# *Interfaces and Pattern Formation in ω-transitions*

**Hanuš SEINER**
*Institute of Thermomechanics,*
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*Prague (CZ)*

**based on joint research with:**

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**Charles University**
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Multidisciplinary Research Center for
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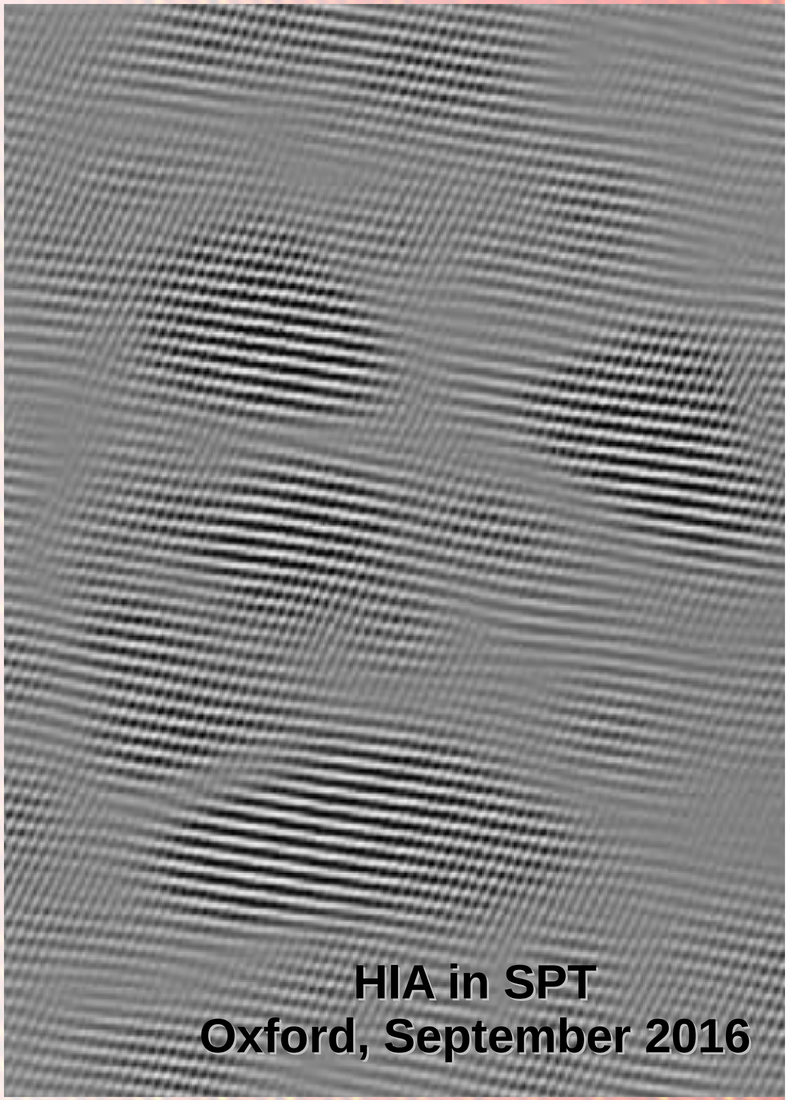

**HIA in SPT**
**Oxford, September 2016**

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(a commented literature search)

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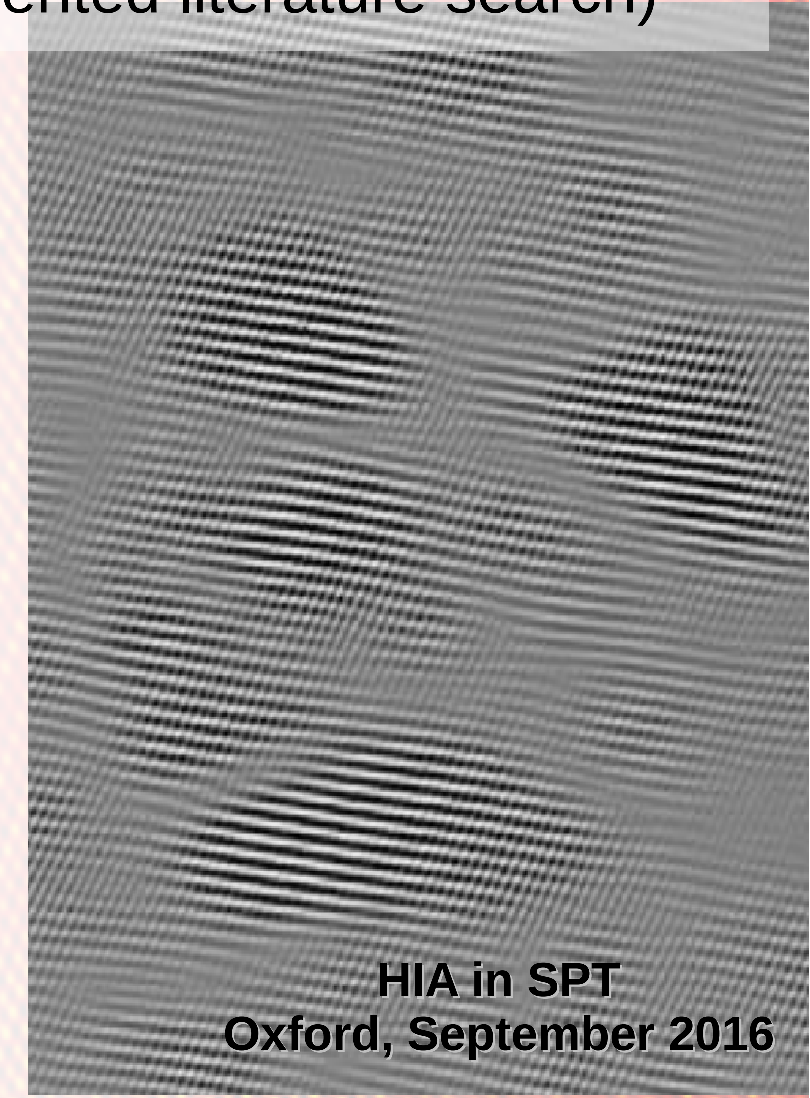

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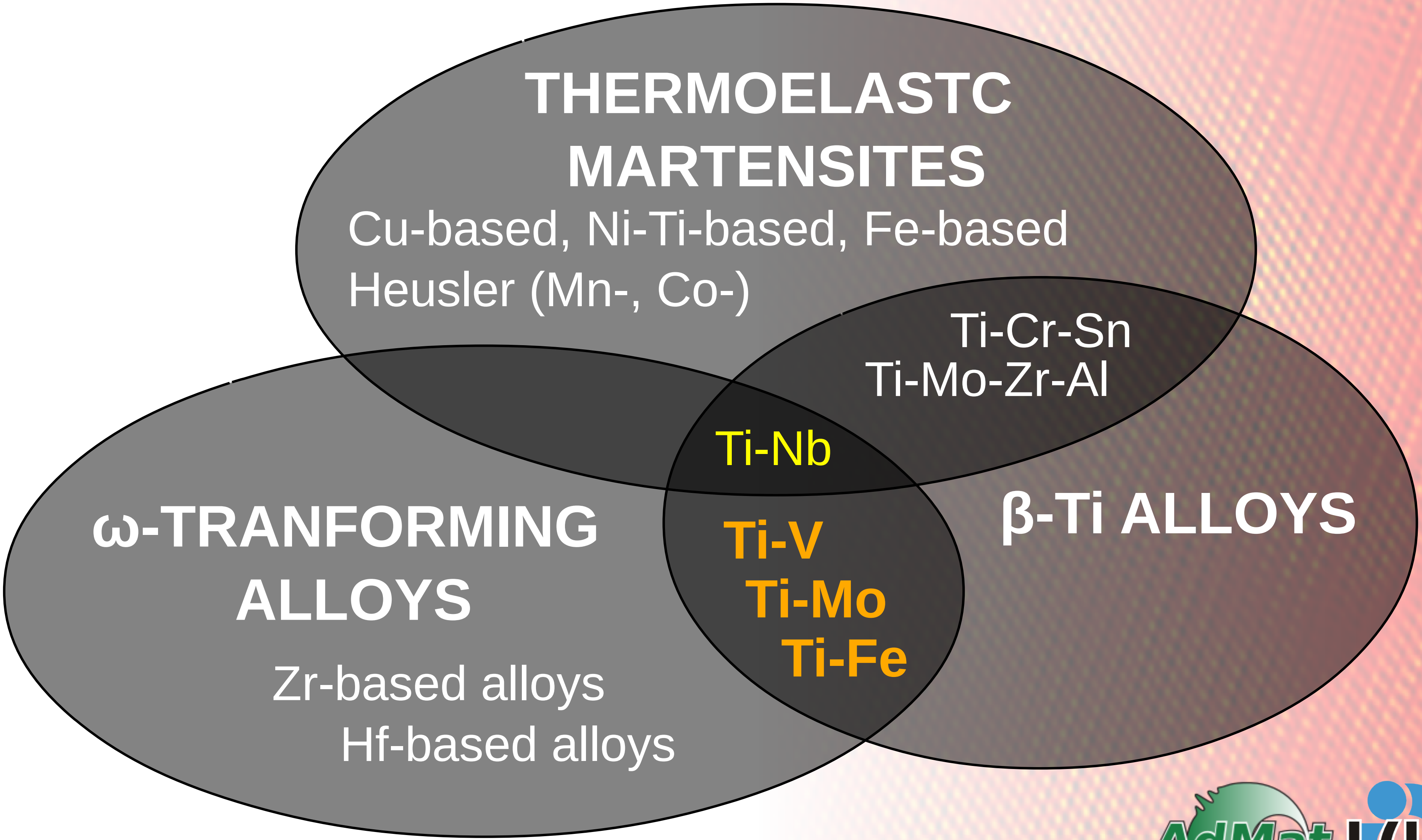
**A. Devaraj et al. / Acta Materialia 60 (2012) 596–609**
**X. L. Wang et al. / Materials Characterization107 (2015) 149–155**
**H. Liu et al. / Acta Materialia 106 (2016) 162-170**
**F. Sun et al. / Acta Materialia 61 (2013) 6406–6417**
**E. Sukedai et al. / Materials Science and Engineering A350 (2003) 133 -138**
**B. Tang et al. / Computational Materials Science 53 (2012) 187–193**
**D. Wang et al. / PRL 105 (2010) 205702**
**X. Ren / Phys. Status Solidi B 251 (2014) 1982–1992**

## Talk outline:

1. What are the ω-transitions and how they differ from (thermoelastic) martensitic transitions
2. Basic thermodynamics and principles
3. Modelling: concepts and tools

# 1. What are the ω-transitions and how they differ from (thermoelastic) martensitic transitions



**THERMOELASTC MARTENSITES**

Cu-based, Ni-Ti-based, Fe-based

Heusler (Mn-, Co-)

Ti-Cr-Sn

Ti-Mo-Zr-Al

Ti-Nb

**ω-TRANFORMING ALLOYS**

**Ti-V**

**Ti-Mo**

**Ti-Fe**

**β-Ti ALLOYS**

Zr-based alloys

Hf-based alloys

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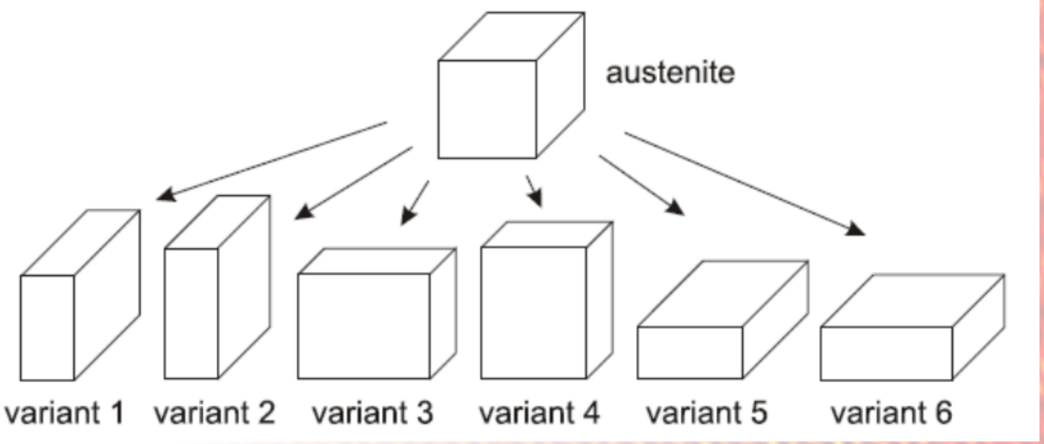
Martensitic transitions:



- the high-symmetry phase (**austenite**) transforms into the low-symmetry phase (**martensite**) upon **cooling**

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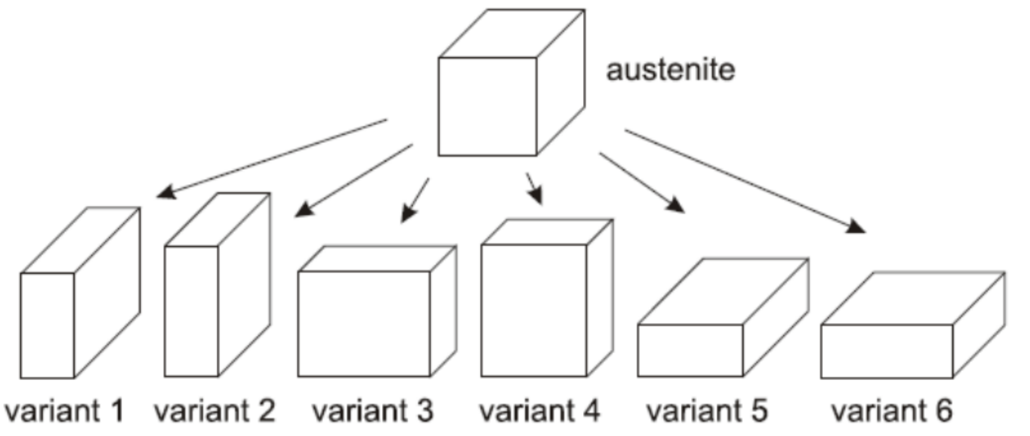

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**or by mechanical loading**

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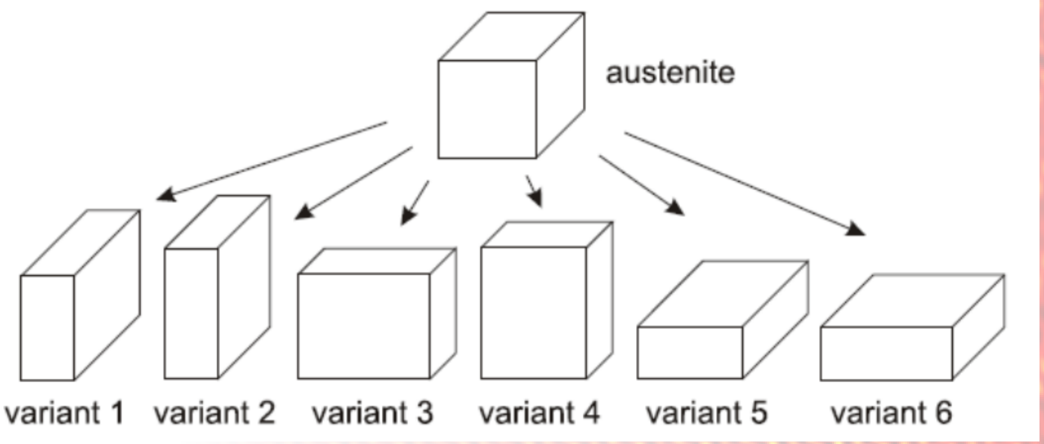

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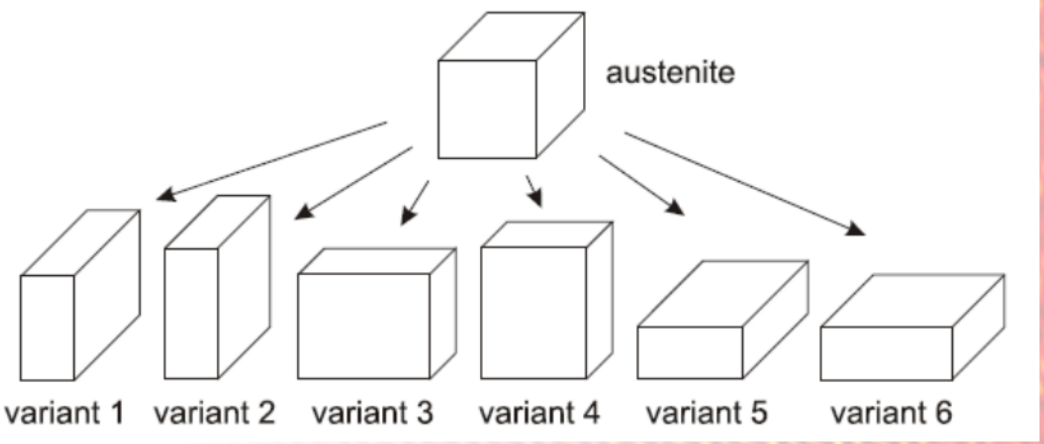

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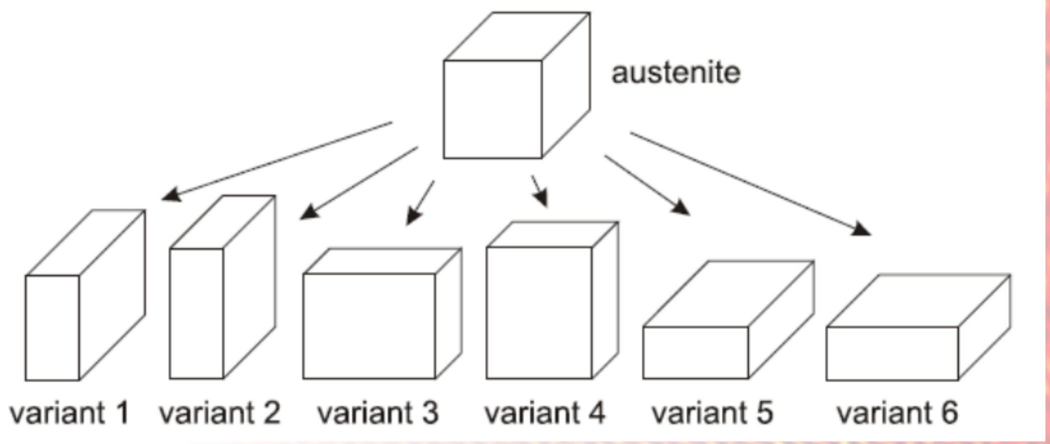

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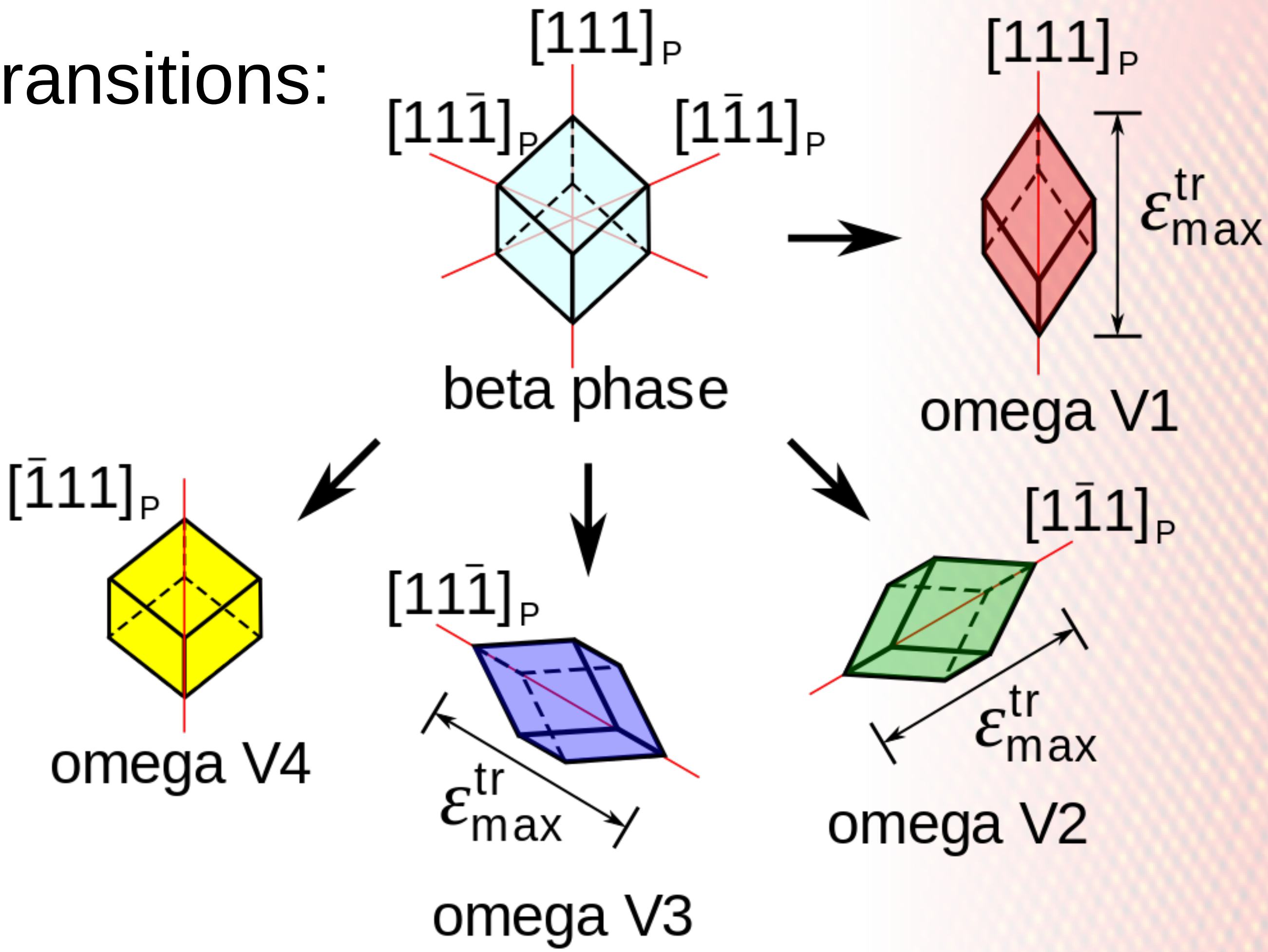

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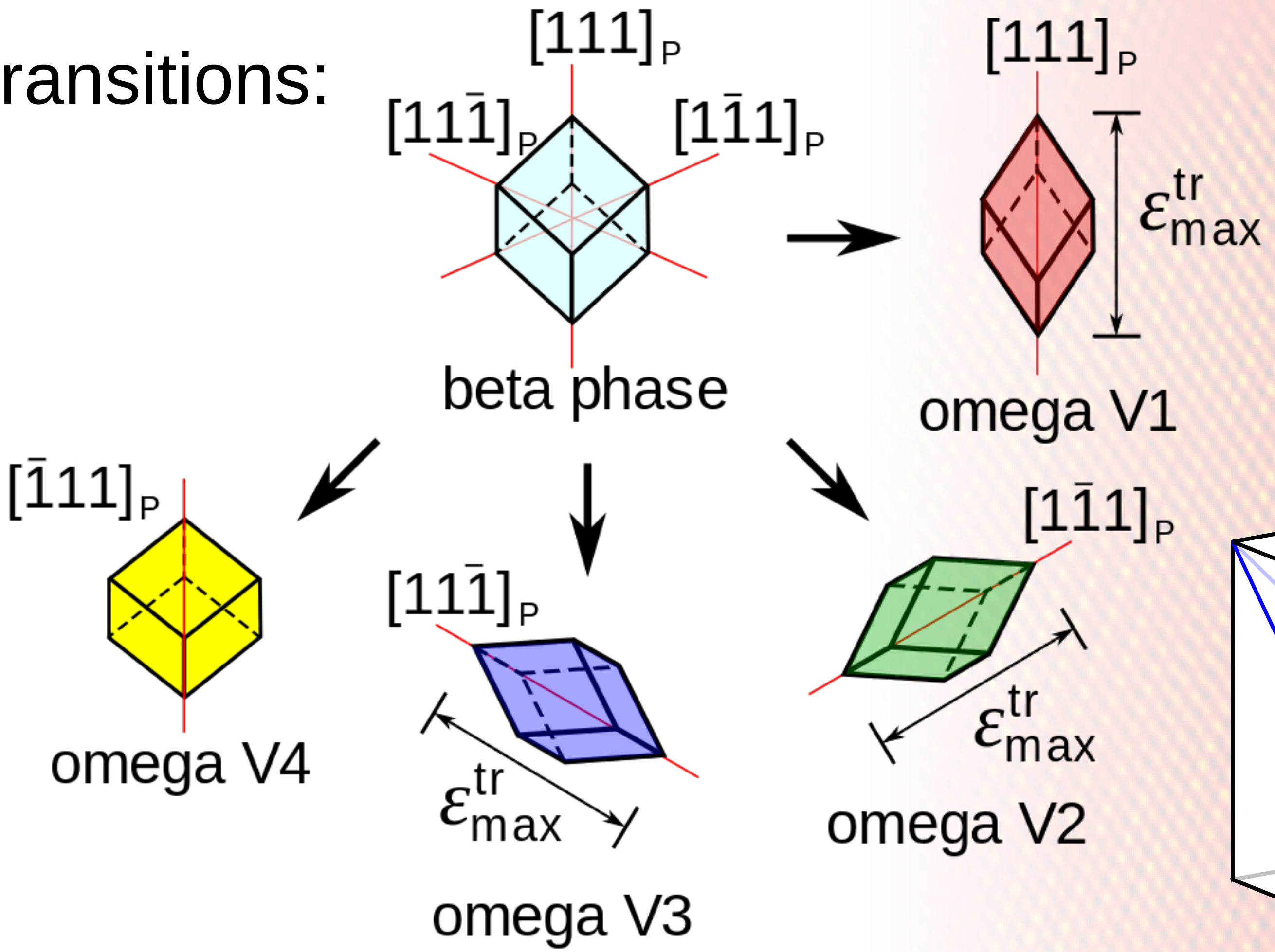

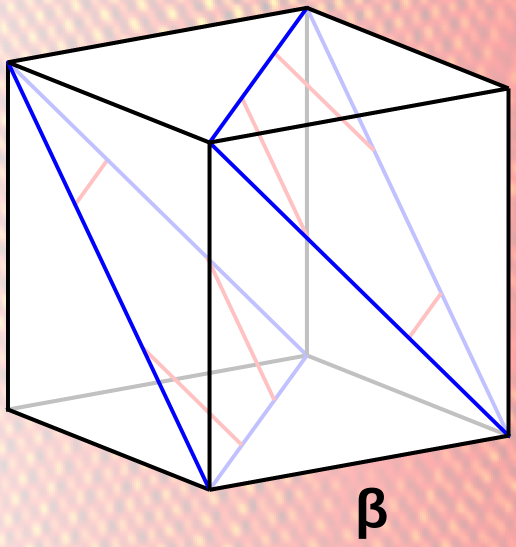

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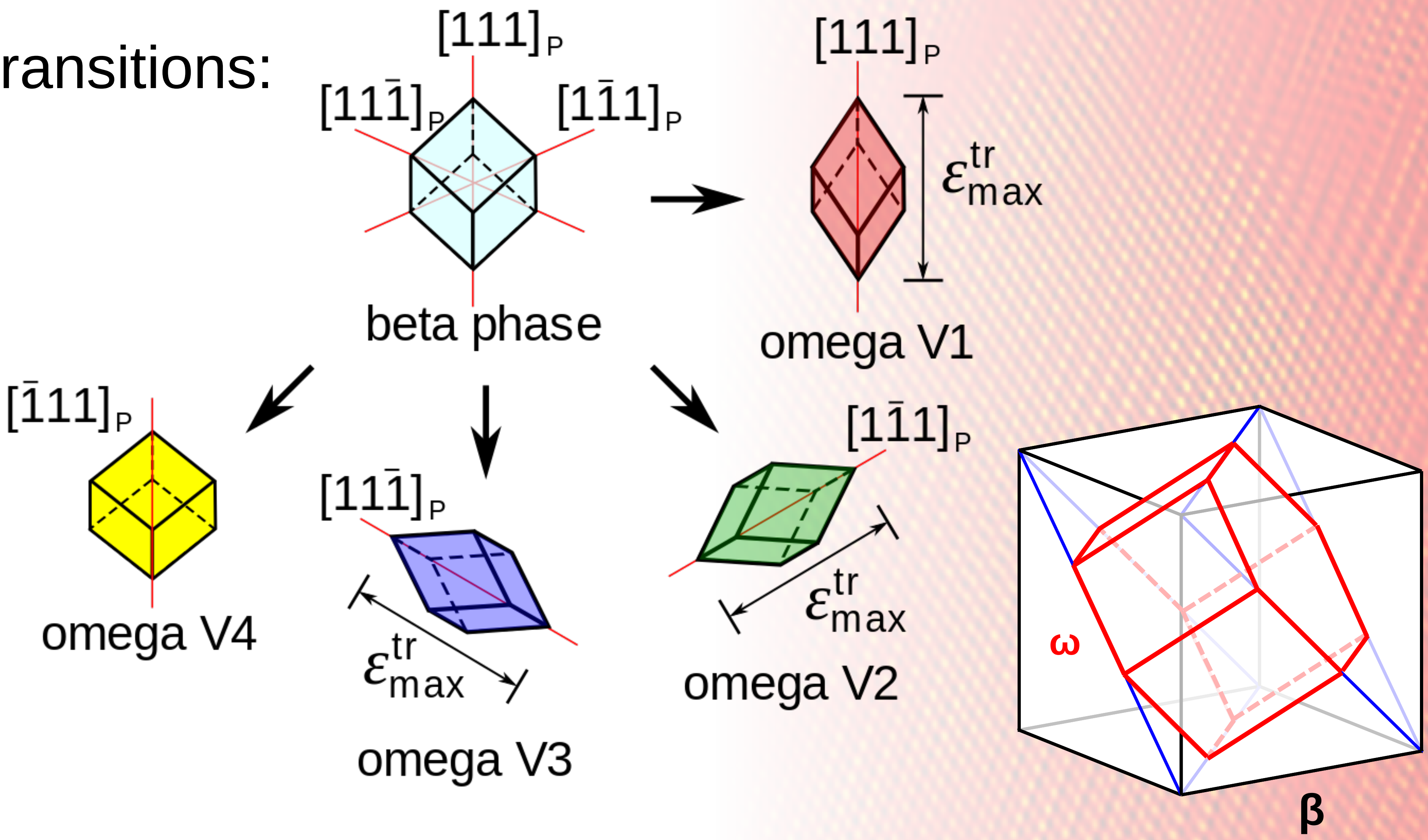

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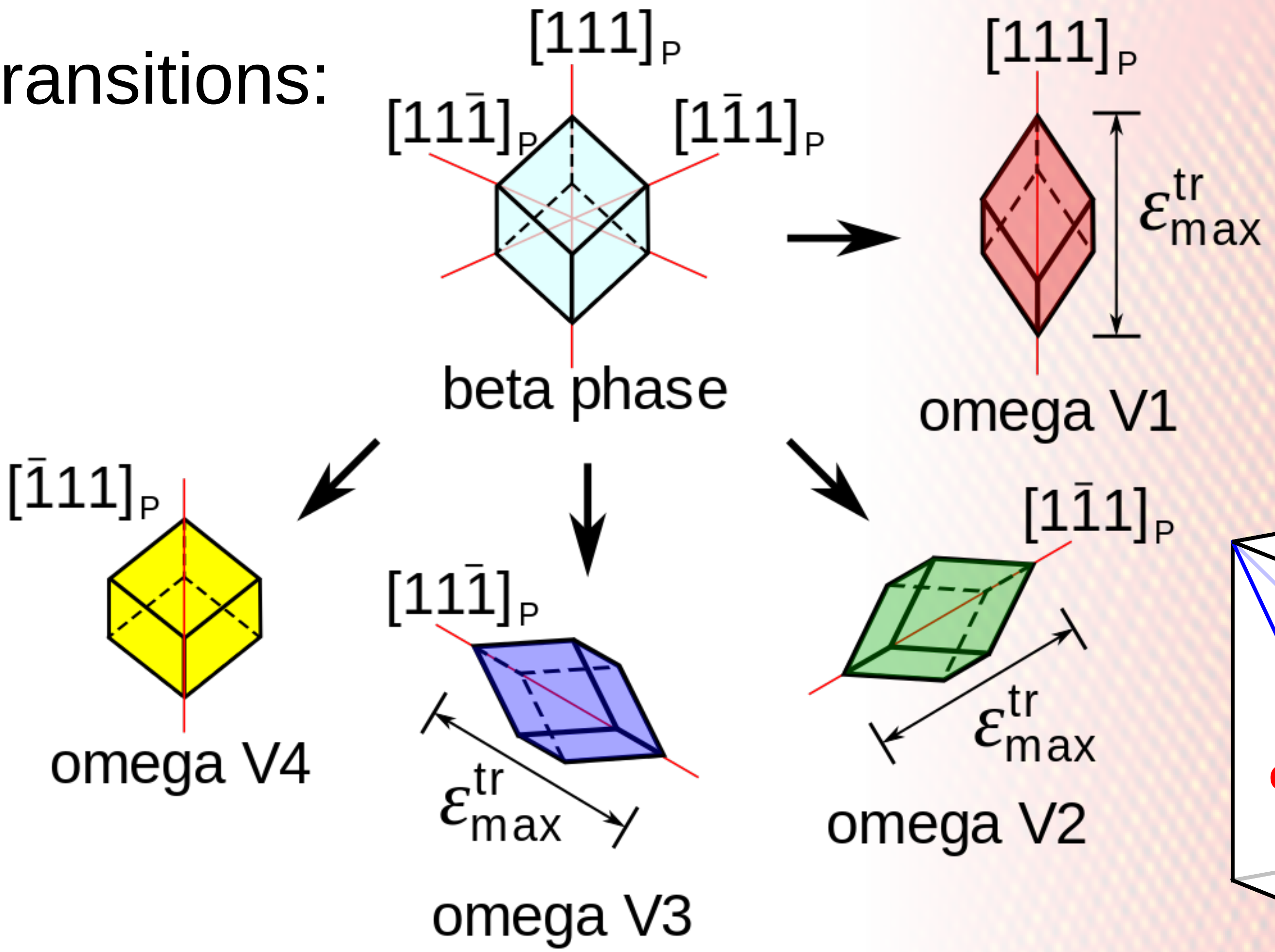

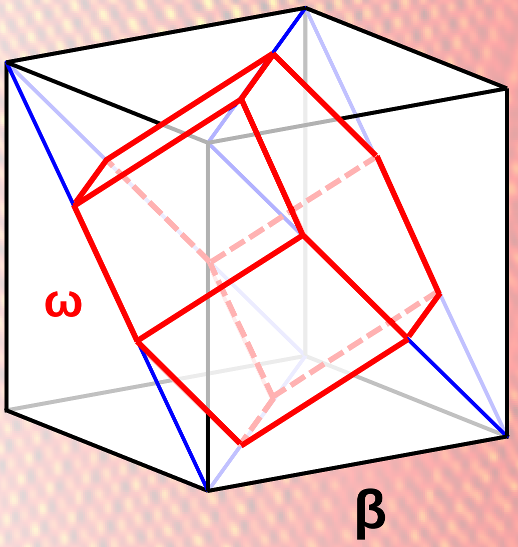

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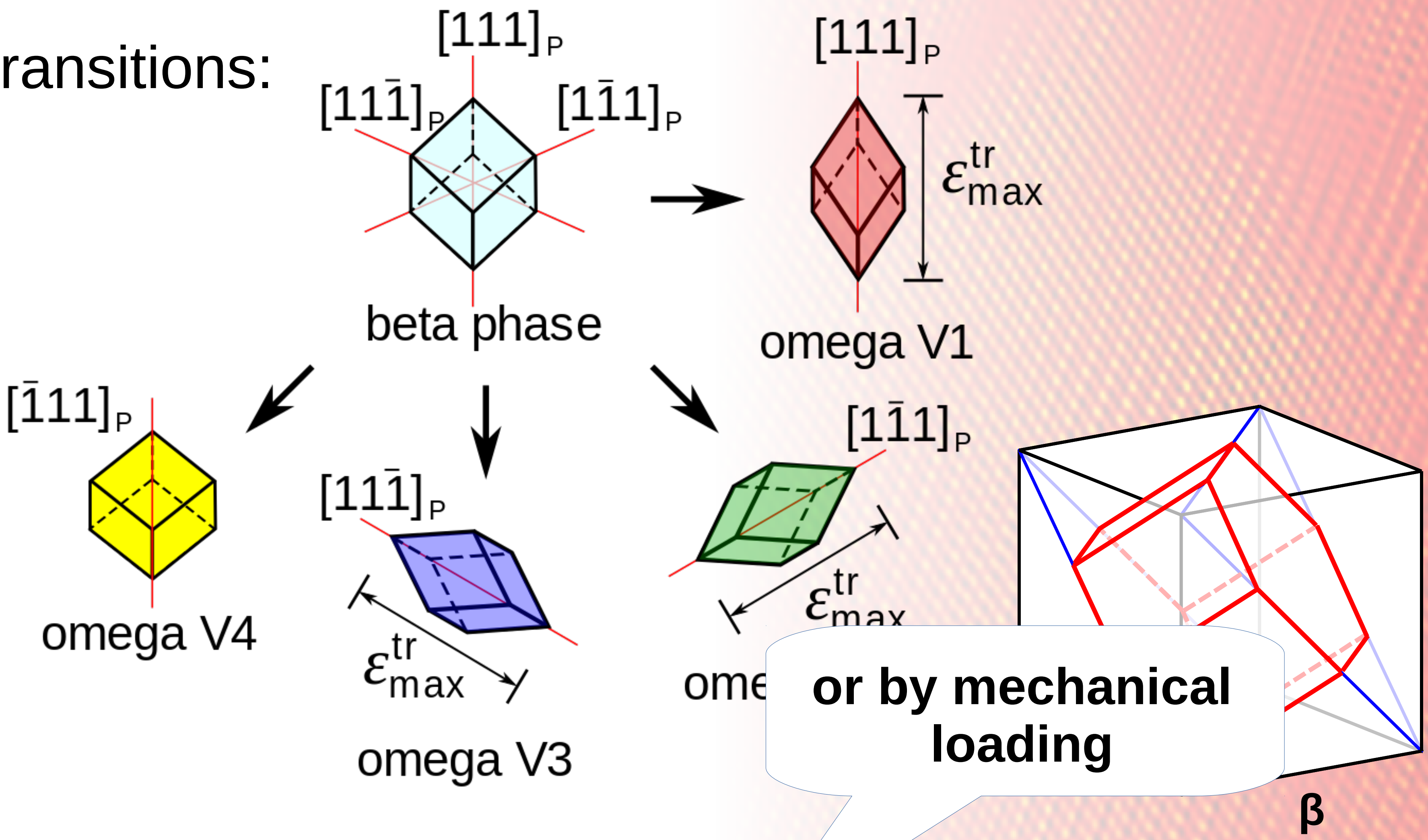

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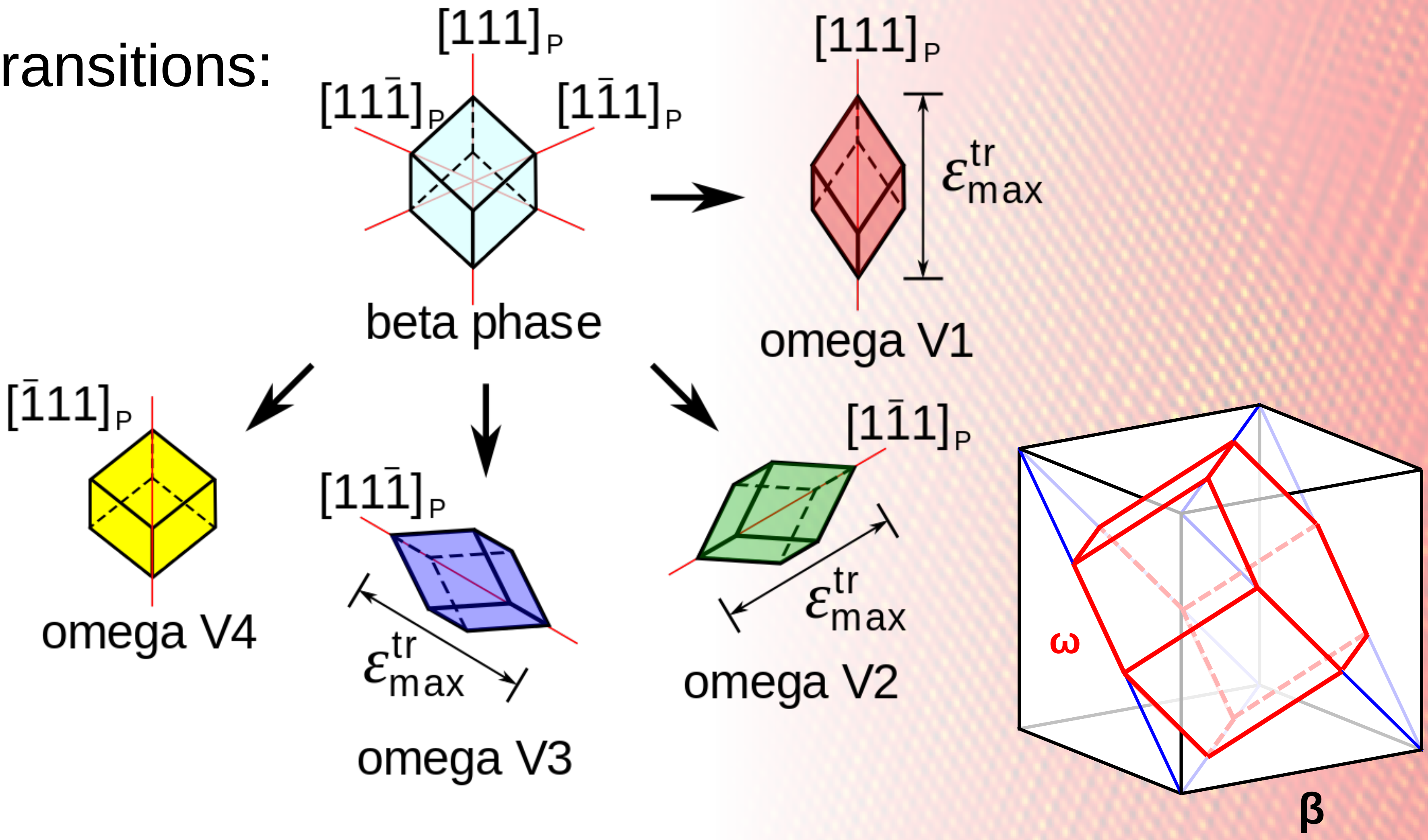

- the **cooling** route is reversible, athermal
- the **heating** route is irreversible, isothermal

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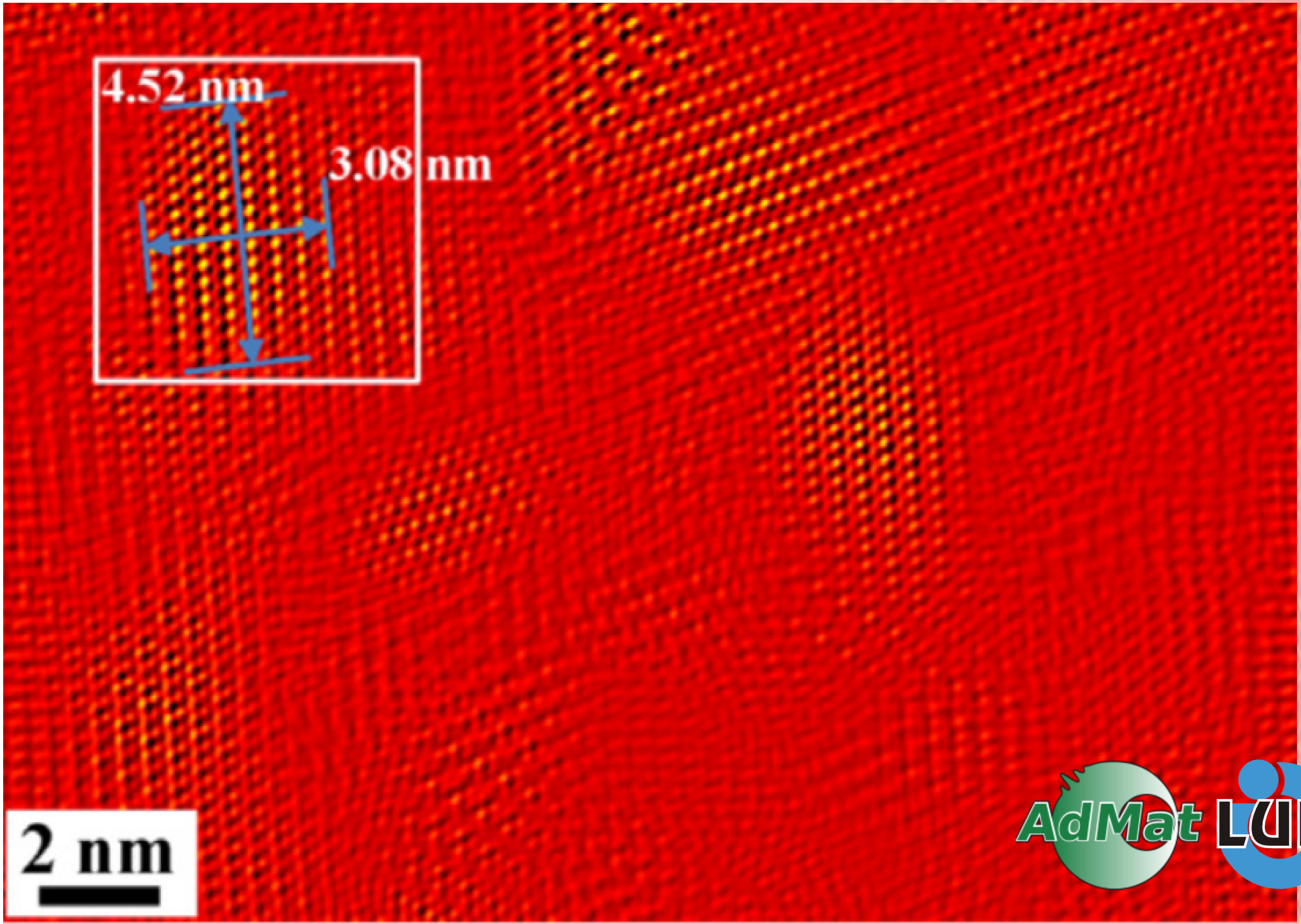
ω-transition patterns - **cooling**



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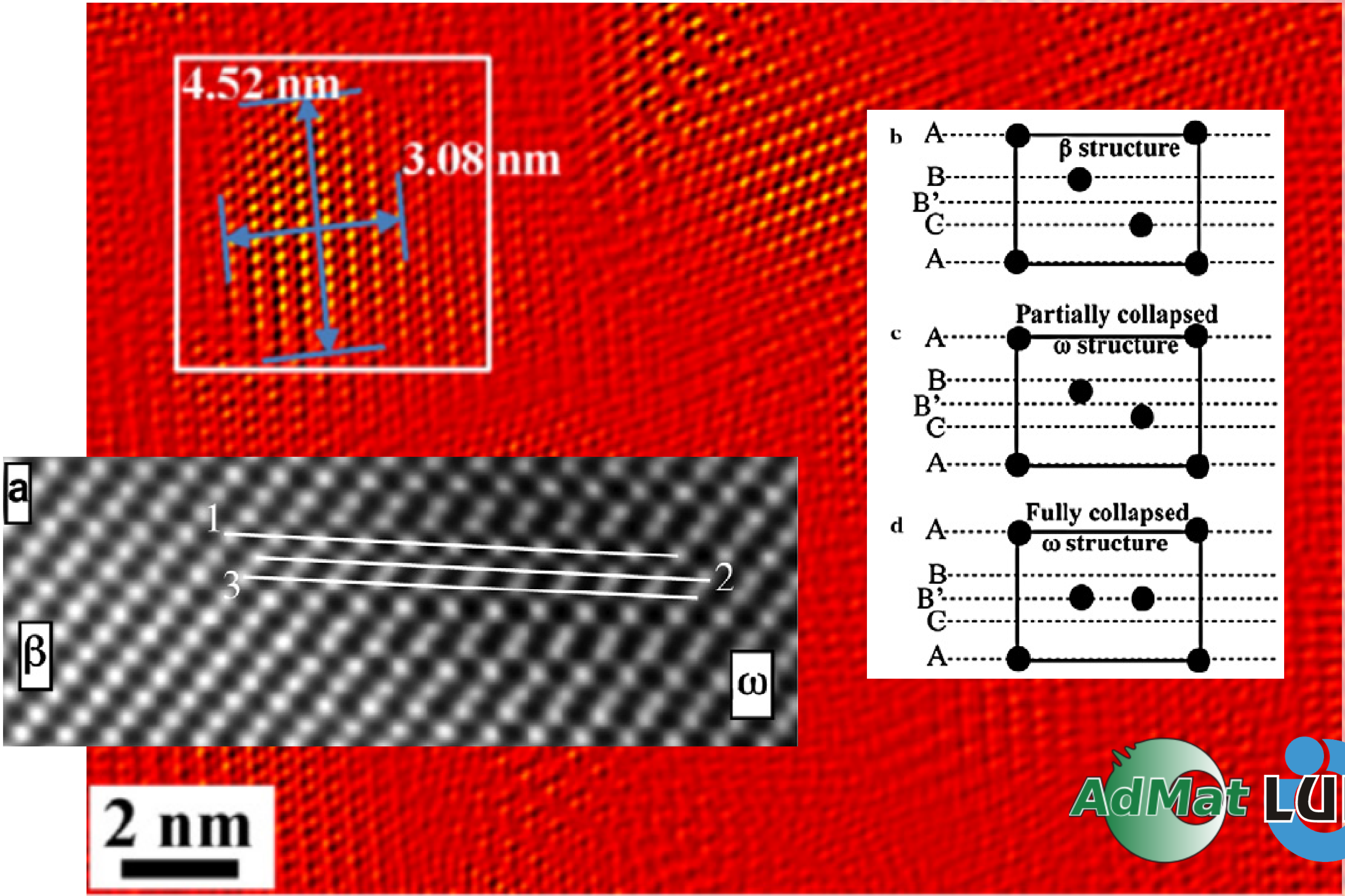

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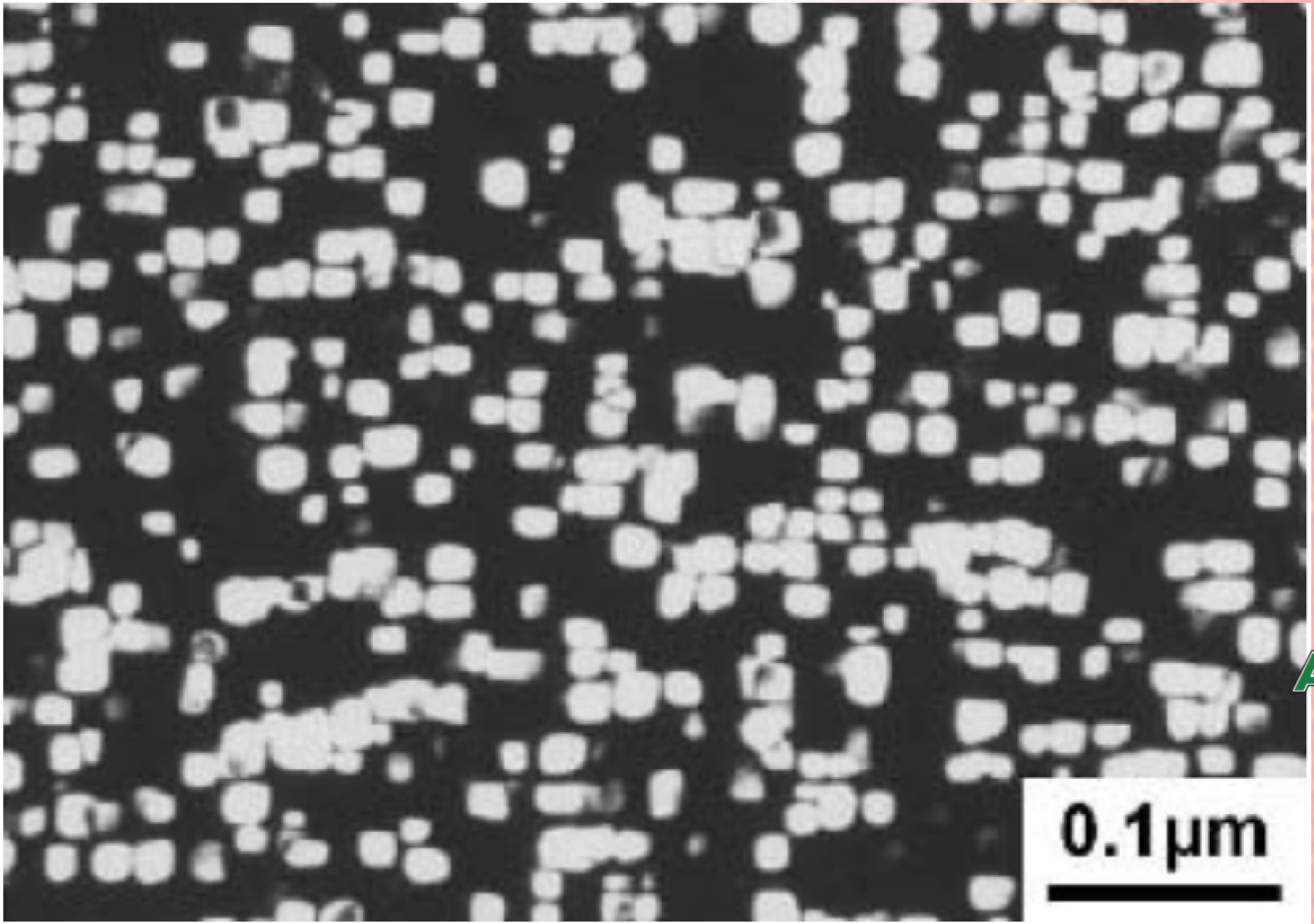

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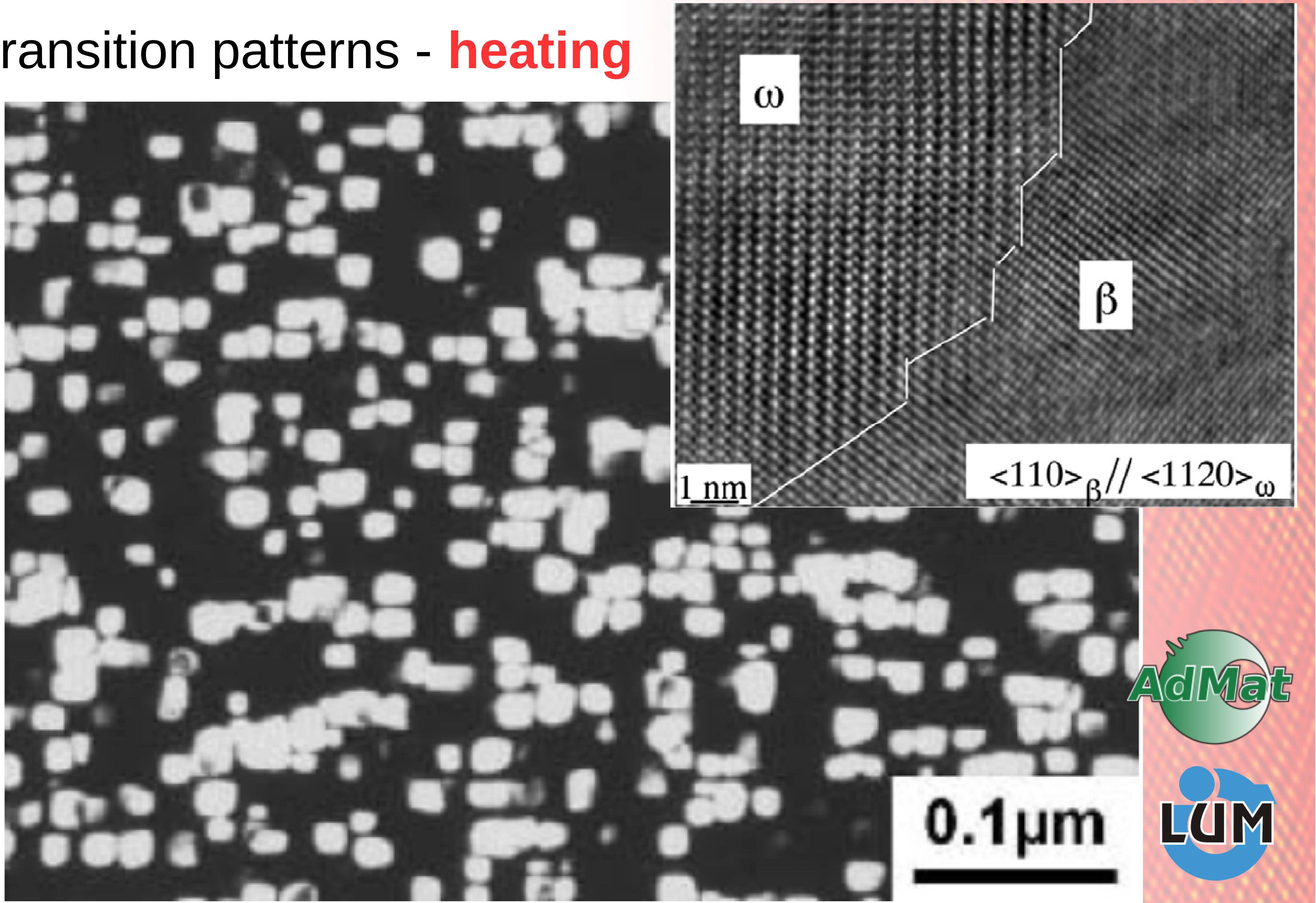

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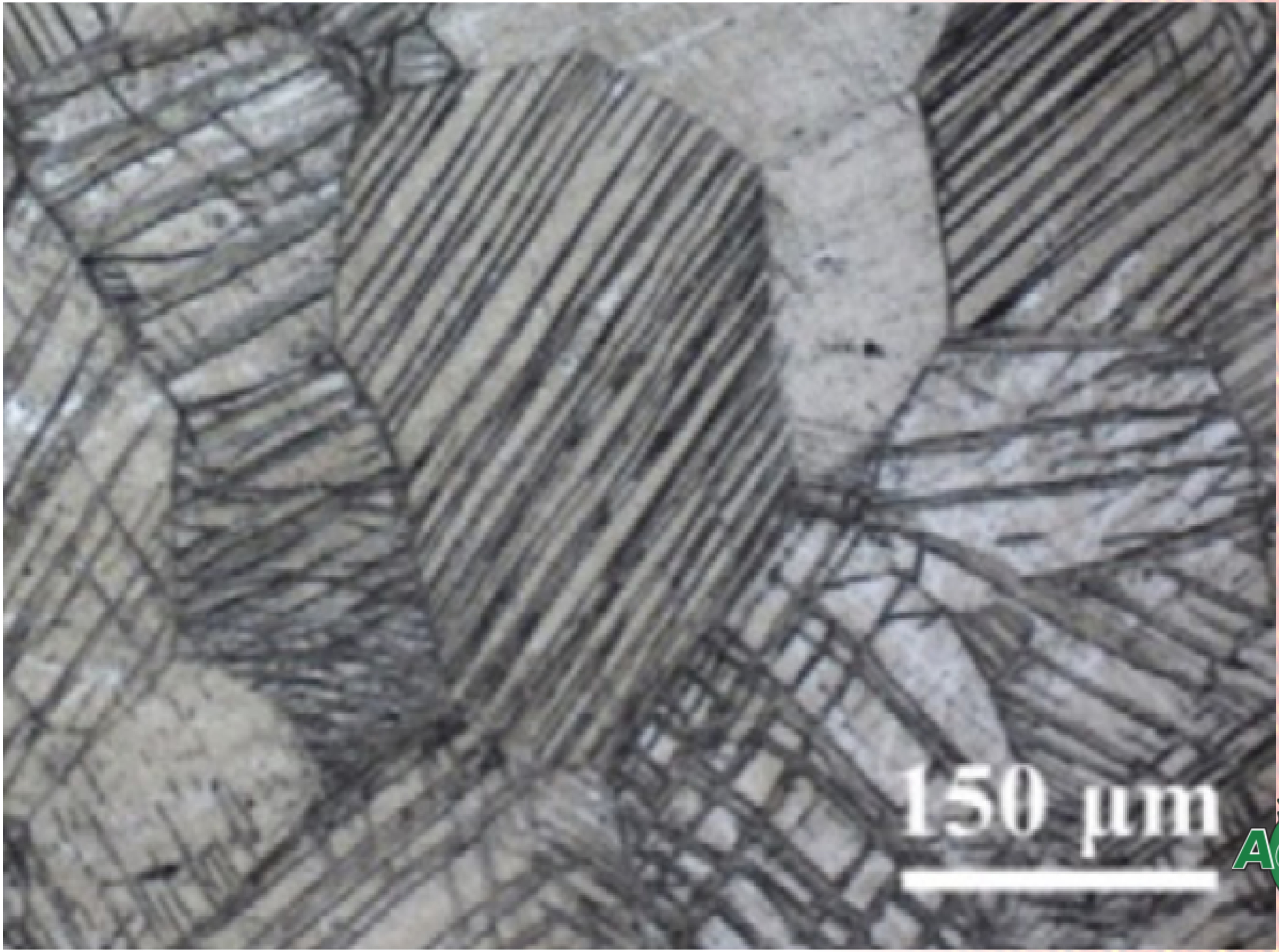

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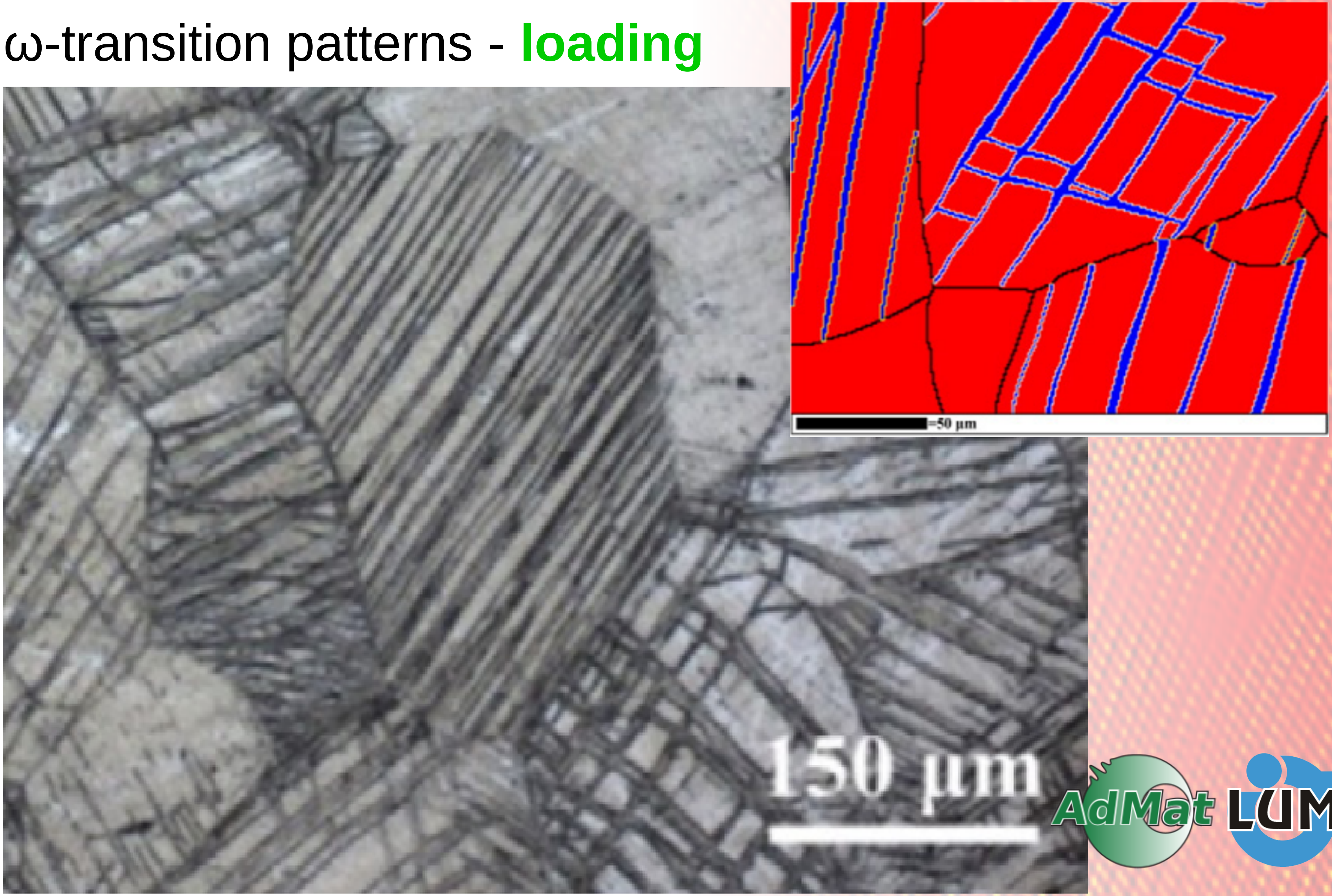
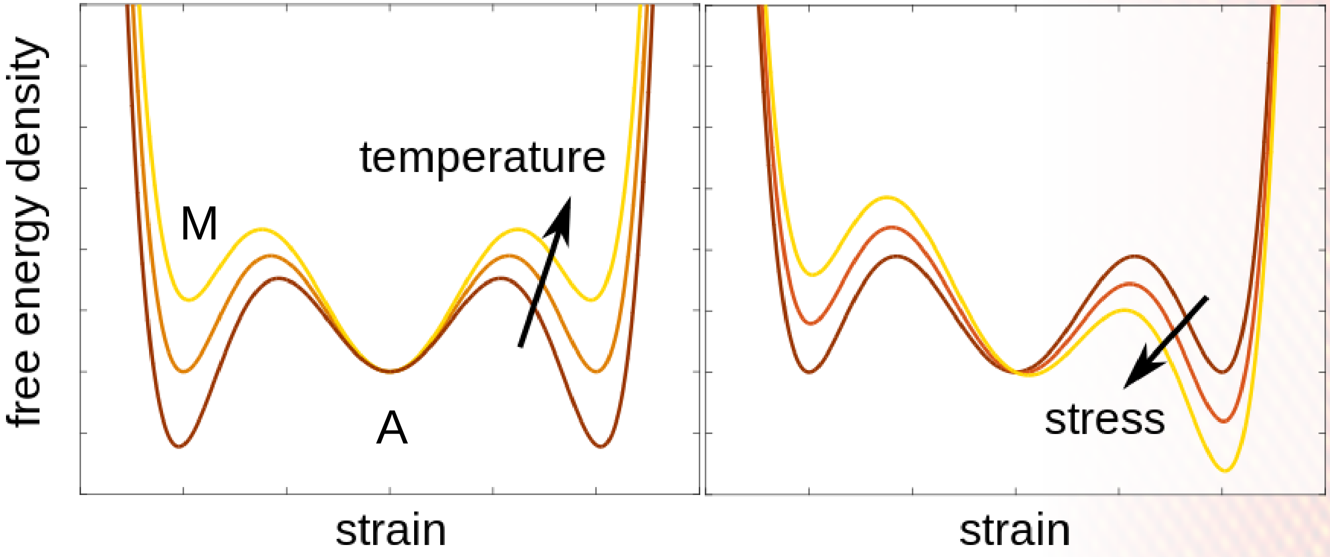
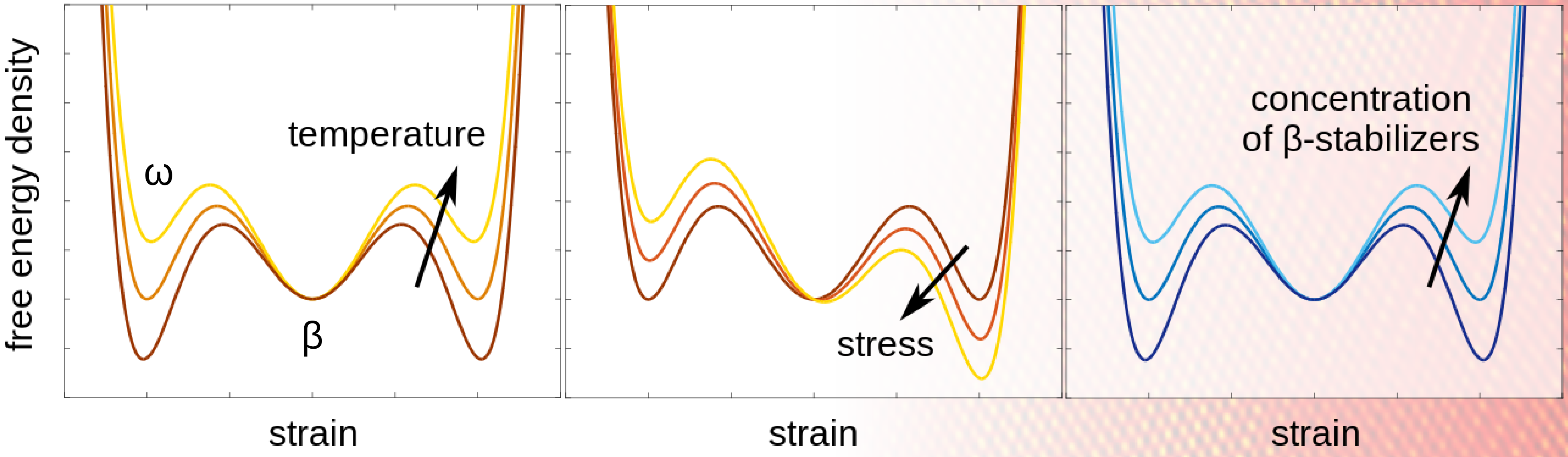


# 2. Basic thermodynamics and principles

## thermoelastic martensites



## ω-transforming materials



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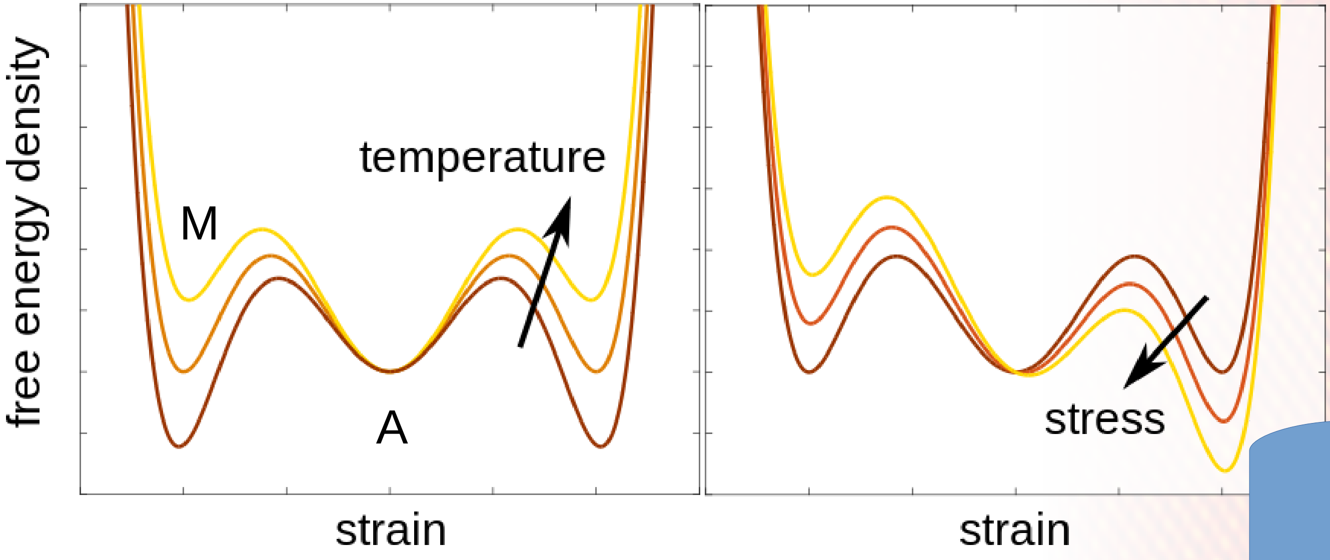
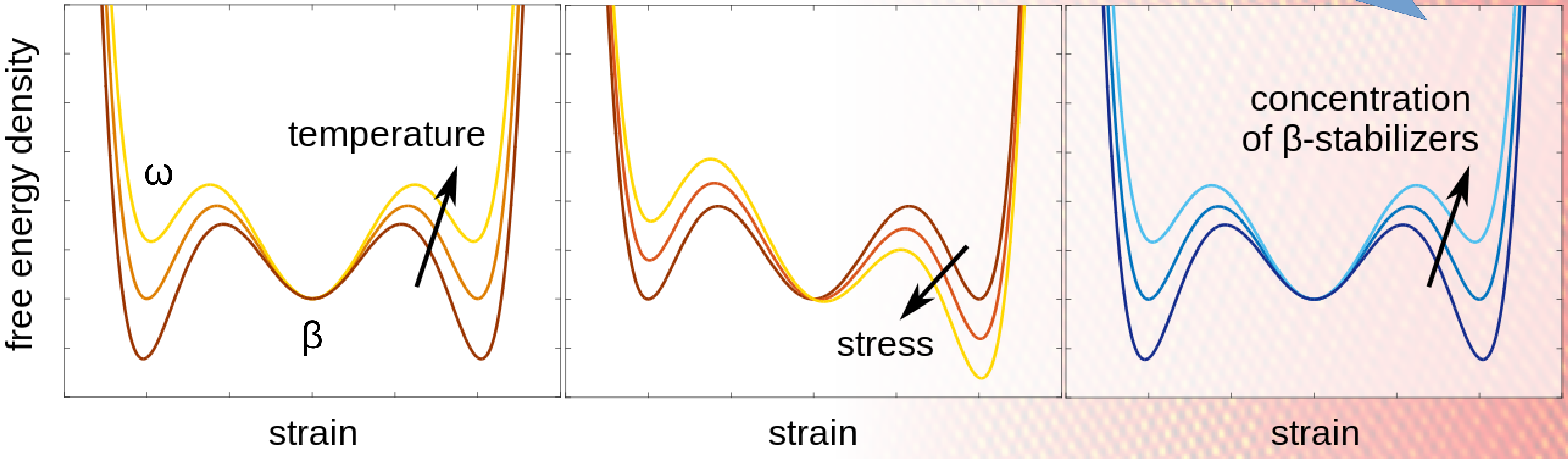
thermoelastic martensites



**Mo, V, Fe, ...**

ω-transforming materials



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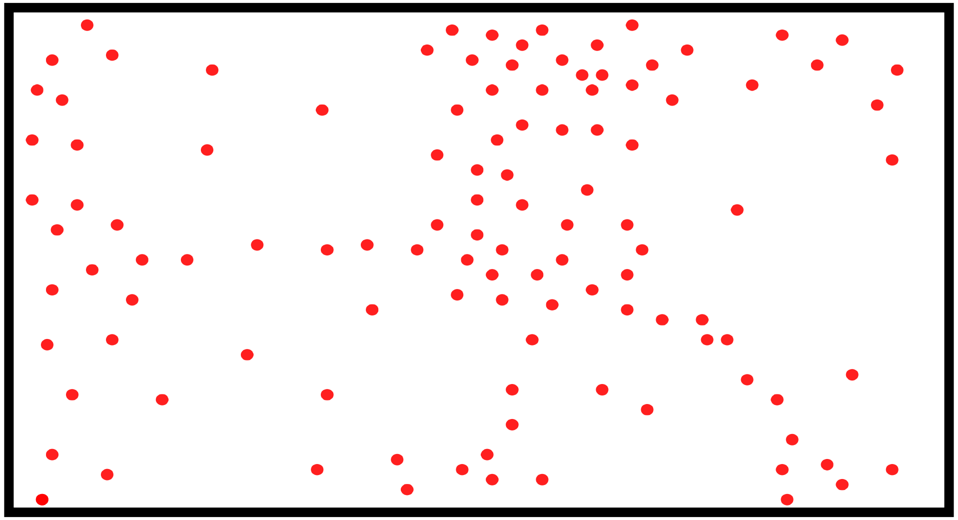
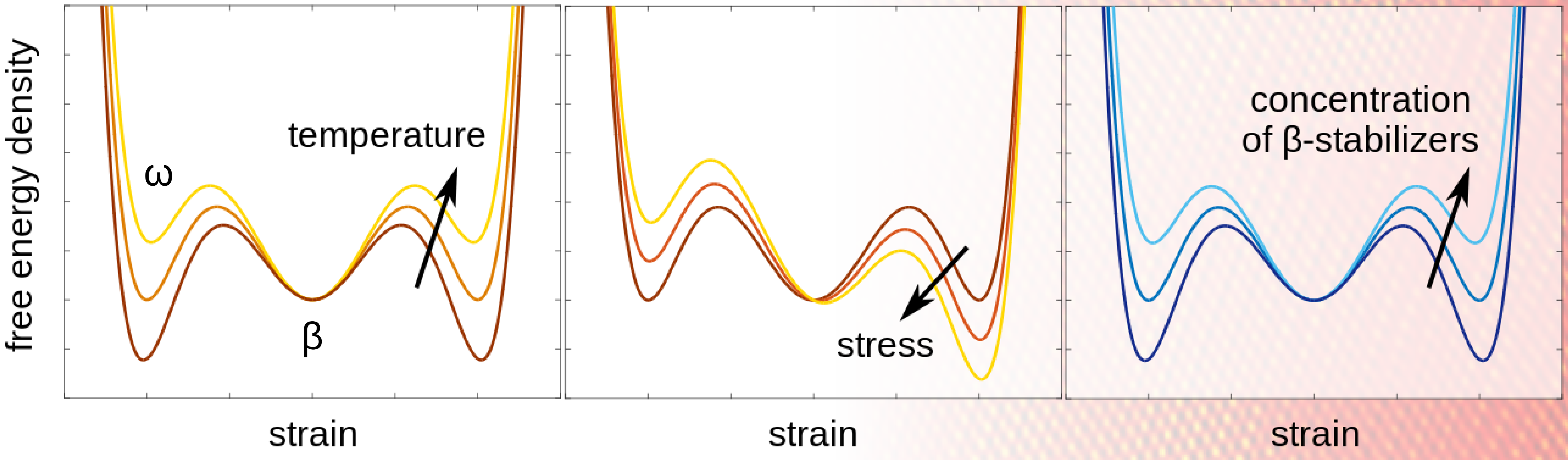
what happens at **low temperatures**?



quenched heterogeneous distribution of β-stabilizers



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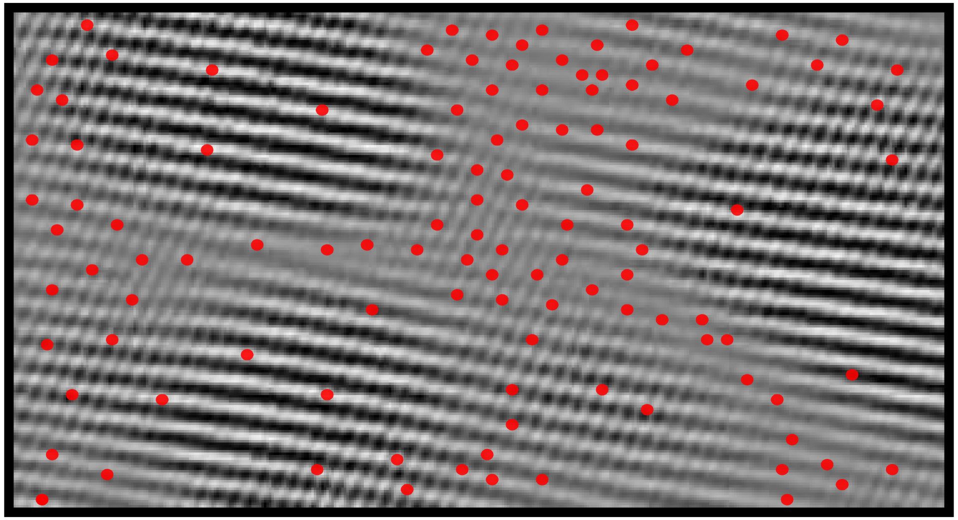
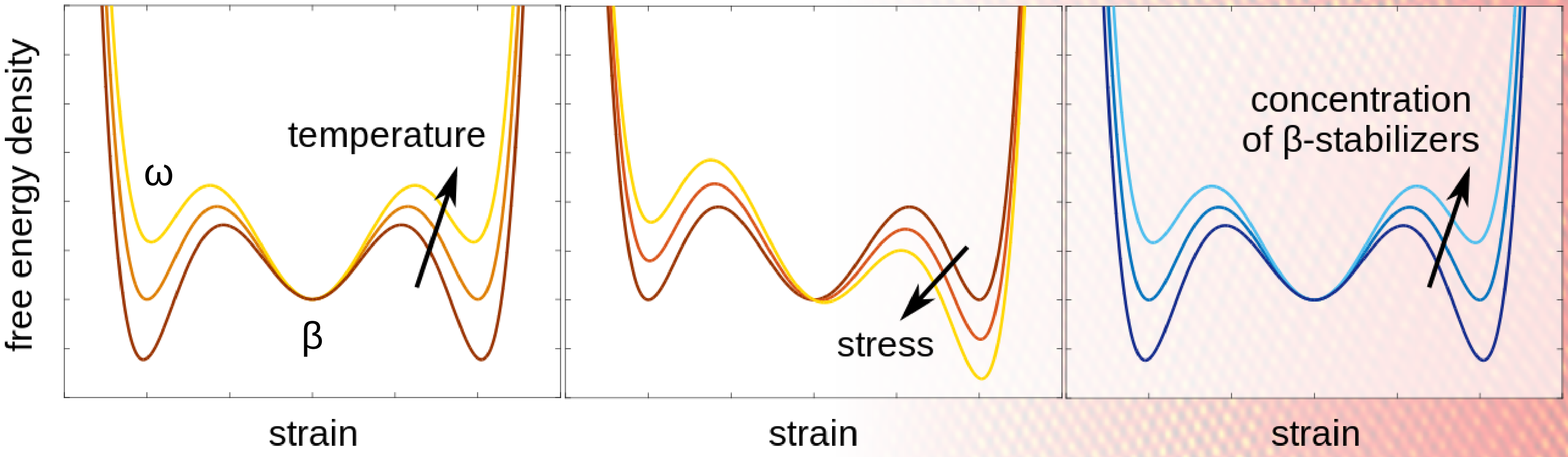


quenched heterogeneous distribution of β-stabilizers

at the low temperature,
the diffusion is not activated



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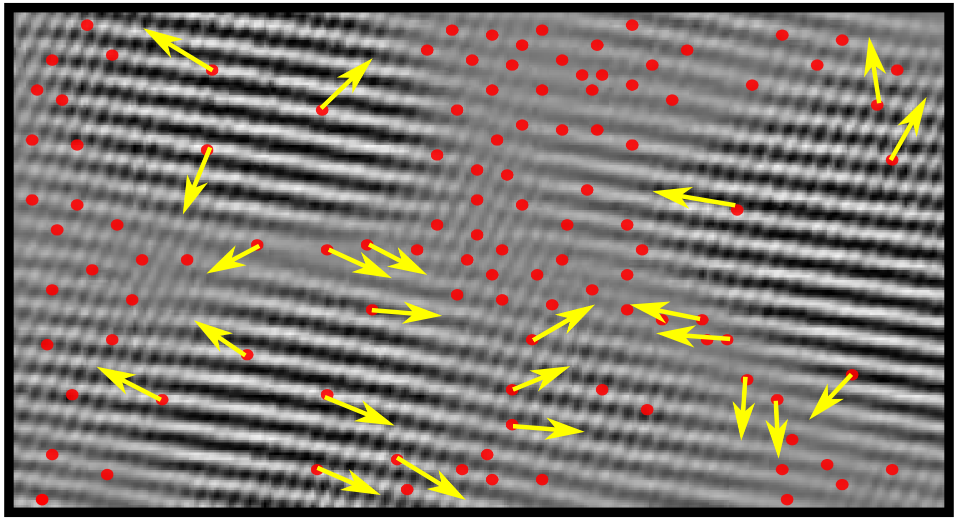
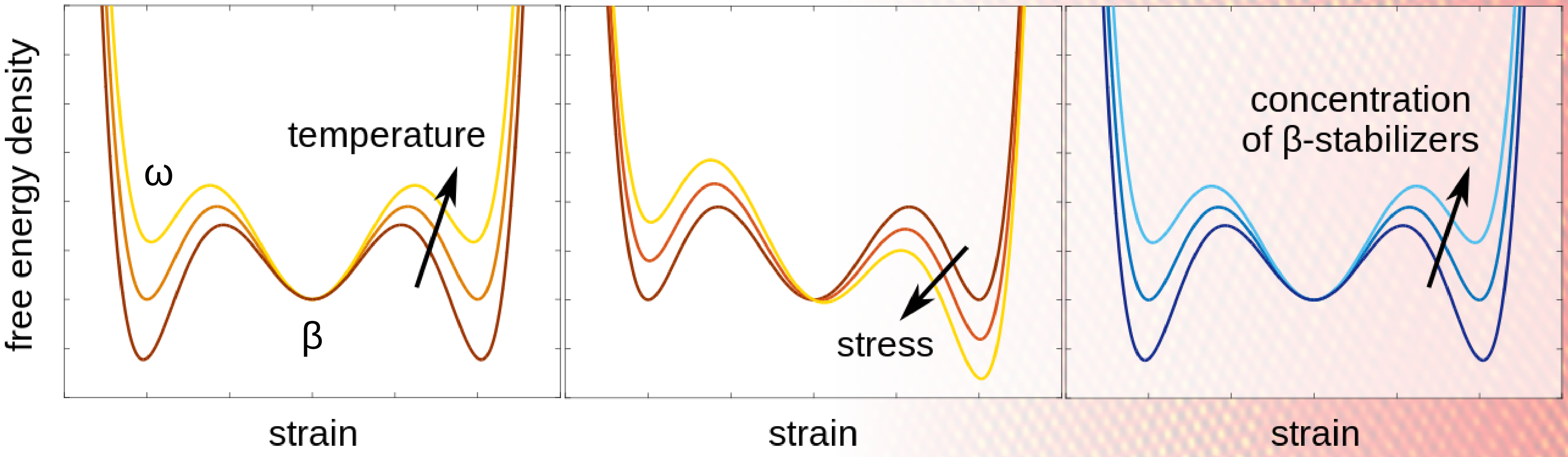
what happens at **high temperatures**?



the of β-stabilizers are repelled from ω-nuclei by diffusion

elastic and diffusional interactions make the ω-particles grow and coalesce



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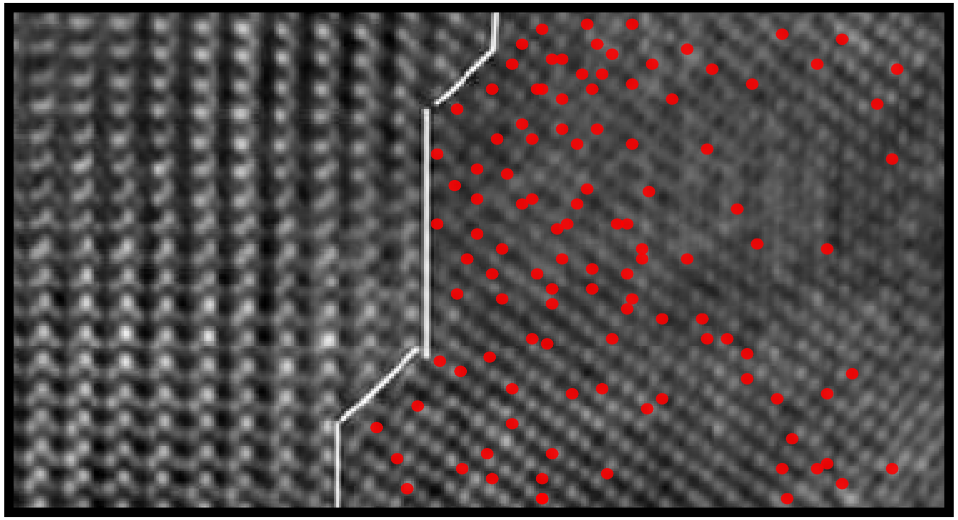

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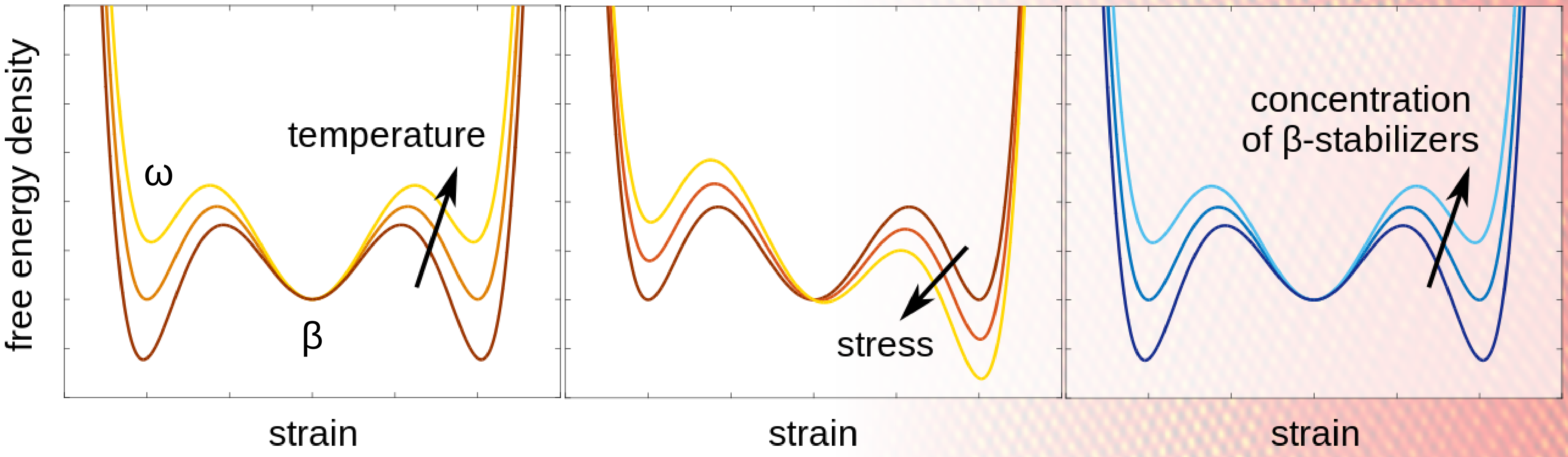

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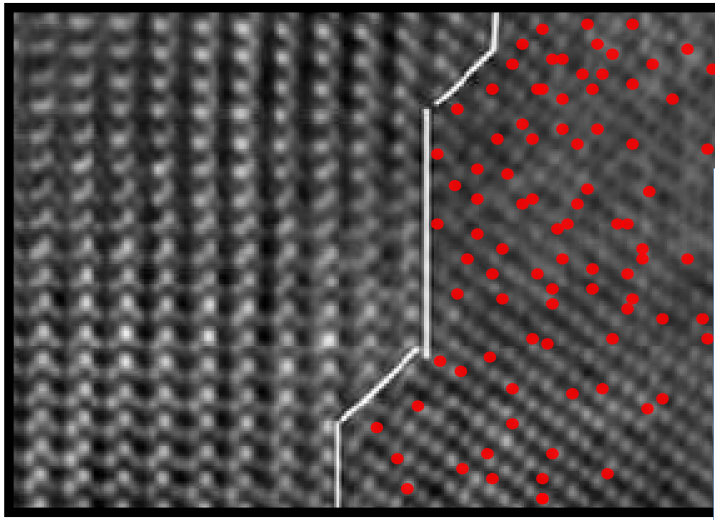

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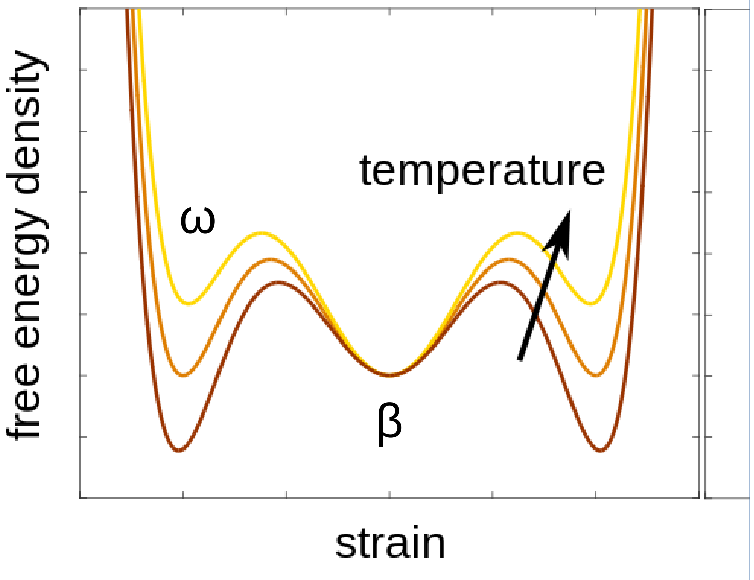
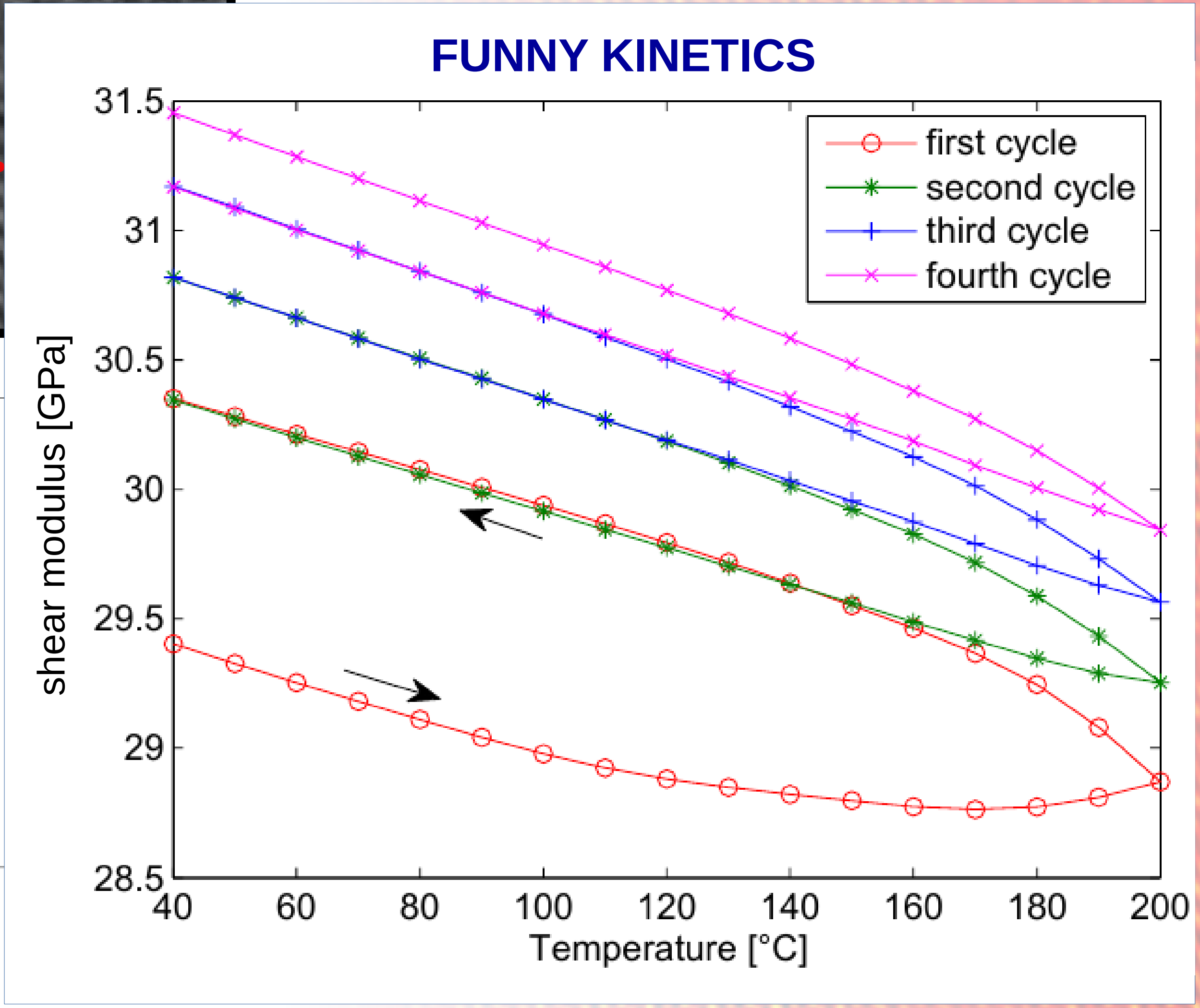
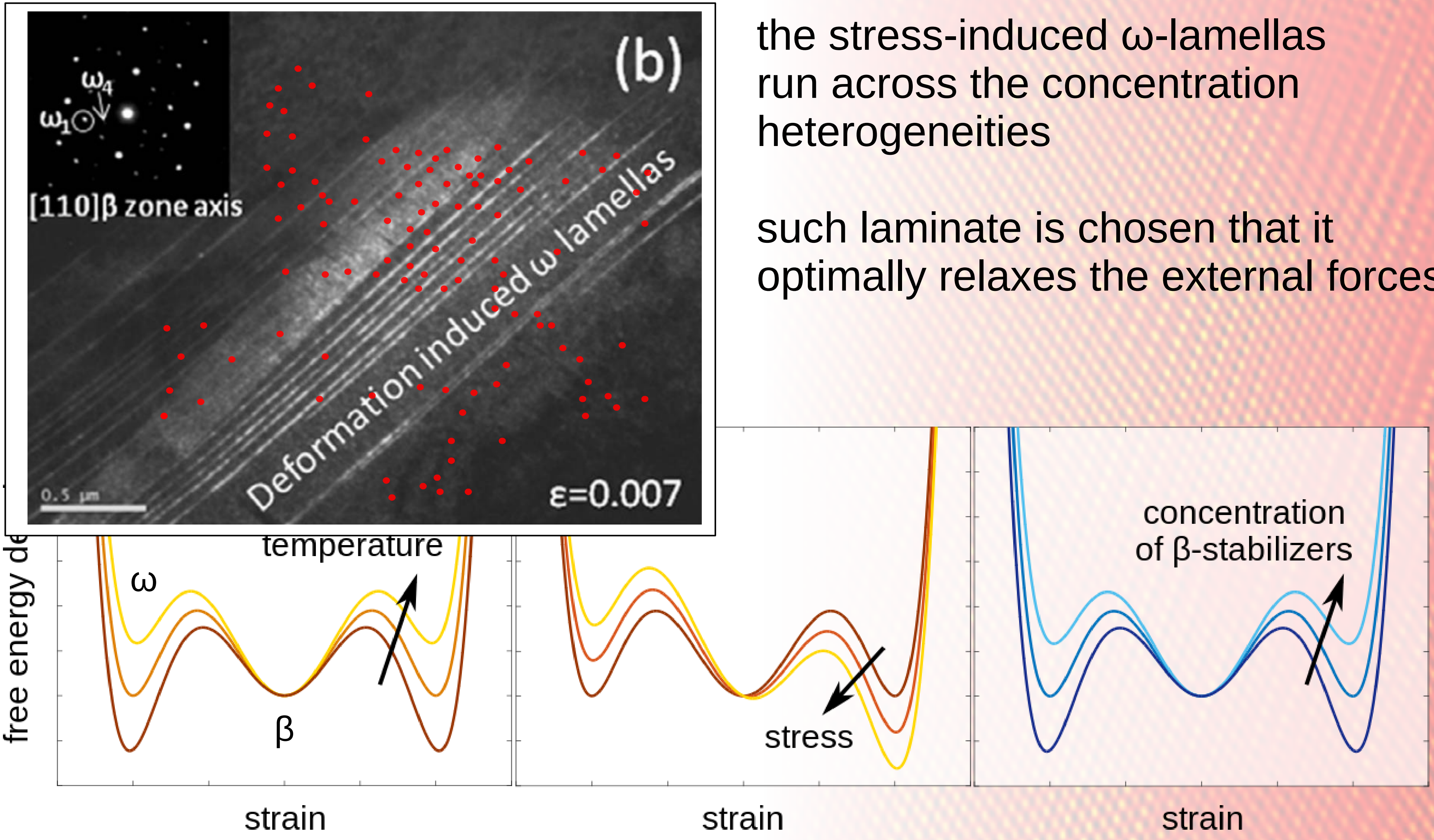




# 2. Basic thermodynamics and principles

what happens **under stress**?

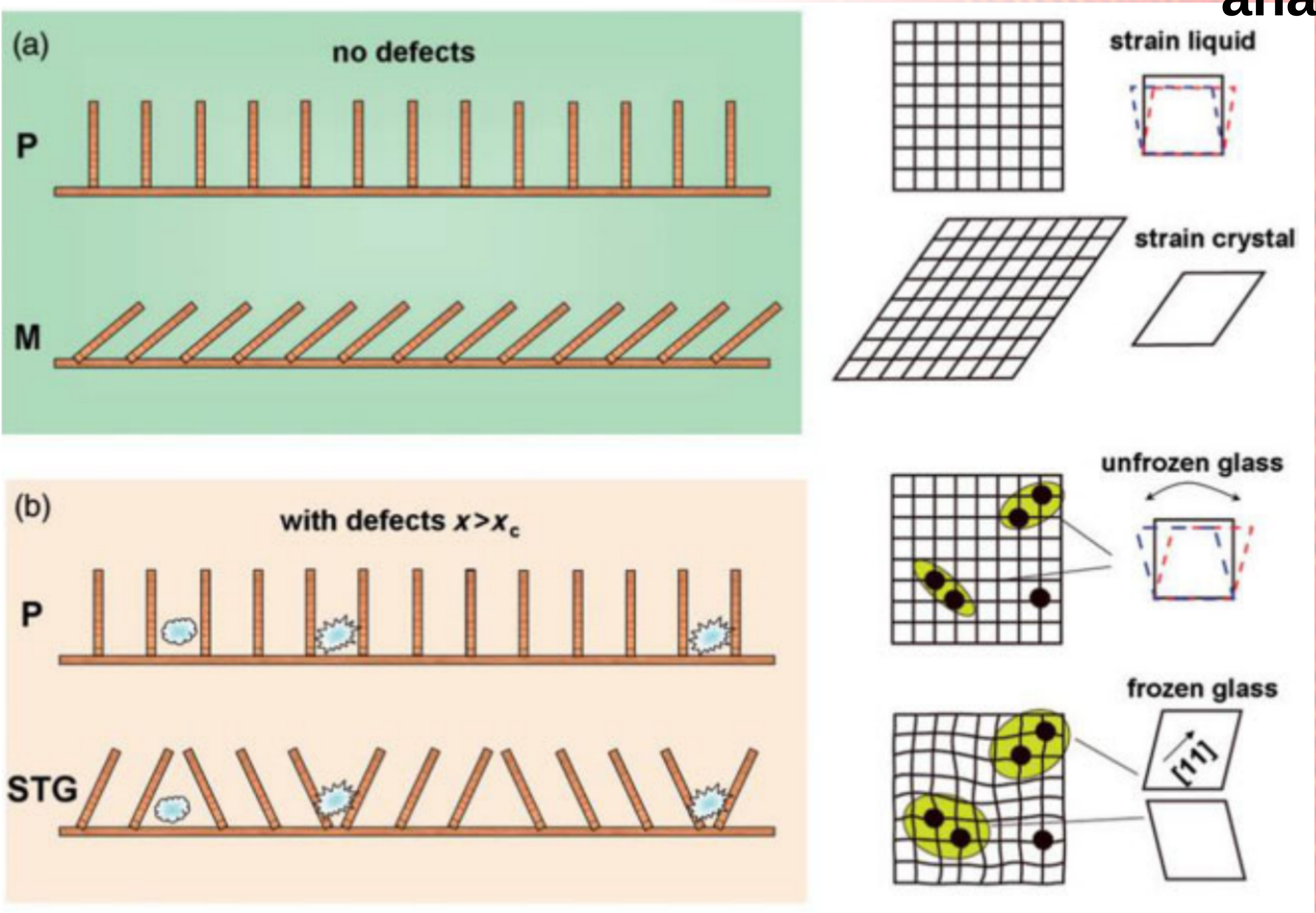


the stress-induced ω-lamellas run across the concentration heterogeneities

such laminate is chosen that it optimally relaxes the external forces

# 3. Modelling: concepts and tools

## **low temperature** behavior – athermal ω – **strain glass analogy**



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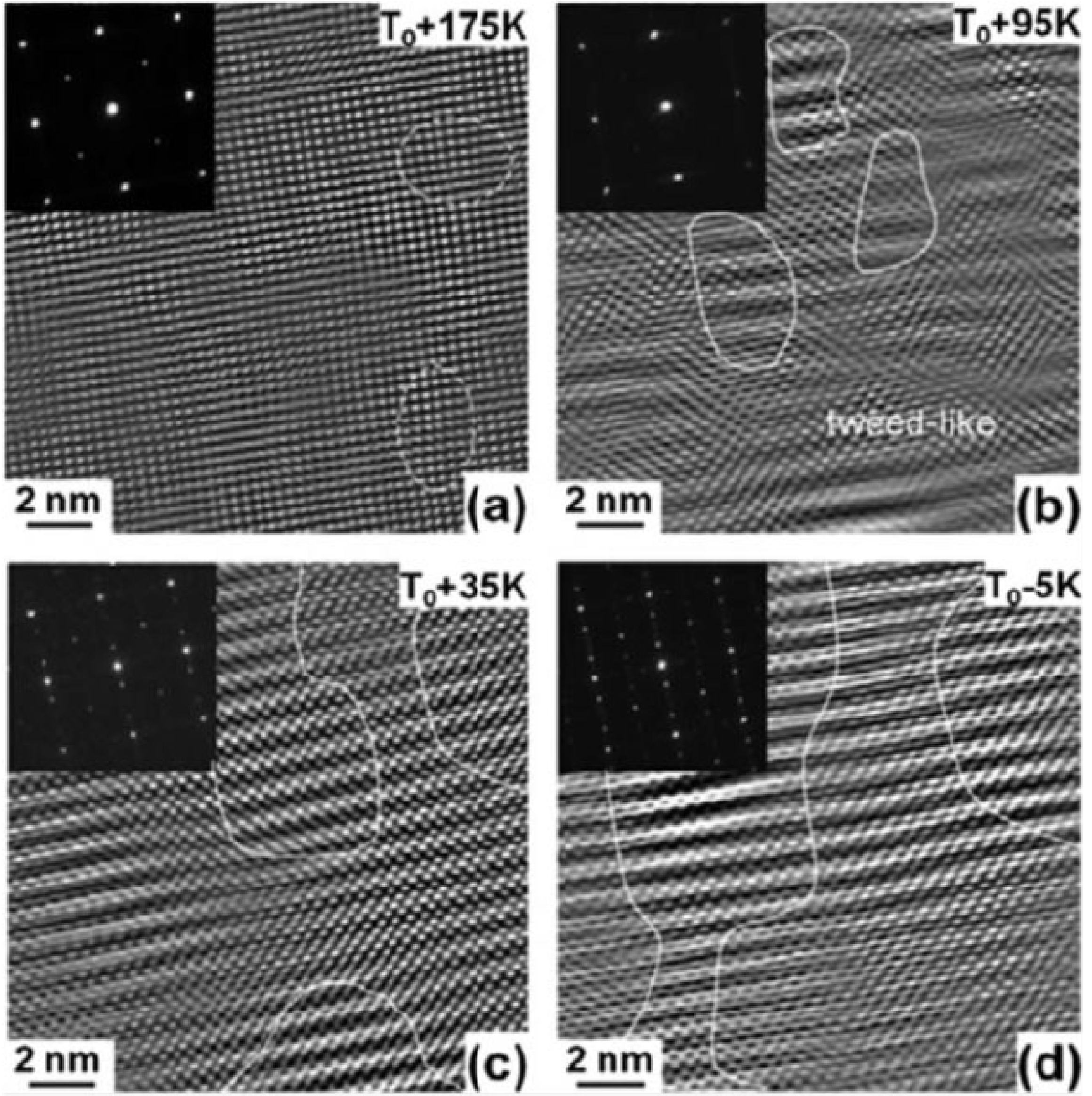

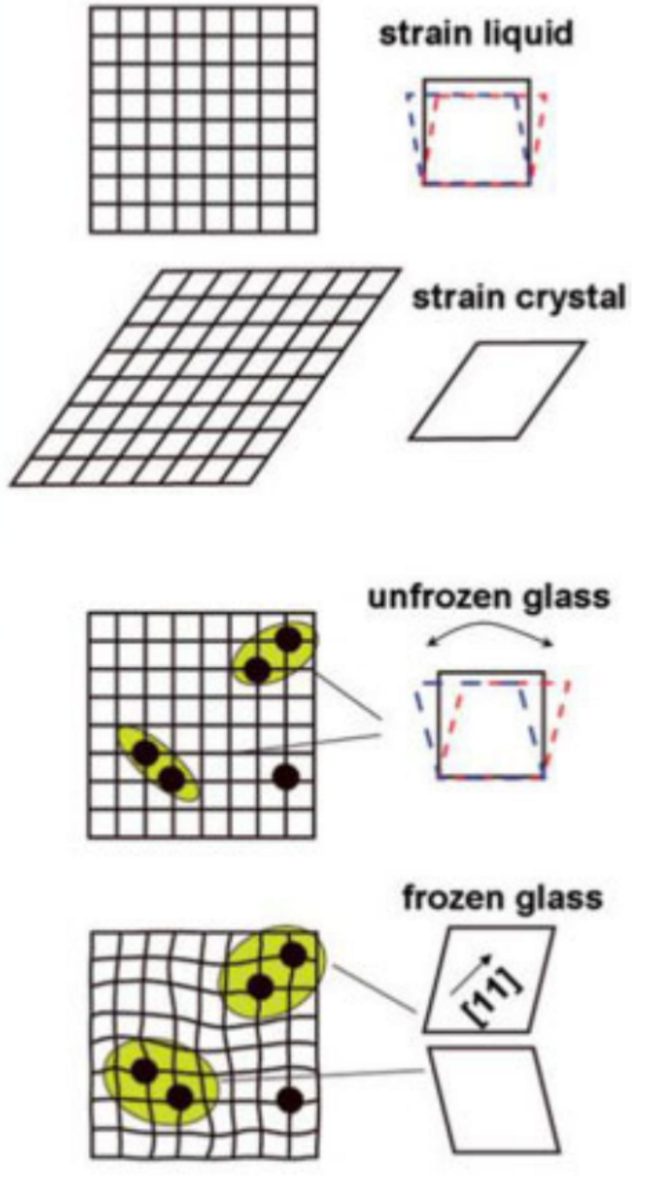

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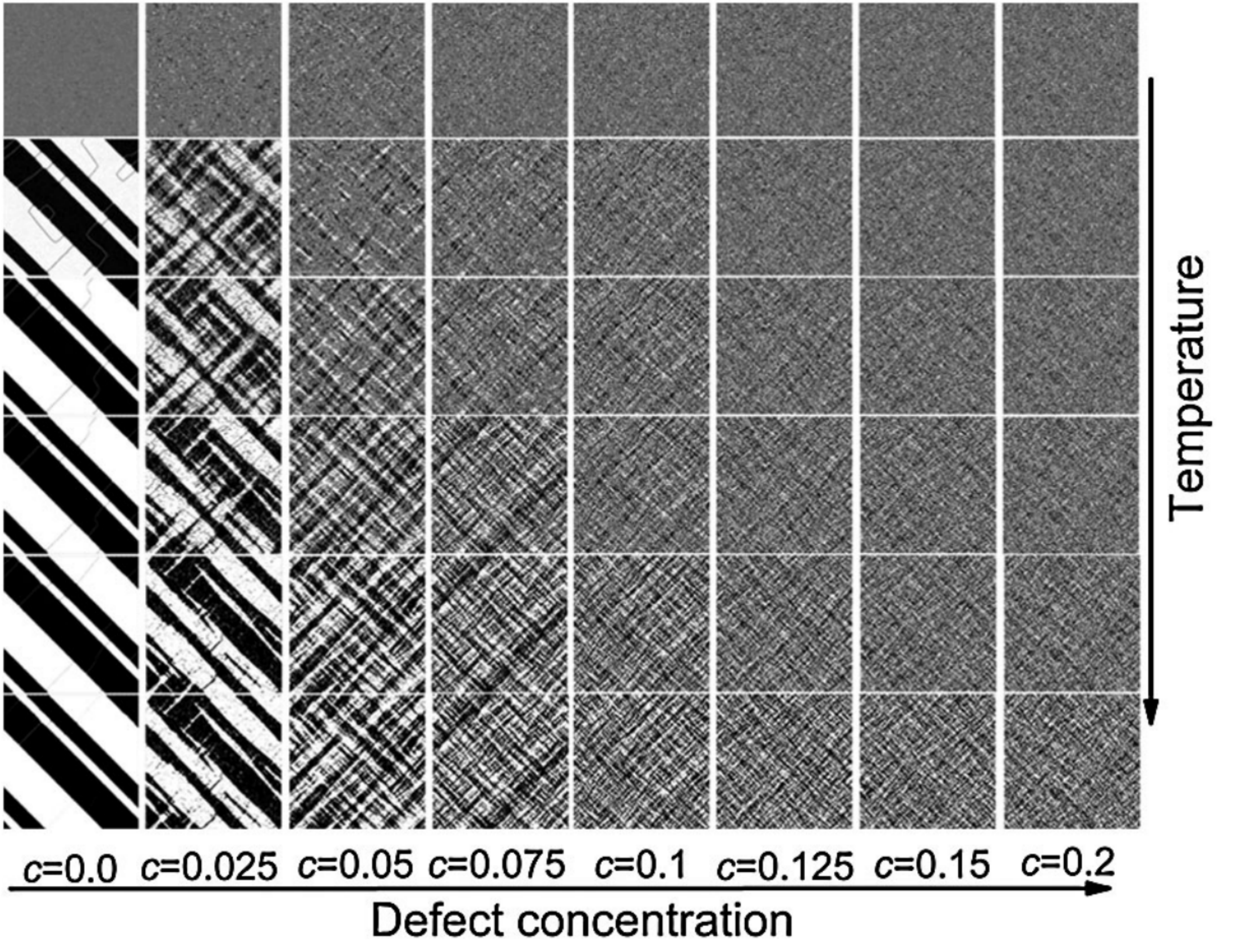

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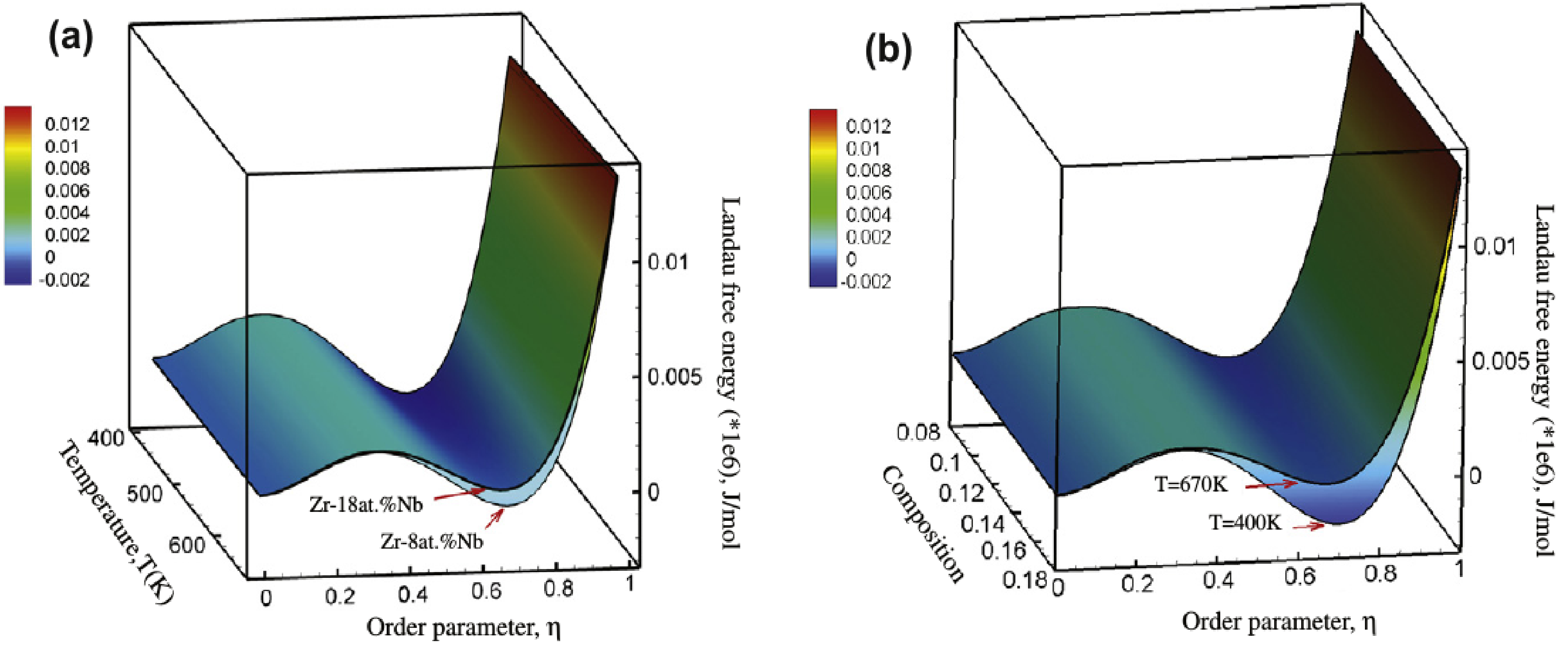
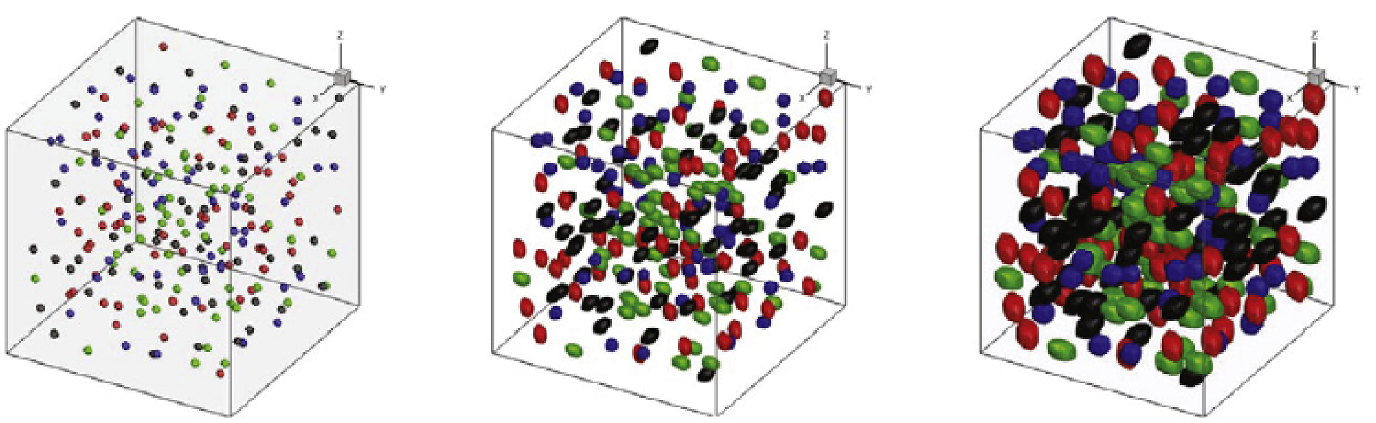
## **high temperature** behavior – isothermal ω – **precipitation**





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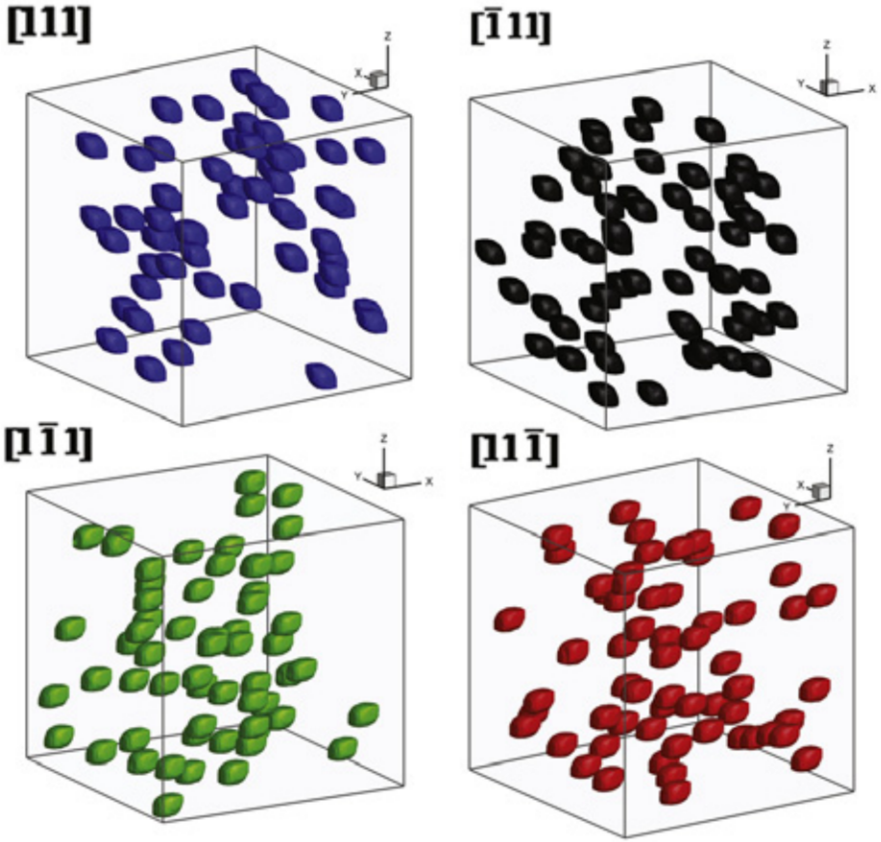
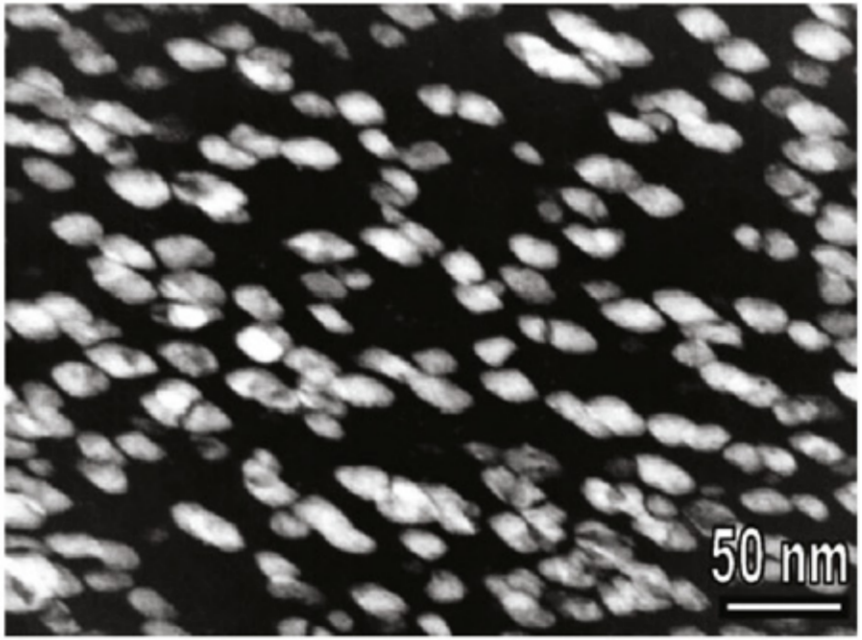
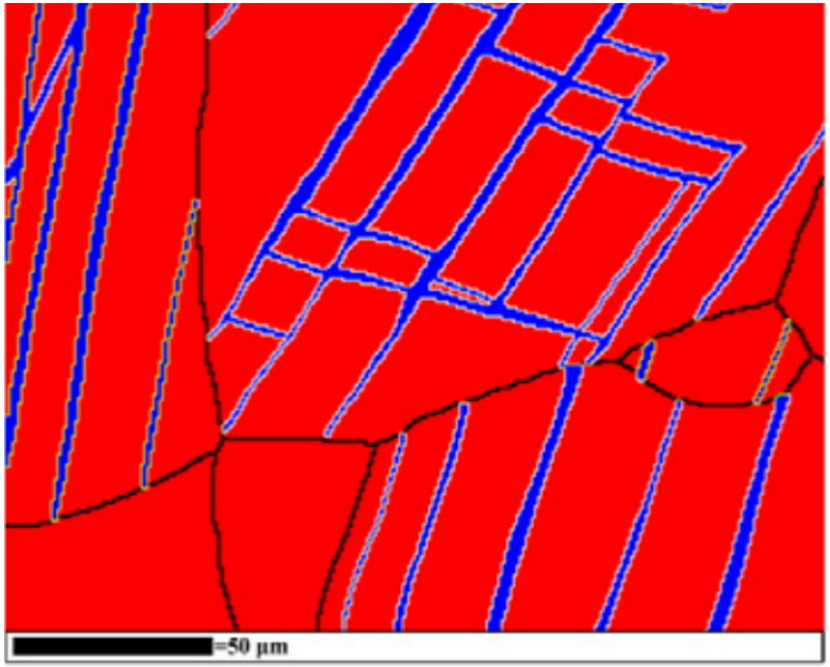




the aspect ratio and preferred orientation of the particles can be controlled by external prestress, **but the model does not predict lamination**

# 3. Modelling: concepts and tools

## stress-induced behavior – **compatibility?**



the stress-induced ω-lamellas does not seem to be internally twinned

however,

$\lambda_2 = 0.984$

**stress-assisted compatibility**

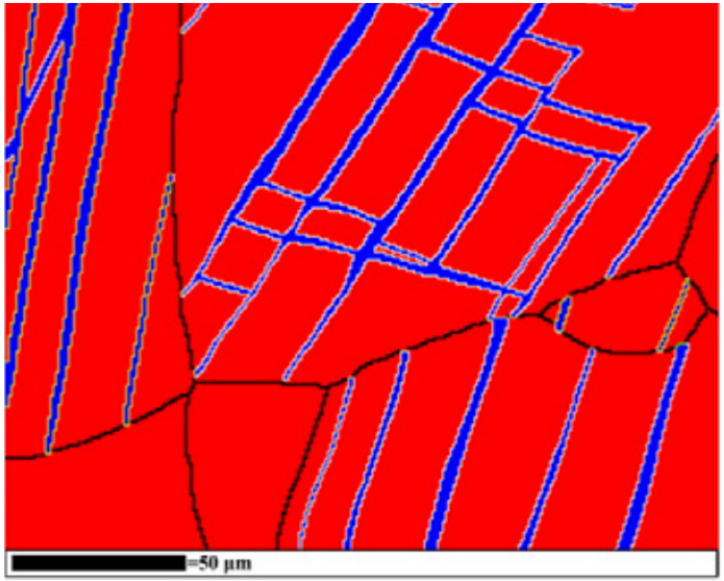
$$F_{el}F - G_{el}G = a \otimes n$$

$$\sigma^{\beta}_{ij} n_j = \sigma^{\omega}{}_{ij} n_j$$

**...the role of diffusion is unclear**

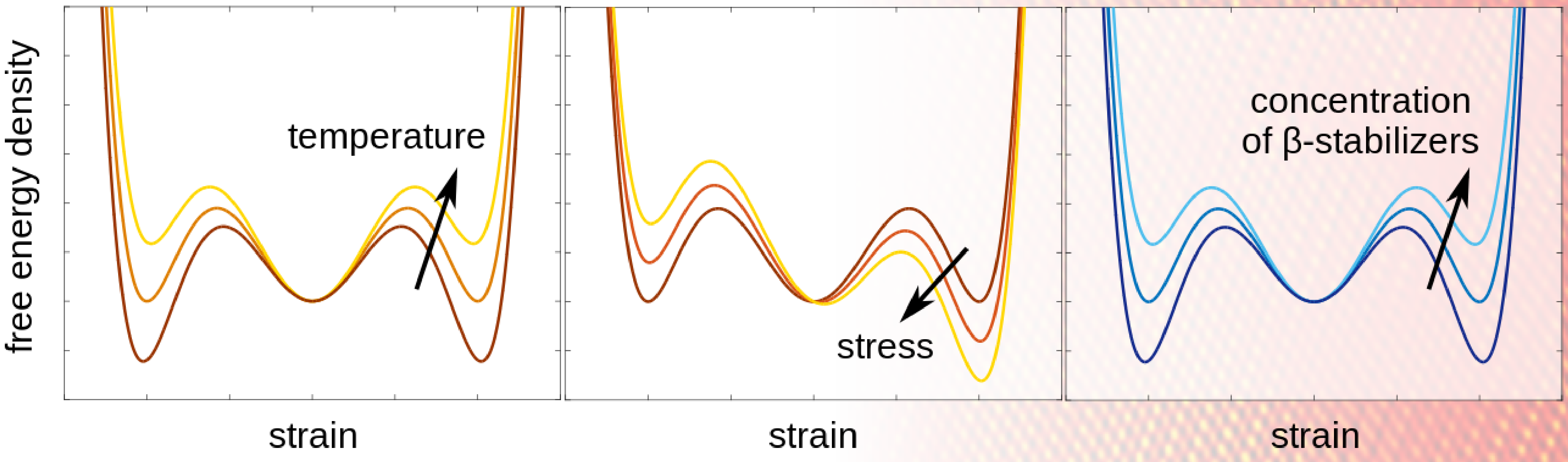
# 3. Modelling: concepts and tools

## stress-induced behavior – compatibility?



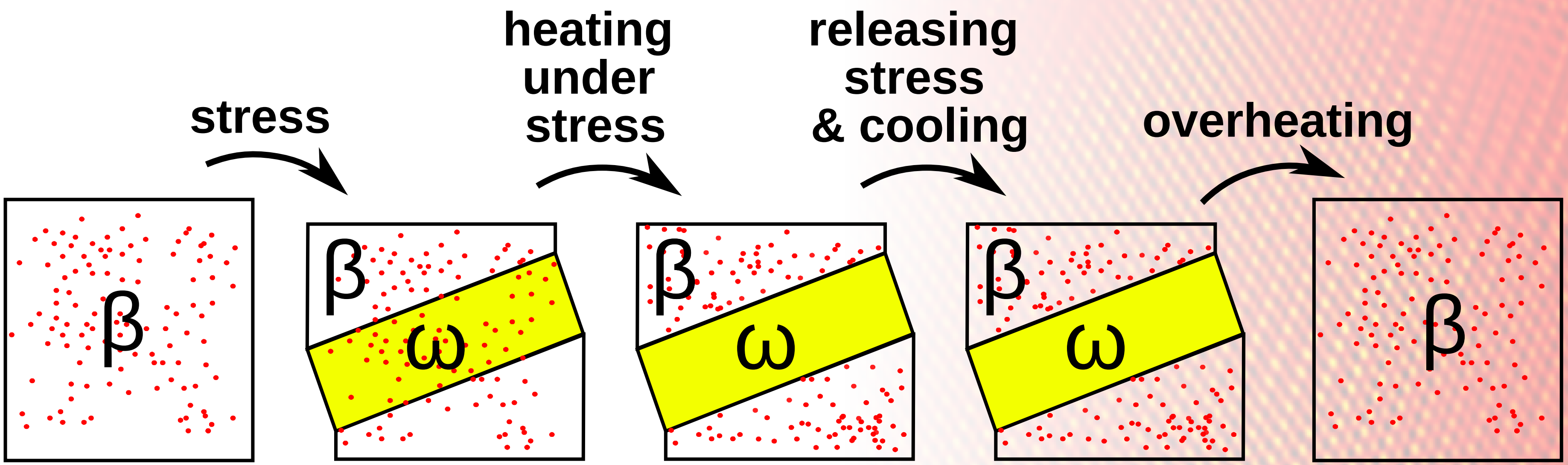
the concentration of β-stabilizers
inside of the ω-lamellas is energetically
very expensive.

Under increased temperature,
they should move out and stabilize
the laminate.



# 3. Modelling: concepts and tools

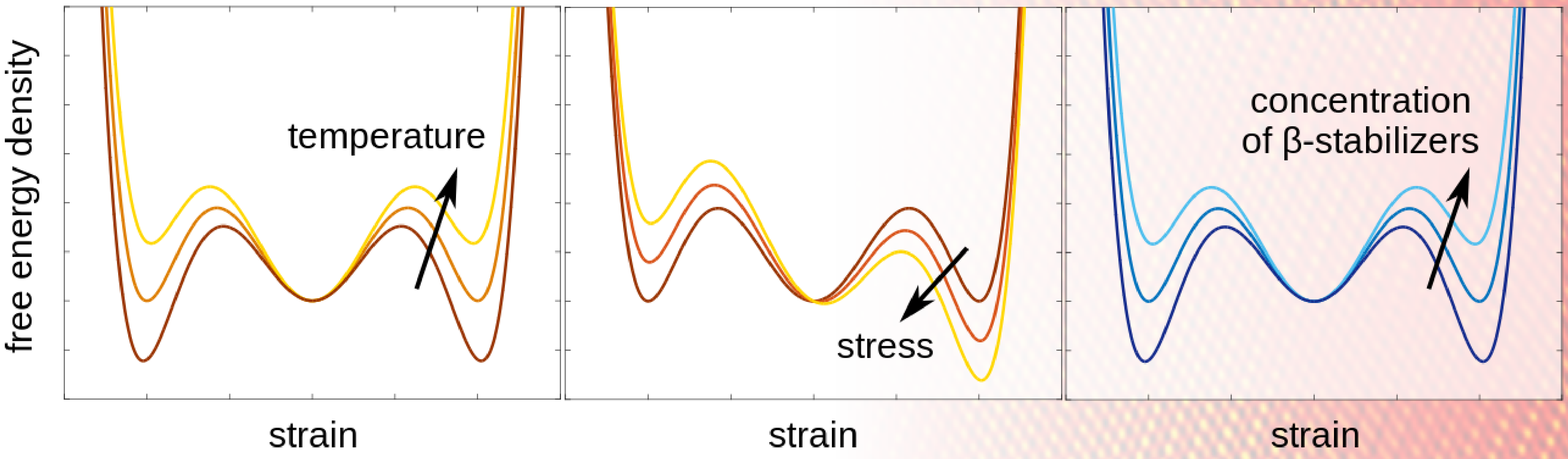
## stress-induced behavior – diffusive SME?


stress

heating under stress

releasing stress & cooling

overheating



# Conclusions

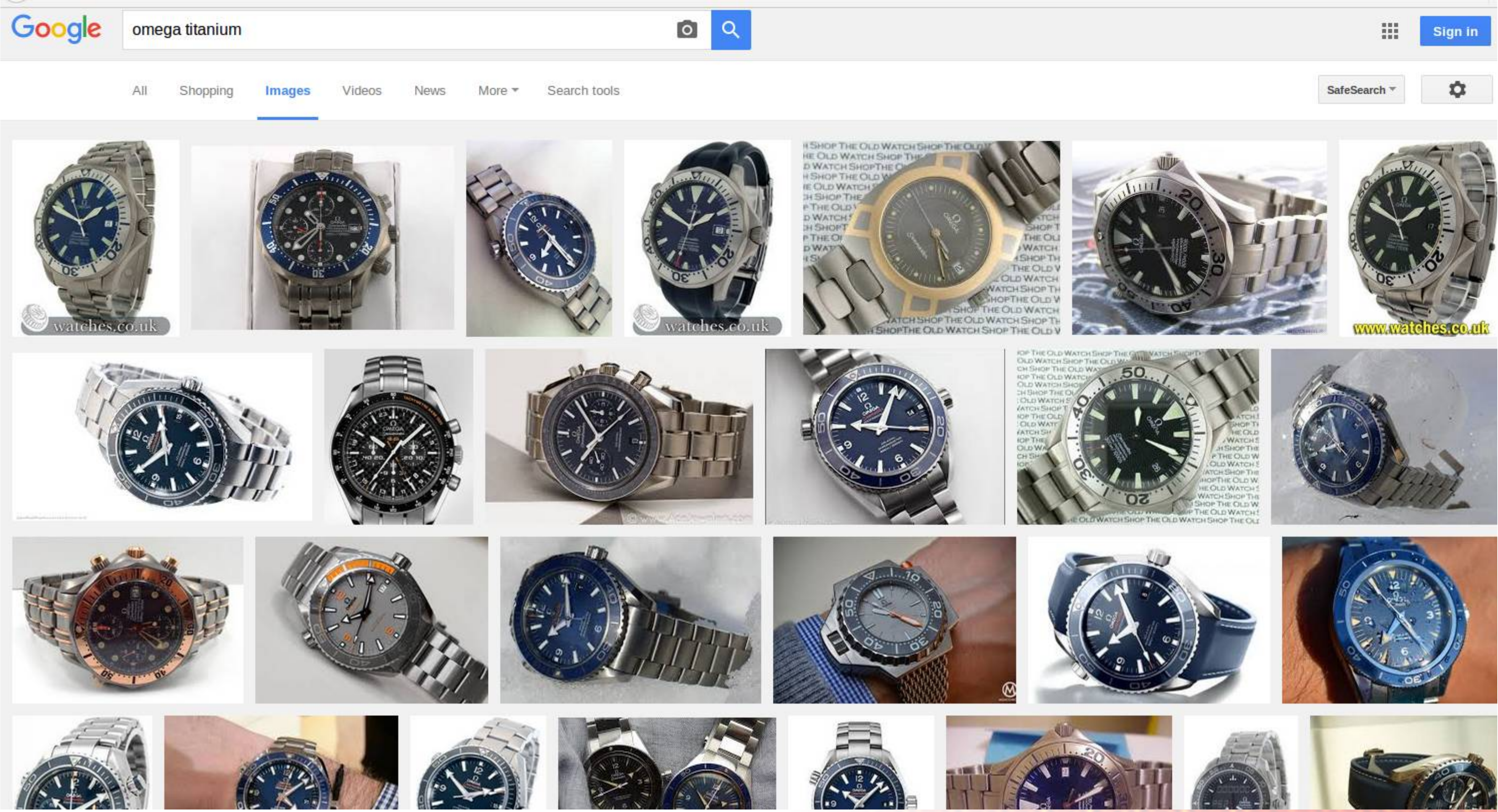
- **there are no real conclusions** – the understanding at the continuum level is still an open question

- understanding the **interplay between the displacive nature of the transition and the diffusion** is essential for **construction of reliable models**

- **modelling so far:** phase field simulations, not capturing the lamination phenomena

- **take-home message:** ω-related phenomena are rather unexplored by the martensites/continuum community. More advertising needed!

# Conclusions



## THANK YOU FOR YOUR ATTENTION