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Temperature hysteresis and latent heat avalanches in $LaFe_xMn_ySi_z$-$H_{1.65}$

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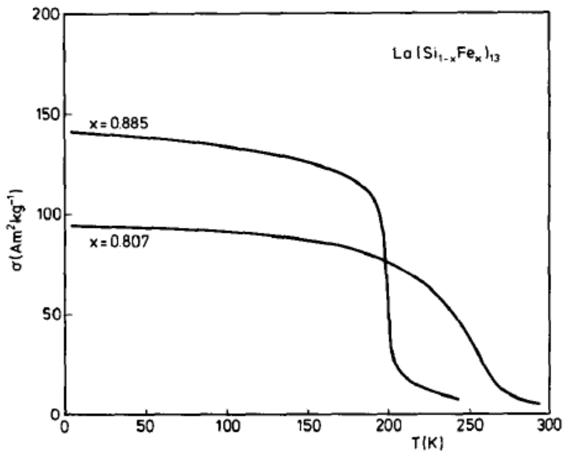
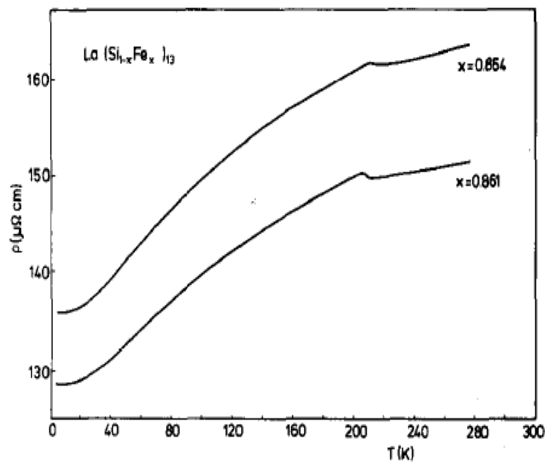
DRREAM

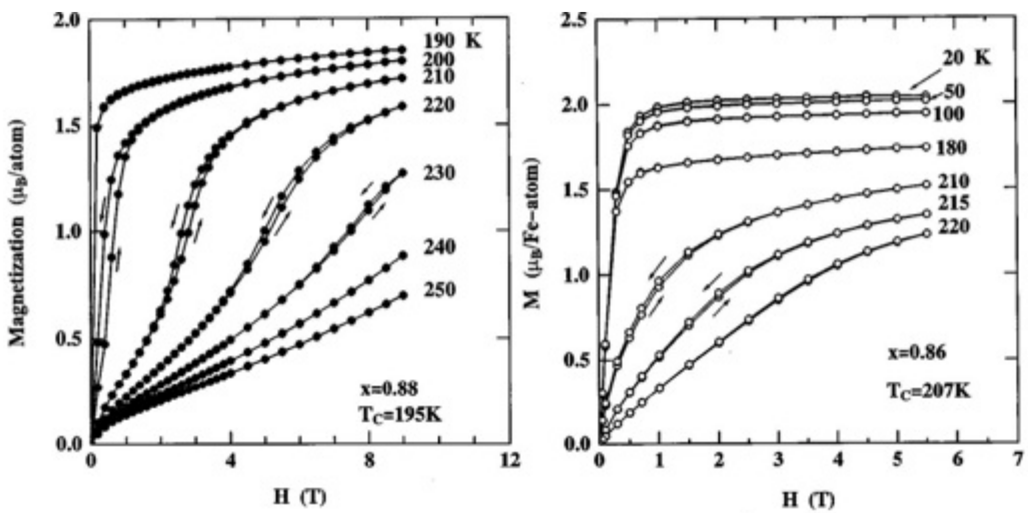
PHASE TRANSITION PROPERTIES IN LaFeSi BASED COMPOUND

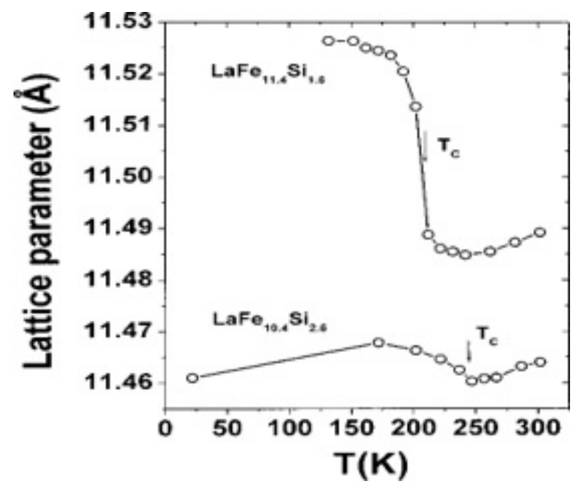




"STUDY OF THE CRITICAL BEHAVIOUR OF THE MAGNETIZATION AND ELECTRICAL RESISTIVITY IN CUBIC La(Fe,Si)₁ COMPOUNDS"

Palstra, T. T. M., et al.
Journal of magnetism and magnetic materials 36.3 **(1983)**: 290-296.





FIELD INDUCED PM TO FM TRANSITION:
T_c INCREASES DUE TO THE EFFECT OF APPLIED FIELD

Fujita et al. *Magnetics, IEEE Transactions on* 35.5 (**1999**): 3796-3798.

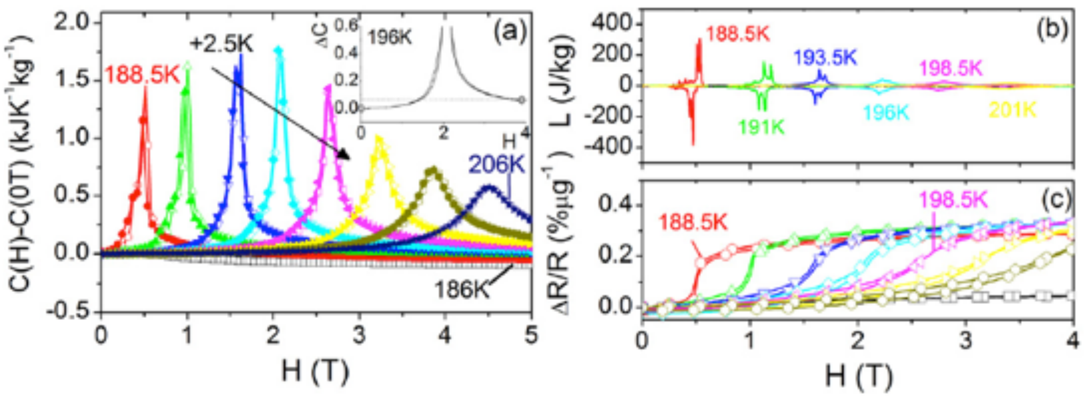
LATTICE CONTRACTION AT PM PHASE

Hu et al. Appl. Phys. Lett., Vol. 78, No. 23, 4 June(**2001**)

- Large MCE values (ΔS_{ISO} 20 kJ/kg K; ΔT_{AD} 10 K)
- Tunable Tc (Ambient temperature)
- **Small thermal and magnetic hysteresis**

Candidate for magneto cooling

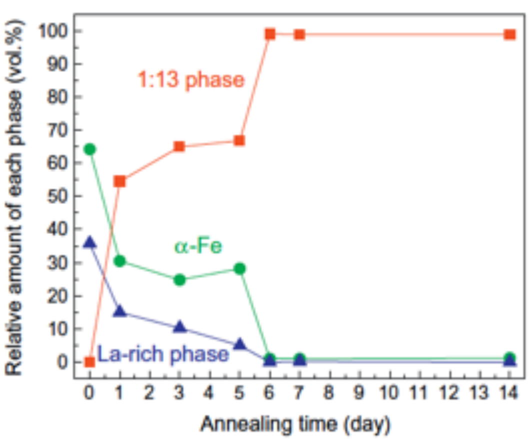
CONTRIBUTIONS TO ΔS_{ISO} IN LaFeSi BASED COMPOUNDS



Lowering of latent heat **by magnetic field** and growths of specific heat of transition

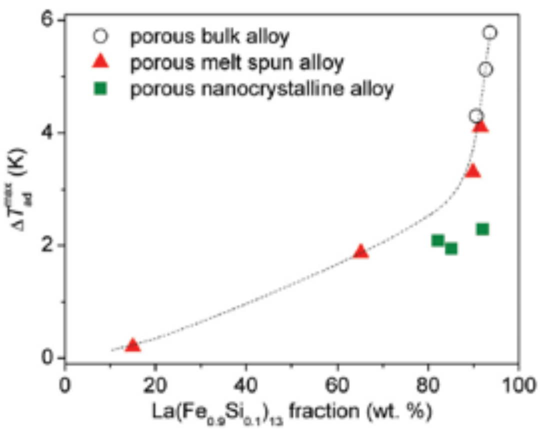
Morrison, K., et al.
Journal of Physics D: Applied Physics 43.13 (**2010**).
Journal of Physics D Applied Physics 45 (**2012**).

SECONDARY PHASES



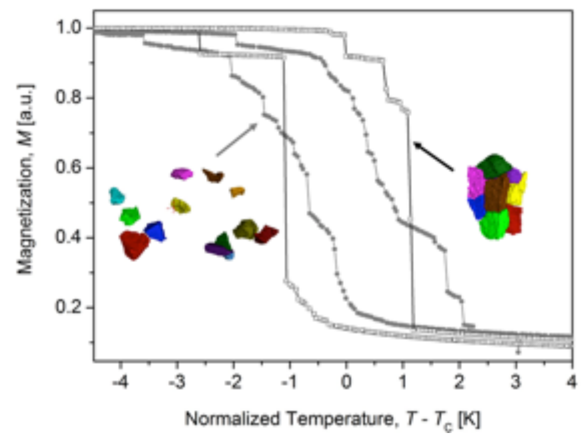
Liu, J. et al.
Acta Materialia 59.9 (**2011**): 3602-3611.

MICROSTRUCTURE



Lyubina, J. et al.
Journal of Applied Physics 109.7 (**2011**)

SAMPLE SIZE

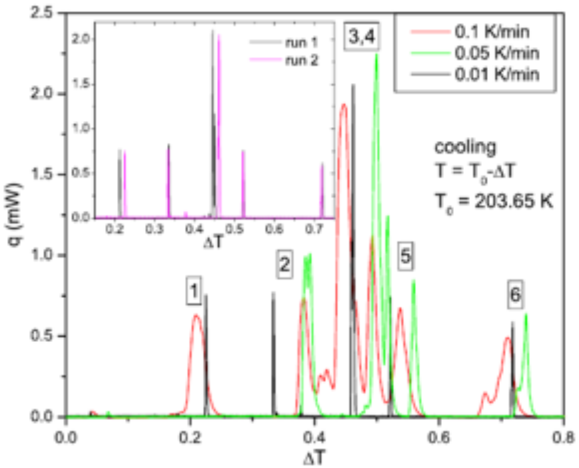


Waske, A., et al.
Phys. Status Solidi RRL **9** (**2015**).

DYNAMICS OF THE PHASE TRANSITION LaFeSi BASED COMPOUNDS

1st order phase transition in fragment (3 mg) of $La(Fe_{0.9}Co_{0.015}Si_{0.085})_{13}$ $T_C = 200$ K

DIFFERENTIAL SCANNING CALORIMETRY



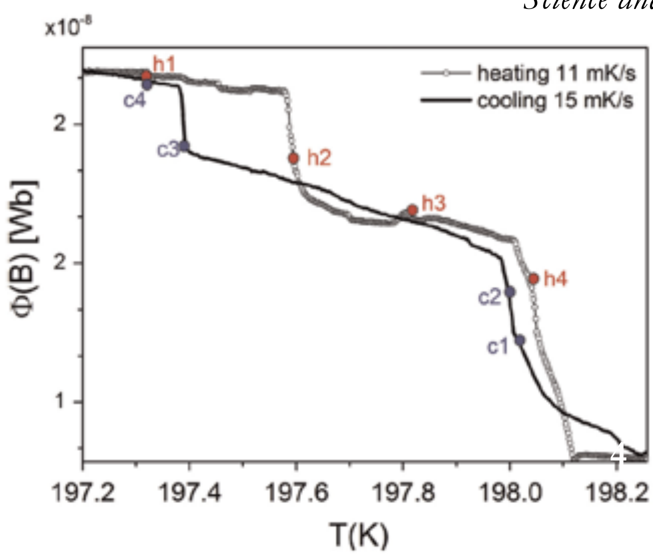
Kuepferling, M., et al.
Journal of Applied Physics 115.17 (**2014**).

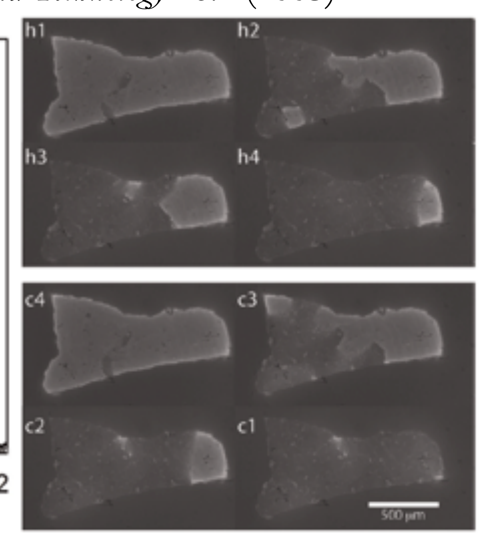
Heat flux spikes are related to fast transformations of volumes and reveal as the FAST process is dominated by the pinning of phase boundaries at defects (cracks).

MAGNETO OPTICS IMAGING TECHNIQUE WITH INDICATOR FILM

Laviano F., et al. *Superconductor Science and Technology* 16.1 (**2003**)

Secondary phases
magnetic in homogeneities not always related to strong changes of the path
but influence the SLOW dynamics





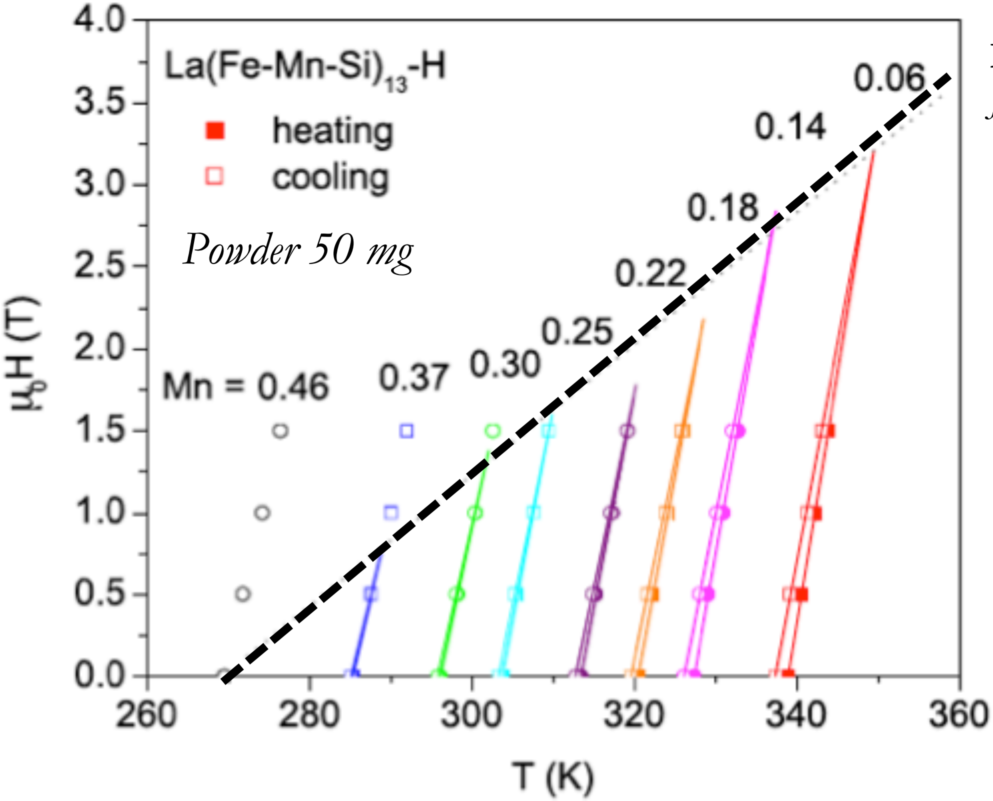
H= 70 mT (small)

Study of the effect of field is required!

Bennati, C., et al
Journal of Magnetism and Magnetic Materials (**2015**).

DYNAMICS OF THE PHASE TRANSITION LaFeSi BASED COMPOUNDS

$LaFe_x\mathbf{Mn_y}Si_z$-$H_{1.65}$



Basso, V., et al.
Journal of Applied Physics 118.5 (**2015**).

SERIES WITH TUNEABLE CRITICAL POINT
Vacuumschmelze GmbH andCoKG

- Mn (174 K/y(Mn))
- H is saturated (+ 150 K)
- Magnetic Field (+4 K/T)

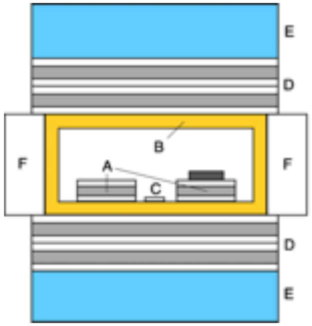
Cross Over between 1st to 2nd order

VAC Code	x (Fe)	y (Mn)	z (Si)	Mass (mg)	Nominal *Tc* (°C)
MCP 37 (1255)	11.60	0.18	1.22	4.79	49
MCP 34 (1252)	11.41	0.30	1.29	4.53	20
MCP 32 (1250)	11.22	0.46	1.32	2.19	-4

SAMPLE DIMENSION:
Powder (50 mg) → fragments (< 5 mg)
(avoid extrinsic factor of powder agglomeration)

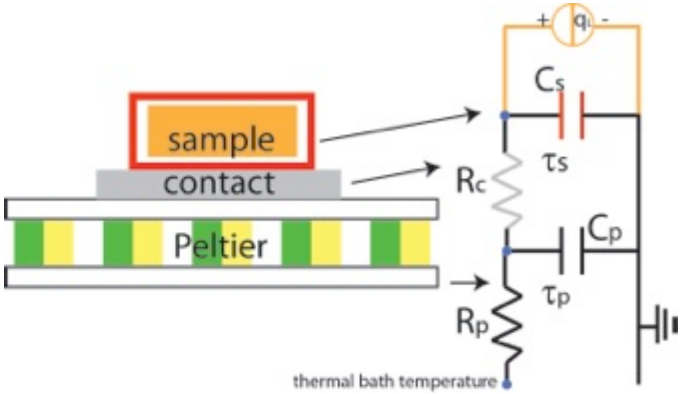
TIME SCALES TO OBSERVE A SINGLE AVALANCHES

PELTIER CELLS DIFFERENTIAL CALORIMETER



Heat diffusion time τ_{EXP}

- PELTIER + CONTACT(MASS)
- dT/dt



Basso, V. *Review of Scientific Instruments* 81.11 (**2010**)
Kuepferling, M. et al., *EPJ Web of Conferences*. Vol. 40. EDP Sciences, **2013**.

Supposing a characteristic time of the single process (I.E. LATENT HEAT RELEASE) τ

$\tau >> \tau_{EXP}$

- Peltier + Contact large
- dT/dt large

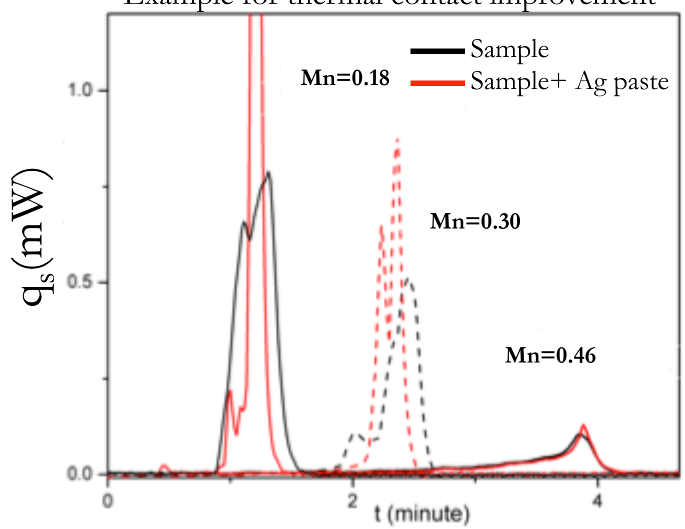
TEMPERATURE OF THE SAMPLE IS MAINLY DRIVED BY RATE (large temperature gradient)

$\tau \approx \tau_{EXP}$

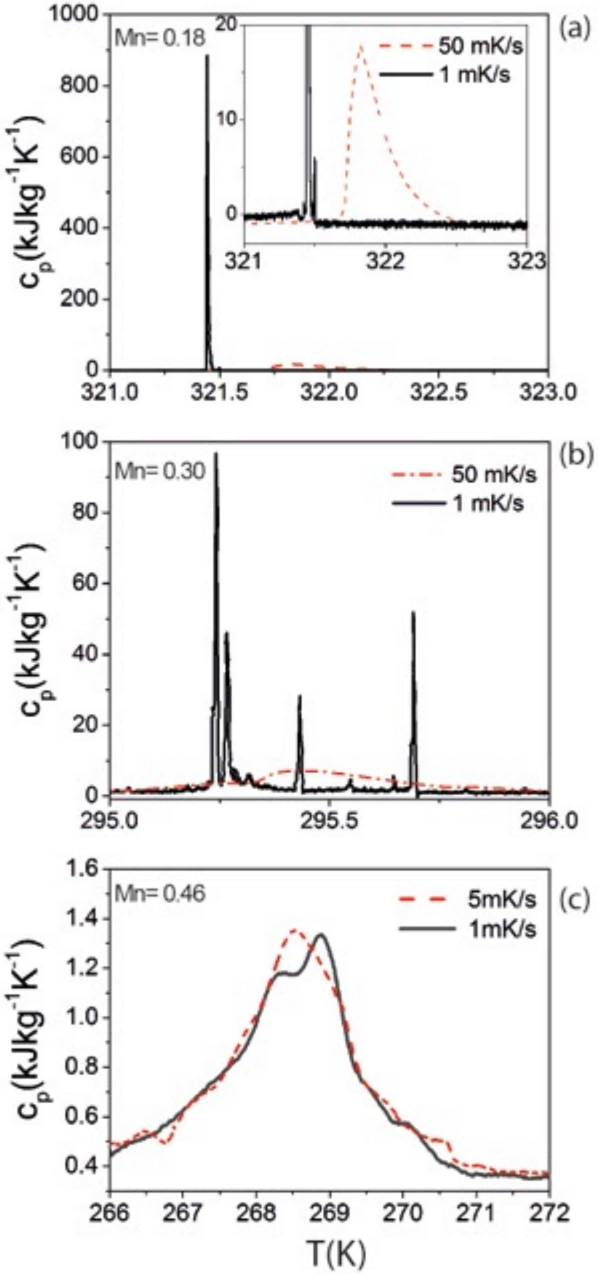
- Peltier + Contact small
- dT/dt → 0

ABSORPTION/RELEASE OF LATENT HEAT CAN CHANGE THE TEMPERATURE INSIDE THE SAMPLE (and be observed).

Example for thermal contact improvement



$LaFe_x\mathbf{Mn_y}Si_z\text{-}H_{1.65}$: EFFECT OF COMPOSITION DISCLOSED BY LOW RATE



<u>H = 0 T and dT/dt → 0</u>

MN =0.18

- (S)Low rate discloses avalanches
- A single avalanche is present

1st order transition

MN =0.30

- Low rate discloses avalanches
- Mn increases the number of avalanches
- Avalanches are lower
- Higher background

1st order transition

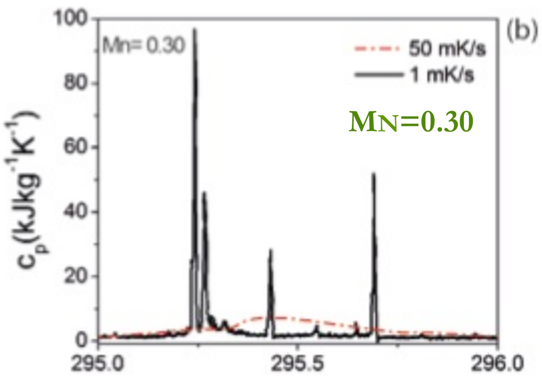
MN =0.46

- Low rate has no effect
- No avalanches and no hysteresis

2nd order transition

Mn > 0.03 should introduce more secondary phases (defects)

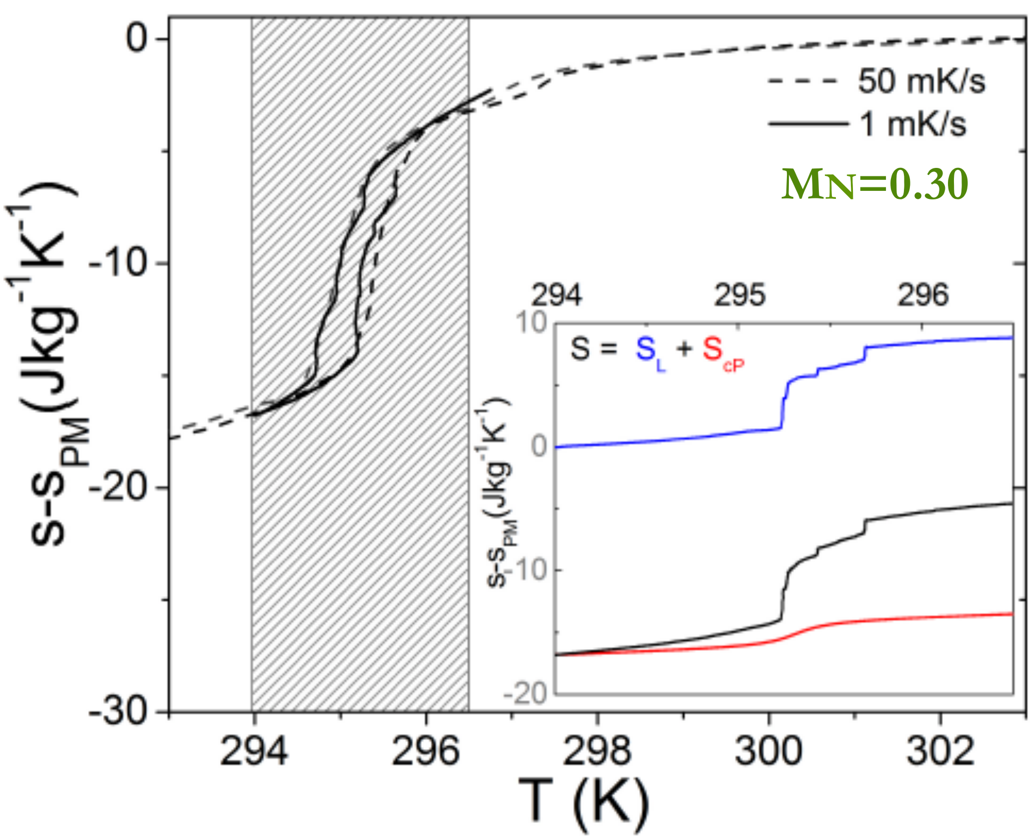
C. Bennati et al, in preparation



ENTROPY CHANGE WITH AVALANCHES τ ≈ τexp

Two contributions from specific heat and latent heat, where background and avalanches are clearly distinguished

$$S - S_{PM} = \Delta S_{c_p} + \Delta S_L = \int_{T_i}^{T_f} \frac{c_p(T)}{T} dT + \sum_i \frac{m_i L}{T_i}$$



SPECIFIC HEAT OF THE TRANSITION

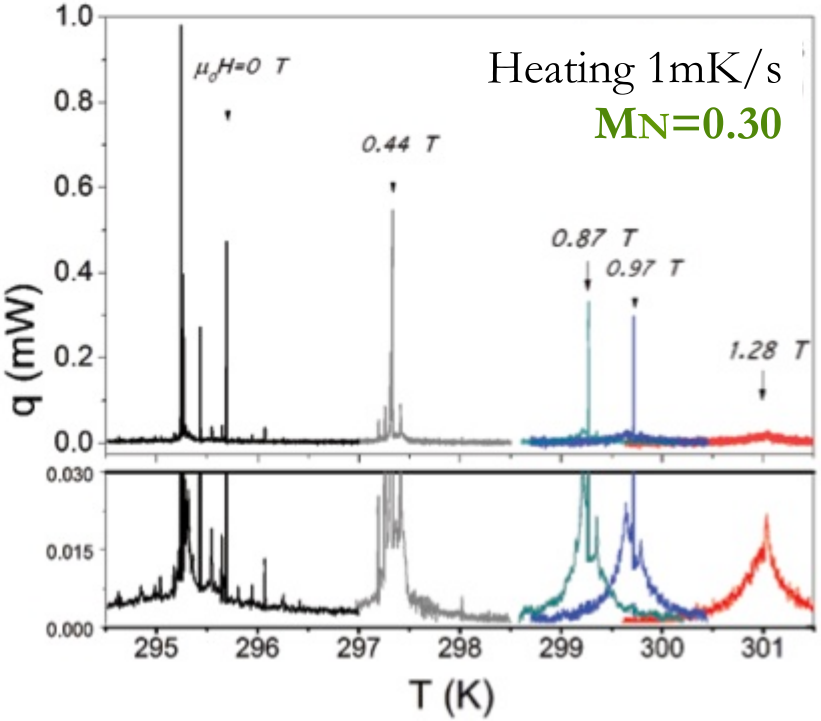
For a system in thermodynamics equilibrium (slow dynamics)

ISOTHERMAL ENTROPY CHANGES

For irreversible processes which act as a source of energy (fast dynamics)

If no irreversibility is present $\Delta S_L = 0$ → as for **MN =0.46**

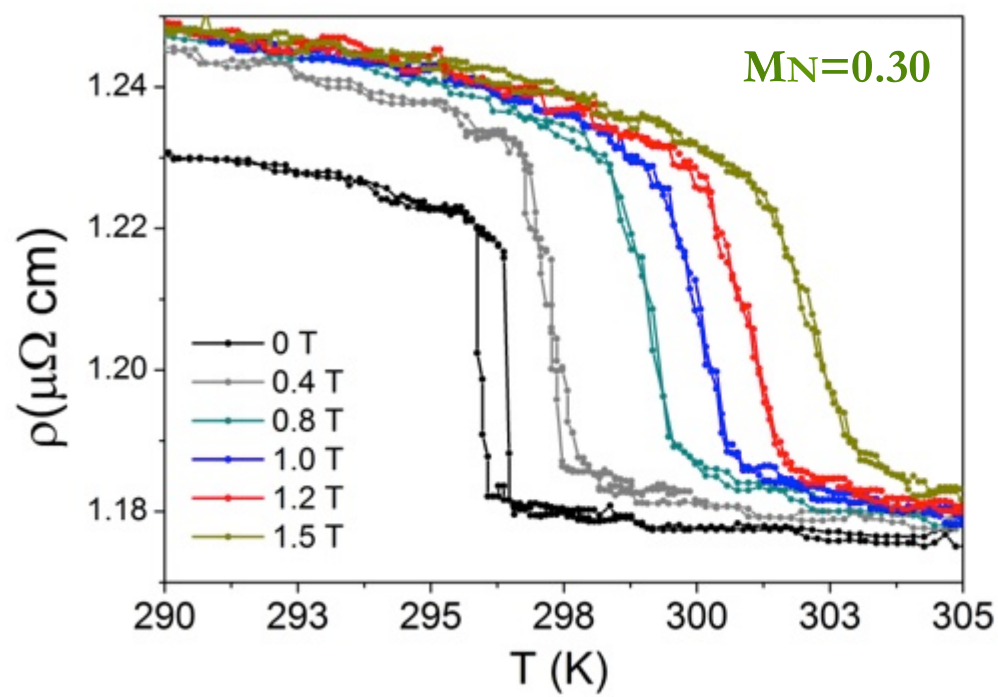
EFFECT OF FIELD ON AVALANCHES: MN = 0.30



AGAIN but with **H**

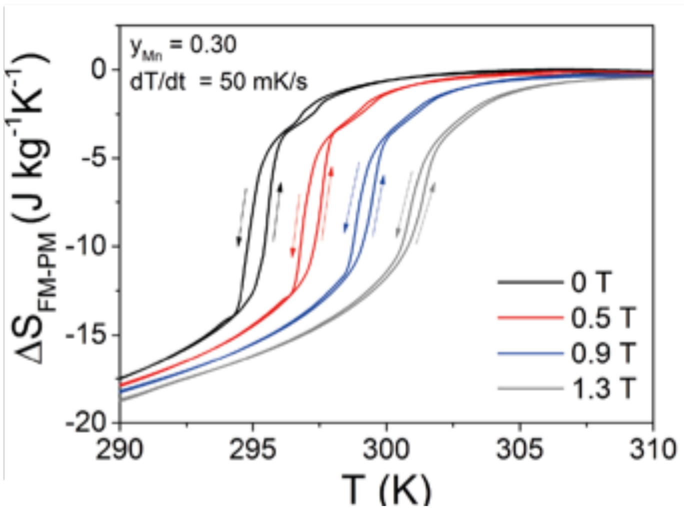
- Avalanches change shape and number and vanish at H > 1.3 T
- Specific heat background grows

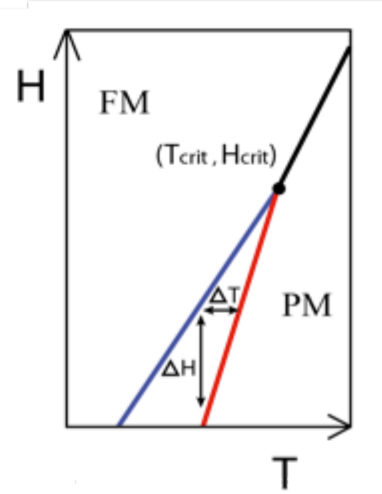
C_p and L compete

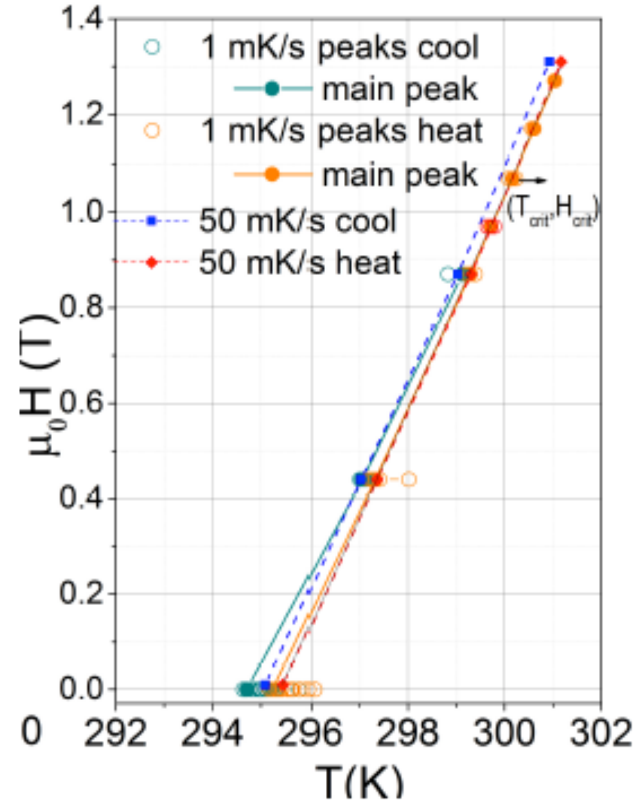


- Magnetic field effect:
  MR 3.7 % up to 5% at 0.8 T
  i.e. **5% K^{th}_{el}(H) of FM**
- Slope with field reflects the volume growth
- Jumps vanish H > 0.8 T

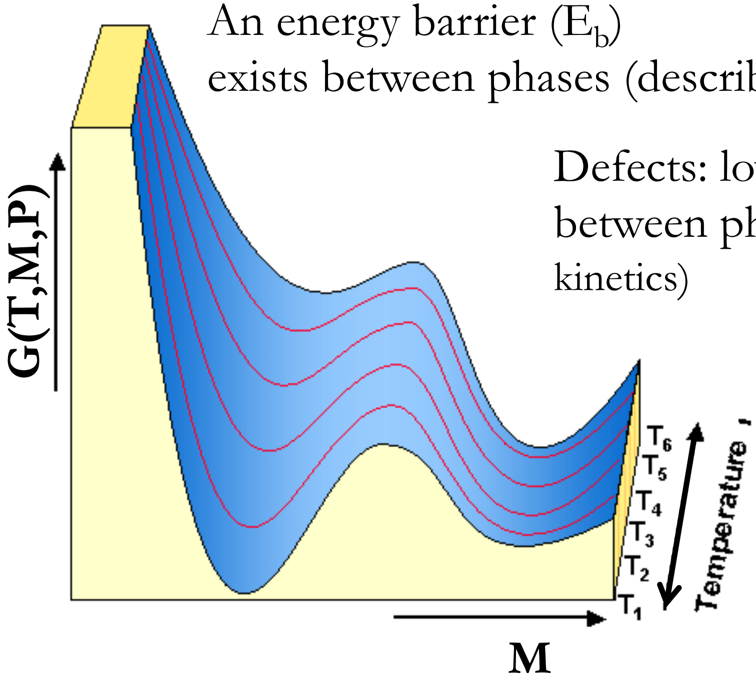
EFFECT OF FIELD ON MAGNETIC PHASE DIAGRAM: MN = 0.30



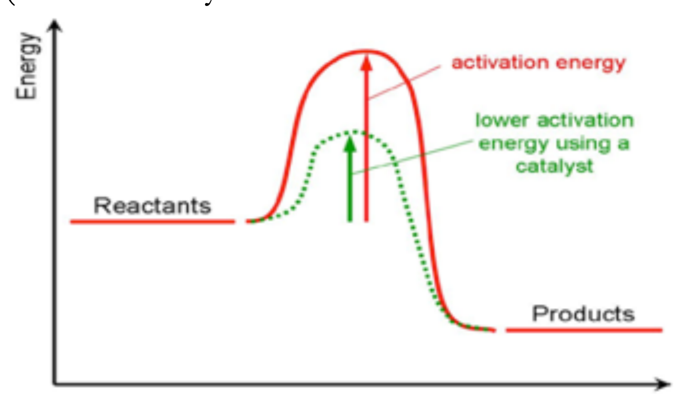




An energy barrier (E_b) exists between phases (described by thermostatics)



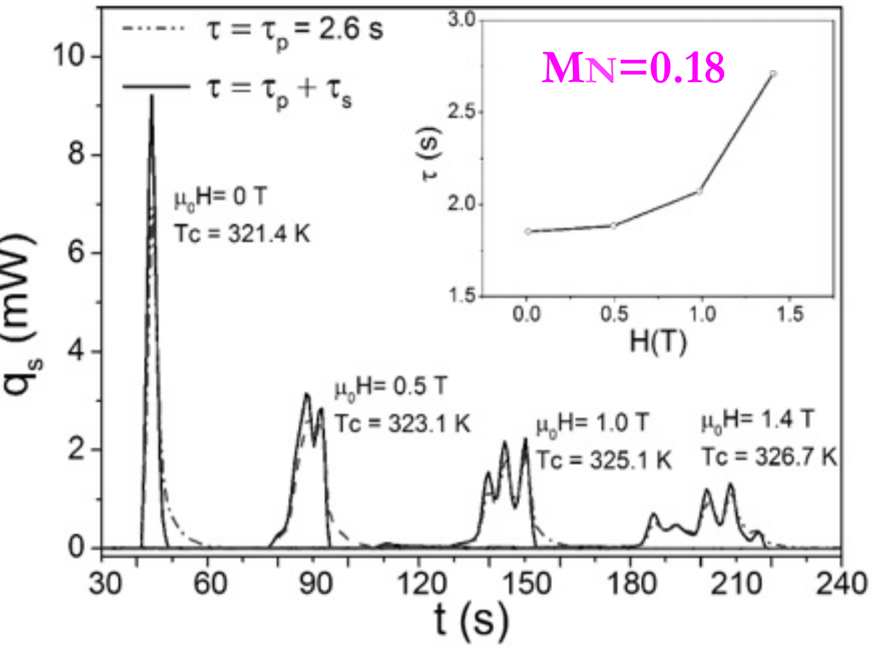
Defects: lower the **Effective E_b** between phases(described by kinetics)



E_b decide which **defect** count for the transition

Lower E_b greater n° of defects

AVALANCHES FAR FROM THE CRITICAL POINT AND SPECIFIC HEAT TOWARD THE CRITICAL POINT

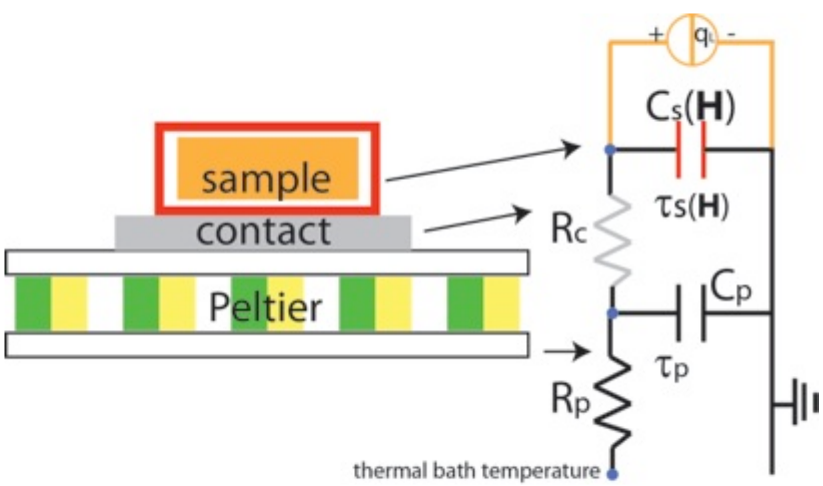


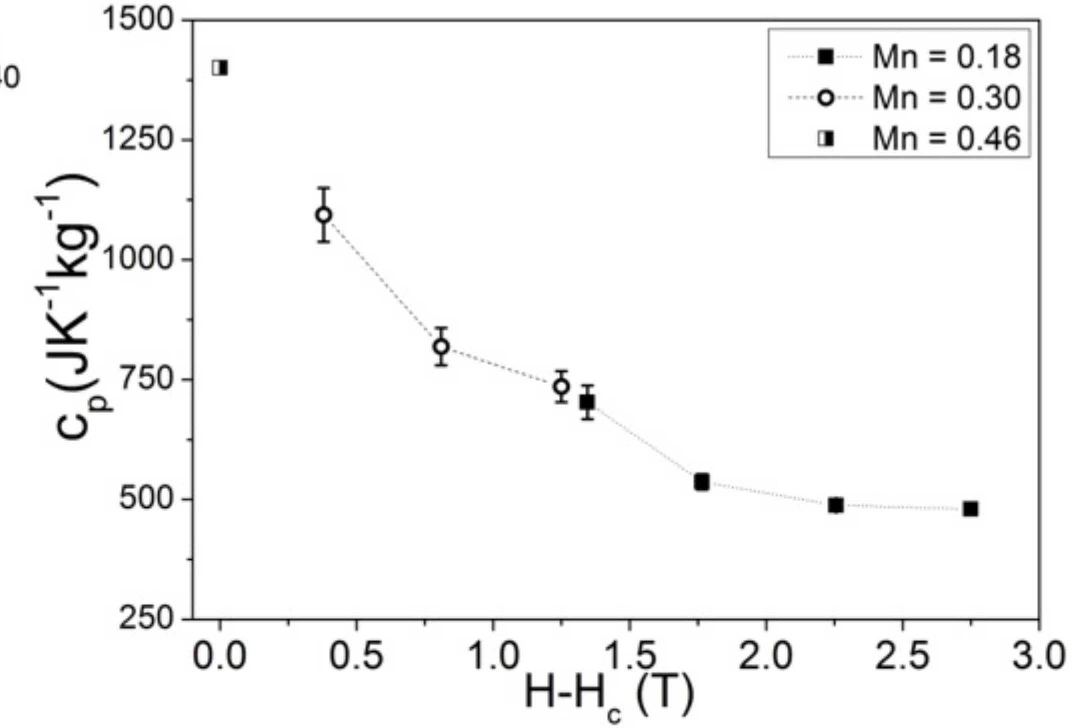
FAR FROM THE CRITICAL POINT **MN = 0.18**

- Increasing **H**, the latent heat terms lower
- Unresolved peaks: $\tau_{exp} << \tau$

As specific heat may depends on **H:** τ_s (**H**)

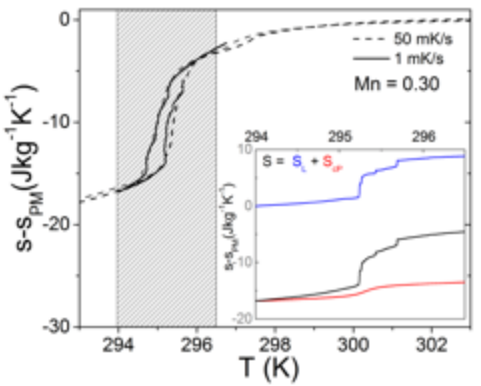
$$\Delta C_s^{th}(H) = m\Delta c_p(H) = \frac{1}{R_s^{th}} \cdot \Delta\tau_s(H)$$





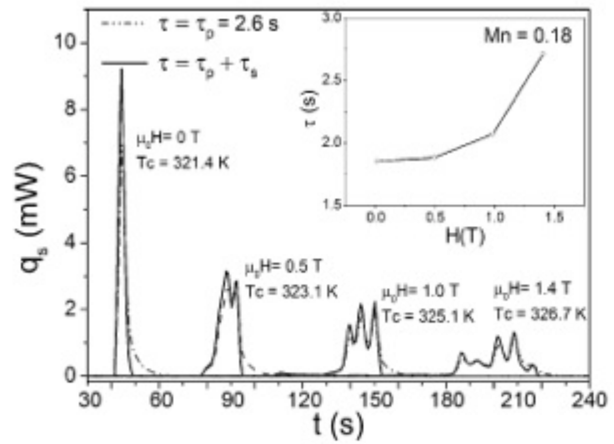
CONCLUSION

DSC at low rates is a powerful tool to determine the first/second order character of the transitions



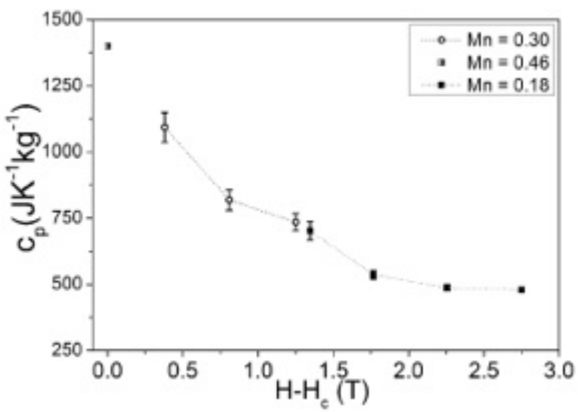
Rate of the experiment 1 mK/s discloses:

- Reversibility → Specific heat background
- Irreversibility → Avalanches of latent heat
- Best evaluation of the Critical Point and hysteresis



Mn/Field effect on Avalanches :

- Change of <u>Number</u> of nucleation events reveals the lower energy gap between phases



Physical properties revealed by avalanches near the critical point

- <u>Shape</u> → Specific heat increases

Thank you for your attention!