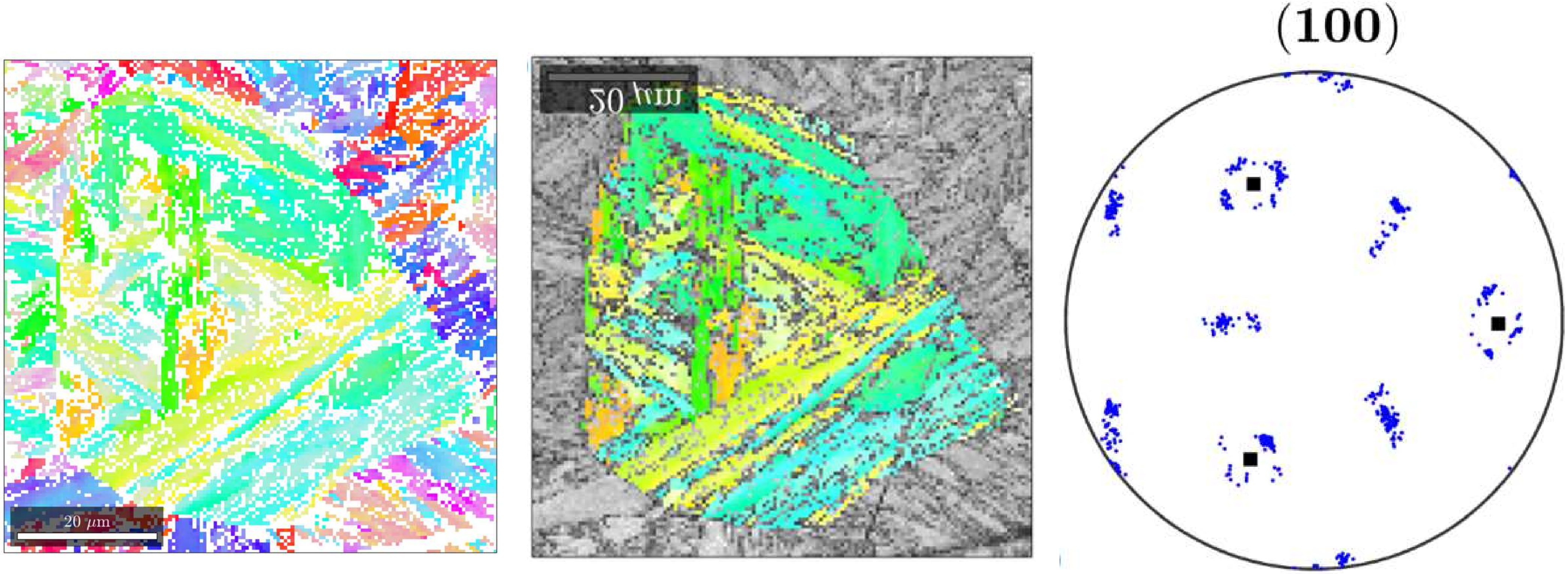
Prior austenite reconstruction: a graph sectioning problem

Tuomo Nyyssönen

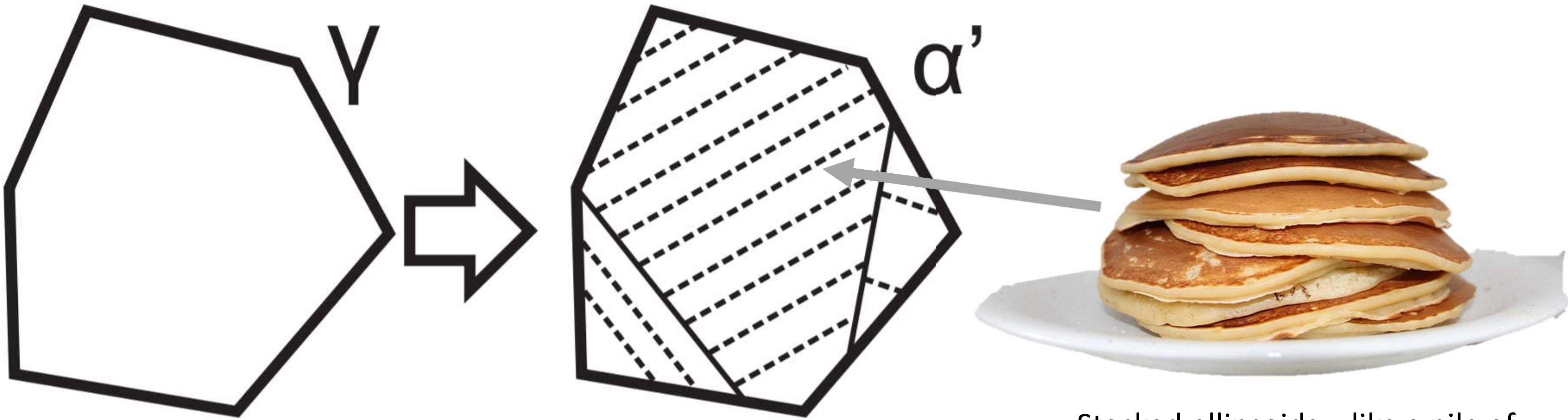
Tampere University

Orientation map of martensite



Martensite is not really composed of grains like ferrite and austenite

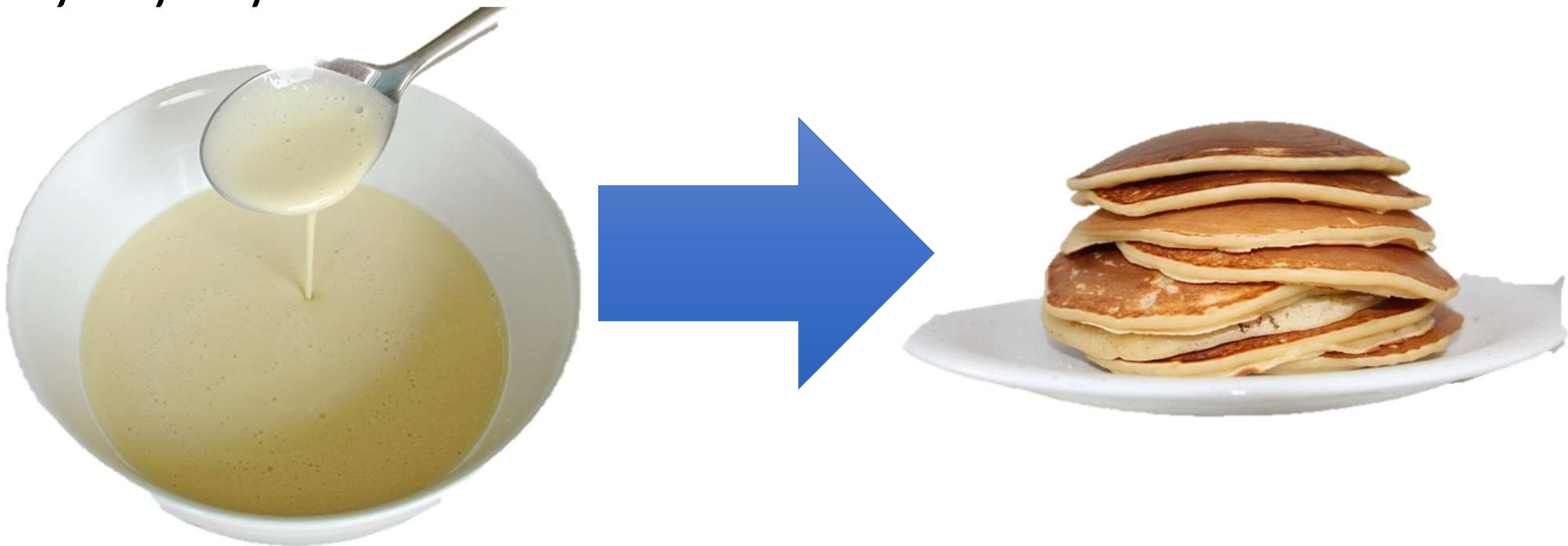
- Instead martensite is composed of laths formed through a shear transformation **from grains**



Stacked ellipsoids – like a pile of pancakes!

THE PROBLEM BEHIND THE PROBLEM

- Pancakes are made from flour mix. But when you make the pancakes, you can’t study the flour mix any more!
- The ”flour mix” here is austenite at ~700 – 1000 °C so it’s a bit tricky to study anyway!



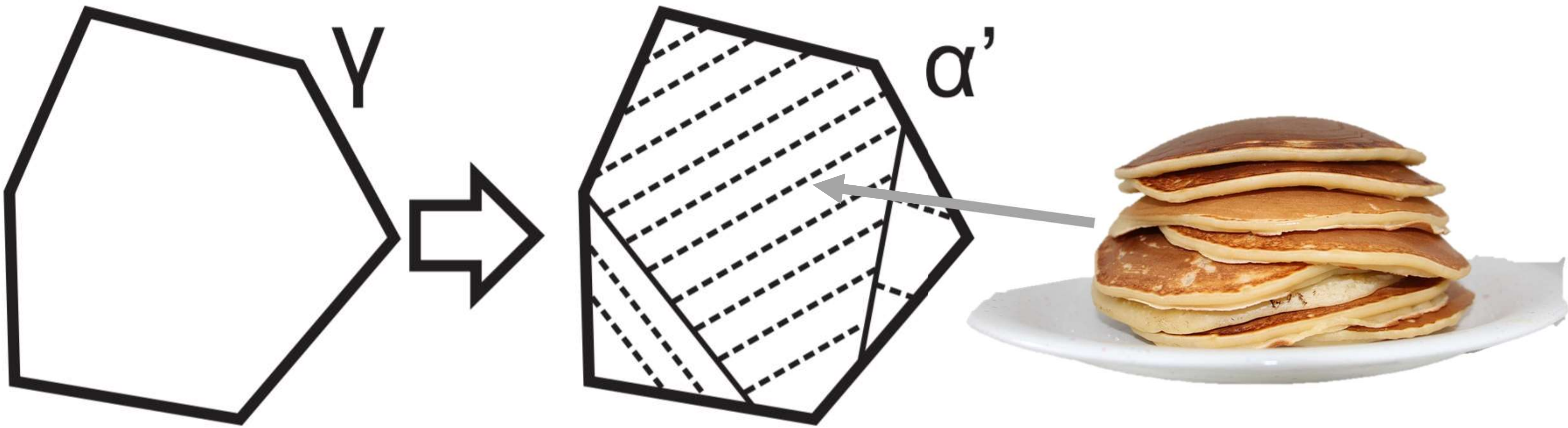
Mathematically, the relationship looks like this:

Relationship of pancake (martensitic lath) to flour mix (parent austenite):

$$O_{\alpha'}(x_i) = O_{\gamma}(x_i) P_i T_{\gamma\to\alpha} C_i$$

24 pancakes (Pi) viewed from 24 directions (Ci)

We are interested in the relationships of the pancakes to each other, however....



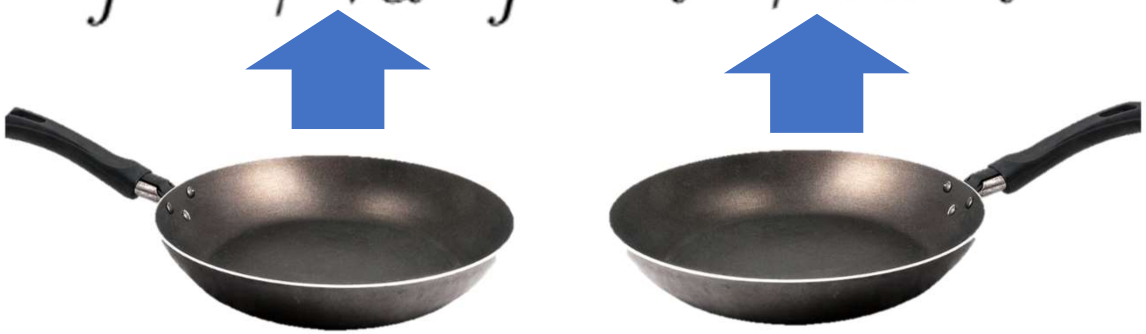
Stacked ellipsoids – like a pile of pancakes!

Mathematically, we therefore need something like this:

Two pancakes (martensitic laths) *i* and *j* originating from the same mix (parent austenite). How to describe their relationship:

$$M = \left(O_\alpha(x_j)\right)^{-1} \left(O_\alpha(x_j)\right)$$

$$M = C_j^{-1} T_{\gamma\rightarrow\alpha}^{-1} P_j^{-1} P_i T_{\gamma\rightarrow\alpha} C_i$$



Only the pan (orientation relationship) is required to describe the relationships between pancakes (martensitic laths)!

Happily…

$$M = C_j^{-1} T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i T_{\gamma\to\alpha} C_i$$

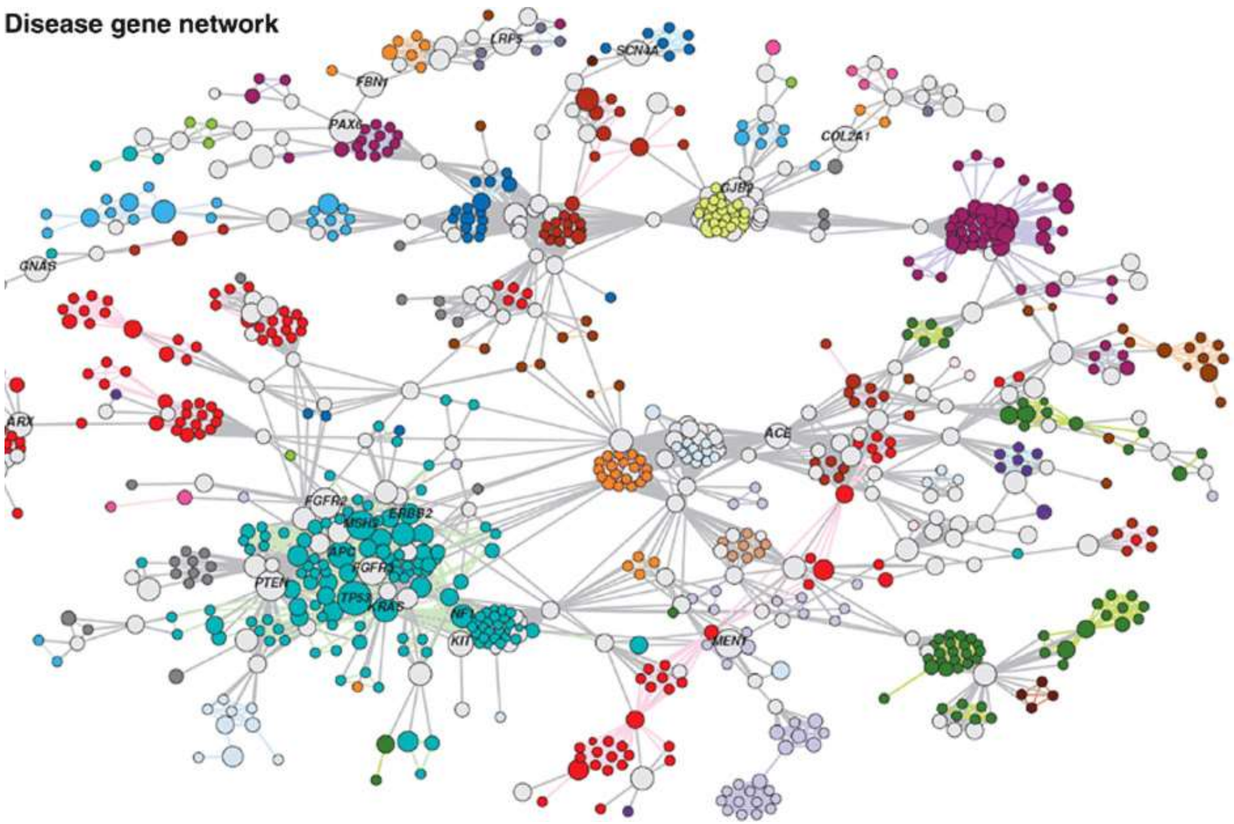
The list describing all possible relationships between pancakes (martensitic laths) has only 24 candidates!

Graph problems

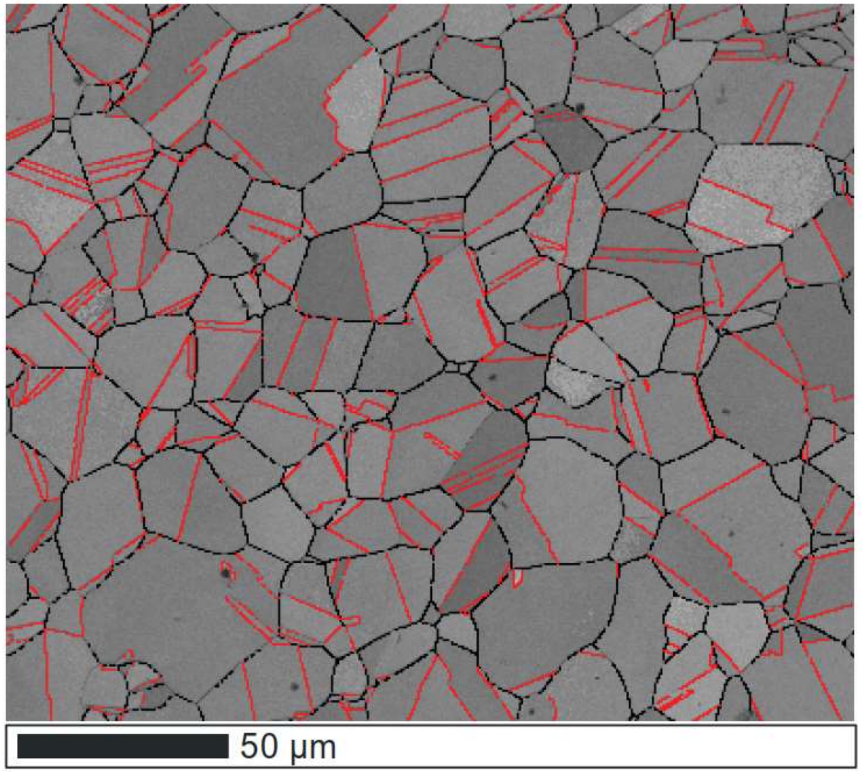
- Modelling of relations and processes in physical, biological, social and informations systems.

A graph is a collection of:
- nodes
- edges

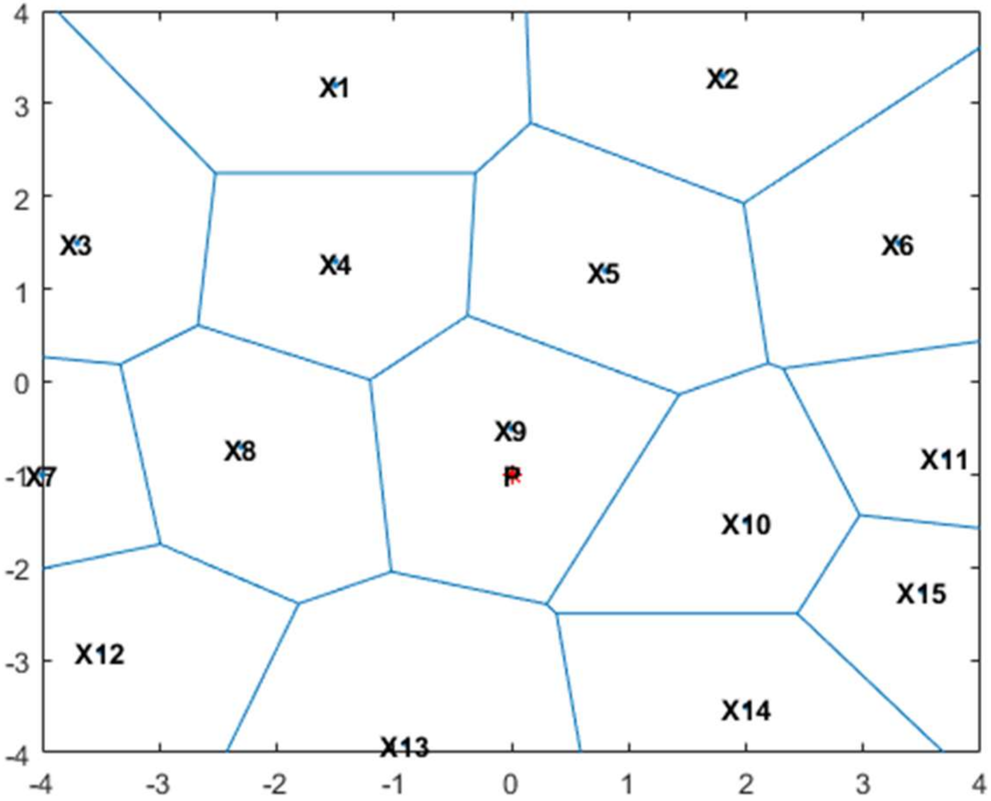
Graph problems: medicine



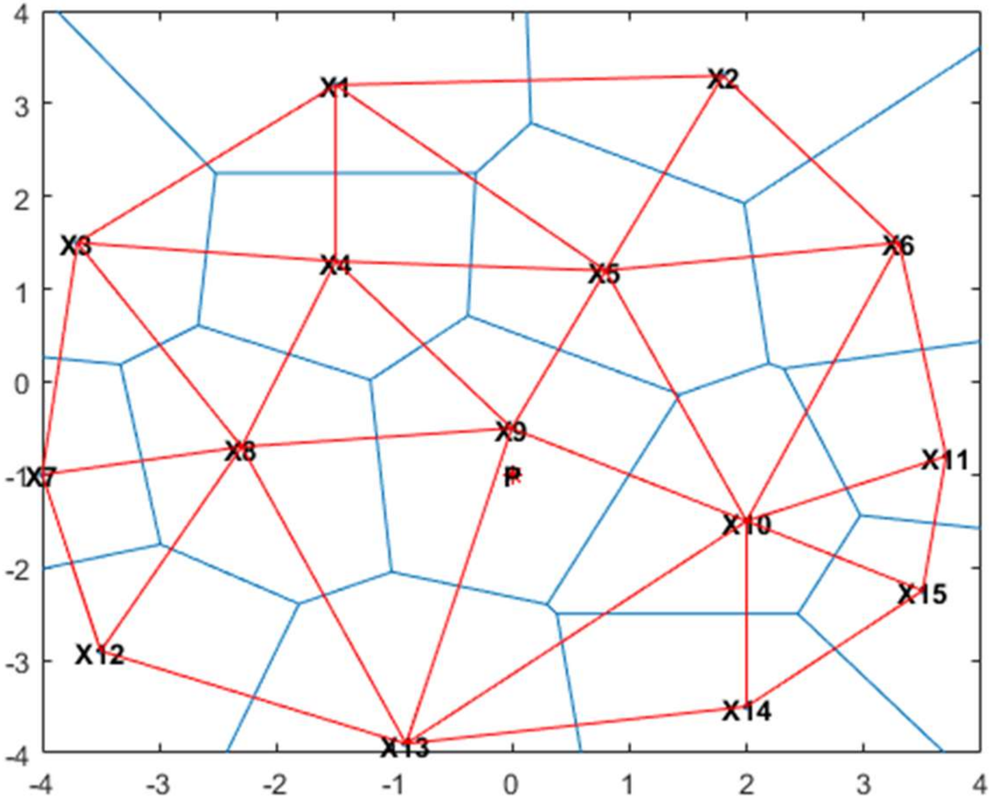
Graphs in steel



Graphs in steel

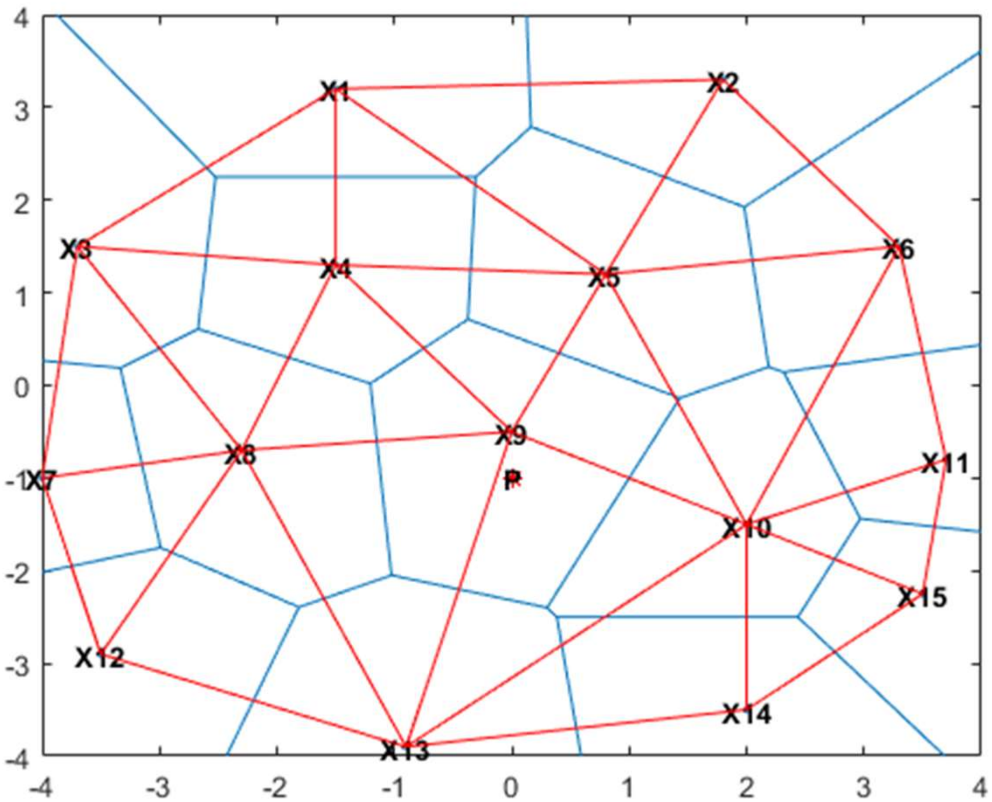


Graphs in steel

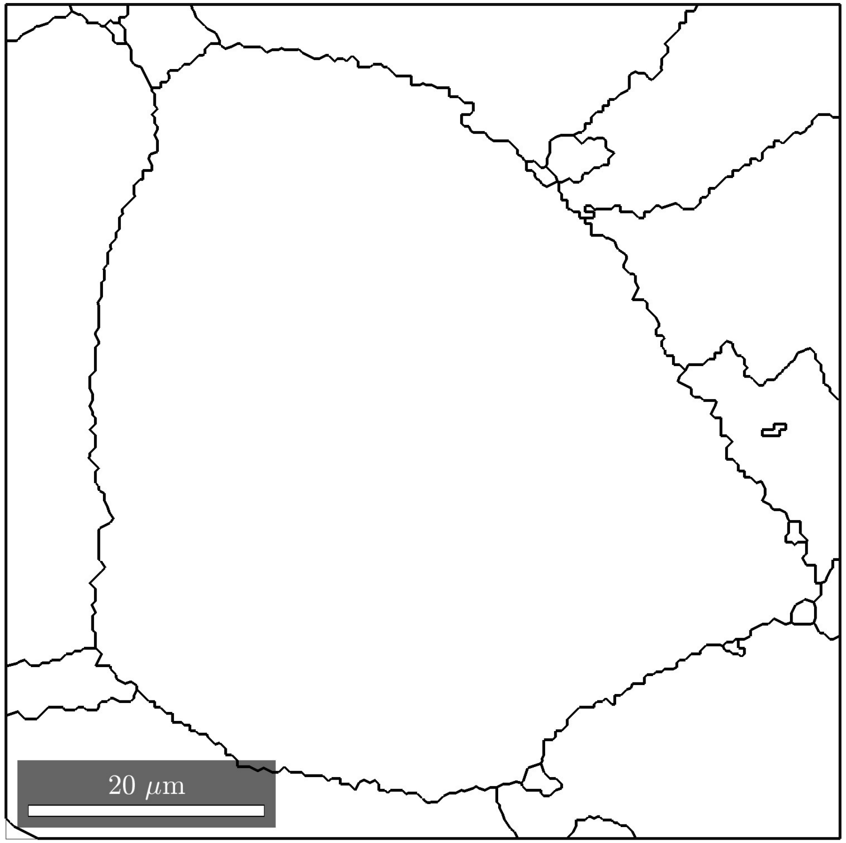


A graph is a collection of:
- nodes
- edges

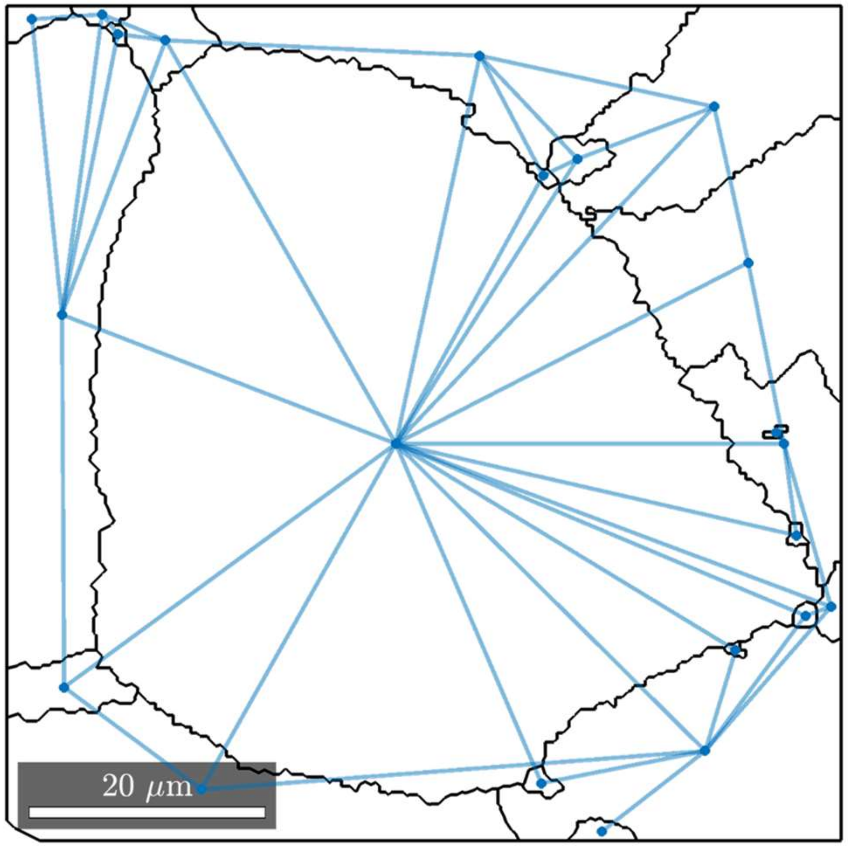
Graphs in steel



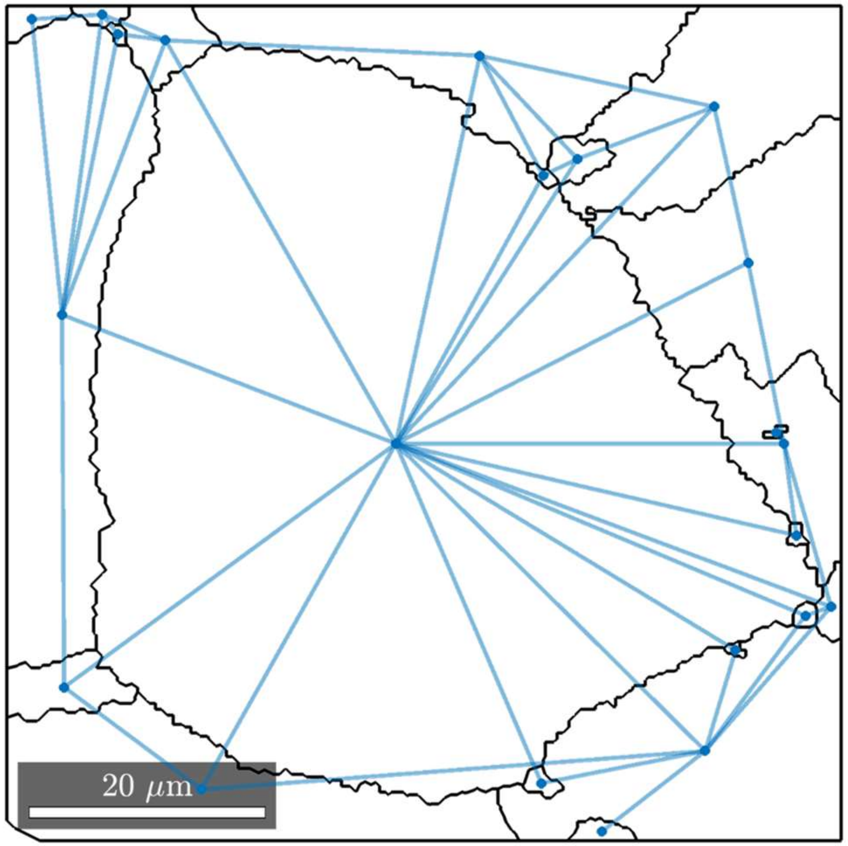
Austenite



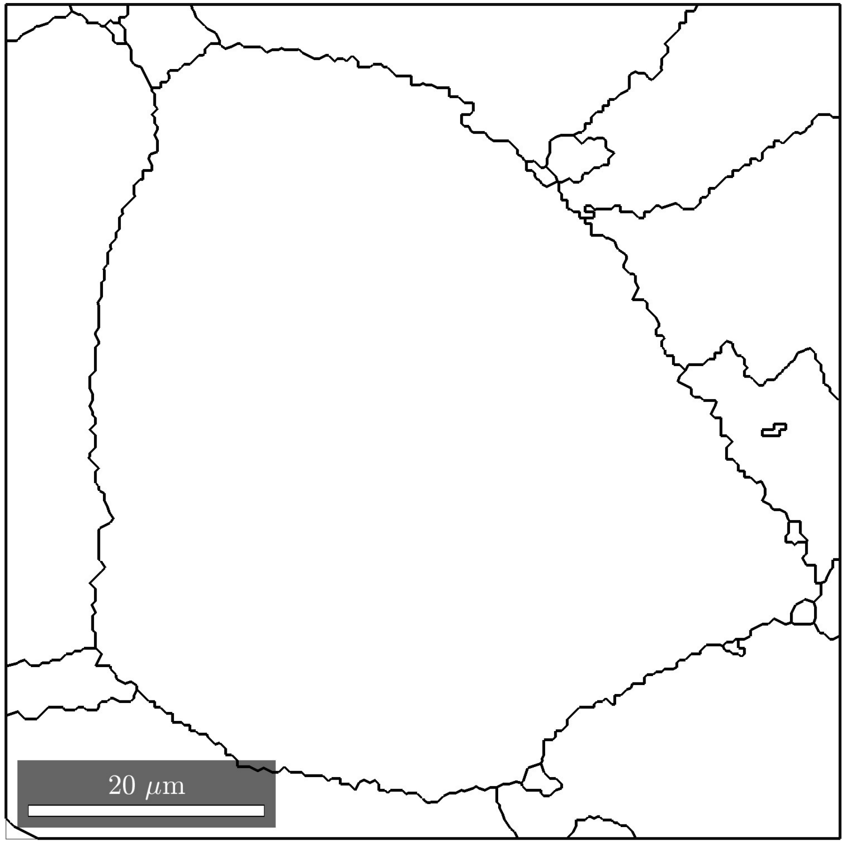
Austenite as a graph



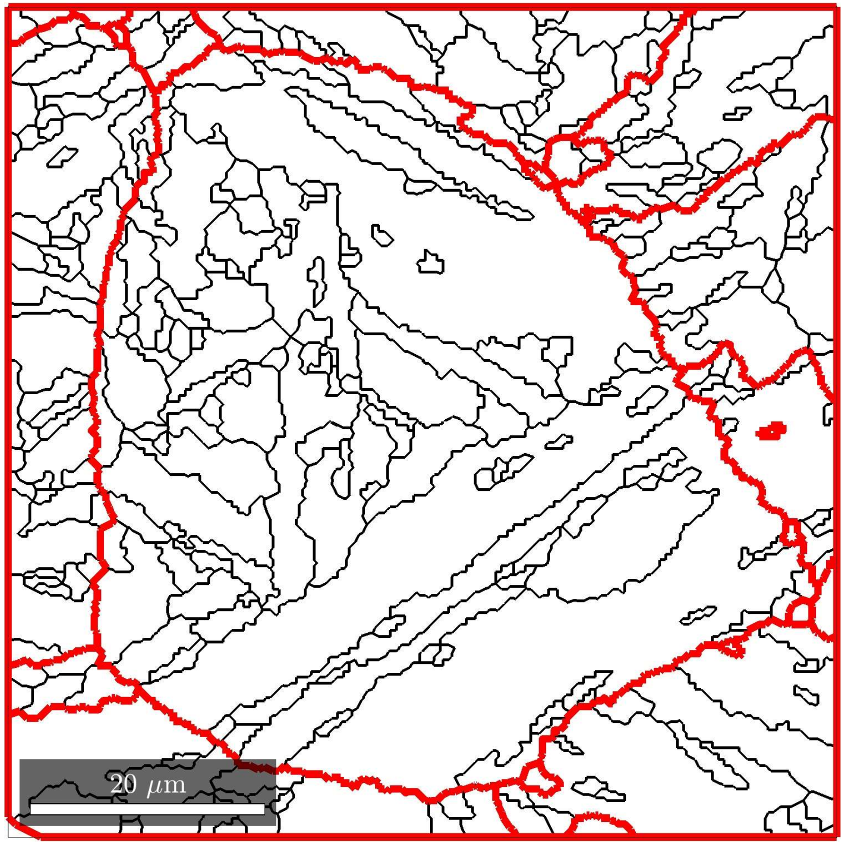
Austenite as a graph



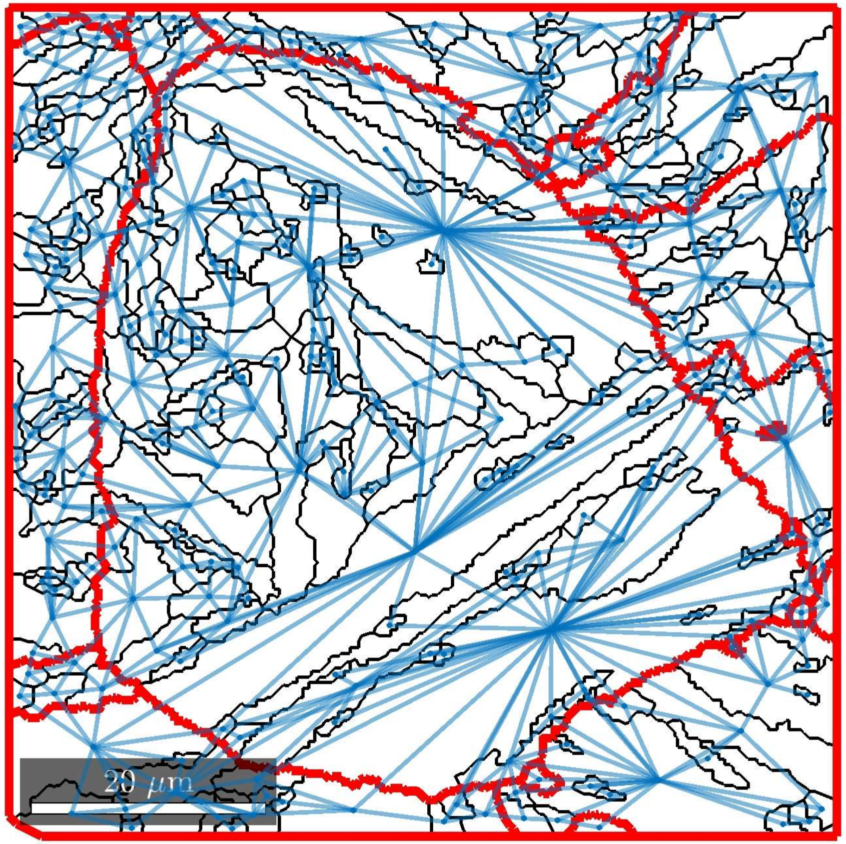
Austenite



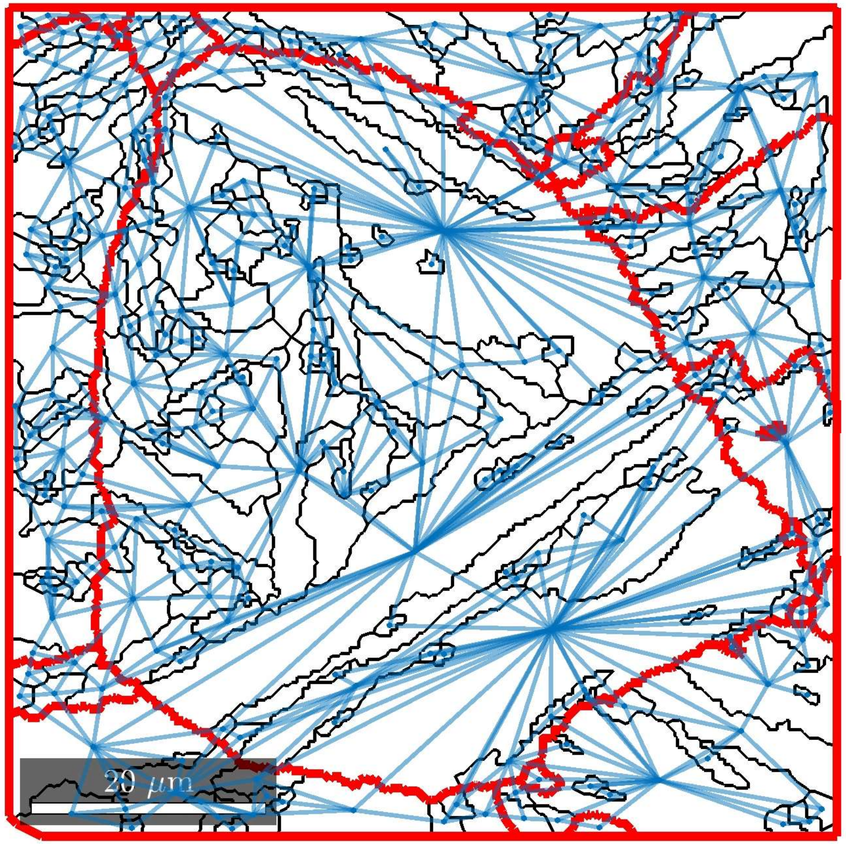
Martensite



Martensite as a graph



Martensite as a graph



$$O_{\alpha'}(x_i) = O_\gamma(x_i) P_i T_{\gamma\to\alpha} C_i$$

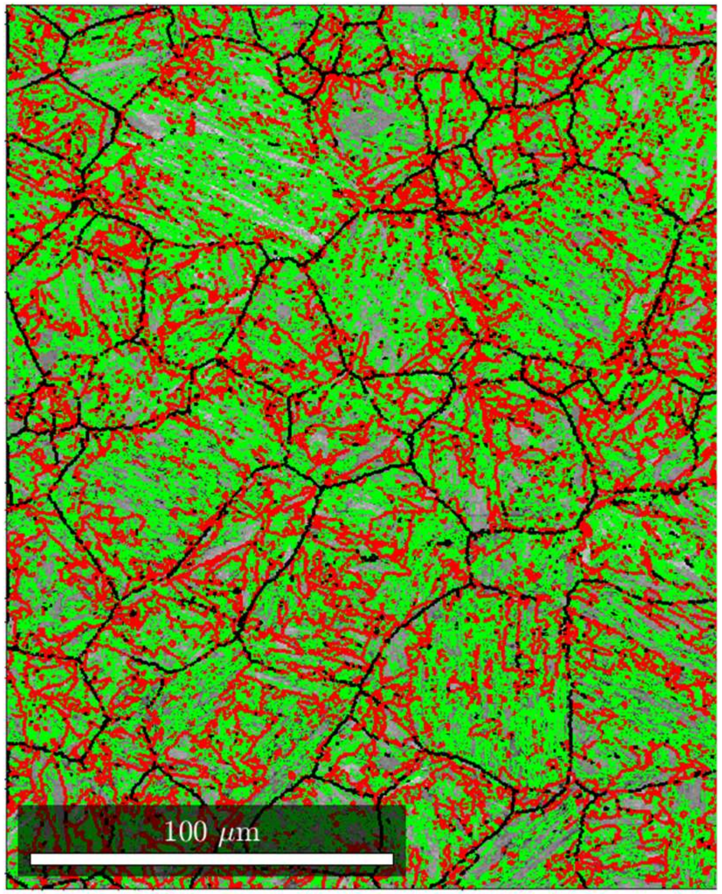
$$M = C_j^{-1} T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i T_{\gamma\to\alpha} C_i$$

Happily...

$$M = C_j^{-1} T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i T_{\gamma\to\alpha} C_i$$

The list describing all possible relationships between pancakes (martensitic laths) has only 24 candidates!

Misorientation-based analysis may help:

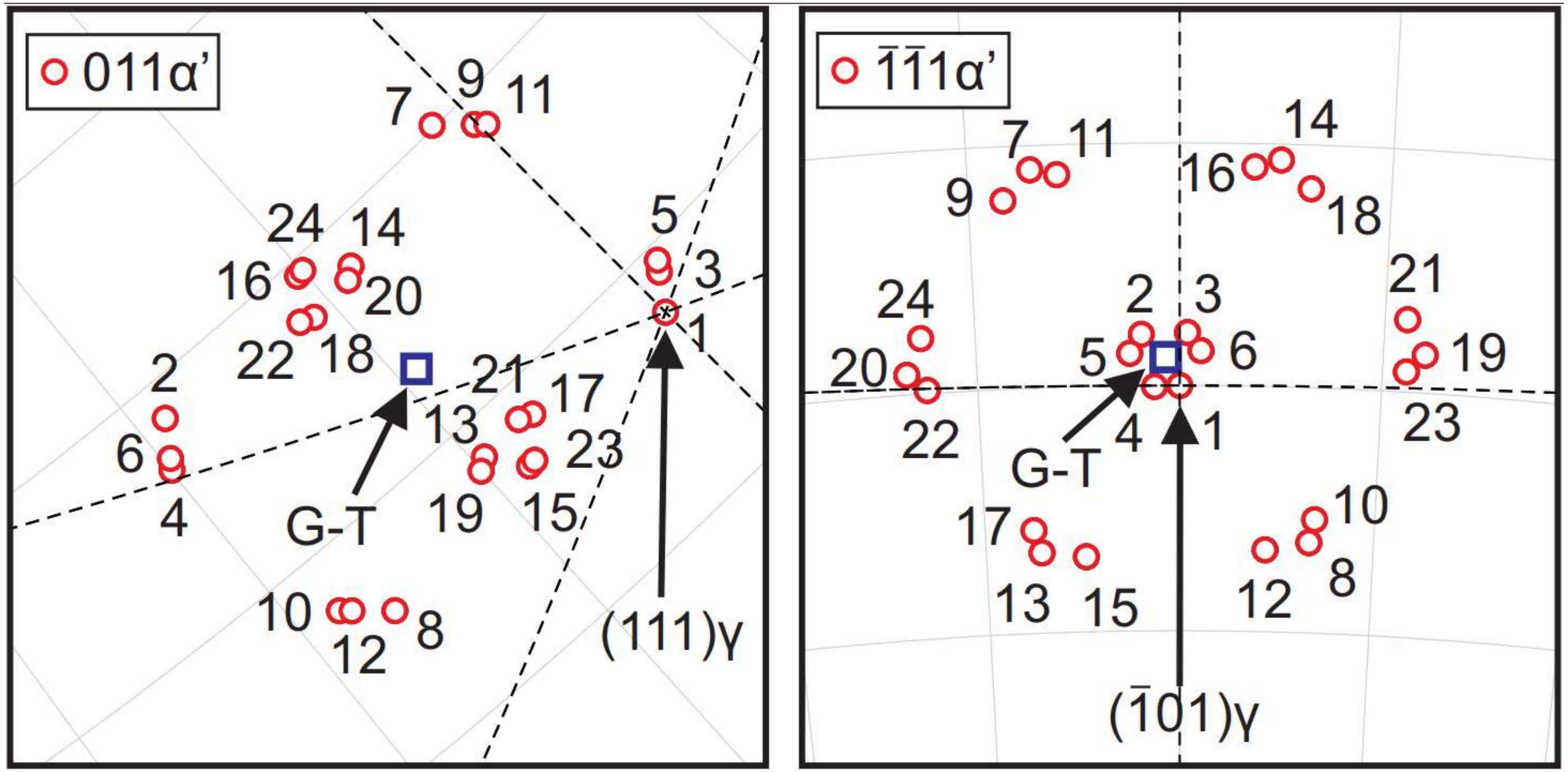


$$M = C_j^{-1} T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i T_{\gamma\to\alpha} C_i$$

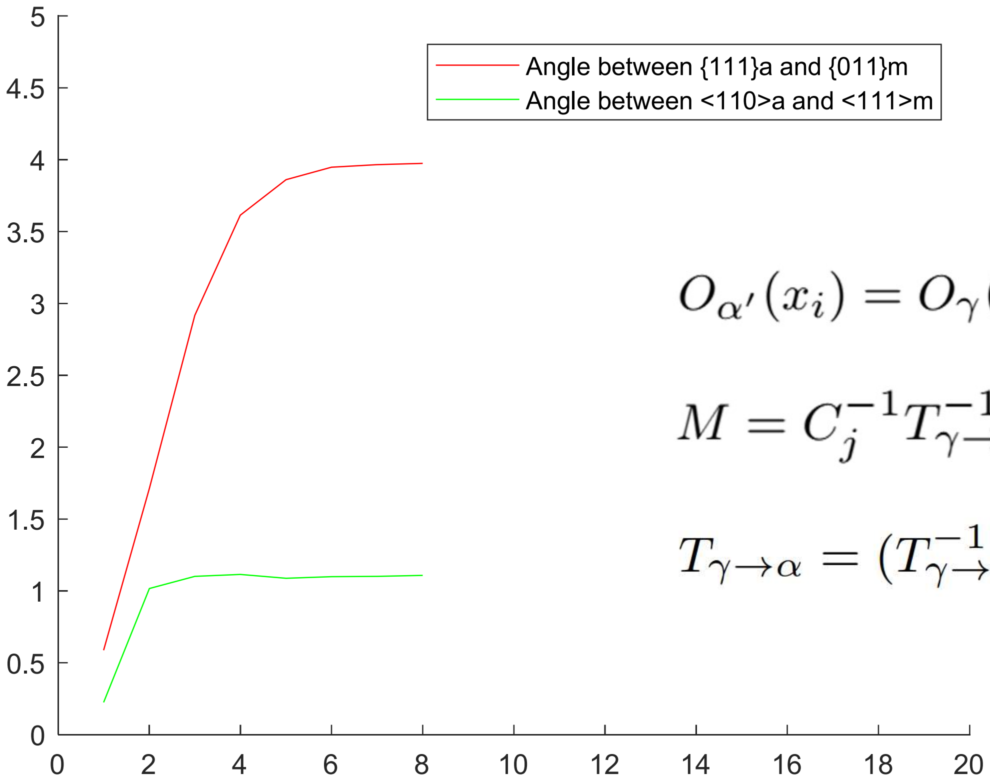
$$T_{\gamma\to\alpha} = (T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i)^{-}1 C_j M_{exp} C_i^{-}1$$

$$T_{\gamma\to\alpha} = (T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i)^{-}1 C_j M_{exp} C_i^{-}1$$

$$T_{n+1}(x_i, x_j) = (\overline{T}_n^{-1} P_j^{-1} P_i)^{-1} C_j M_{x_i,x_j} C_i^{-}1$$



Iterative procedure gives you a decent result!



$$O_{\alpha'}(x_i) = O_\gamma(x_i)P_iT_{\gamma\to\alpha}C_i$$

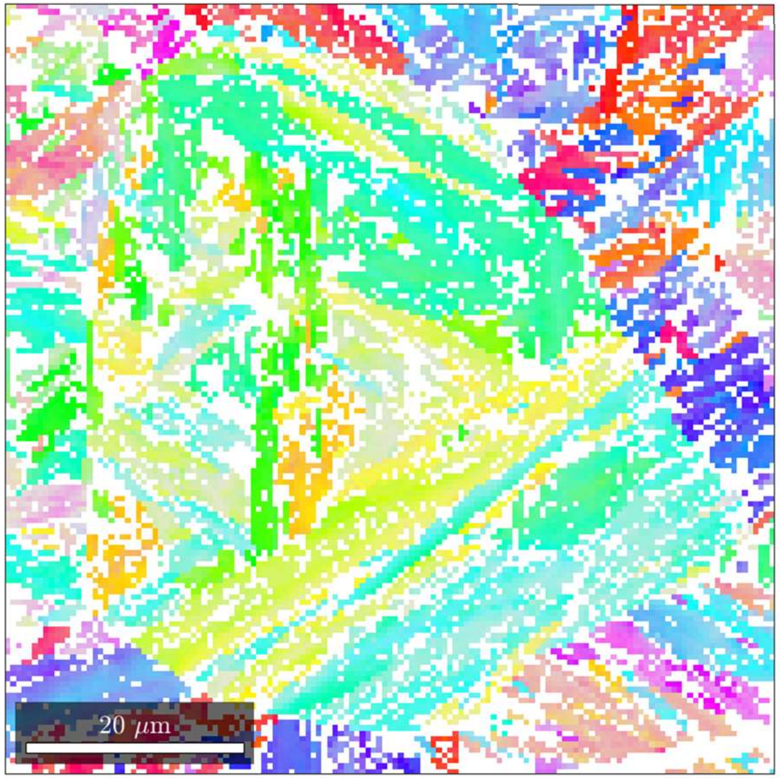
$$M = C_j^{-1}T_{\gamma\to\alpha}^{-1}P_j^{-1}P_iT_{\gamma\to\alpha}C_i$$

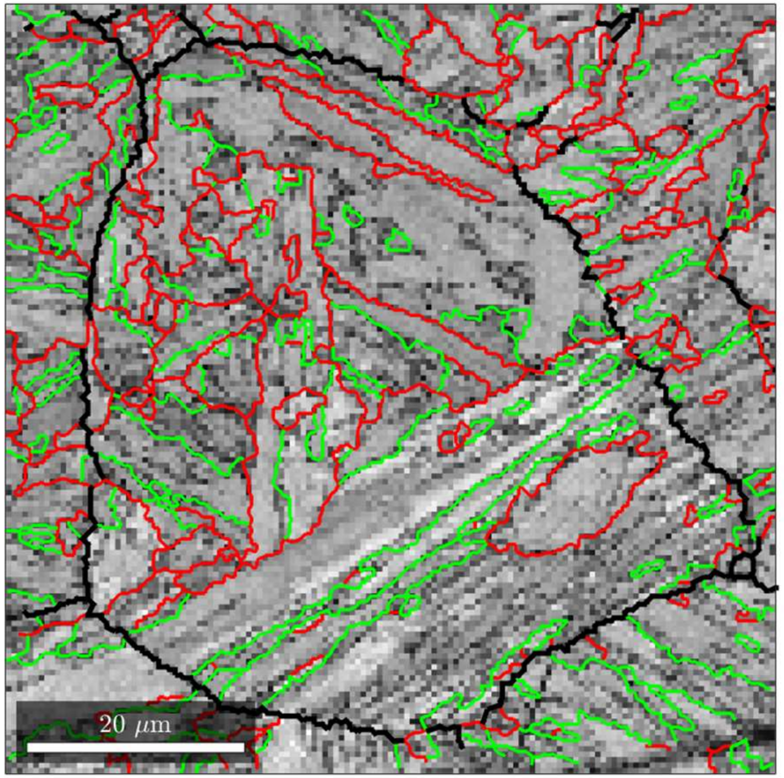
$$T_{\gamma\to\alpha} = (T_{\gamma\to\alpha}^{-1}P_j^{-1}P_i)^{-}1C_jM_{exp}C_i^{-}1$$

We can now do the following:

We have an orientation map measured via EBSD from a martensitic surface. We will now divide the boundaries between laths (pancakes) to block and packet boundaries using the definition:

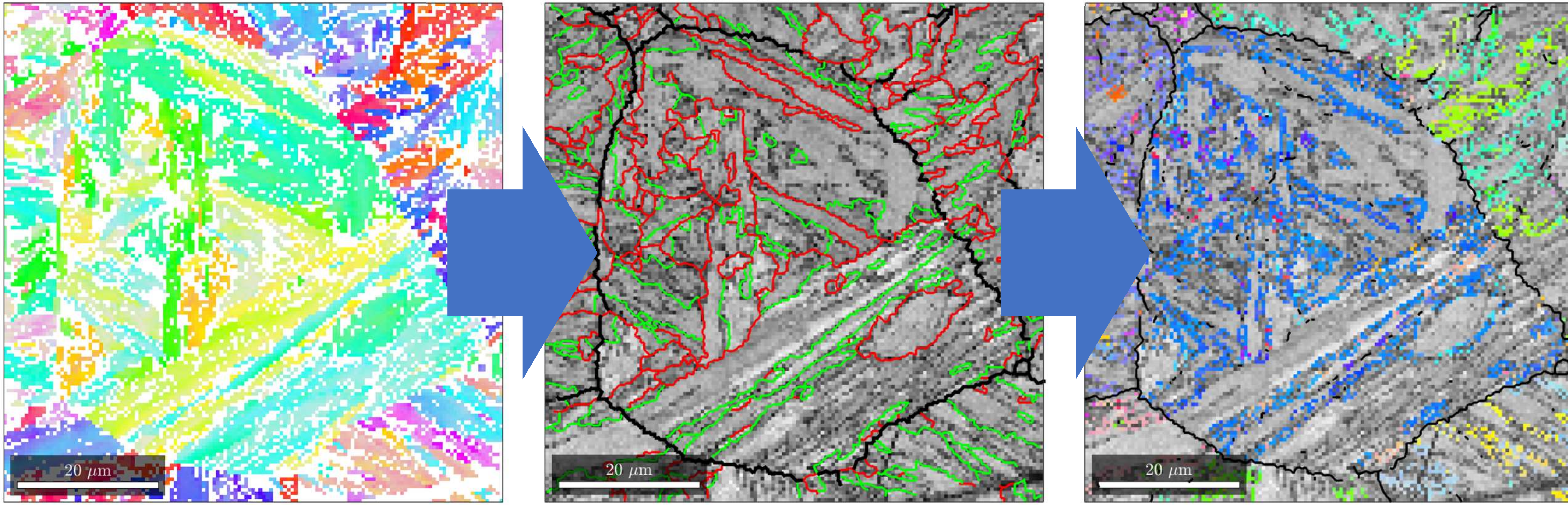
$$M = C_j^{-1} T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i T_{\gamma\to\alpha} C_i$$



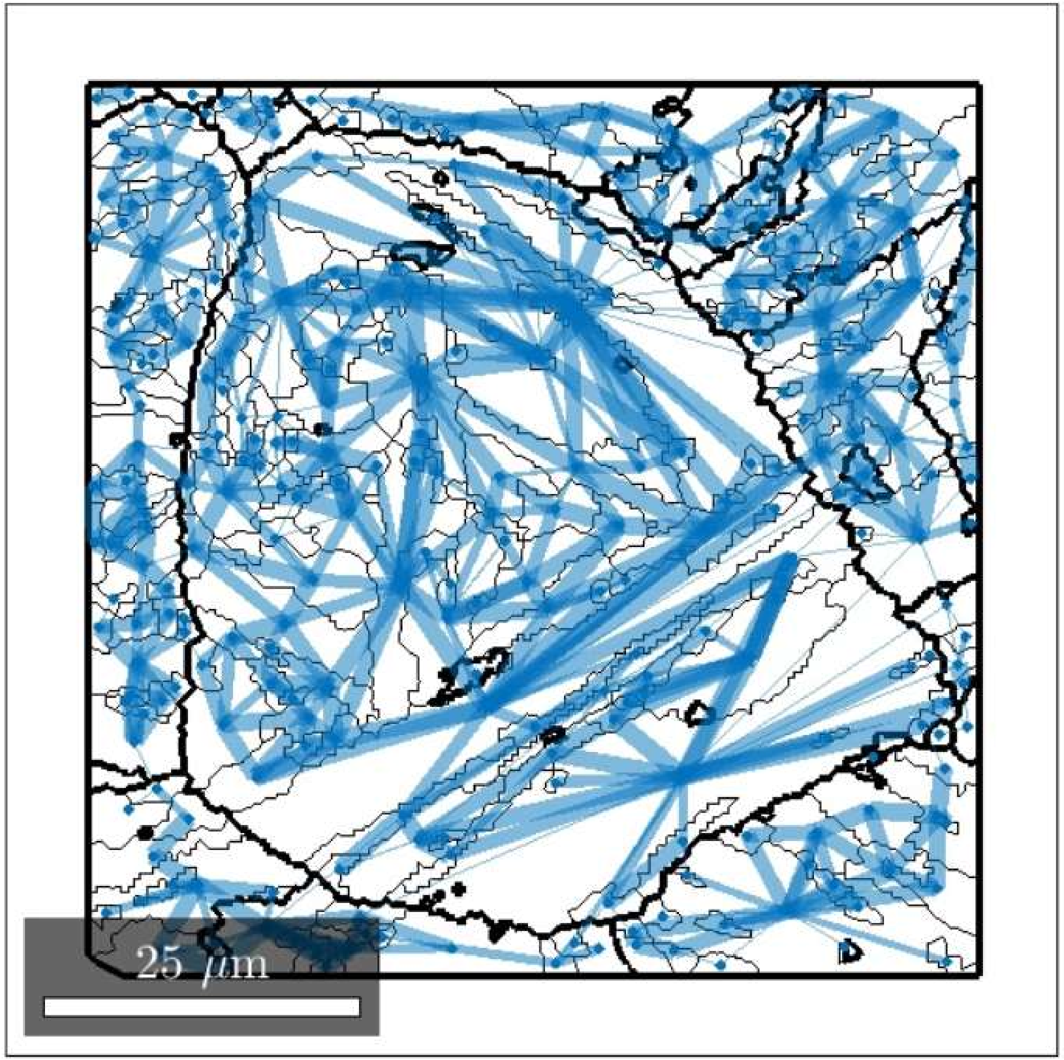


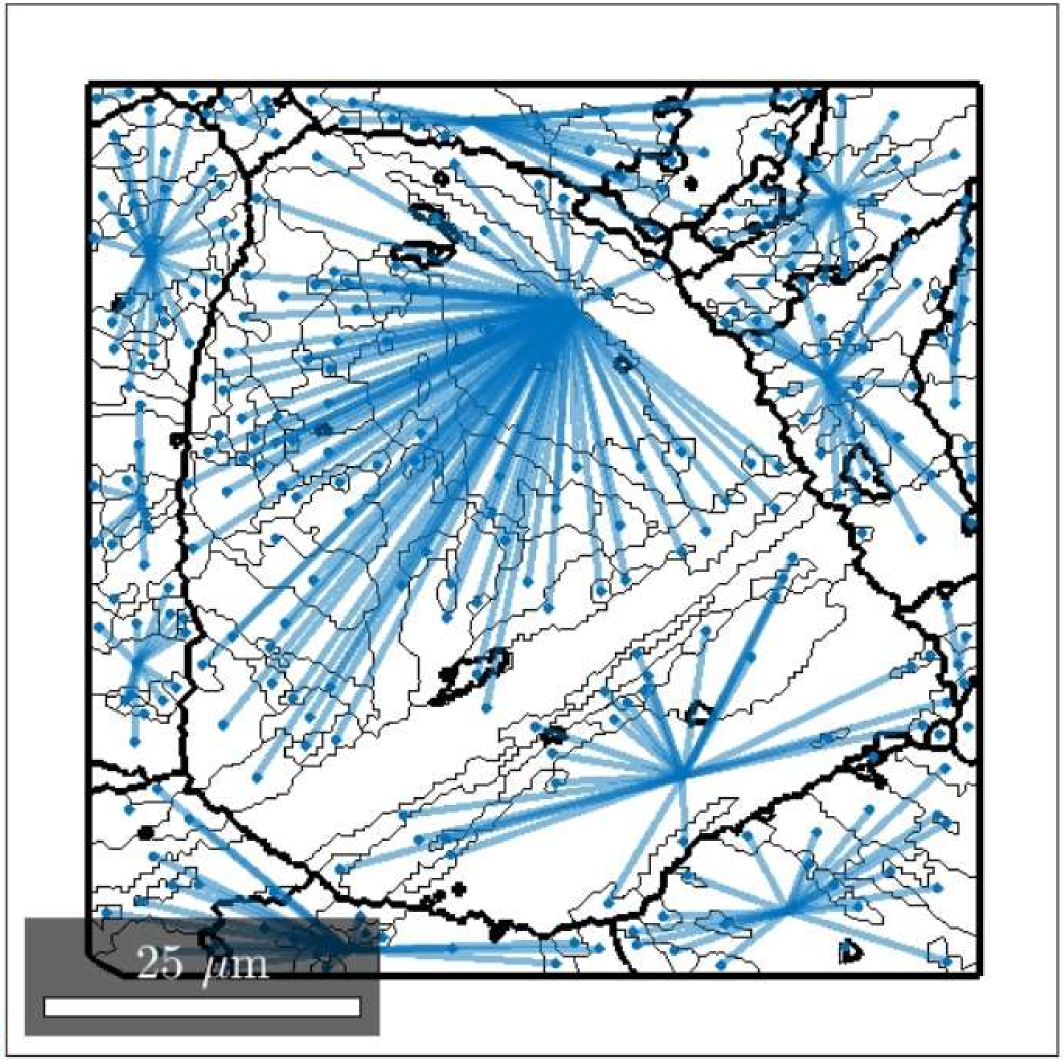
While doing so...

- We have essentially defined parent orientations for all the analyzed misorientations! $M = C_j^{-1} T_{\gamma\to\alpha}^{-1} P_j^{-1} P_i T_{\gamma\to\alpha} C_i$

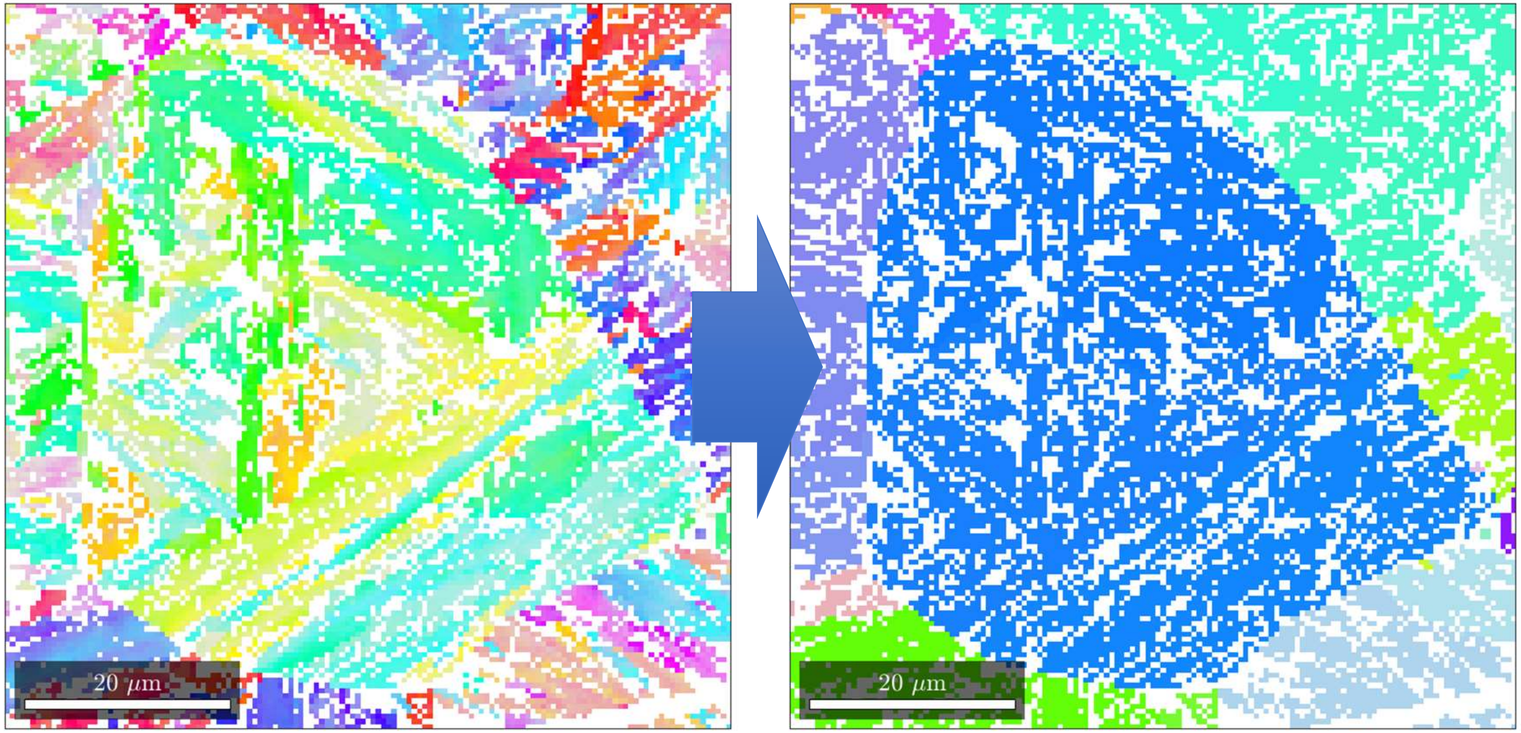


What does MCL do?

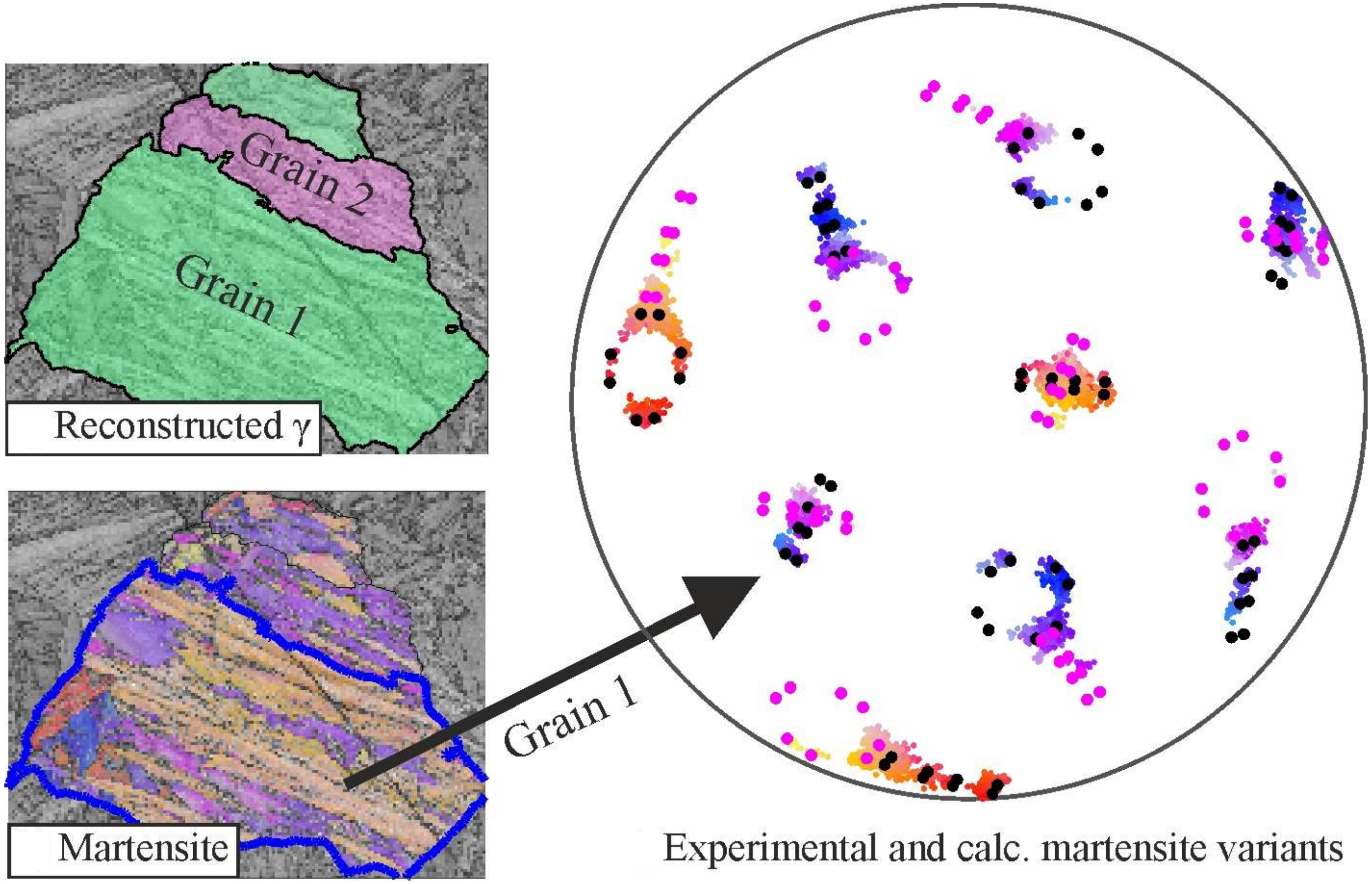




What we get!

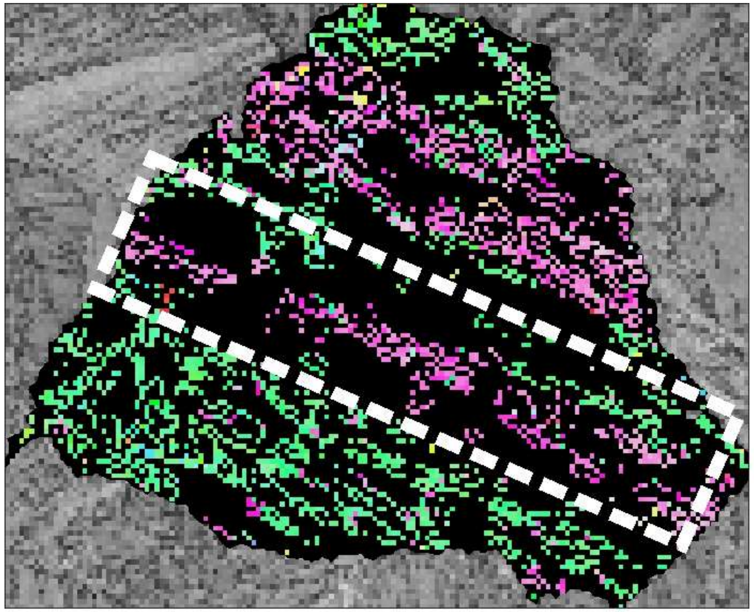


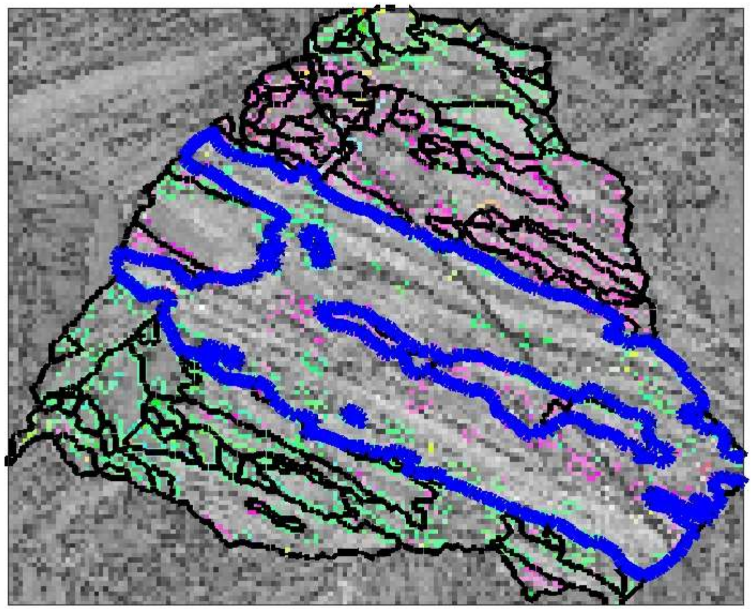
Quite often the problem is twinning.



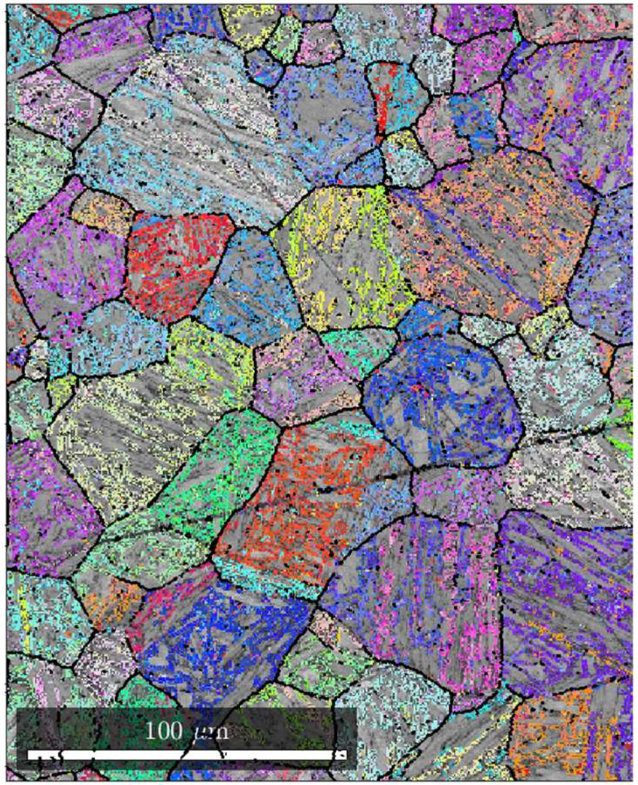
$$O_\gamma(x_i)P_i = O_{\alpha'}(x_i)(T_{\gamma\to\alpha}C_i)^{-1}$$

$$O_\gamma(x_j)P_j = O_{\alpha'}(x_j)(T_{\gamma\to\alpha}C_j)^{-1}$$





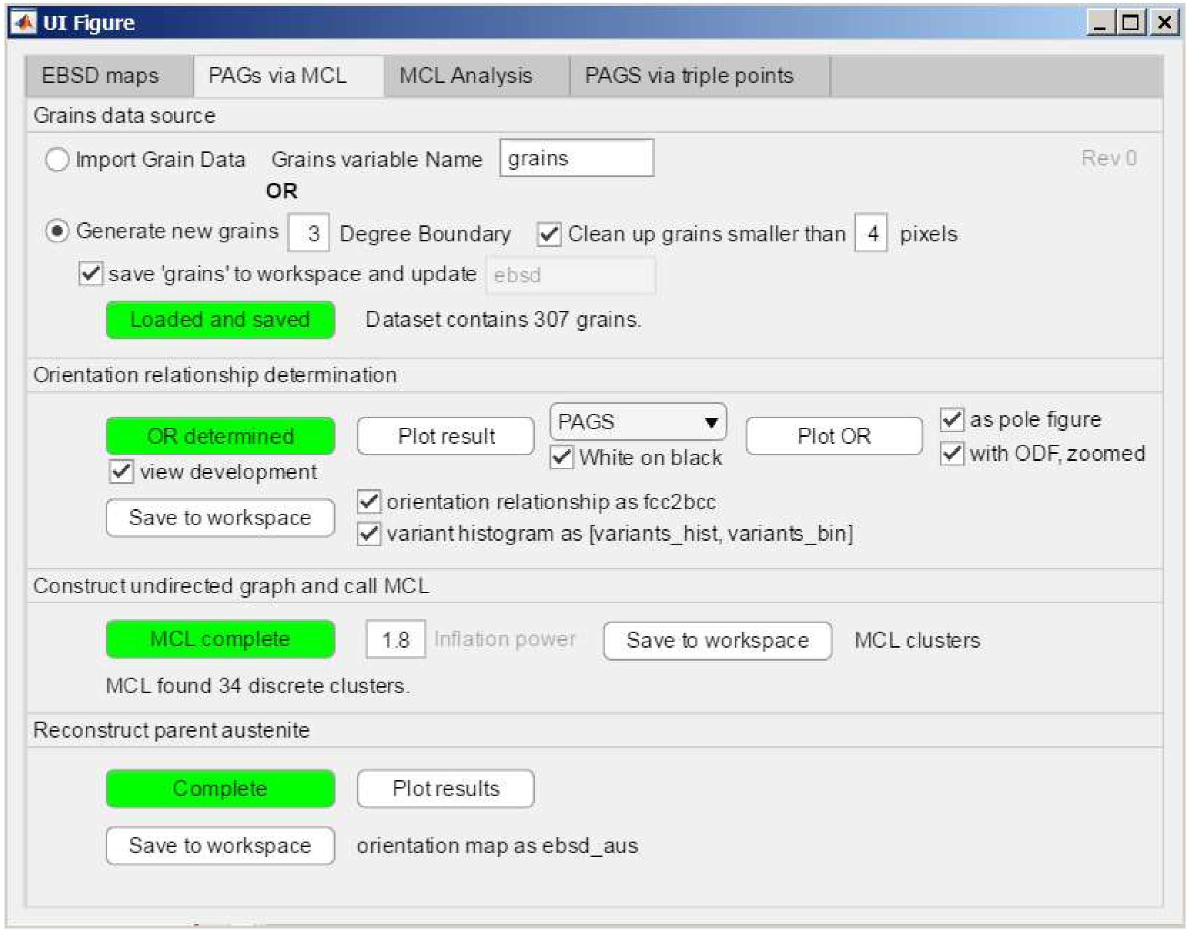
A reference map becomes available for comparison with whatever algorithm.



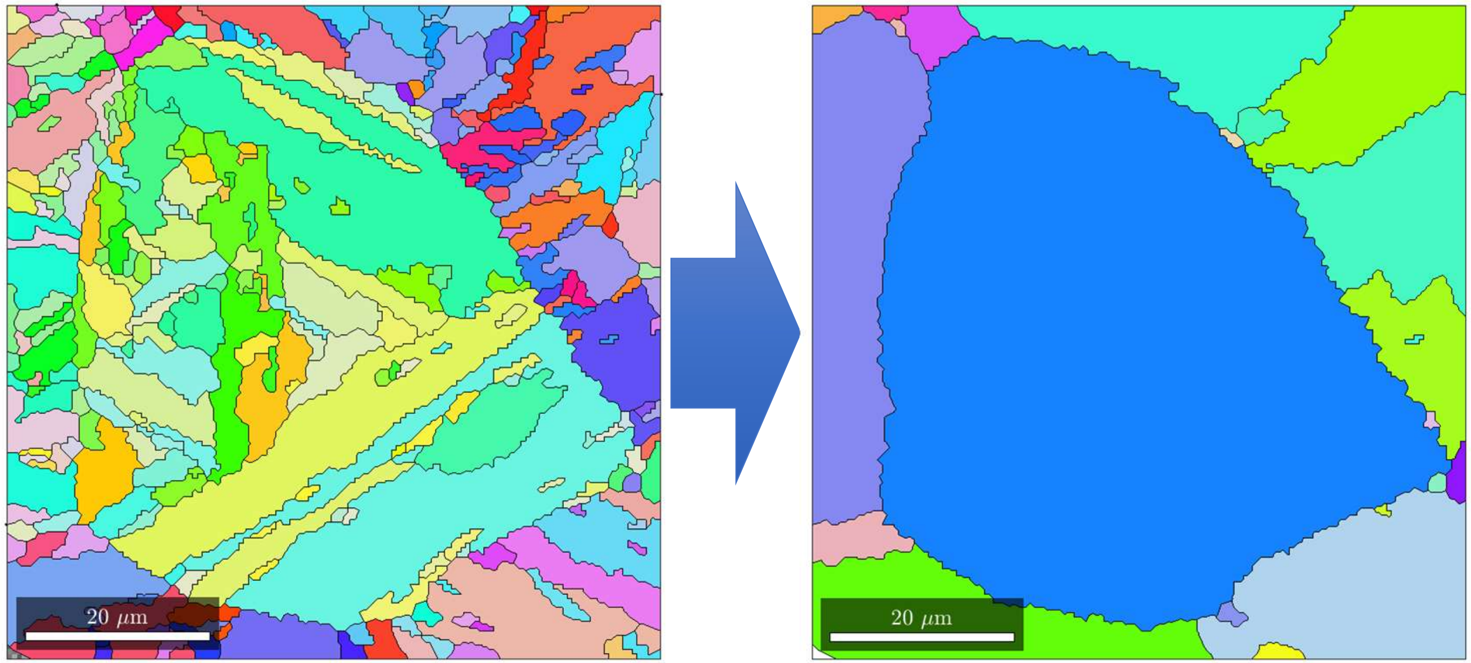
$$O_\gamma(x_i)P_i = O_{\alpha'}(x_i)(T_{\gamma\to\alpha}C_i)^{-1}$$

$$O_\gamma(x_j)P_j = O_{\alpha'}(x_j)(T_{\gamma\to\alpha}C_j)^{-1}$$

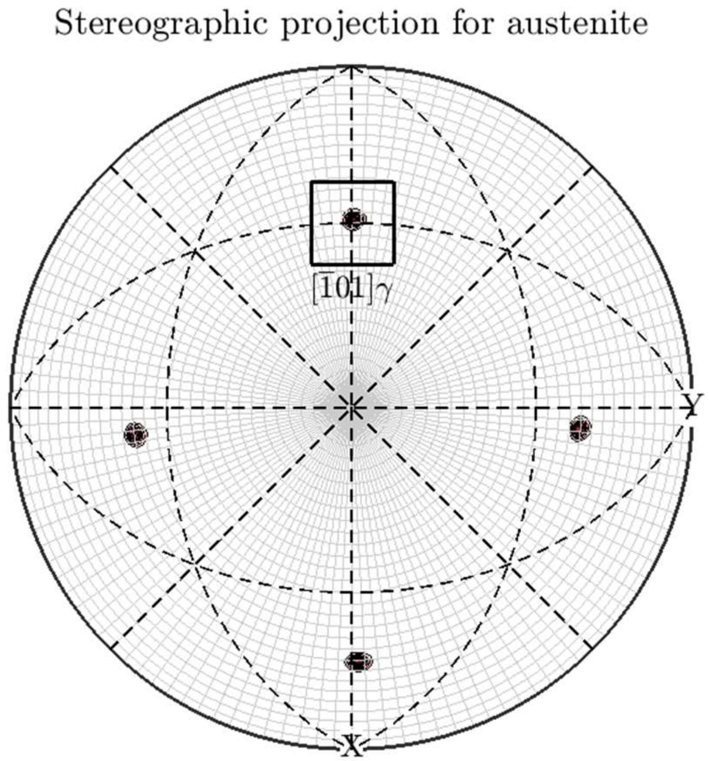
Software for analysis

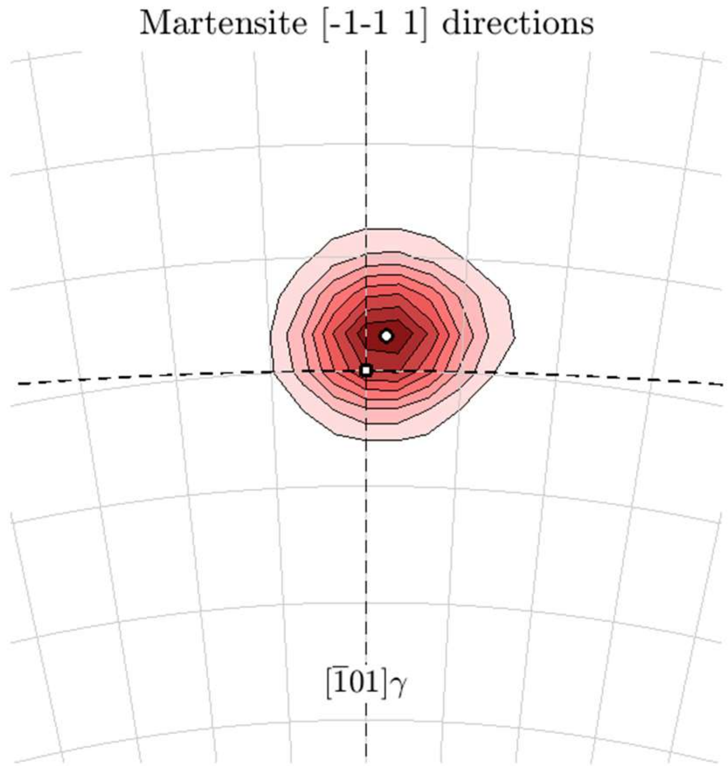


Software for analysis



Software for analysis





More details

Metallurgical and Materials Transactions A manuscript No.
(will be inserted by the editor)

Crystallography, Morphology, and Martensite Transformation of Prior Austenite in Intercritically Annealed High-Aluminum Steel

T. Nyyssönen · P. Peura ·
V.-T. Kuokkala

Received: date / Accepted: date

Abstract The crystallography and morphology of the intercritical austenite phase in two high-aluminum steels annealed at 850 °C was examined on the basis of electron backscattered diffraction analysis, in concert with a novel orientation relationship determination and prior austenite reconstruction algorithm. The formed intercritical austenite predominantly shared a Kurdjumov-Sachs type semicoherent boundary with at least one of the neighboring intercritical ferrite grains. If

Software for analysis

Researchgate

Parent austenite reconstruction for Matlab
with MTEX: graphical user interface
Tuomo Nyyssönen

e-mail

tuomoknyyssonen@gmail.com

Github

https://github.com/nyyssont/parent_austenite_reconstruction

Two basic reconstruction methods: