

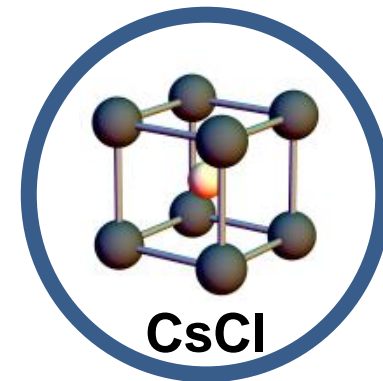
Speziřni toplinski kapacitet ErCu duř osi teške magnetizacije

Nives Bonaćić

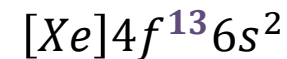
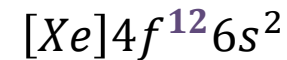
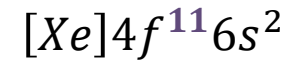
Mentor: Prof. dr. sc. Christian Pfeleiderer

1																	18	
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	113	Fl	115	Lv	117	118

Lanthanides	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Actinides	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



Ho
Er
Tm



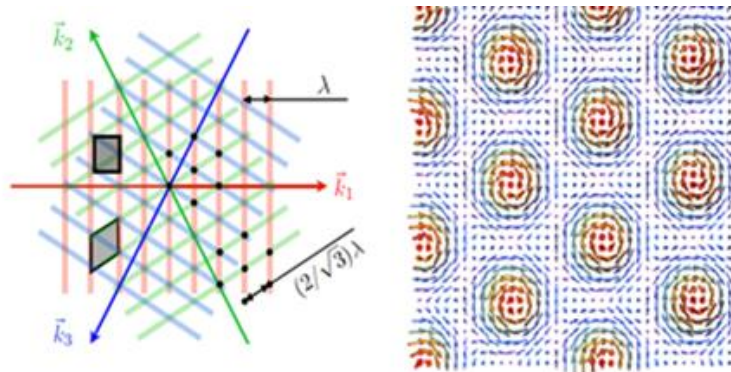
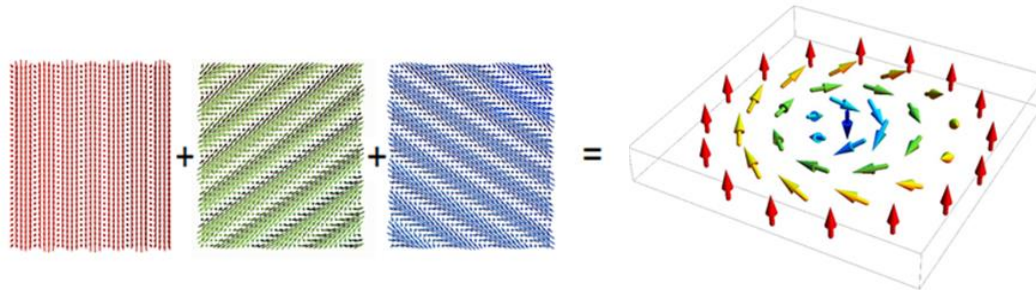


Uvod



antiferromagnetsko uređenje u više k smjerova

-> netrivialna topologija?



		light rare earths					heavy rare earths								
		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
non-magnetic partner	Mg		A 20	A 45									A 1.3		
	Cu							A 140 185	A 115 115	A 63	A 27	A 16	A 8		
	Zn	A 30	A 52	A 70				F 269	F 200	F 139	F 75	F 20	F 8		
	Ag	F 6 16	A 11	A 22				A 104	A 57	A 33	A 18	A 10			
	Cd	A 17	A 41	F 121				F 258	F 158	F 80	F 17	F 3			3

ferromagnetic / antiferromagnetic → F/A27
 multi-k spin structure → 185
 modulated spin structure → 3
 magnetic ordering temp. (K) → 27
 martensitic transition temp. (K) → 185
 quadrupolar transition temp. (K) → 3

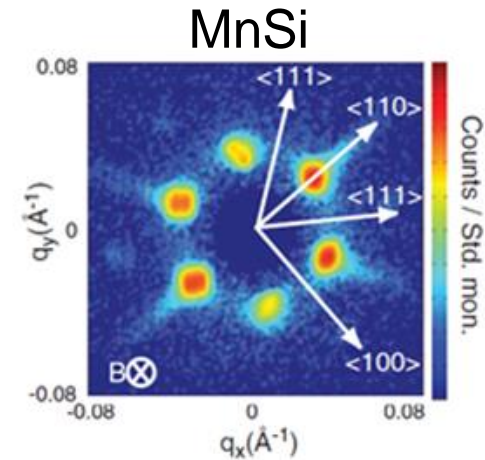
[1] P. Morin, D. Schmidt, Quadrupole interactions and magneto-elastic effects in rare earth intermetallic compounds, Ferromagnetic materials 5 (1990)



„mjerenje“ topologije

neutronska raspršenja

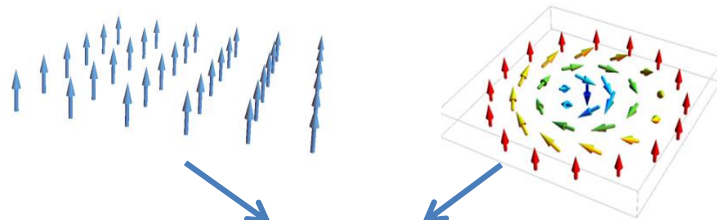
Hallov efekt



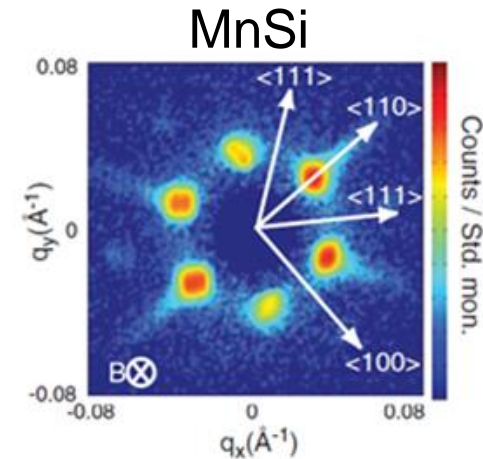
„mjerenje“ topologije

neutronska raspršenja

Hallof efekt



$$\begin{aligned} \rho_{xy} &= \rho_{xy}^N + \rho_{xy}^A + \rho_{xy}^{\text{top}} = \\ &= R_0 H + R_S M + P \cdot R_0 \cdot B_{\text{eff}} \end{aligned}$$



$$\Omega(\mathbf{r}) = \frac{1}{4\pi} \mathbf{n} \cdot \left(\frac{\partial}{\partial x} \mathbf{n} \times \frac{\partial}{\partial y} \mathbf{n} \right) \sim \rho_{xy}^{\text{top}}$$



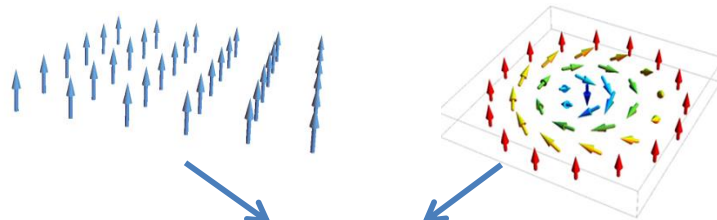
Motivacija - RZ-Cu spojevi



„mjerenje“ topologije

neutronska raspršenja

Hallov efekt

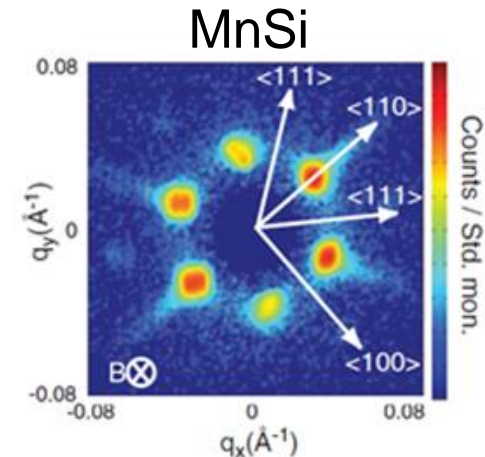


$$\rho_{xy} = \rho_{xy}^N + \rho_{xy}^A + \rho_{xy}^{\text{top}} =$$

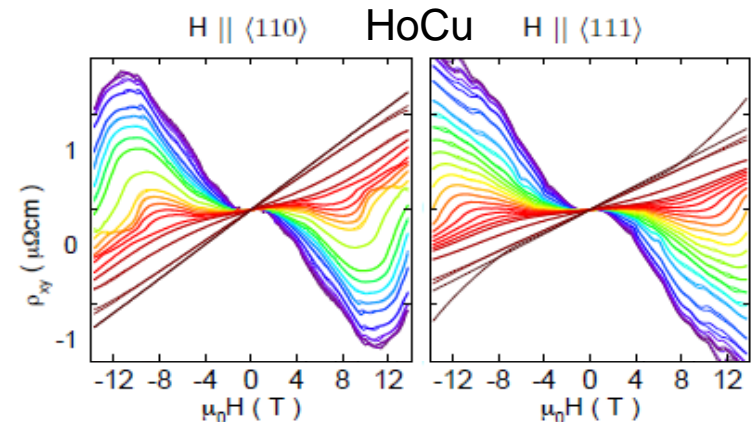
$$= R_0 H + R_S M + P \cdot R_0 \cdot B_{\text{eff}}$$

$$\frac{\rho_{xy}^{\text{top, HoCu}}}{\rho_{xy}^{\text{top, MnSi}}} = 500$$

$$\rho_{xy}^{\text{top}} \propto B_{\text{eff}} \propto \lambda^{-2}$$



$$\Omega(\mathbf{r}) = \frac{1}{4\pi} \mathbf{n} \cdot \left(\frac{\partial}{\partial x} \mathbf{n} \times \frac{\partial}{\partial y} \mathbf{n} \right) \sim \rho_{xy}^{\text{top}}$$





zakretanje spinova

MnSi nema centar inverzije

Dzyaloshinskii-Moriya $E_{DM} = \sum_{i,j} \mathbf{D}_{ij} \cdot (\mathbf{S}_i \times \mathbf{S}_j)$

RZ-Cu kubne strukture

RKKY - 4s elektroni Cu

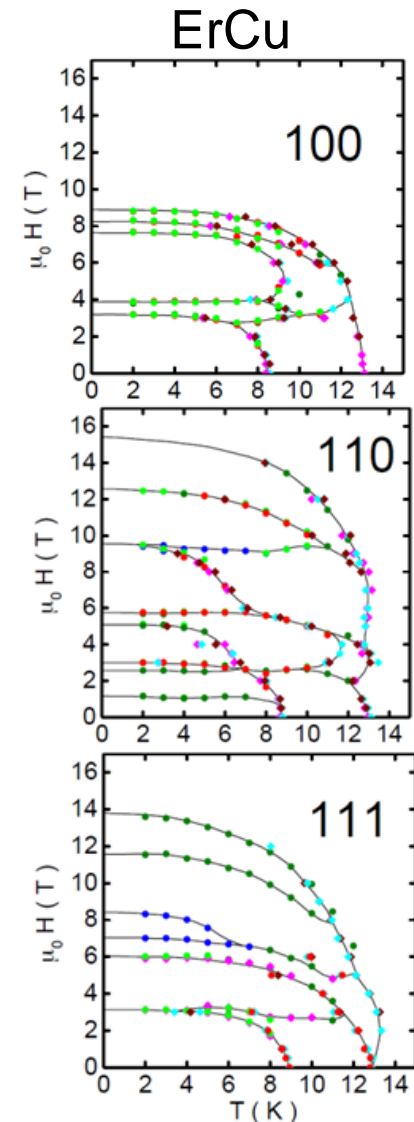
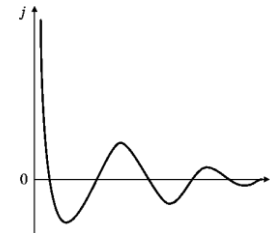
4f RZ spin-polariziraju 4s Cu

indirektna FM izmjena 5d-5d RZ

CEF – utjecaj kristalne strukture

uklanja degeneraciju – $\langle 100 \rangle$, $\langle 110 \rangle$, $\langle 111 \rangle$

kvadrupolni moment jezgre

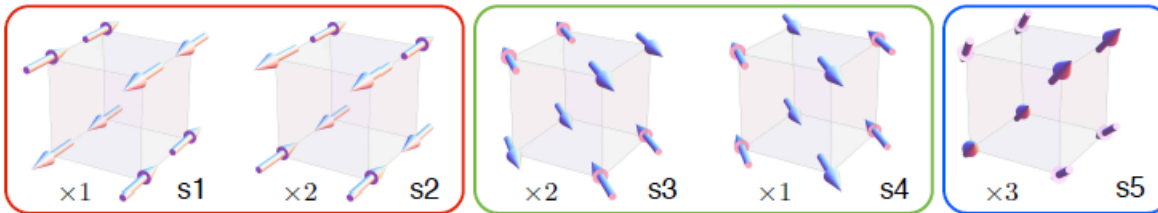




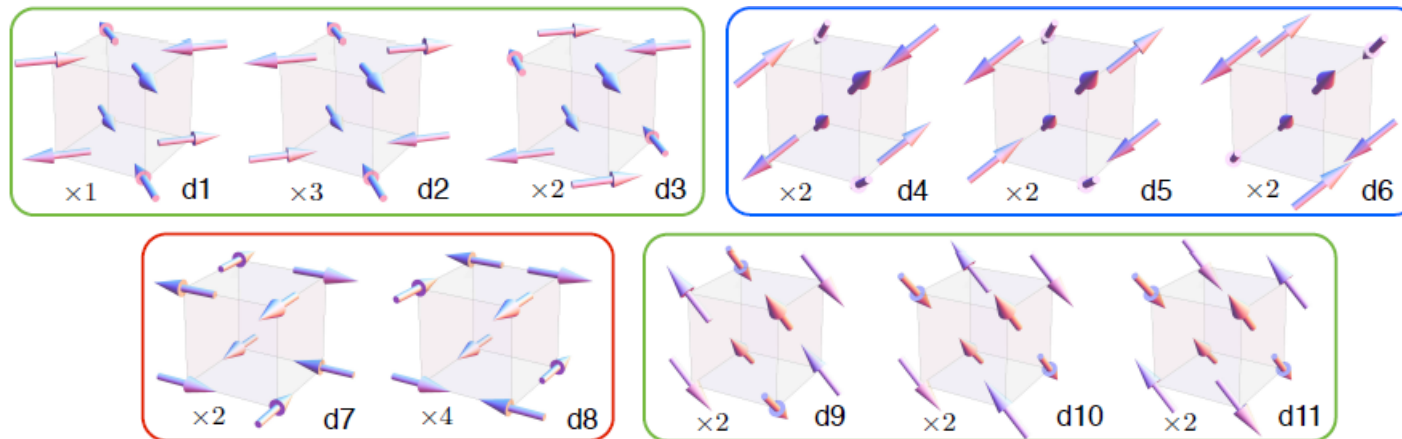
Moguća multi-k uređenja

$\langle 100 \rangle$ $\langle 110 \rangle$ $\langle 111 \rangle$ laka os magnetizacije

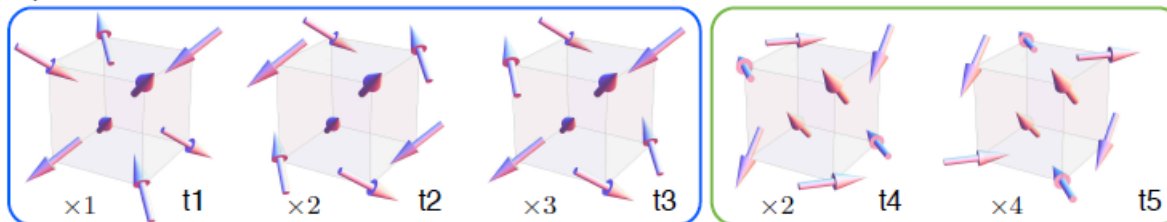
single-k structures



double-k structures



triple-k structures





pojednostavljena faznog dijagrama

fazni prijelazi

tipovi faznog prijelaza

promjena entropije na prijelazu -> magnetski moment J

$$\Delta S = R \ln(2J + 1)$$

vrste pobuđenja



pojednostavljena faznog dijagrama

fazni prijelazi

tipovi faznog prijalaza

promjena entropije na prijelazu -> magnetski moment J

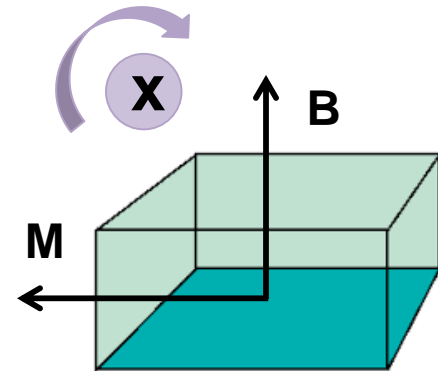
$$\Delta S = R \ln(2J + 1)$$

vrste pobuđenja

u magnetskom polju duž osi teške magnetizacije

magnetski moment na uzorak

zakreće ga u polju, mjerenja nisu jednoznačna





pojednostavljena faznog dijagrama

fazni prijelazi

tipovi faznog prijalaza

promjena entropije na prijelazu -> magnetski moment J

$$\Delta S = R \ln(2J + 1)$$

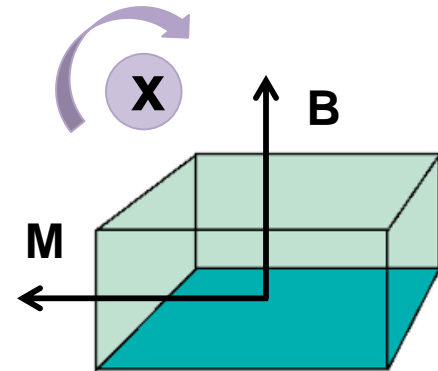
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zakreće ga u polju, mjerenja nisu jednoznačna

CILJ: razvoj metode mjerenja





Toplinski kapacitet u PPMS-u



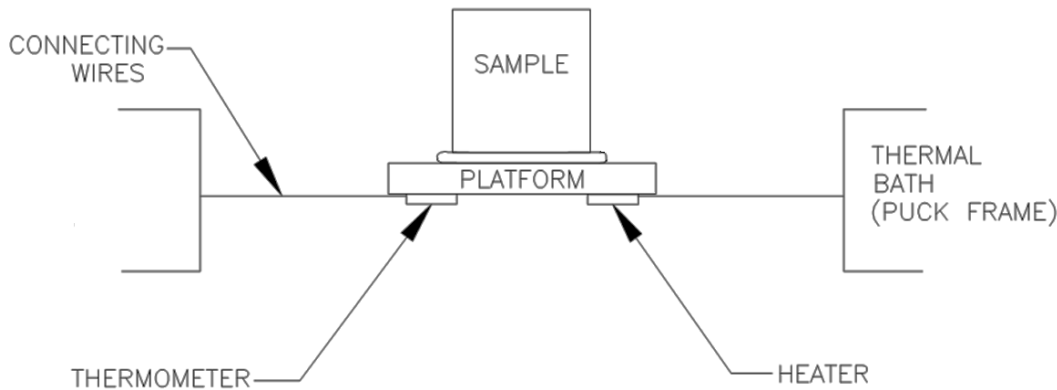
PPMS – Physical properties measurement system

komercijalni uređaj 14T, (1.8-400)K

*magnetizacija, ac-susceptibilnost, otpornost, Hall efekt
prilagođavanje mjerenja*

Toplinski kapacitet
relaksacijska tehnika

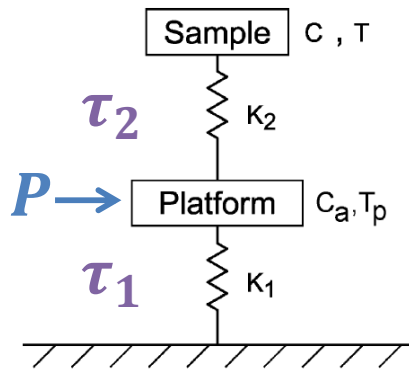
$$C_p = \left(\frac{dQ}{dT} \right)_p$$



mehanički
električni
termalni } kontakt



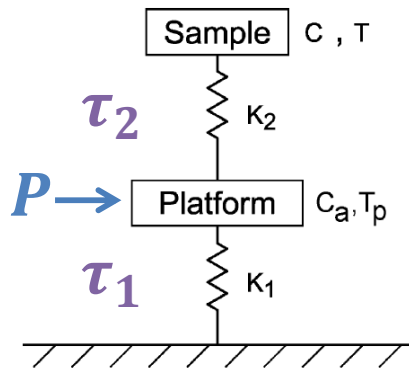
primjenimo puls snage P zadanog $\%T$ i trajanja na grijaču



$$P = C_a \frac{dT_p}{dt} + K_2(T_p - T) + K_1(T_p - T_b)$$
$$0 = C \frac{dT}{dt} + K_2(T - T_p)$$



primjenimo puls snage P zadanog $\%T$ i trajanja na grijaču



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pratimo temperaturu platforme u vremenu

idealizacija: $K_2 \gg K_1$ $\tau_2 \ll \tau_1$

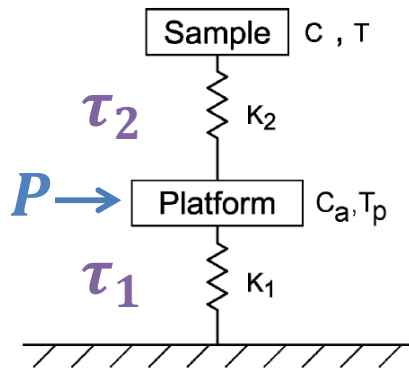
$$T_p = T_b + \Delta T \exp(-t/\tau) \quad \Delta T \ll T$$

izmjeren puls

$$T_p(t) = T + A \exp(-t/\tau_1) + B \exp(-t/\tau_2)$$



primjenimo puls snage P zadanog $\%T$ i trajanja na grijacu



$$P = C_a \frac{dT_p}{dt} + K_2(T_p - T) + K_1(T_p - T_b)$$

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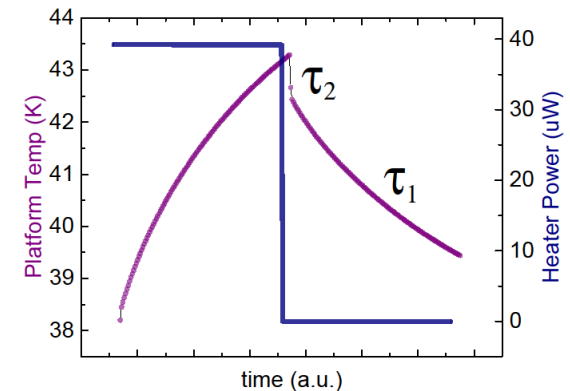
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MultiVu software

kalibracija bez probe - C_a, K_1

256 točaka puls – prilagodba

$$\begin{array}{l} \tau_1 = C_{total}/K_1 \\ \tau_2 = C/K_2 \end{array} \longrightarrow C$$



MultiVu software

kalibracija bez probe - C_a, K_1

256 točaka puls – prilagodba

$$\begin{aligned} \tau_1 &= C_{total}/K_1 \\ \tau_2 &= C/K_2 \end{aligned} \longrightarrow C$$

Small pulse (0.1-2)%T

pouzdan za $C \sim const.$ tijekom pulsa

!fazni prijelaz

velik broj pulseva

dugo trajanje



MultiVu software

kalibracija bez probe - $C_a K_1$

256 točaka puls – prilagodba

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Small pulse (0.1-2)%T

pouzdan za $C \sim const.$ tijekom pulsa

!fazni prijelaz

velik broj pulseva

dugo trajanje

Large pulse >10%T

$$C_{tot}(T) = \frac{-K_2(T - T_b) + P(T)}{dT/dt}$$

post-processing

moving average %, exclude %

grijanje, hlađenje, **dual-slope**

$$C_{tot} = \frac{P_h(T) - P_c(T)}{\left. \frac{dT}{dt} \right|_h + \left. \frac{dT}{dt} \right|_c}$$



Konvencionalni

$3 \times 3 \text{ mm}^3$ Al_2O_3 /safirna platforma obješena na osam 75 μm Au-Pd žica za grijač i termometar

mehanička = **termalna** K_1 = **električna** veza

uzorak učvršćen Apiezon N mašču





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mehanička = **termalna** K_1 = **električna** veza

uzorak učvršćen Apiezon N mašču



Al pločica

mehanički stabilna 0.5mm Al pločica

na podloščima od staklenog vlakna - **termalni** kontakt

četiri 30 μm manganin žice (**električni** spoj)

uzorak zalijepljen Stycastom





Omjer dodatnog toplinskog kapaciteta i vodljivosti očuvan!

temperaturni senzor CX-1010 i grijač RX-102A

chipovi sa stražnje strane pločice (GE), spojeni sa srebrnom pastom

kalibracija termometra u polju



Omjer dodatnog toplinskog kapaciteta i vodljivosti očuvan!

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kalibracija termometra u polju

toplinski kapaciteta postava \approx HC pločice

uzorak tipičnog kapaciteta (2-10)mJ/K na 15K

dobra rezolucija do 50K



Omjer dodatnog toplinskog kapaciteta i vodljivosti očuvan!

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toplinski kapaciteta postava \approx HC pločice

uzorak tipičnog kapaciteta (2-10)mJ/K na 15K

dobra rezolucija do 50K

at 15K	K_1	C_a	$\tau_a = C_a/K_1$
conventional	6mW/K	35 μ J/K	\sim 6ms
Al plate	0.1W/K	0.5mJ/K	\sim 5ms

* za niske temperature je u izradi postav s Ag pločicom koja visi na Kevlar nitima

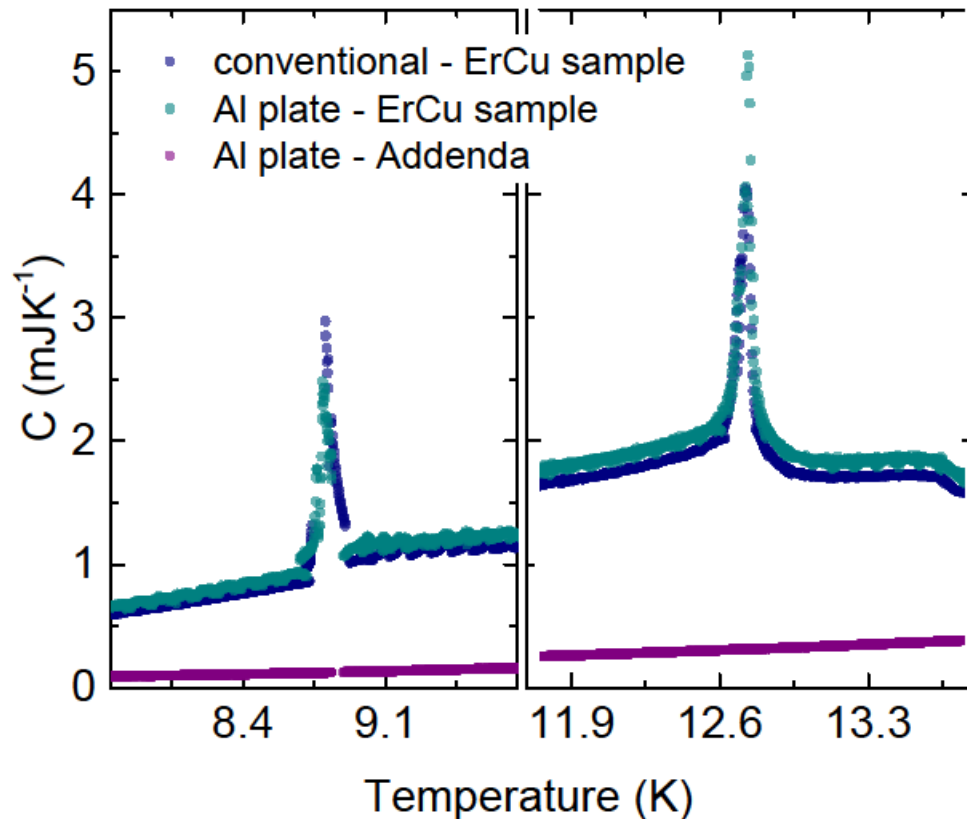


Usporedba postava



ErCu uzorak mjeren dvama postavima (usporedba HC postava)

Small pulse 2%, moving average 5%, exclusion 5%





1 puls = 256 točaka

Small pulse (0.1-2)%T:

velik broj pulseva -dugo trajanje

min: jedan fazni prijelaz

Large pulse (>10%T):

prekriti cijeli rapon temp.

inercija zbog uzorka

max: broj točaka pri grijanju,

višestruki bliski fazni prijelazi



1 puls = 256 točaka

Small pulse (0.1-2)%T:

velik broj pulseva -dugo trajanje

min: jedan fazni prijelaz

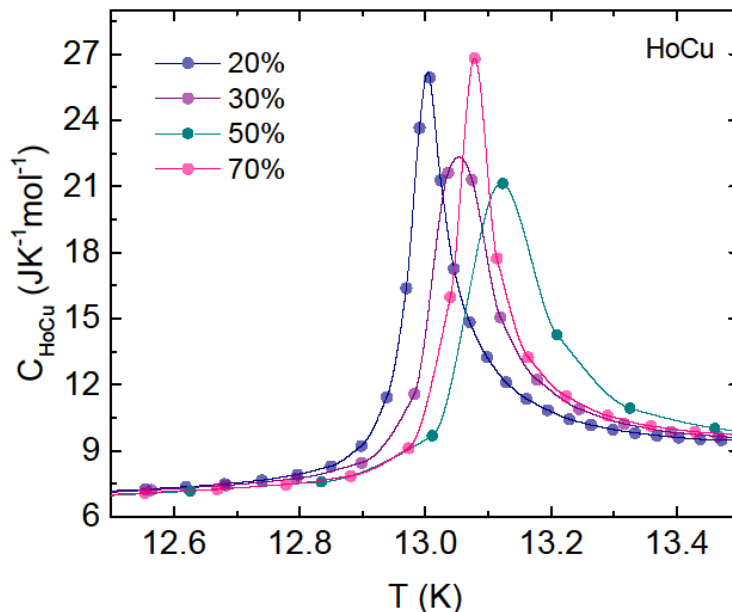
Large pulse (>10%T):

prekriti cijeli rapon temp.

inercija zbog uzorka

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višestruki bliski fazni prijelazi



RE-Cu - (10-20)% puls

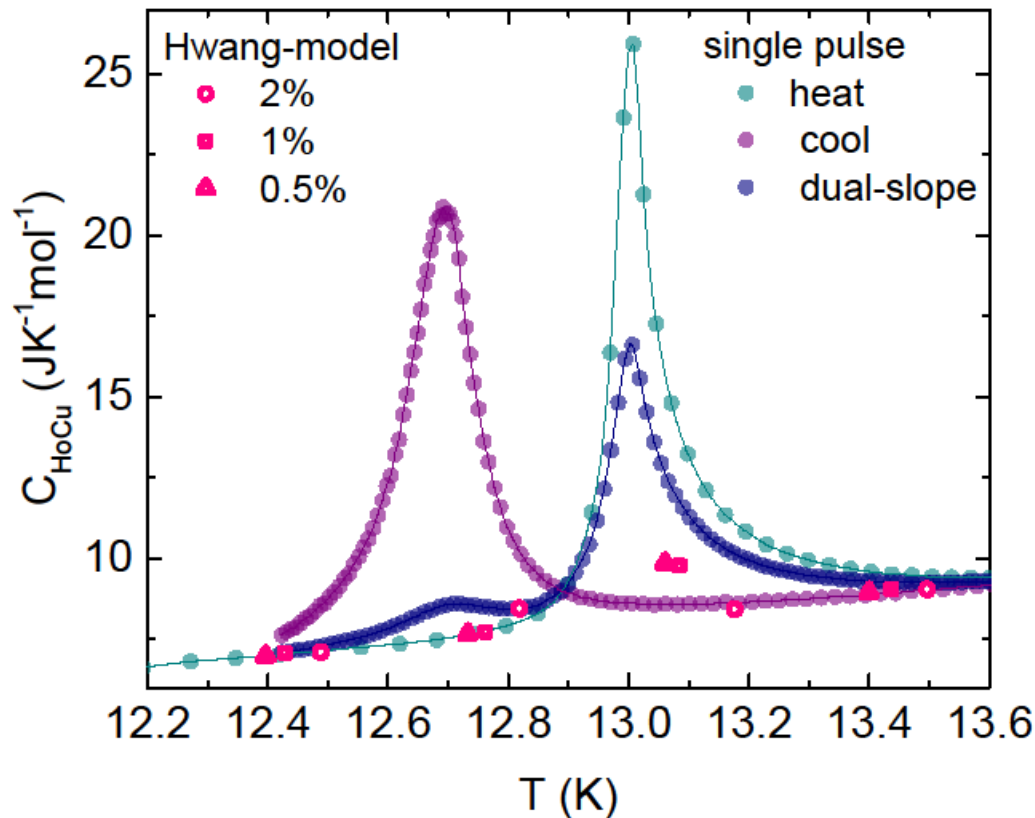
fazni prijelazi (7-30)K, širine >0.2K

Specifični HC HoCu na faznom prijelazu grijanje (20-70)%



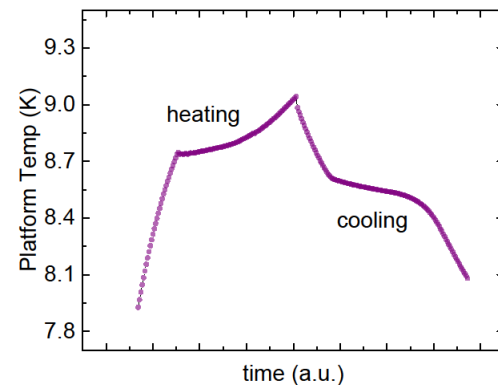
Post-processing:

grijanje/hlađenje ili obe krivulje (**dual-slope**)



moving average (5-10)%
izgladuje krivulju

initial exclusion (1-10)%
uklanja utjecaj grijača i τ_2 efekt

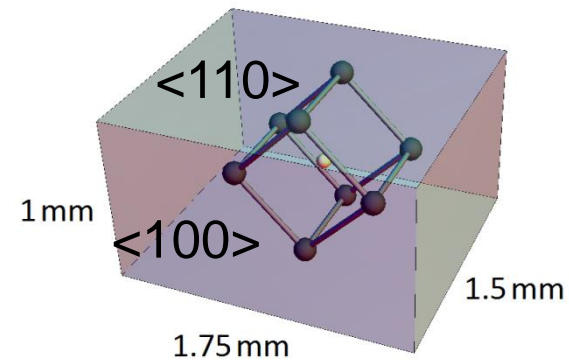
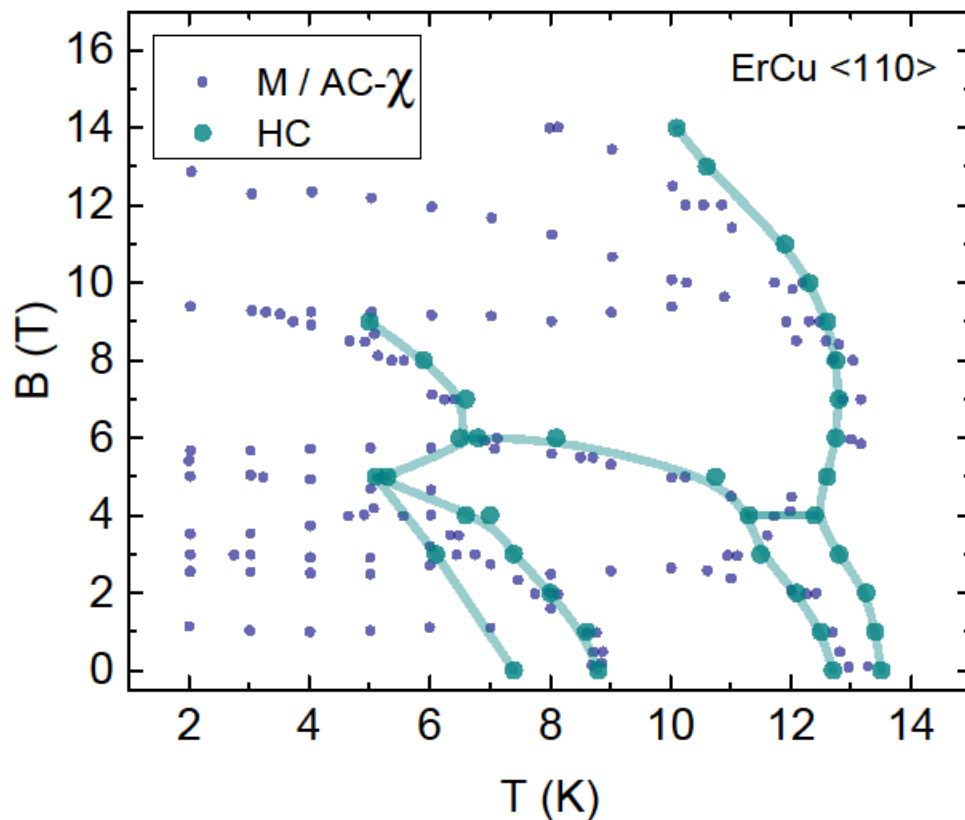




Fazni dijagram (B-T) ErCu <110>



najmanji trenutno dostupan uzorak
velik HC -> duga τ



*ostali kristali pripremljeni
izrada orijentiranih uzoraka

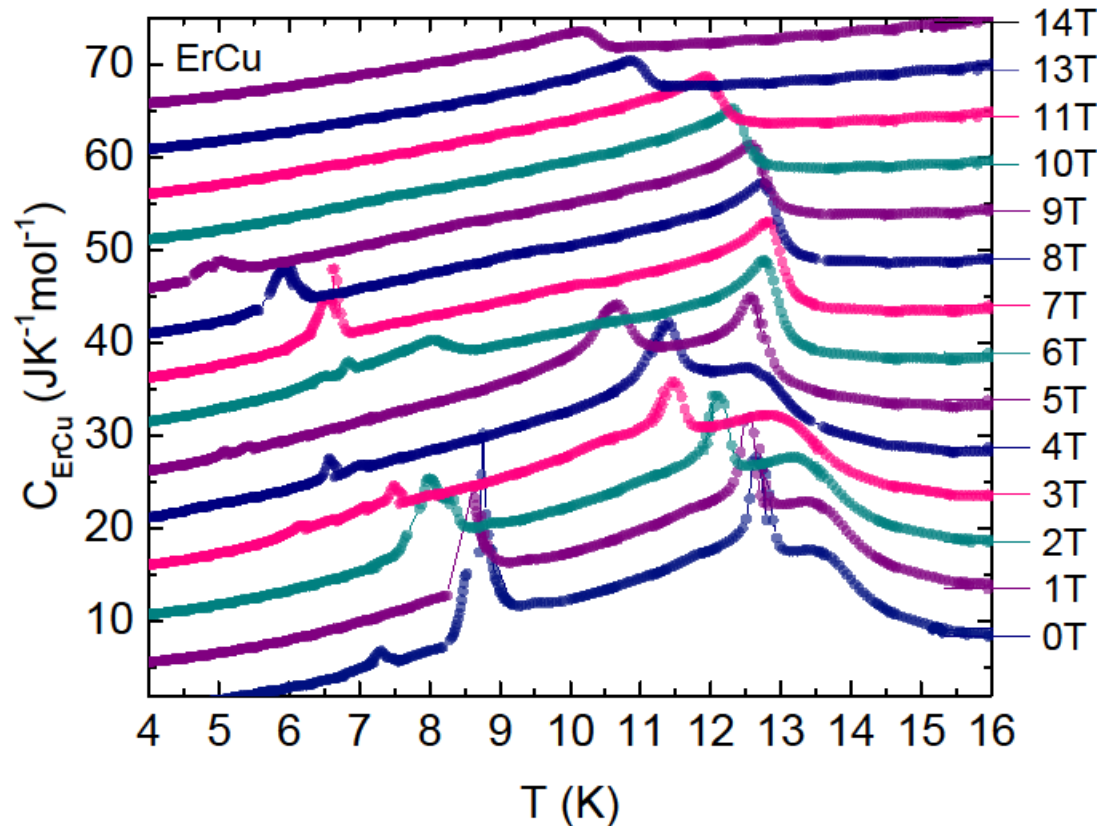


Specifični toplinski kapacitet ErCu <110>



20% pulsevi, moving average 10%, exclusion 10%

rezultati za polja razmaknuti $5\text{JK}^{-1}\text{mol}^{-1}$

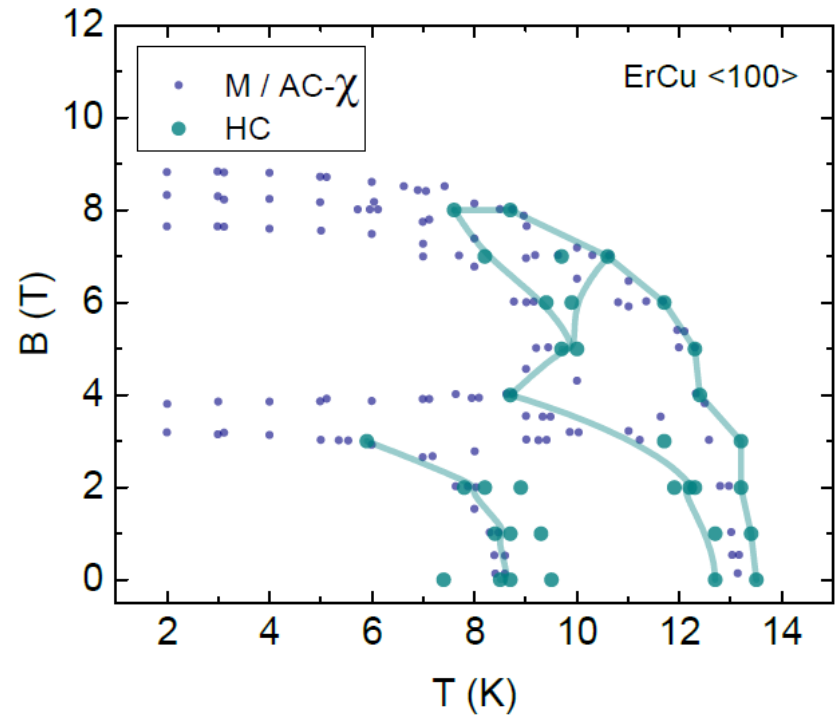
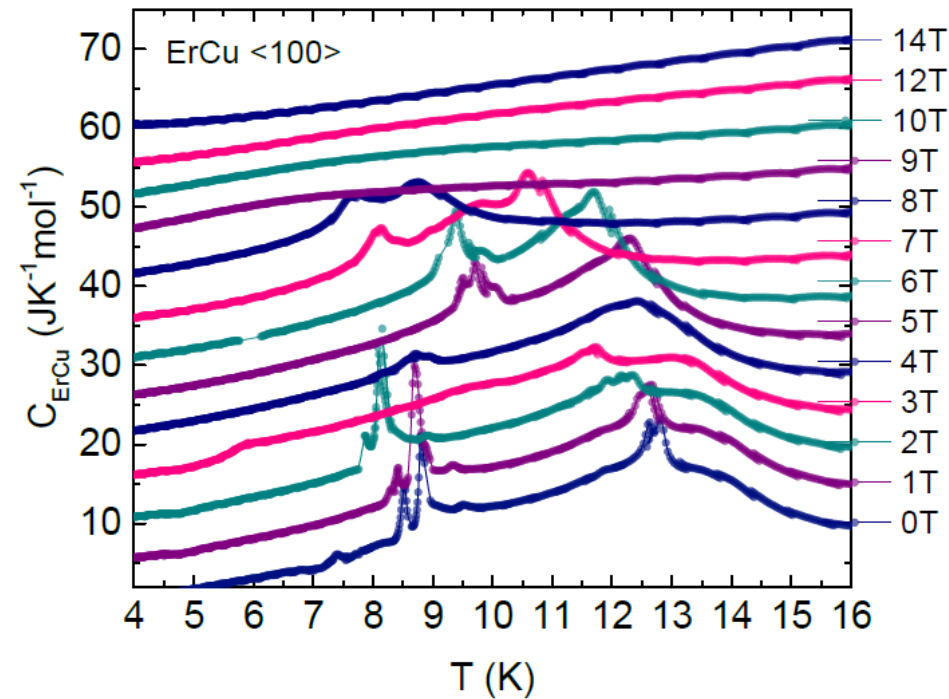




ErCu <100>



20% pulsevi, moving average 10%, exclusion 10%
rezultati za polja razmaknuti $5\text{K}^{-1}\text{mol}^{-1}$

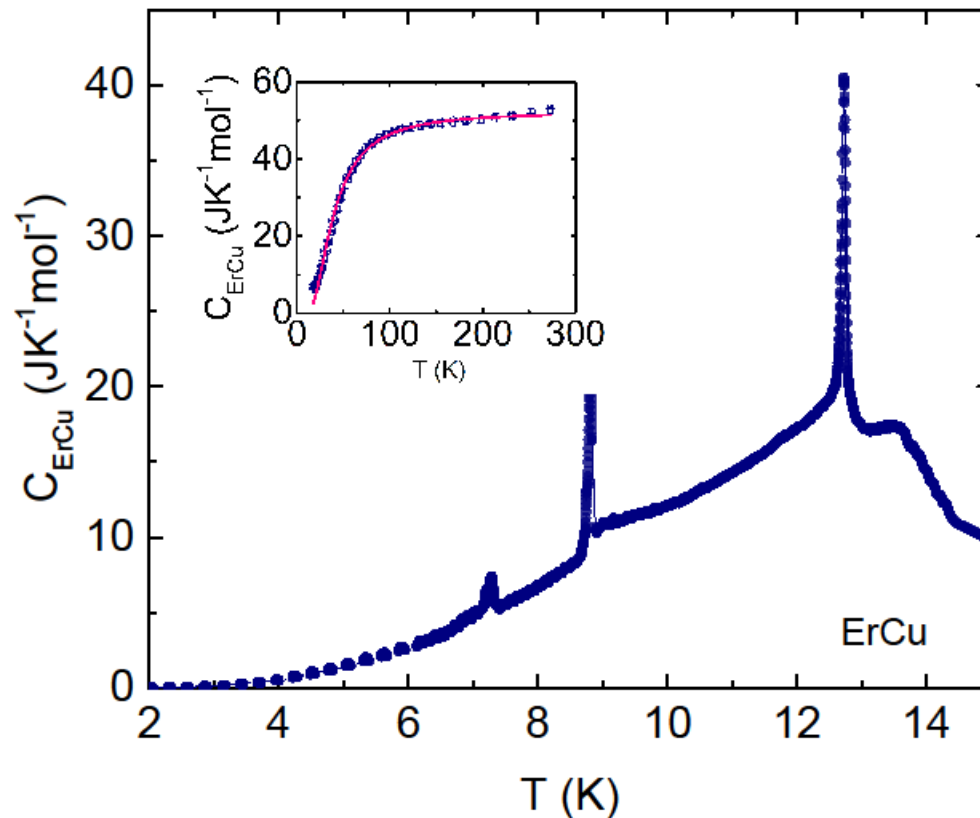




Anomalije: 7.4K, 8.8K, 12.7K i 13.5K

$T_N=12.7\text{K}$ (AFM)

$T_1=7.4\text{K}$ i $T_2=8.8\text{K}$ – magnetske reorientacije spinova (multi-k mogućnosti)



$T_3=13.5\text{K}$ fazni prijelaz 2. reda strukturni u FeB?

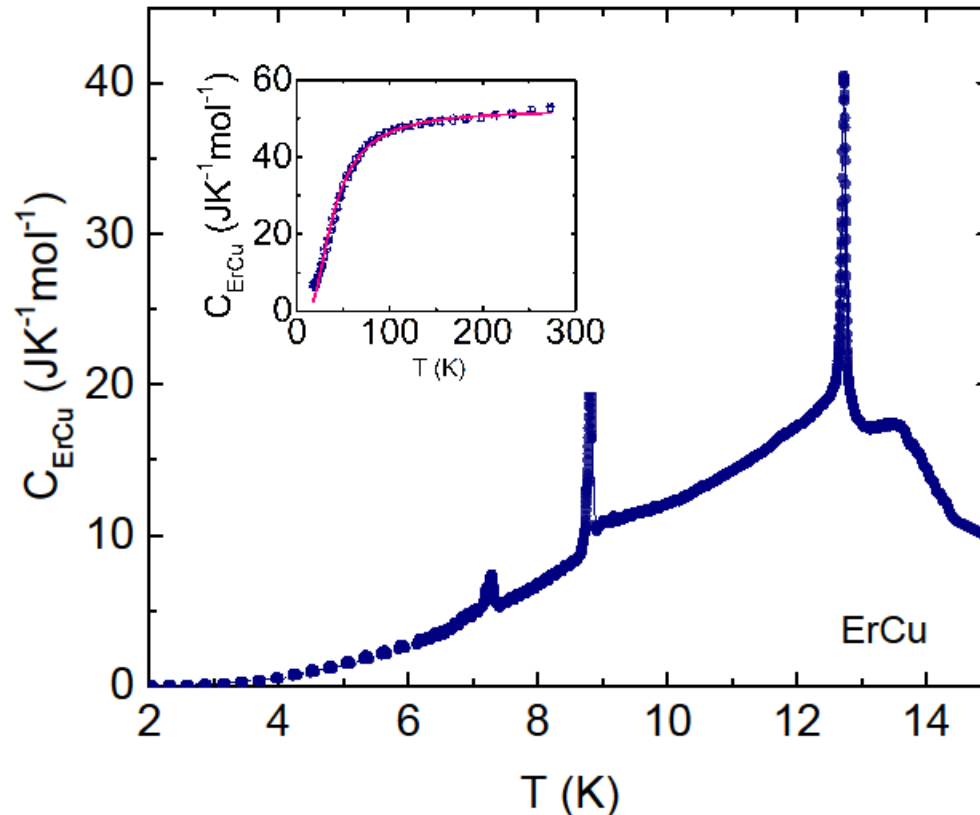


Specifični toplinski kapacitet ErCu 0T



Anomalije: 7.4K, 8.8K, 12.7K i 13.5K

$T_N=12.7K$ (AFM)



konvencionalnim postavom
Small pulse 2% do 300K

fit Einsteinovog modela

$$T_D = T_E / \sqrt[3]{\pi/6}$$

$$T_D = (149 \pm 2)K$$

saturacija na

$$(51 \pm 1) JK^{-1} mol^{-1}$$

~Dulong-Petit vrijednosti
el. doprinos?

*LuCu nemagnetični ekvivalent (pune 4f orbitale), oduzimanje fononskog doprinosa



Mjerenje specifičnog HC duž osi teške magnetizacije

u RZ-Cu za $T < 50\text{K}$ – područje faznih prijelaza

Izrada i karakterizacija postava s Al pločicom

Ustanovljen način mjerenja i obrade podataka



Mjerenje specifičnog HC duž osi teške magnetizacije

u RZ-Cu za $T < 50\text{K}$ – područje faznih prijelaza

Izrada i karakterizacija postava s Al pločicom

Ustanovljen način mjerenja i obrade podataka

...

Priprema i mjerenje HoCu, ErCu, TmCu - $\langle 100 \rangle$, $\langle 110 \rangle$ i $\langle 111 \rangle$

usporedba s magnetskim faznim dijagramom

nemagnetični LuCu

Kevlar postav ($T < 2\text{K}$)

razdvaja meh., term. i el. kontakt

