# A Glass Form of Martensite
# --Strain Glass and Strain Glass Transition

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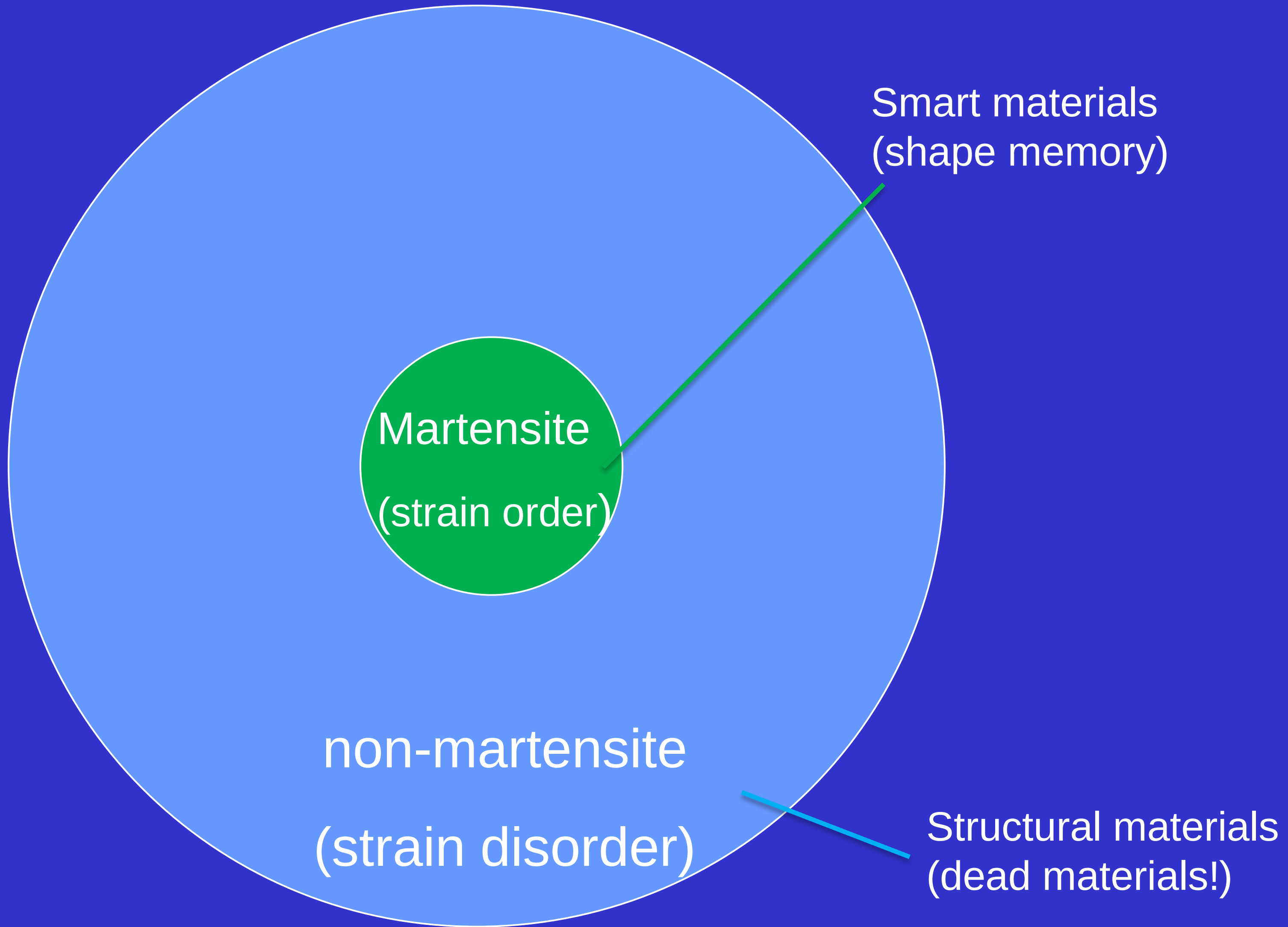
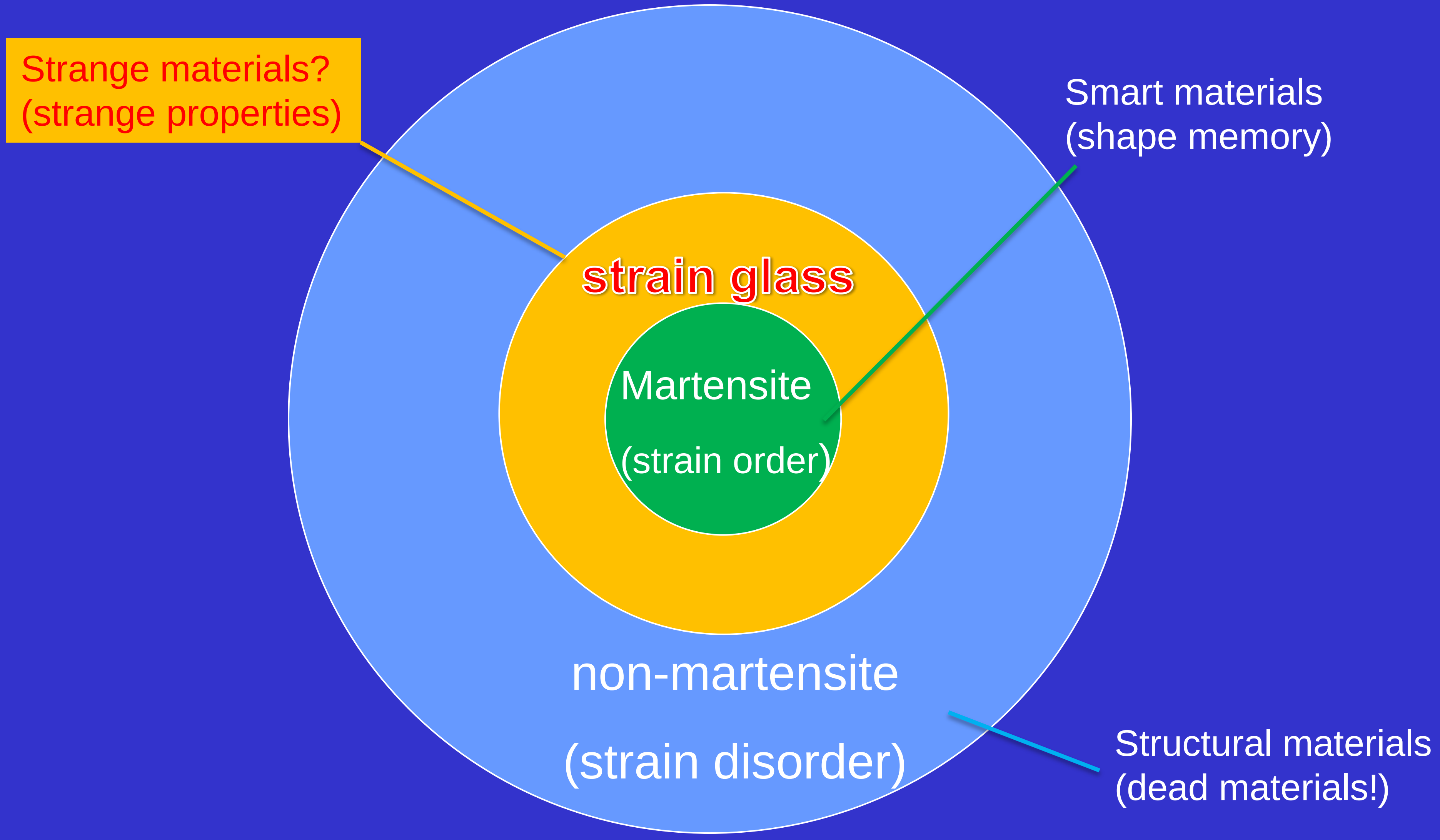



(Lattice) Strain perspective of the world of crystalline materials



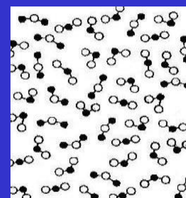

(Lattice) Strain perspective of the world of crystalline materials

# Outline

- Disorder-order and disorder-glass transition in nature: Anticipation of strain glass transition and strain glass
- Generality of strain glass
- Signatures of strain glass and analogy with other glasses --unifying concepts in glasses
- Examples of “strange” properties of strain glass
- Origin of strain glass: strain domino jamming? theoretical modeling/simulations (more details:Turab Lookman talk)
- Summary

# Anticipation of Strain Glass

# Two large classes of transitions in nature

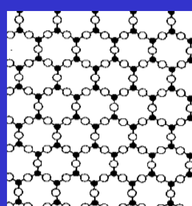


disorder

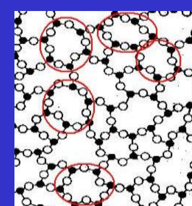
- •Liquid
- •Paramagnetic
- •Paraelectric
- •Paraelastic (parent phase)

Thermodynamic transition

Non-thermodynamic transition



order



glass (frozen disorder/SRO)

| order | glass |
| --- | --- |
| •Crystalline solid | •Structural glass ← Amorphous structure |
| •ferromagnetic | •Spin glass |
| •ferroelectric | •Relaxor |
| •Ferroelastic (martensite) | •Strain glass??? |

Spin glass, Relaxor, Strain glass???: Crystalline structure

# Where is a strain glass and generality of strain glass

Ideas borrowed from other glass systems.

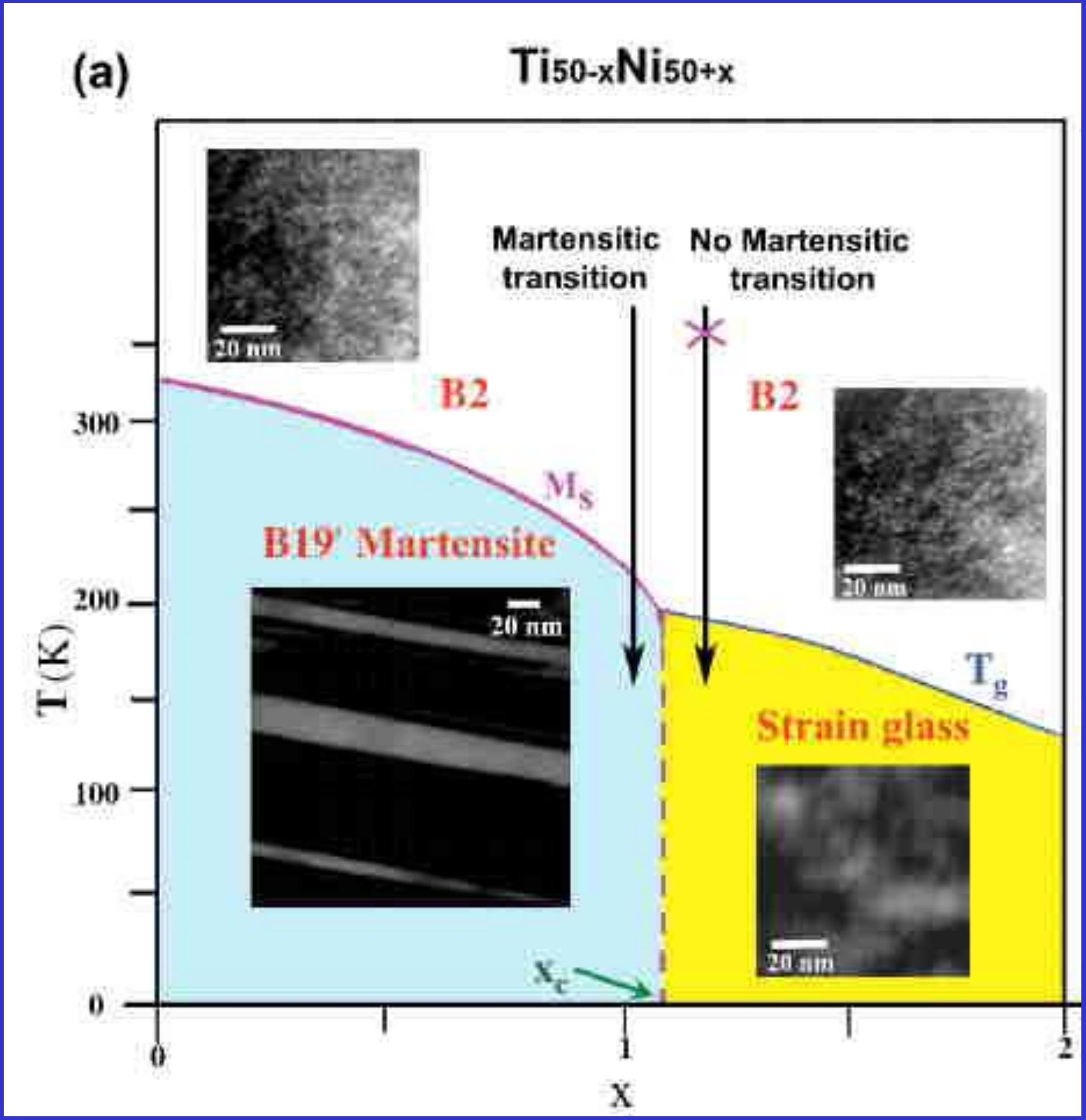
•Cluster spin glass:  doping defects to a ferromagnetic system

•Ferroelectric relaxor: doping defects to a ferroelectric system

•Strain glass →

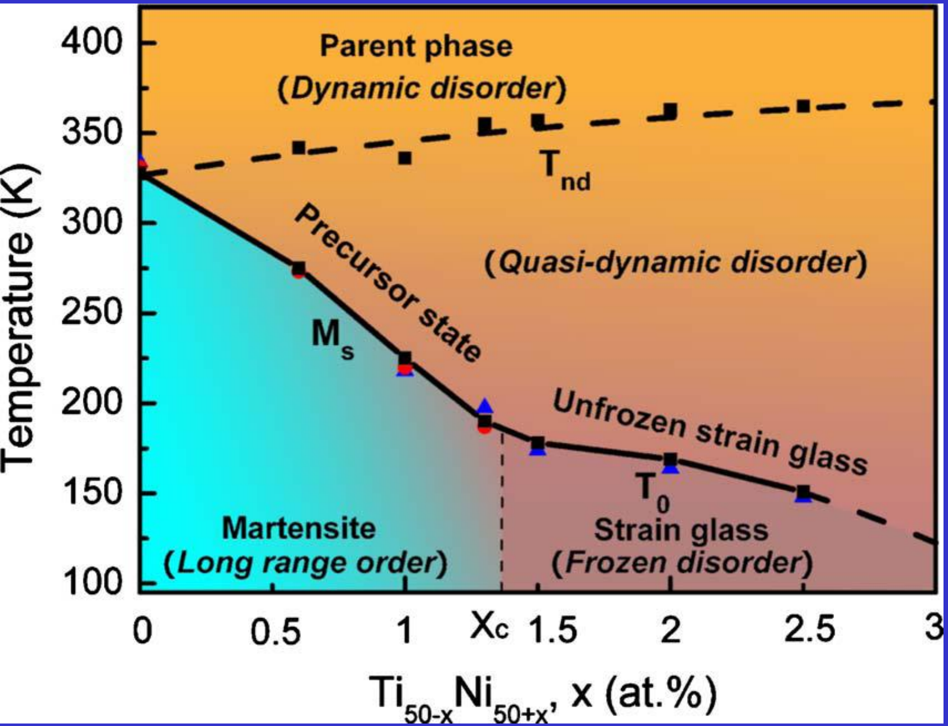
doping defects to a ferroelastic/martensitic system

Ferroelastic
"water-gelletin system"!

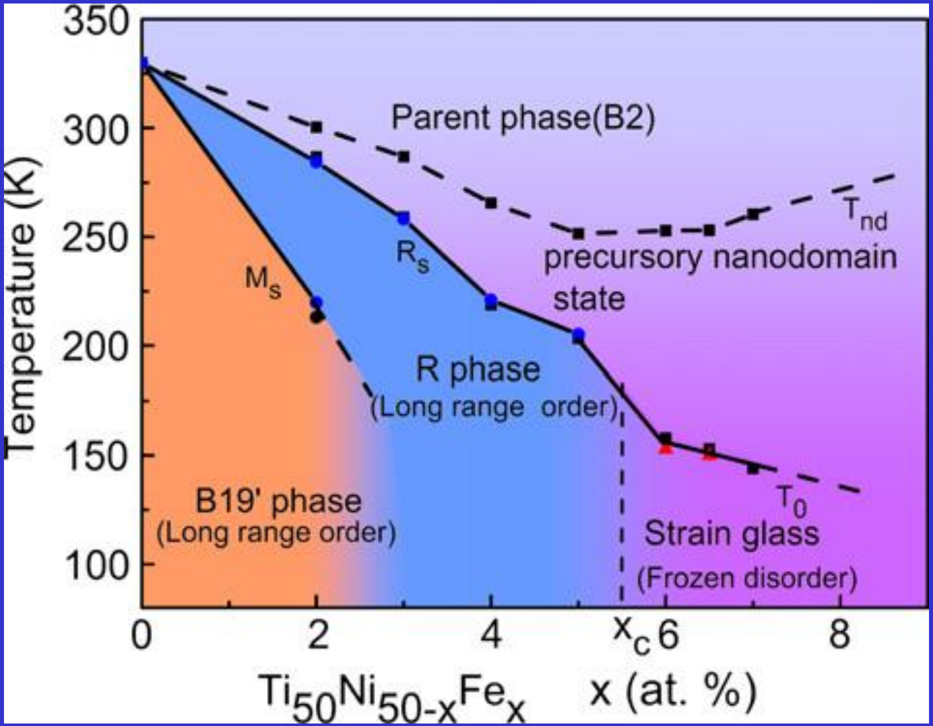



martensitic transformation ($x<x_c$) and strain glass transition ($x>x_c$) in $Ti_{50-x}Ni_{50+x}$ system. S. Sarkar et al, PRL 2005

# Similarity of Strain Glass Phase Diagram: Crossover from M to STG



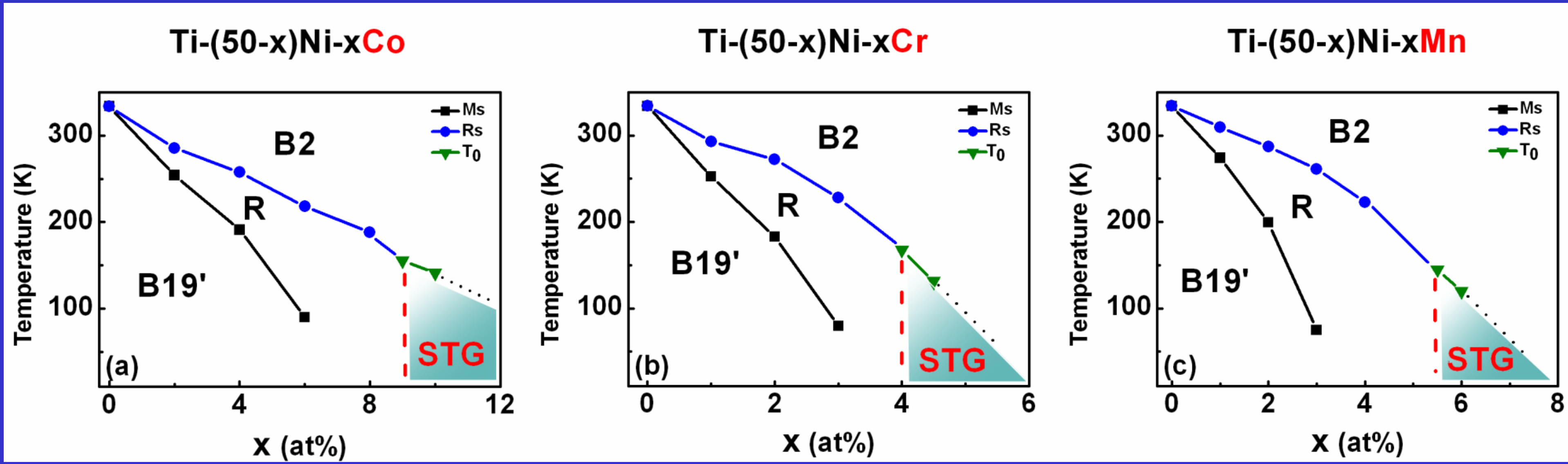

Z. Zhang, PRB 2010



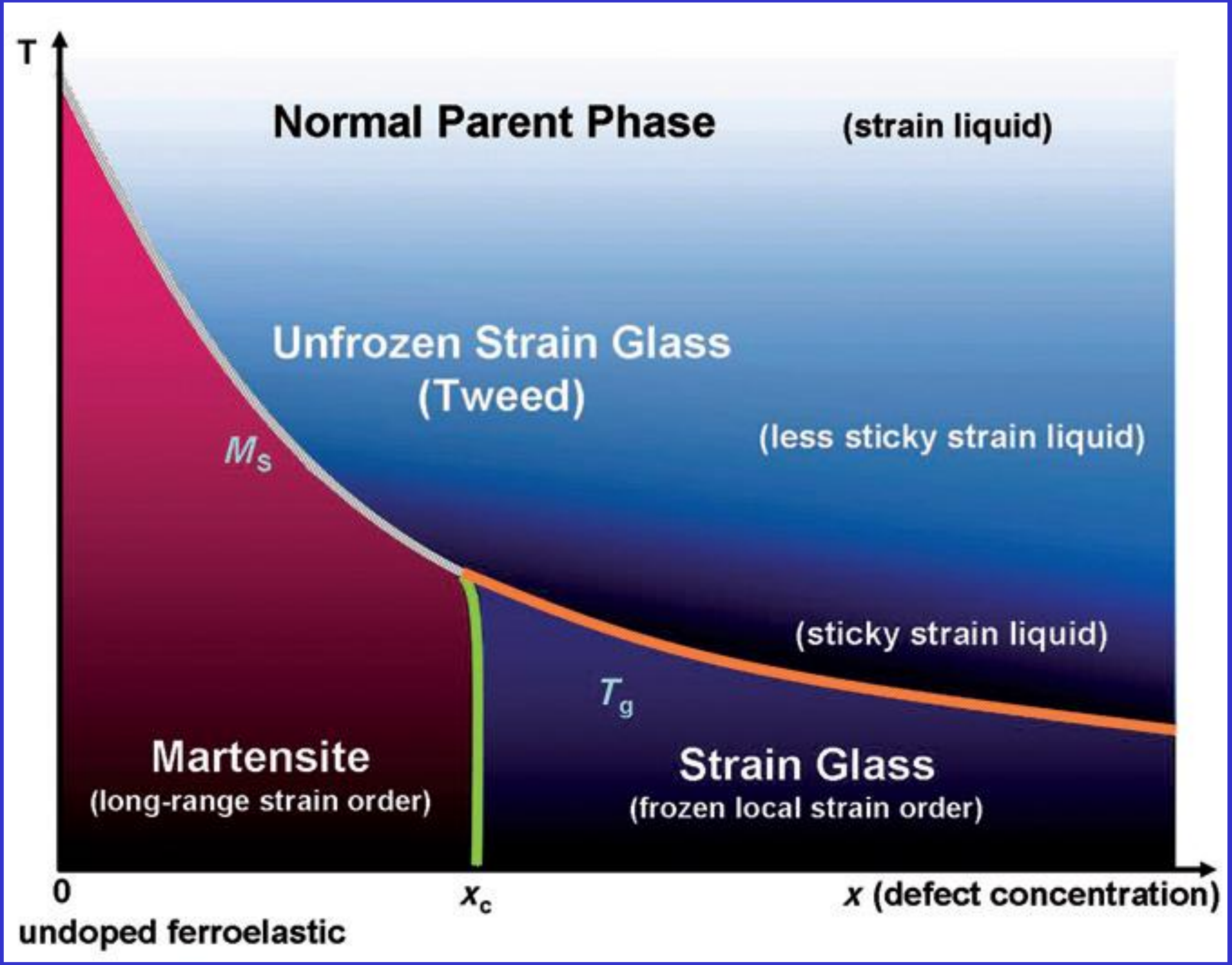

D. Wang, Acta Mater 2010

# Generality of strain glass

-- Strain glass is everywhere!

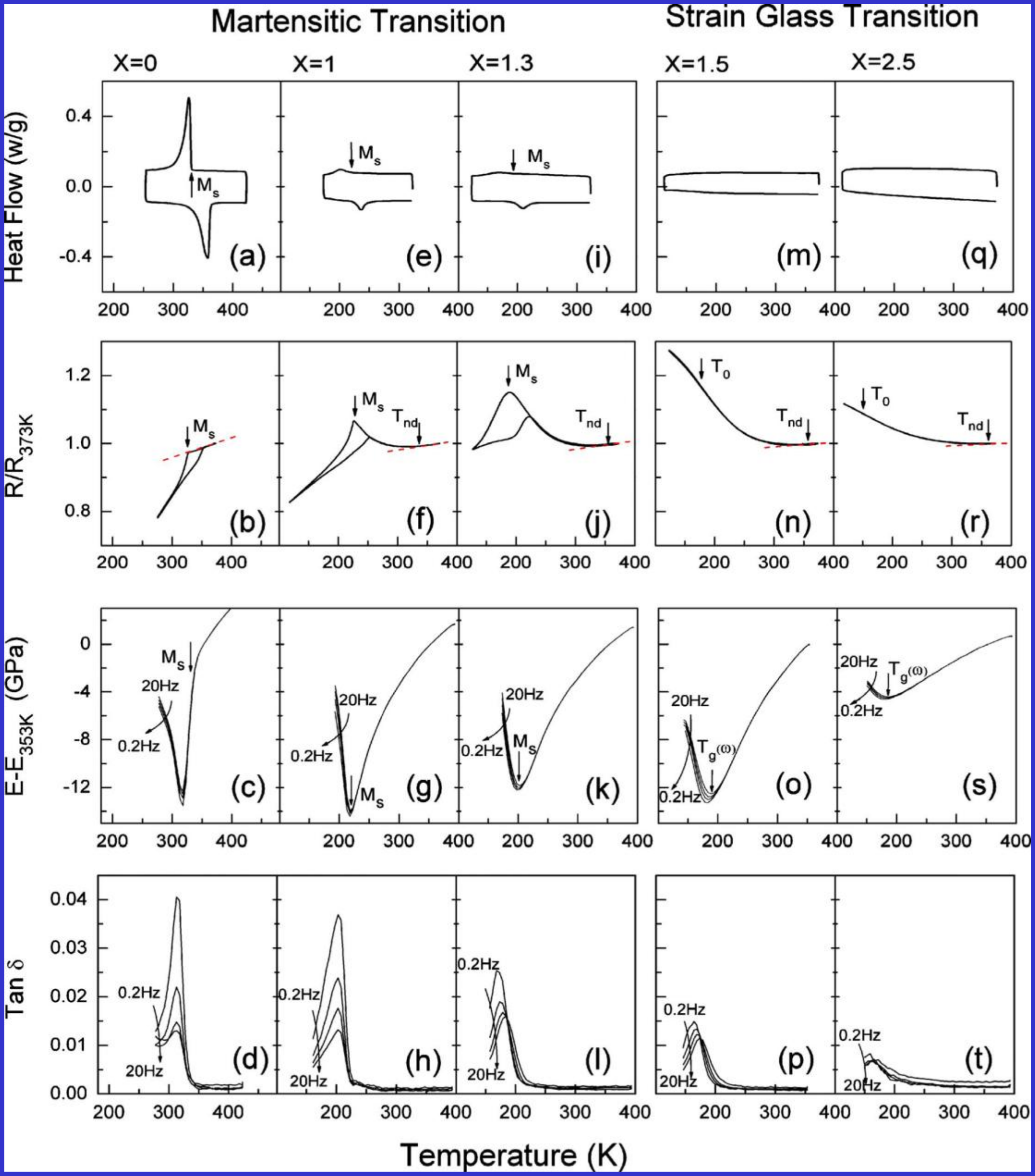



Y.M. Zhou et al., Acta Mater., 2010




A generic temperature vs. defect-concentration phase diagram for a defect-containing ferroelastic system. X. Ren, et al, MRS Bulletin, 2009

Z. Zhang, PRB 2010

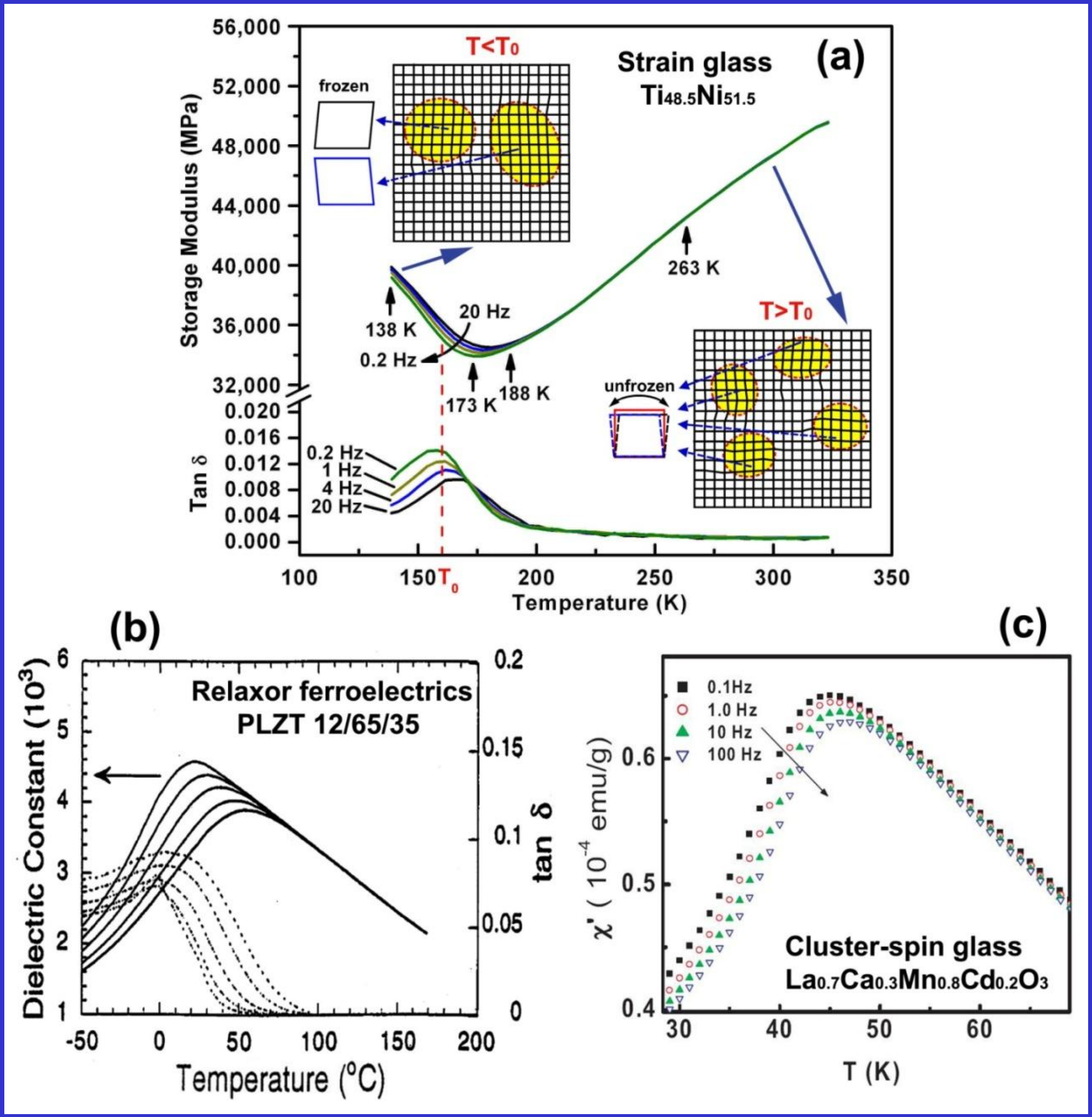



Transition behavior of $Ti_{50-x}Ni_{50+x}$ as a function of point-defect concentration x

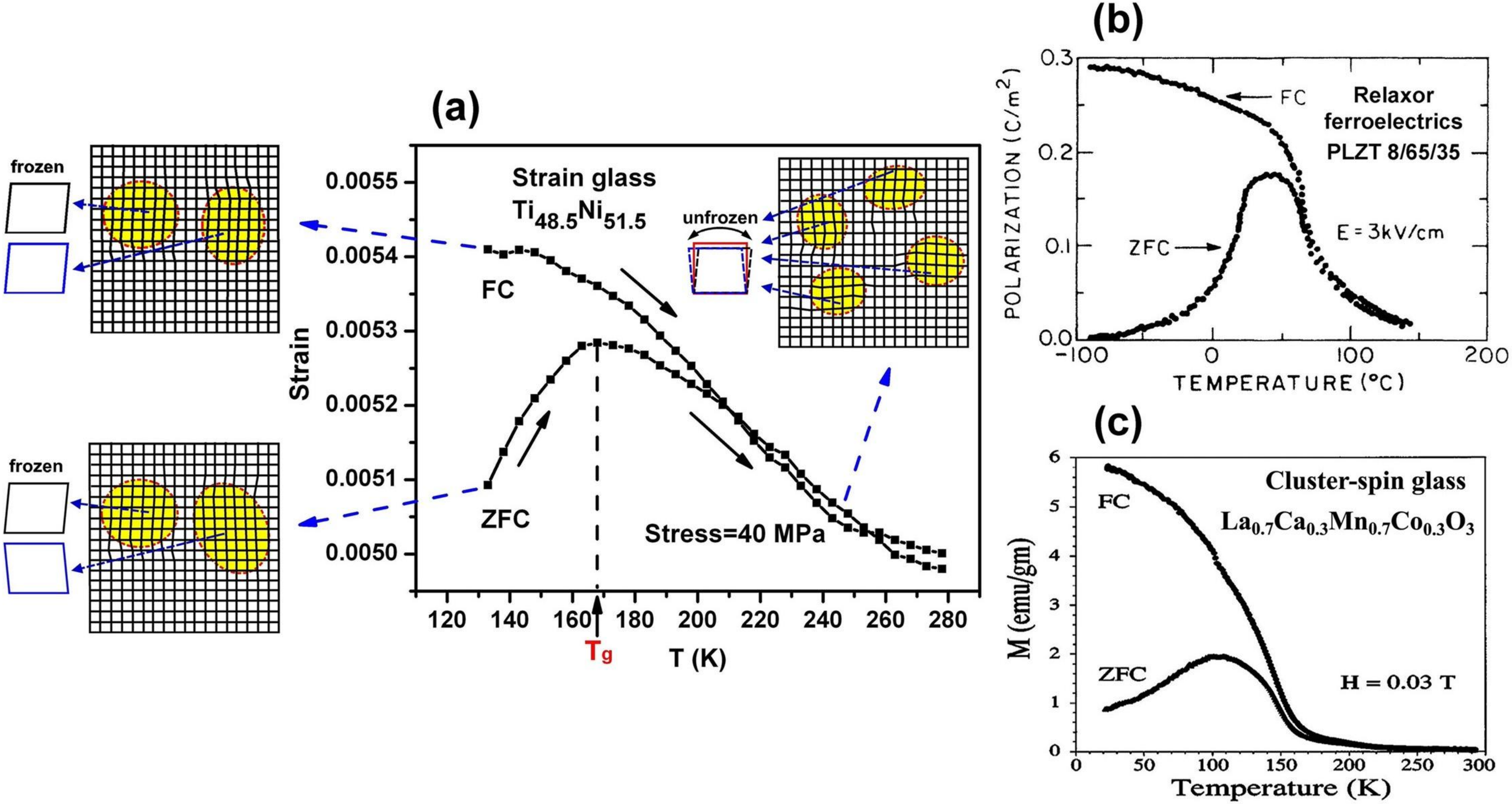
# How to prove a strain glass?

- Frequency dispersion of anomalies in dynamic properties (elastic modulus, internal friction)
- ZFC/FC experiment (non-ergodicity)
- No change in average structure
- Frozen nanodomains

**Strain glass** ⟷ (parallel) **Cluster spin glass, Relaxor ferroelectrics**

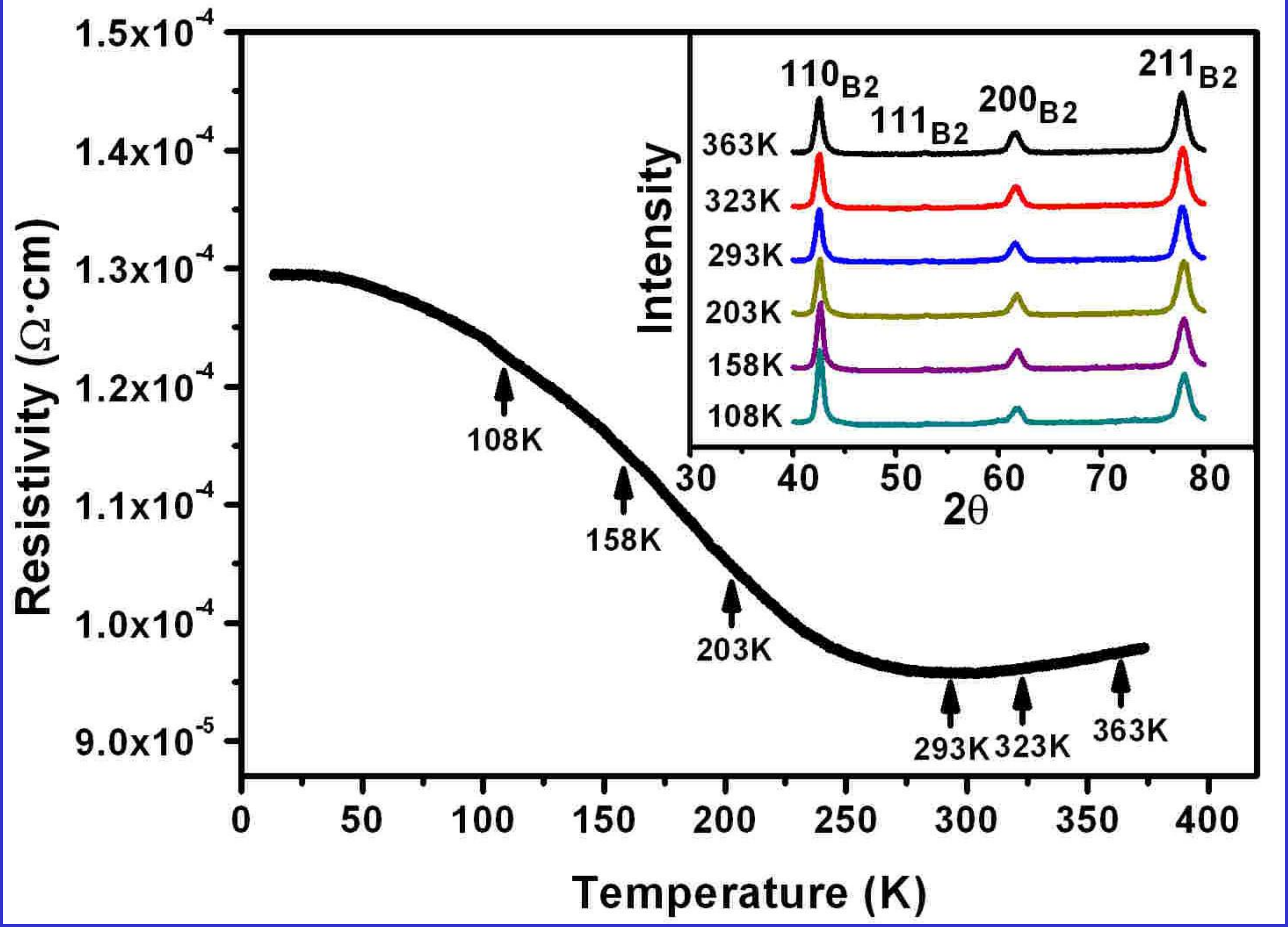



Strain glass transition is characterized by a frequency-dependent dip/peak in the AC elastic modulus/loss vs. temperature curve



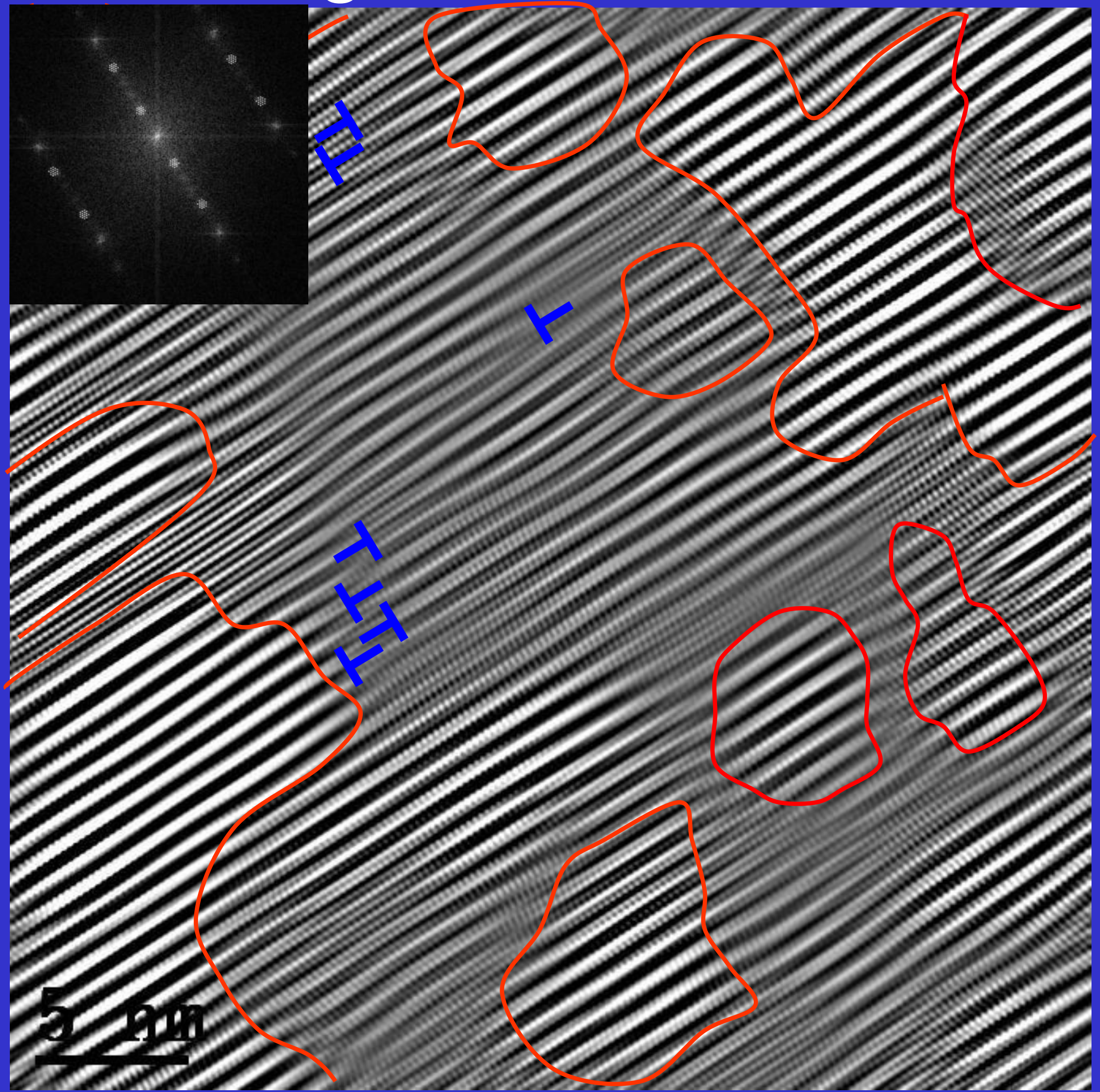

ZFC/FC curves of $Ti_{48.5}Ni_{51.5}$ strain glass show a large deviation below $T_g$ (168K).

Y. Wang, PRB 2007



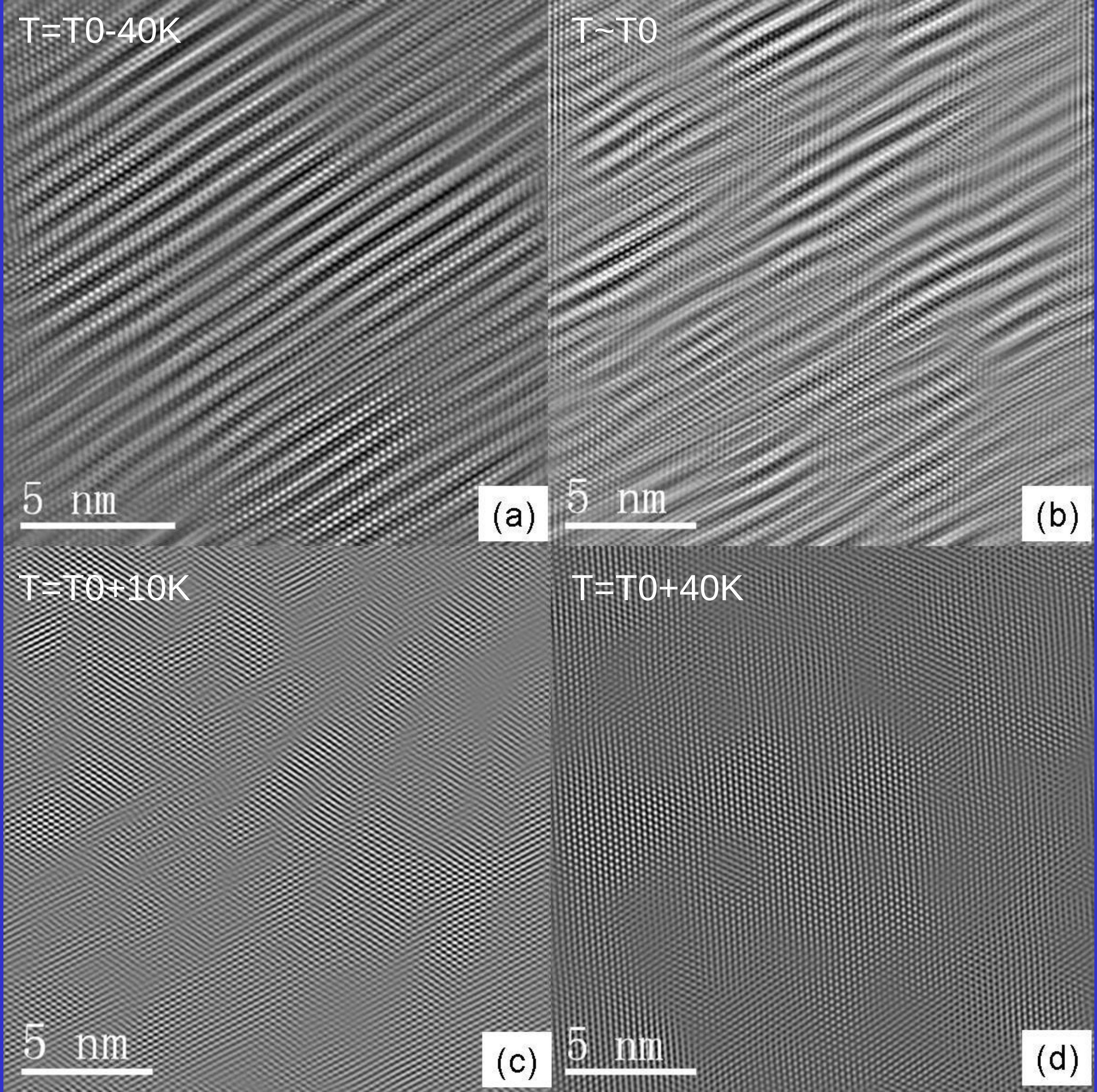

Average structure remains invariant during a strain glass transition,

# HREM observation of local strain/shuffle order in strain glass

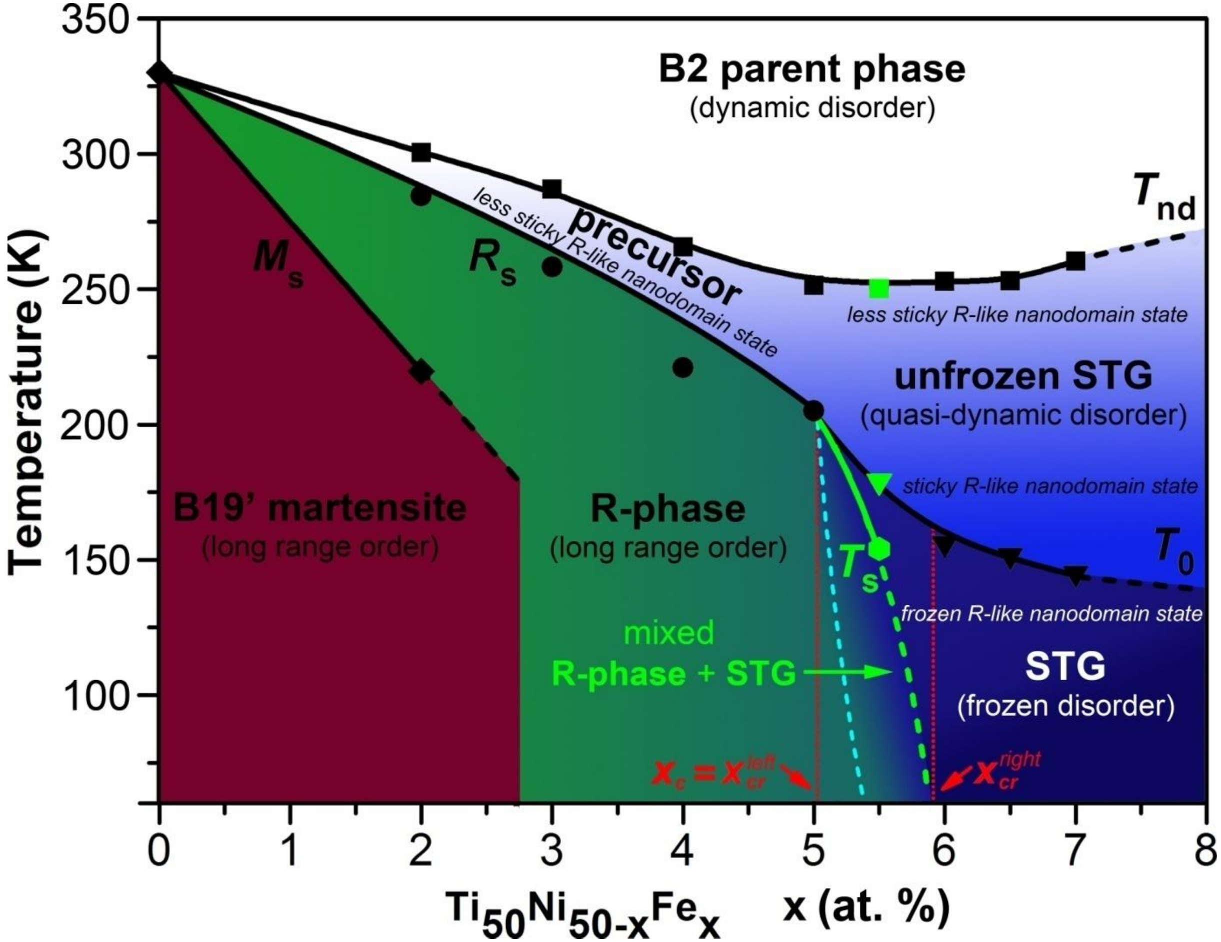



Ti-40Pd-10Cr

Strain glass


T=T0-40K
5 nm
(a)
T~T0
5 nm
(b)
T=T0+10K
5 nm
(c)
T=T0+40K
5 nm
(d)

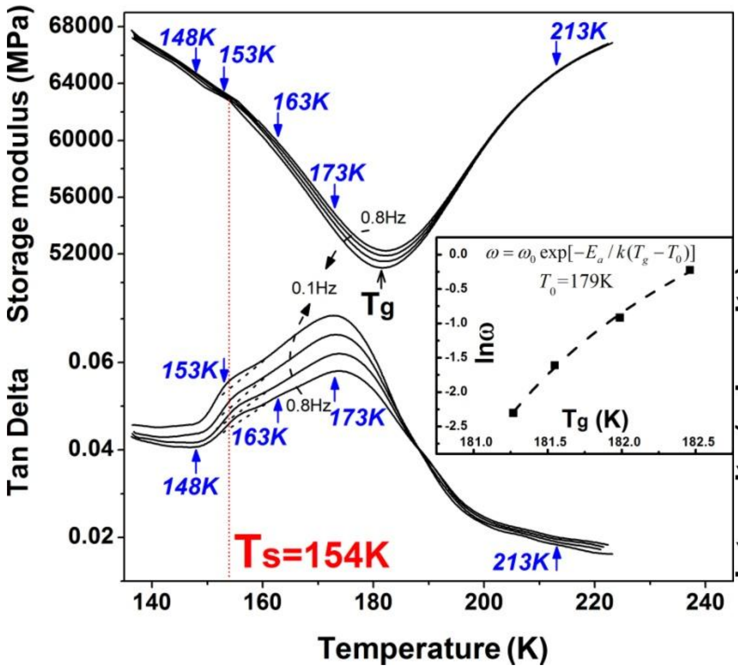
# Spontaneous strain-glass to martensite (R) transition in a $Ti_{50}Ni_{44.5}Fe_{5.5}$ strain glass

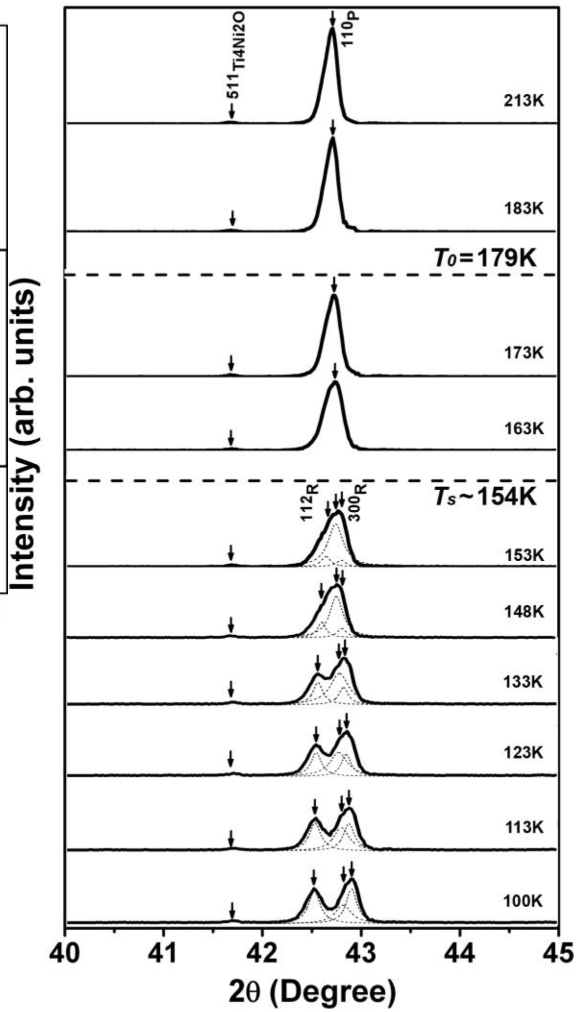


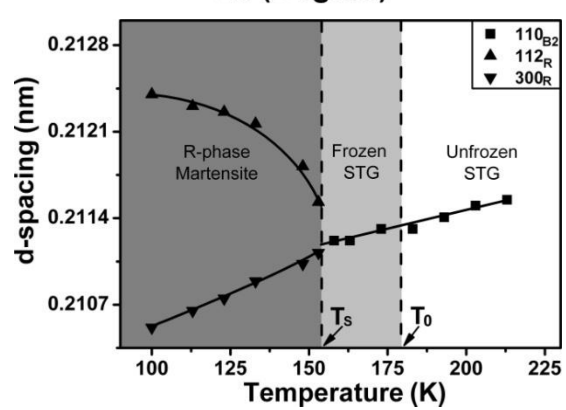

*Martensite phase transformation*
thermodynamic free energy lowering

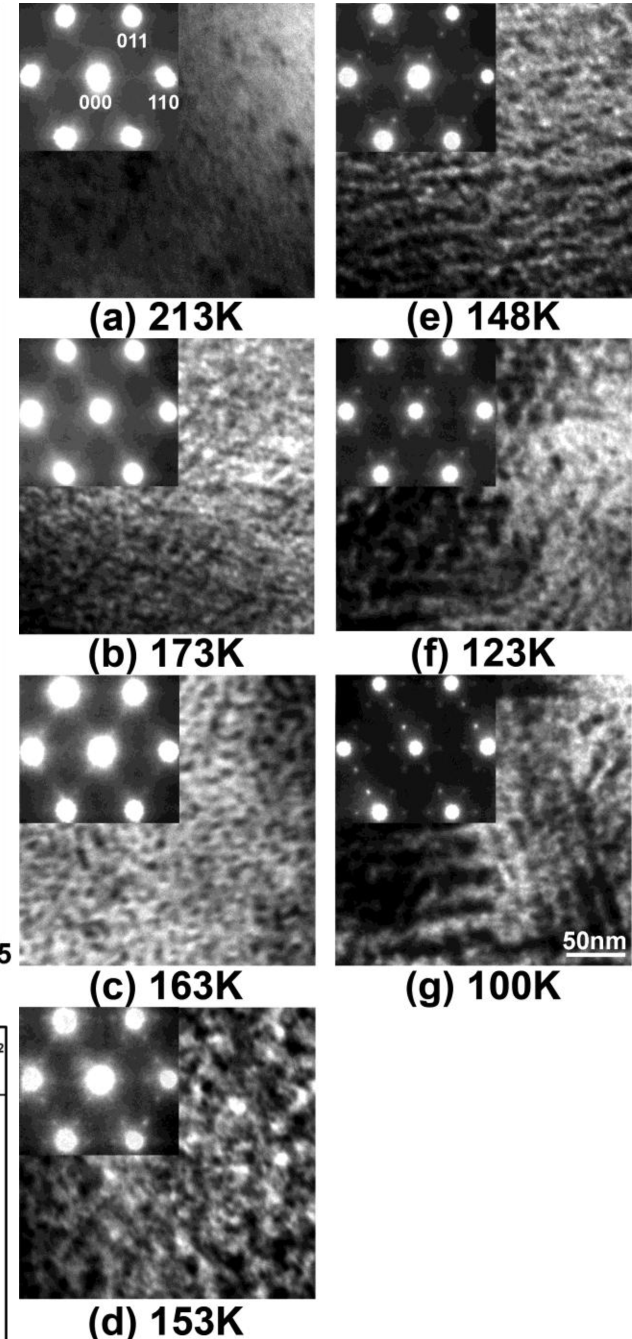
*Strain glass transition*
kinetic slowing-down

[Zhang J and Ren, X et. al PRB 214201,](#)



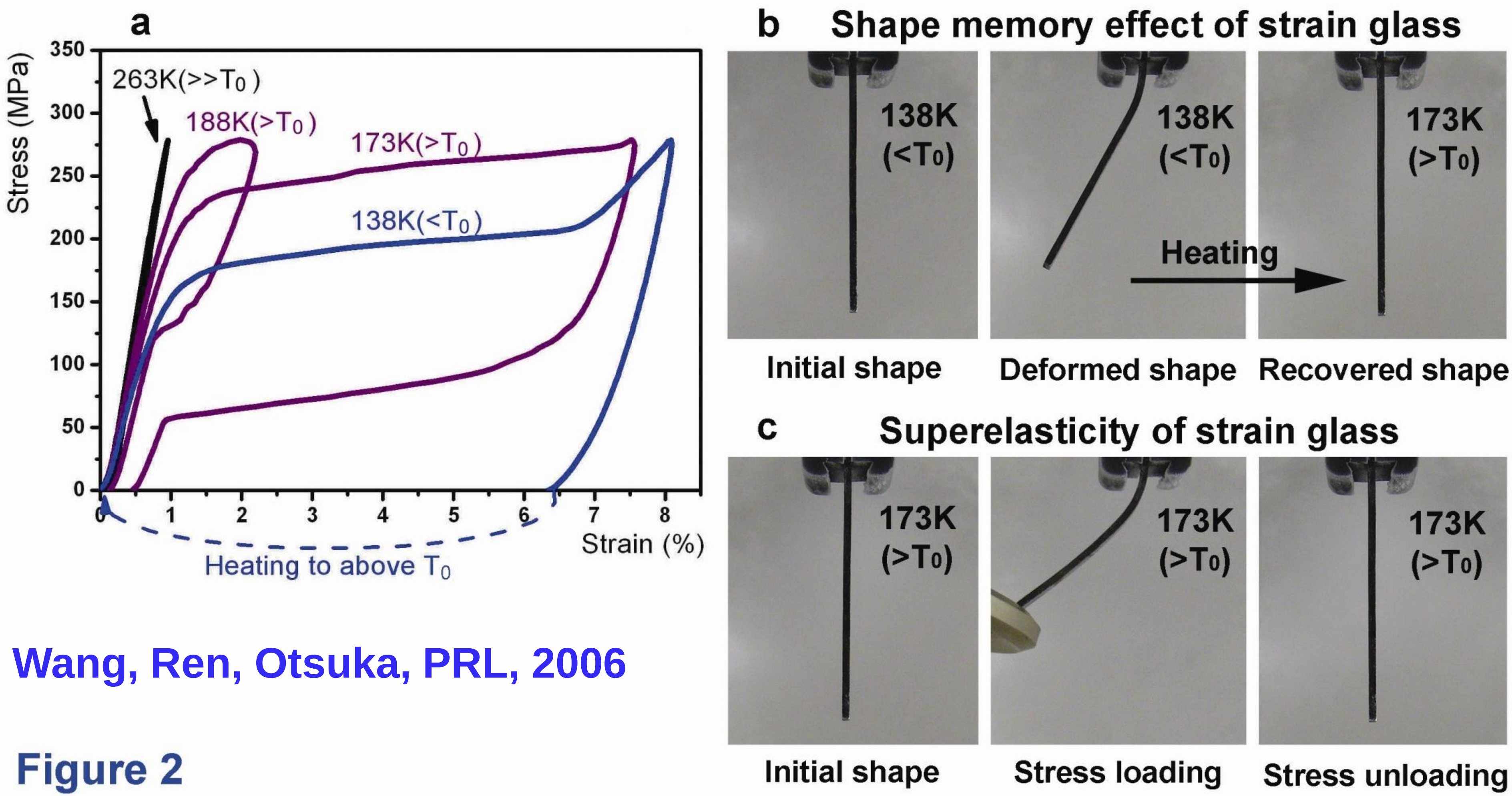

Experimental proofs of spontaneous STG to R-phase transition in $Ti_{50}Ni_{44.5}Fe_{5.5}$

Zhang J and Ren, X et. al PRB 214201, 20.

# “Strange” properties of strain glass

- Shape memory and superelasticity of non-martensite
- Invar effect (a Nobel-prize discovery but a century-old puzzle)
- Anisotropic Invar effect in Gum metal

# Shape memory and superelasticity of strain glass Ti-51.5Ni



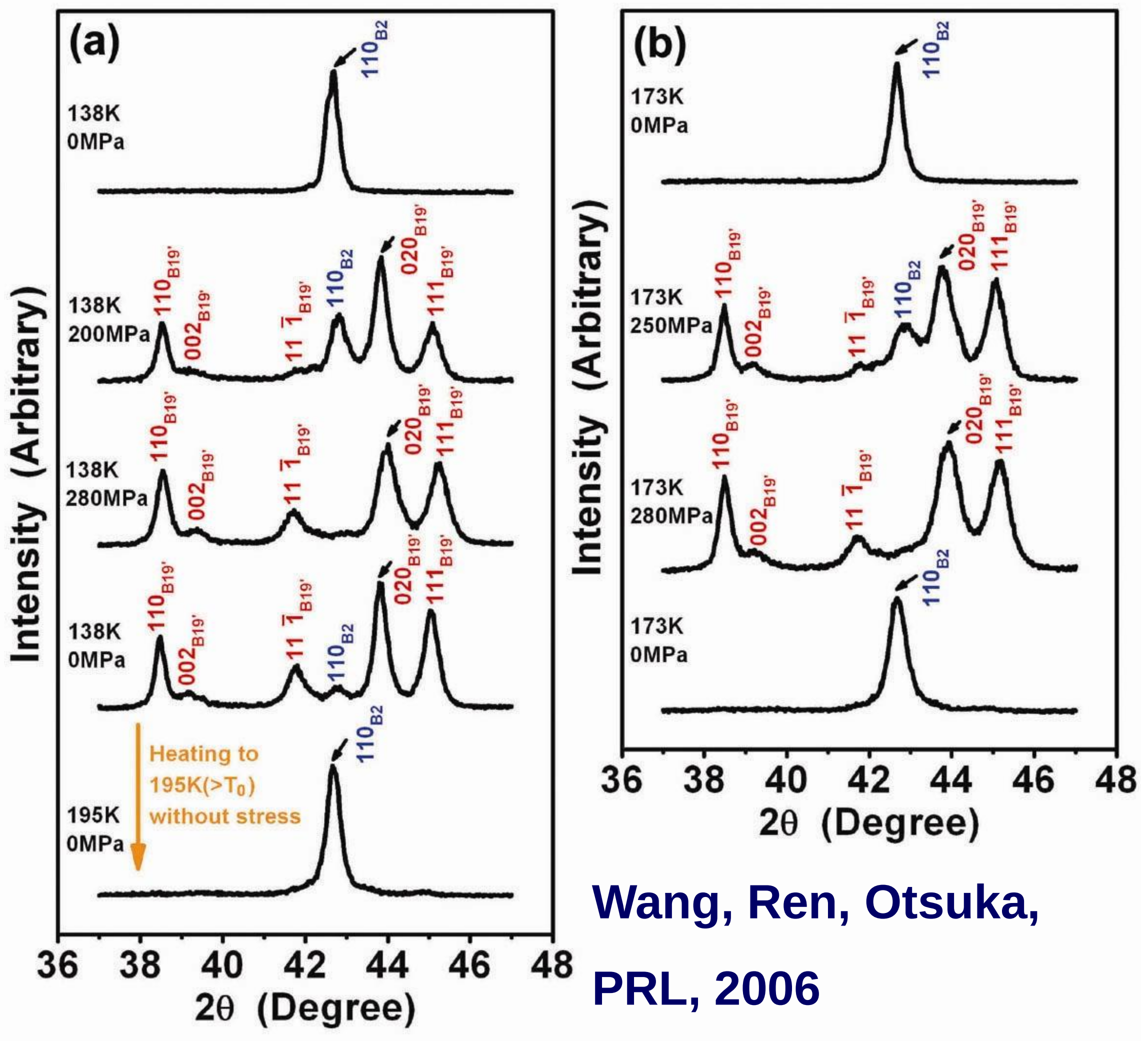

**Wang, Ren, Otsuka, PRL, 2006**

Figure 2

# Microscopic mechanism of the shape memory and superelasticity in strain glass

Tension at T<<Tg and then heating to T>Tg

Tension at T>Tg




Tg=160K

**Wang, Ren, Otsuka, PRL, 2006**

# Origin of Strain Glass and Modeling

(more details→ Turab Lookman talk

# Microscopic origin of strain glass

- **Random point defects destroy long-range strain ordering and form a locally ordered state.**

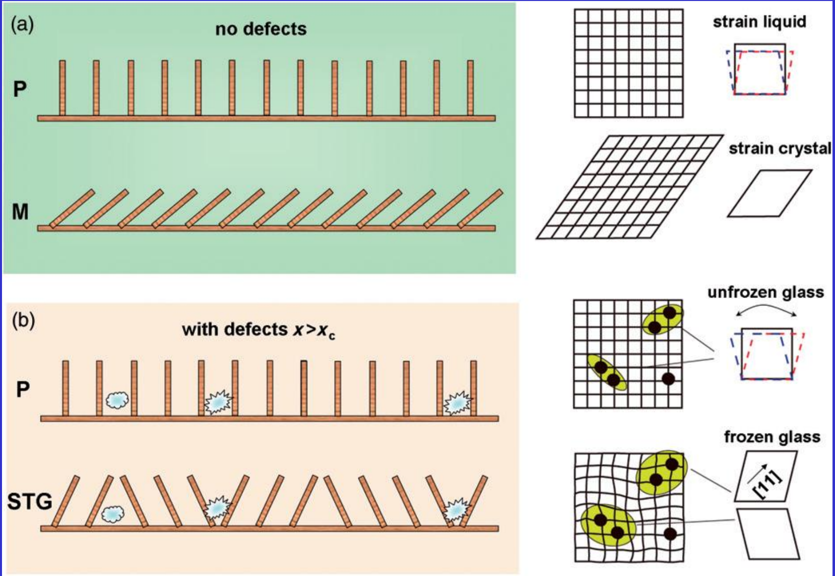
Analogy: domino strain glass (A Cartoon)

Parent phase

martensite

Parent phase

Strain glass



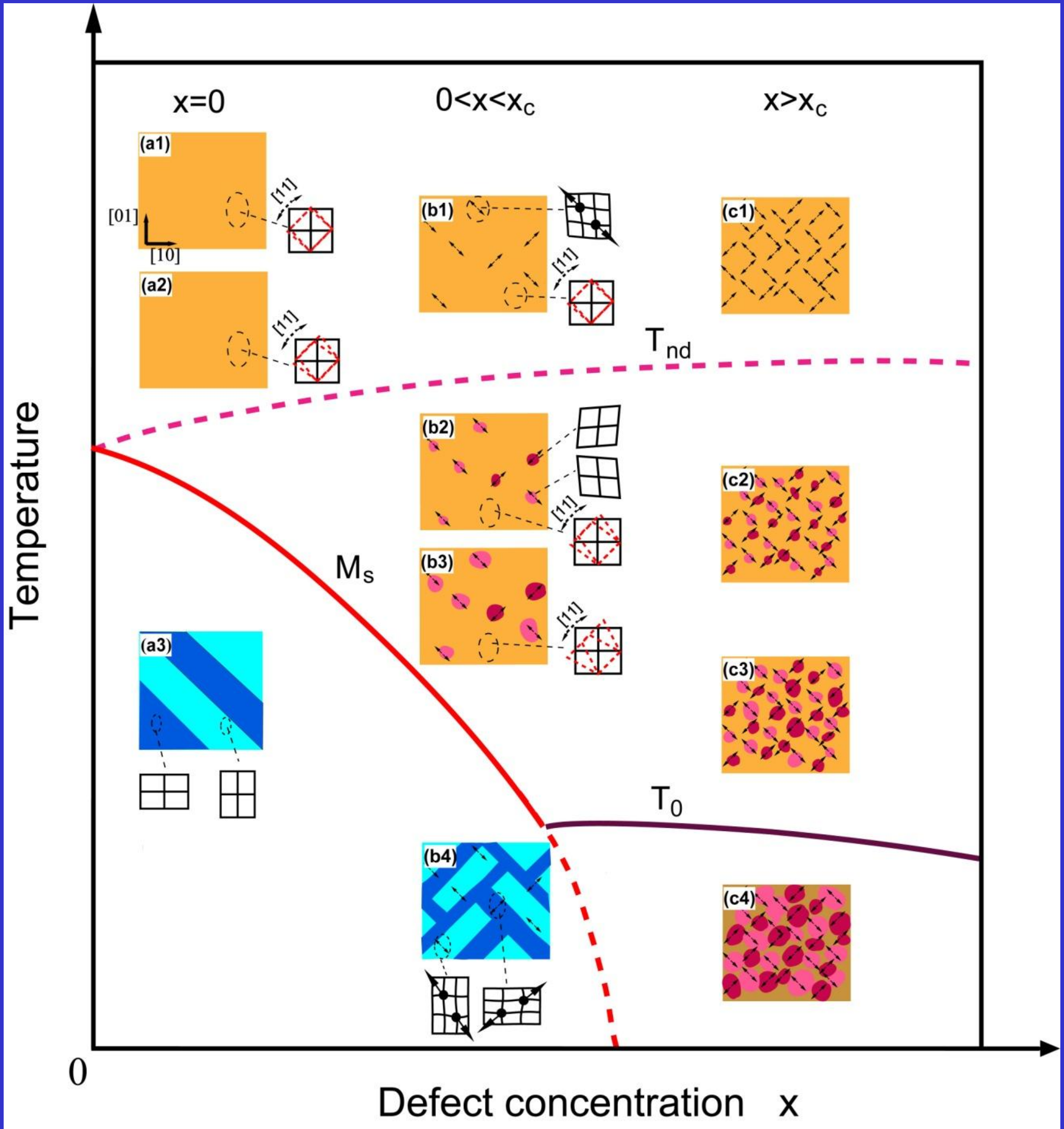

Normal martensitic transition

(LRO)

Strain glass transition

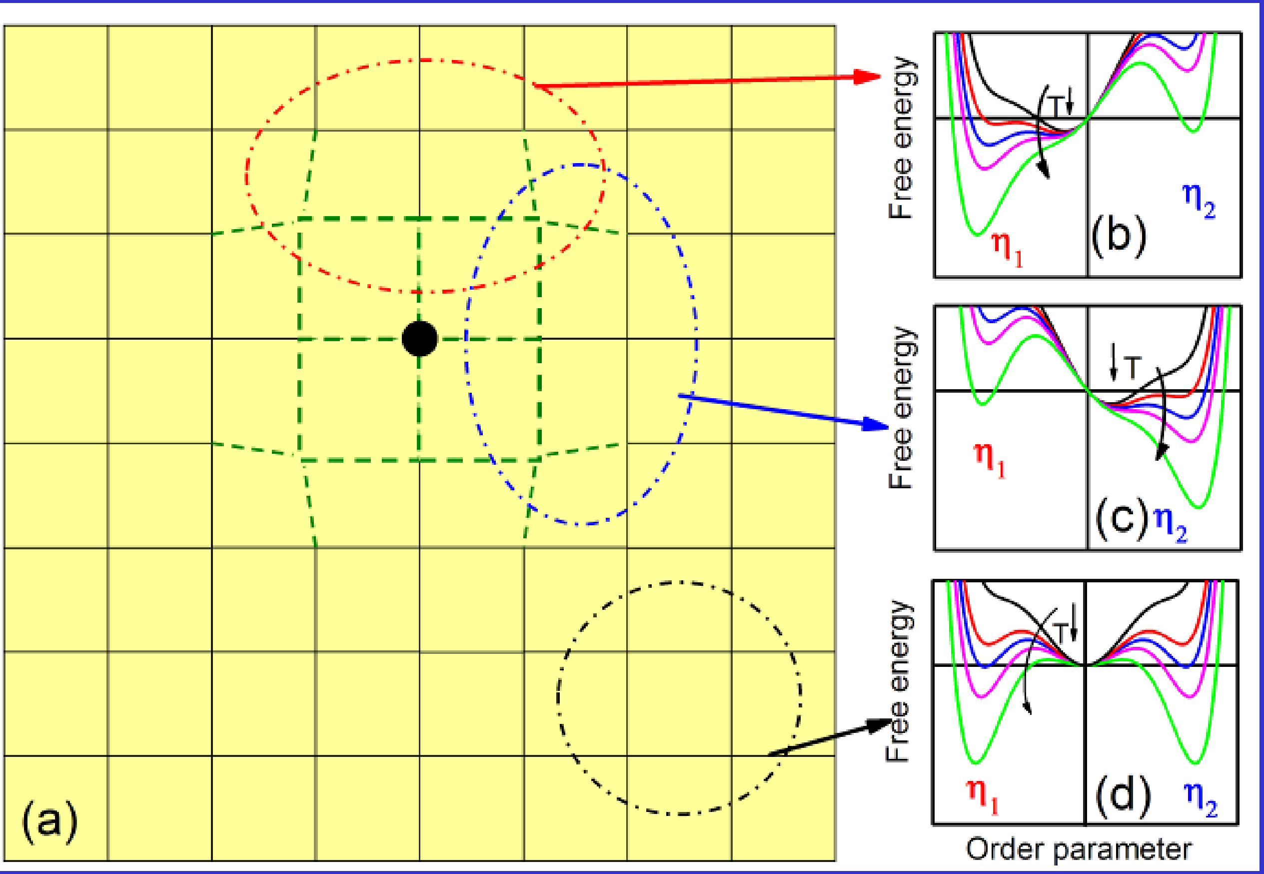
(frozen SRO)

# Microscopic picture of the crossover




Z. Zhang, PRB 2010

# Phenomenological theory of strain glass and computer simulations




Basic idea:
Point defects/ dopants cause random local stresses and breaks local symmetry

# model

D. Wang et al, PRL 2010

$$f_{ch}(\eta_1,\eta_2)=\frac{1}{2}A_1(\eta(r)_1^2+\eta(r)_2^2)-\frac{1}{4}A_2(\eta(r)_1^4+\eta(r)_2^4)+\frac{1}{4}A_3(\eta(r)_1^2+\eta(r)_2^2)^2+\frac{1}{6}A_4(\eta(r)_1^2+\eta(r)_2^2)^3$$

$$A_1=A_1^0\cdot(T-T^0(c))$$

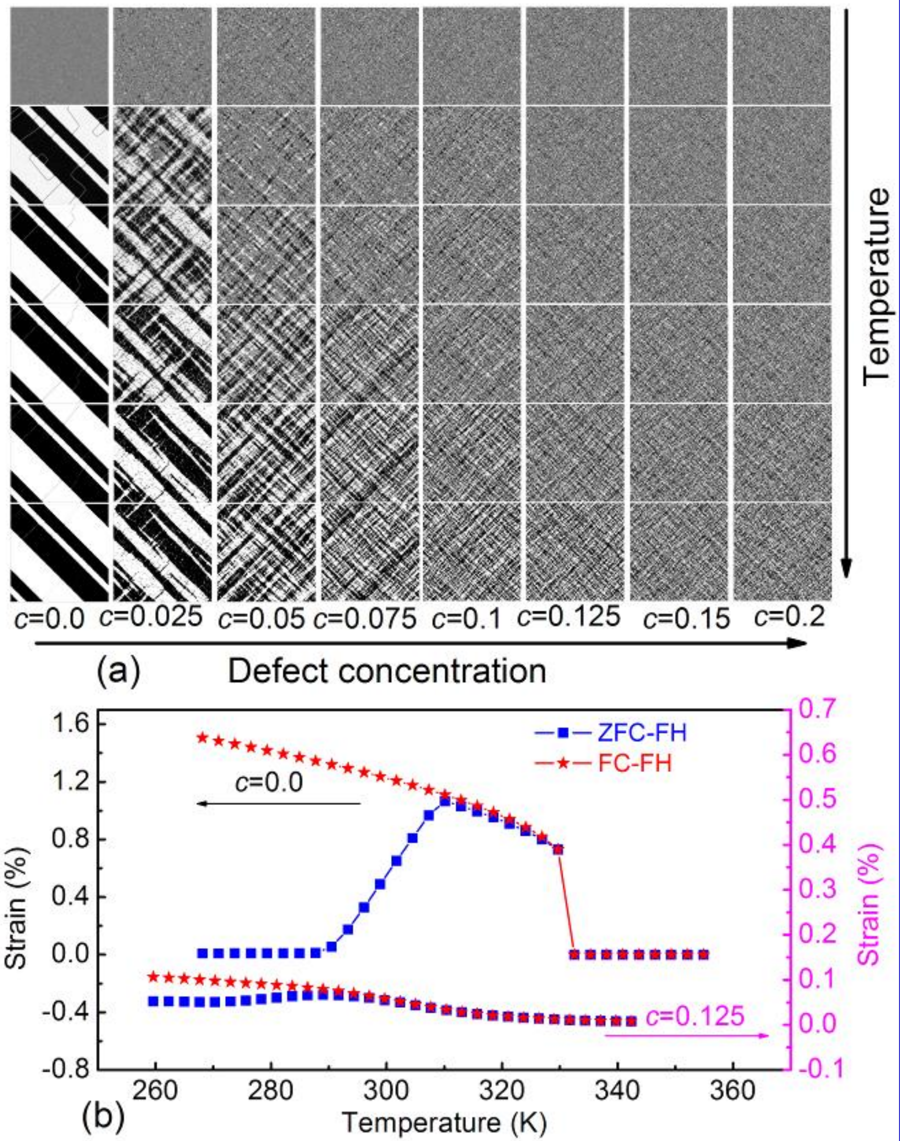
$$T^0(c)=T^{00}+b\cdot c$$

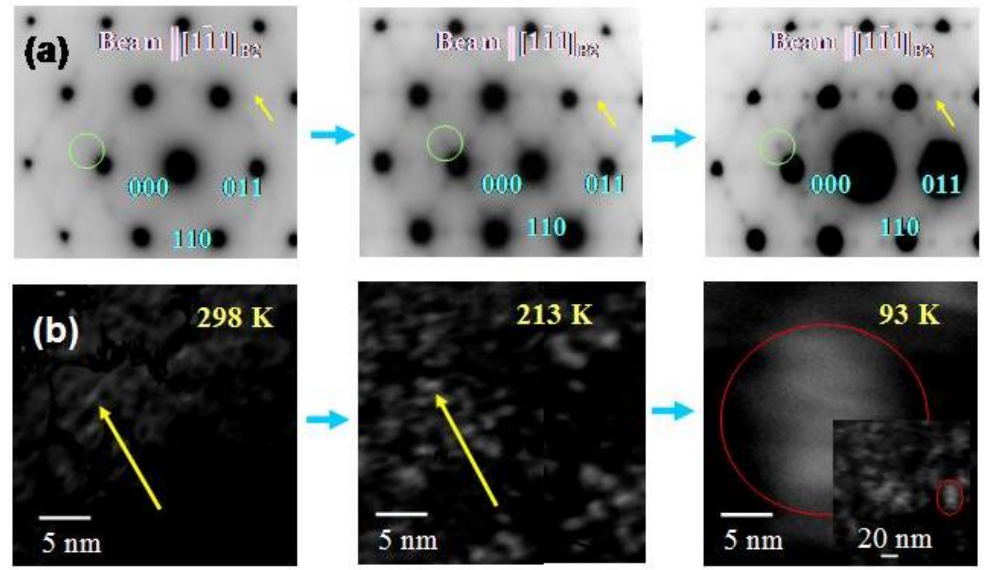
$$f_L(r)=\sum_{i,j=1,2;m=1,3,5}\eta_i^{local}(r)\cdot(\eta(r)_j)^m$$

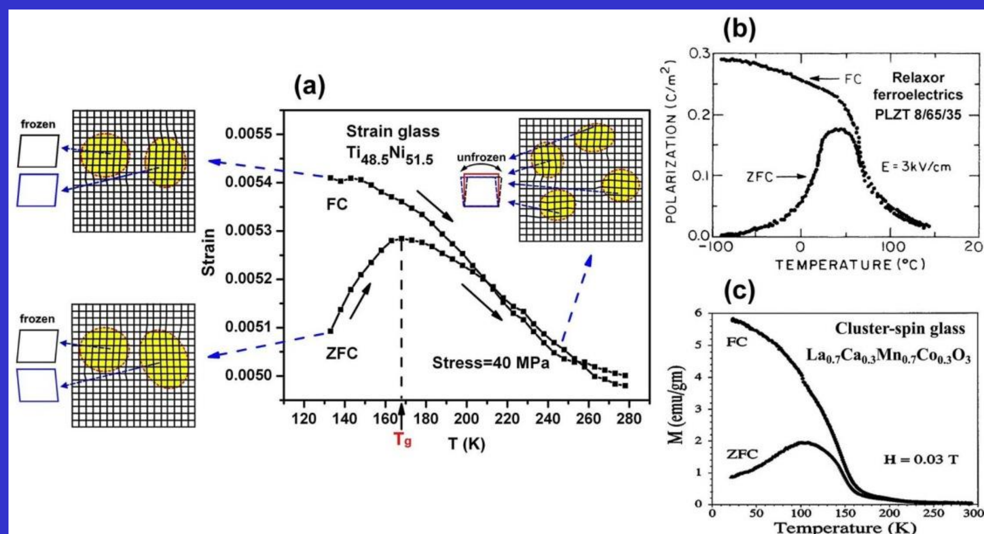
$$F=\int d^2r[\frac{1}{2}\beta(\nabla\eta_1)^2+\frac{1}{2}\beta(\nabla\eta_2)^2+f_{ch}(\eta_1,\eta_2)+f_L(r)]+E_{el}$$

$$E_{el}=\frac{1}{2}c_{ijkl}\sum_{p=1}^{2}\sum_{q=1}^{2}\varepsilon_{ij}^{00}(p)\varepsilon_{ij}^{00}(q)\int\eta_p^2(r)\eta_q^2(r)d^3r-\frac{1}{2}\sum_{p=1}^{2}\sum_{q=1}^{2}\int\frac{d^2k}{(2\pi)^2}B_{pq}(\frac{\vec{k}}{k})\{\eta_p^2(r)\}_k\{\eta_q^2(r)\}_k^*$$

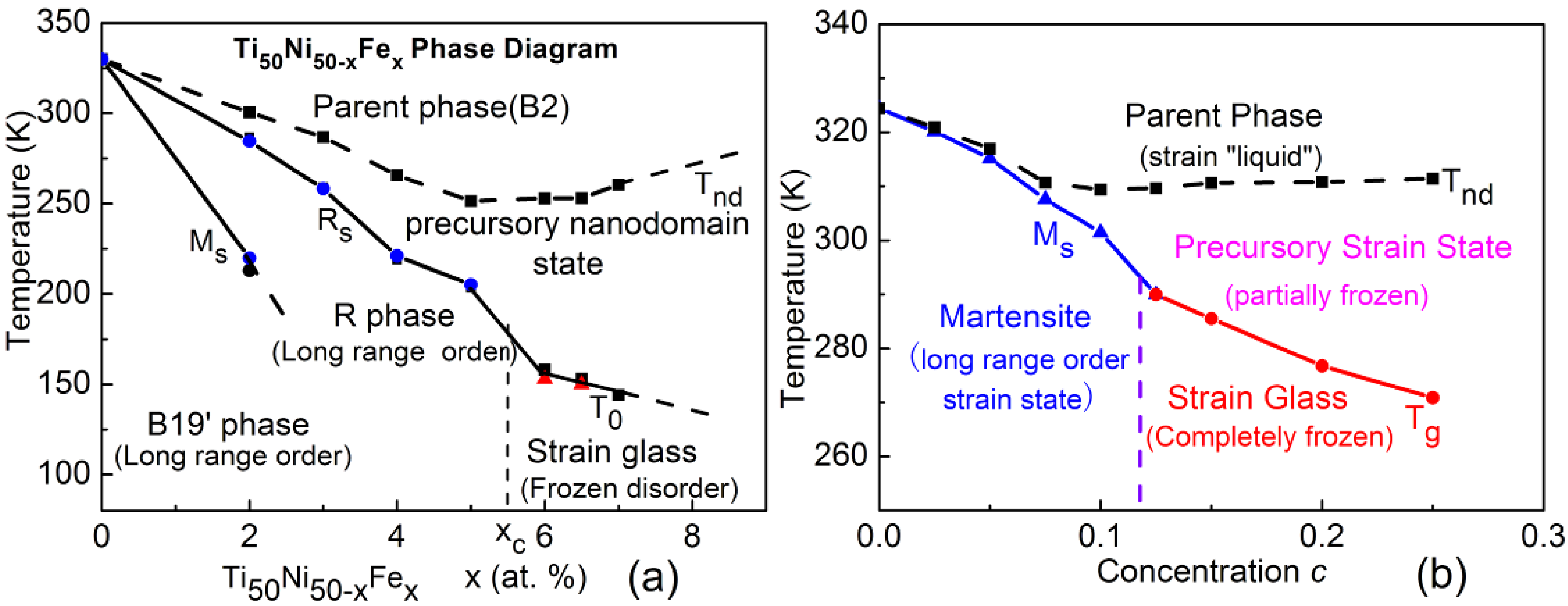
# Calculated results and comparison with experiment D. Wang et al, PRL 2010,



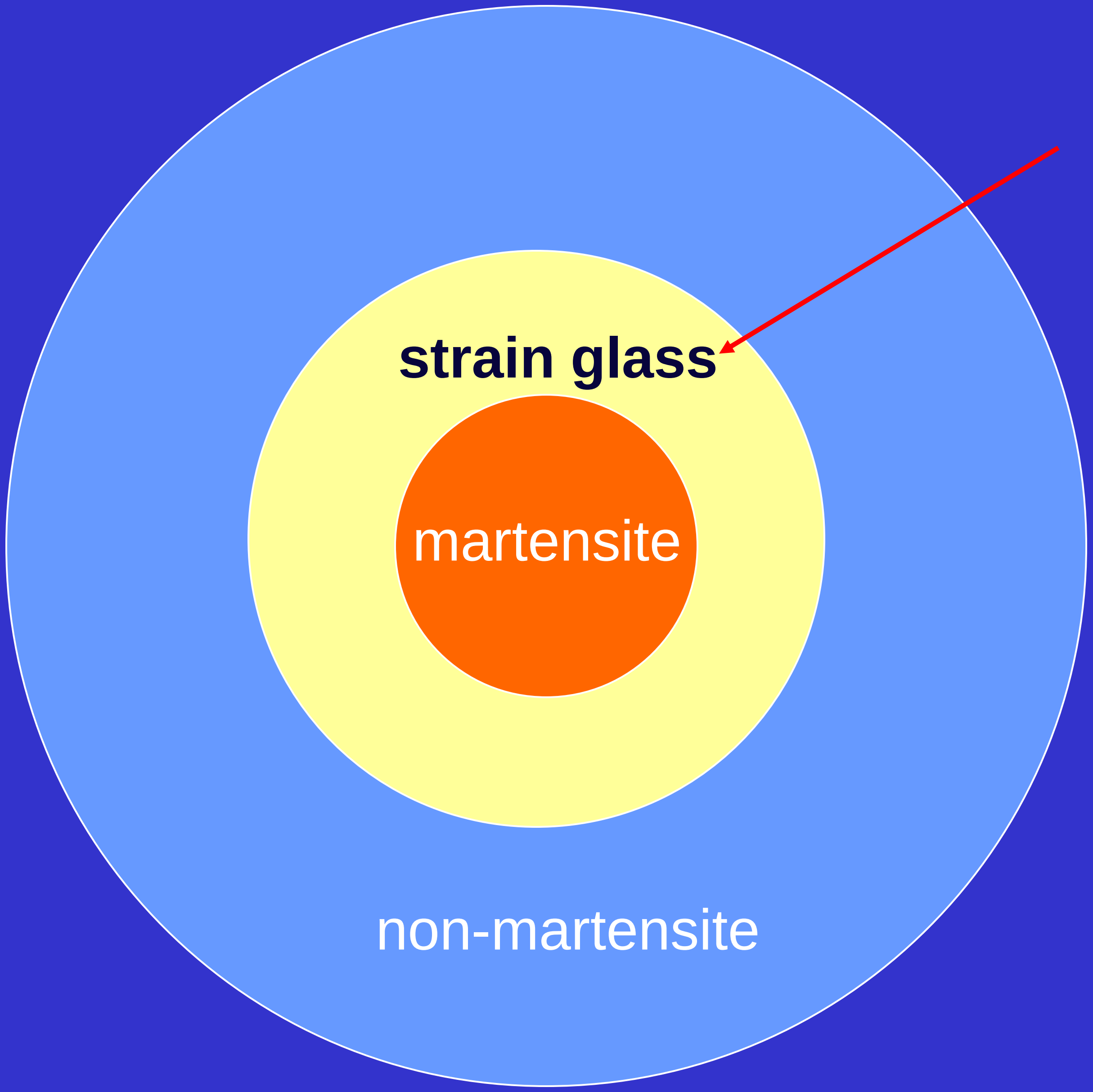



# Comparison between calculated phase diagram and experimental phase diagram




D. Wang et al, PRL 2010

# An emerging new field: strain glass




1. **New physics**
2. **New properties**
3. **New applications**