The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2035-1

Conference on Superconductor-Insulator Transitions

18 - 23 May 2009

Comparsion of superconductor-insulator transitions in different materials

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Superconductor – insulator transitions
in
different materials

Trieste
May 2009

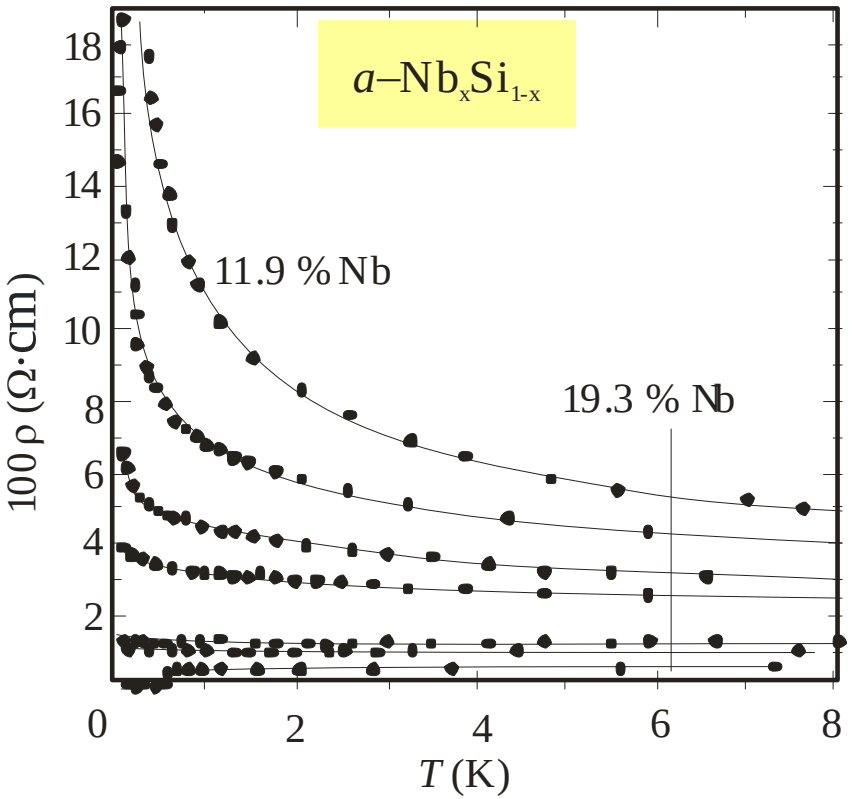
Bureaucratic classification

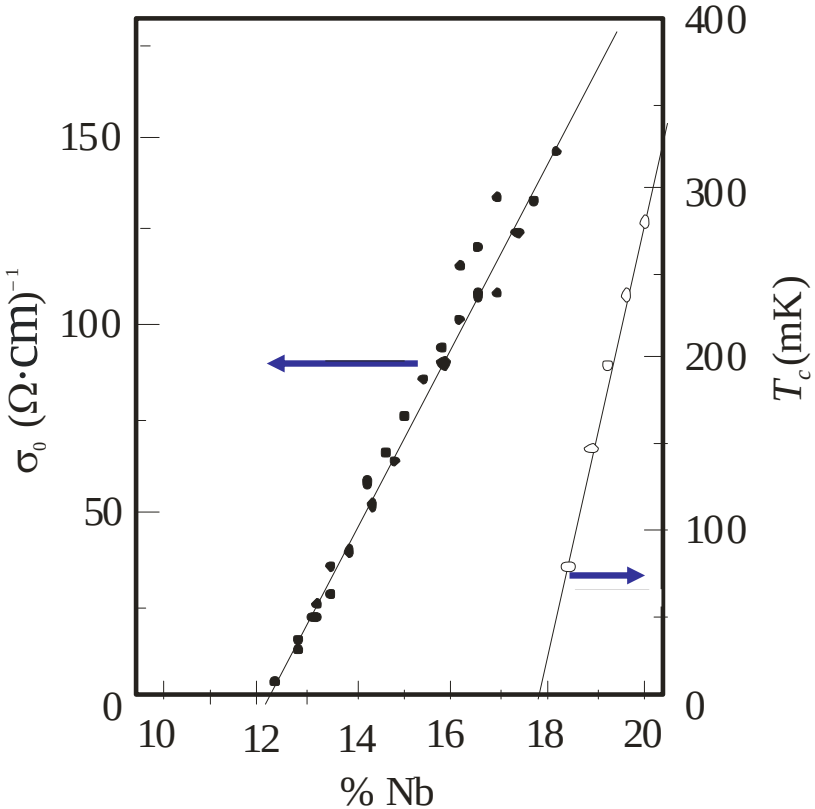
1. Ultrathin films **Bi, Be, Pb, Al, Ga, Ta**

2. Materials with variable content **InO, TiN, NbSi, MoGe, MoSi**

3. High-T_c superconductors **BiSrCaCuO, YBaCuO, LaSrCuO, NdCeCuO**

Split transition :
superconductor – normal metal – insulator





D.J. Bishop, E.G. Spencer, and R.C. Dynes,
Solid St. Electron. **28**, 735 (1985)

Let quantum phase transition

from superconducting ground state to nonsuperconducting

at $T = 0$ ***in the disordered media***

be tuned by some control parameter

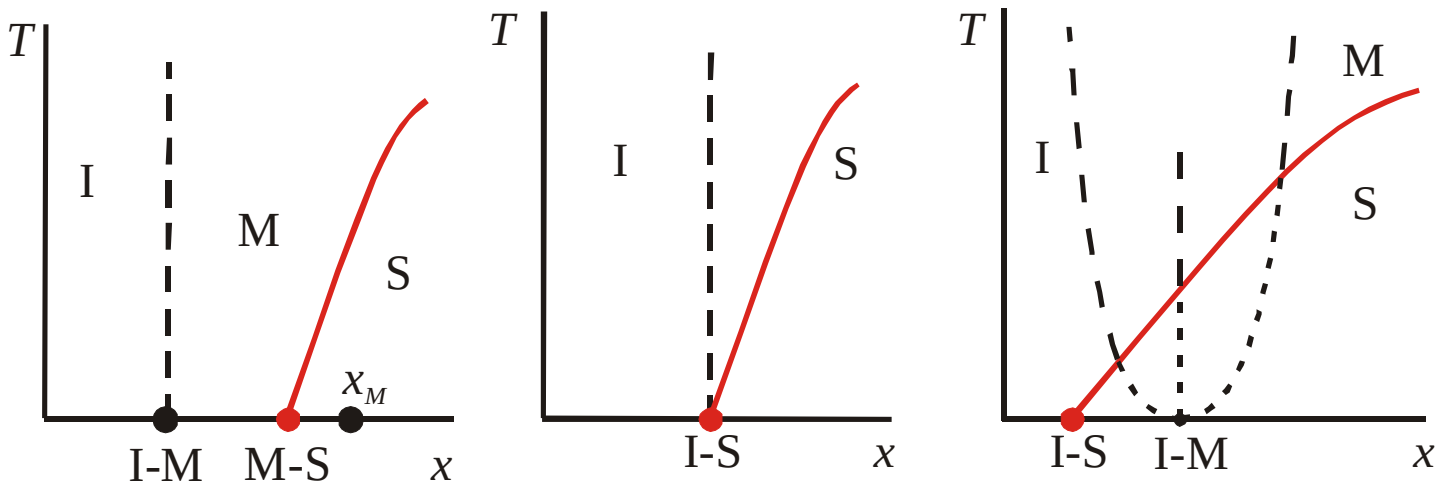
It should be compared with

Anderson normal-metal – insulator transition

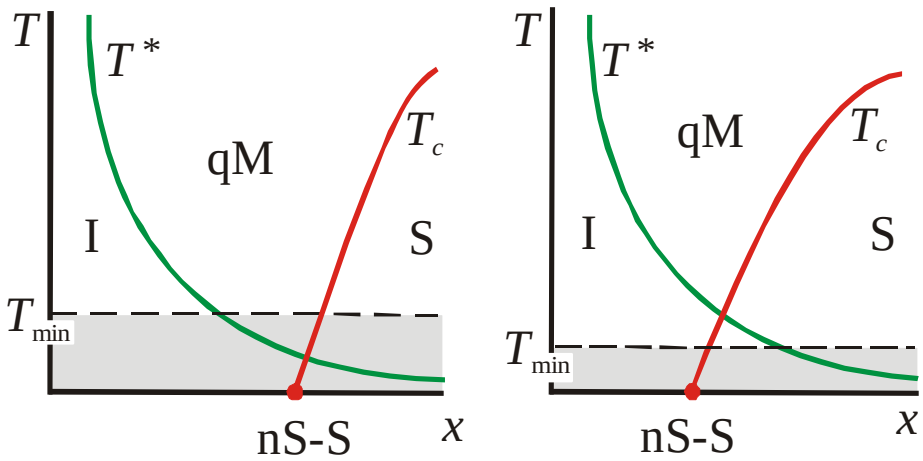
What happens first ?

Variants of the (x,T) – phase diagram

3D



2D



Bureaucratic classification

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semiBureaucratic classification

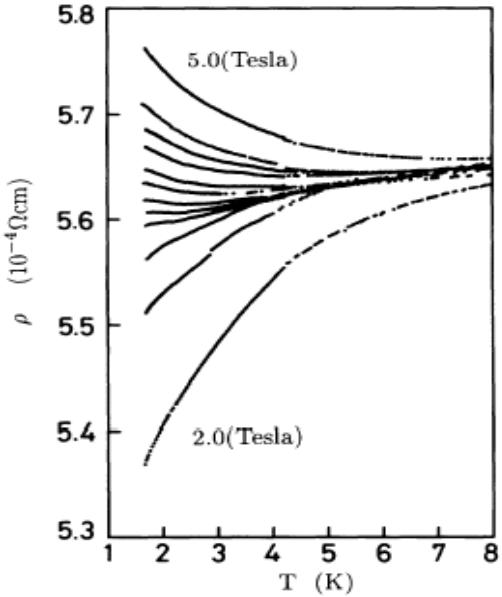
1. Ultrathin films **Bi, Be, Pb, Al, Ga,** Ta

2. Materials with variable content **InO, TiN,** NbSi, MoGe, MoSi

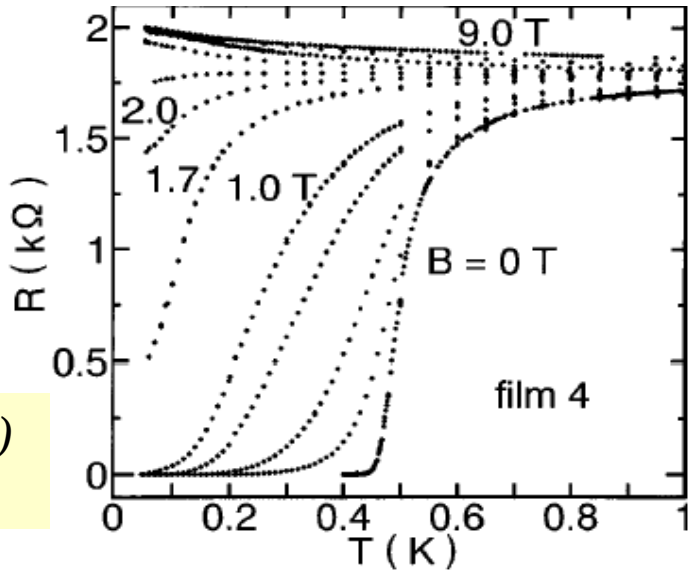
3. High-T_c superconductors **BiSrCaCuO, YBaCuO, LaSrCuO,** NdCeCuO

4. Crossover from superconductor – normal-metal to superconductor – insulator transition
Ta, NbSi, MoGe, MoSi, NdCeCuO

Transitions into "bad" metals

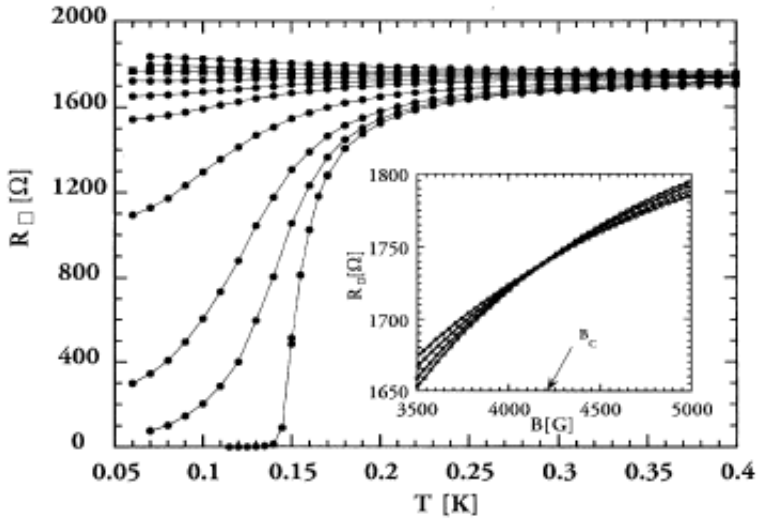


Tanda et al. (1992)
$Nd_{2-x}Ce_xCuO_4$

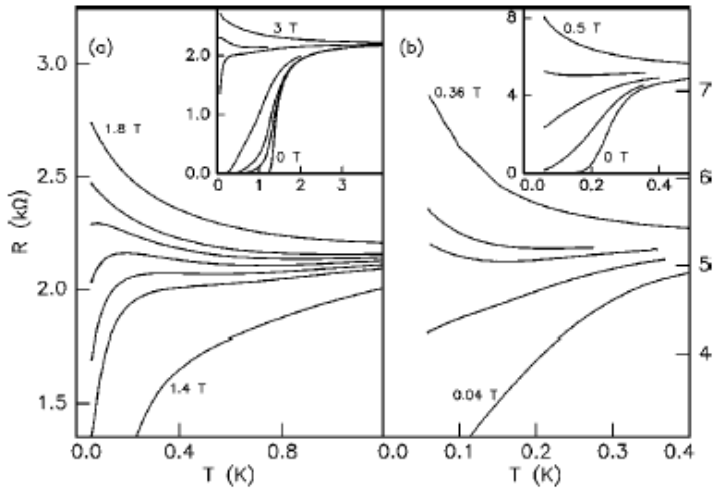


S. Okuma et al. (1998)
Mo_xSi_{1-x}

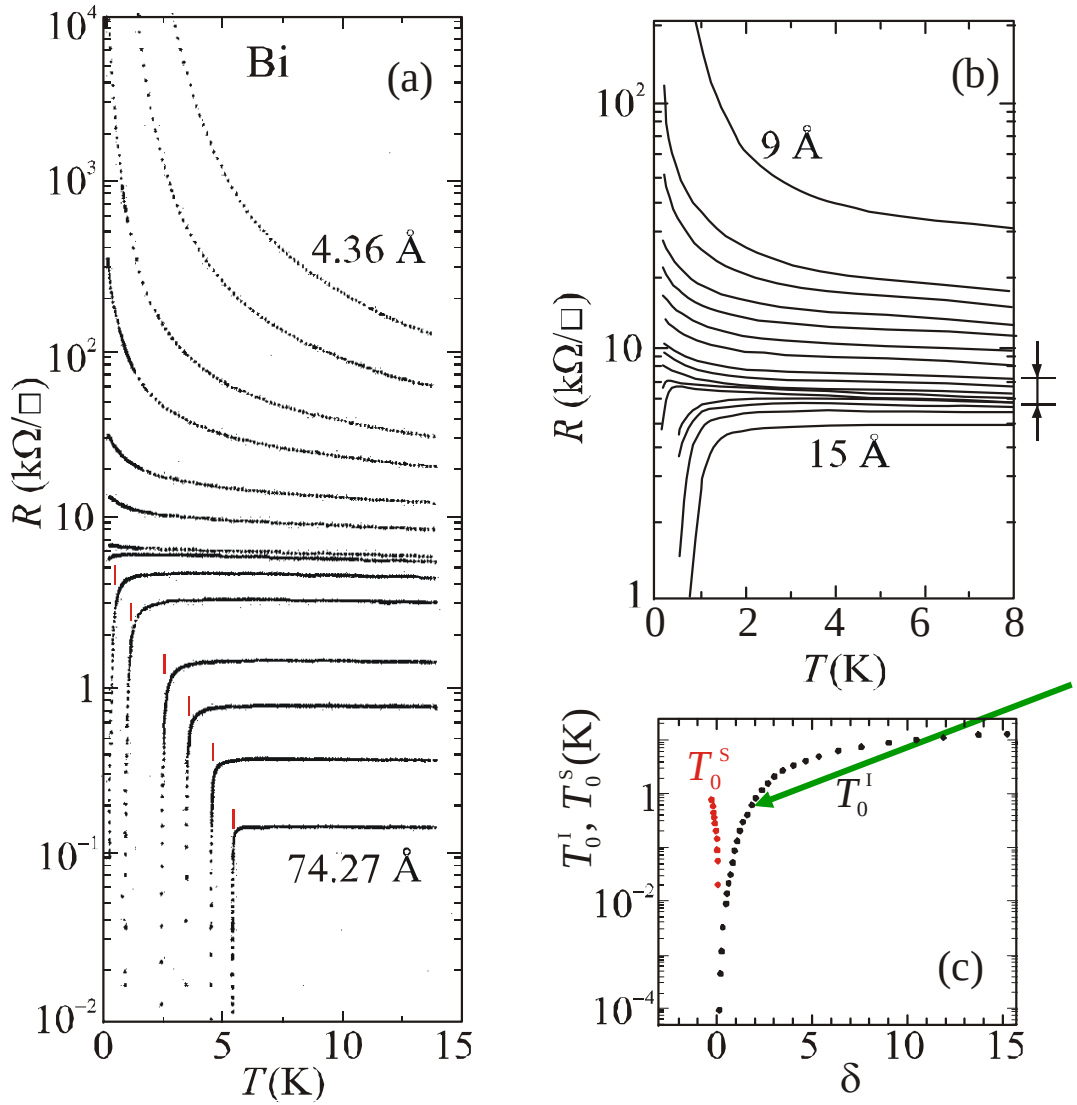
A.Yazdani and A.Kapitulnik (1995)
a-MoGe



J. A. Chervenak and J. M. Valles, Jr (2000)
Bi/Sb



Ultra thin **Bi** films – transition induced by thickness changes



Experimental curves are analysed by the help of one of these three expressions

$$g = g_0 \exp(-T_0^I / T)$$

$$g = g_0 \exp[-(T_0^I / T)^{1/2}]$$

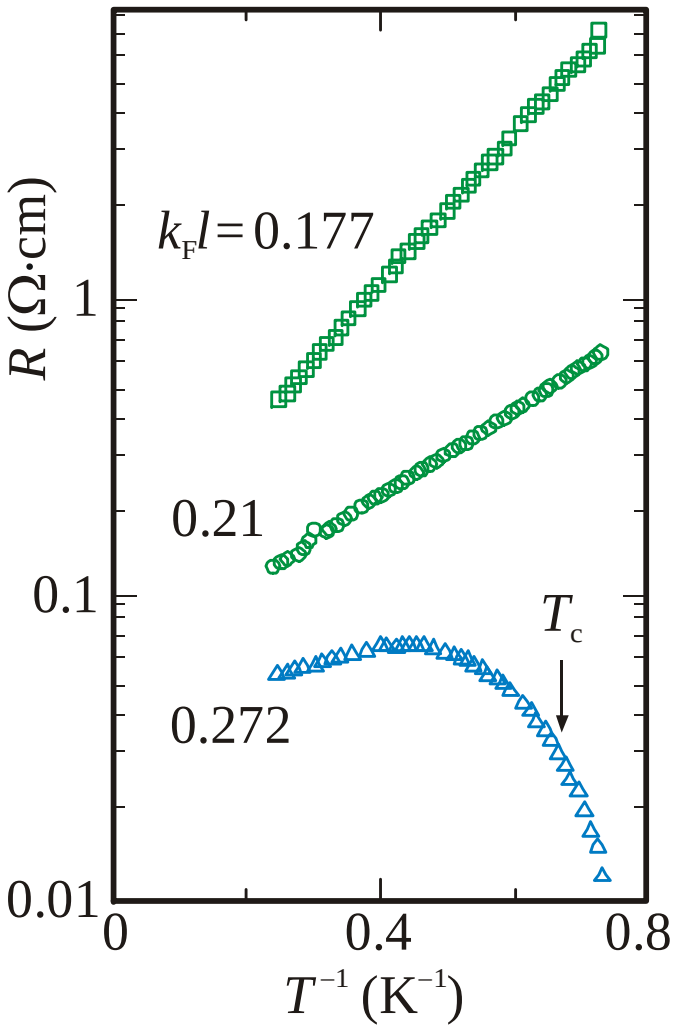
$$g = g_0 - \ln(T / T_0^I)$$

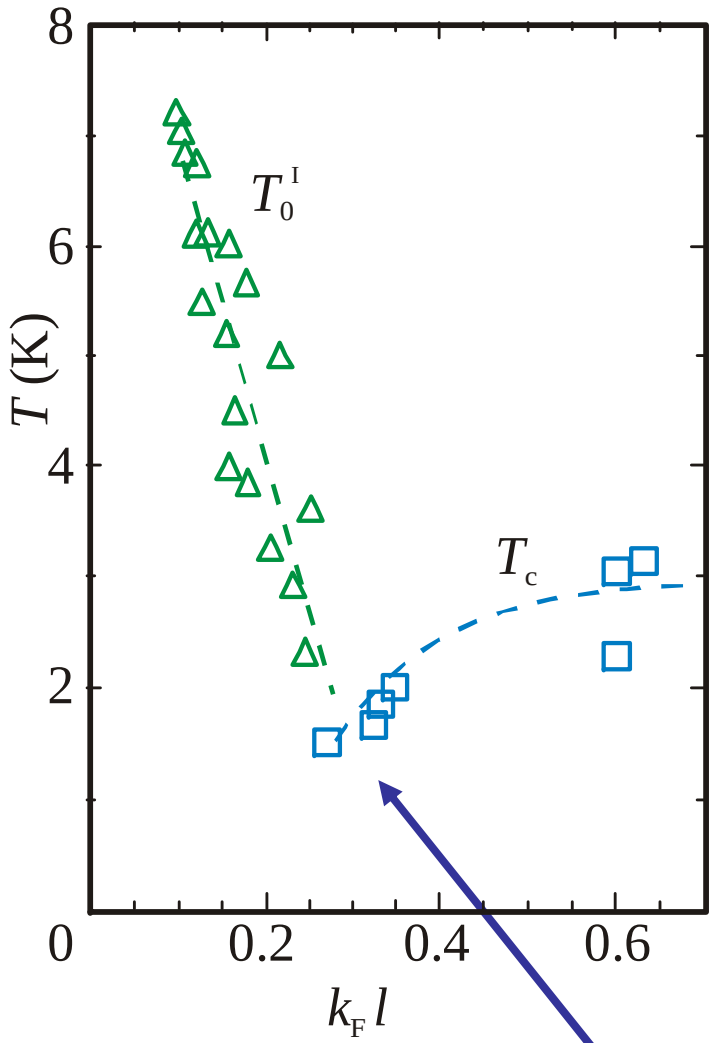
D.B. Haviland, Y. Liu, A.M. Goldman et al.,

Phys. Rev. Lett. **62**, 2180 (1989); **81**, 5217 (1998);

Phys. Rev. B **47,** 5931 (1993)

a – InO_x *films*





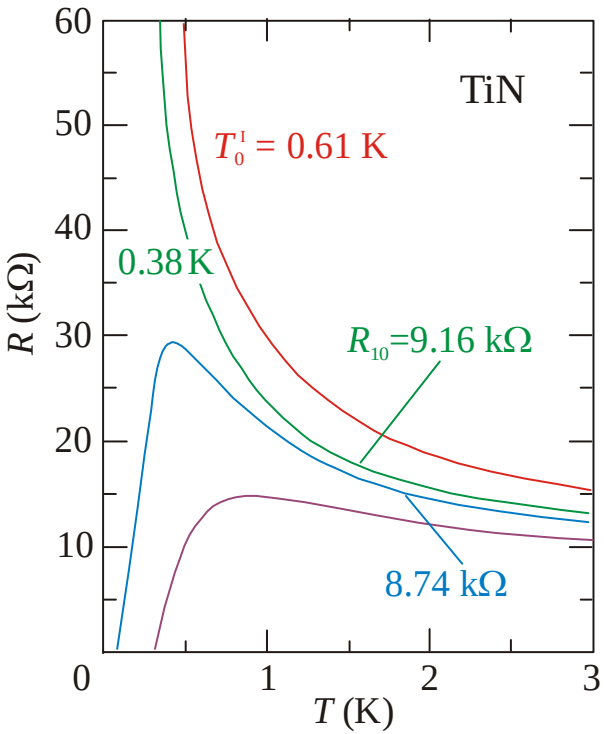
D. Shahar and Z. Ovadyahu,
Phys. Rev. B **46**, 10917 (1992)

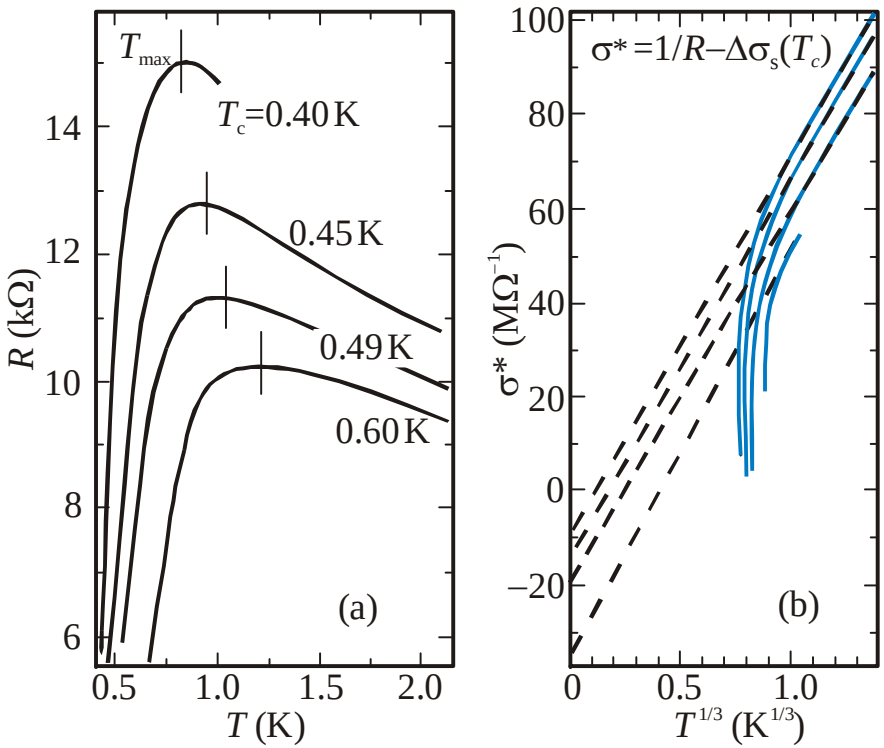
Transition is not split

TiN *films, thickness 5* nm

T.I. Baturina, A.Yu. Mironov, V.M. Vinokur, M.R. Baklanov, and C. Strunk

Phys. Rev. Lett. **99**, 257003 (2007)

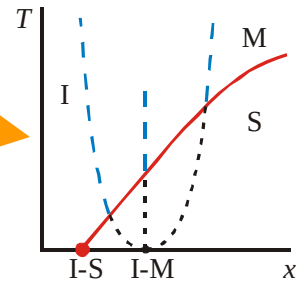




T.I. Baturina, D.R. Islamov, J. Bentner, C. Strunk, M.R. Baklanov, and A. Satta,

JETP Lett. **79**, 337 (2004)

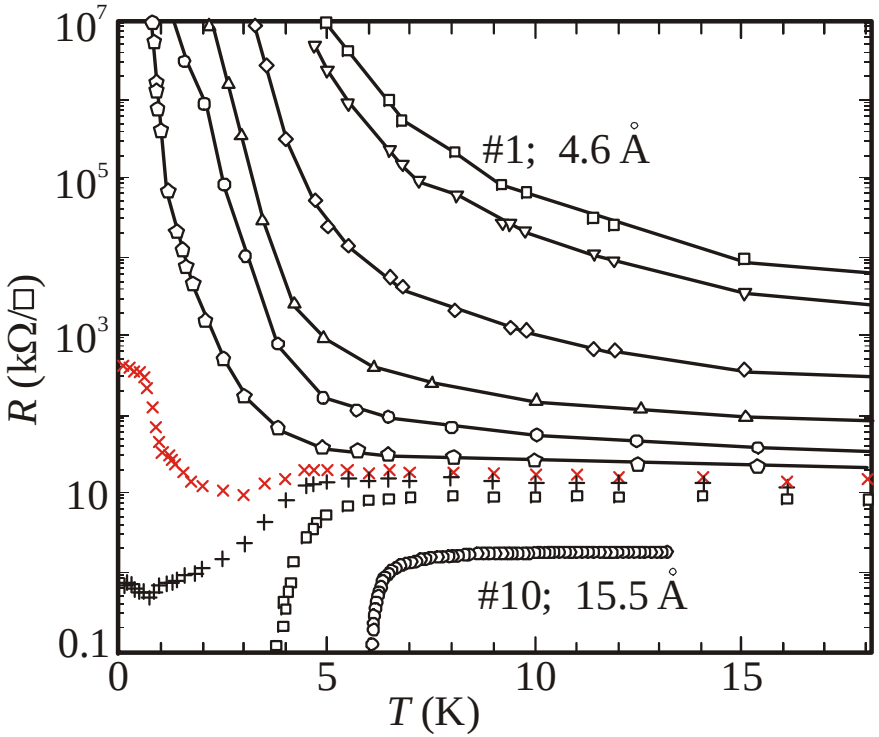
$$a + bT^{1/3}$$

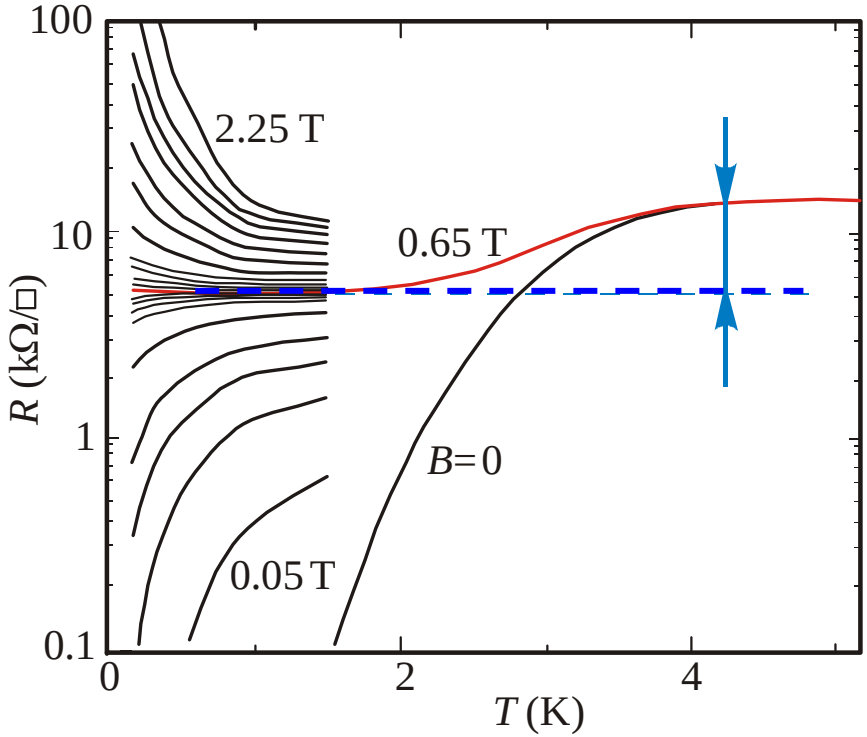


A.I. Larkin,

Ann. Phys. (Leipzig) **8**, 794 (1999)

Ultra thin **Be** films

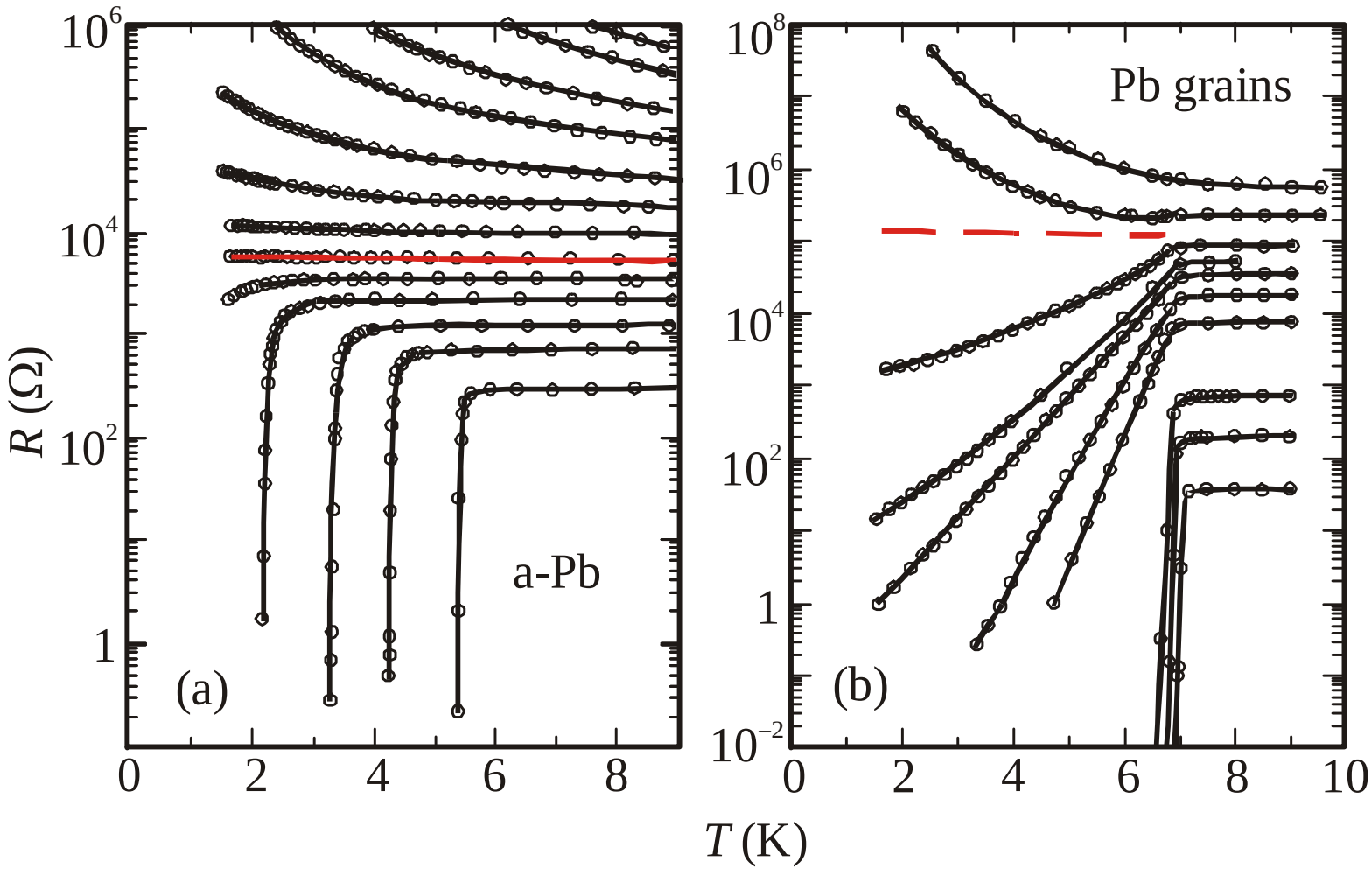




Transition induced by thickness changes

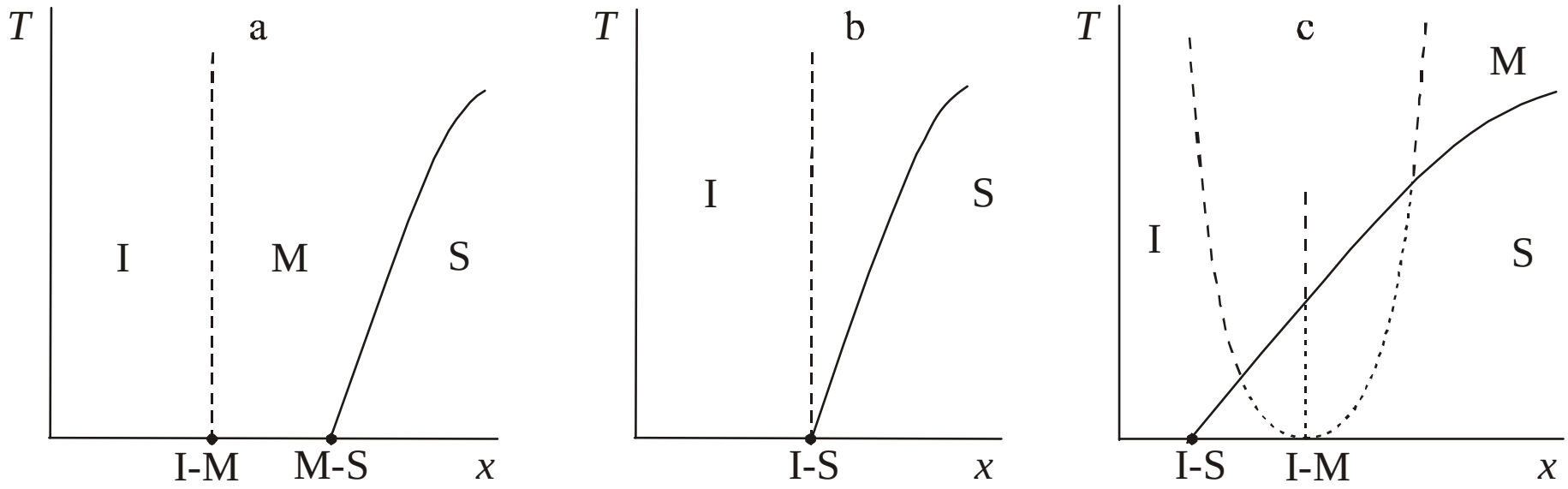
Transition induced by magnetic field

E. Bielejec and Wenhao Wu, Phys. Rev. Lett. **88**, 206802 (2002)



A. Frydman, Physica C **391**, 189 (2003)

Three different phase transition diagrams



split ***single*** ***overlapped***

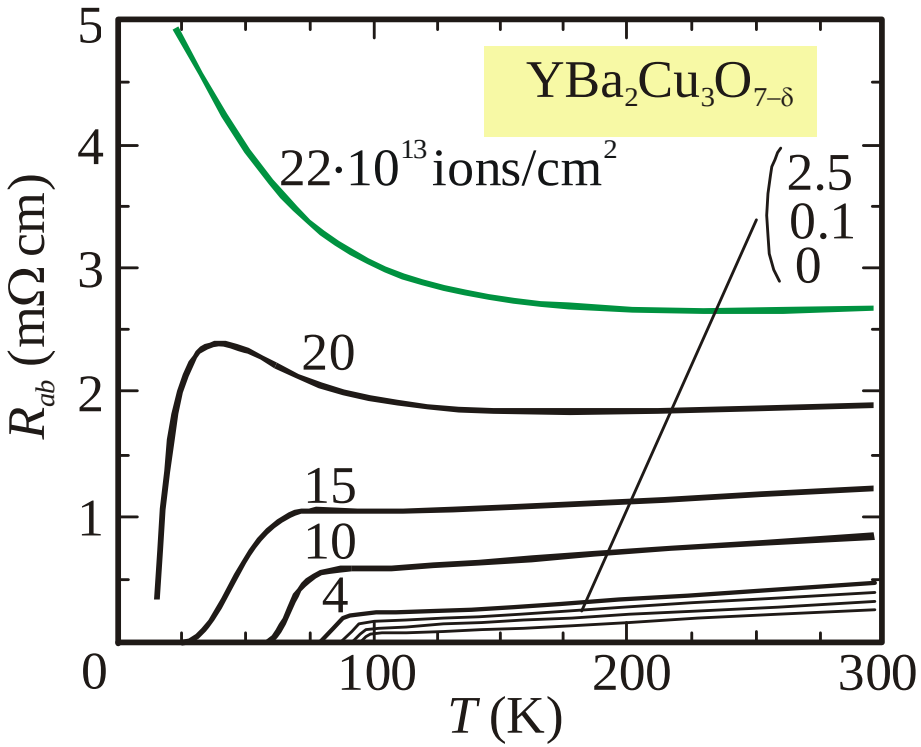
Nb_xSi_{1-x} ***a*-Bi** **TiN_x**

NdCeCuO **InO_x**

Ta ?? ***a*-Be**

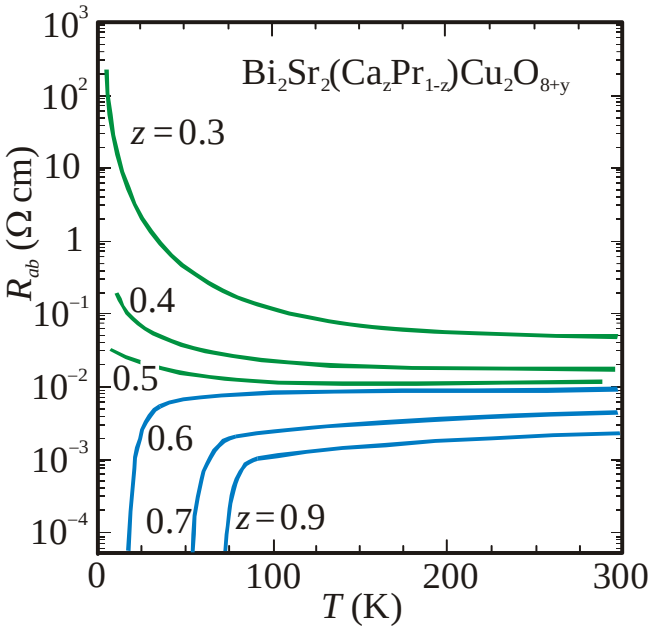
S – I transitions in High-T_c Superconductors

High-T_c superconductivity to arise the complicate anisotropic crystalline field is necessary



J.M. Valles, Jr., A.E. White, K.T Short, R.C. Dynes, J.P.Garno, A.F.J. Levi, M. Anzlowar, and K. Baldwin,

Phys. Rev. B **39**, 11599 (1989)

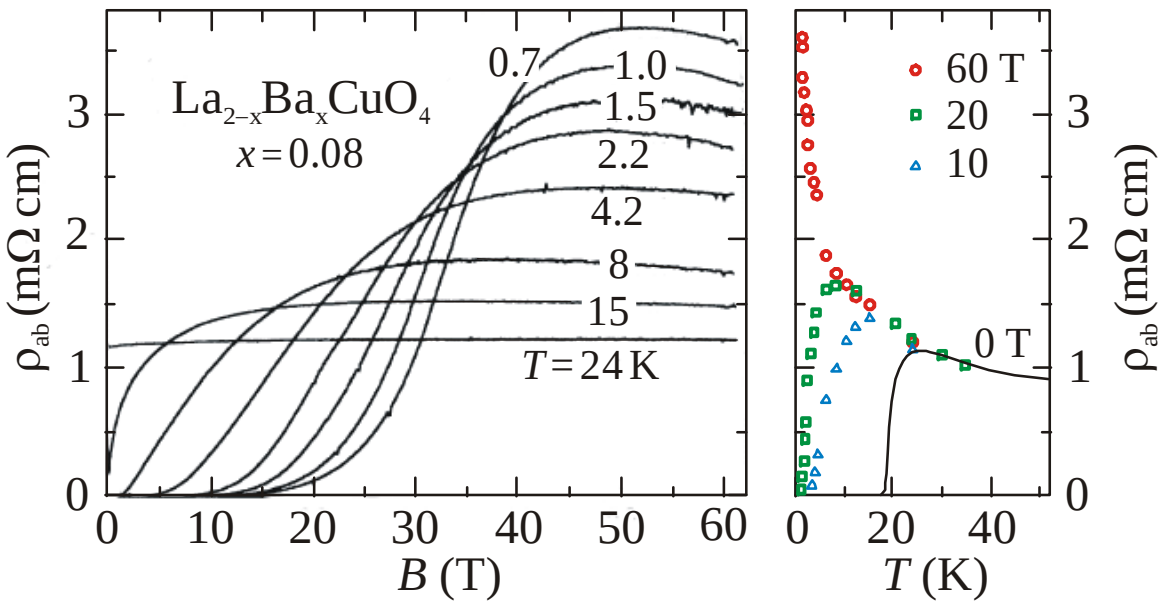


Transition induced by underdoping

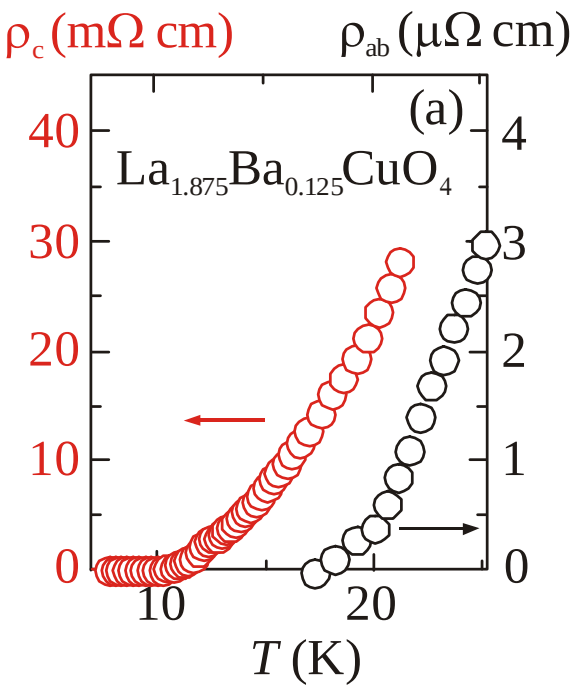
B. Beschoten, S. Sadewasser, G. Guntherodt, and C. Quitmann,
Phys. Rev. Lett. **77**, 1837 (1996)

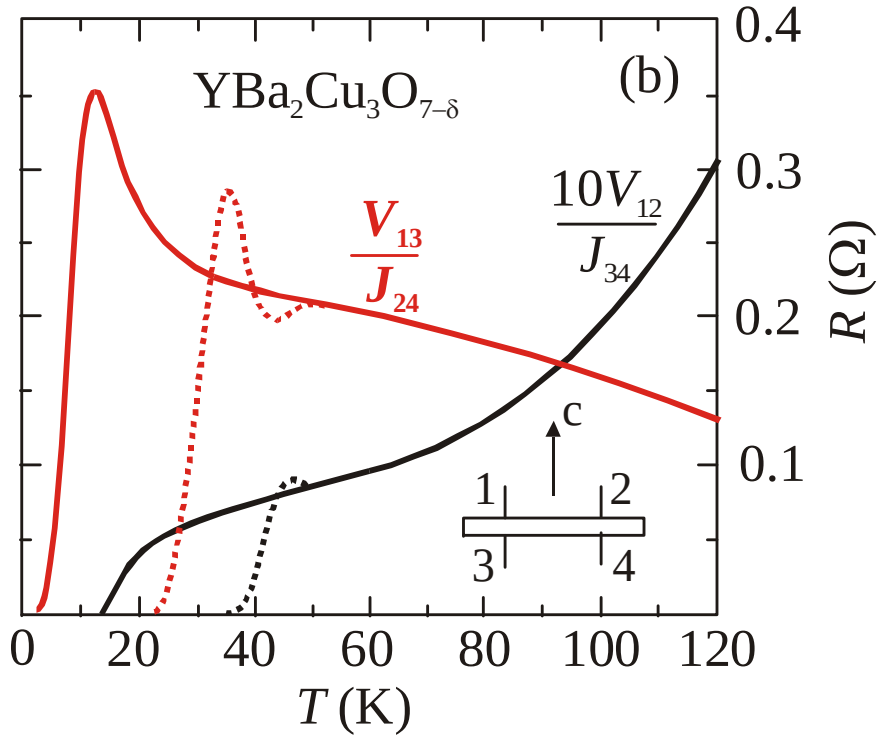
Field induced transition

Y. Ando, G.S. Boebinger, A. Passner, T. Kimura, and K. Kishio,
Phys. Rev. Lett. **75**, 4662 (1995)



Friedel effect





Q. Li, M. Huecker, G.D. Gu, A.M. Tsvelik, and J.M. Tranquada,
Phys. Rev. Lett 99, 067001 (2007)

V.N. Zverev, D.B. Shovkun, I.G. Naumenko,
JETP Lett. **68**, 332 (1998)

Two possible scenarios

The order parameter $\Phi(\mathbf{r}) = \Delta \exp(i\varphi(\mathbf{r}))$

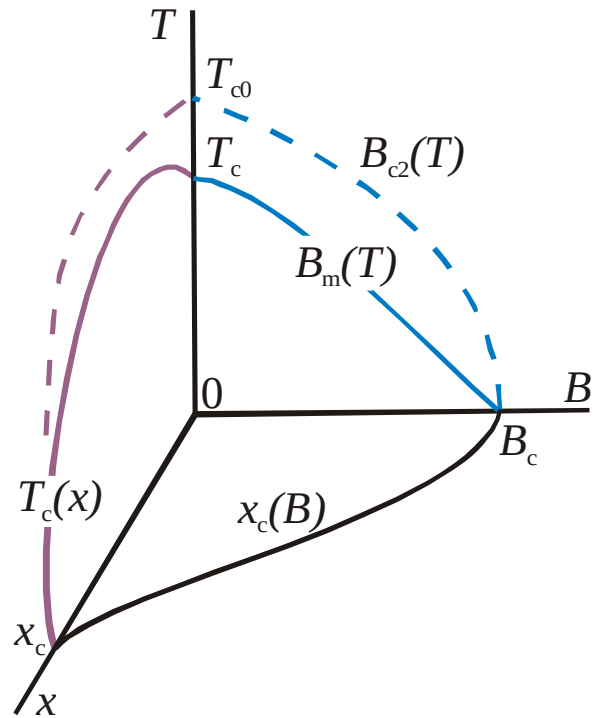
Fermionic scenario

$$\Delta \to 0$$

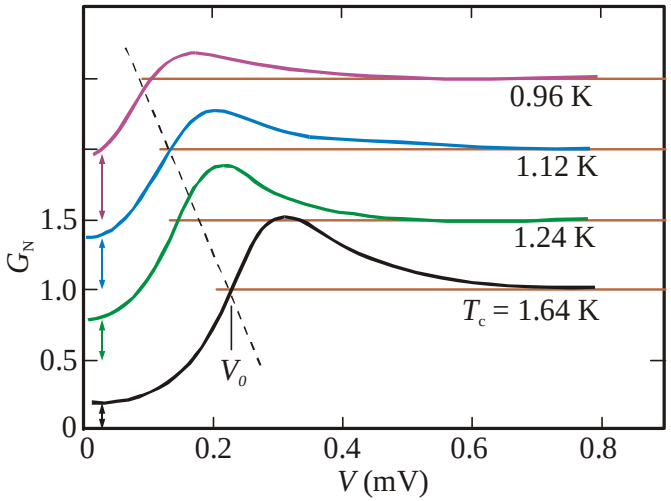
Bosonic scenario

Δ *remains finite, but*

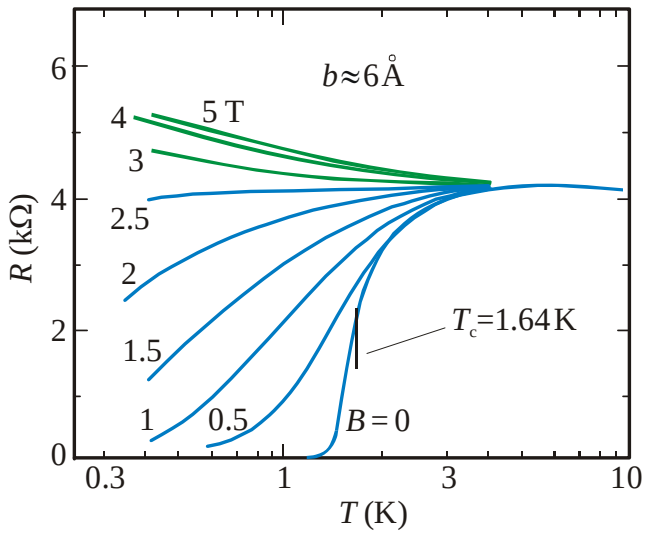
$$G(\mathbf{r}) = \langle \Phi(\mathbf{r})\Phi(0) \rangle \to 0 \quad \textit{when} \quad |\mathbf{r}| \to \infty$$

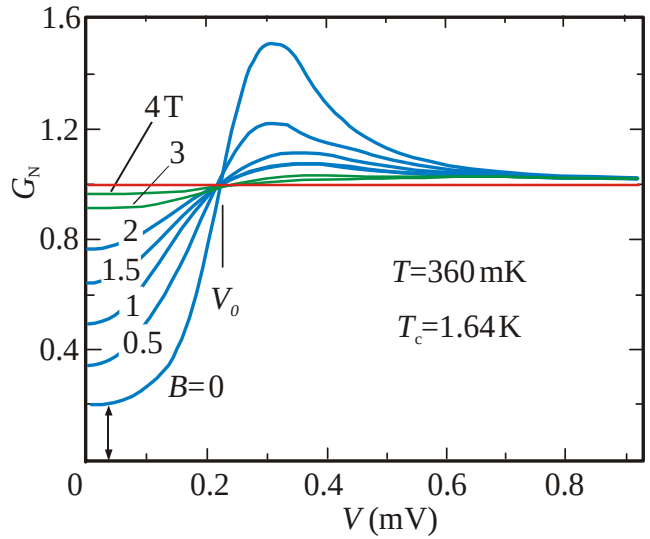


Ultrathin **Bi** *films – tunnel measurements*



Four films of different thickness in zero magnetic field

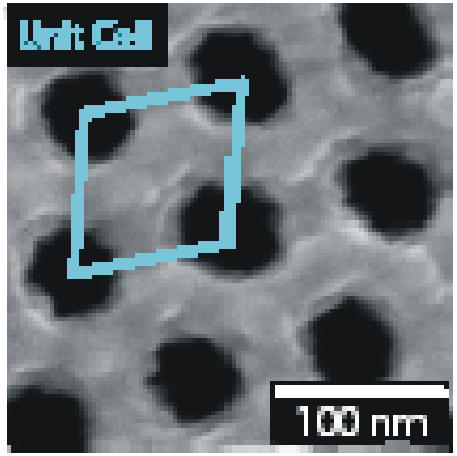


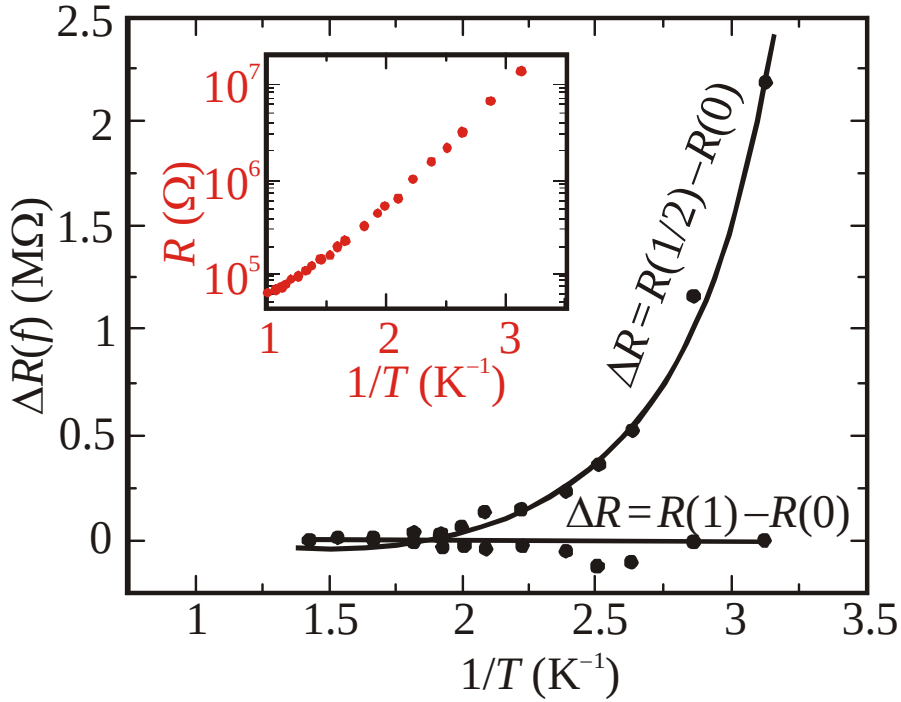


Field dependence for one of these films

S.-Y. Hsu, J.A. Chervenak, and J.M. Valles, Jr., Phys. Rev. Lett. **75,** 132 (1995)

Finite ξ of localized superconducting pairs

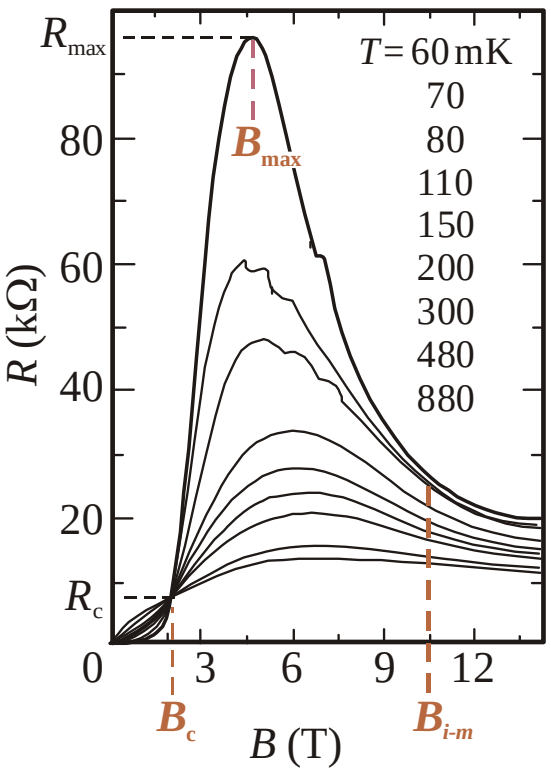




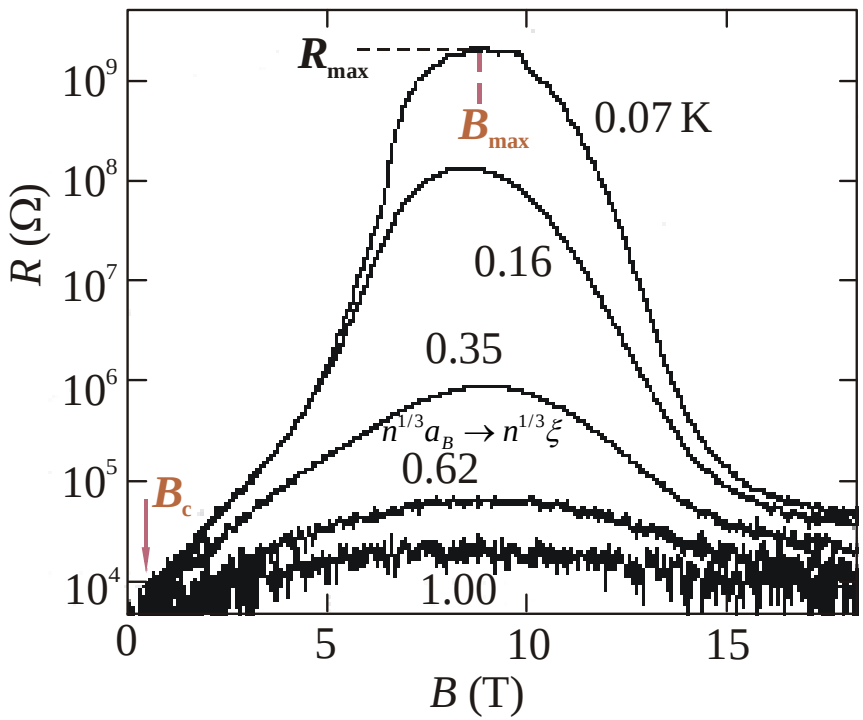
M.D. Steward Jr, A. Yin, J.M. Xu, and J.M. Valles Jr,

Science **318**, 1273 (2007)

Negative magnetoresistance in InO films



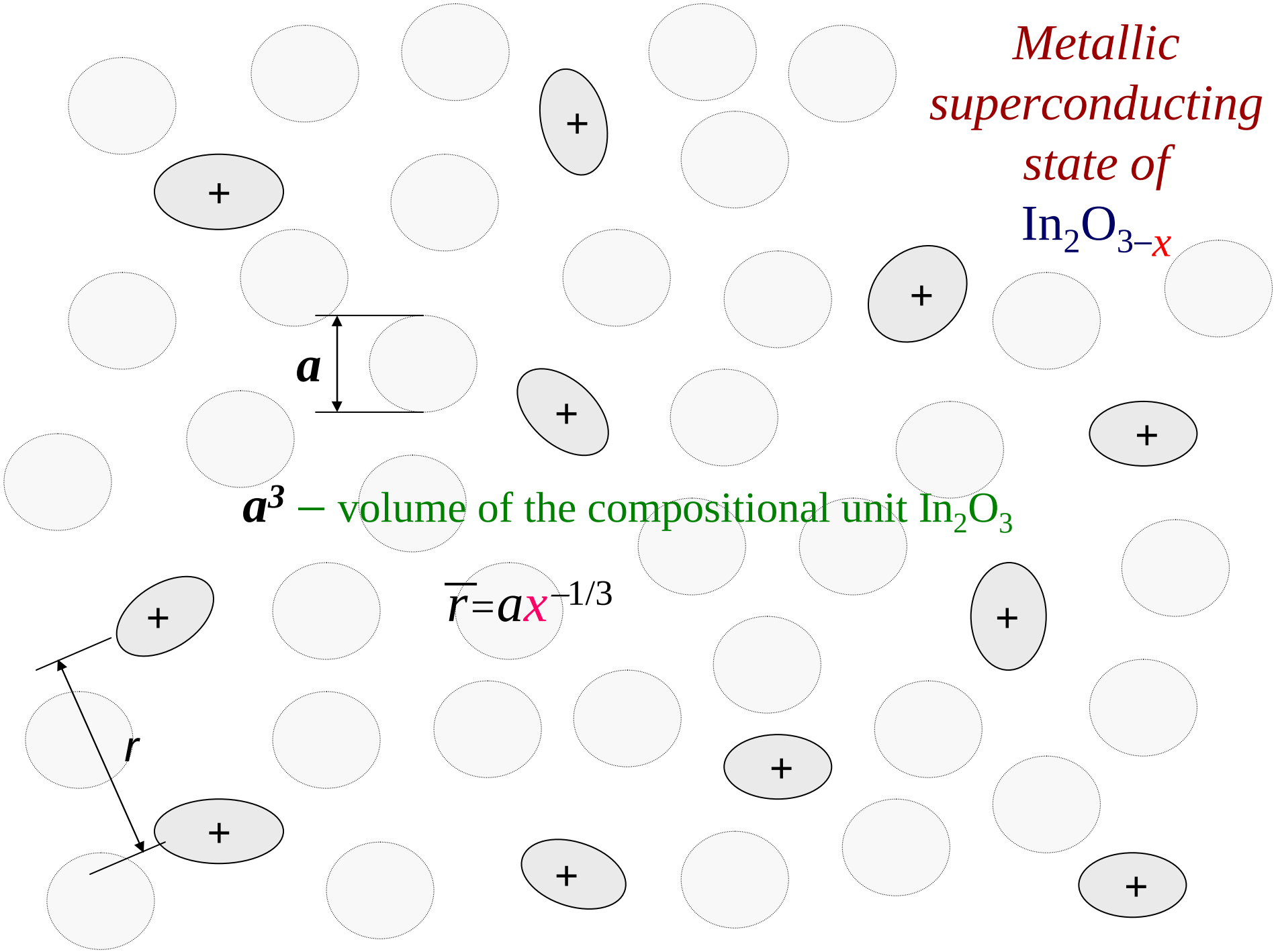
V.F. Gantmakher, M.V. Golubkov, V.T. Dolgopolov, A.A. Shashkin, and G.E. Tsydynzhapov,
JETP Lett. **71**, 473 (2000)



G. Sambandamurthy, L.W. Engel, A. Johansson, and D. Shahar,
Phys. Rev. Lett. **92**, 107005 (2004)

$B_{max} >> B_c$ $\qquad n^{1/3}a_B \to n^{1/3}\xi$ $\qquad \xi = \xi(B - B_c, \varepsilon(B))$

Metallic superconducting state of In_2O_{3-x}



a^3 – volume of the compositional unit In_2O_3

$$\overline{r} = a x^{-1/3}$$