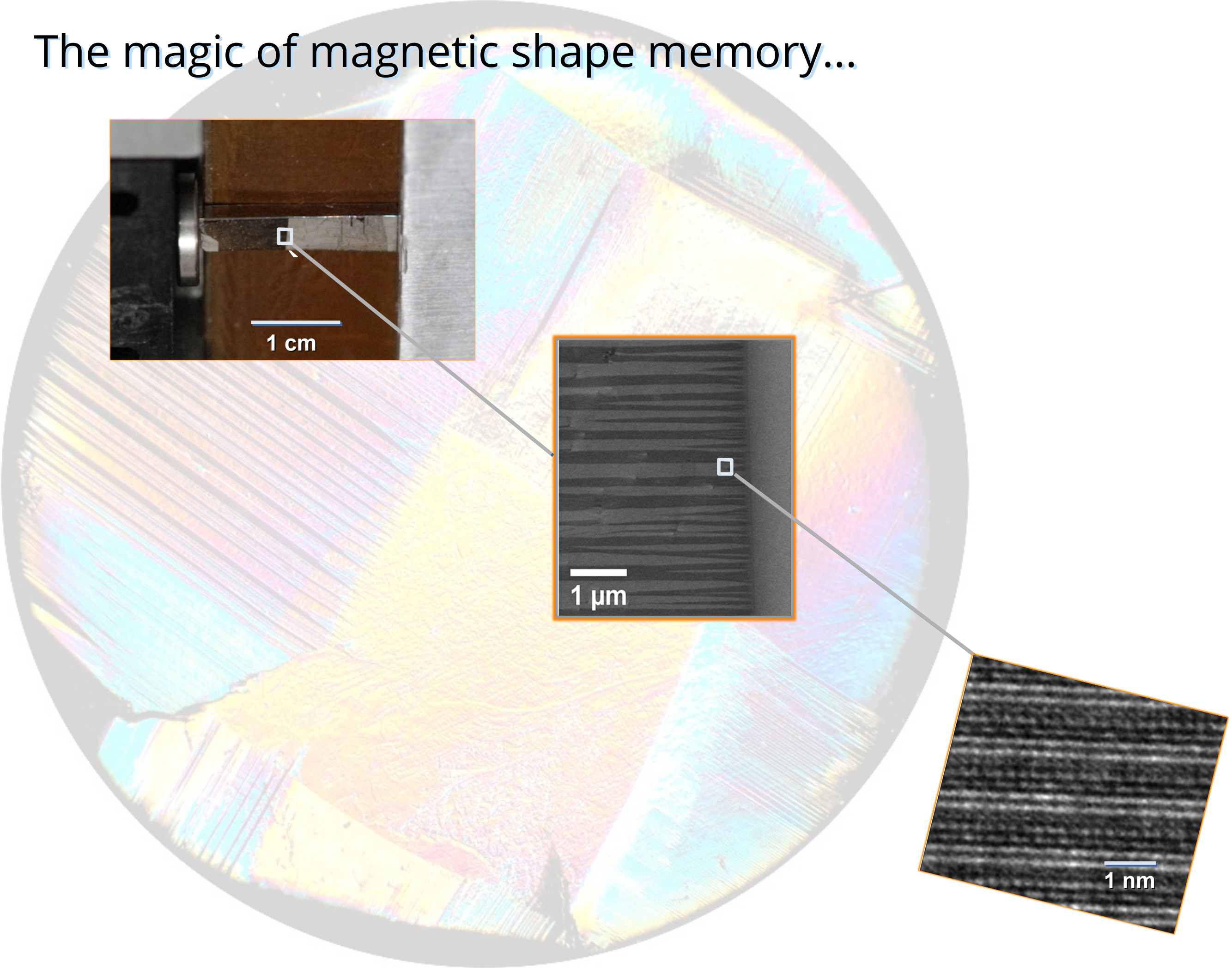
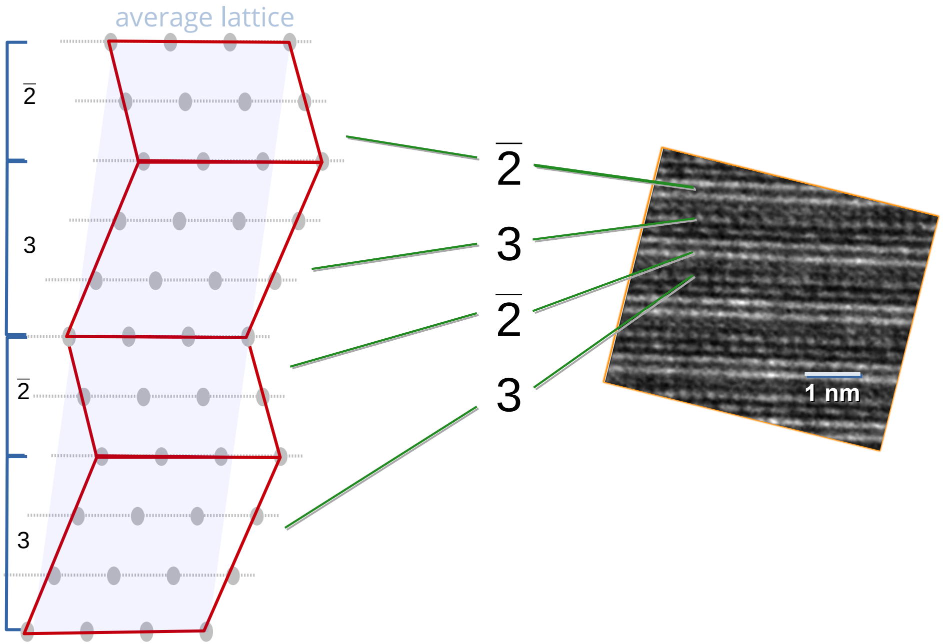
The magic of magnetic shape memory…

- Intro & macrotwins
- *Movie with examples*
- Microtwins
- Nanotwins
- Summary



Structure as a $3\bar{2}$ stacking sequence



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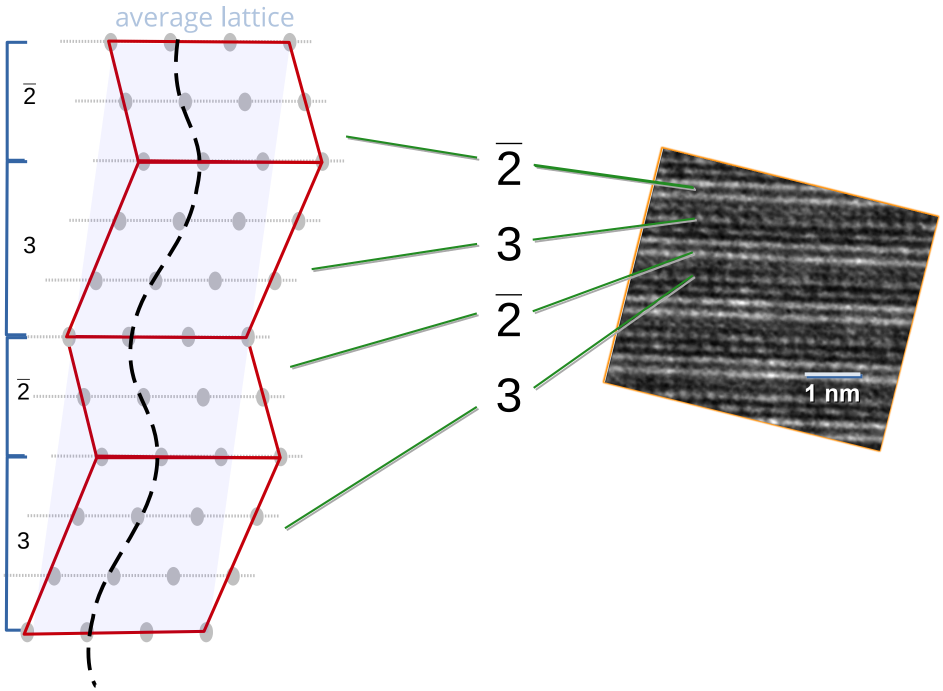

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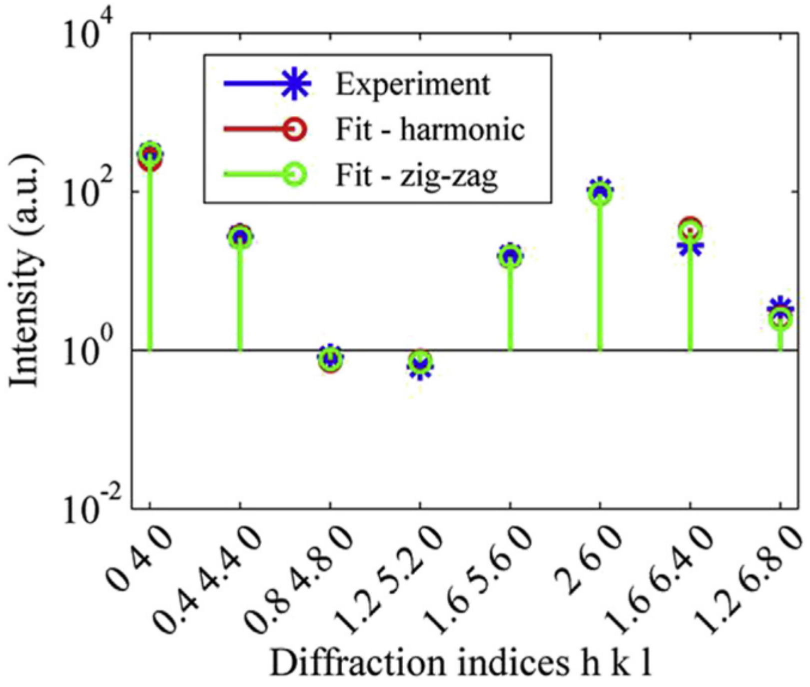

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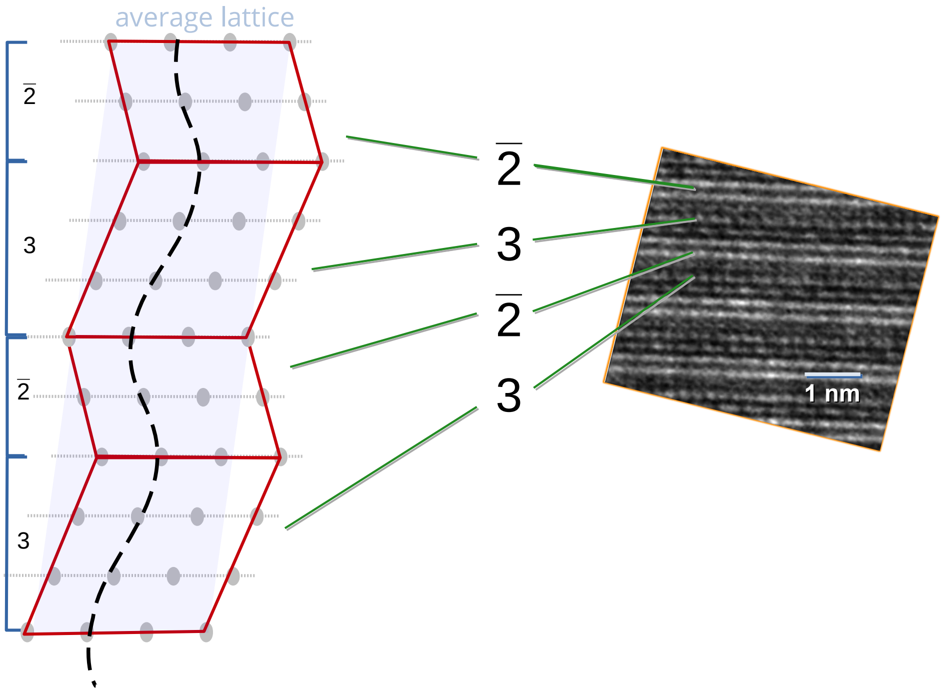

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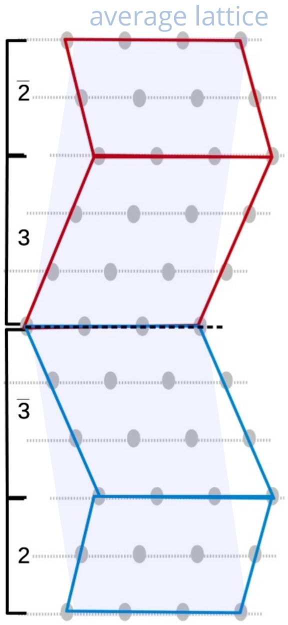

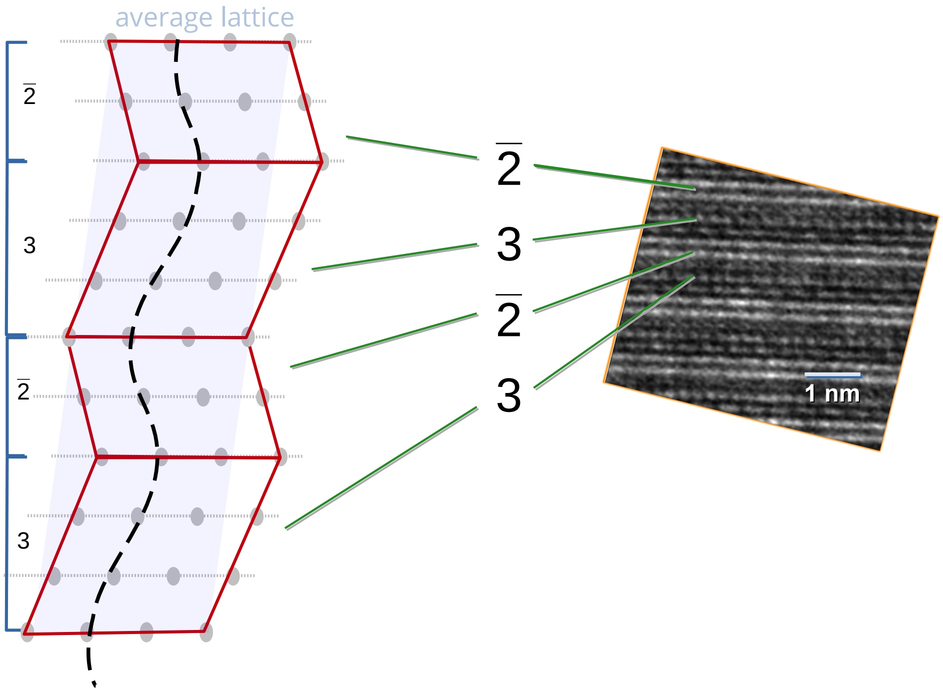

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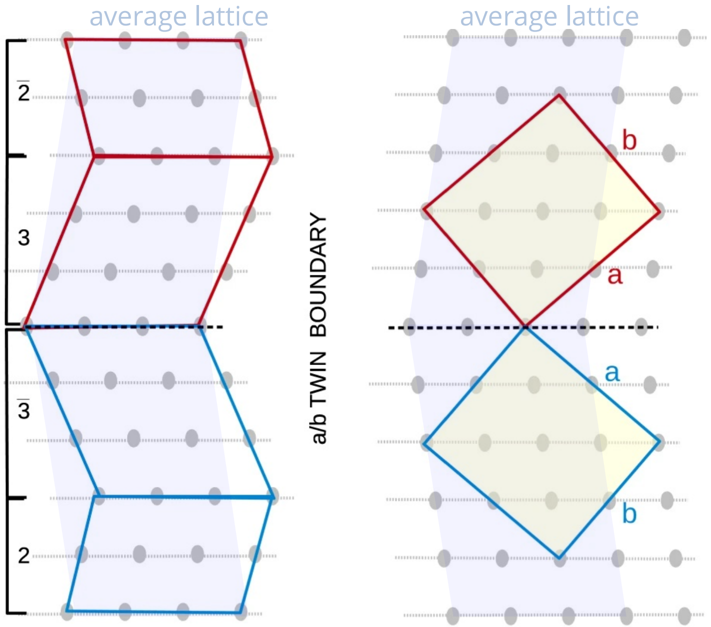

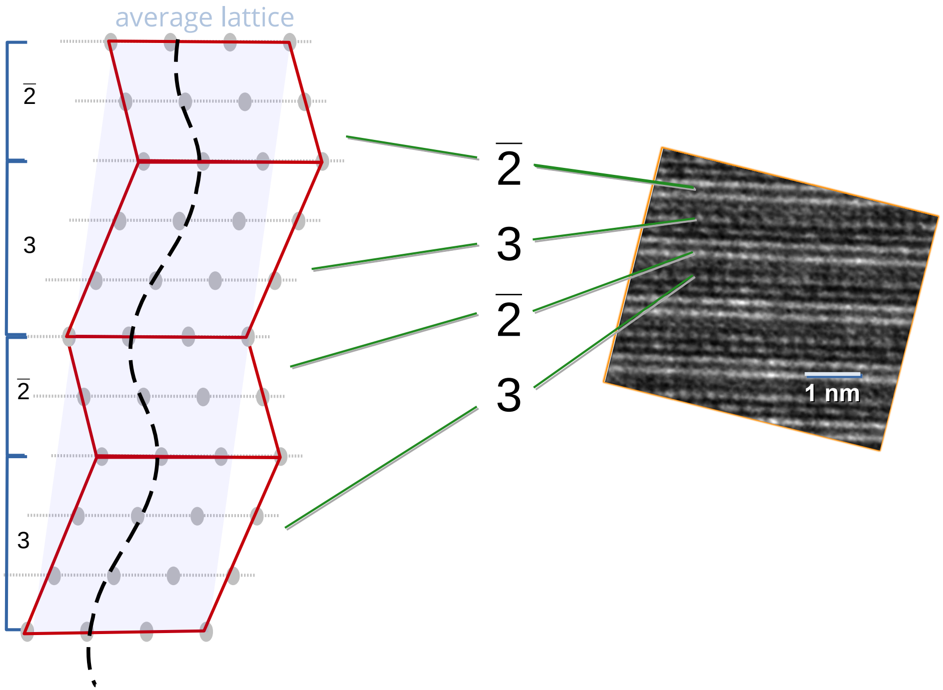

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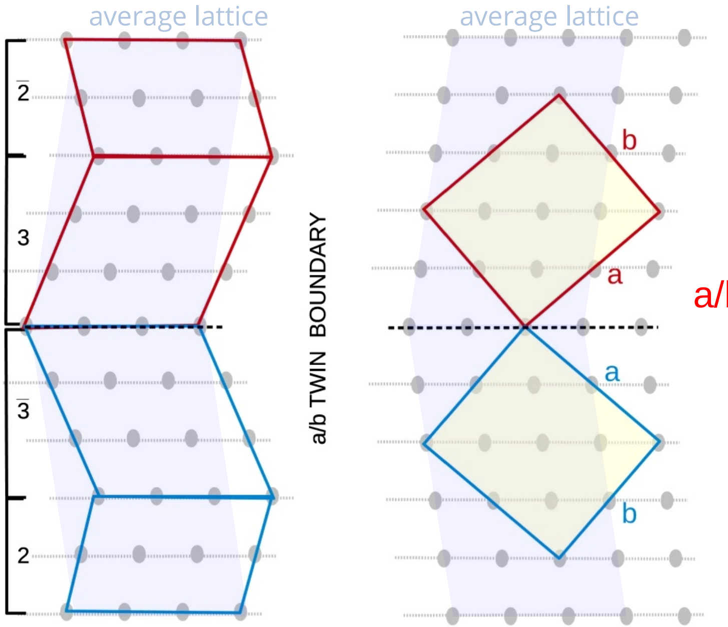
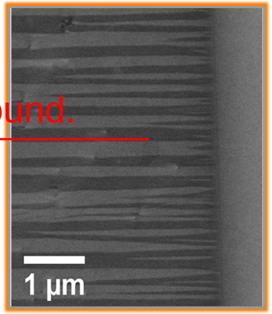
a/b twins as a 3$\bar{2}$ stacking sequence inversion

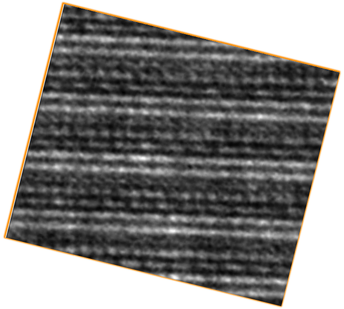
a/b twin boundary = stacking sequence inversion …3$\bar{2}$3$\bar{2}$3$\bar{2}$|23̄23̄23̄…



a/b twin bound.

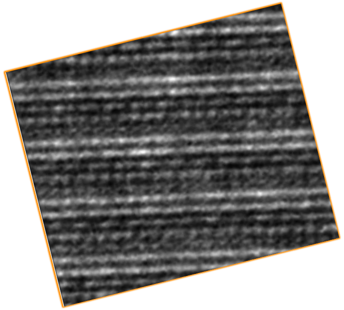


$\bar{2}$
3
$\bar{2}$
3



a/b twin bound.

$\bar{3}$
2
$\bar{3}$
2



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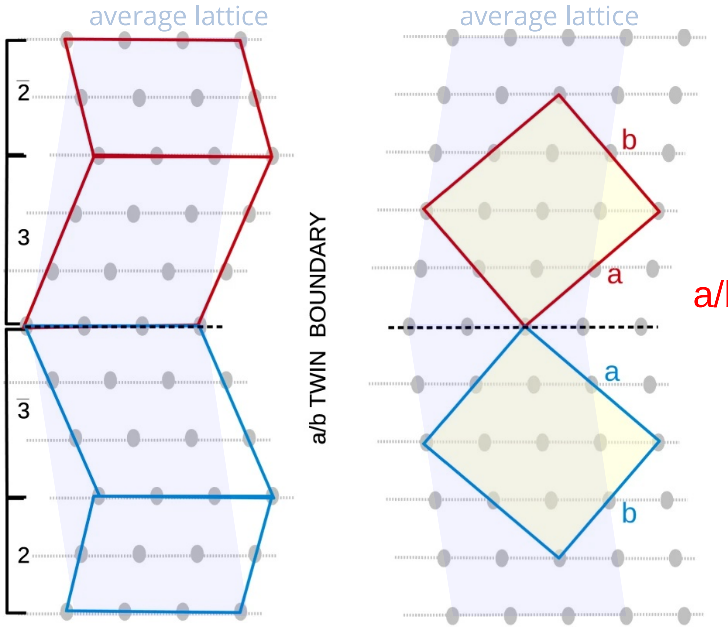

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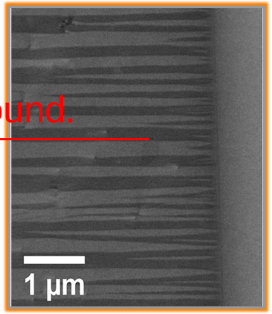

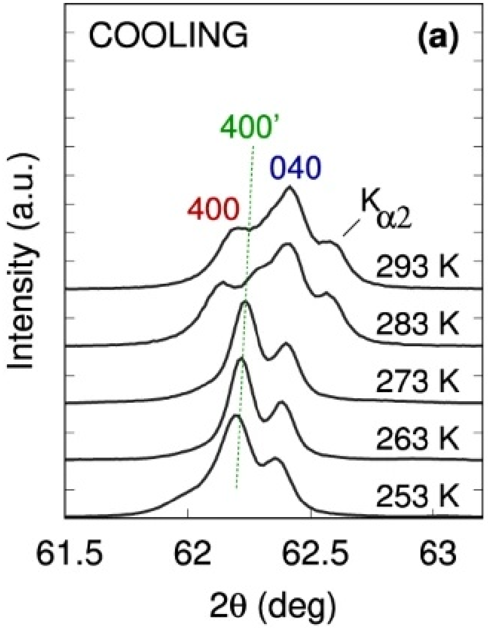

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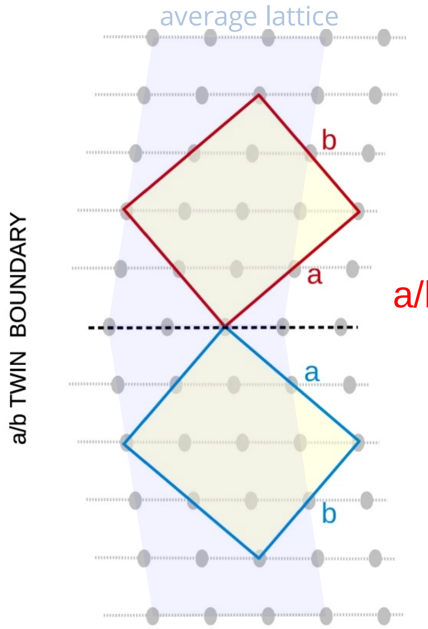

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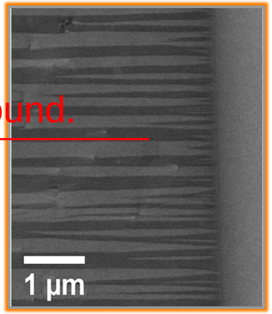

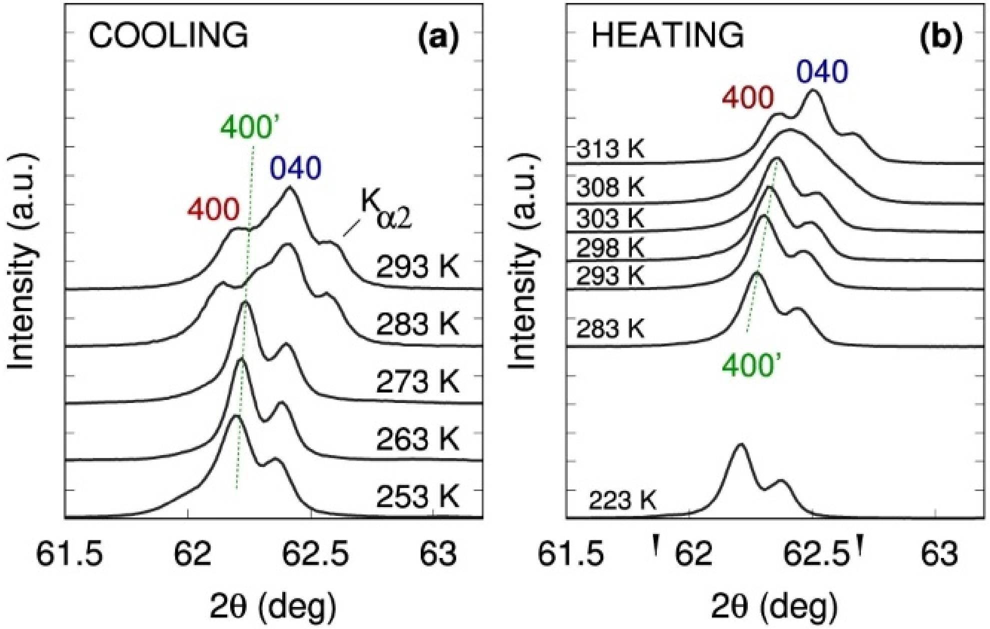

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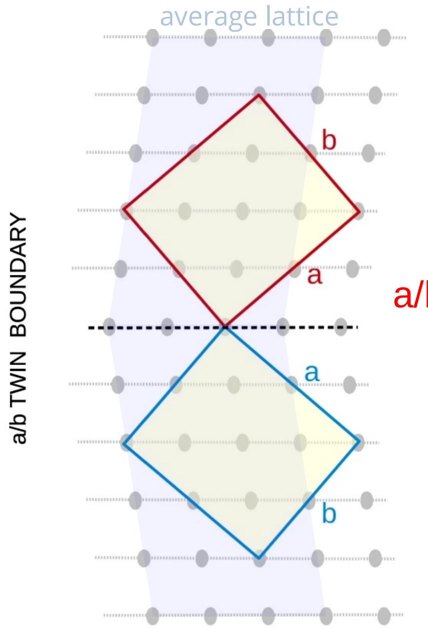

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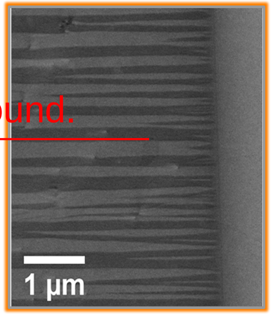

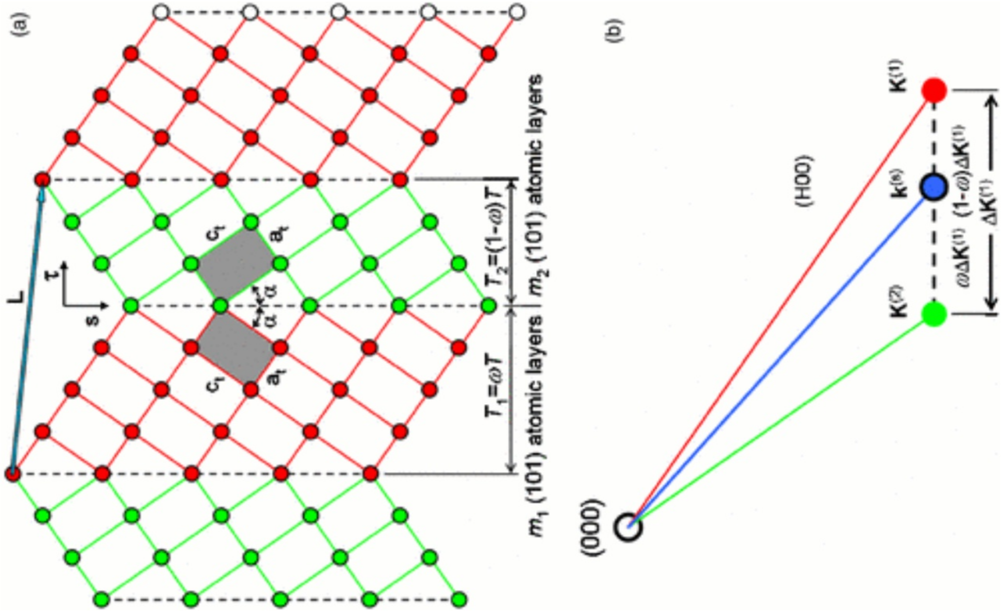

Yu U. Wang, Phys. Rev. B 74 (2006), 104109
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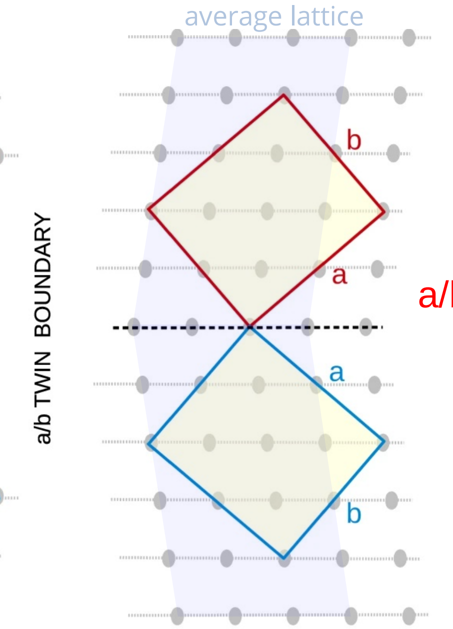

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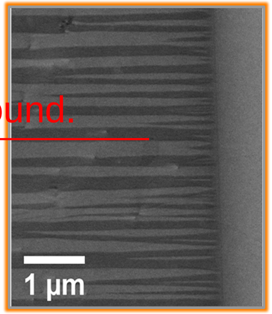

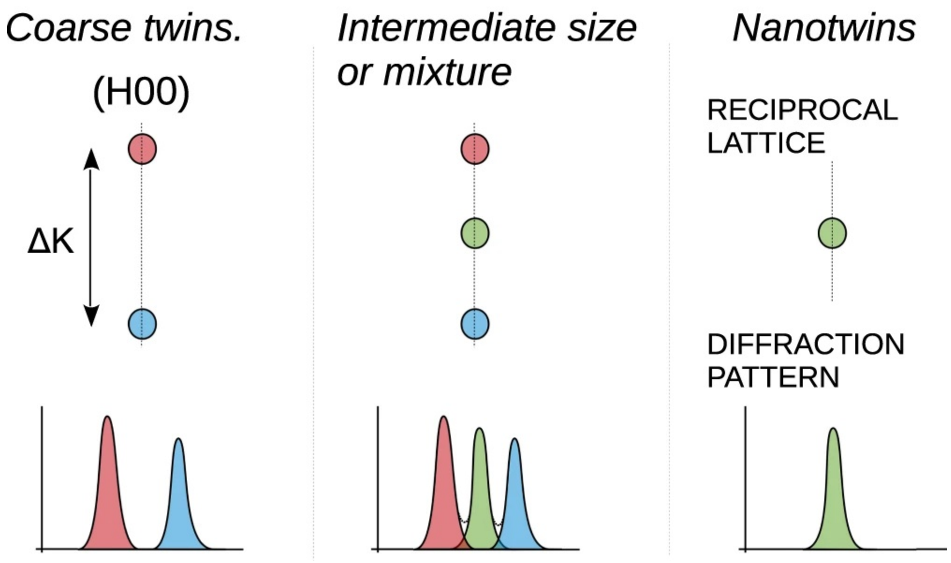

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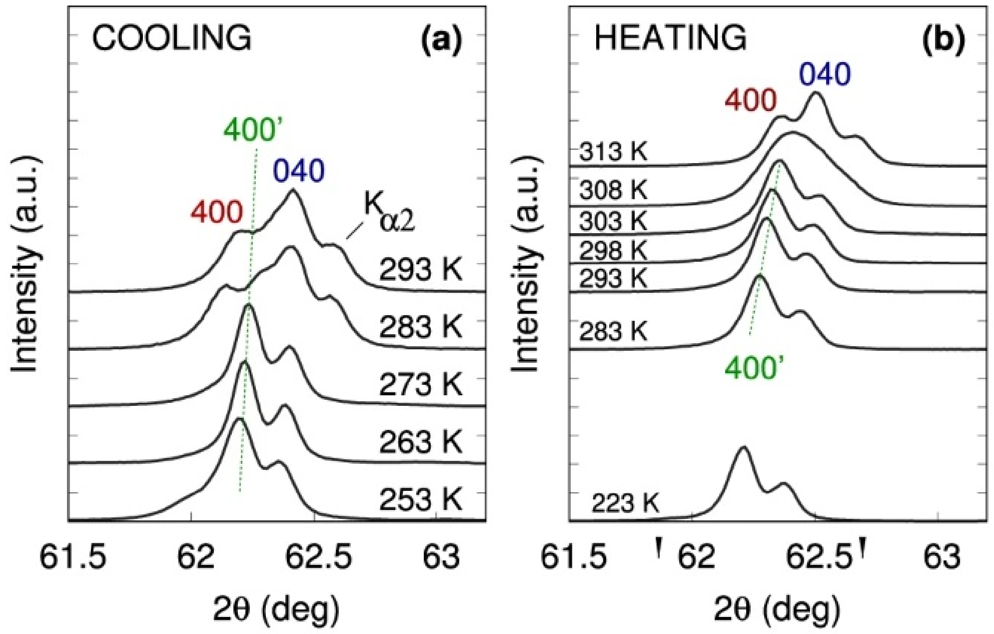

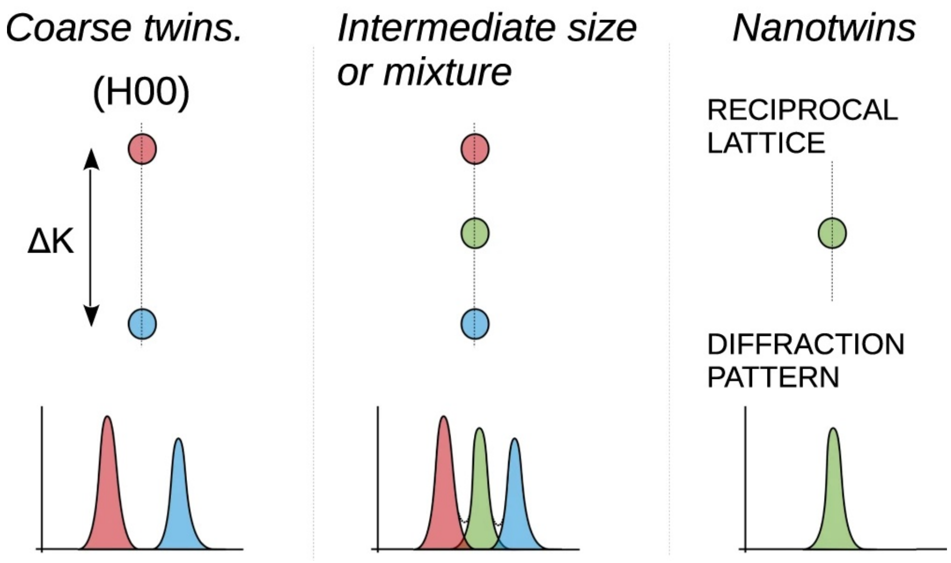

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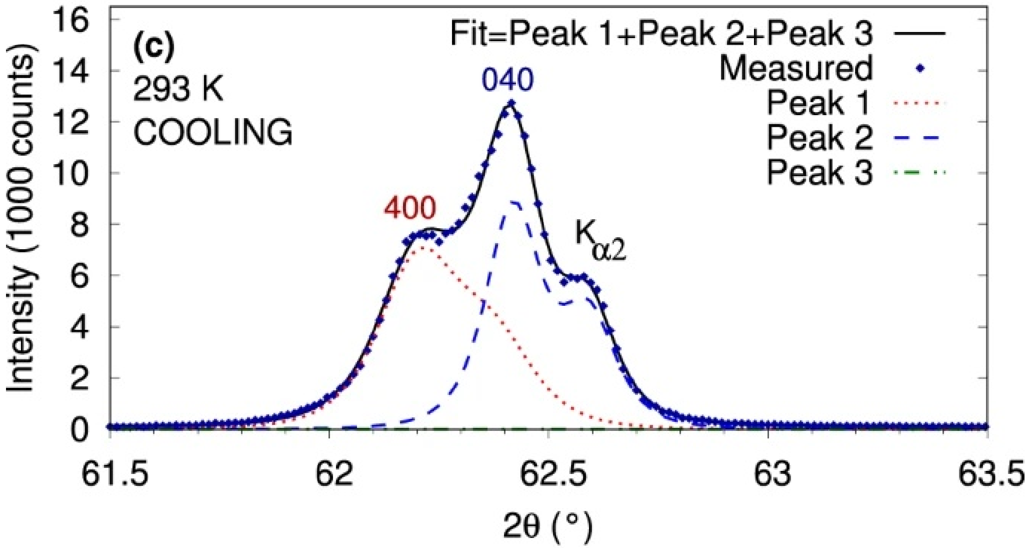

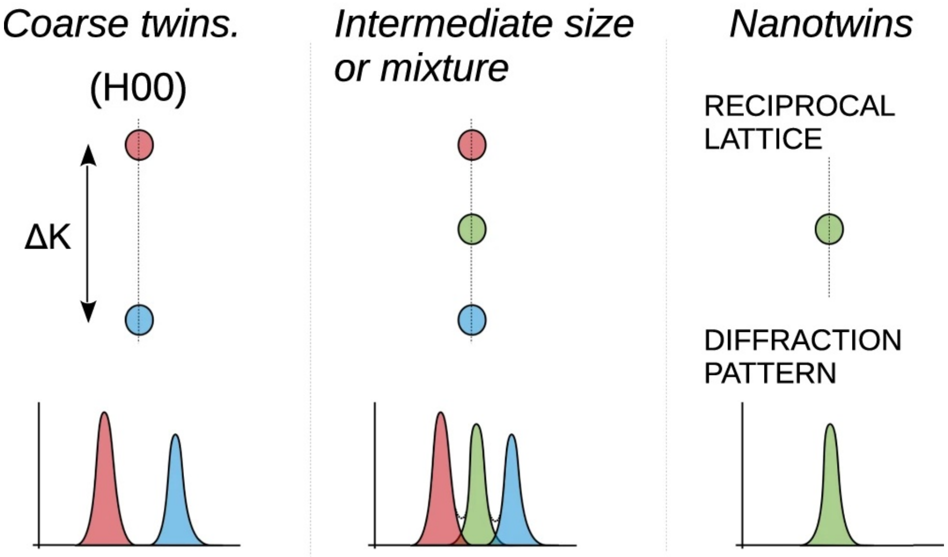

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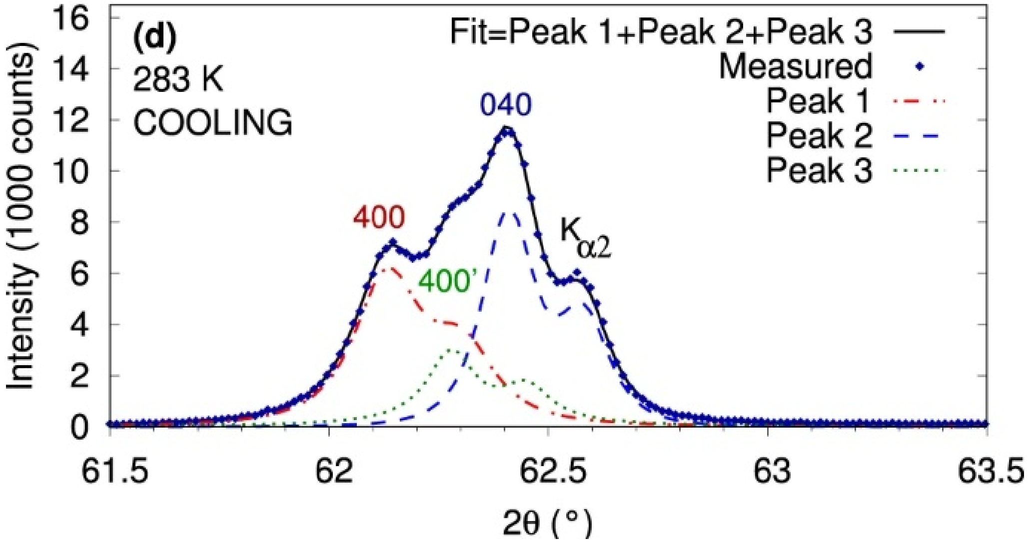

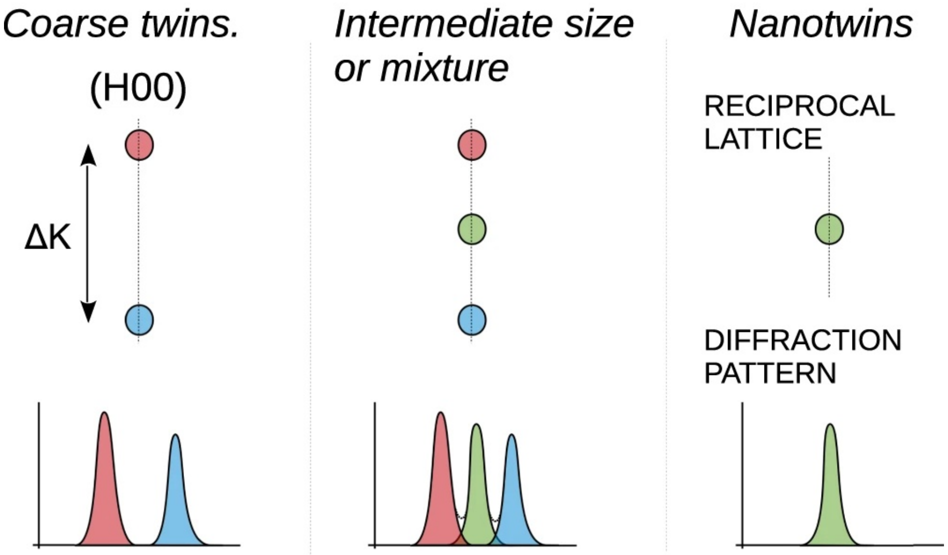

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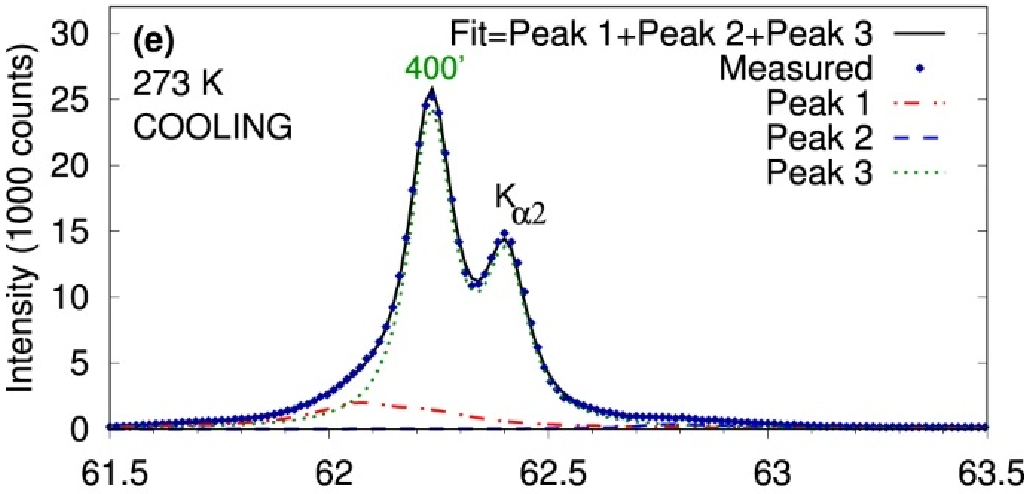

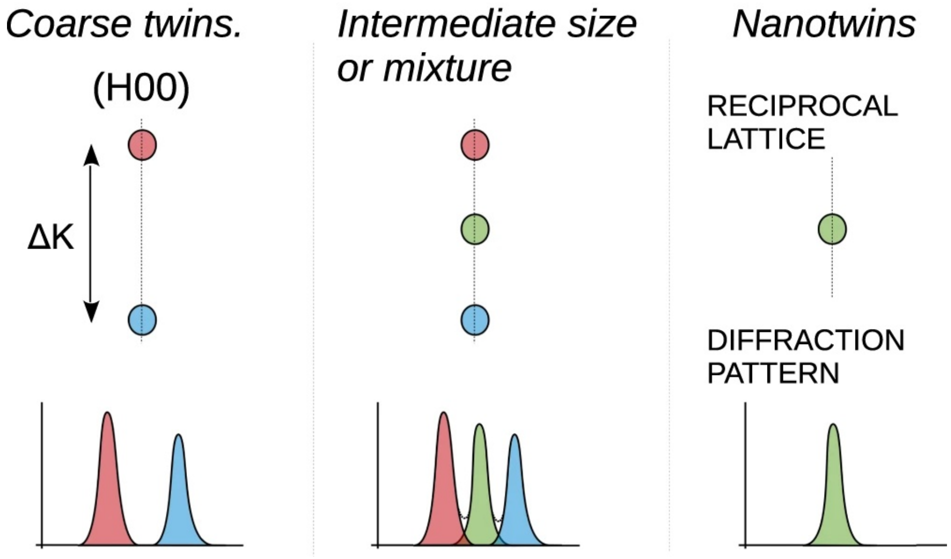

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Nanotwins - adaptive diffraction condition:

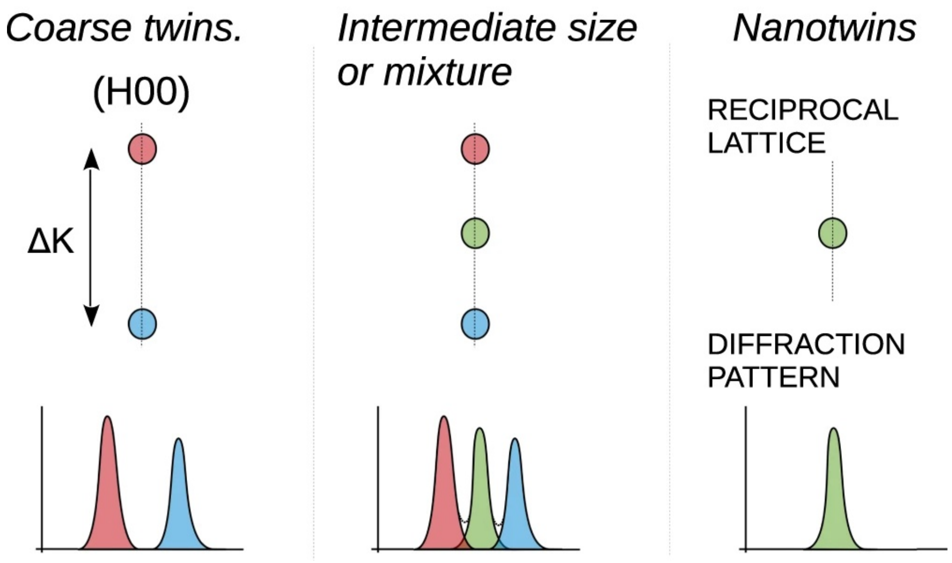
$$m < 2/sH$$

where s = 0.0045 is twinning shear and H = 4 is reciprocal space coordinate

=>

size of a/b twin

$$m < 20 \text{ nm (100 atomic planes)}$$



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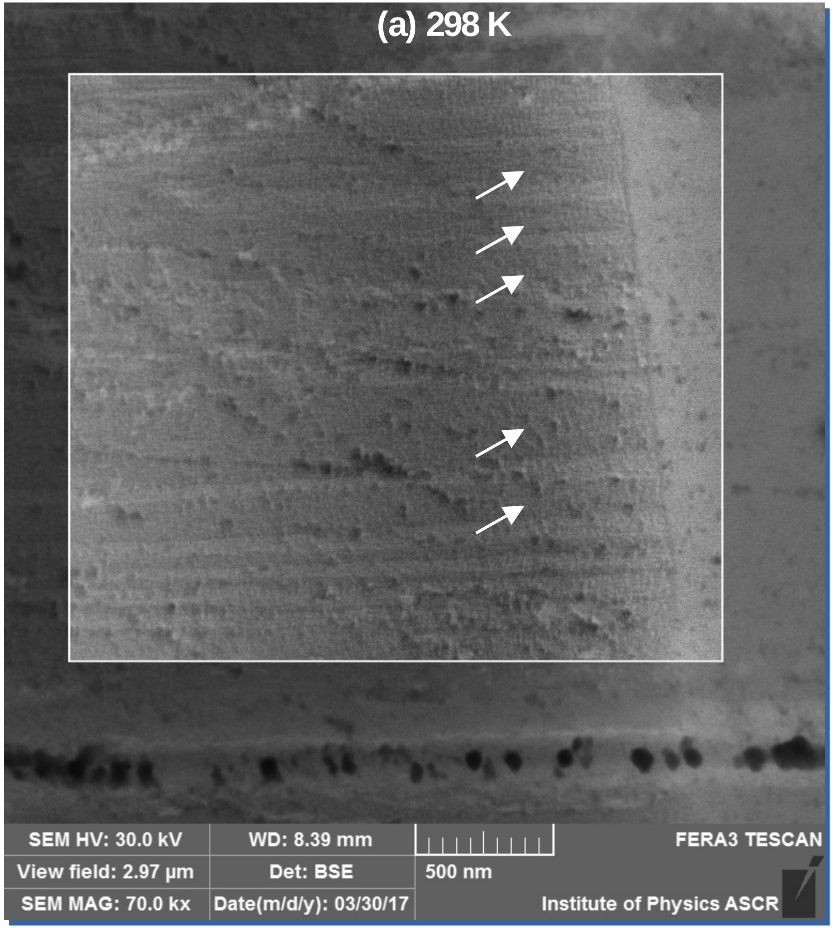

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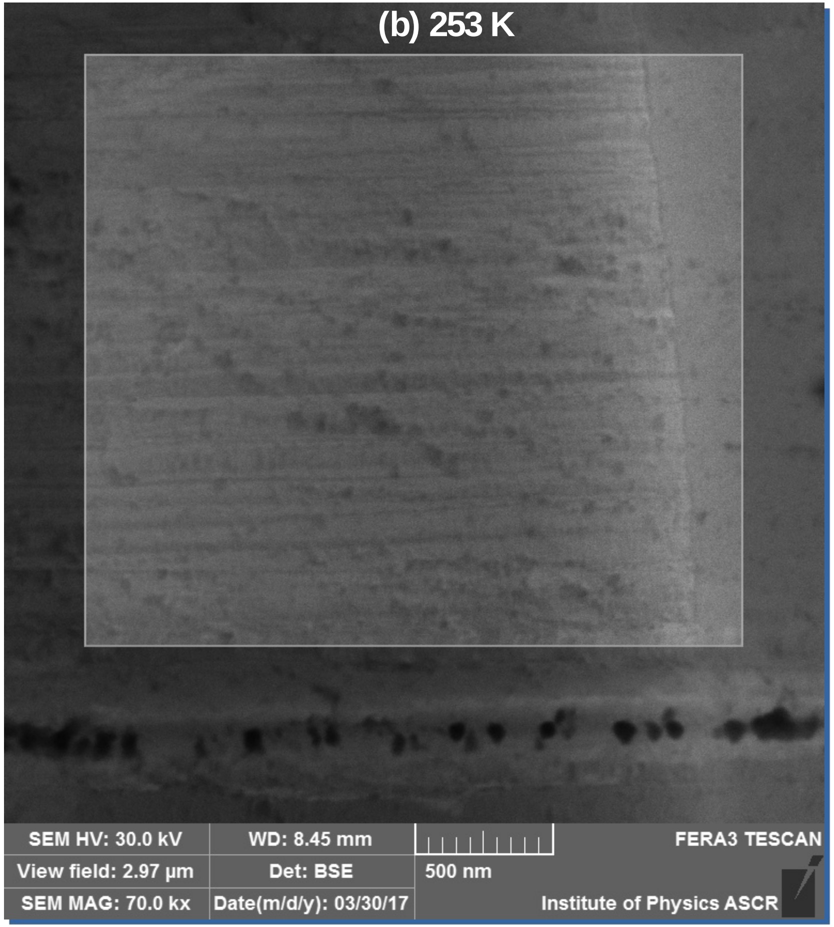

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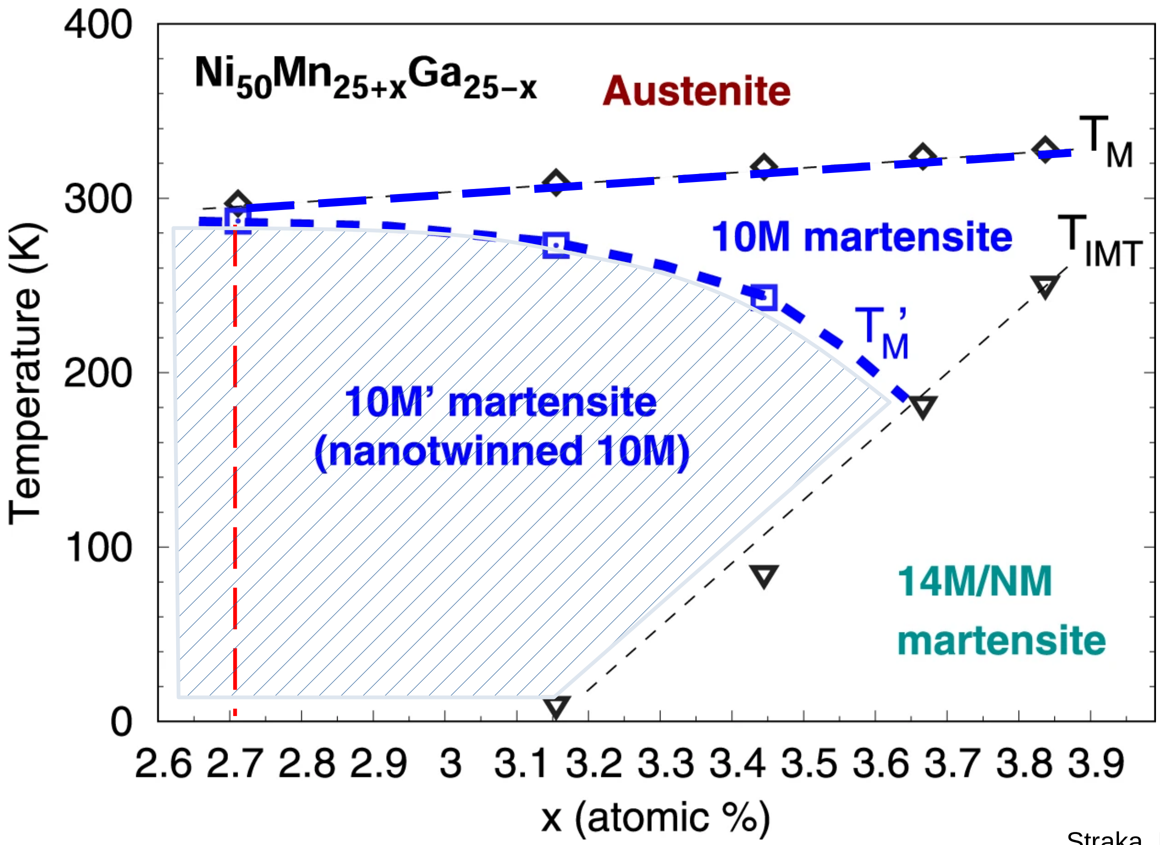

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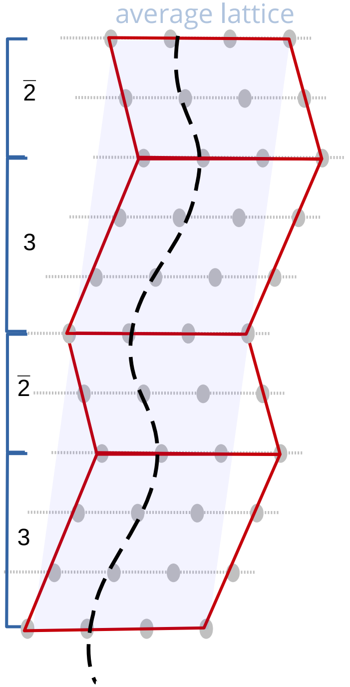
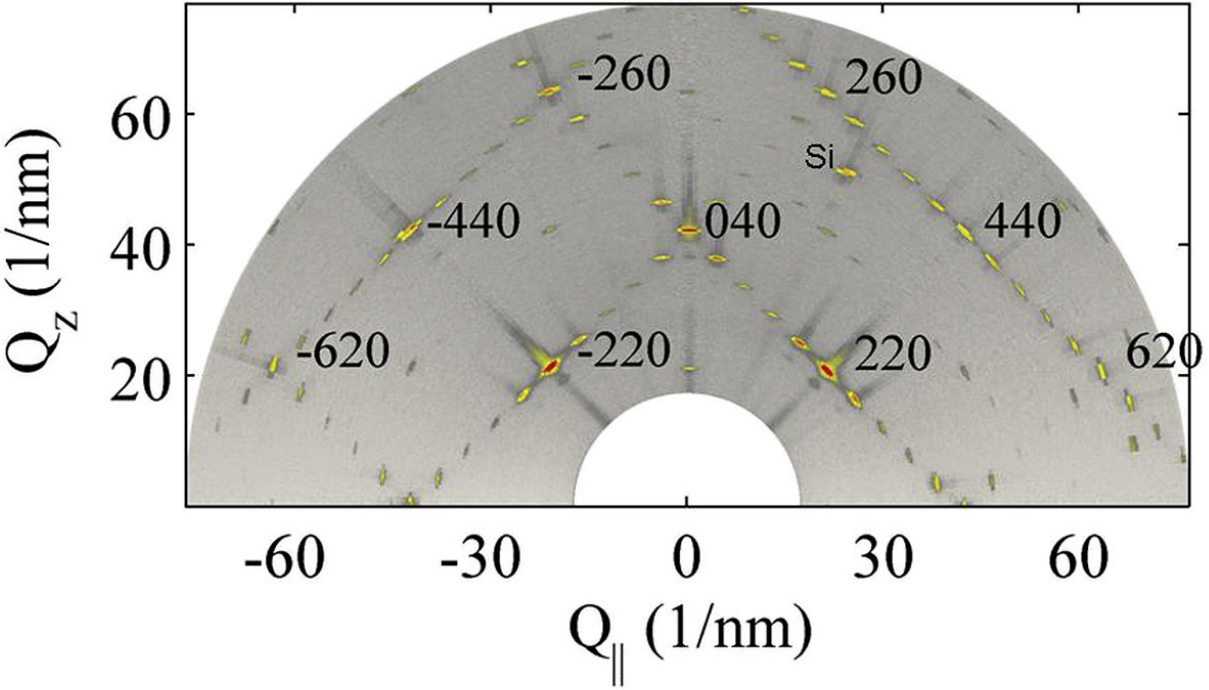
Modulation





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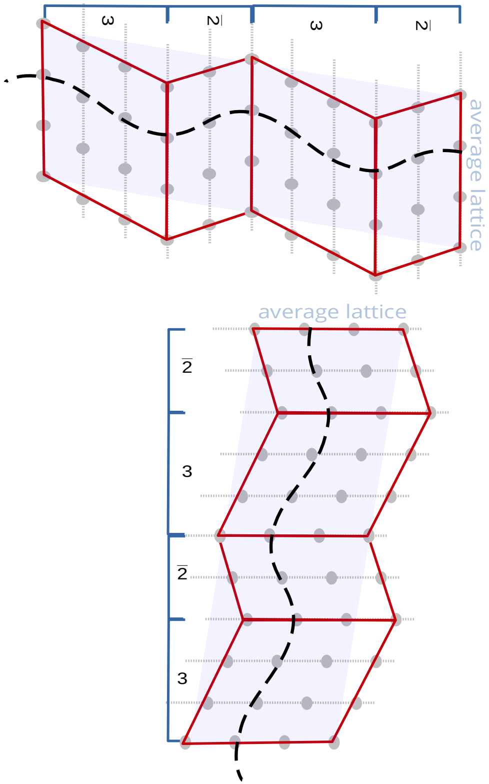

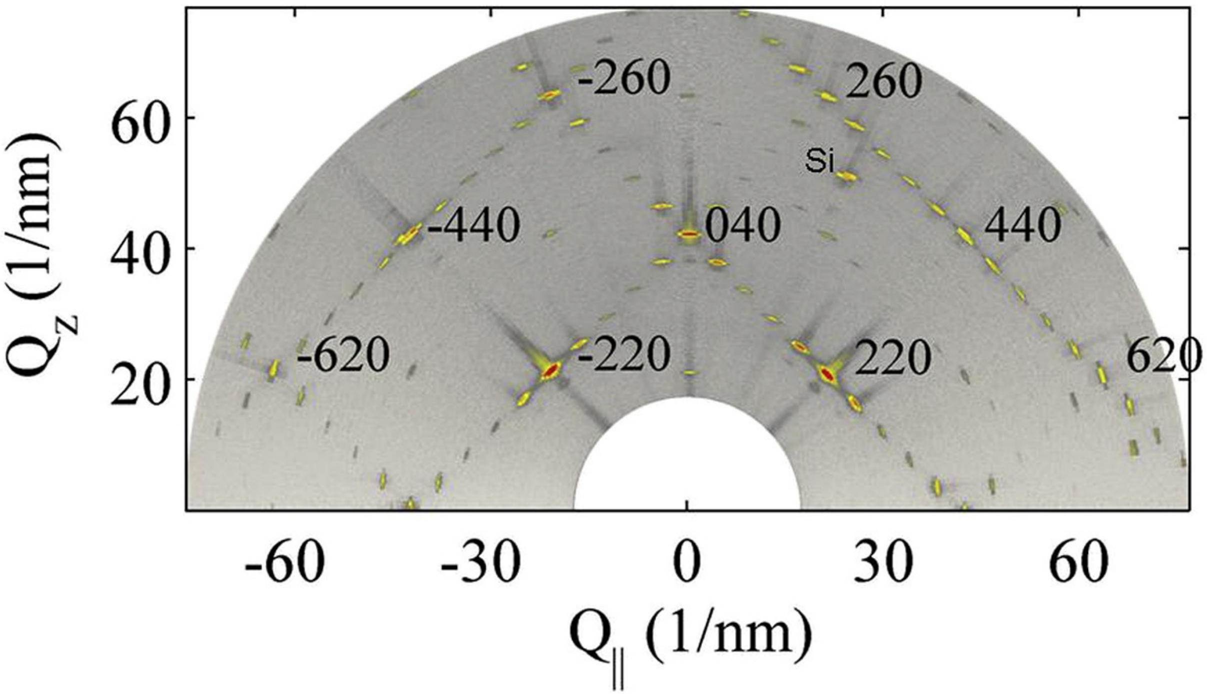

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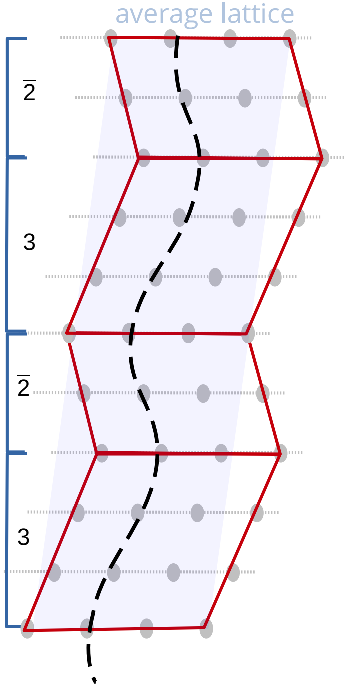
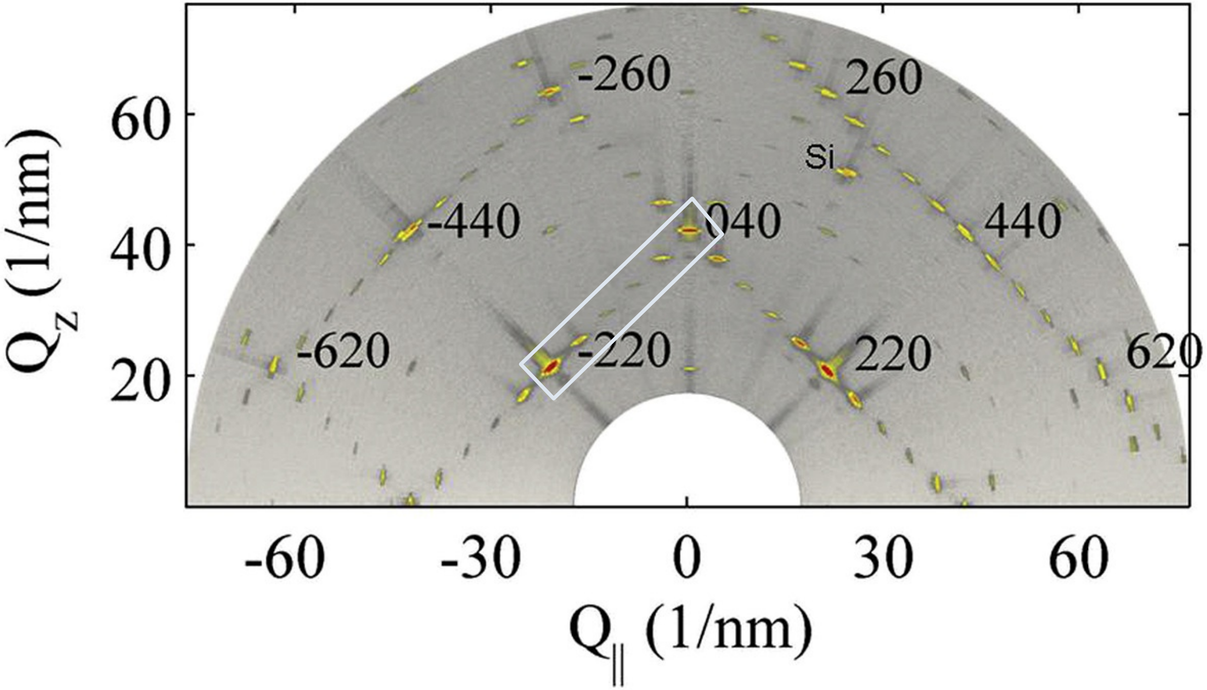
Modulation – study by high-resolution q-scan





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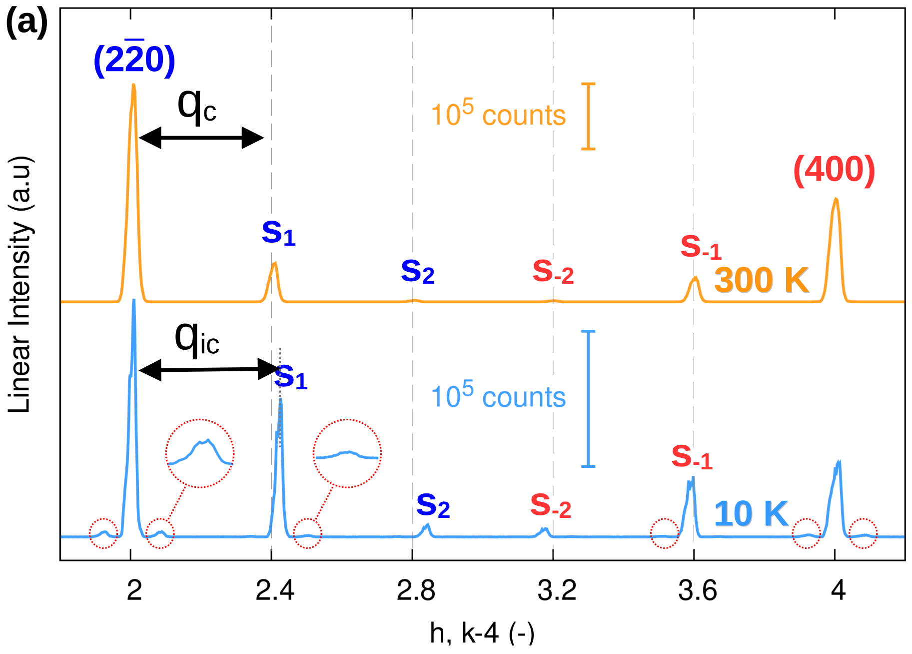

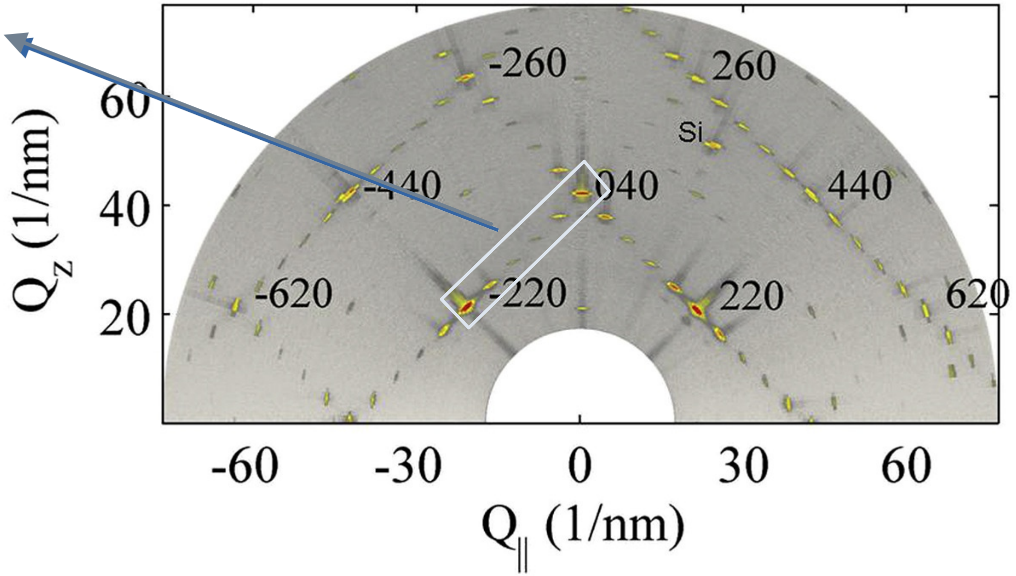

q=(q,q,0)
q'=2/q

Straka L. et al., submitted, http://dx.doi.org/10.2139/ssrn.4771525 Heczko, Oleg, et al. Acta Materialia 115 (2016): 250-258.

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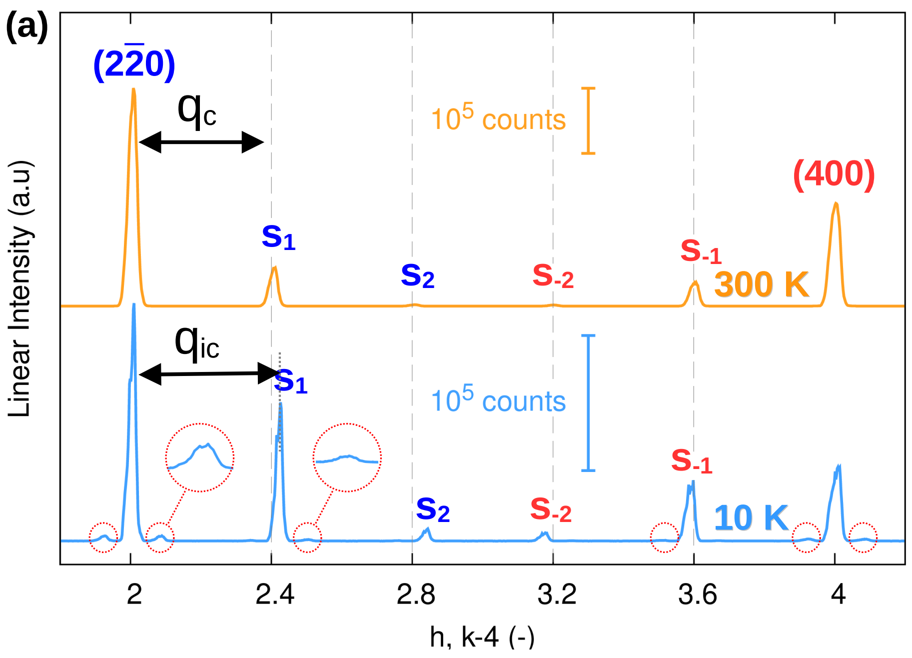

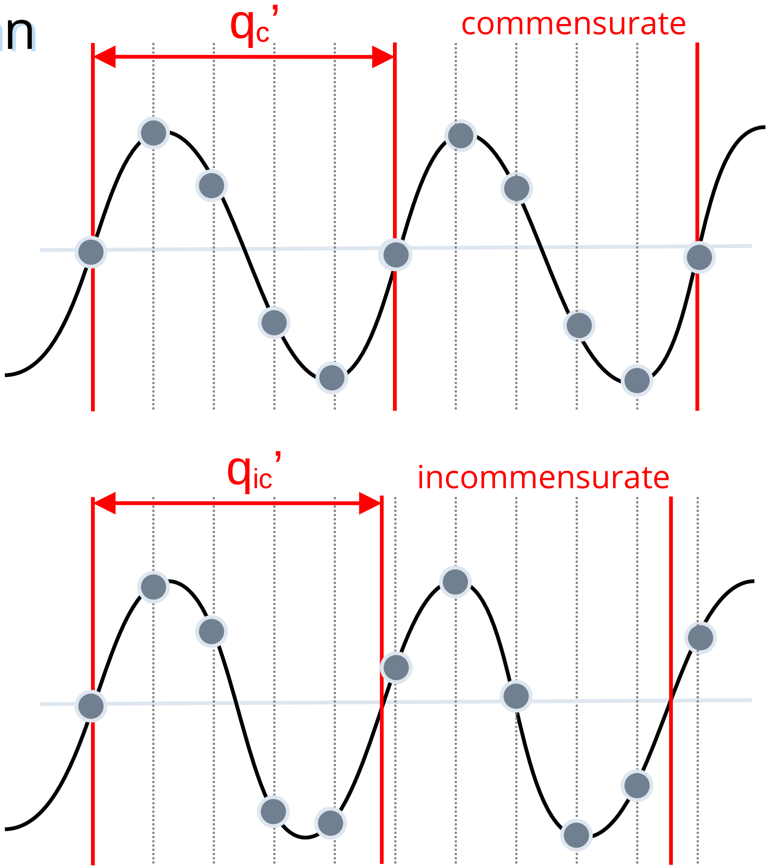

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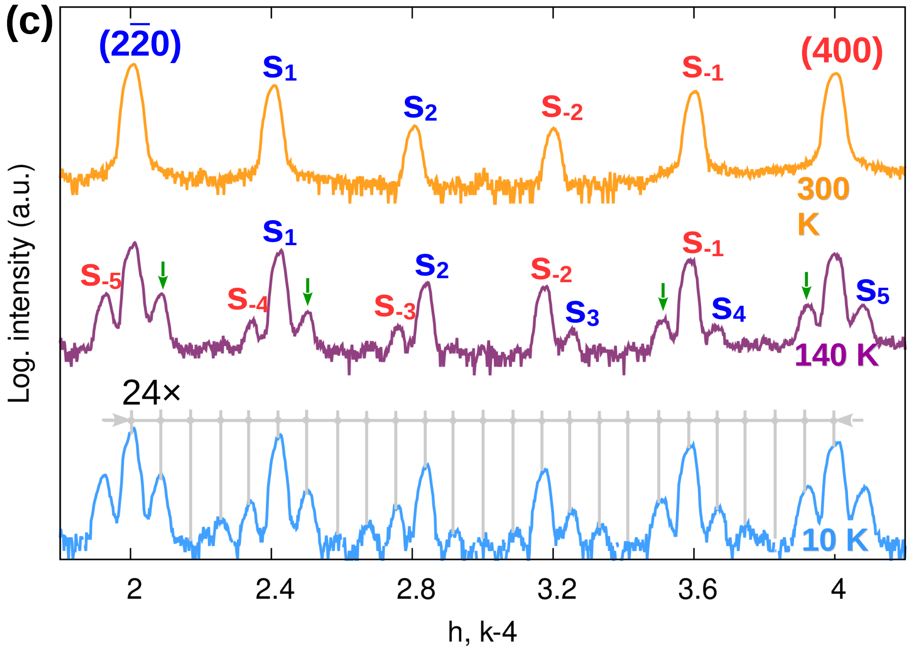

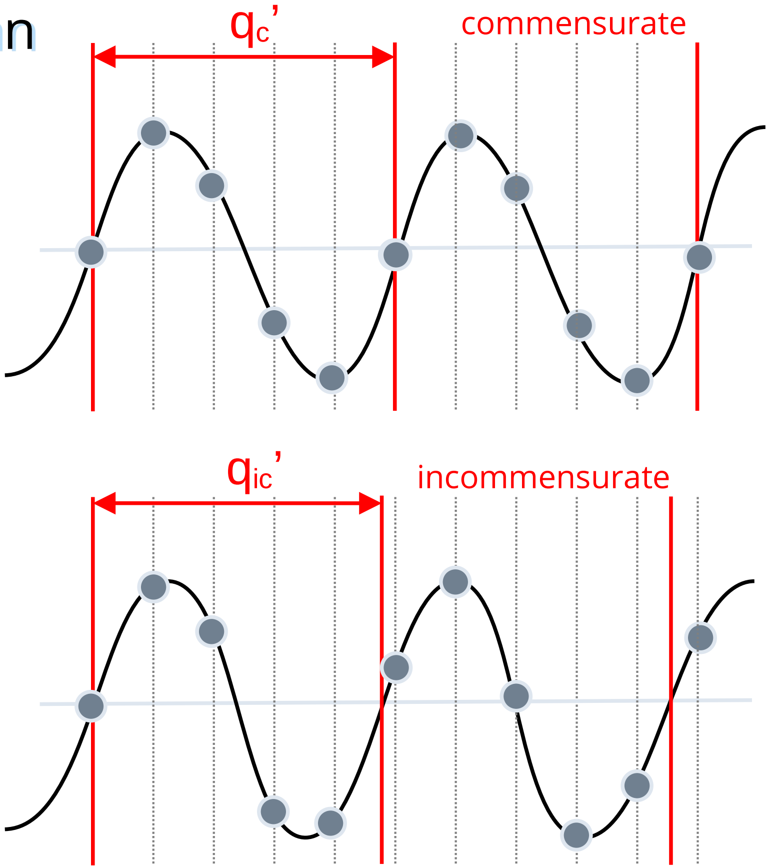

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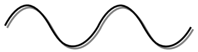
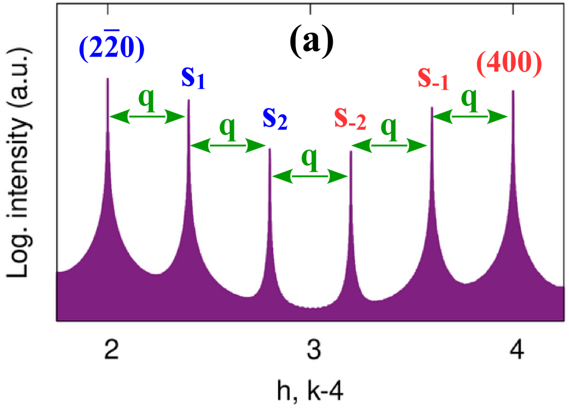
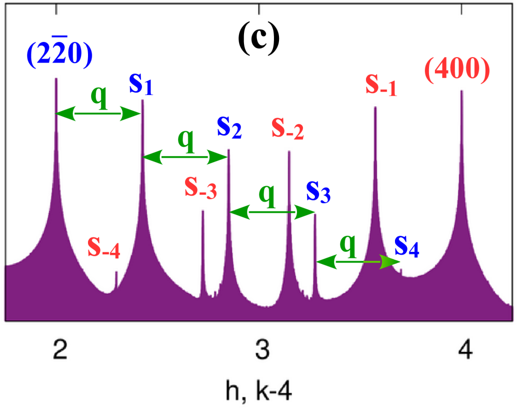
Harmonic modulation (sine)



Commensurate (q=0.400)



Incommensurate (q=0.428)



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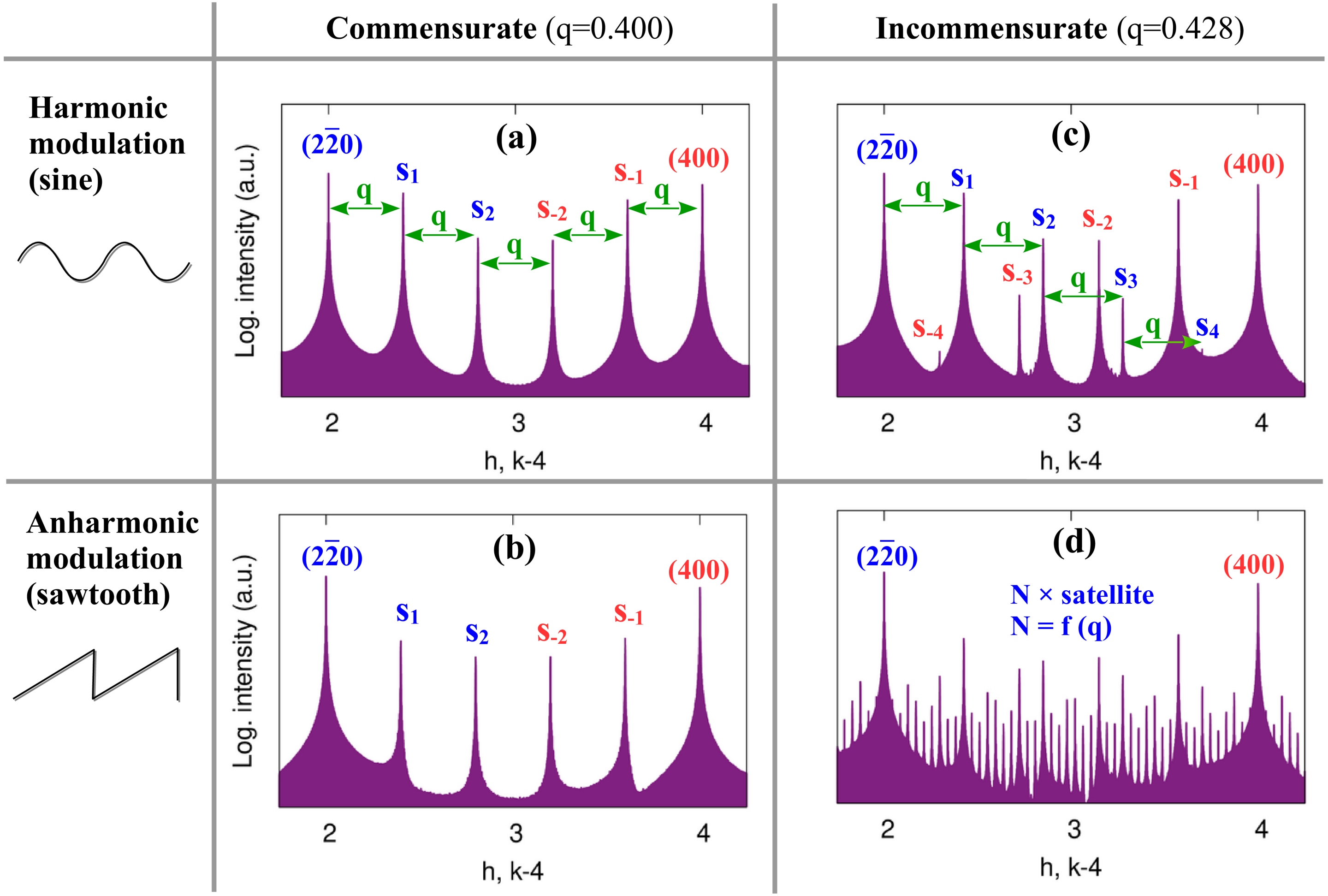

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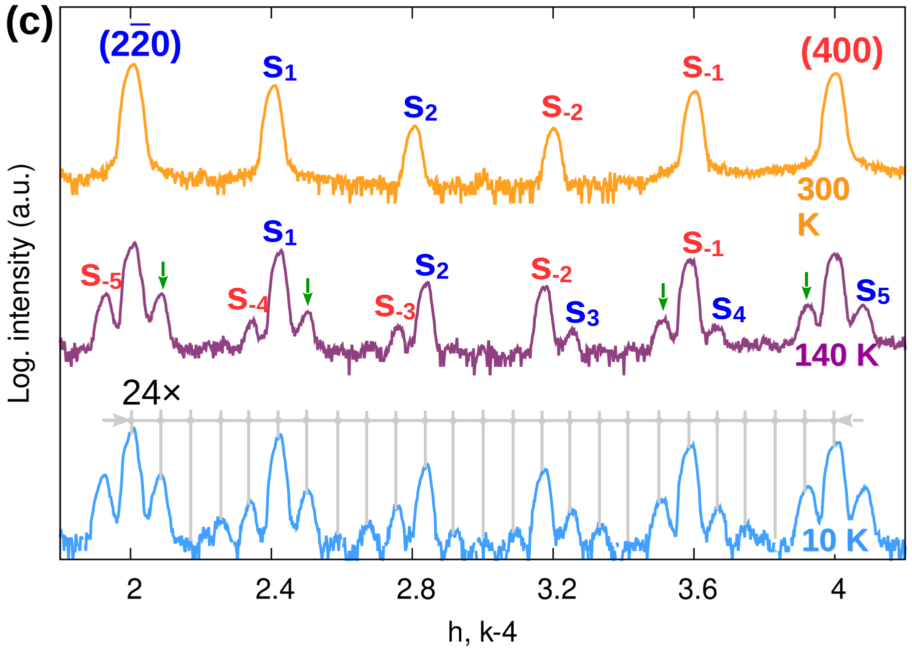

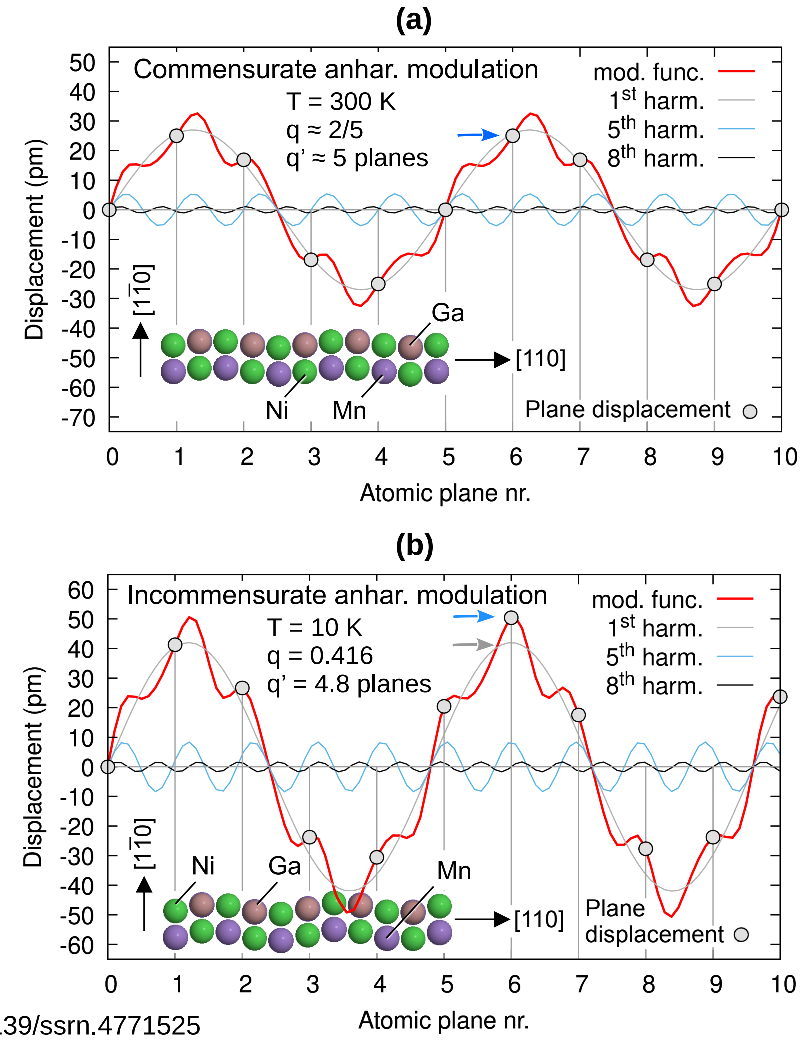

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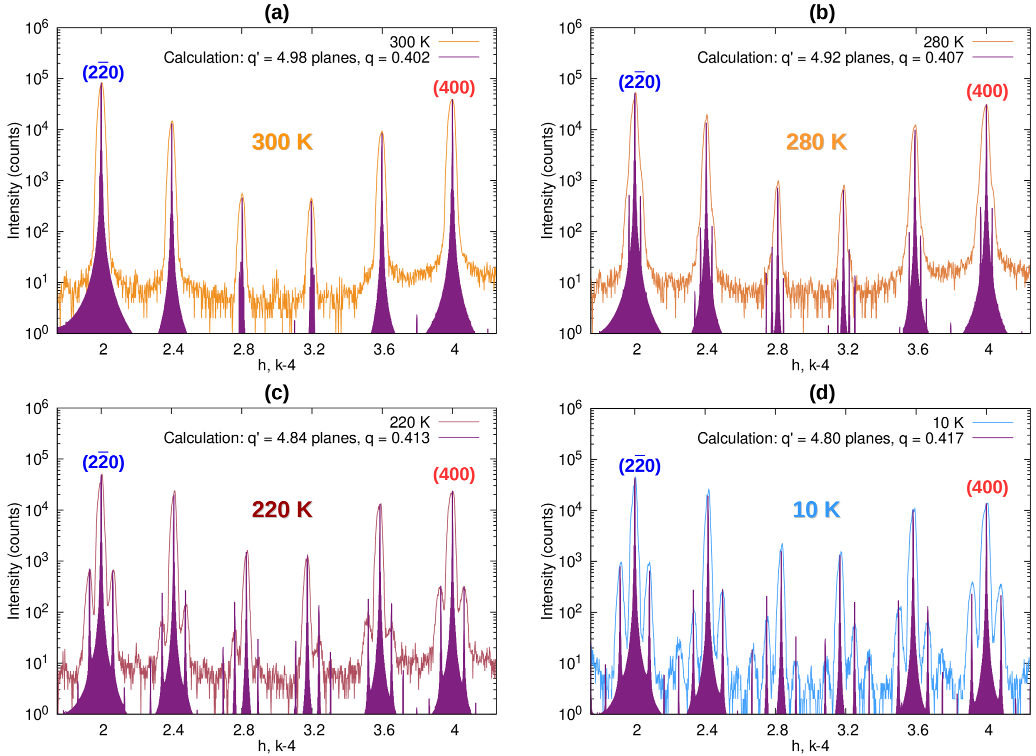
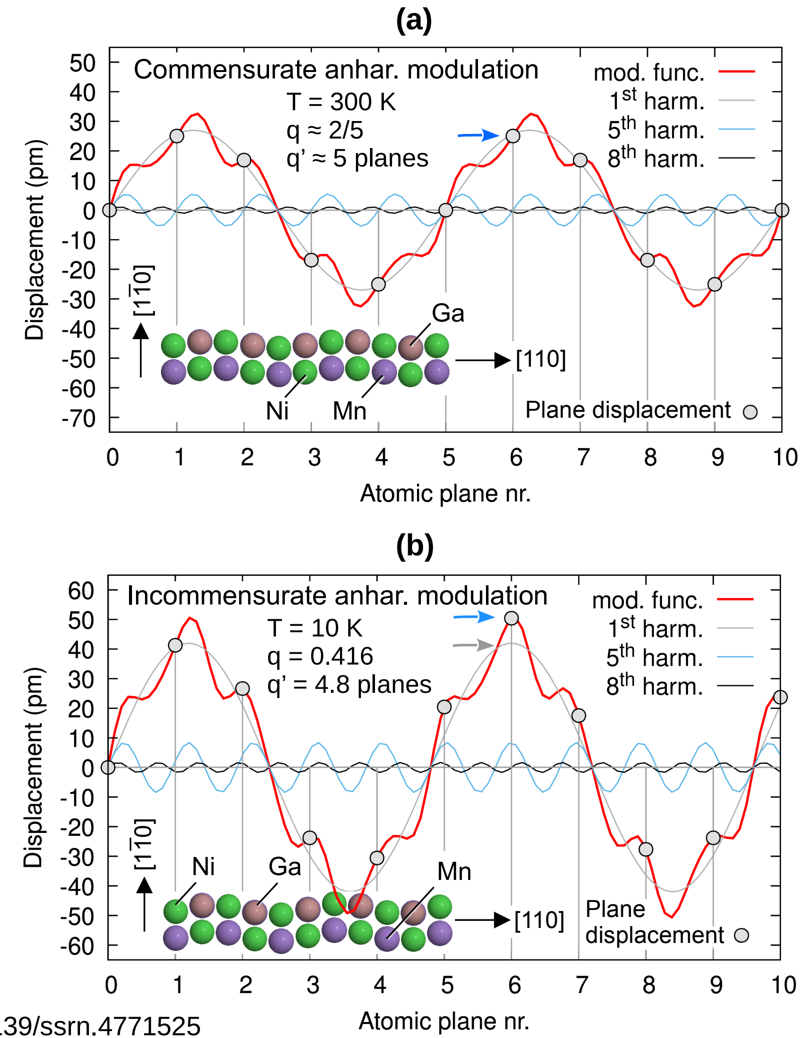
Modulation – study by high-resolution q-scan

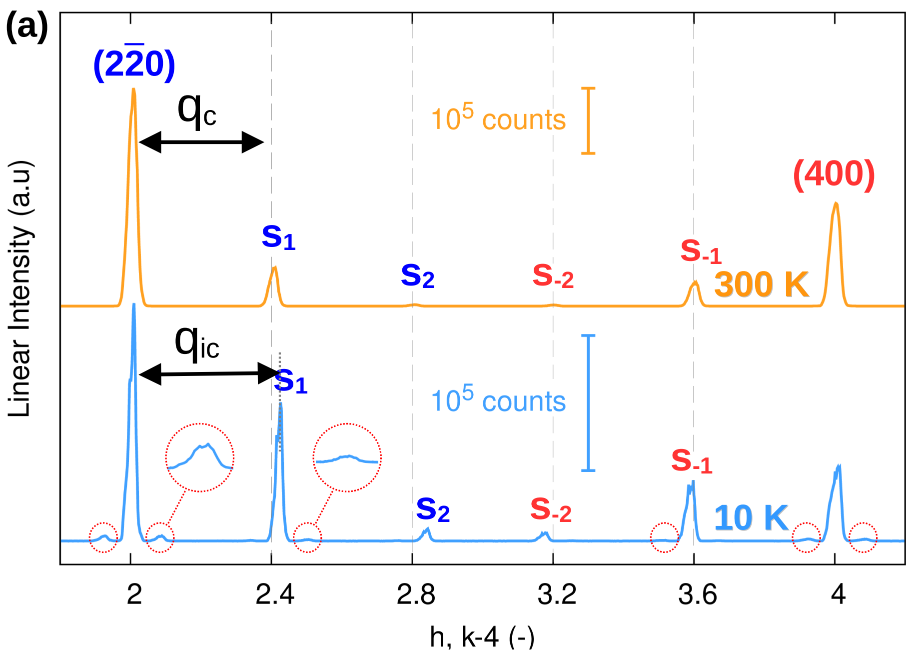


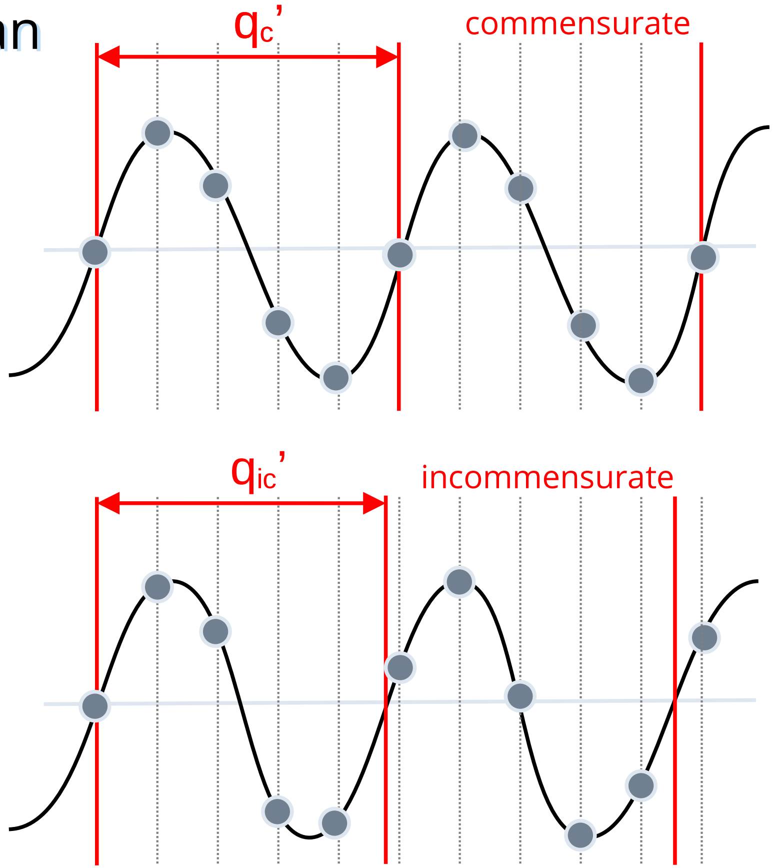


HKL(T) = f(q(T))

Straka L. et al., submitted, http://dx.doi.org/10.2139/ssrn.4771525

Aperiodicity – study by high-resolution q-scan

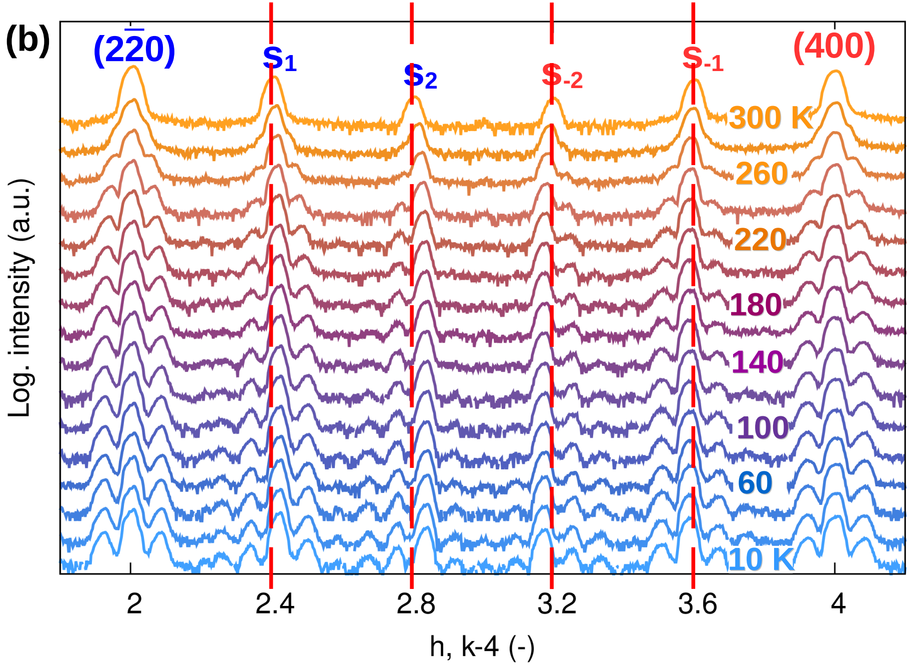


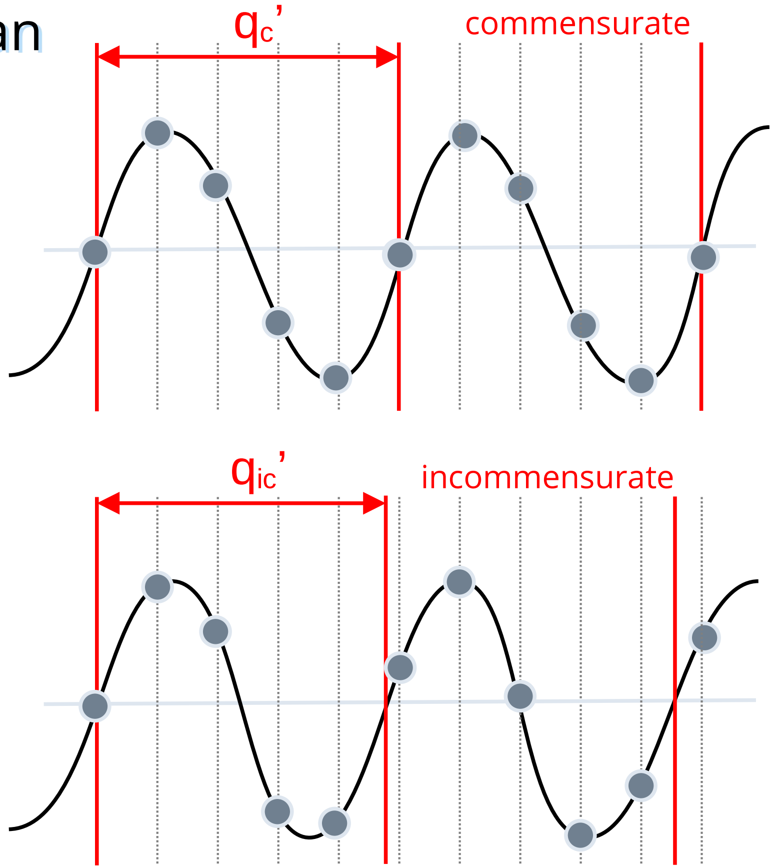


q=(q,q,0)
q'=2/q

Straka L. et al., submitted, http://dx.doi.org/10.2139/ssrn.4771525

Aperiodicity – study by high-resolution q-scan





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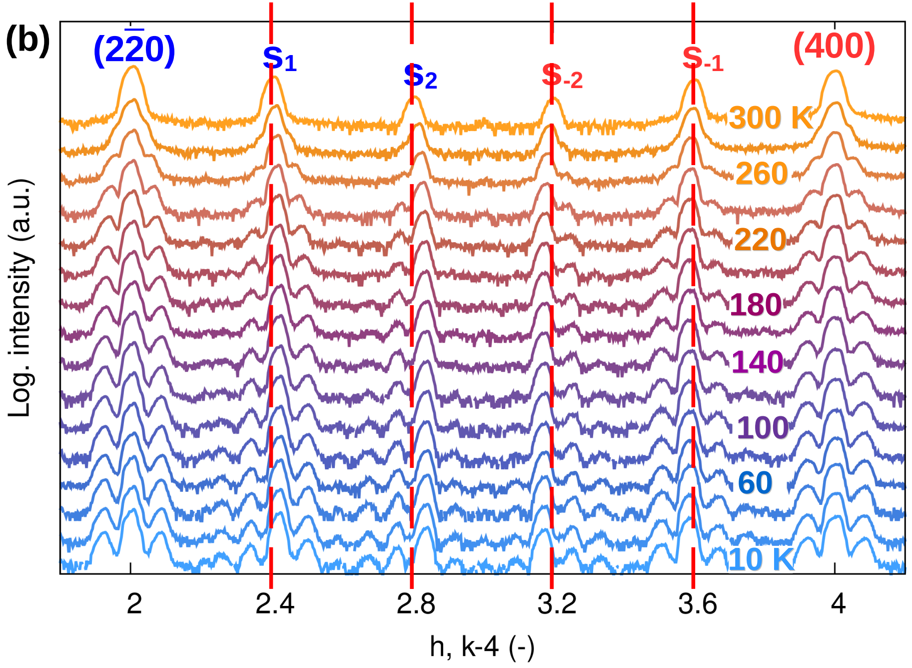

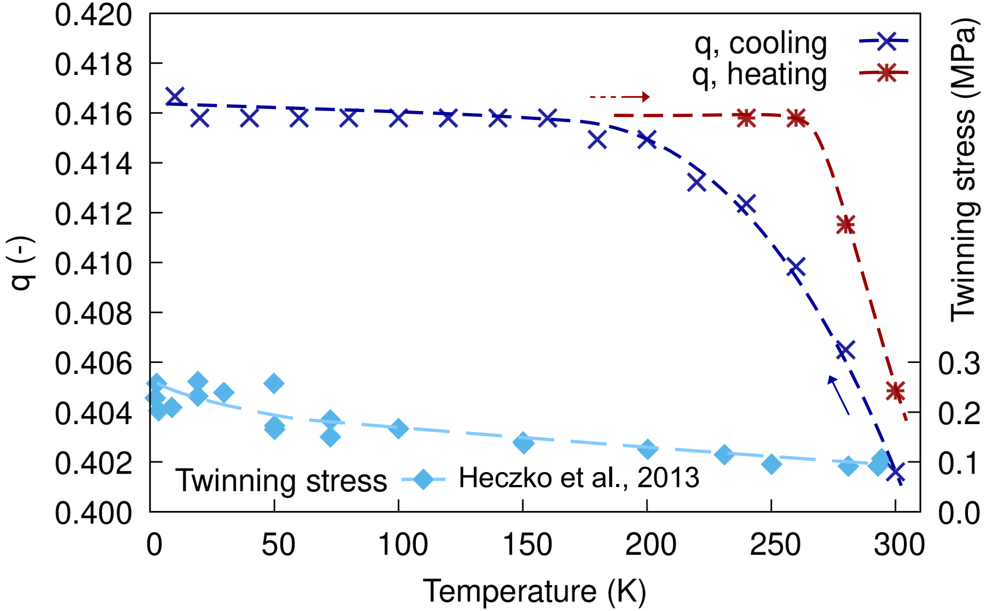

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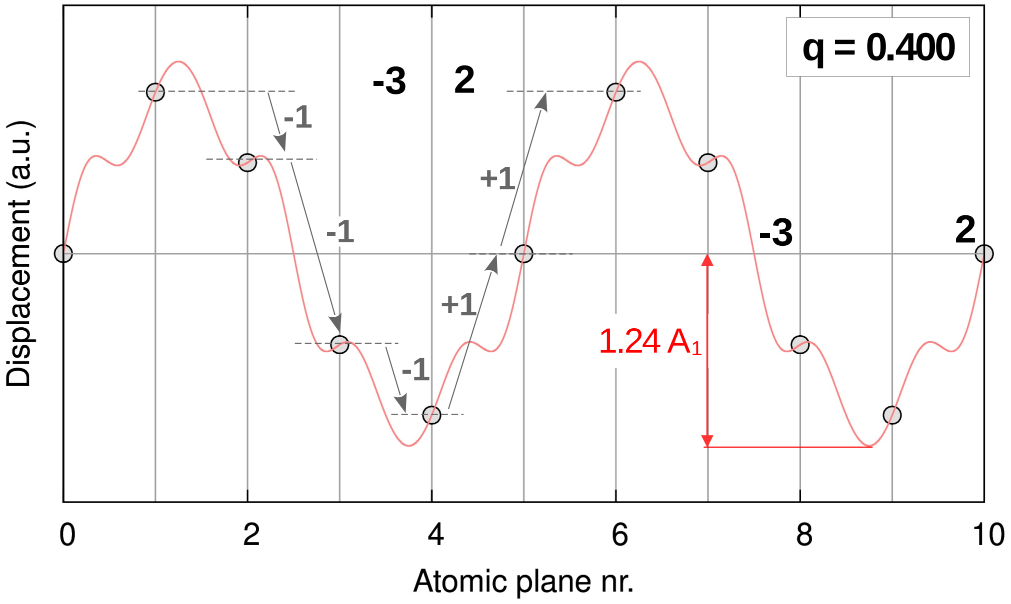
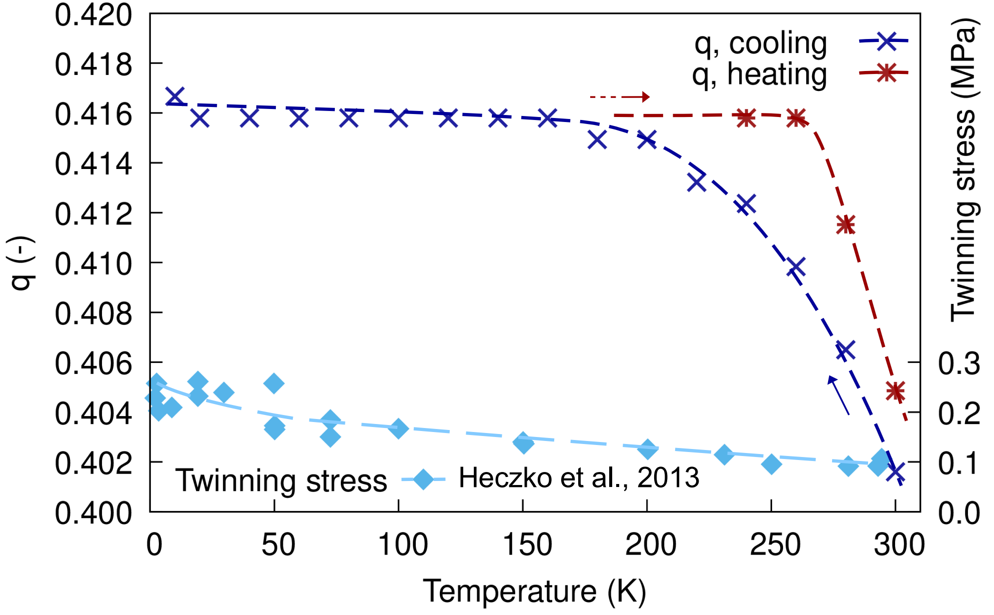
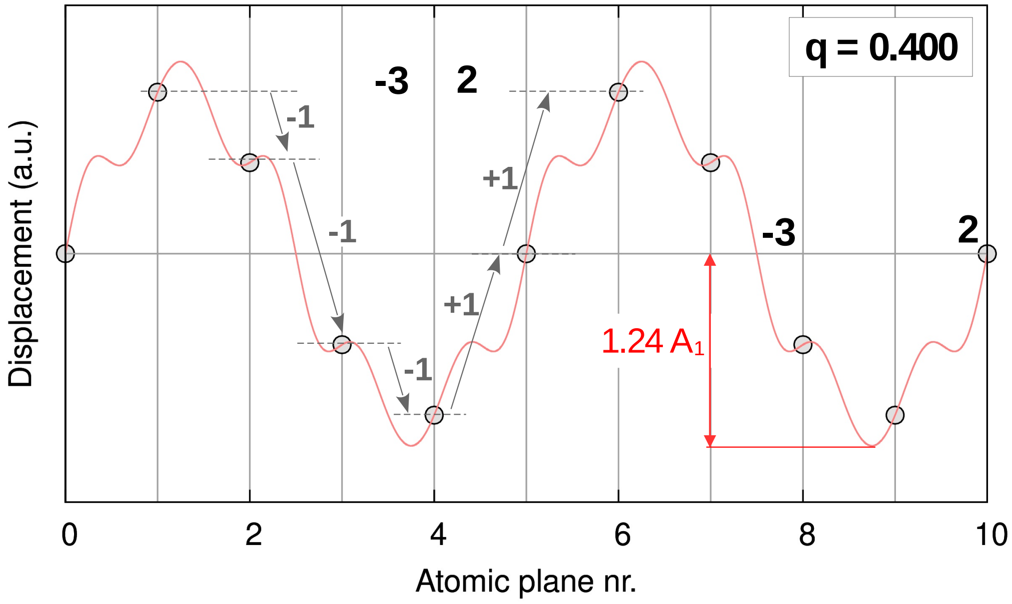
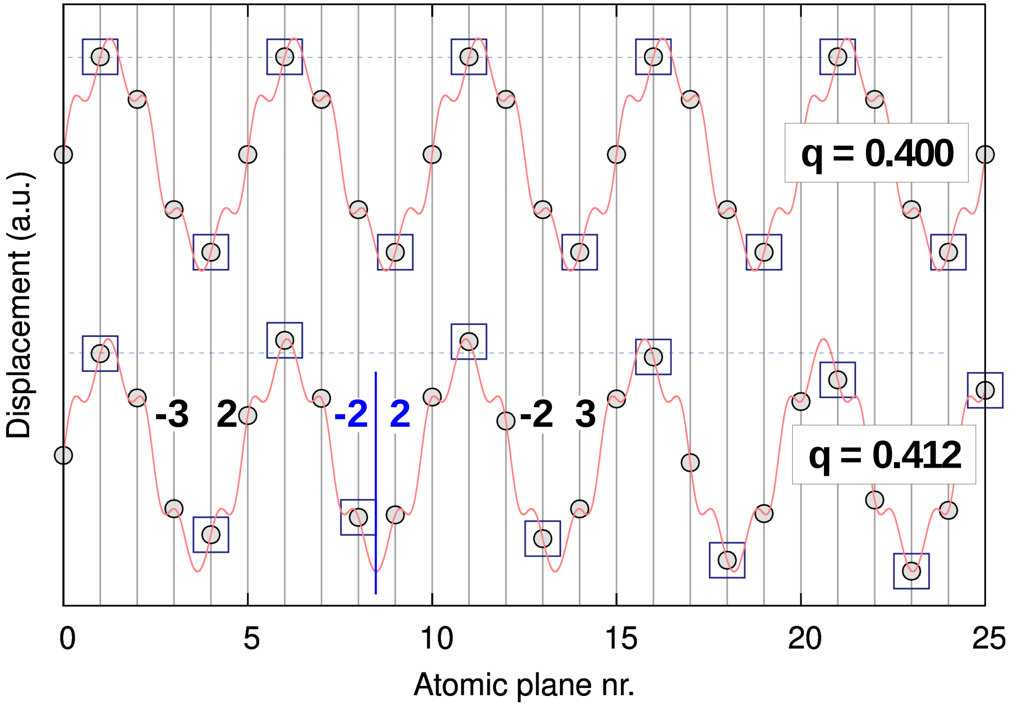




Straka L. et al., submitted, http://dx.doi.org/10.2139/ssrn.4771525

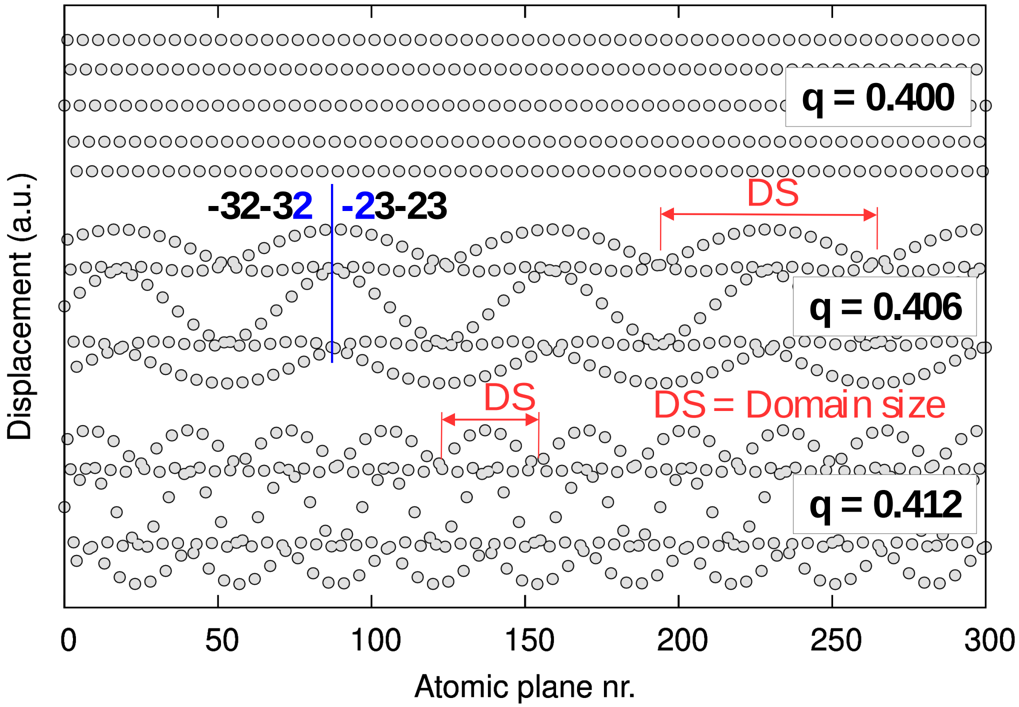
Aperiodicity – study by high-resolution q-scan

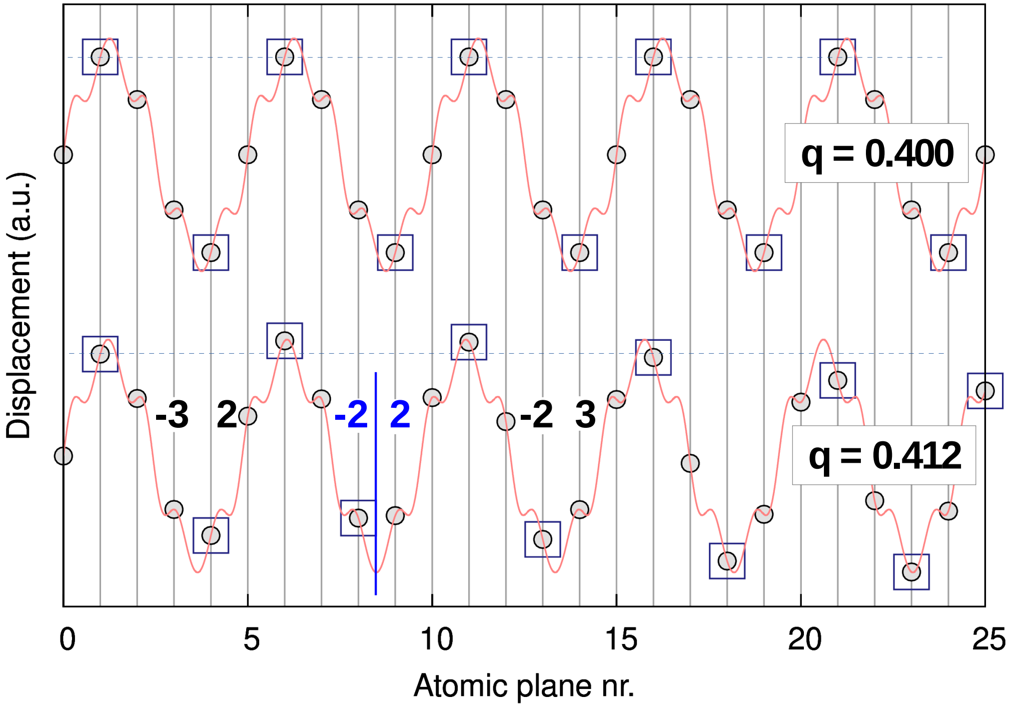




Straka L. et al., in preparation

Aperiodicity results in a/b nanotwinning (!!!)





Straka L. et al., in preparation

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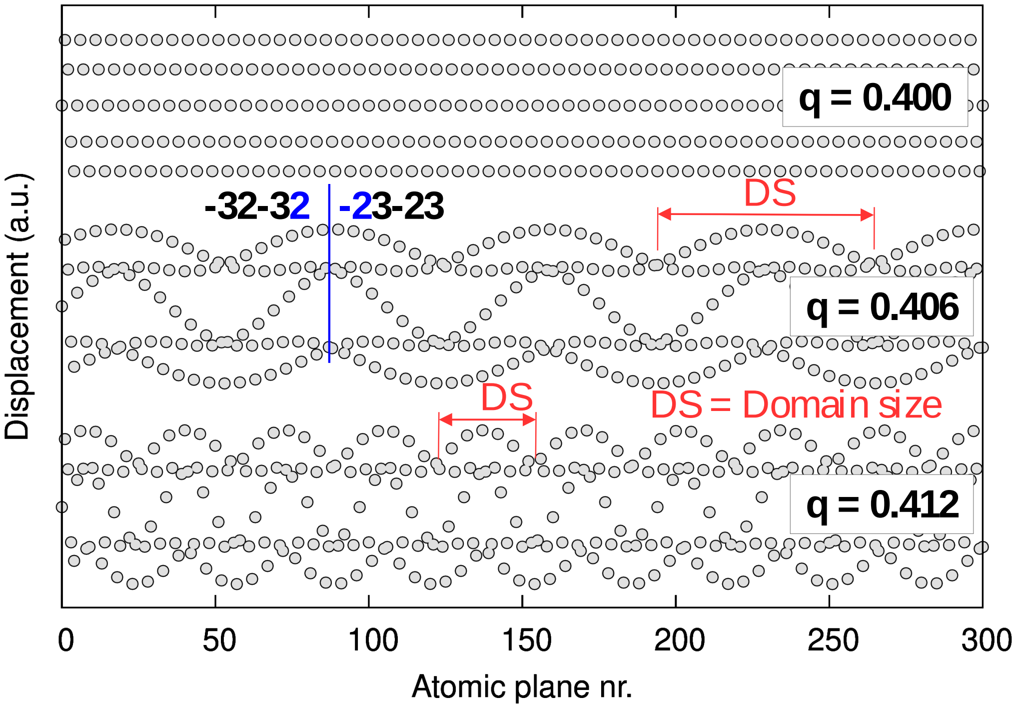
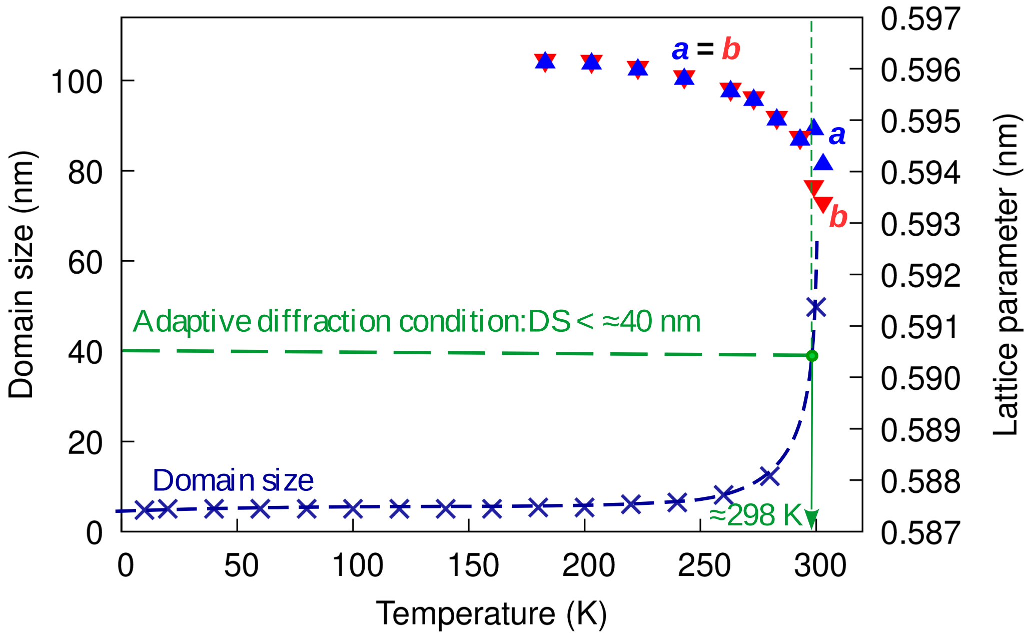
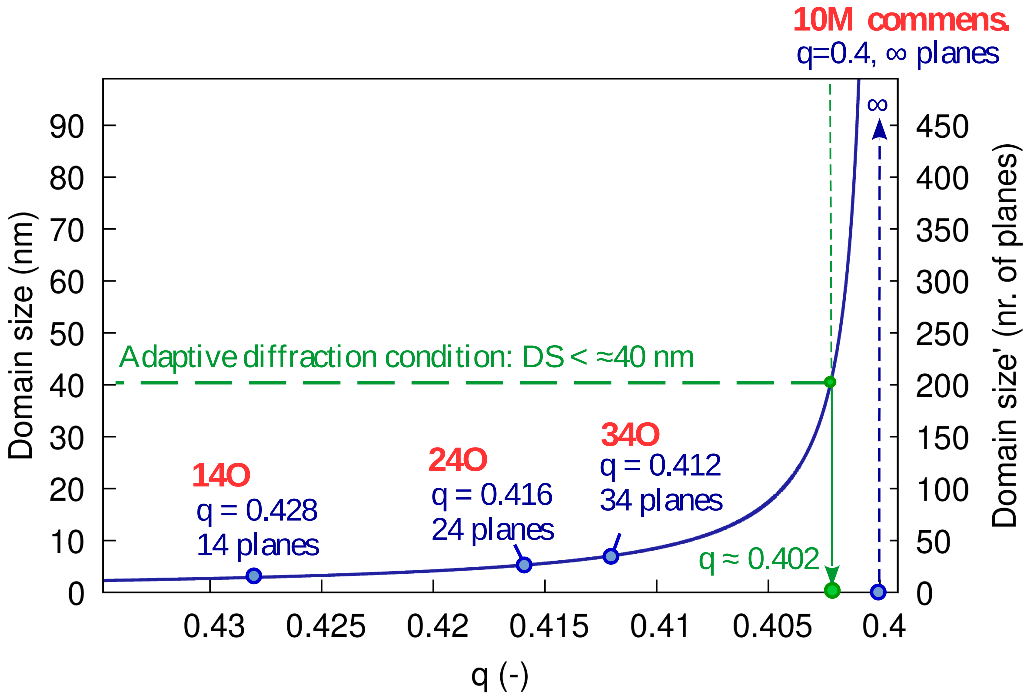
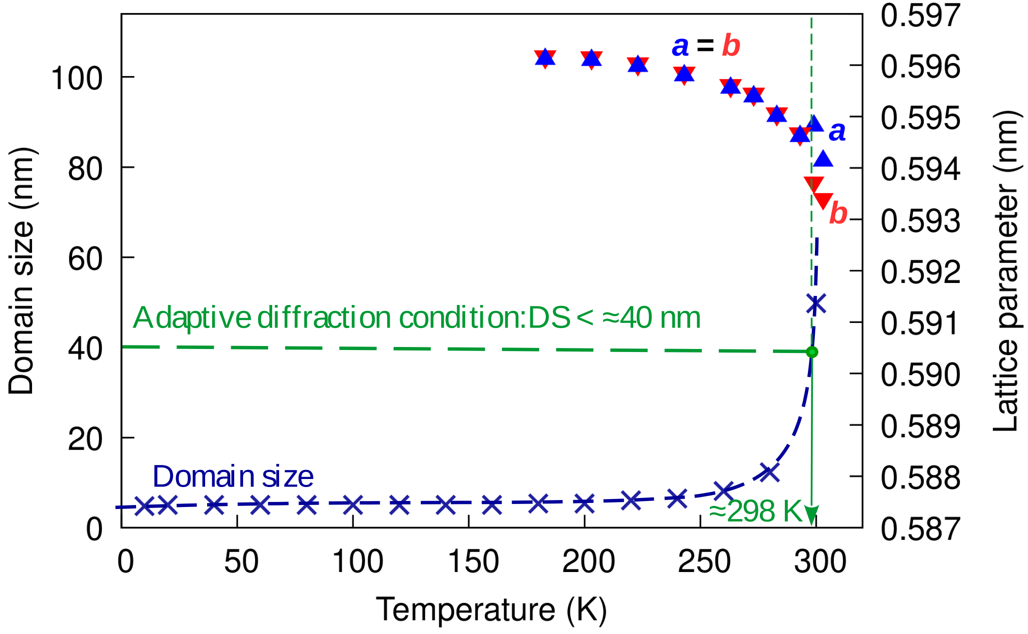




Straka L. et al., in preparation

Aperiodicity results in a/b nanotwinning (!!!)

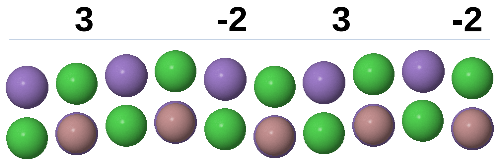




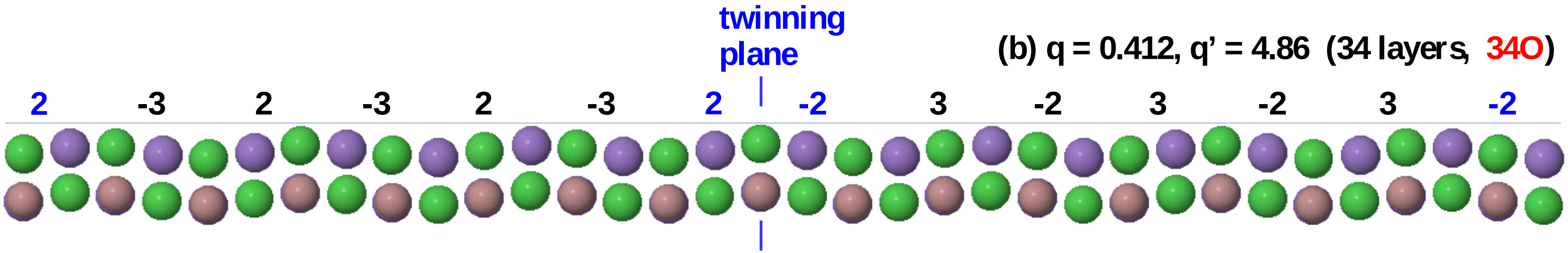
Straka L. et al., in preparation

Distinct identified nanotwins/structures

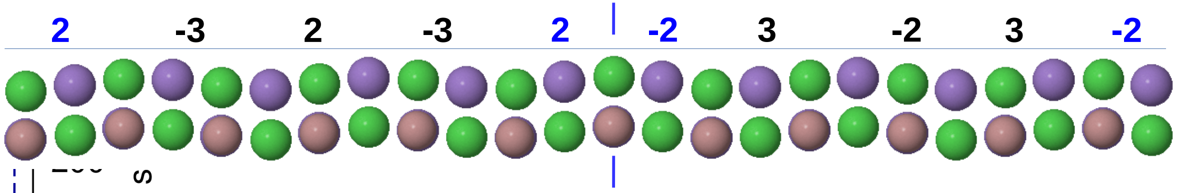
(a) q = 0.400, q' = 5.00 (10M commensurate)

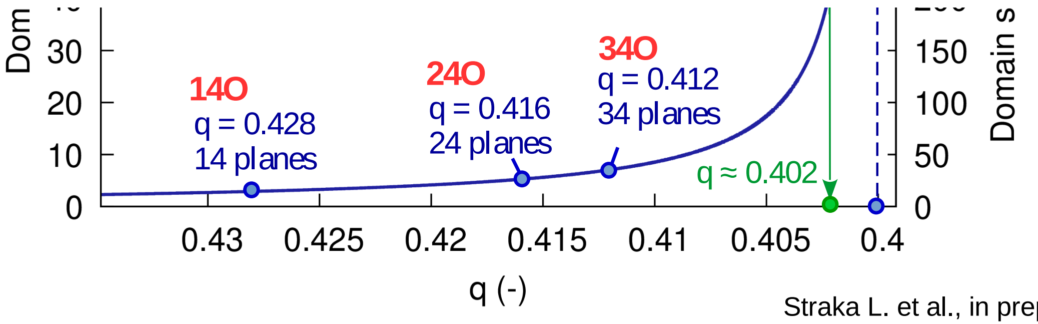


(b) q = 0.412, q' = 4.86 (34 layers, 34O)

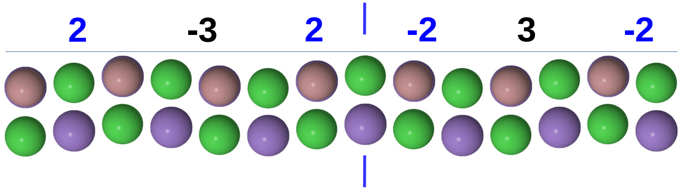


(c) q = 0.416, q' = 4.80 (24 layers, 24O)



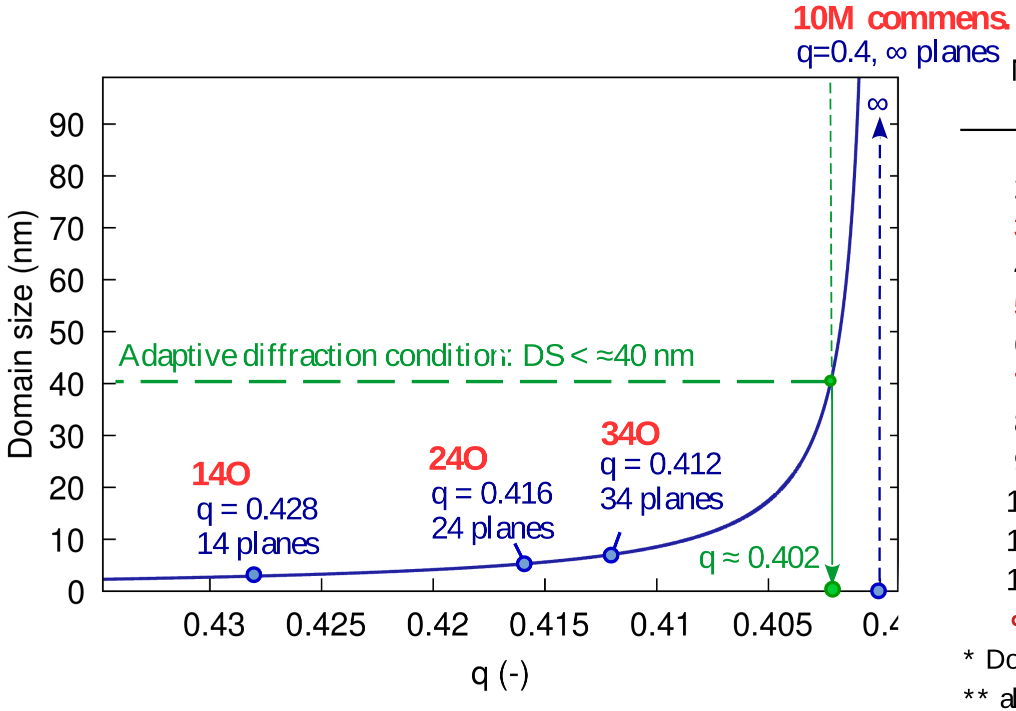


(d) q = 3/7 (0.428), q' = 4.70 (14 layers, 14O)



Straka L. et al., in preparation

Distinct identified nanotwins/structures



N -	q' (planes)	q (-)	Domain size (planes)	Domain size (nm)	Marking -
1	4.000	0.5000	4	0.8	4O
2	4.500	0.4444	9	1.9	18O*
3	**4.667**	**0.4286**	**14**	**2.9**	**14O**
4	4.750	0.4211	38	8.0	38O*
5	**4.800**	**0.4167**	**24**	**5.0**	**24O**
6	4.833	0.4138	58	12.2	58O*
7	**4.857**	**0.4118**	**34**	**7.1**	**34O**
8	4.875	0.4103	78	16.4	78O*
9	4.889	0.4091	44	9.2	44O
10	4.900	0.4082	98	20.6	98O*
11	4.909	0.4074	54	11.3	54O
12	4.917	0.4068	118	24.8	118O*
∞	**5.000**	**0.4000**	**∞**	**∞**	**10M comm.****

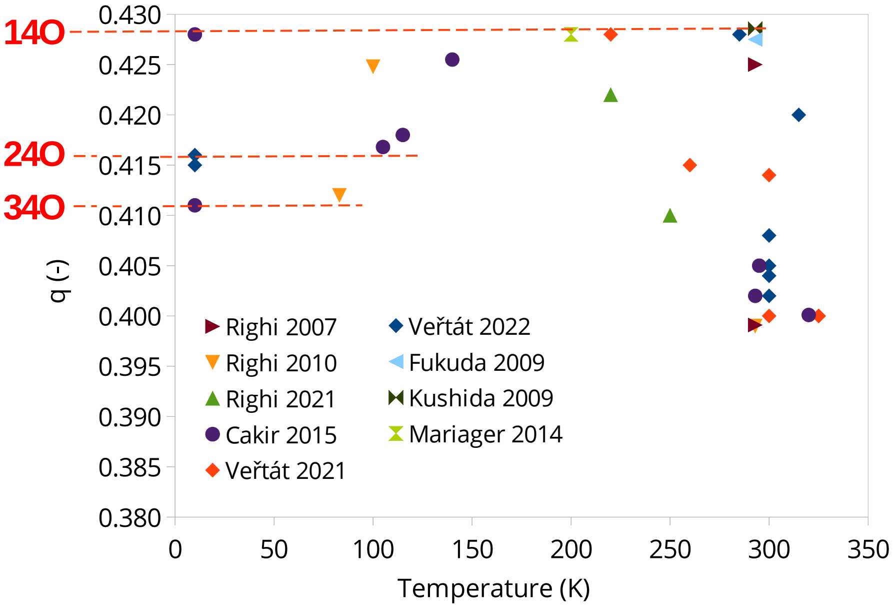
* Double cell size to comply with the $L2_1$ order.

** also marked as 5M when neglecting ordering.

Straka L. et al., in preparation

Distinct identified nanotwins/structures as low energy/low temperature states

Hypothesis yet to be tested: q converges to one of the nanotwinned states



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* Double cell size to comply with the $L2_1$ order.

** also marked as 5M when neglecting ordering.

Straka L. et al., in preparation

Summary IV

Aperiodic crystal
Anharmonic modulation

Wave modulation perspective **vs nanotwinning** perspective:

- **not exclusive concepts but complementary/intertwinned concepts in Ni-Mn-Ga**
- **nanotwinning is a result of crystal aperiodicity**
- Low temperature states are nanotwinned
- Nanotwinning ON/OFF (at r.t.)

Summary

Magnetic shape memory (Ni-Mn-Ga)

- very interesting at all scales
- magnetism important but (micro)structure critical for MSM functionality
- **a great platform for**
    - magnetoelastic and magnetomechanical effects (up to 12% deformation in mag. field)
    - martensite crystallography (deeply hierarchical martensite)
    - nanotwinning and aperiodic crystal concepts (**nanotwins on/of, aperiodicity on/offf**)
- major **future** tasks: alternatives & applications


Thank you!