Spin and Charge Density Wave coupling in chromium through the spin-flip transition

Statics and ultrafast dynamics

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## Spin- and Charge-Density-Waves (SDW/CDW) in Chromium
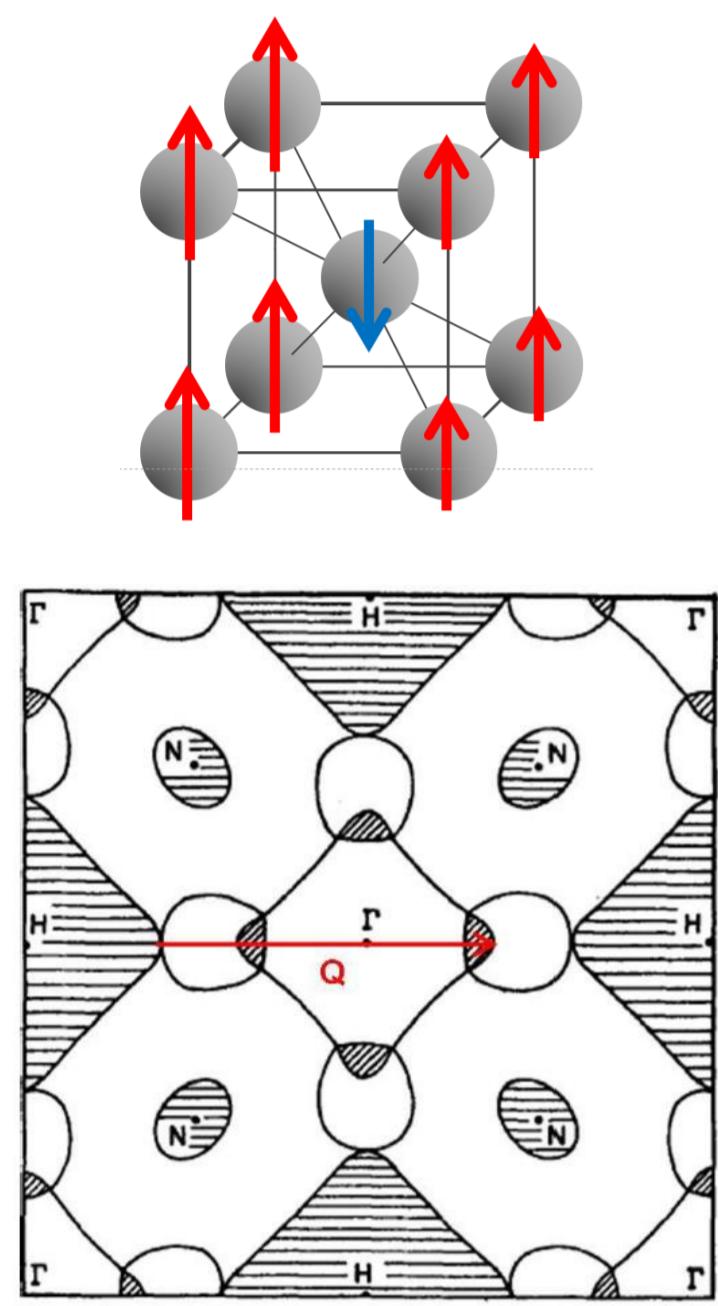
CDW and SDW appear at T_N=311K

Spin-Flip transition at low temperature (T_{SF}<123K)

Longitudinal SDW

Transverse SDW

T_N = 300 K
T_{SF} = 85 K

SPIN-FLIP TRANSITION
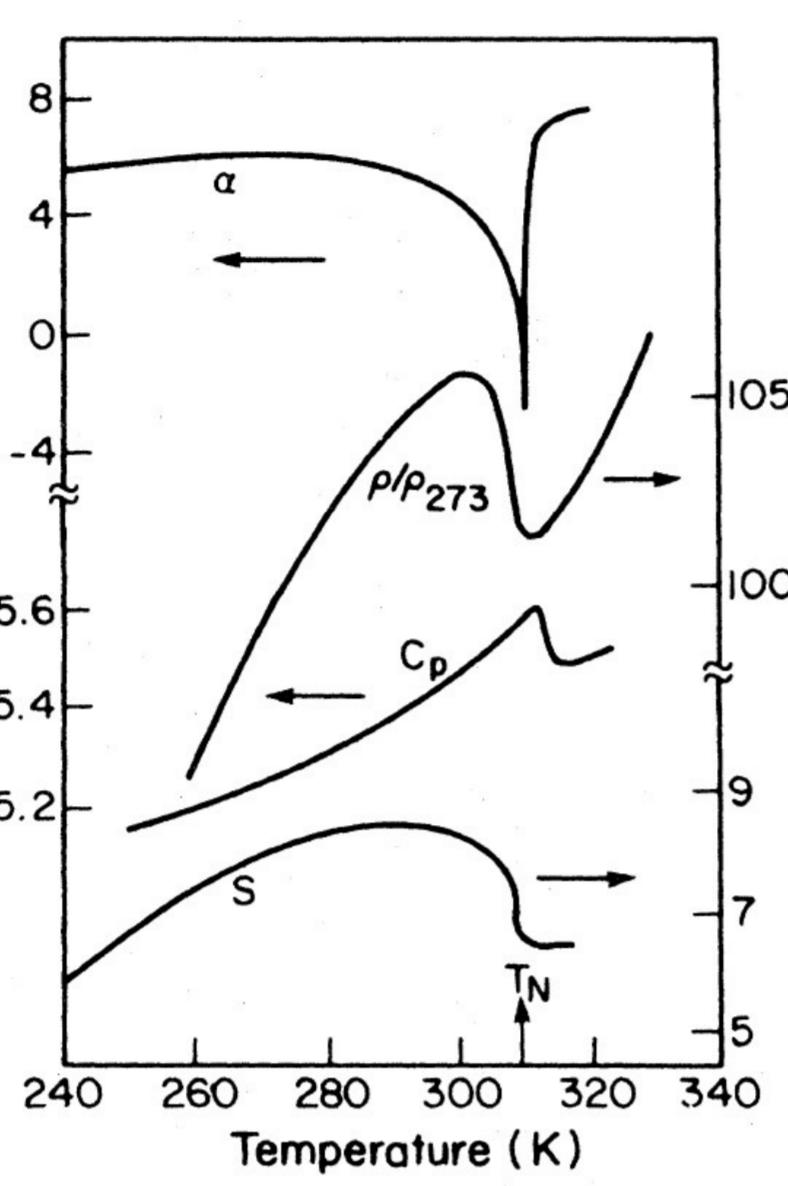
NEEL TRANSITION

Fawcett, Rev. Mod. Phys. 60, 209 (1988)
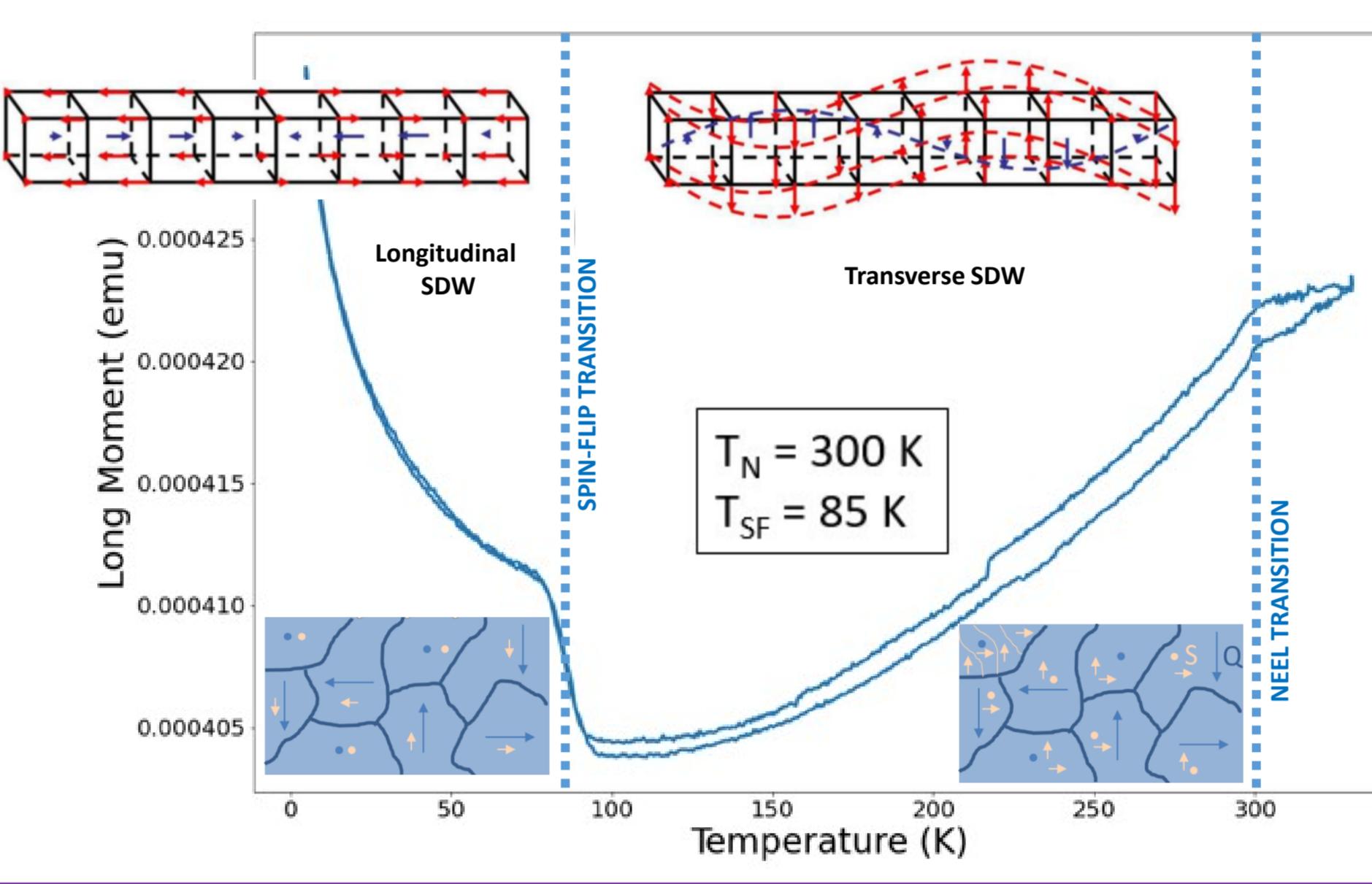
SDW and CDW measurable in diffraction (x-ray and neutron)

- Lattice
- Magn.
- Charge

001-δ

(b)

(a)

T_{SF}

(0,0,1-δ)

(0,1,δ)

T_N

Longitudinal SDW

Transverse SDW
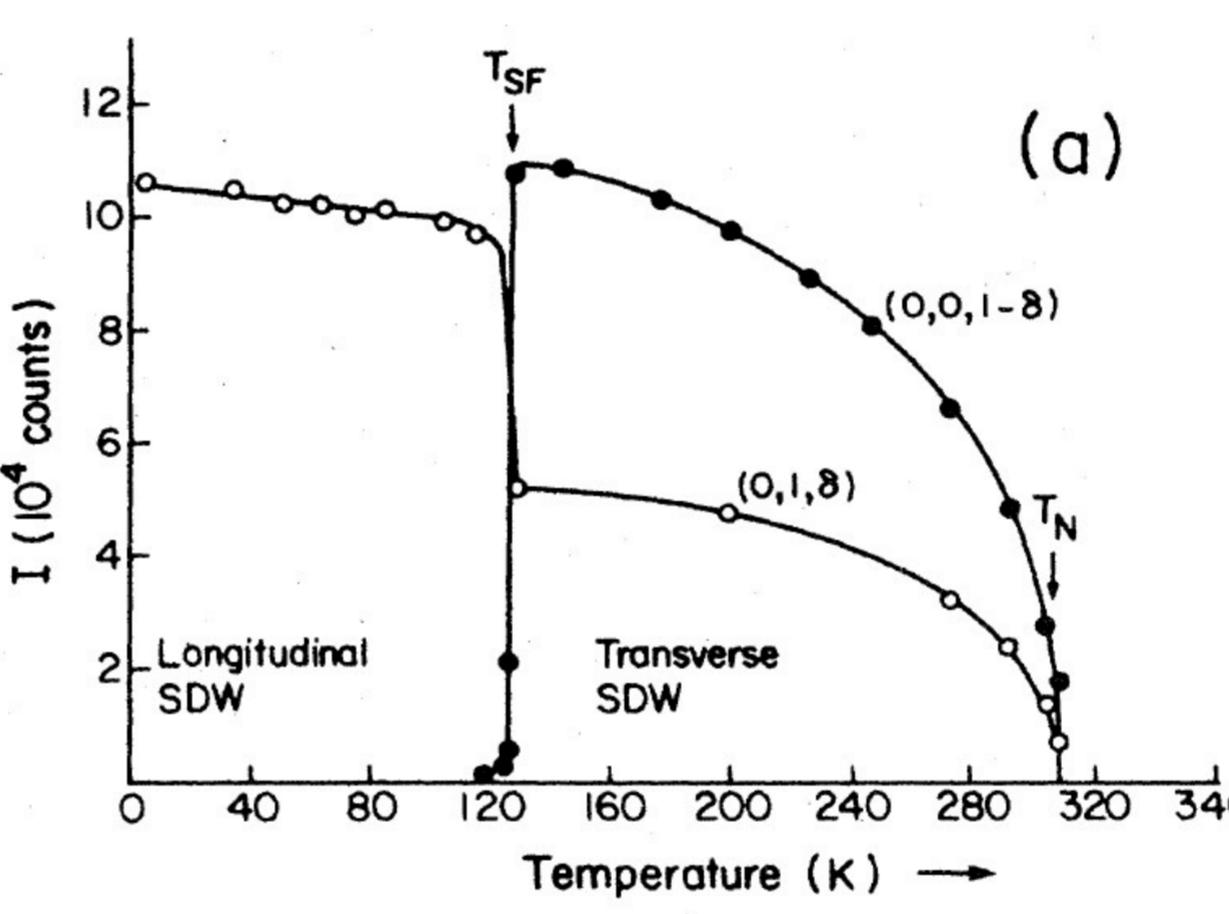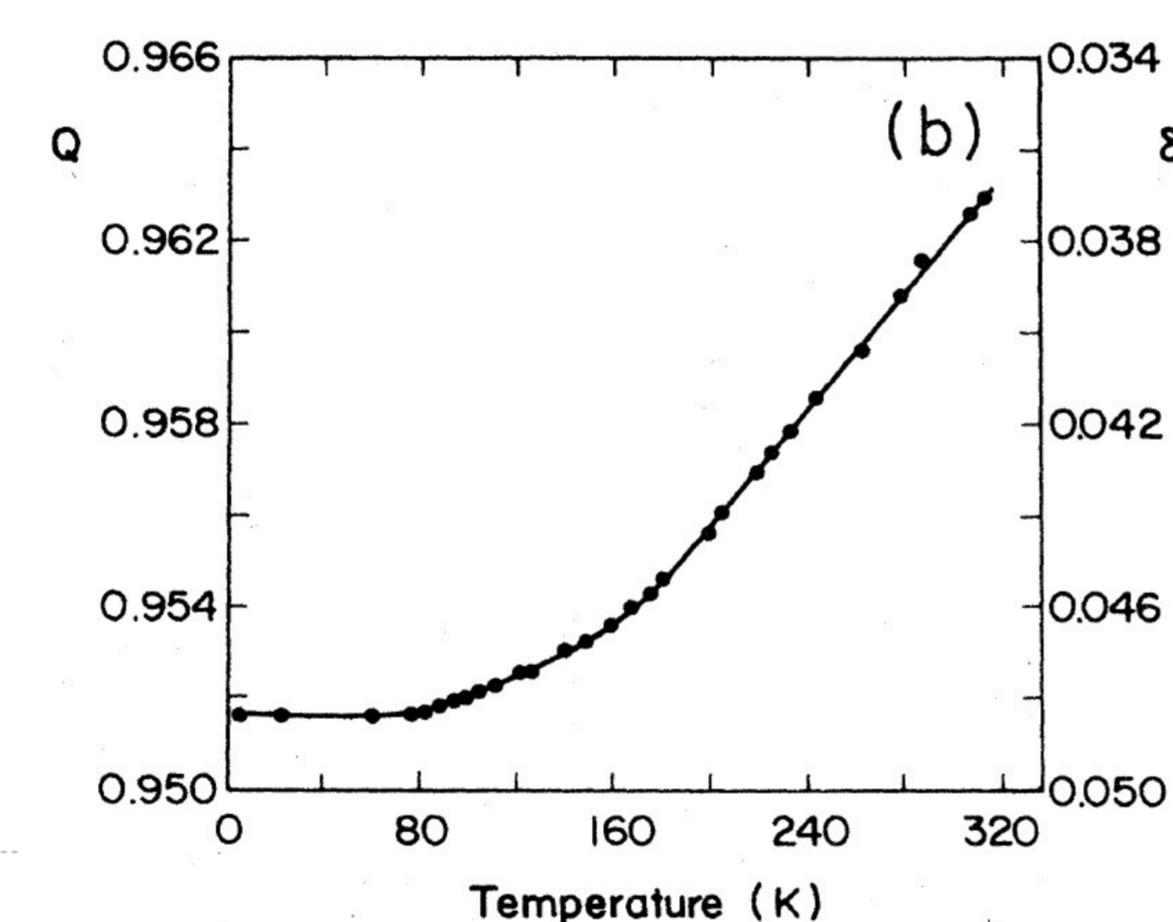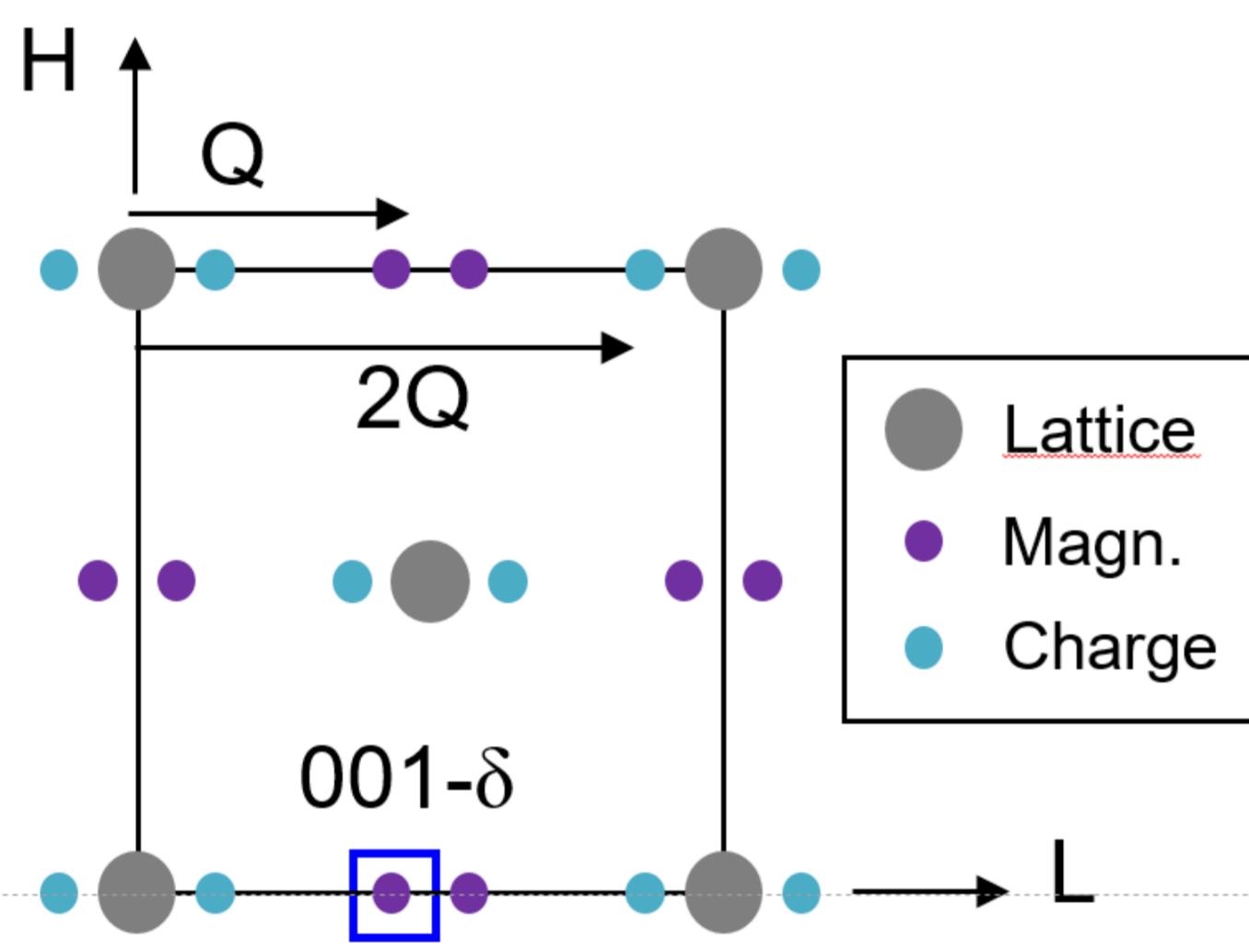
X-ray microdiffraction on SDW and CDW from previous experiments

A SDW   100 µm
B CDW   100 µm

SDW intensity counts s⁻¹

SDW through spin-flip transition

140 K   130 K   125 K   120 K
119 K   115 K   110 K

$Q \parallel (001)$ and $S \perp Q$
$Q \perp (001)$ or $S \parallel Q$
≥4
≤1

CDW through spin-flip transition

A 130 K   10 µm
B 110 K   10 µm
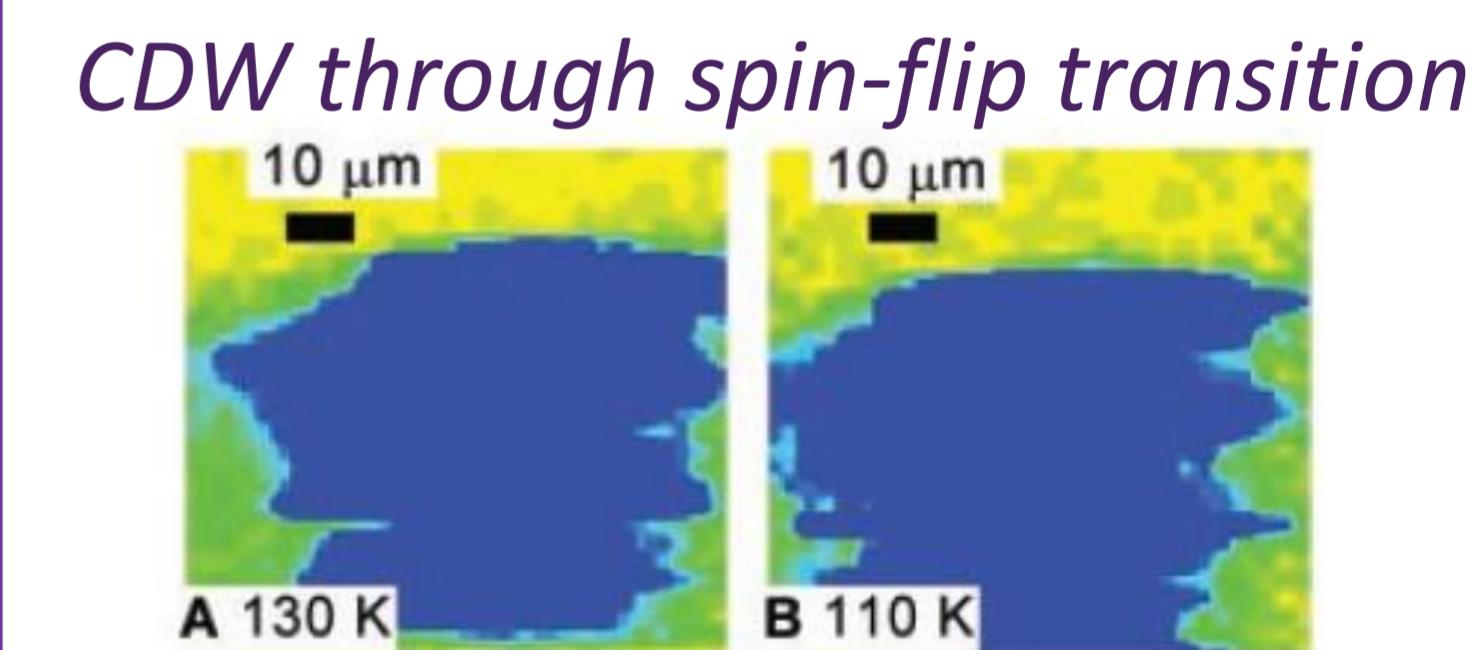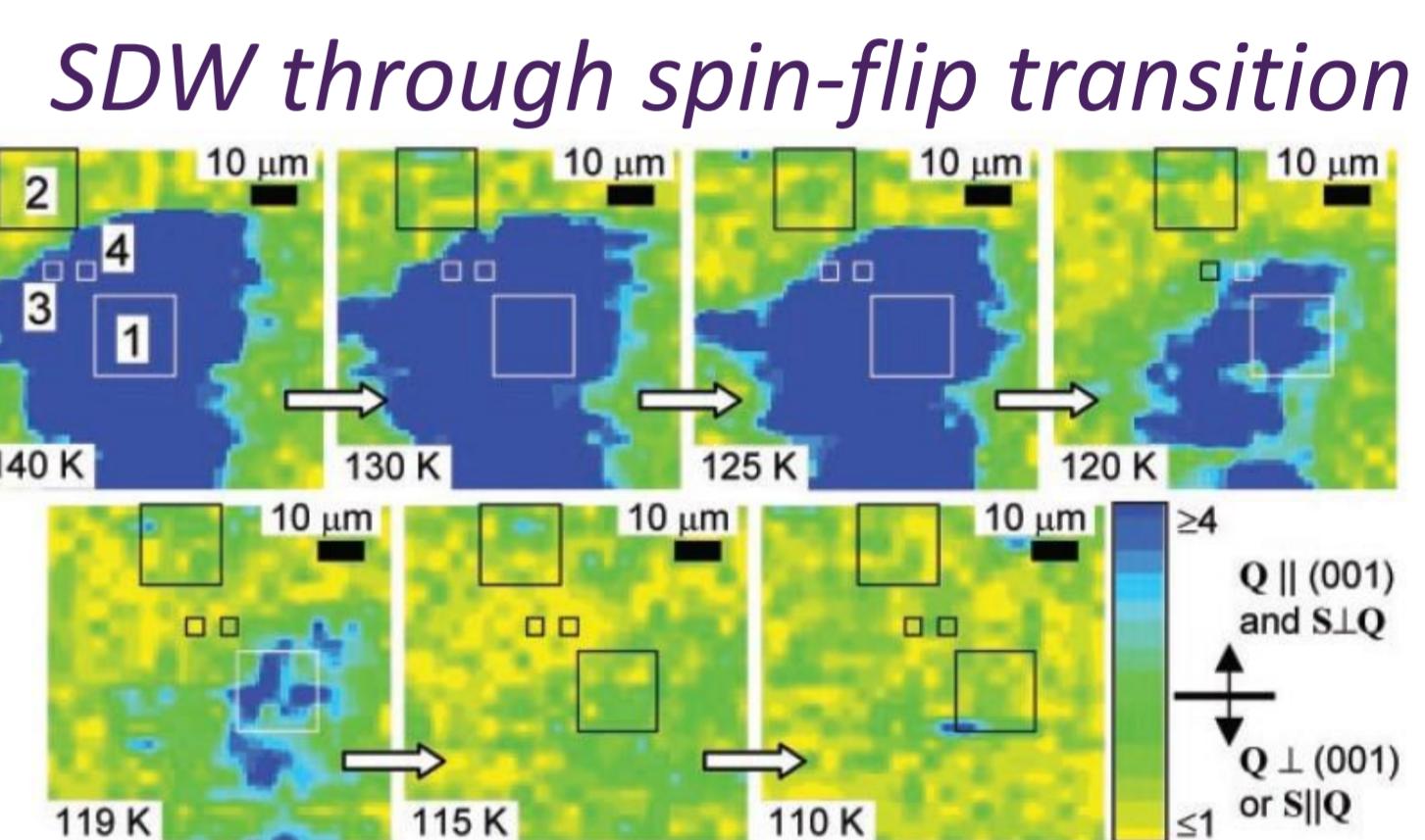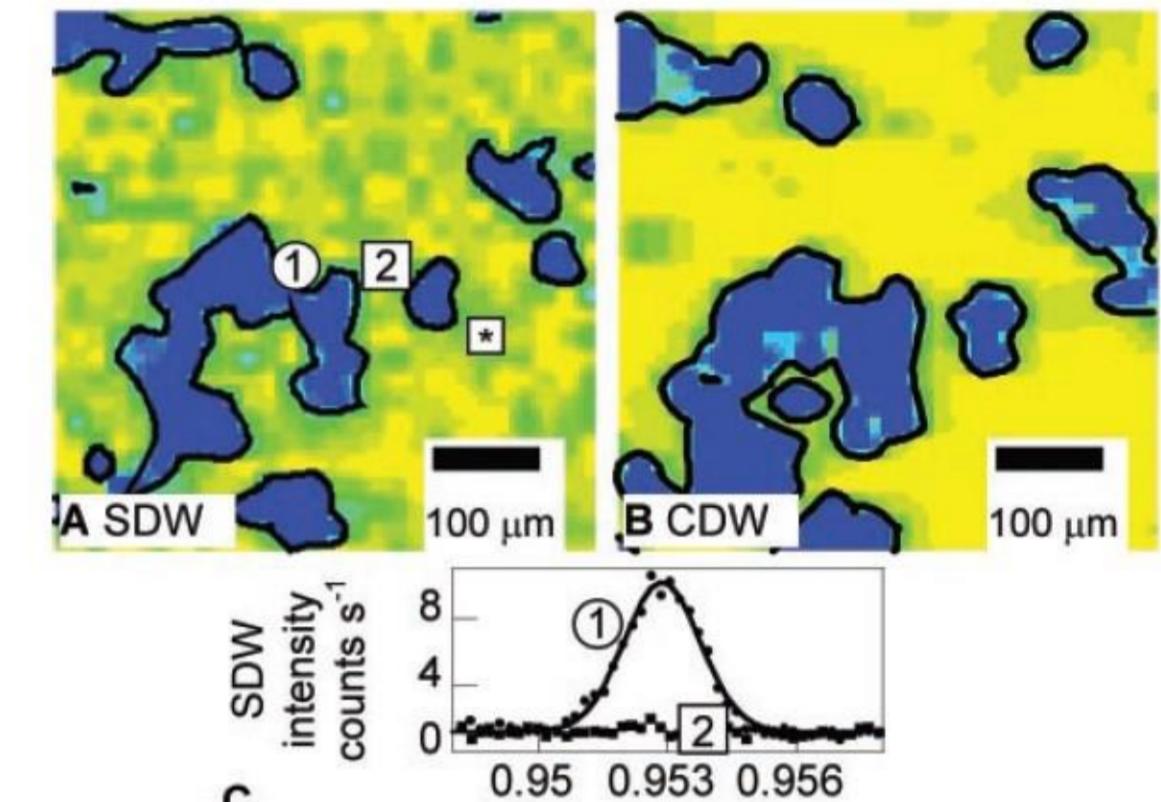
Evans et al., Science 295, 1042 (2002)

Coherent and simultaneous x-ray diffraction on CDW and SDW

CDW $Q_C(1\ 1-2\delta\ 0)$
SD and CD

SDW $Q_S(0\ 1-\delta\ 0)$
CD

T = 140 K

140 K

Jacques et al. PRB 89, 245127 (2014)

SDW : **perfect order** with infinite correlation lengths
CDW : **many phase defects** with sub-micrometer correlation lengths

T~60K T~70K T~76K T~84K T~88K T~92K T~96K T~100K

CDW intensity through SFT

Spin-Flip Temperature

SDW intensity through SFT

T_N = 300 K
T_{SF} = 85 K

TSDW

CDW sensitive to magnetic domain wall reorganization

LSDW

CDW dynamics after laser excitation: decoupling from lattice

(a)

Laser pump
X-ray probe
X-ray detection
Δt
Φ

CRISTAL, SOLEIL (France)

(b)

- Lattice (0 1 1)
- CDW (0 1-2δ 1)

Pic position

Δt (ns)

$\Delta\delta$ (r.l.u.)

$\Delta\alpha$ (deg.)

Δt (ns)

CDW
0 ns   0.5 ns   3 ns
Δα
Δδ

Lattice
0 ns   3 ns

Jacques et al., PRL 117, 156401 (2016)

- pumped - unpumped

Laser-induced strain gradient → CDW tilt

Mirror H
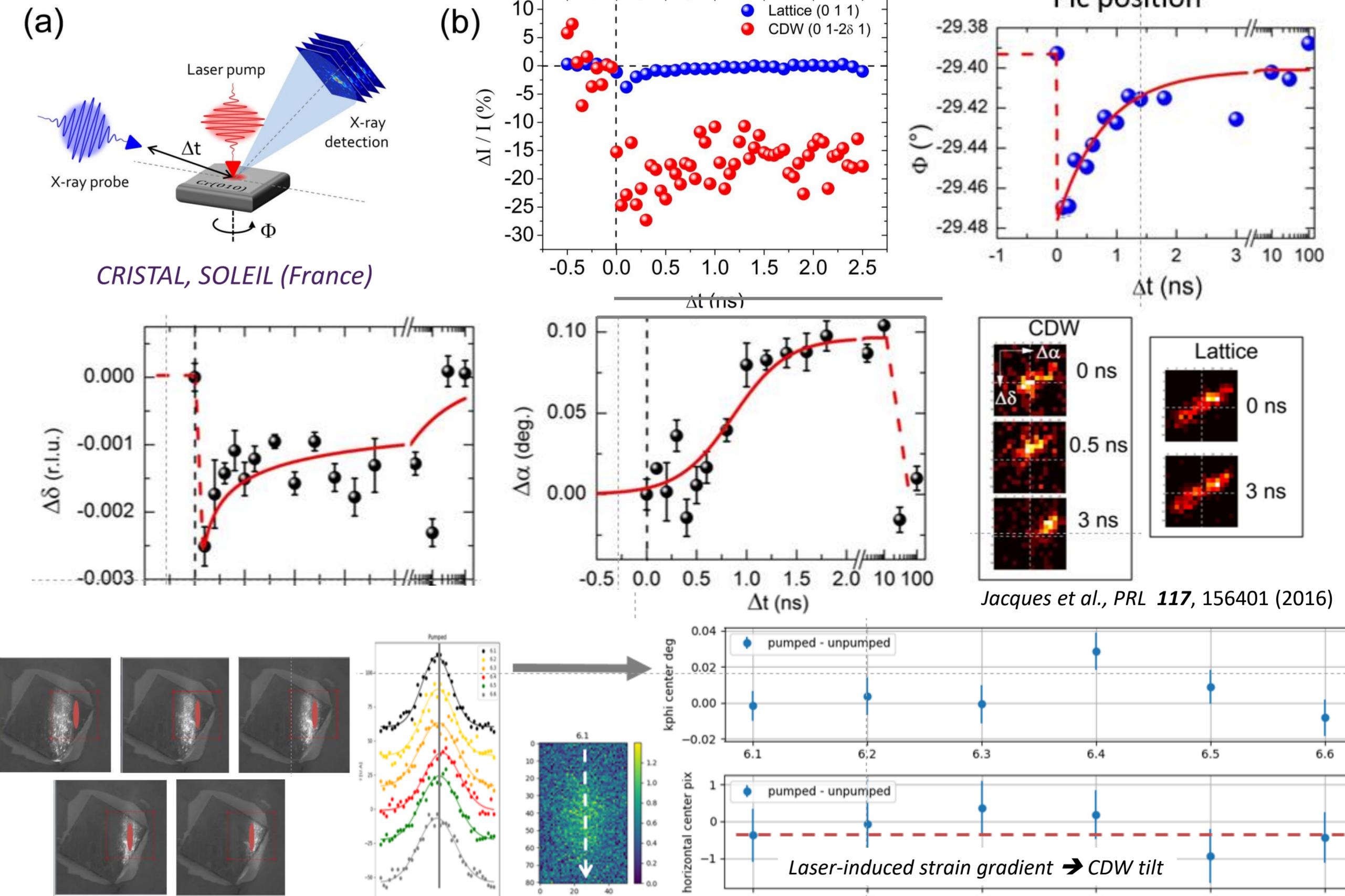
CDW dynamics through SF-transition with fs time resolution @FXE, European XFEL (Hamburg)

- T = 140K
- T = 85K
- T = 74K

TR signal (arb. units)

Time delay (ps)
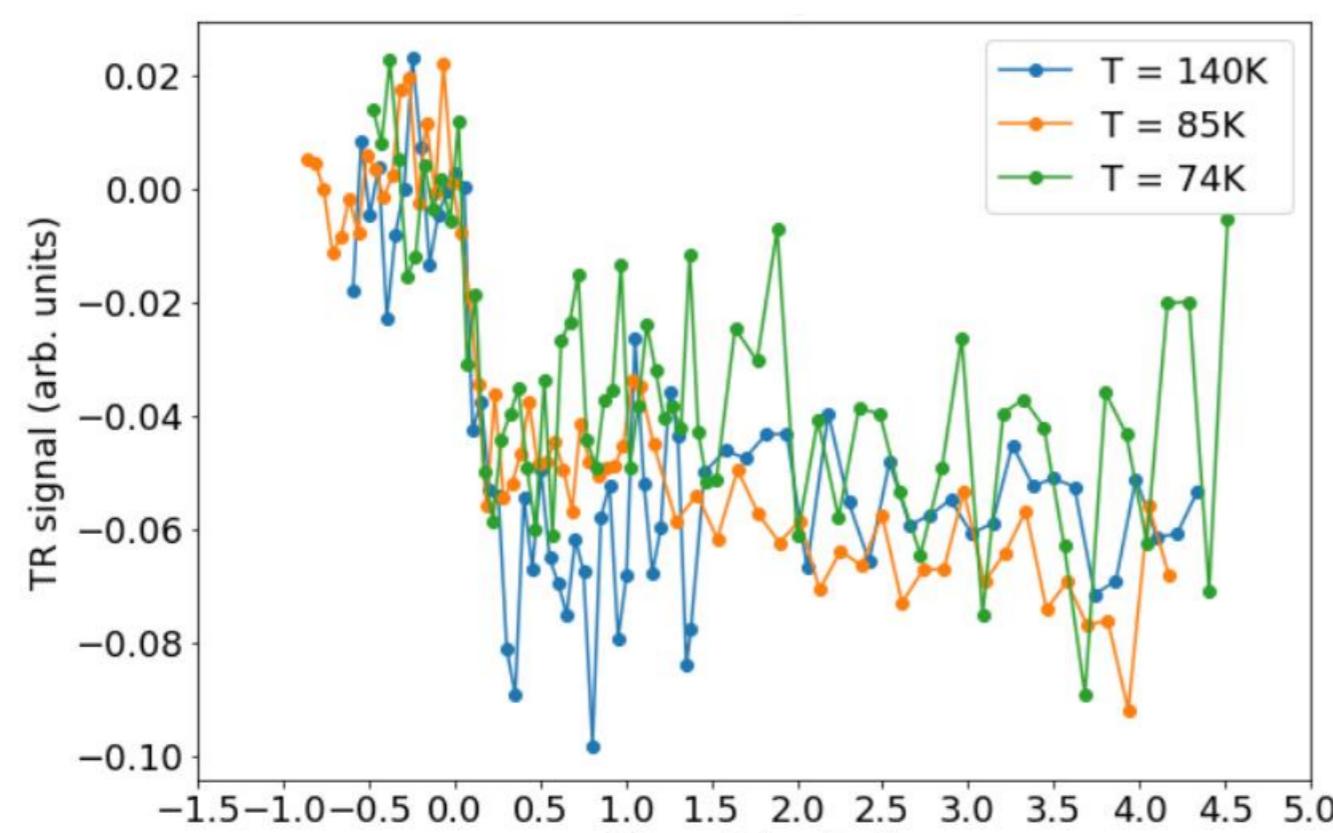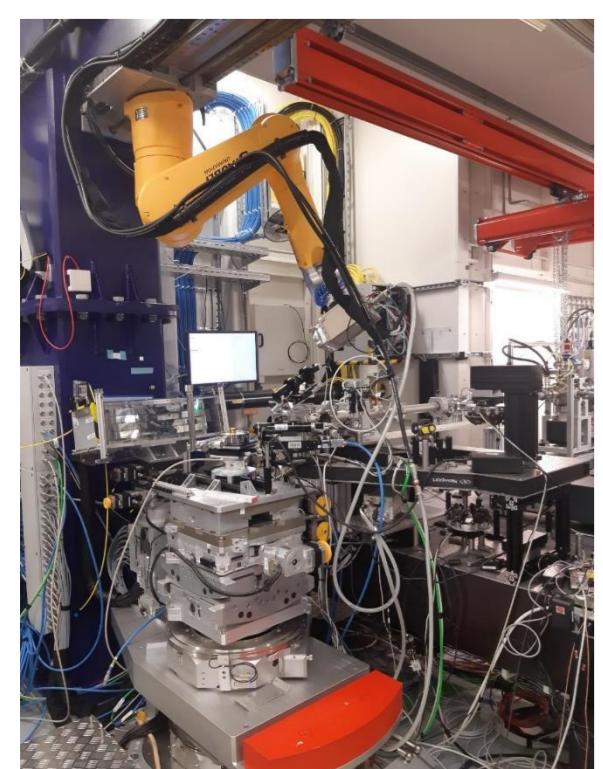
3 successive steps:

1. **Ultrafast decay (~100fs)** → CDW excitation
2. **Partial recovery (~1ps)** → CDW reapparition
3. **Longer-time decay (>1ps)** → start of thermal transfer

Dynamics of step 2 (CDW reapparition) is different (longer) near Spin-Flip temperature

In a nutshell ...

- Static SDW and CDW have **very different correlation length** ξ
  - SDW : $\xi_{SDW} \rightarrow \infty$
  - CDW : ξ_{CDW} < 1µm

- CDW through the spin-flip transition :
  - CDW **domains are preserved** but **CDW 'feels' the transition** :
    - correlation length decreases
    - Amplitude decreases
    - ps CDW partial recovery dynamics is different at spin-flip transition

- **CDW decoupling from lattice** ~2ns after laser excitation, due to strain gradient