SYMPOZJUM DOKTORANCKIE

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COEXISTENCE OF LONG-RANGE ORDERS IN SOLIDS

Coexistence of long range magnetism and superconductivity

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Overview

- superconductivity and long range magnetism: introduction, interplay, coexistence
- superconductivity and AFM in classic/low-T_c superconductors (CSC/LTSC)
- anomalous flux penetration into CSC with AFM ordering
- superconductivity and AFM ordering in high-T_c superconductors (HTSC)
- superconductivity and FM ordering in unconventional (UCSC) superconductors
- superconductivity and FM ordering in Y_9Co_7
- Summary

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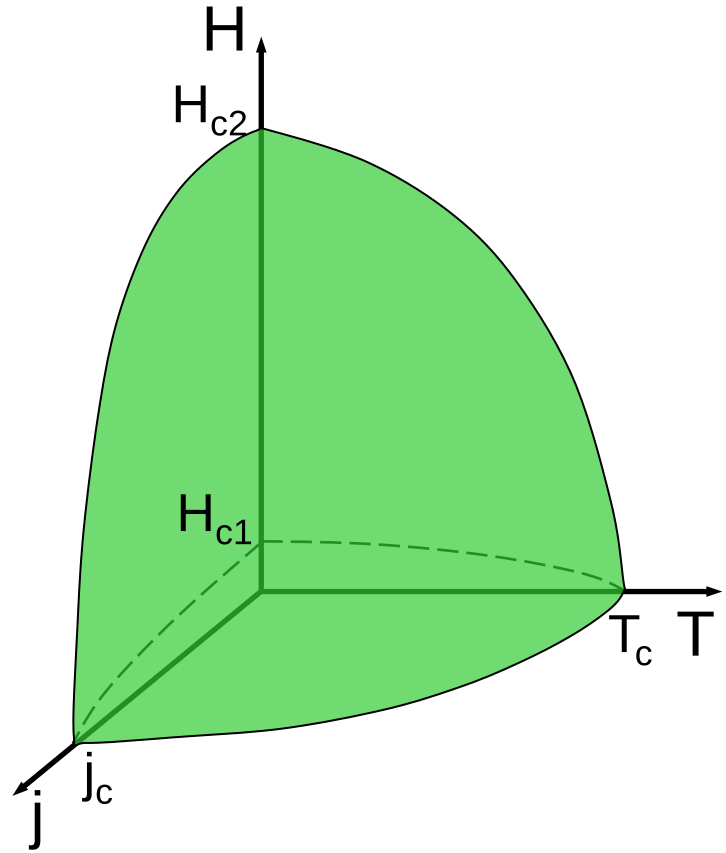
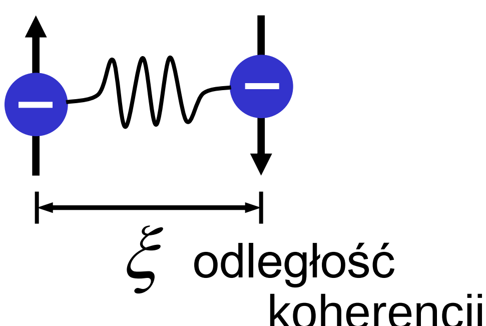
Type-II superconductivity:

- $\boldsymbol{R} = \mathbf{0}$; $T < T_c$, $j < j_c$, $H < H_{c2}$
- $\boldsymbol{B} = \mathbf{0}$, Meissner state; $H < H_{c1}$



Microscopic mechanism (BCS theory): $\boldsymbol{T_c} \leq \mathbf{30\ K}$

- Cooper pairs
- condensation of pairs (phase coherent state)



spin	orb. mom.	Ψ sym.	superconductivity
$s = 0$	$l = 0$	s	classic
$s = 0$	$l = 2$	d	unconventional
$s = 1$	$l = 1$	p	
....	....	....	

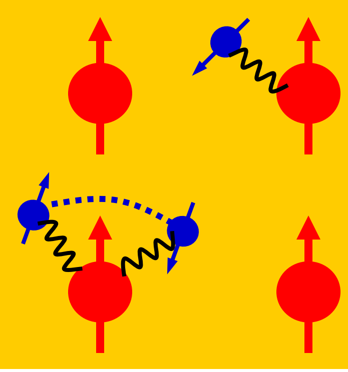
Why the interaction between localized magnetism and superconductivity is important ?

- basic properties of superconductors

  (coexistence of two competing phenomena)

- nature of superconductivity in:
  - UCSC (H. Suhl, PRL 87, 167007 (2001); A.A. Abrikosov, J.Phys.: Condens. Matter 13, L943 (2001))
  - HFSC ($CePt_3Si$; E. Bauer et al., PRL 92, 027003 (2004))

„inverted“ RKKY exchange interaction



- magnetism is weak
- superconductor is a HF type

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- basic properties of superconductors

  (coexistence of two competing phenomena)

- nature of superconductivity in:
  - UCSC (H. Suhl, PRL 87, 167007 (2001); A.A. Abrikosov, J.Phys.: Condens. Matter 13, L943 (2001))
  - HFSC ($CePt_3Si$; E. Bauer et al., PRL 92, 027003 (2004))

- application of superconductors:
  - improving critical currents (E.W. Hudson et al., Nature 411, 920 (2001))
  - ”switching off/on” the superconducting state (?)

Interplay between magnetism and superconductivity (history)

1957 – theory; V.L. Ginzburg,

Sov. Phys. JETP 4, 153 (1957)

1958 – $La_{1-x}RE_x$; B.T. Matthias et al.,

Phys. Rev. Letters 1, 449 (1958)

....

1976 – review; M.B. Maple,

Appl. Phys. 9, 179 (1976)

(influence of paramagnetic impurities on superconductivity; the summary)

1975 – $REMo_6S_8$; Ø. Fischer et al.,

Solid State Commun. 17, 21 (1975)

Localized AFM and superconductivity in LTSC

1975 – **$REMo_6S_8$**; Ø. Fischer et al.,
Solid State Commun. 17, 21 (1975)

1976 – **$REMo_6Se_8$**; R.N. Shelton et al.,
Phys. Lett. 56 A, 213 (1976)

1977 – **$RERh_4B_4$**; W.A. Fertig et al., B.T. Matthias, M.B. Maple,
Phys. Rev. Lett. 38, 987 (1977)

1994 – **$RENi_2B_2C$**; R.J. Cava et al., C. Mazumdar et al., R. Nagarajan et al.

(UPt_3, URu_2Si_2, UNi_2Al_3, UPd_2Al_3)

Localized AFM and superconductivity in HTSC

1987 – $\mathbf{REBa_2Cu_3O_7}$; M.K. Wu, P.H. Hor, C.W. Chu

1997 – $\mathbf{RuSr_2RECu_2O_8}$; H.F. Braun et al. (1995), I. Felner et al., J.L. Tallon et al.

Itinerant FM and LTSC

2000 – UGe_2 ; S.S. Saxena et al., Nature **406**, 587 (2000)

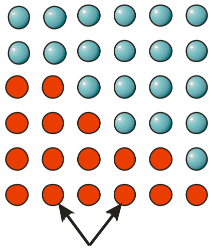
~~2001 – $ZrZn_2$;~~ C. Pfleiderer et al., Nature **412**, 58 (2001)

2001 – URhGe ; D. Aoki, et al., Nature **413**, 613 (2001)

1980 – $\mathbf{Y_9Co_7}$; A. Kołodziejczyk et al., J. Phys. F 10, L33 (1980)

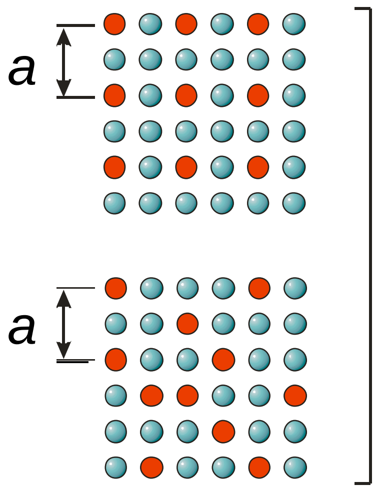
(weak itinerant FM and LTSC)

Definition of the coexistence of magnetism and superconductivity



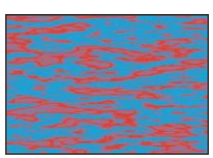
magnetic ions

no coexistence (space separation)



$a > \xi$, no coexistence (?)

$a < \xi$, coexistence !



(Y_9Co_7, UGe_2)

band electrons contribute both to magnetism and to superconductivity

"super coexistence"

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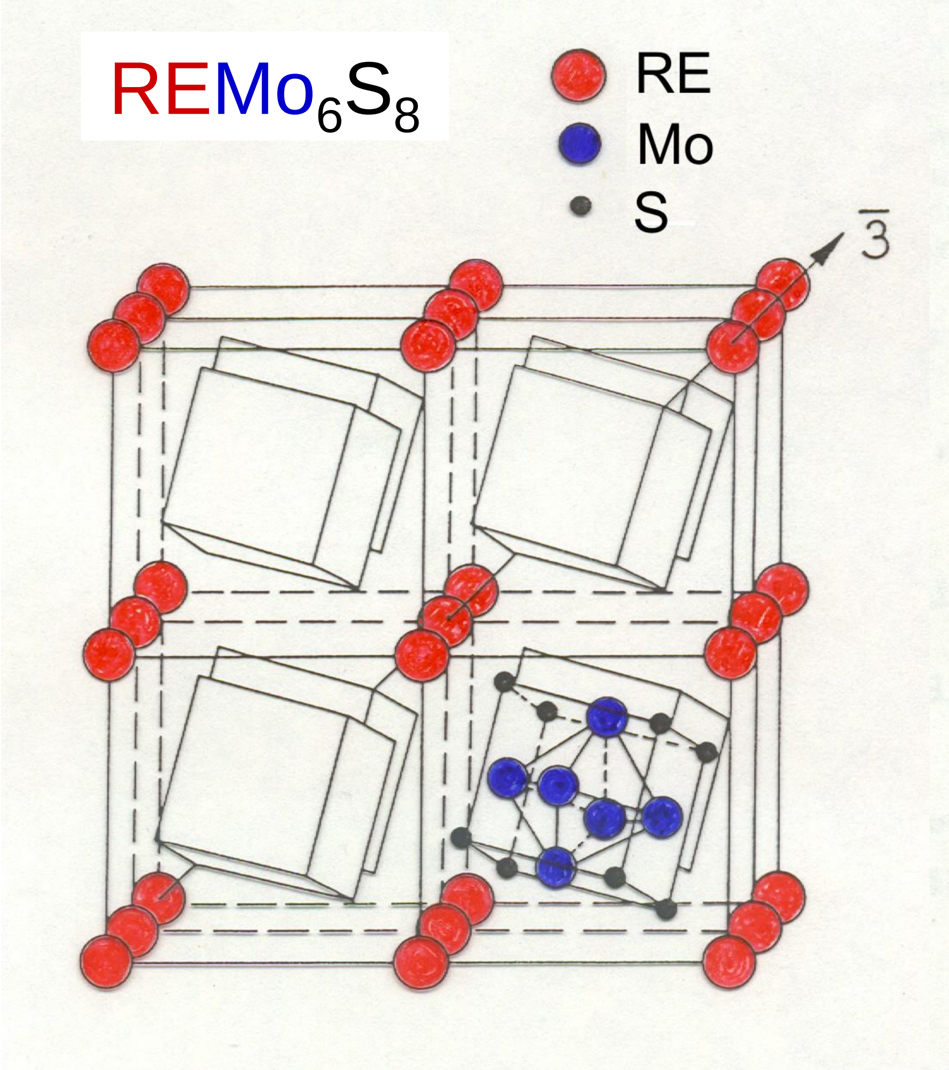
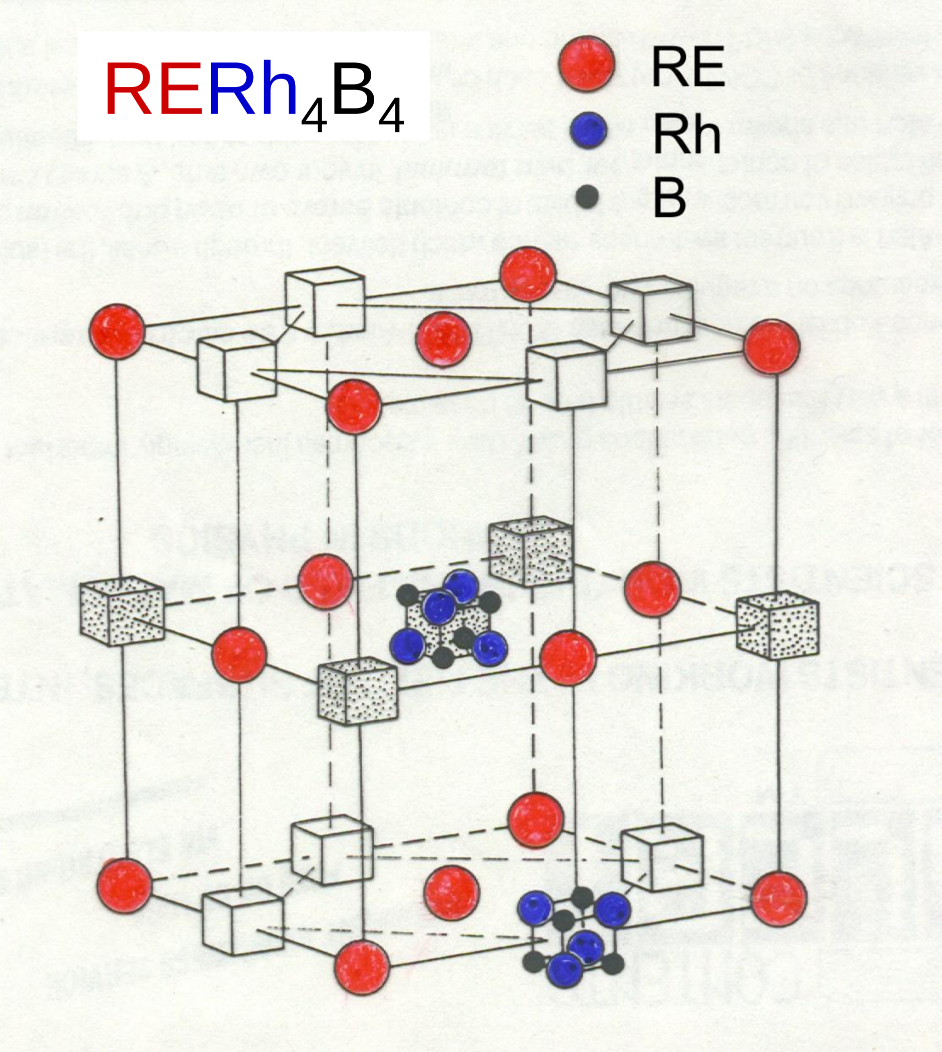
Classic magnetic superconductors (4f - 4d)





Interaction between localised spins and conduction electrons in magnetic superconductors:

- ♣ socalled sf interaction

$$g\mu_B I \underbrace{\Psi^{+}\boldsymbol{\sigma}\Psi}_{\text{electron}} \cdot \mathbf{S}$$

I — sf coupling constant; $\mathbf{S}$ — localized spin

- ♣ electromagnetic interactions

  - minimal interaction

$$-\,\mathbf{j}(\Psi^{+},\Psi)\cdot\mathbf{a}$$

$\mathbf{j}$ — total current; $\mathbf{a}$ — vector potential

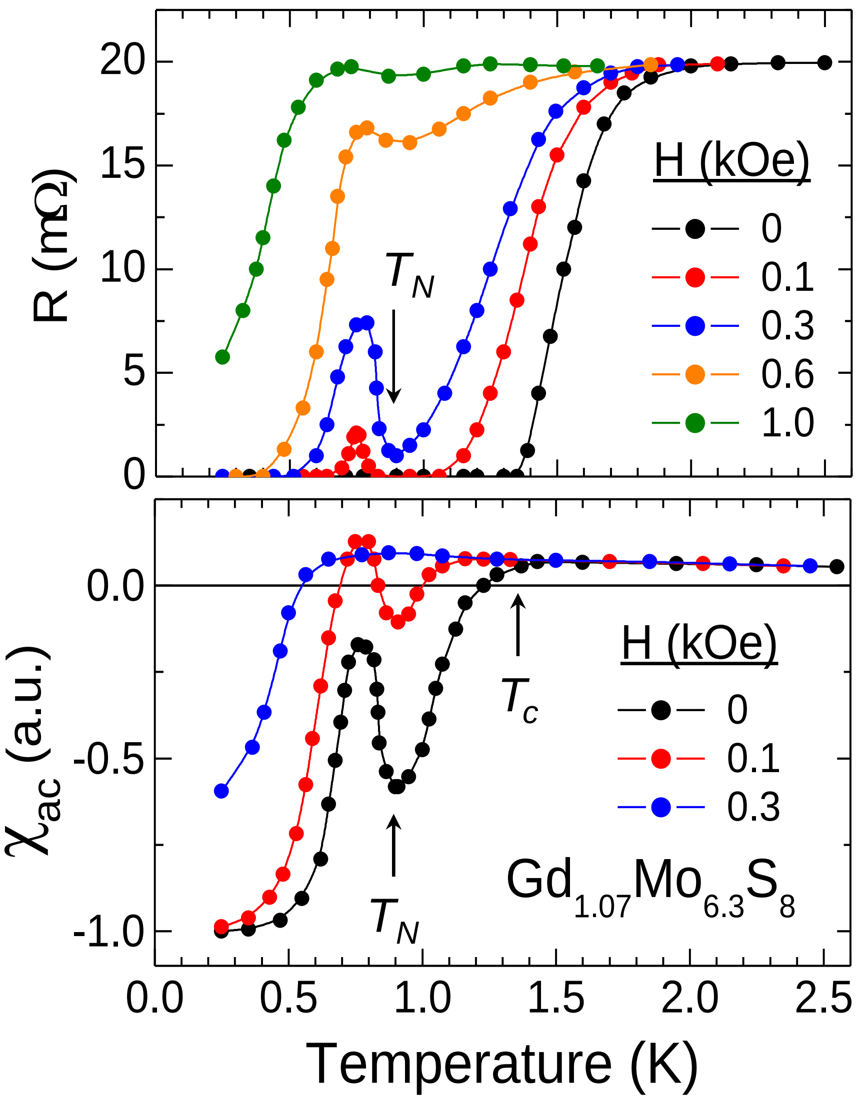
  - dipole interaction

$$-\,g\mu_B\,\mathbf{b}\cdot\mathbf{S}$$

$\mathbf{b}$ — magnetic induction

What kind of the interaction is important for the interplay between magnetism and superconductivity we observe ?

Typical anomalous features observed for classic AFM superconductors



localized long-range AFM order and superconductivity interact

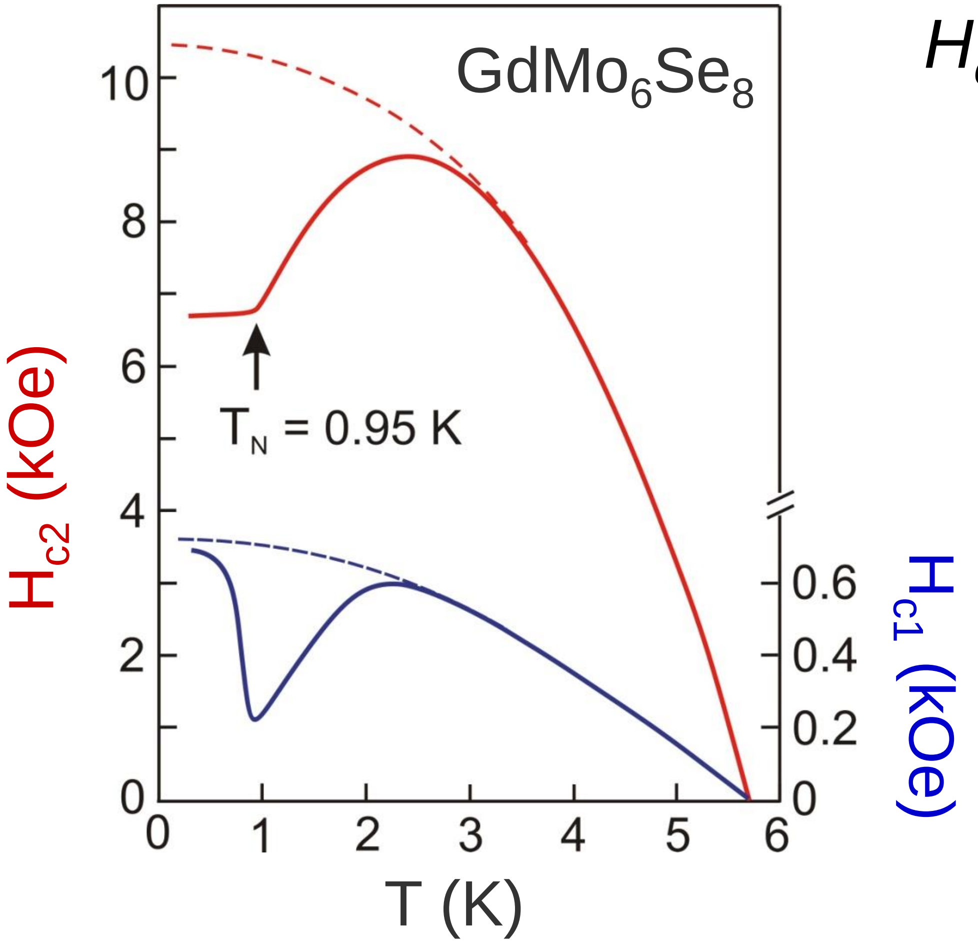
⇩

an increase of the pairbreaking effects are expected due to enhanced magnetic fluctuations near T_N

⇩

pronounced anomaly in $R(T)$ and $\chi(T)$ near T_N

Typical approach to study the interaction between magnetism and superconductivity



$H_{c2}(T)$ and $H_{c1}(T)$ can be analyzed in the frame of:

- sf exchange interaction
- electromagnetic interaction

………. ?

For high-T_c cuprates:

H_{c2} ~ 150 T at T_N ~ 1 K

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Collaborators:

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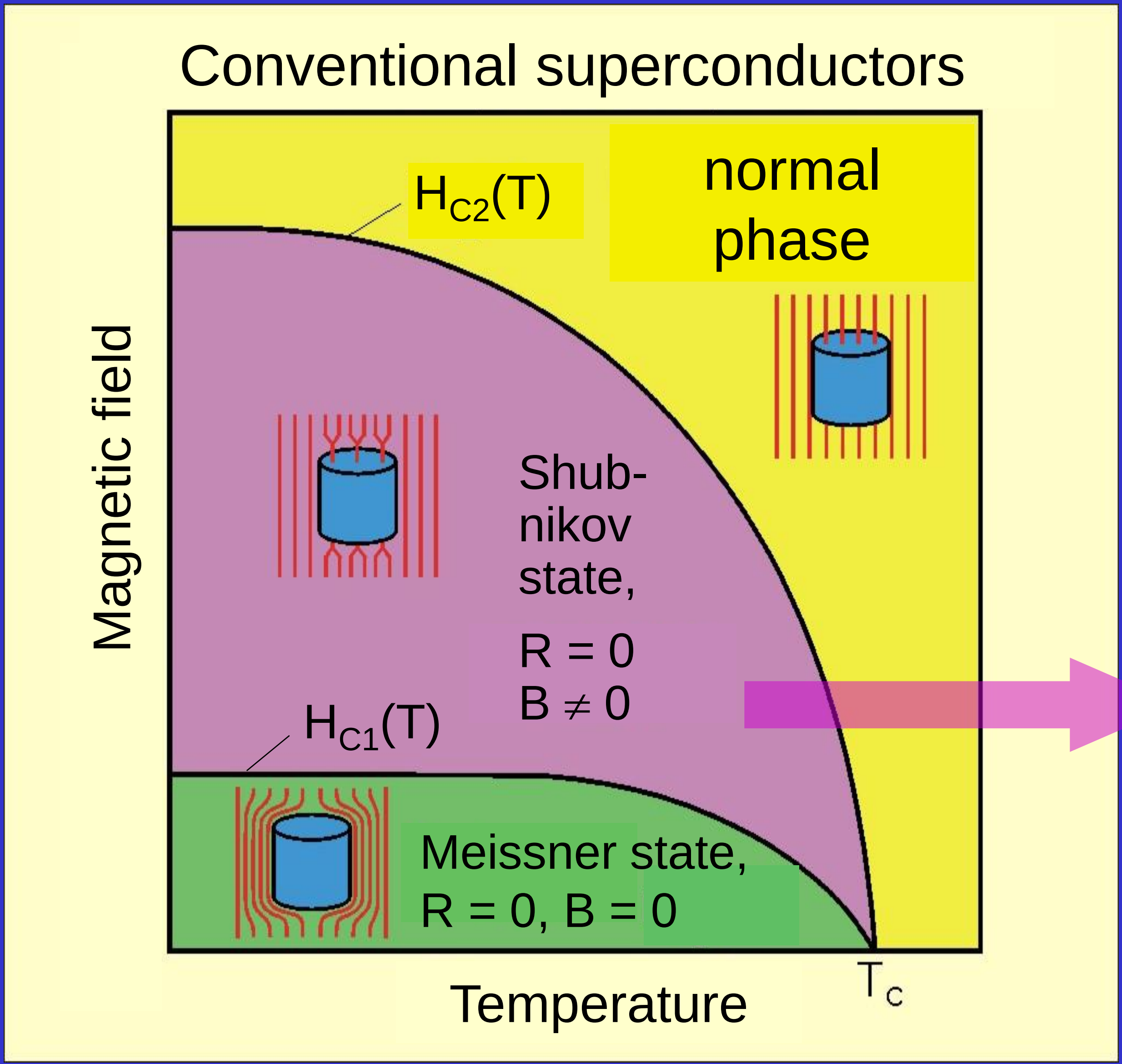
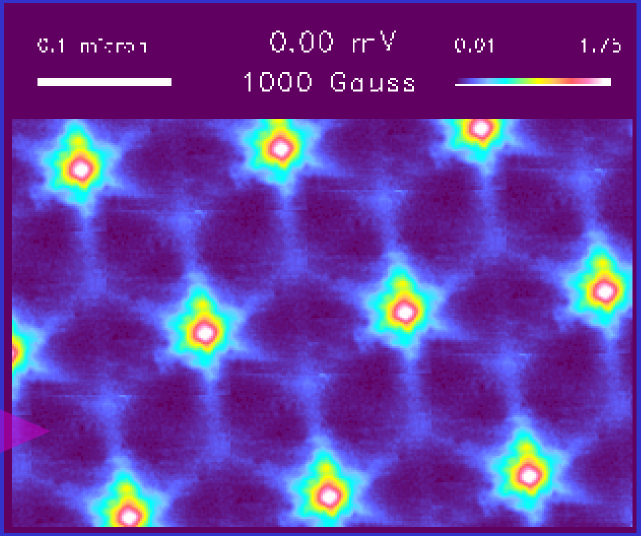
Phase diagram of a type II superconductor



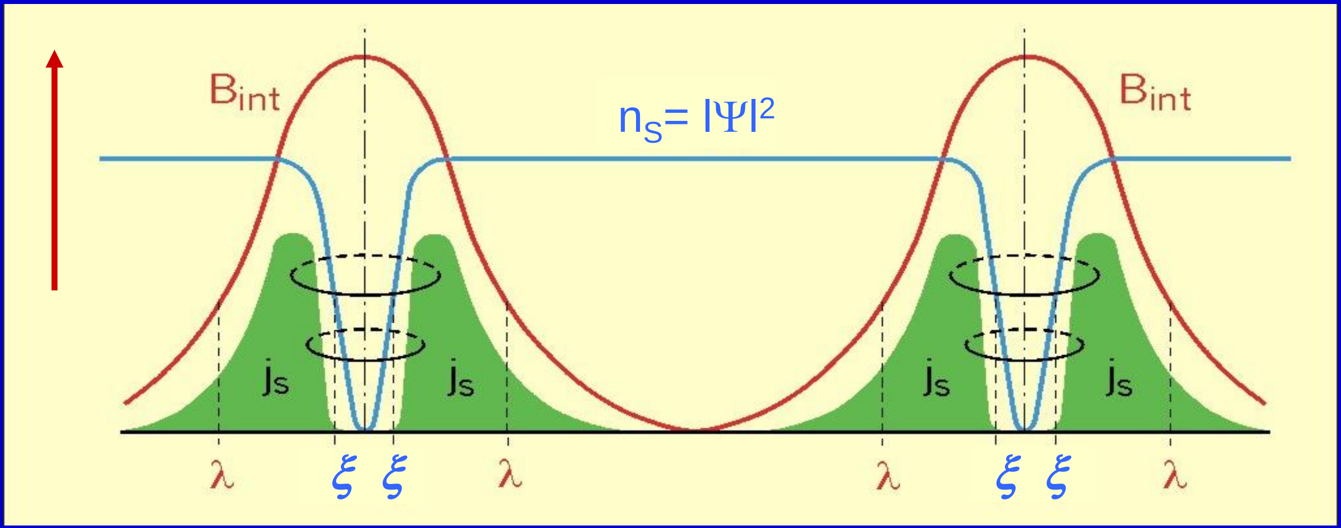


Vortex lattice observed by STM in $NbSe_2$

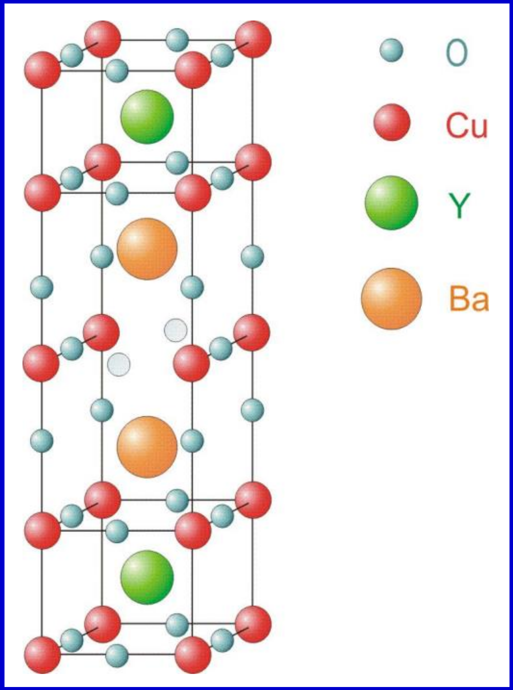
H. Hess, R.B. Robinson, and J.V. Waszczak, Physica B **169** (1991) 422.

Structure of an isolated vortex

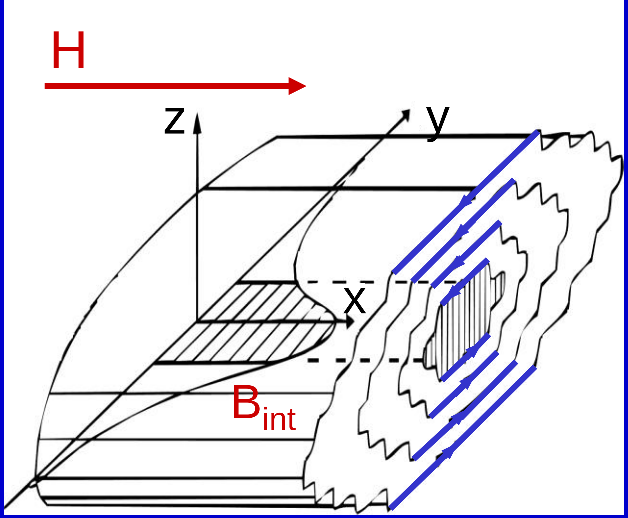
Conventional superconductors (low T_C)



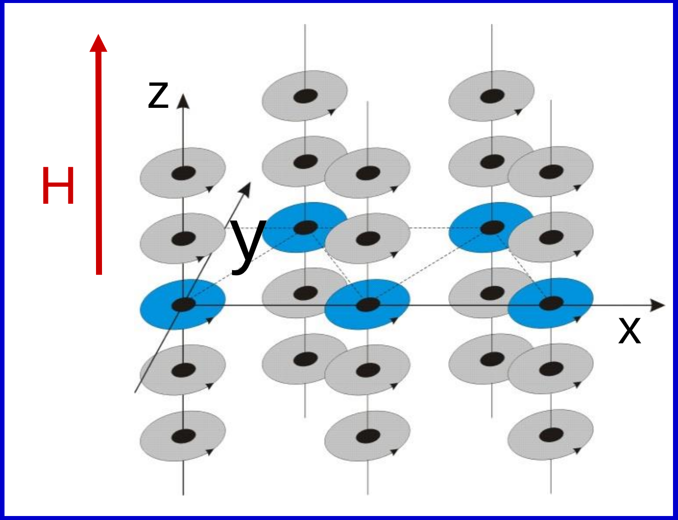
High-T_C superconductors



Josephson vortices

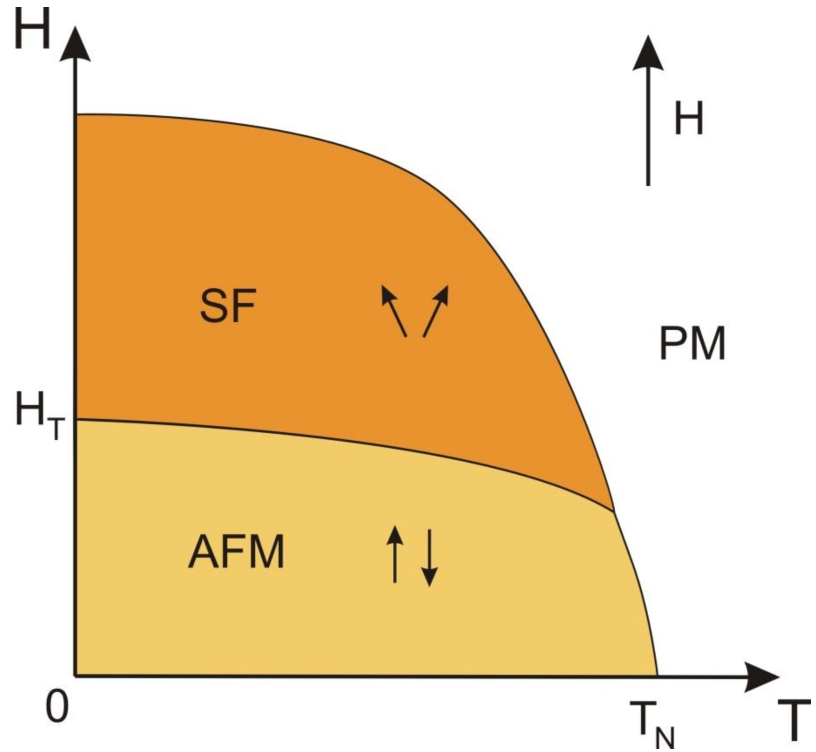


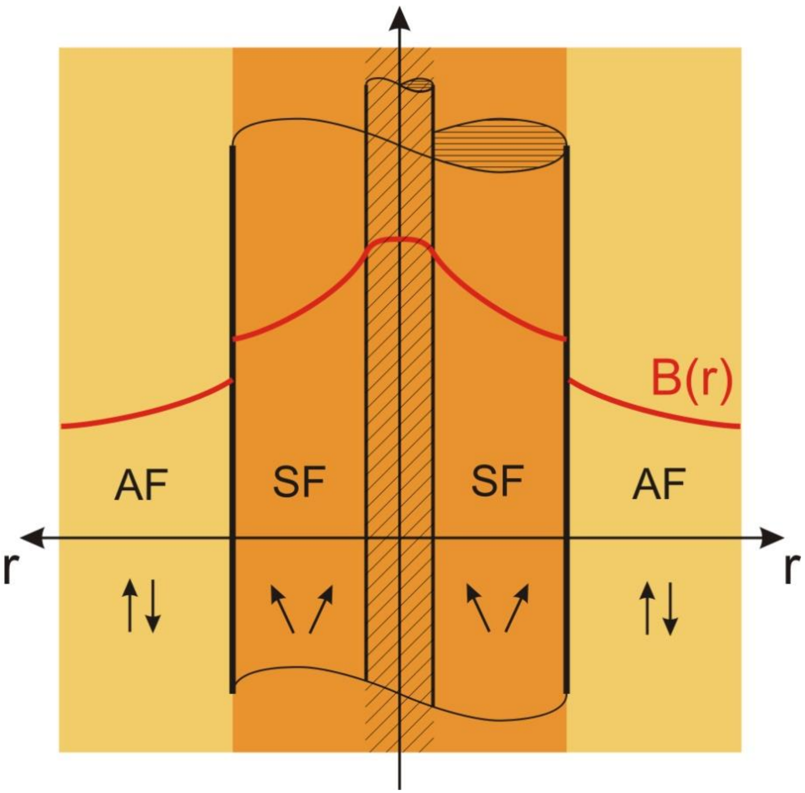
2D pancake vortices



Vortex with magnetic structure

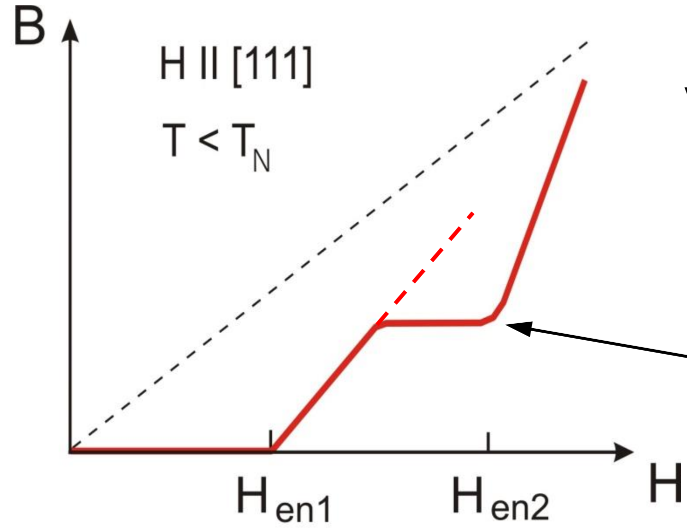
two-sublattice AFM with
the easy-axis II H



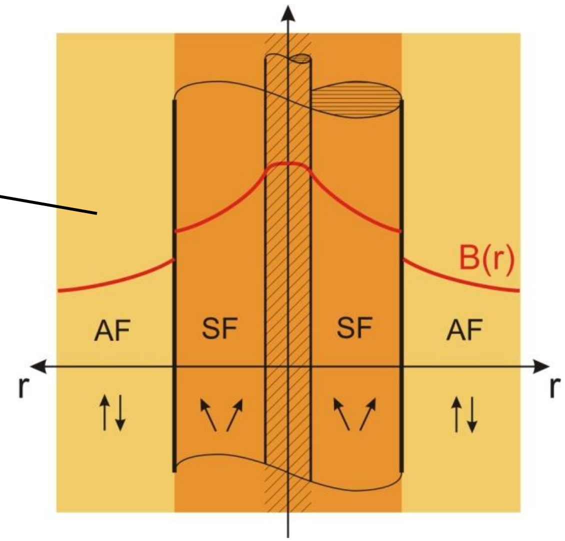


magnetic induction B(r) and magnetic domains around the vortex core

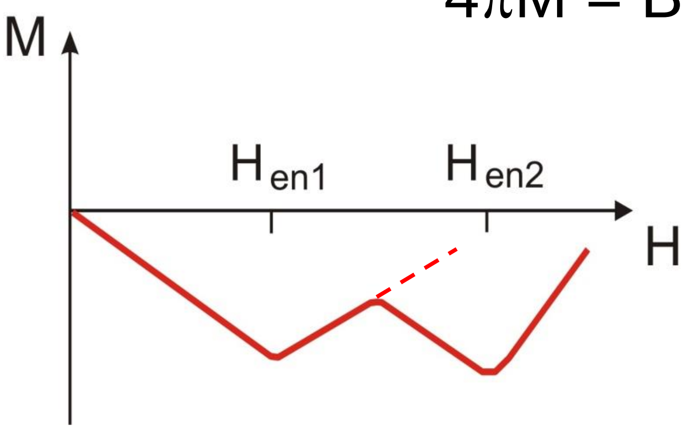
Two-step flux penetration in AFM superconductor



virgin sample in increasing field at $T < T_N$



$4\pi M = B - H$

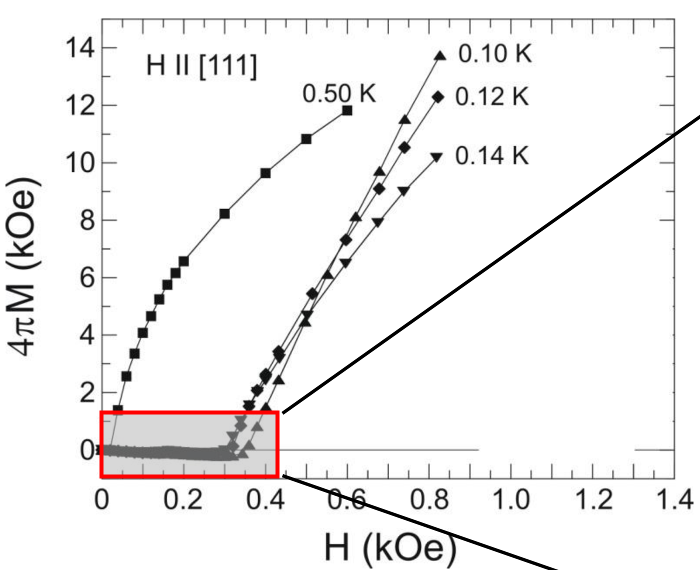


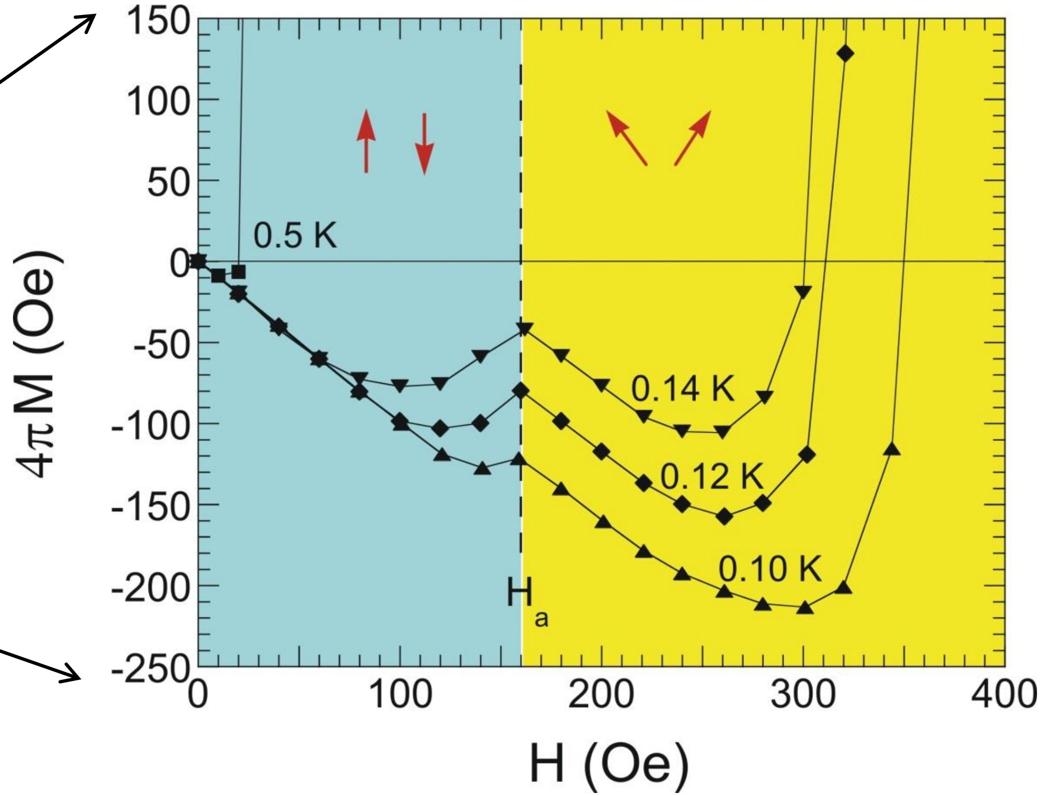
<u>$DyMo_6S_8$:</u> $H_{en2} \sim 260$ Oe

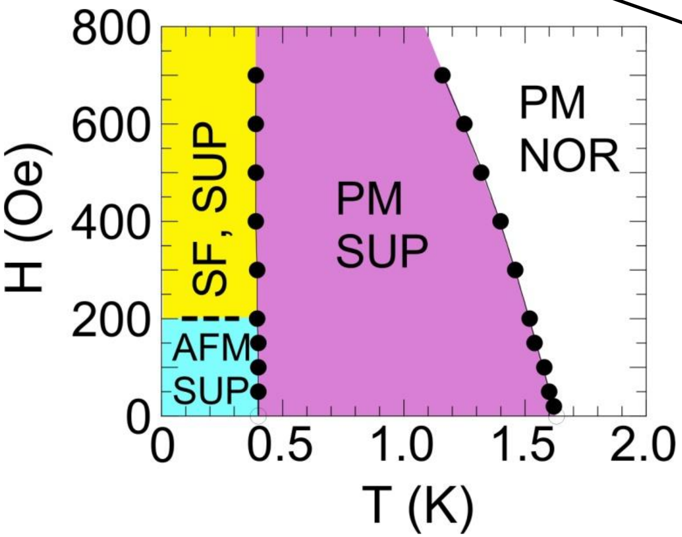
T. Krzysztoń, Phys. Lett. <u>104A</u>, 225 (1984)

Magnetisation of the $DyMo_6S_8$ single crystal (virgin curves)

K. Rogacki et al., PRB 64, 94520 (2001)







at $T < T_N = 0.4$ K:

- $H < 200$ Oe, superconductivity coexists with the AFM phase
- $H > 200$ Oe, superconductivity coexists with the spinflop (SF) phase

Phenomenological theory

Free energy of the magnetic superconductor

$$F = \int \left\{ f_S + f_M + \frac{1}{8\pi}(\mathrm{B} - 4\pi \mathrm{M})^2 \right\} dv$$

- superconducting component

$$f_S = \frac{\hbar^2}{2m} \left| \left(\nabla - \frac{2ie}{c\hbar} \mathrm{A} \right) \Psi \right|^2 + \alpha |\Psi|^2 + \frac{1}{2} \beta |\Psi|^4$$

- antiferromagnetic component

$$f_M = J \mathrm{M}_1 \mathrm{M}_2 + K \sum_{i=1}^{2} \left(M_i^{\,z} \right)^2 - |\gamma| \sum_{i=1}^{2} \sum_{j=x,y,z} \left(\nabla M_i^{\,j} \right)^2$$

- coupling between **Ψ** and **M**

$$\mathrm{B} = \nabla \times \mathrm{A} = \mathrm{H} + 4\pi \mathrm{M}, \qquad \mathrm{j}_S(\Psi^+, \Psi) = \frac{c}{4\pi} \nabla \times \mathrm{H}$$

Phenomenological theory (cont.)

Final results: $$H_{en2}(B) = \sqrt{B^2 + H_{en2}^2(0)}$$

where:

$$2H_{en2}(0) = \frac{H_{SF}}{\sqrt{\frac{\varphi_0}{\pi\lambda^2 B_{SF}} \ln\left(\frac{\pi\lambda^2 B_{SF}}{\varphi_0}\right)}}$$

$$H_{SF} = 2H_{c1} + z\frac{\varphi_0}{2\pi\lambda^2} K_0\left(\frac{r_o}{\lambda}\right)$$

r_o – the radius of the spin-flop domain

Experiment versus theory:

T [K]	H_{en2}(exp) [Oe]	H_{en2}(cal) [Oe]
0.10	310	265
0.12	290	240
0.14	270	215

Conclusion:

The twostep flux penetration can be quantitatively described by a model in which the electromagnetic interaction is dominant.

What more can be obtained from the two-stage flux penetration process ?

Approach to estimate:

- number of magnetic ions in the vortex core (*No*)
- superconducting coherence length (ξ)
- London penetration depth (λ)
- GinzburgLandau parameter (κ)

(in magnetic super-conducting state)

Free energy of an AFM superconductor:

$$F(H,T) = E_v^o n + U(n) - BH/4\pi \,, \qquad H_{c1} < H < H_{SF} << H_{c2}$$

$$F(H,T) = (E_v^o + \boldsymbol{E_{exch}})n + U(n) - BH/4\pi \,, \qquad H_{SF} < H << H_{c2}$$

where: E_v^o selfenergy of the vortex ($H_{c1} = 4\pi E_v^o/\phi_o$),

$\boldsymbol{E_{exch}} = \alpha(H - H_{SF}) = N_o e_{exch}$ (due to the SF transition in the vortex core)

n vortex density,

$U(n)$ interaction energy between the vortices,

$BH/4\pi$ field energy ($B = n\phi_o$).

K. Rogacki, et al., PRB **64**, 094520 (2001)

What more can be obtained from the two-stage flux penetration process ?

Results:

$T = 0.7$ K $\rightarrow$ 0.1 K : ($T_N = 0.4$ K)

- $\xi \cong 550$ Å $\cong$ const
- $\lambda \cong 6000$ Å $\rightarrow$ 1300 Å
- $\kappa \cong 11 \rightarrow 2.5$

Conclusions:

• reduction of λ, observed in the AFM/SF superconducting state, leads to the strong compression of the quantized flux and results in a considerable decrease of the GL parameter,

• appearance of the SF phase in the superconducting state (first in the vortex core) *forces the type-II magnetic superconductor to change towards the ”type-I” superconductor*, as predicted by the theory

(M. Tachiki, H. Umezawa, et al., 1983)

Possible explanation:

One reason for the observed “type-II $\rightarrow$ type-I” crossover could be *the attractive force between vortices*.

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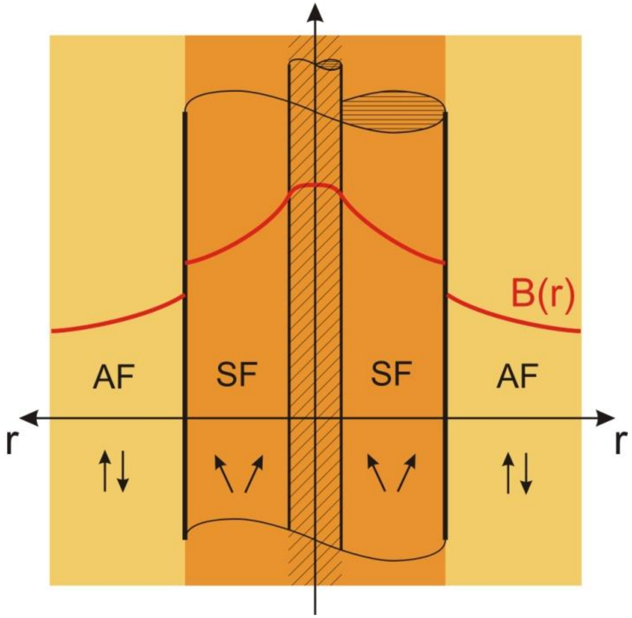
The attractive force between vortices could be a result of *current inversion* in a part of the vortex with the domain magnetic structure.



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The current inversion seems to be the direct consequence of *the quantization of the total flux of a single vortex*, which in a magnetic superconductor is *a sum of the spin and current contribution*.

Summary

Classic AFM superconductors

interaction between long-range AFM order and SC order is present $\Leftrightarrow$ $H_{c2}(T)$, $\chi_{ac}(T)$, $H_{c1}(T)$ and $M(H)$ dependencies reveal anomalies at T_N and H_{SF}

$H_{c2}(T)$, $H_{c1}(T)$ and $M(H)$ dependencies (with the anomaly) are known $\Rightarrow$ nature of the interaction between AFM and SC orders can be analysed

$M(H)$ dependence (with the anomaly) is known $\Rightarrow$ ξ and λ can be estimated in the AFM-SC state

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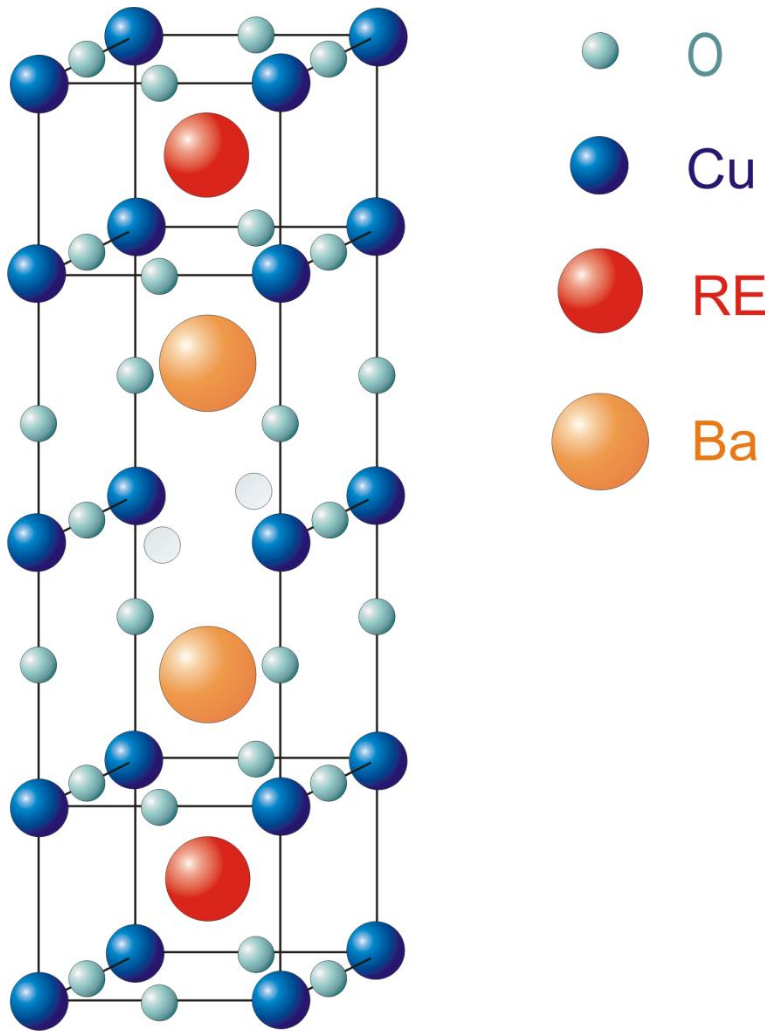
Argonne National Laboratory, Argonne, USA

High-T_c AFM superconductors

(4f - 3d4s,2p)



$REBa_2Cu_3O_{7-d}$

$T_c \approx 92$ K

RE	T_N [K]	H_{SF} [kOe]
Nd	0.53	30
Sm	0.61	> 50
Gd	2.24	30
Dy	0.91	10
Er	0.61	8
Yb	0.25	6

Where the interaction between AFM and superconductivity can be found in RE123 ?

$REBa_2Cu_3O_7$, $T_C \approx 92$ K

RE	T_N [K]	H_{SF} [kOe]
Nd (s)	0.53	30
Sm (s)	0.61	> 50
Gd (s, ns)	2.24	30
Dy (s)	0.91	10
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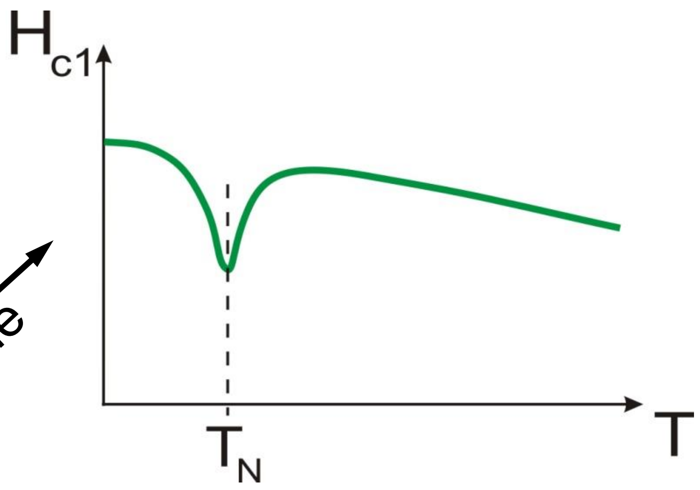
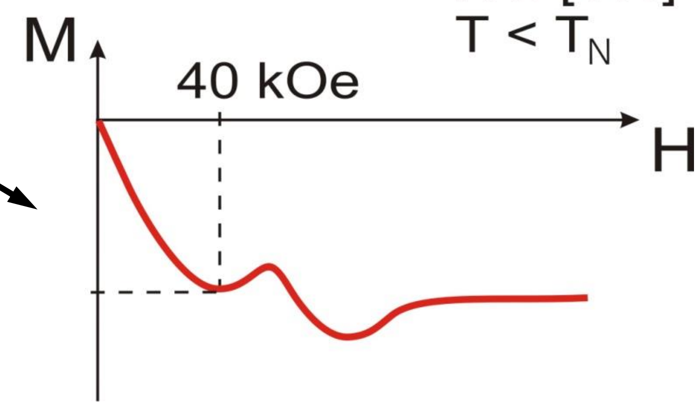
polycrystalline samples



single crystals



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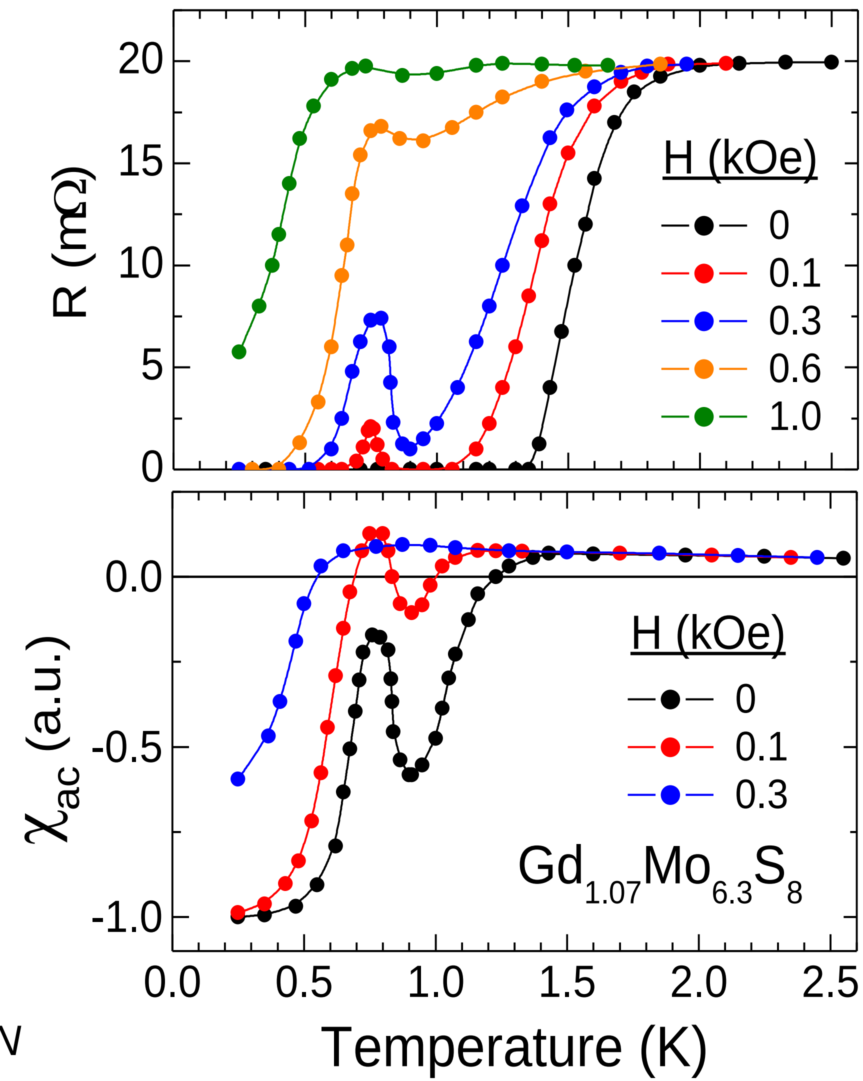
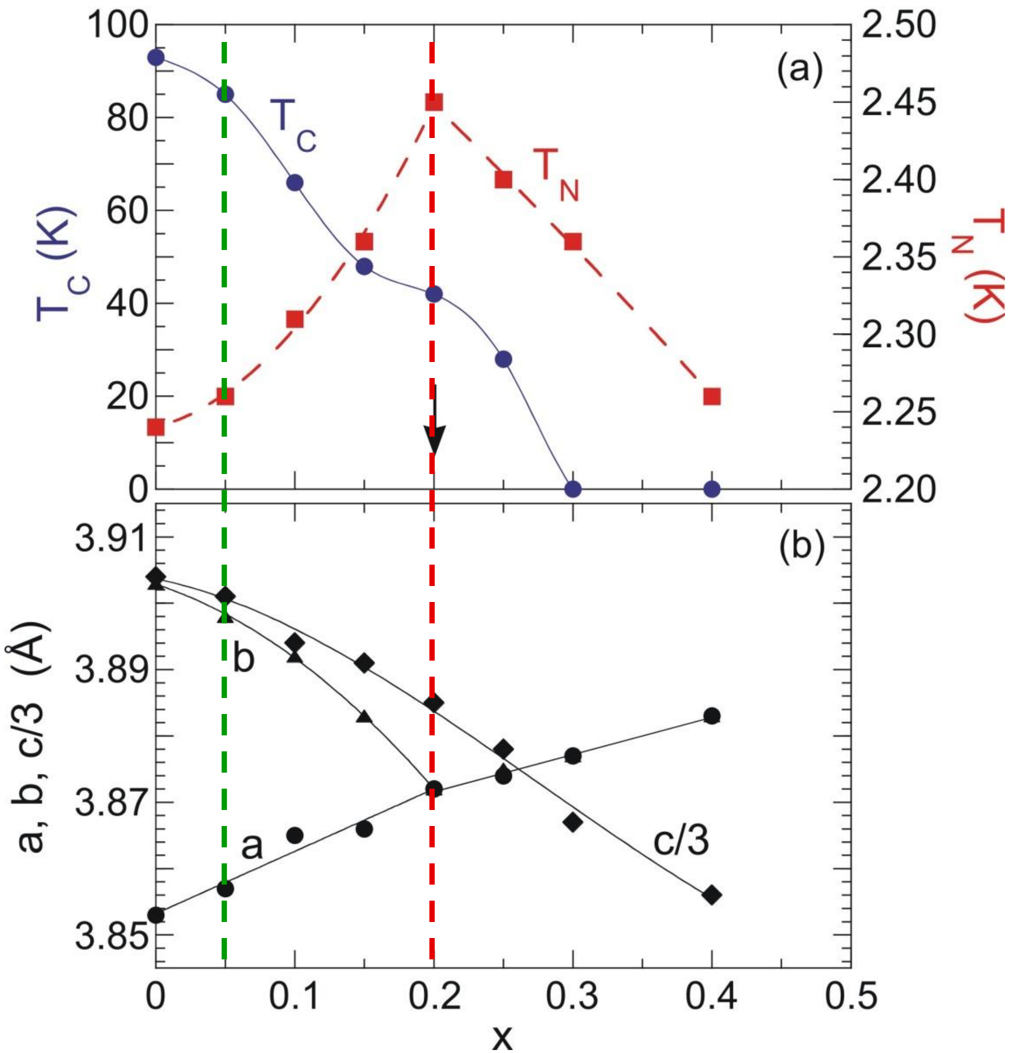


R(T), $\chi_{ac}(T)$ – no anomaly at T_N

Is it possible to diminish superconductivity and enhance the AFM interaction in HTSC ?



$Gd_{1+x}Ba_{2-x}Cu_3O_{7\pm y}$

method to decrease T_C
and increase T_N

chemical substitution

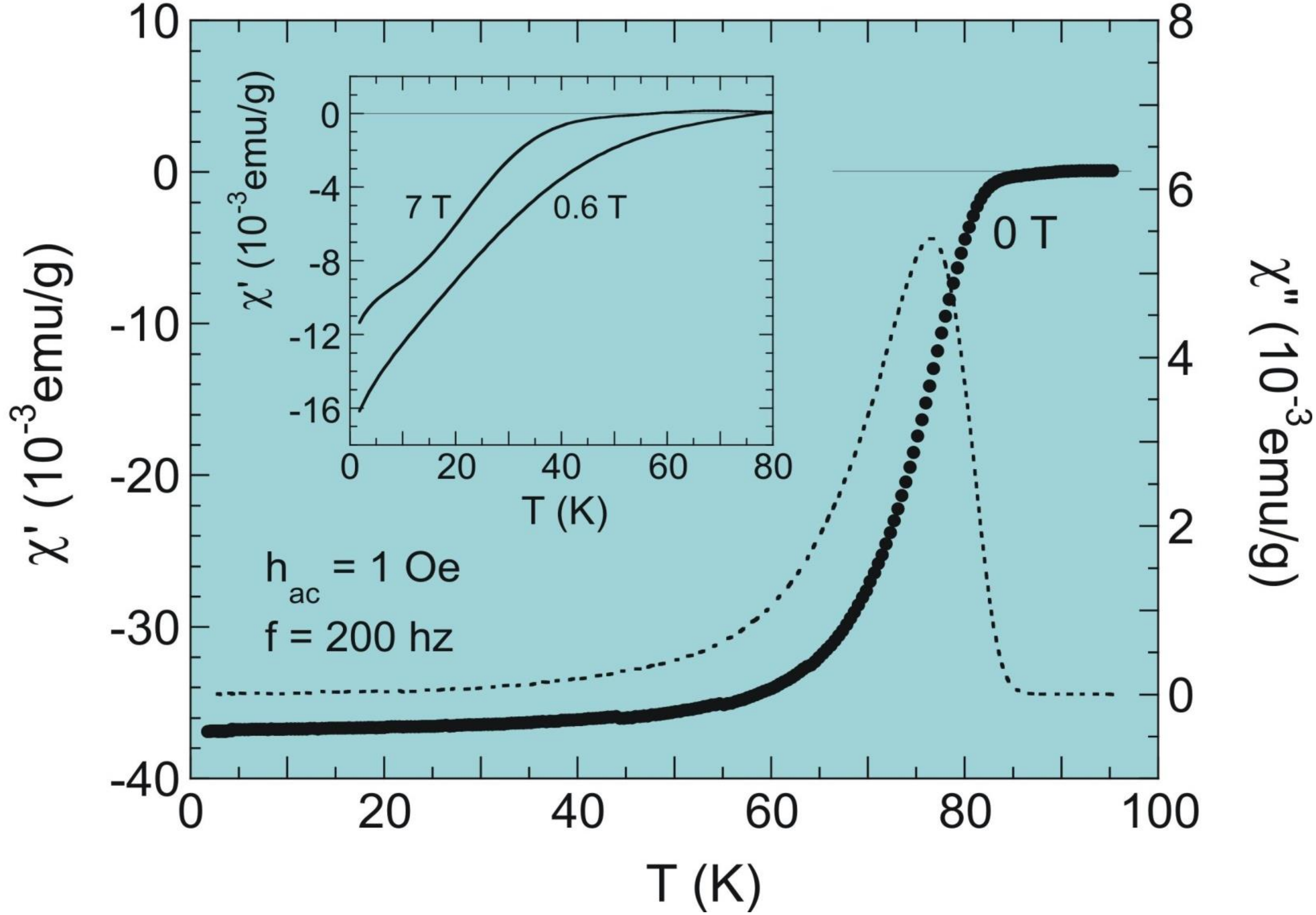
$Gd_{1.05}Ba_{1.95}Cu_3O_{7-y}$

$Gd_{1.2}Ba_{1.8}Cu_3O_{7+y}$

Searching for the interaction between the AFM order and superconductivity in:

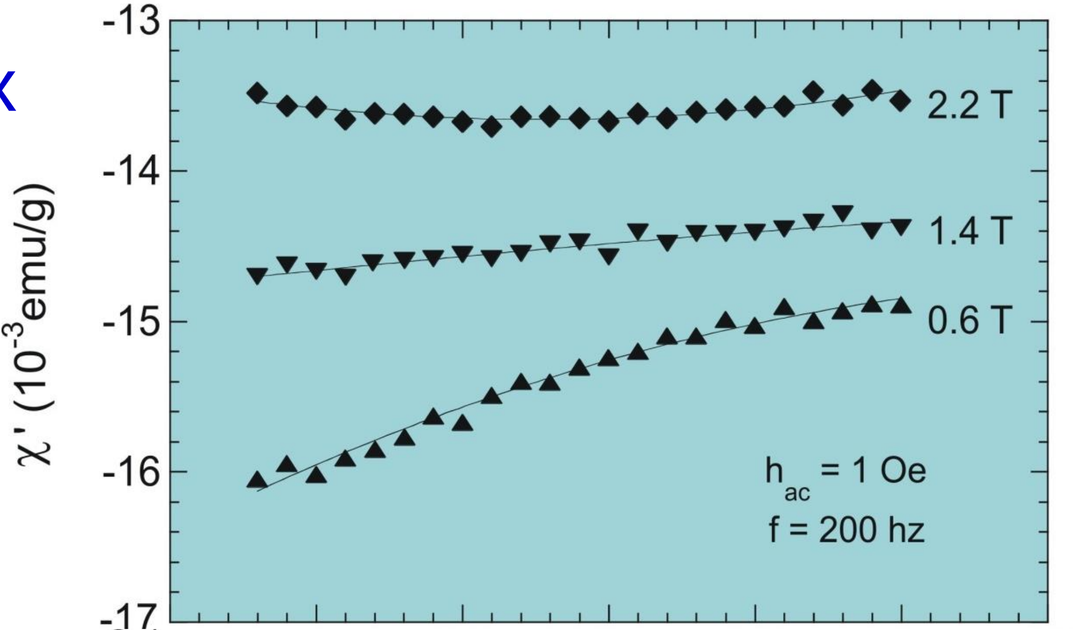
$Gd_{1.05}Ba_{1.95}Cu_3O_{7-y}$ /ox

T_C = 85 K, T_N = 2.26 K



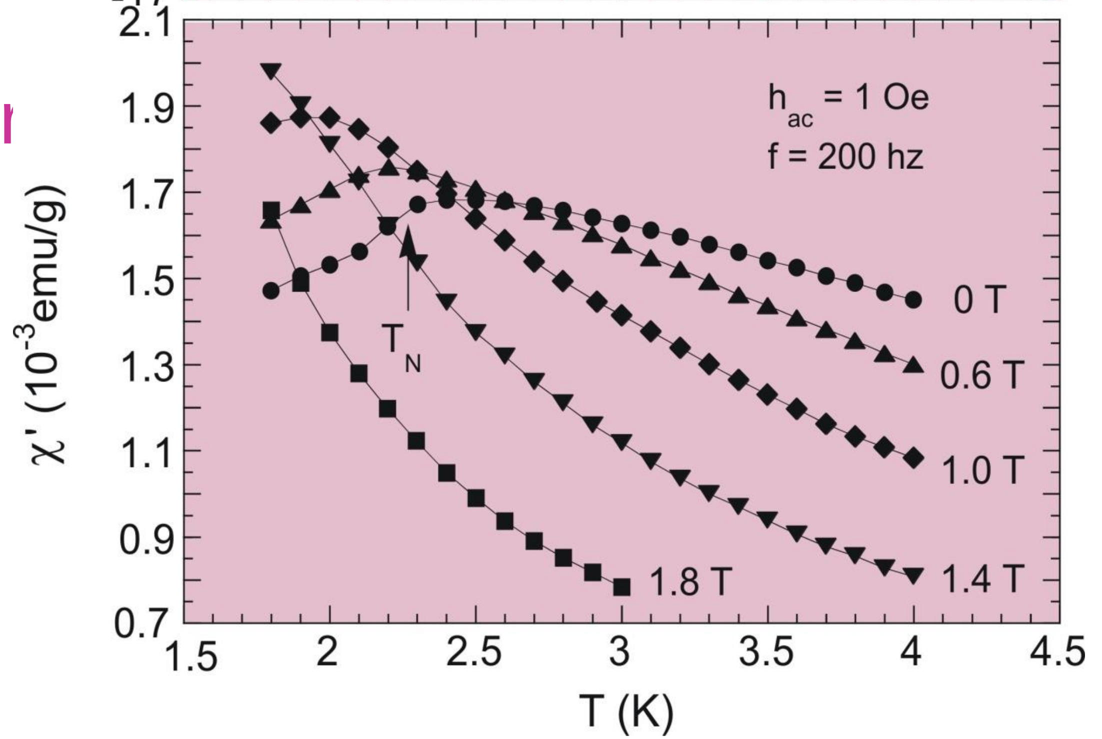
$Gd_{1.05}Ba_{1.95}Cu_3O_{7-y}$ /ox

sample annealed in oxygen (T_c = 85 K, T_N = 2.26K)



$Gd_{1.05}Ba_{1.95}Cu_3O_{6.3}$ /Ar

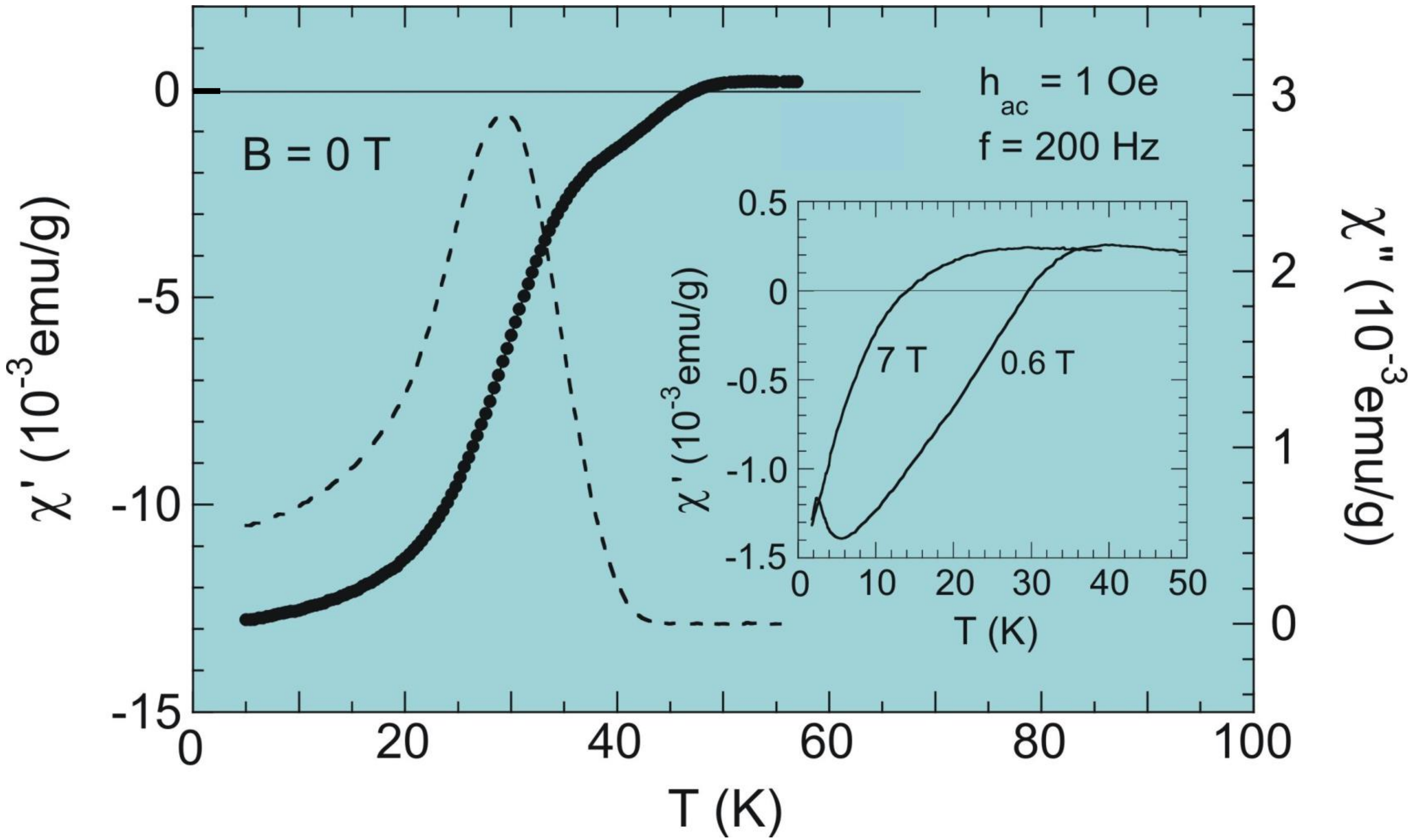
sample annealed in argon (nonsuperconducting)

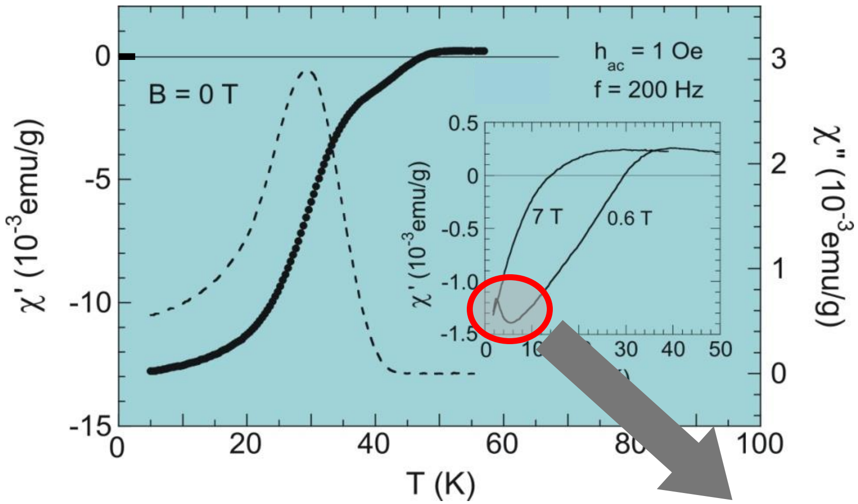


Searching for the interaction between the AFM order and superconductivity in:

$Gd_{1.2}Ba_{1.8}Cu_3O_{7+y}$ /ox

T_C = 42 K, T_N = 2.45 K

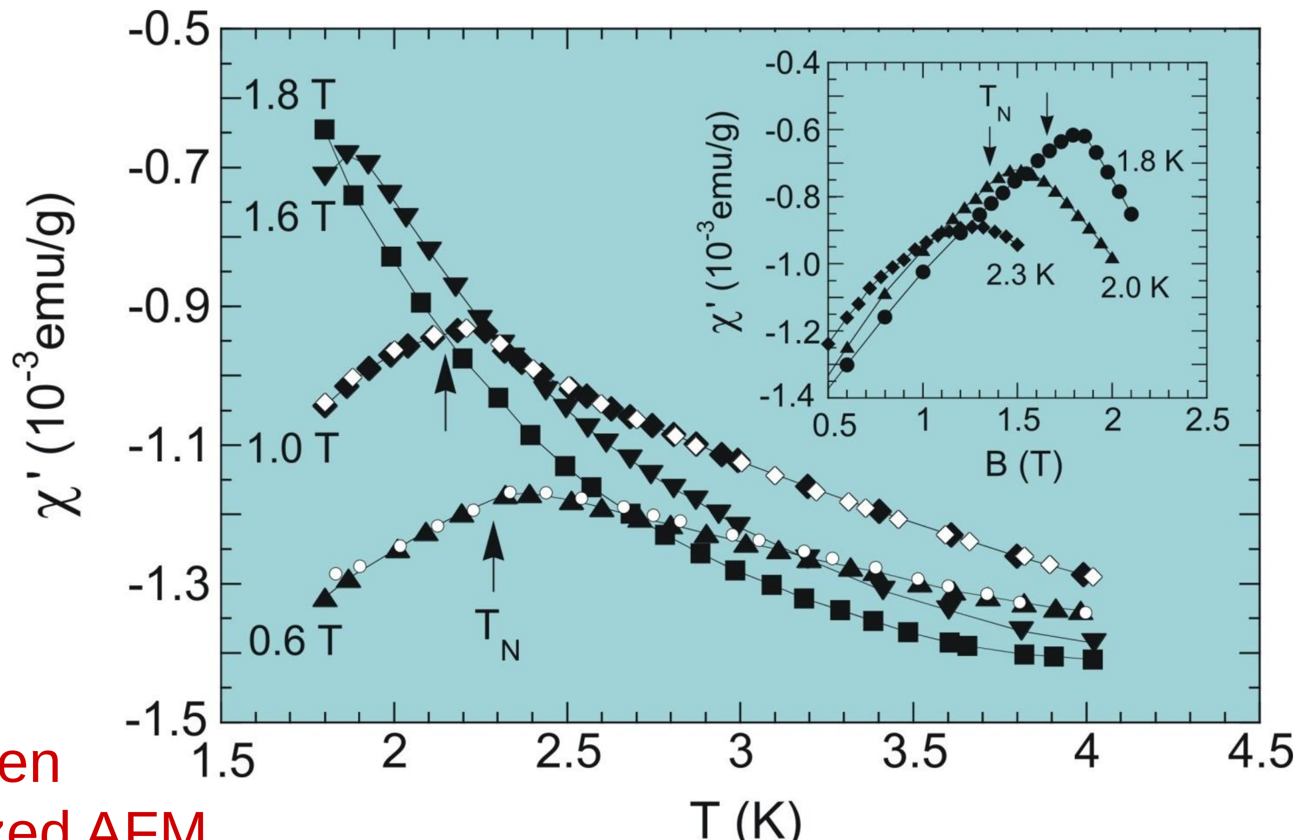




$Gd_{1.2}Ba_{1.8}Cu_3O_{7+y}$/ox

T_C = 42 K, T_N = 2.45 K

K. Rogacki, PRB 68, 100507(R) (2003)



maximum in $\chi'(T)$ at $T \sim T_N$

⇒ evidence for pair breaking

⇒ evidence for interaction between HTSC and localized AFM

Maximum in $\chi(T)$ at $T \approx T_N$
- direct evidence for the pair breaking effect

- enhancement of the spin scattering near the transition to the AFM state is expected and thus an increase of the pair breaking parameter ρ^* at $T \approx T_N$ has to appear

$$\rho^* = (3J^2/\pi)\sum \Phi(\mathbf{q})\chi(\mathbf{q})$$

J - exchange constant for the interaction $\boldsymbol{\sigma}$ - $\boldsymbol{S}$

$\Phi(\mathbf{q})$ - density of states for the conduction electrons

$\chi(\mathbf{q})$ - magnetic susceptibility (wave-vector dependent)

$T \rightarrow T_N$ (for RE123)

$\Rightarrow$ $\chi(\mathbf{q})$ wide maximum is expected just above T_N

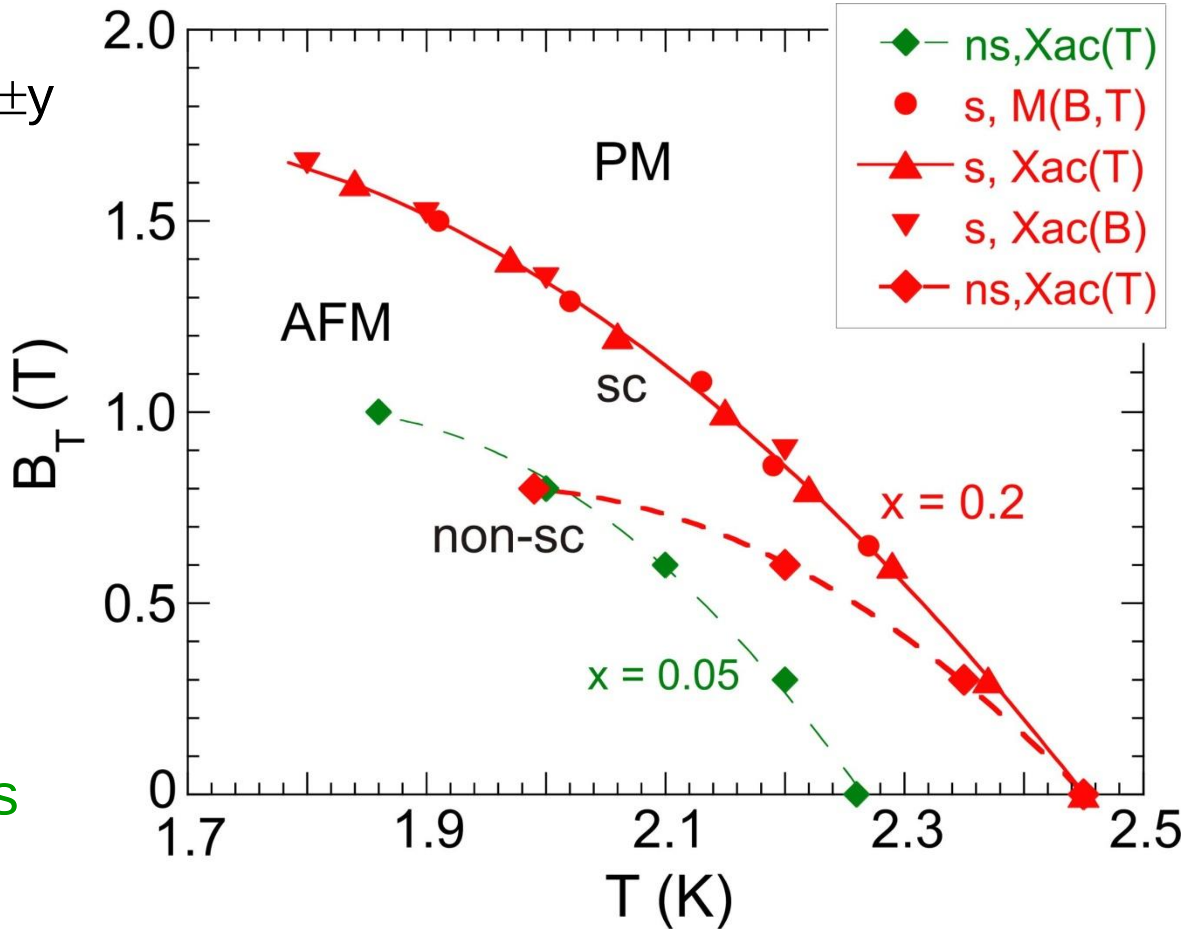
$\Rightarrow$ $R(T \approx T_N) \neq 0$ (?), not necessary

B_T-T phase diagram

- evidence that the sample is homogeneous

$Gd_{1+x}Ba_{2-x}Cu_3O_{7\pm y}$

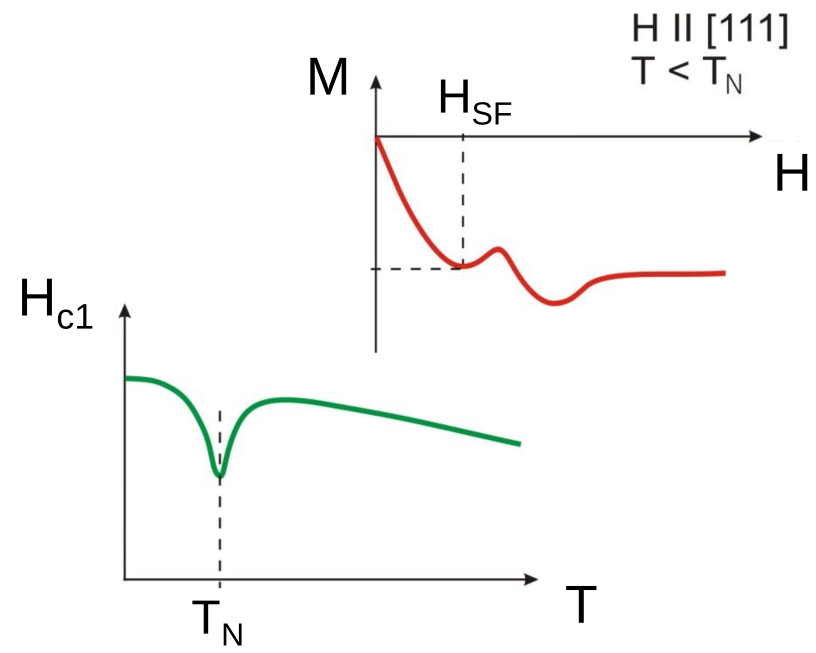
different T_N is observed for superconducting & non superconducting samples in *B*



single maximum is observed at T_N for $\chi'(T)$ dependencies measured in *B*

→ spatial separation of the *superconducting* and the *normal-magnetic* phases is excluded

Summary for high-T_c AFM superconductors



$\chi_{ac}(T)$, $H_{c1}(T)$ i $M(H)$ were studied for:

- $DyBa_2Cu_3O_7$ (crystals)
- $GdBa_2Cu_3O_7$ (powder)

→ no anomaly for $H_{c1}(T)$, $M(H)$ and $\chi_{ac}(T)$ dependencies has been observed at T_N and H_{SF}

$\chi_{ac}(T)$ was studied for:

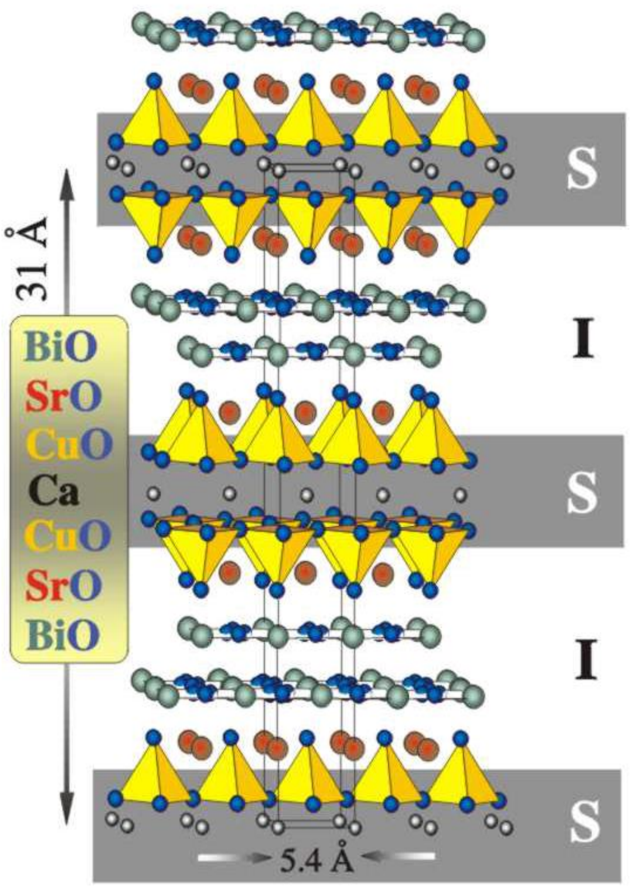
- $Gd_{1.2}Ba_{1.8}Cu_3O_7$ (powder) T_c = 42 K i T_N = 2.45 K

→ evidence for the interaction between AFM and SC orders has been found as the pair breaking effect revealed in $\chi_{ac}(T)$ near T_N

<u>High-T_c superconductors</u> – unconventional layered superconductors

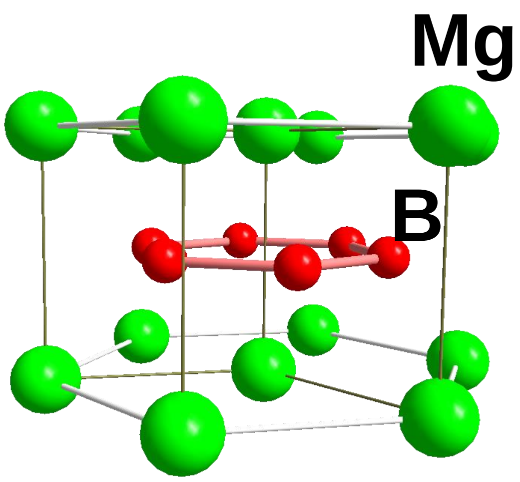
<u>cuprates</u>

e.g. $Bi_2Sr_2CaCu_2O_8$



$T_{c,max}$= 135 K ($HgBa_2Ca_2Cu_3O_8$)

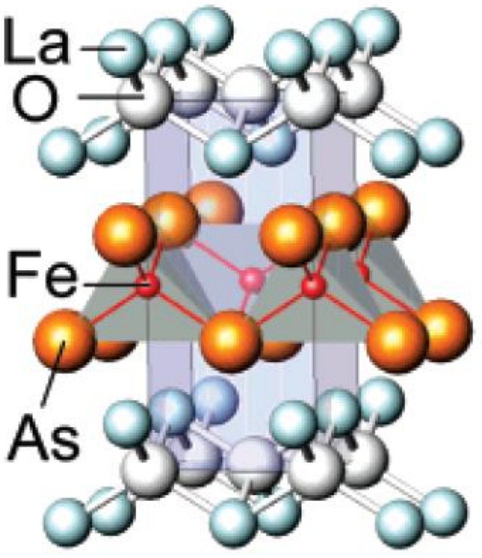
<u>MgB_2</u>



$T_{c,max}$= 40 K

<u>pnictides</u>

e.g LaFeAsO:F



$T_{c,max}$= 55 K (SmFeAsO:F)

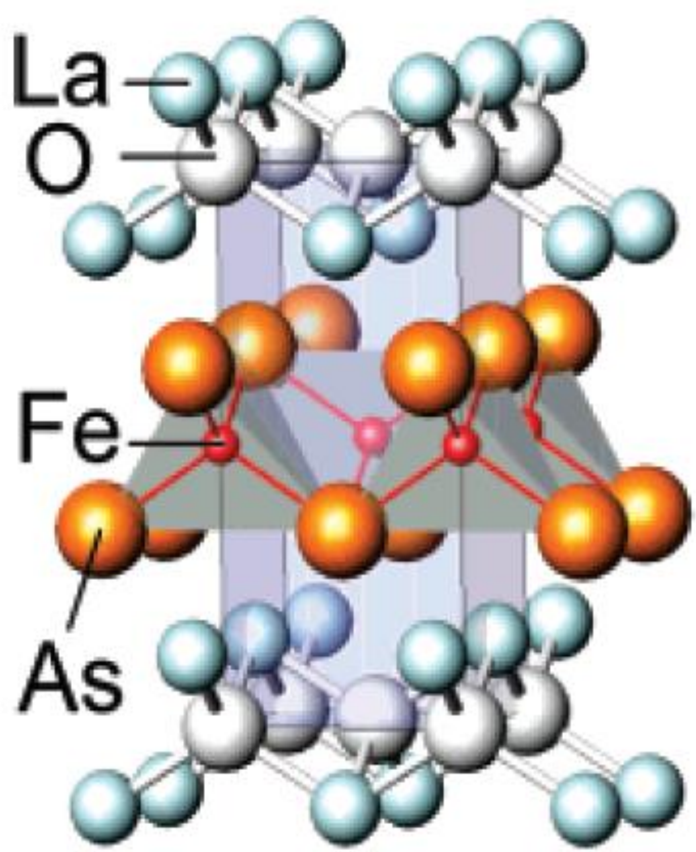
Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05−0.12) with T_c = 26 K

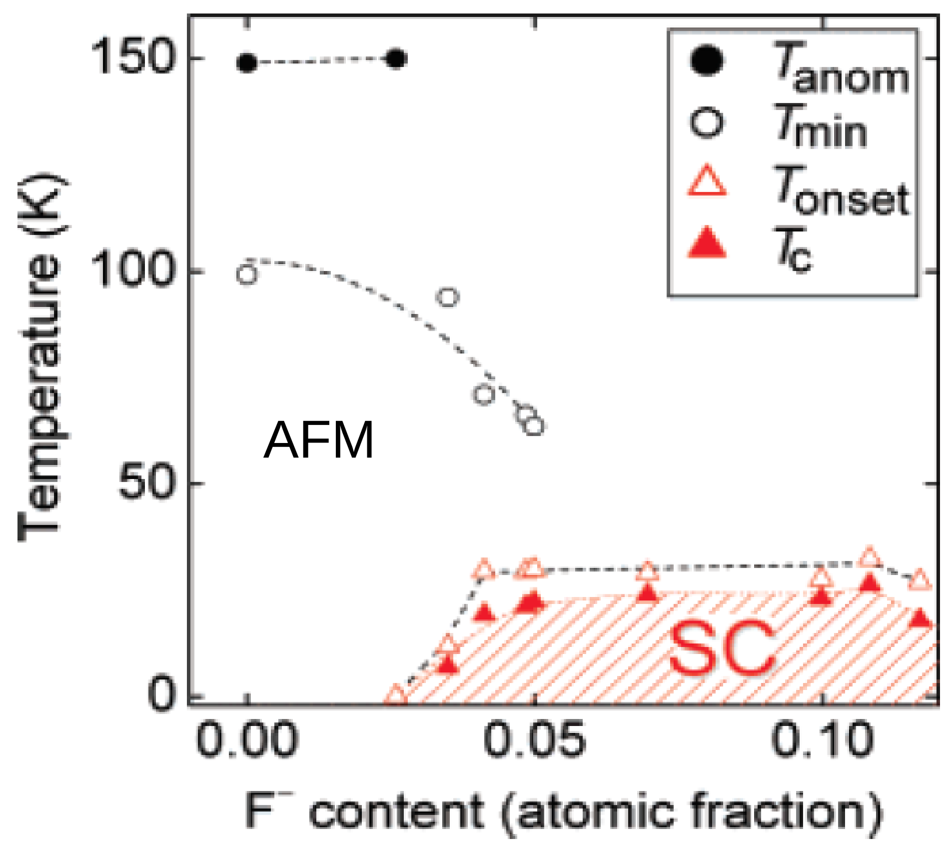
Yoichi Kamihara,*,† Takumi Watanabe,‡ Masahiro Hirano,†,§ and Hideo Hosono†,‡,§

ERATO-SORST, JST, Frontier Research Center, Tokyo Institute of Technology, Mail Box S2-13, Materials and Structures Laboratory, Tokyo Institute of Technology, Mail Box R3-1, and Frontier Research Center, Tokyo Institute of Technology, Mail Box S2-13, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan

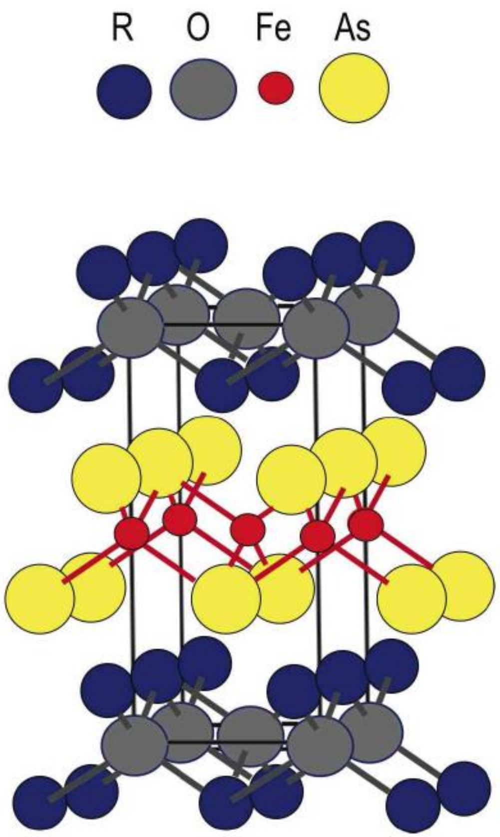
Received January 9, 2008; E-mail: hosono@msl.titech.ac.jp

J.Am.Chem.Soc., 2008





New class of HTSC: REFeAsO & $BaFe_2As_2$



Crystal structure:
(ZrCuSiAs type)

P4/nmm
$z = 2$
$a = 4.035$ Å
$c = 8.741$ Å

alternating layers of corner shared $FeAs_4$ & REO_4 tetrahedra

Basic properties:

- layered, quasi-2D system
- large spin fluctuations (**μ** SR)
- charge carriers; electrons (R_H)

LaFeAsO:

- AFM ($T_N \approx 140$ K, $\mu_{Fe} \approx 0.5\ \mu_B$)
- non-superconducting

⇩ doping with ~0.05 carriers/Fe

$LaFeAsO_{1-x}F_x$: x = 0.1

- paramagnetic ($\mu_{Fe} \geq 0$)
- superconducting $T_c = 28$ K
- $\boldsymbol{T_c \sim \lambda_{ab}(0)^{-2}}$, $\lambda_{ab} \approx 200$ nm, $\xi_{ab} \approx 2$ nm, $\kappa_c = \lambda_{ab}/\xi_c \approx 200$

Pairing:

- spin singlet; extended *s*-wave, *d*-wave ? (Knight shift)
- high frequency phonon involved (Raman, Infrared)
- non-BCS; 2 gaps, $2\Delta_1 \approx 3k_BT_c$, $2\Delta_2 \approx 8k_BT_c$ (no coherence Hebel-Slichter peak below T_c)

- PrFeAsO:F, $T_c = 52$ K
- NdFeAsO:F, $T_c = 53$ K
- SmFeAsO:F, $T_c = 55$ K
- GdFeAsO, $T_c = 55$ K

Overview

- superconductivity and long range magnetism: introduction, interplay, coexistence
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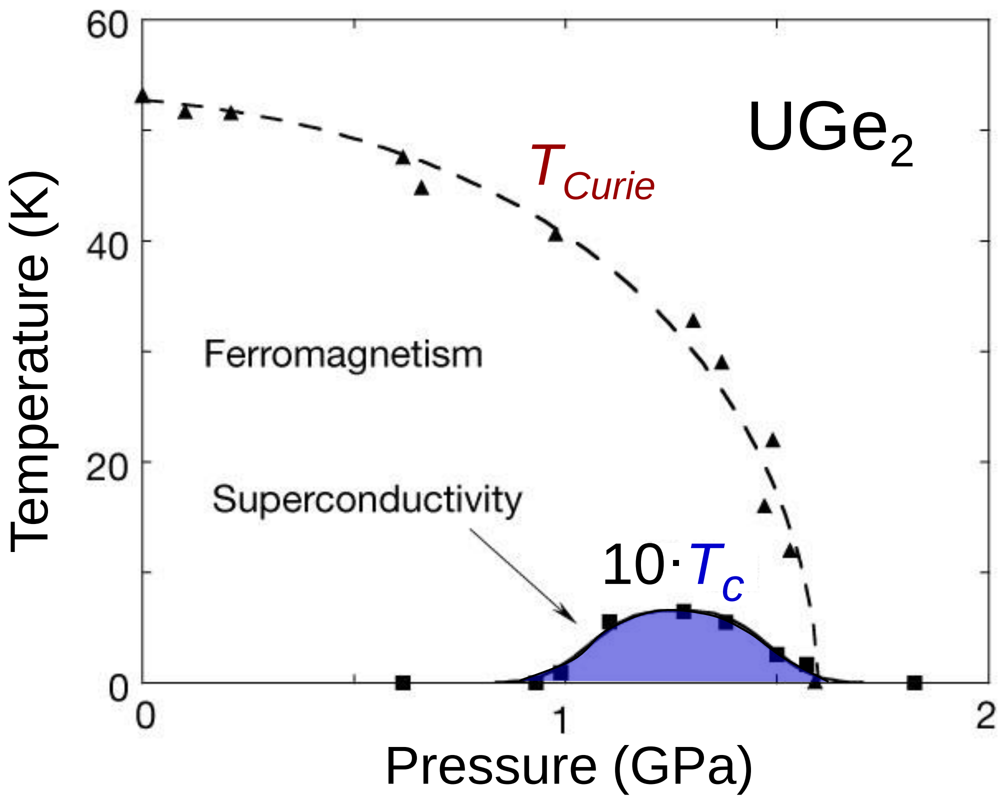
- superconductivity and FM in unconventional superconductors
- superconductivity and FM in Y_9Co_7
- Summary

UGe_2 ferromagnetic superconductor:

is it really possible to combine water with fire ?

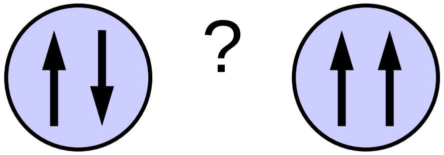
S.Saxena et al., Nature 406, 587 (2000)



Properties of UGe_2:

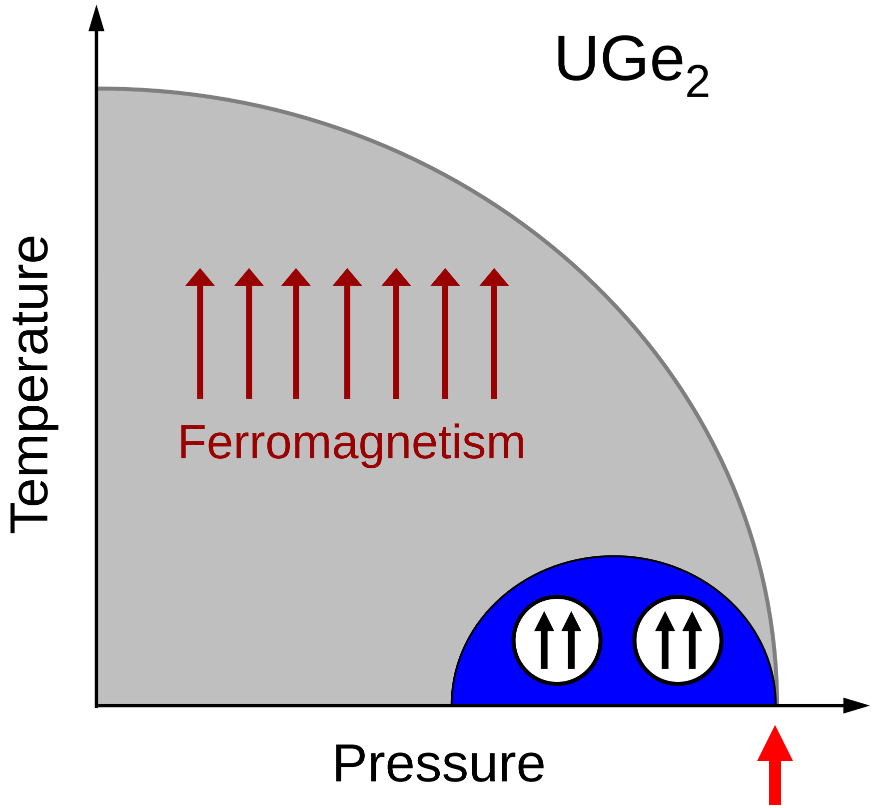
- T_{Curie} = 52 K, p = 0 Gpa
- T_c^{max} = 0.6 K, p= 1.25 Gpa
- m = 1.4 μ_B/U atom

Important question:



What type of Cooper pairs can be responsible for superconductivity which coexsists with ferromagnetism ?

Coexistence (cooperation ?) of unconventional superconductivity and itinerant FM



Why the triplet state ?

- $H_{ex} \sim (T_{Curie}/\mu_B) \gg H_p \sim (T_c/\mu_B)$
- $H_{c2} \gg H_p$
- $I_{MAG}(T)$ = constant when crossing T_c in H

Tryplet superconductivity (S=1) and itinerant FM ***coexsist*** *and, moreover, it appears that they are linked !*

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Collaborators:

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Institute of Low Temperature and Structure Research,
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AGH, Kraków

Coexistence of superconductivity and itinerant ferromagnetism in Y_9Co_7

J. Phys. F: Metal Phys., 10(1980)L333–7. Printed in Great Britain

LETTER TO THE EDITOR

Magnetism and superconductivity in a transition metal compound: Y_4Co_3

A Kolodziejczyk†, B V B Sarkissian and B R Coles
Blackett Laboratory, Imperial College, London SW7, England, UK

Received 22 September 1980

Abstract. Measurements of AC susceptibility and electrical resistivity show the onset of magnetic order at about 5 K and the onset of superconductivity at about 1·5 K in samples of Y_4Co_3 which are believed to be single phase. Interpretations are considered which take into account the characteristic structure of the compound and different possible types of magnetic ordering.

Coexistence of superconductivity and itinerant ferromagnetism in Y_9Co_7

properties of „old" samples:

- no anomaly in the specific heat $C_p(T)$ dependence at T_c and T_{Curie}
- low magnetic moment $\mu \approx 0.08\ \mu_B$/f.u.

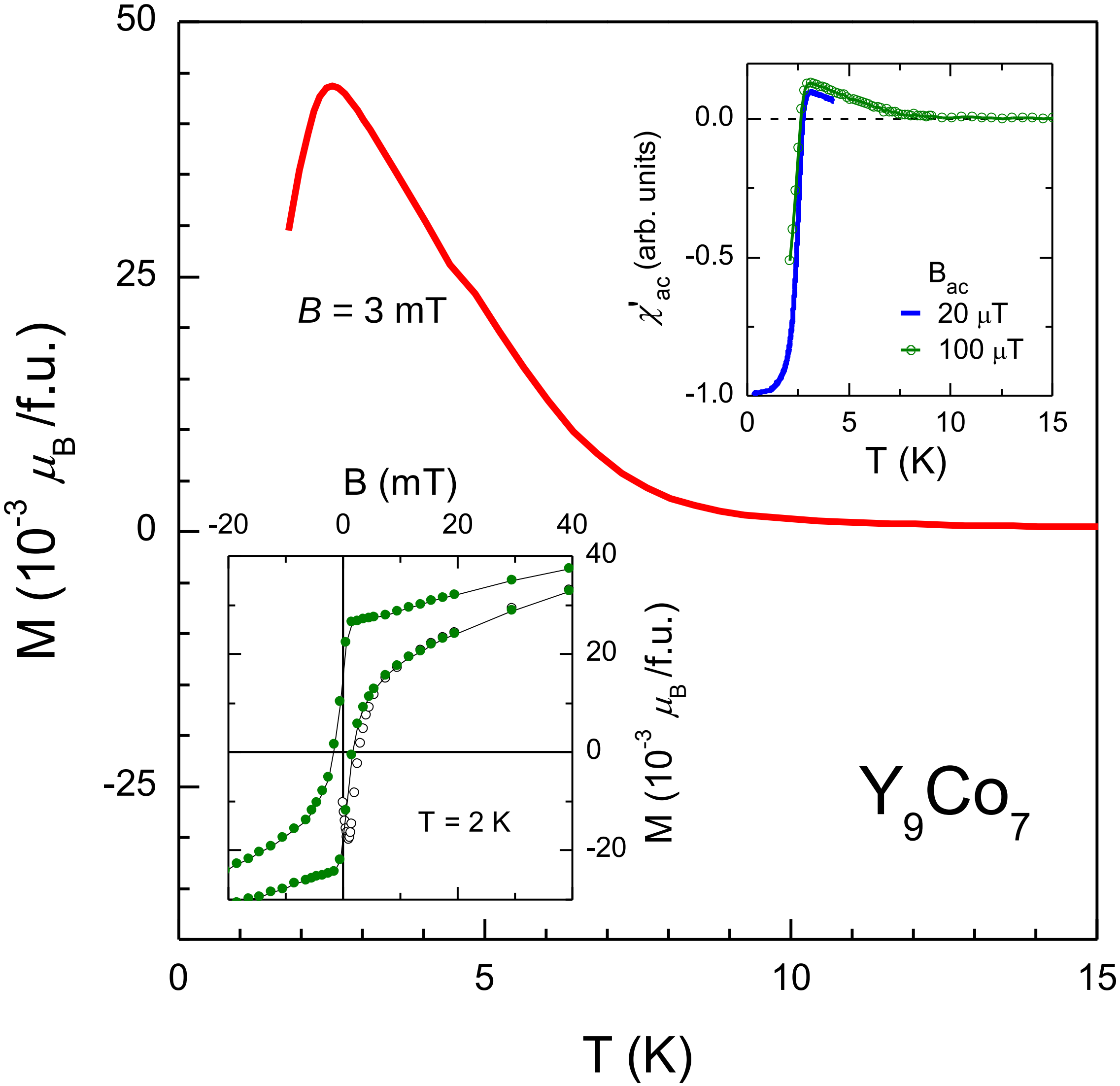
➡ superconductivity ($T_c \approx 1.5 - 2$ K) is present in PM phase immersed in FM material ($T_{Curie} \approx 6 - 8$ K) ??

properties of „new" samples:

- clear anomaly in $C_p(T)$ at T_c and T_{Curie}
- low magnetic moment $\mu \approx 0.06\ \mu_B$/f.u.
- bulk superconductivity ($T_c = 2.95$ K) present in FM phase ($T_{Curie} = 4.5$ K)

Coexistence of superconductivity and itinerant ferromagnetism in Y_9Co_7

ŁB, KR, AK, TC, PRB **91**, 235314 (2015); KR, AK, LB, TC, Phil. Mag. **95**, 503 (2015)



Coexistence of superconductivity and itinerant ferromagnetism in Y_9Co_7

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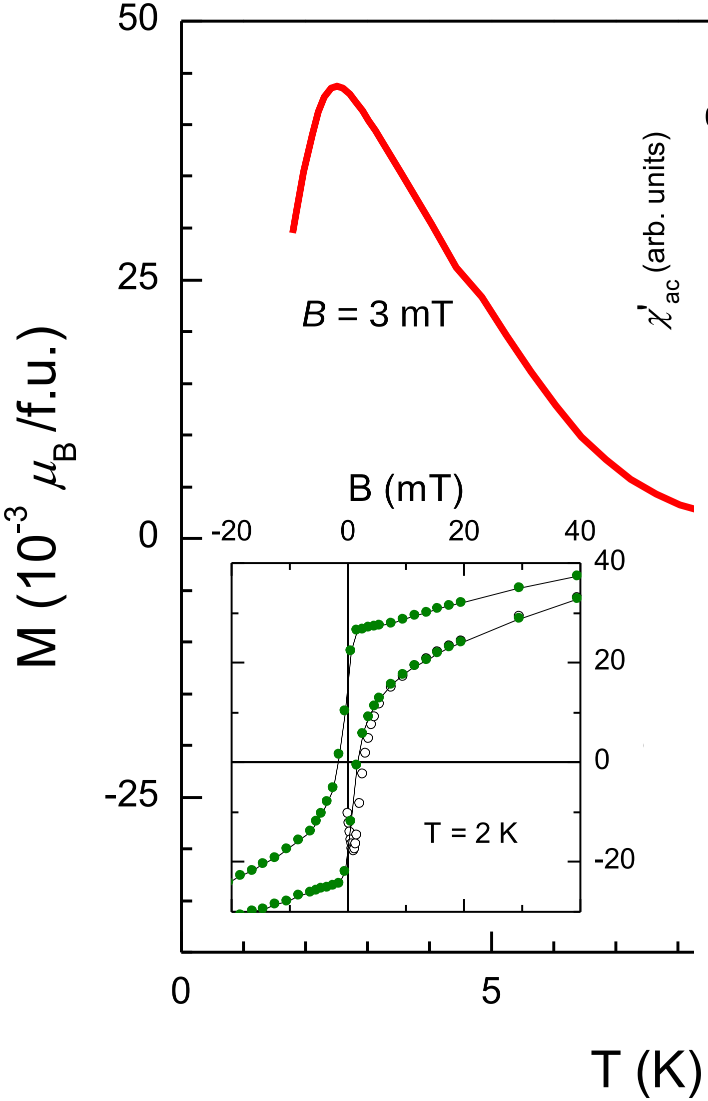
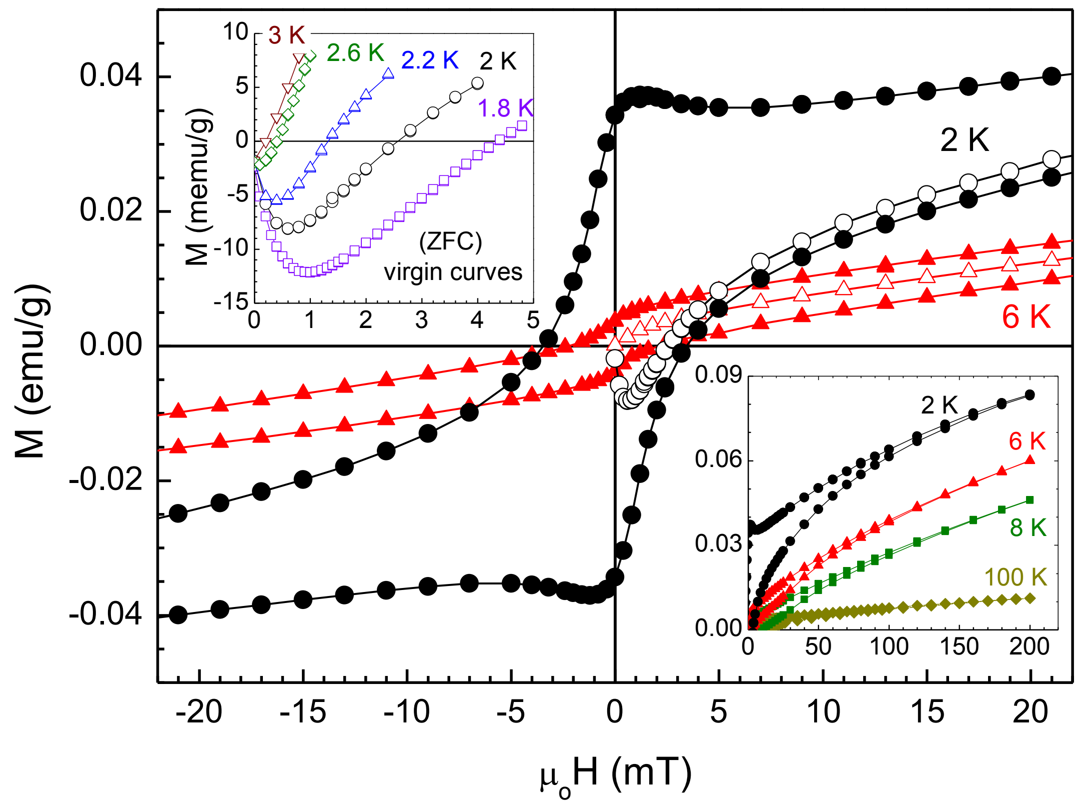


full diamagnetism:
→ *bulk superconductivity*



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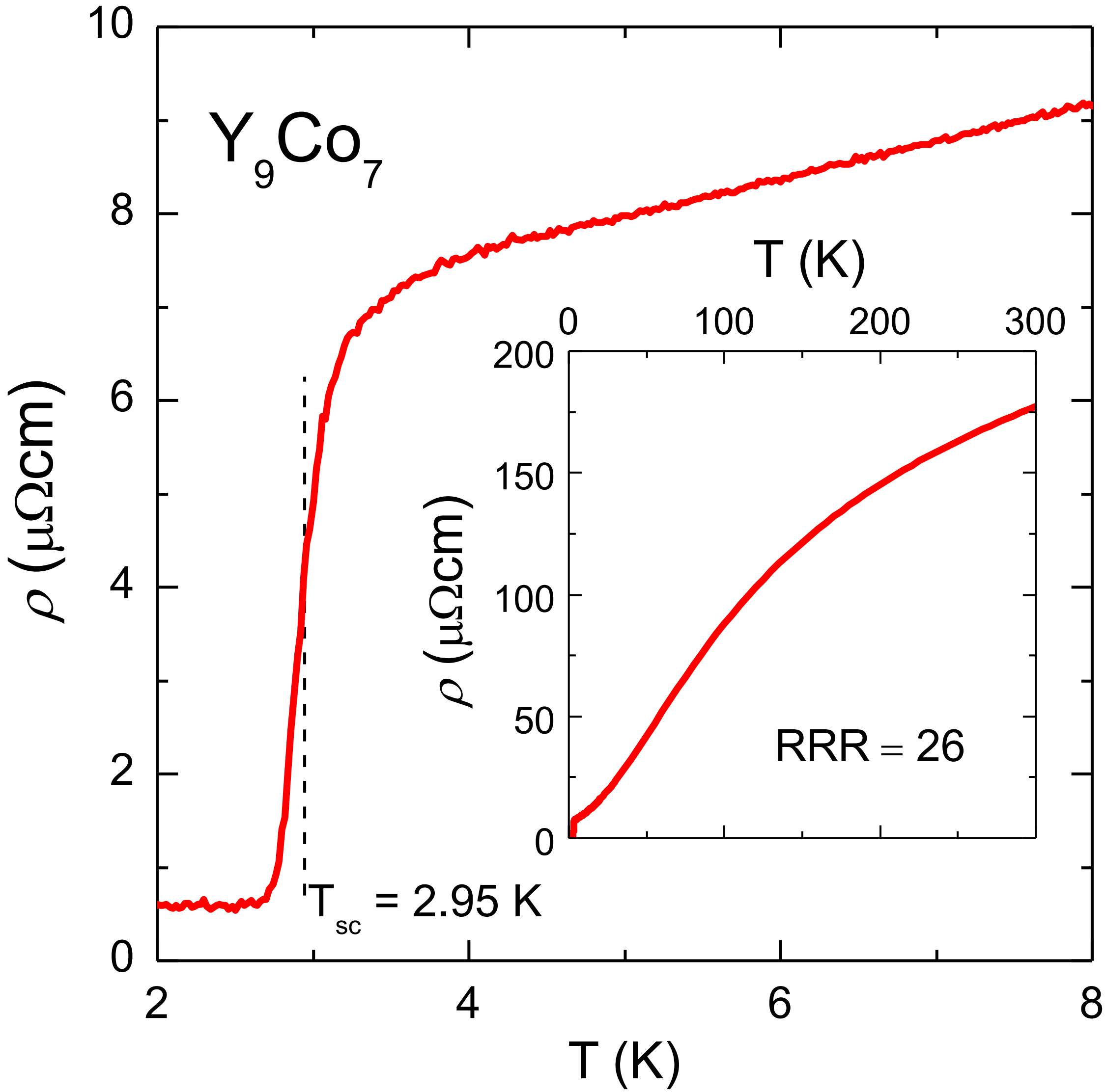

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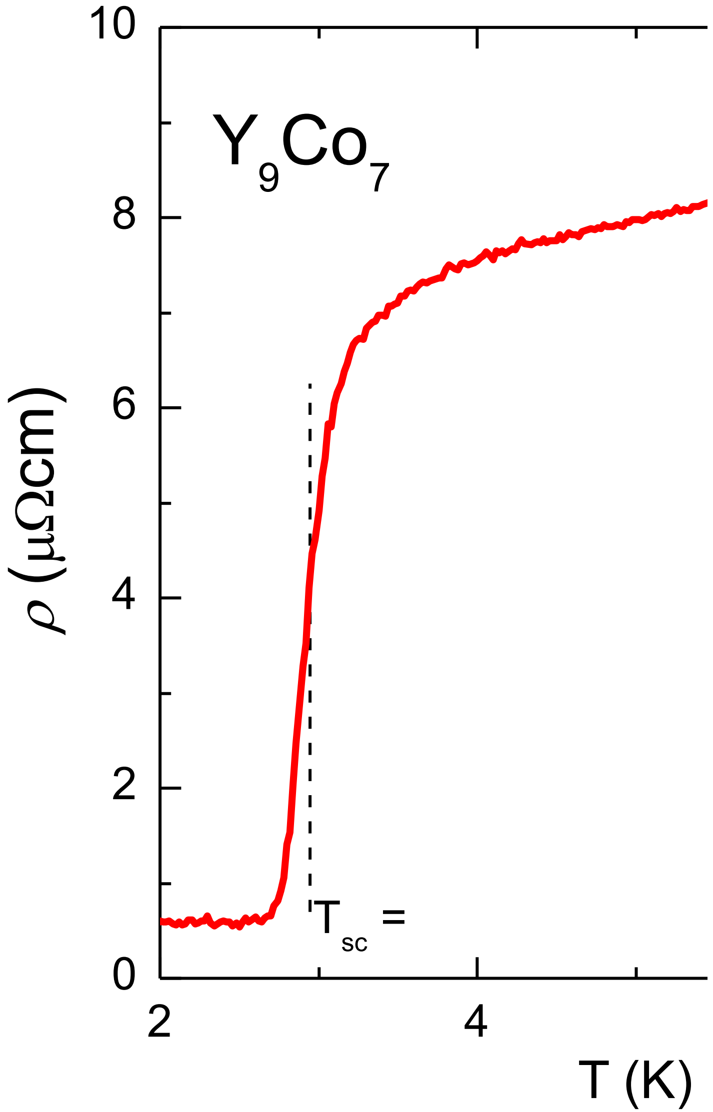
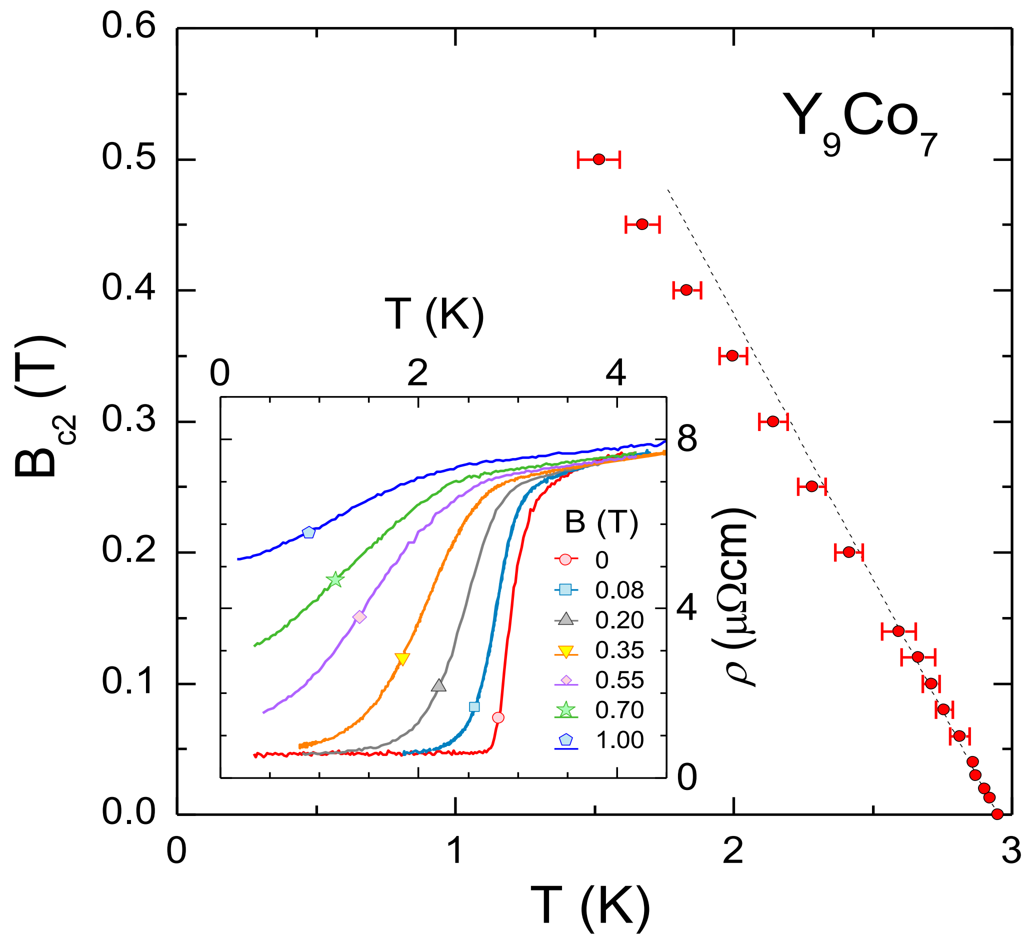
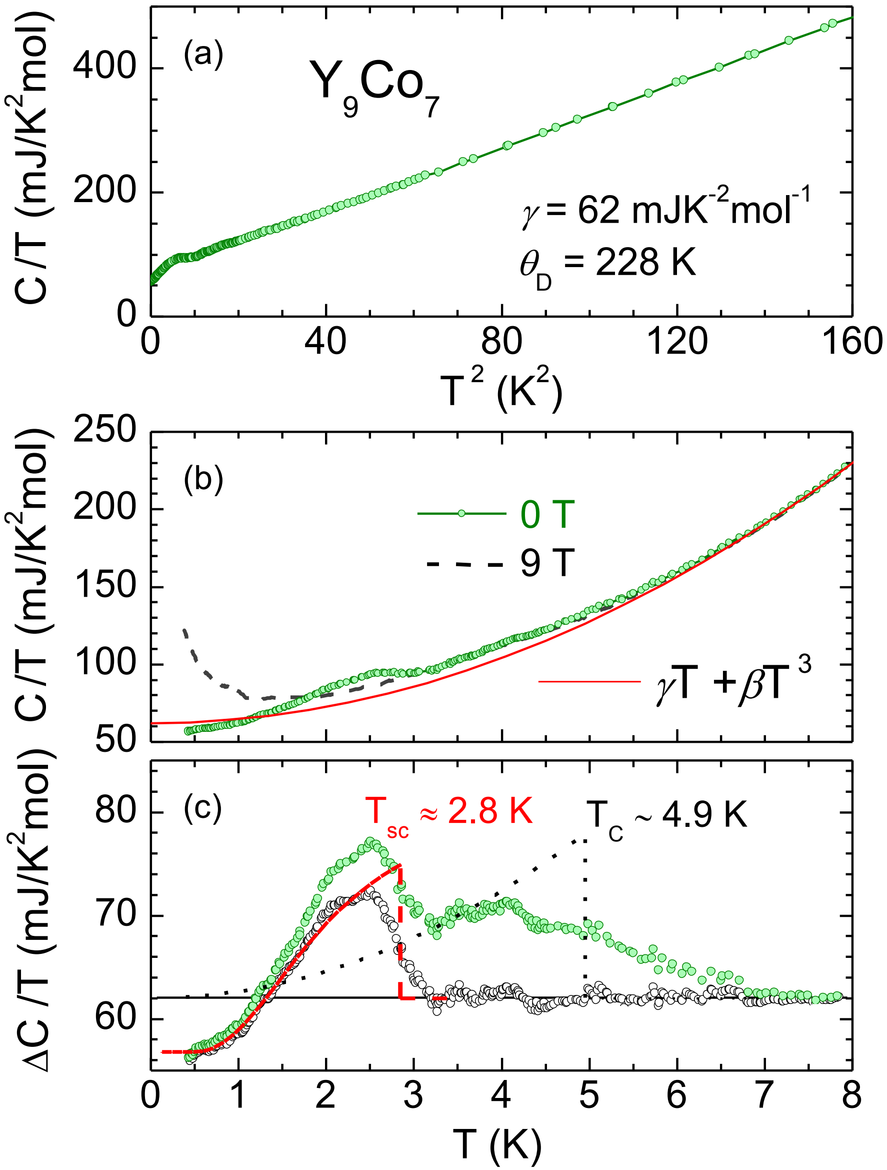




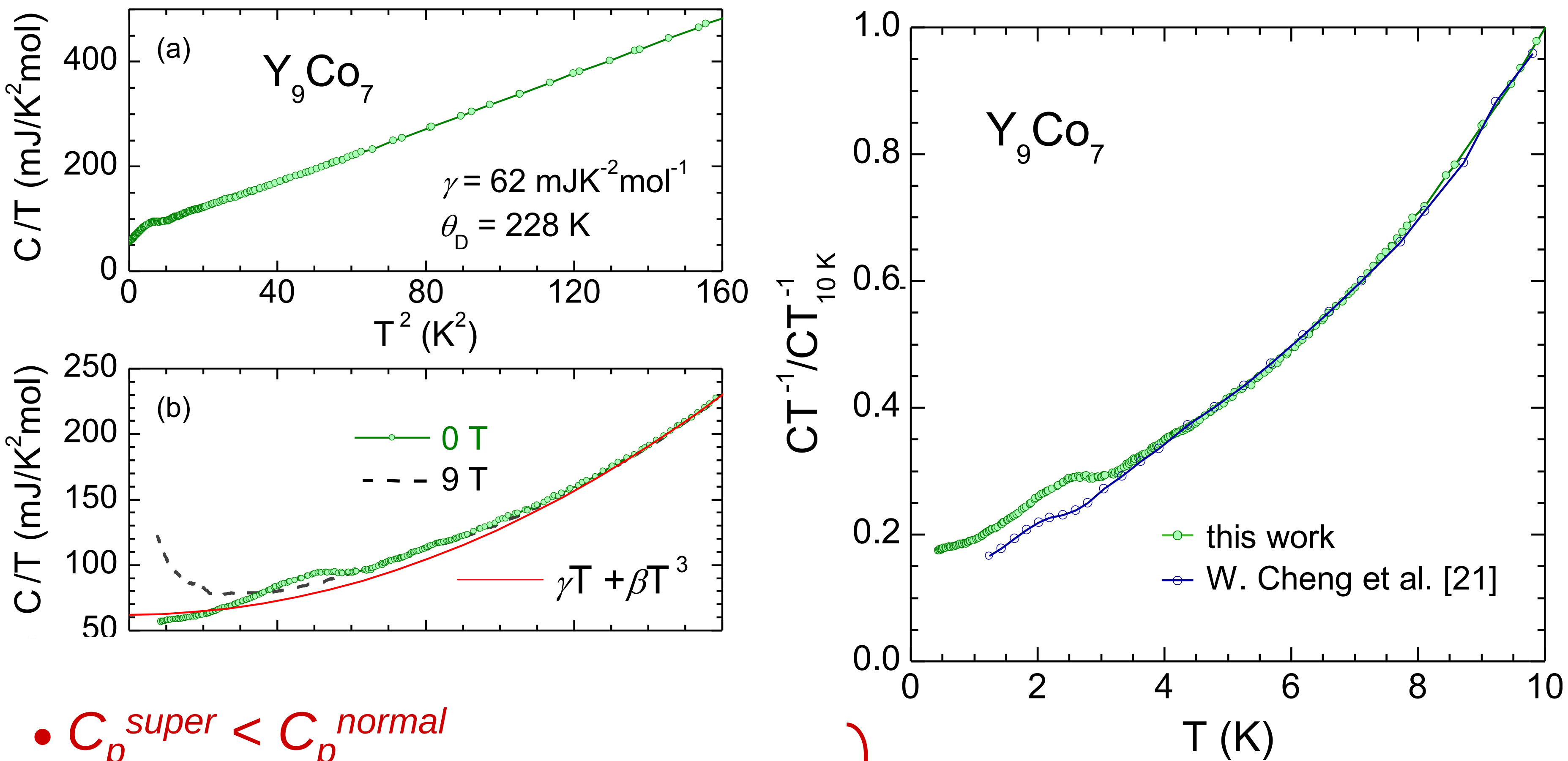
- $\xi \approx$ 240 Å
- $l \approx$ 2 200 Å

} → „clean-limit"

Coexistence of superconductivity and itinerant ferromagnetism in Y_9Co_7



Coexistence of superconductivity and itinerant ferromagnetism in Y_9Co_7



- $C_p^{super} < C_p^{normal}$
- increased amount of SC phase for samples with increased quality
- fixed amount of FM phase

→ *SC and FM show bulk (volume) properties and coexist in the microscale*

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Collaborators:

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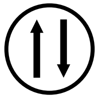
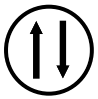
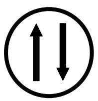
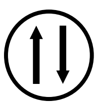
AGH

Summary:

-  **superconductivity** and **localized AFM** *coexist and interact each other* ($HoNi_2B_2C$, $GdBa_2Cu_3O_7$)

-  **superconductivity** and **localized FM** *don't want to coexist – they are enemies* ($HoMo_6S_8$, $ErRh_4B_4$)

-  **superconductivity** and **weak itinerant FM** *coexist and interact each other* (**Y_9Co_7**)

-  **superconductivity** and **strong itinerant FM** *can't coexist* ($H_{ex} >> H_p$) (Fe, REFeAs(O,F))

-  **superconductivity** and **strong itinerant FM** *coexist and it seems that they even cooperate* (UGe_2, URhGe, UCoGe)