

Little-Parks Oscillations in an Insulator

Dan Shahar

The Weizmann Institute

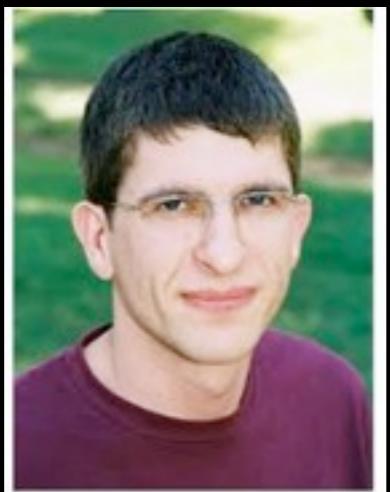


Argonne, 2012



Benjamin Sacépé's

(CNRS Grenoble)



Gregory Kopnov
(LMCMI Toulouse)

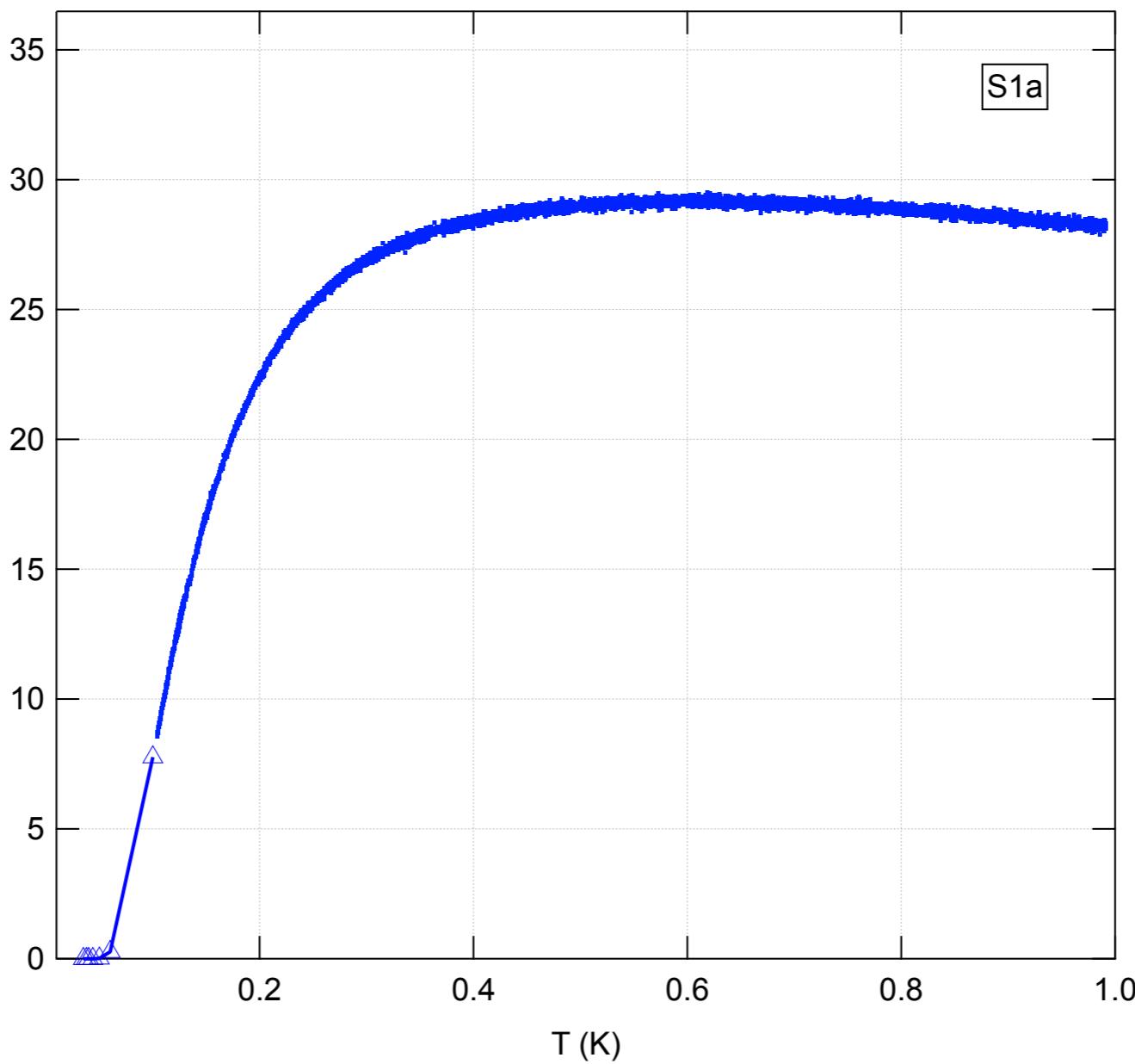


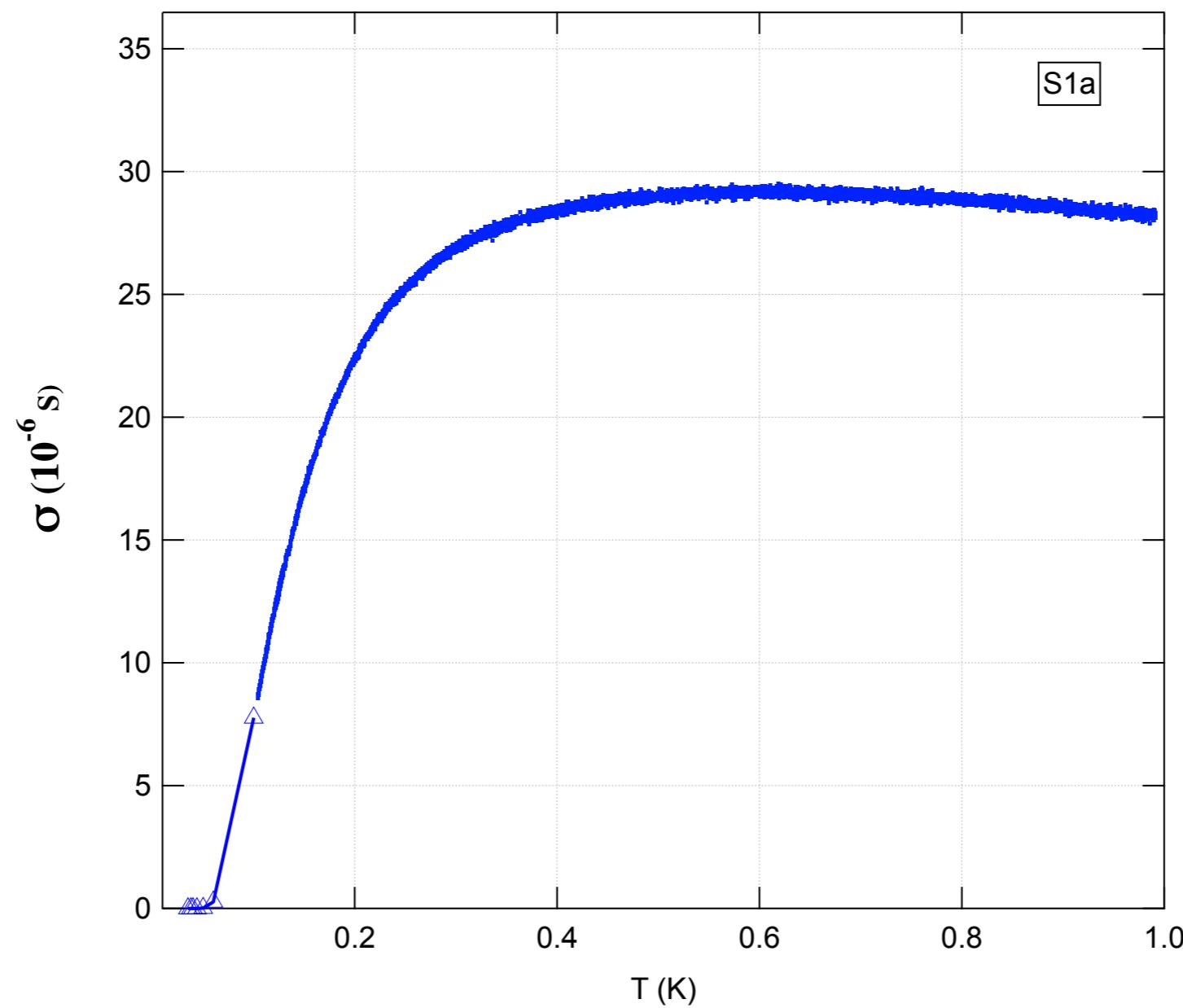
Maoz Ovadia

Weizmann

David Kalok

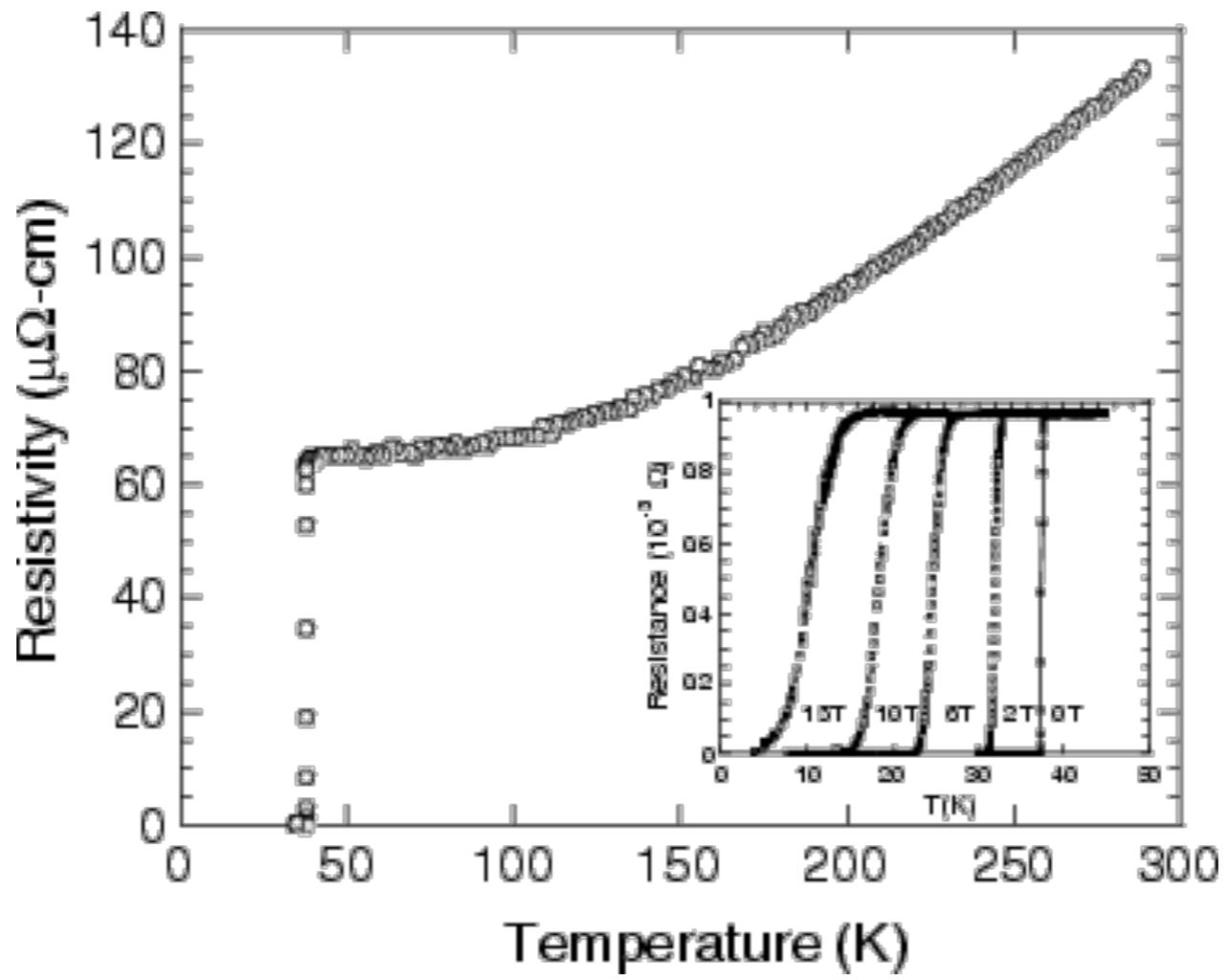




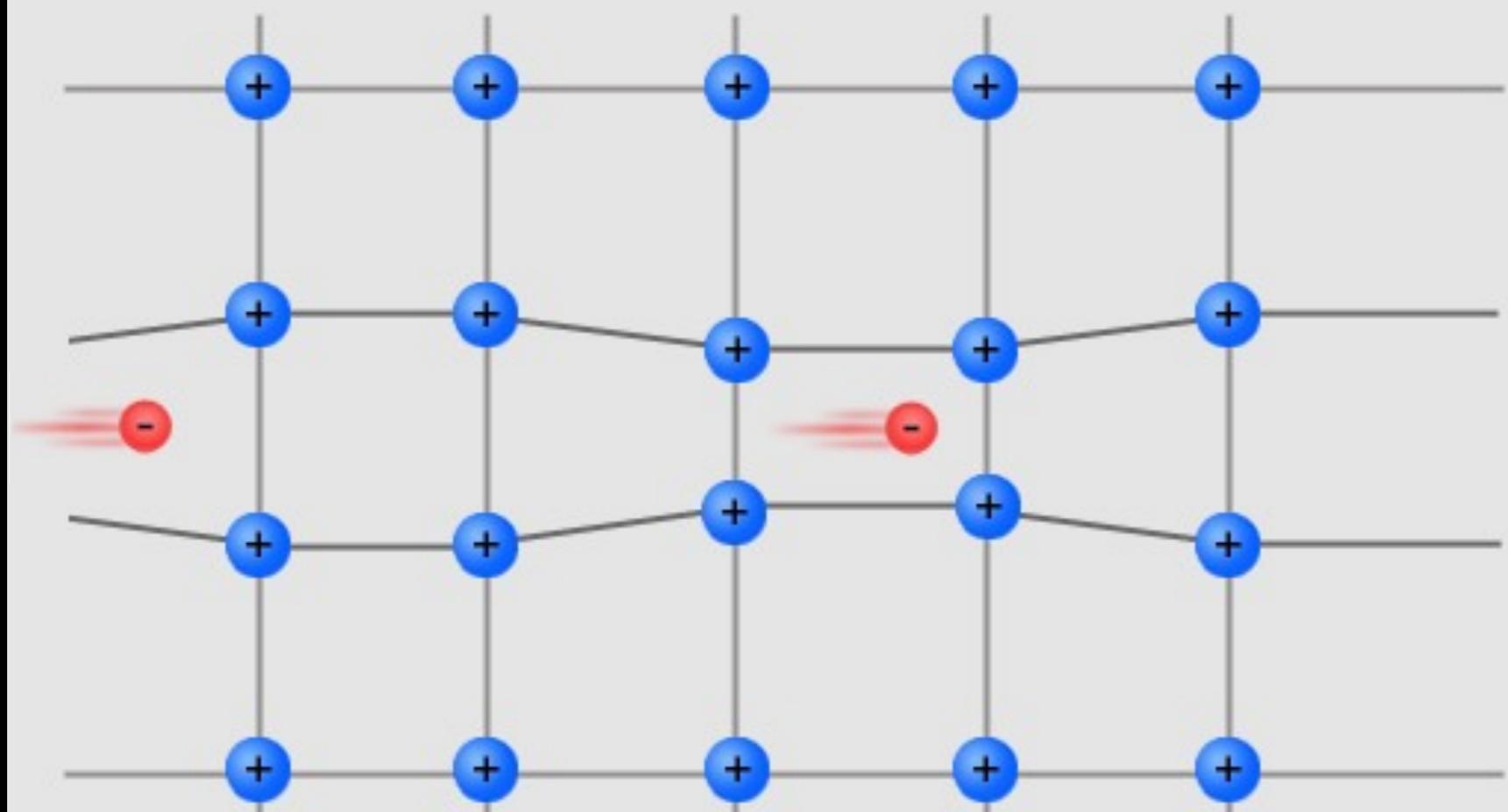


Introduction

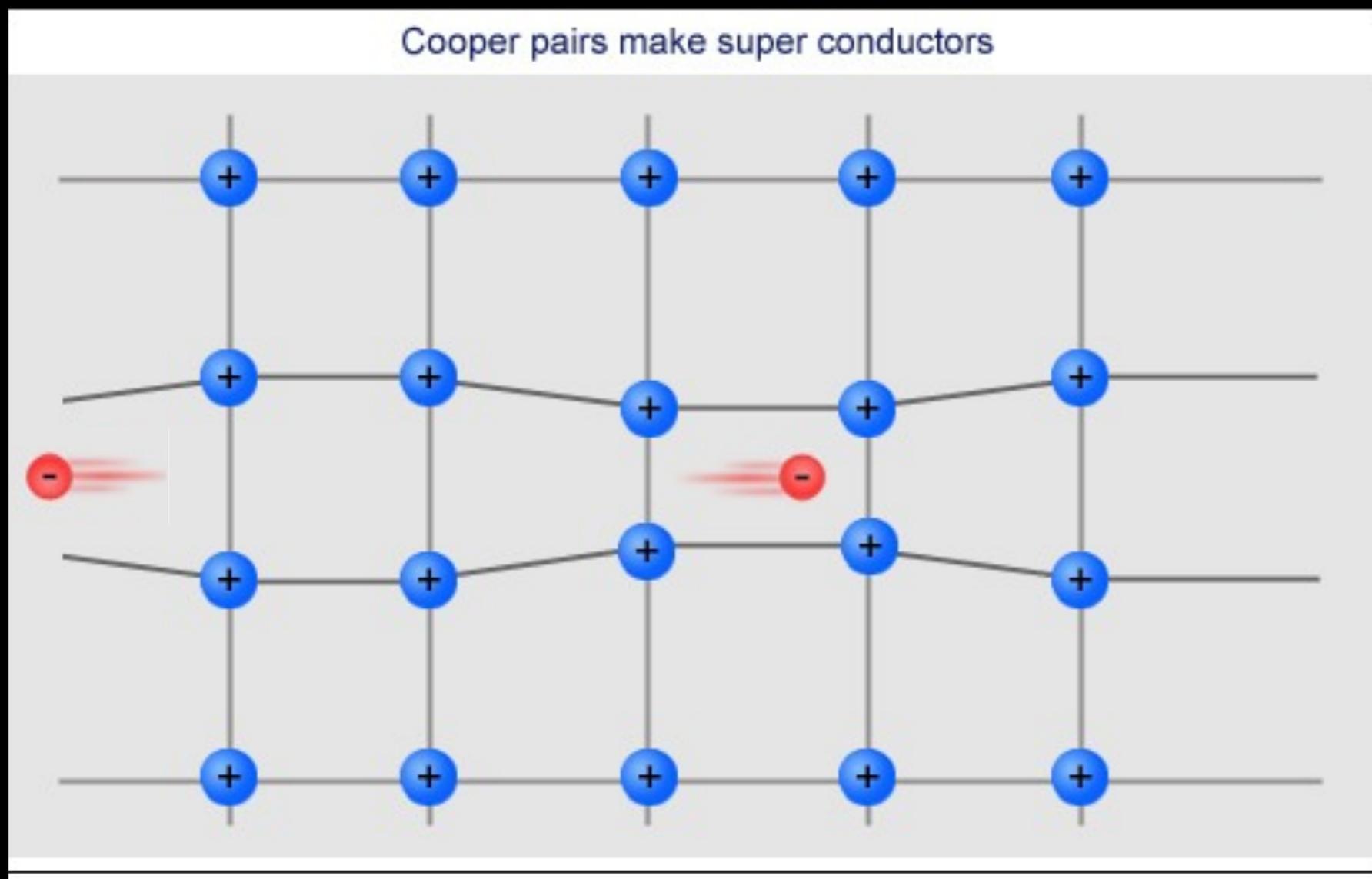
Superconductivity



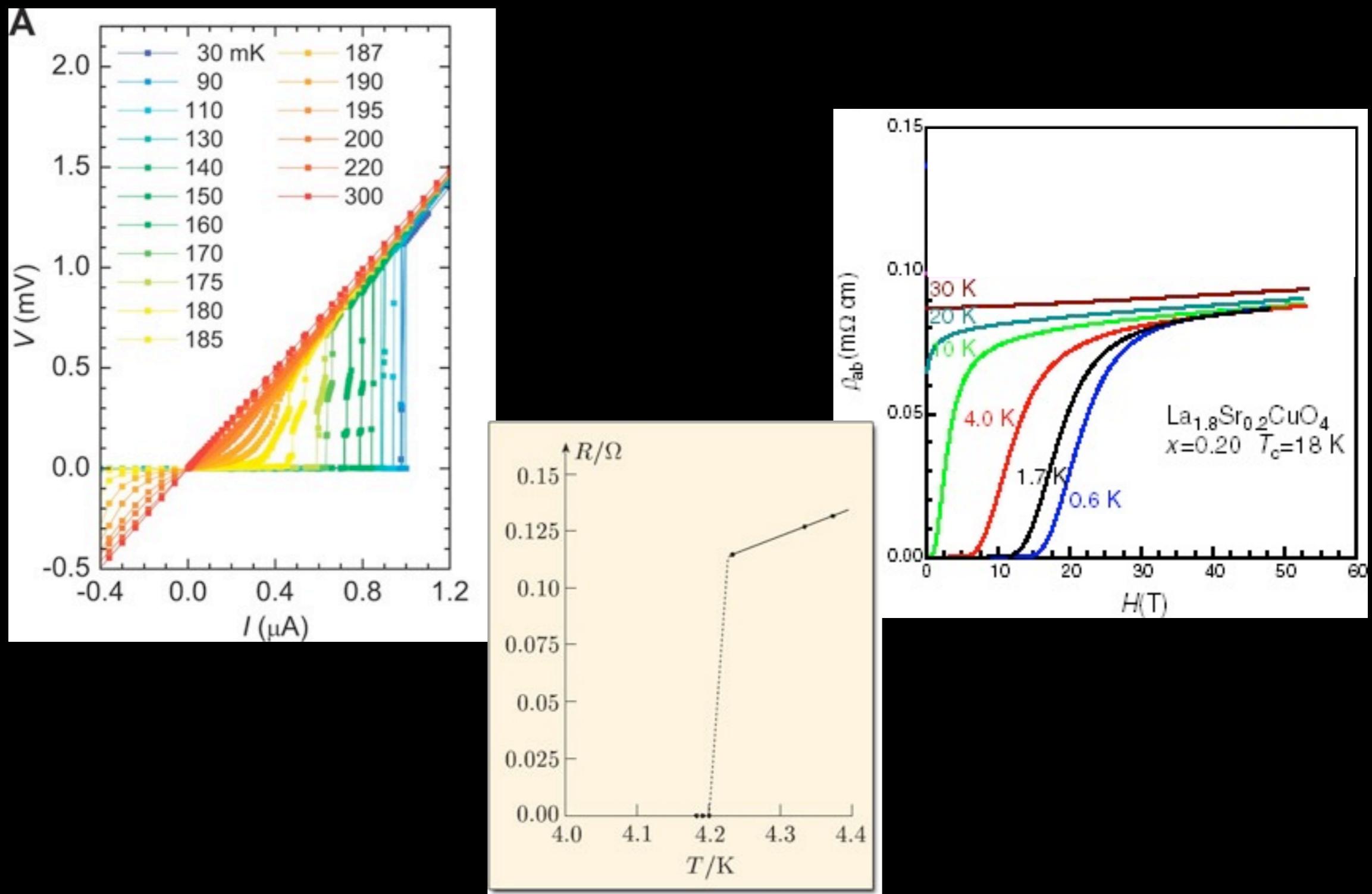
Cooper pairs make super conductors



$$|k\uparrow\rangle, |-k\downarrow\rangle$$



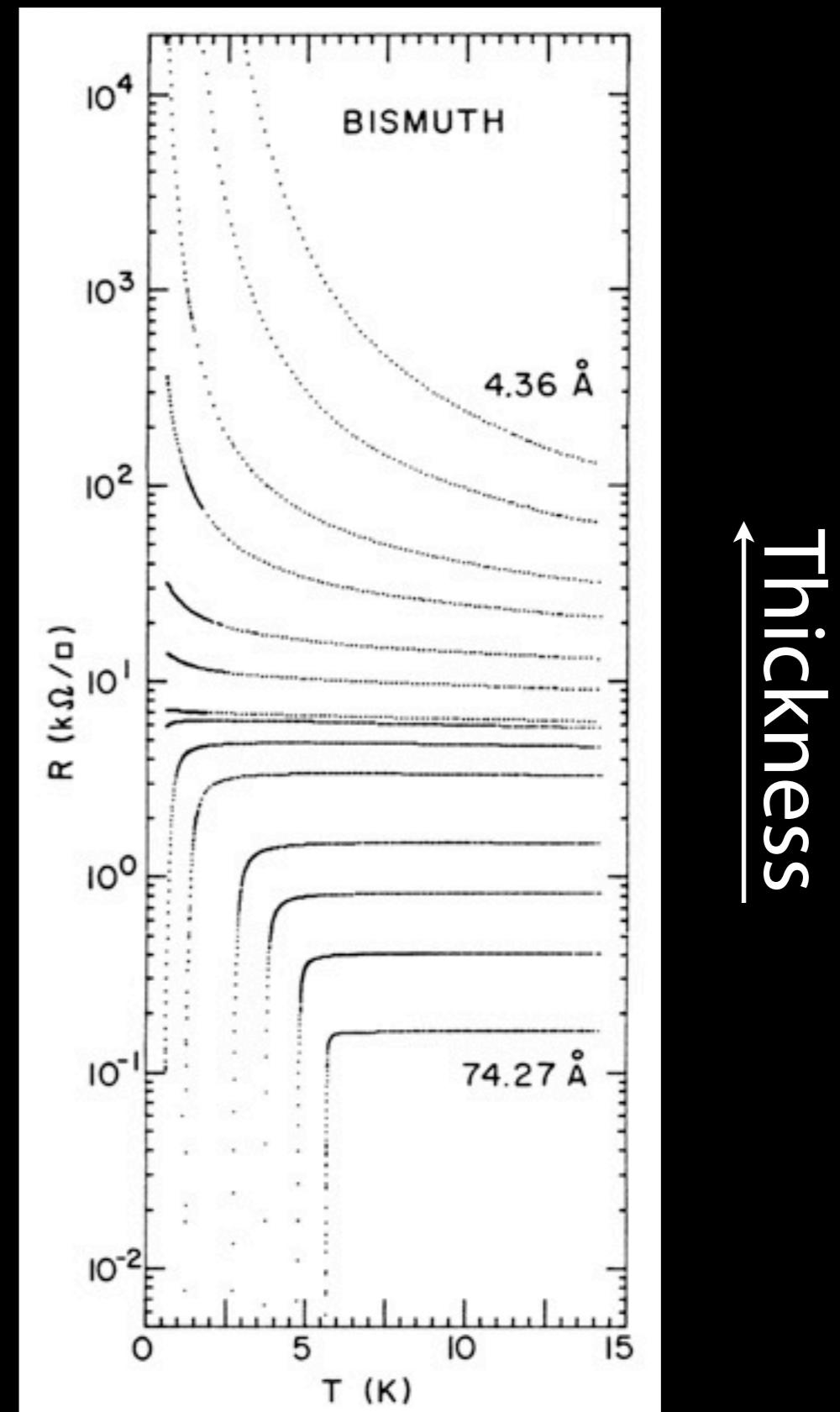
Destroying superconductors



M. Strongin, et. al., Phys. Rev. B1, 1078 (1970).

Haviland, Liu and Goldman,
Phys. Rev. Lett. 62, 2180 (1989)...

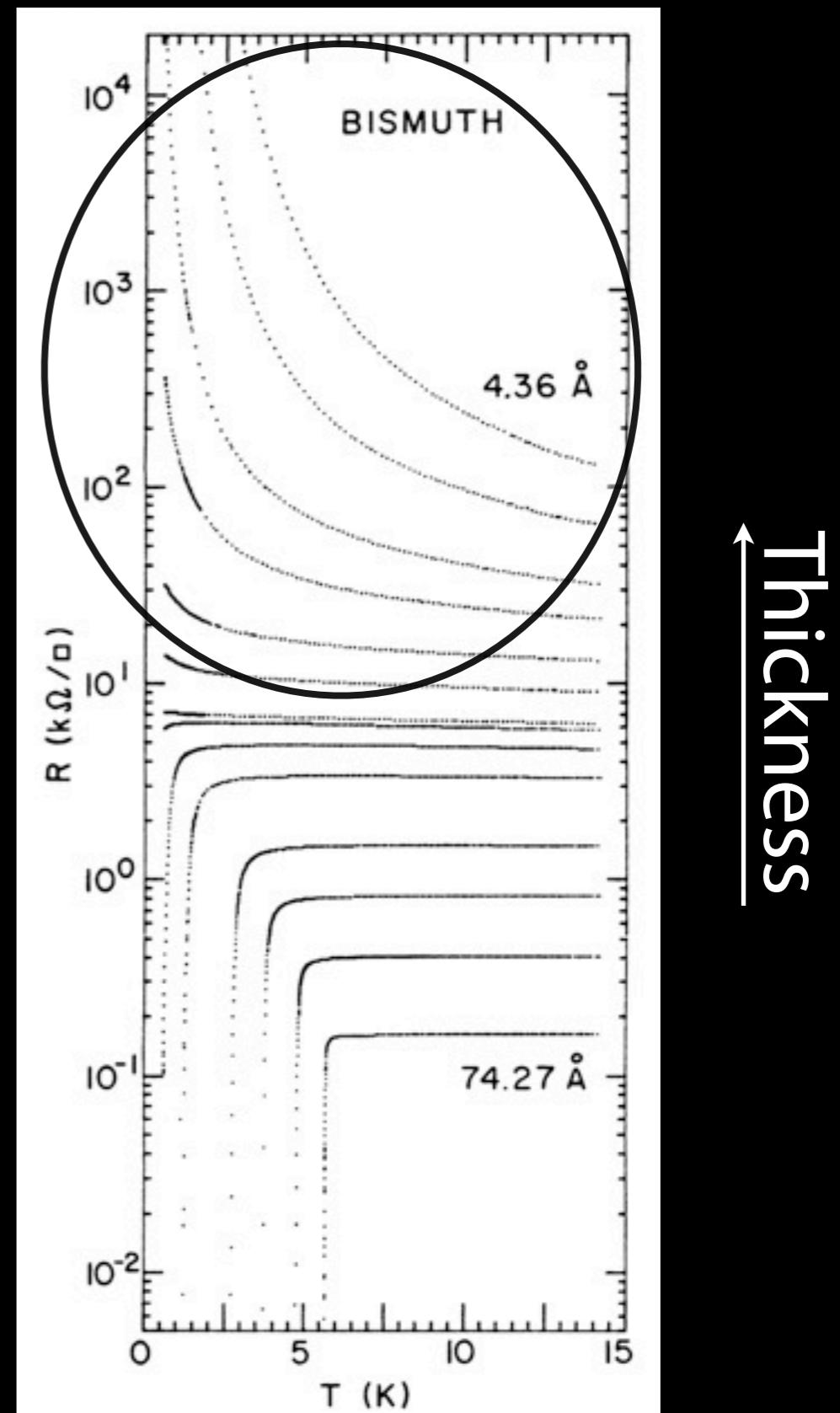
Reviews: Finkl'stein ('94)
Markovic and Goldman ('98)
Gantmakher and Dolgopolov ('10)



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Reviews: Finkl'stein ('94)
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Where is the normal state?

VOLUME 42, NUMBER 10

PHYSICAL REVIEW LETTERS

5 MARCH 1979

Scaling Theory of Localization: Absence of Quantum Diffusion in Two Dimensions

E. Abrahams

Serin Physics Laboratory, Rutgers University, Piscataway, New Jersey 08854

and

P. W. Anderson,^(a) D. C. Licciardello, and T. V. Ramakrishnan^(b)

Joseph Henry Laboratories of Physics, Princeton University, Princeton, New Jersey 08540

(Received 7 December 1978)

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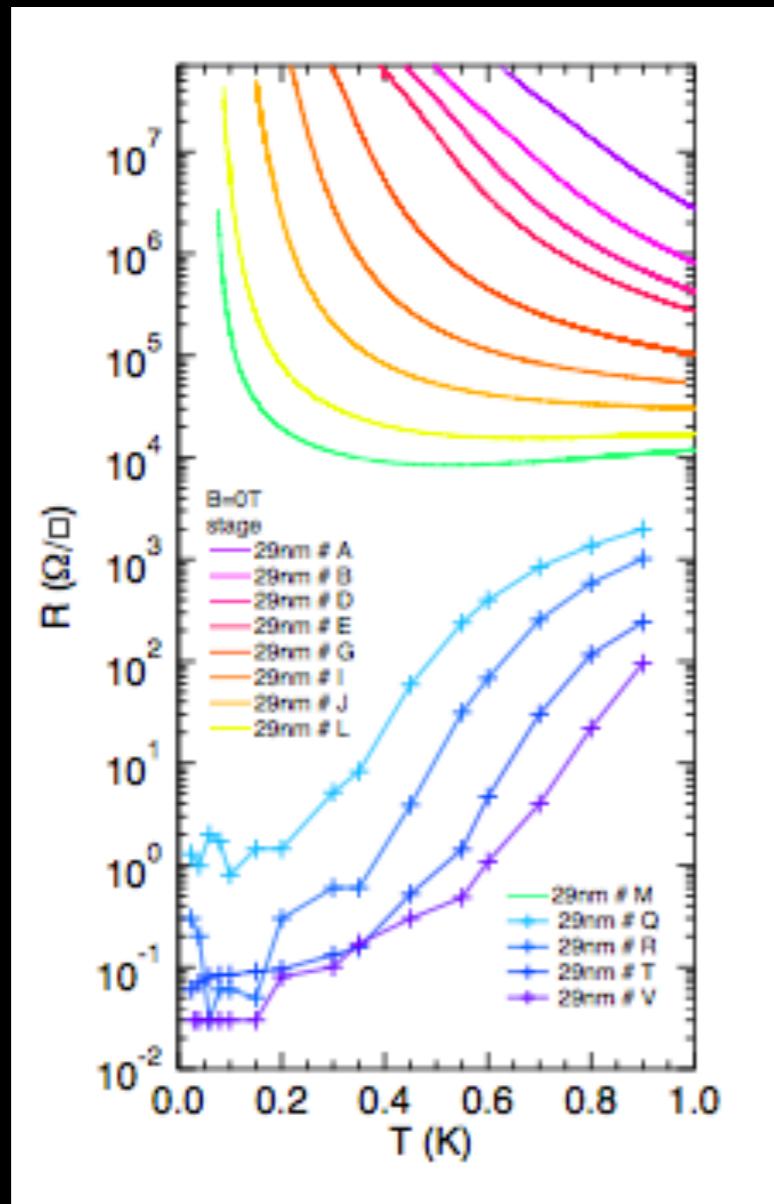
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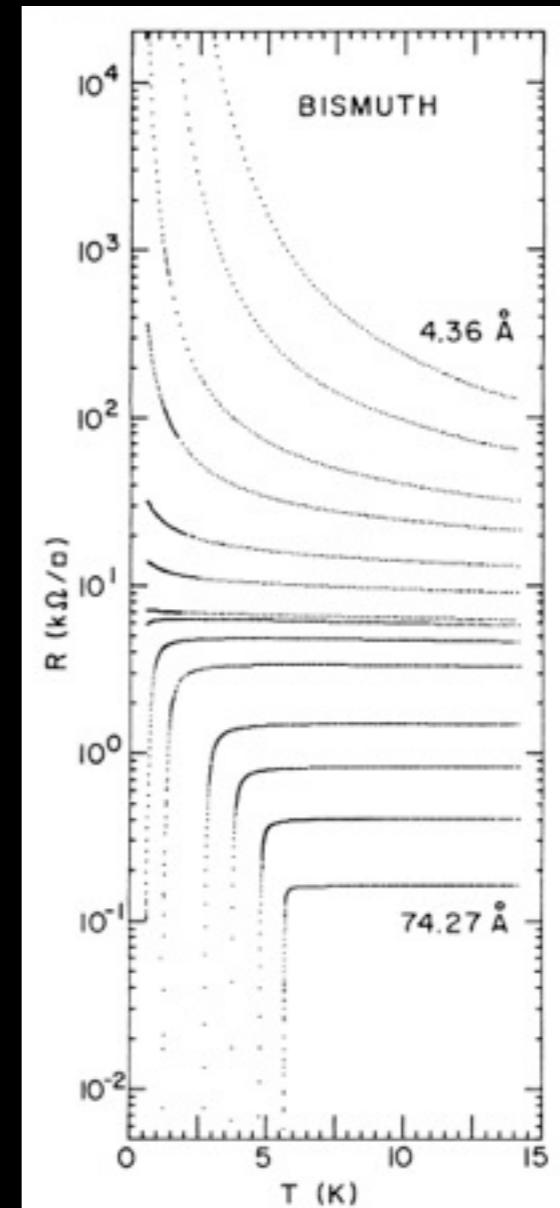
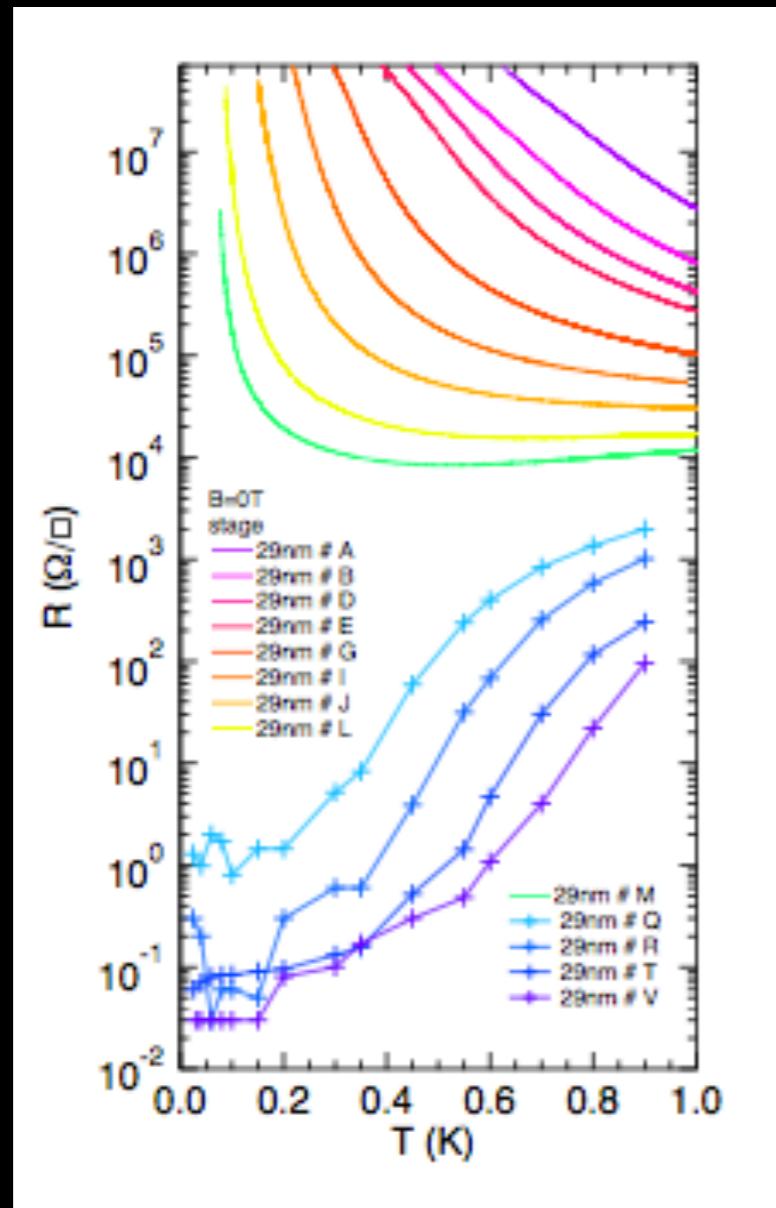
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Kravchenko, PRB ('94)

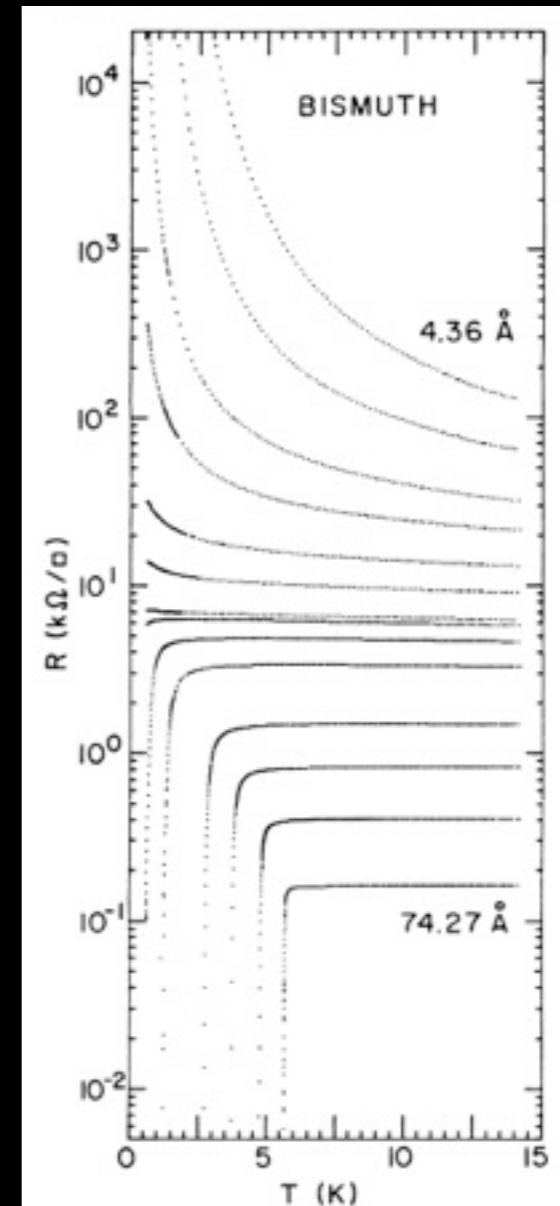
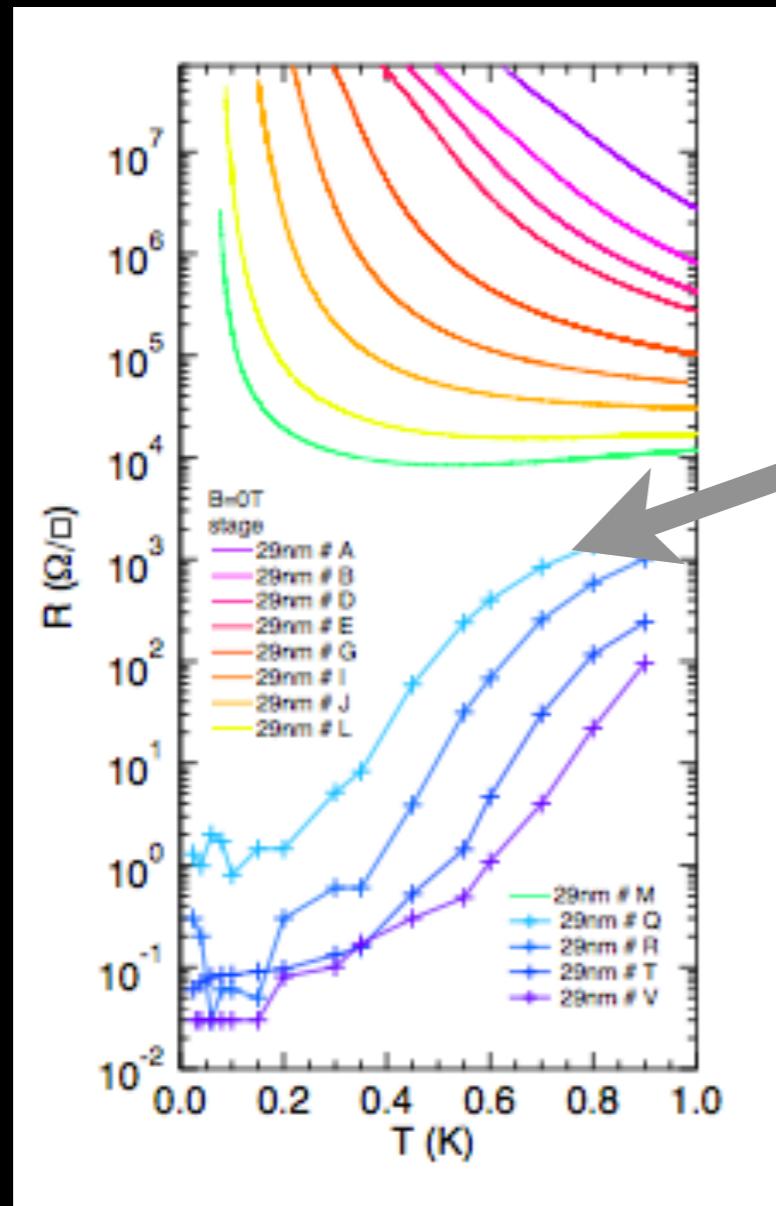
Amorphous Indium-Oxide



Amorphous Indium-Oxide



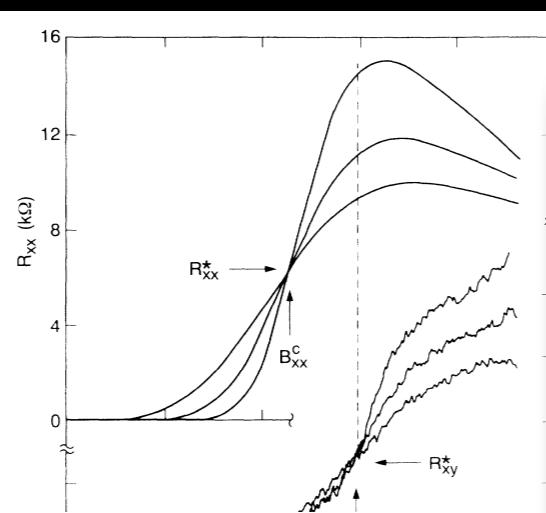
Amorphous Indium-Oxide



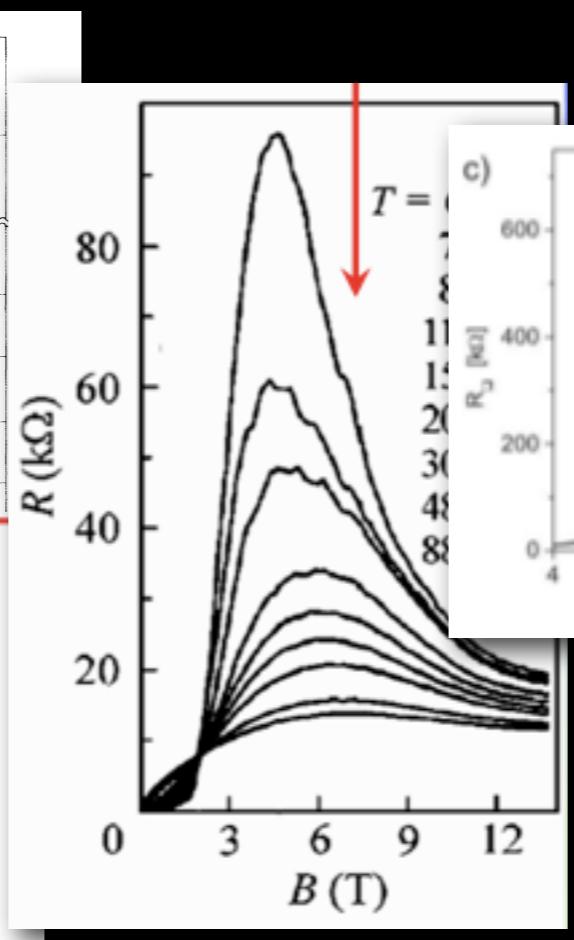
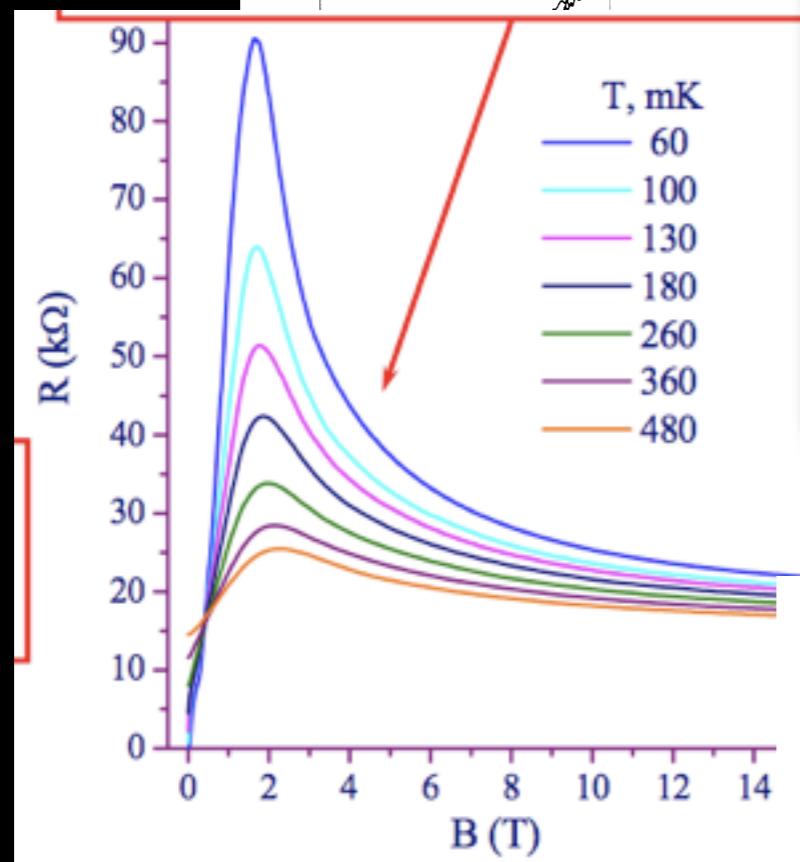
Magnetic-field dependence

**What is the insulating phase?
(experimental)**

Paalanen et al, '92

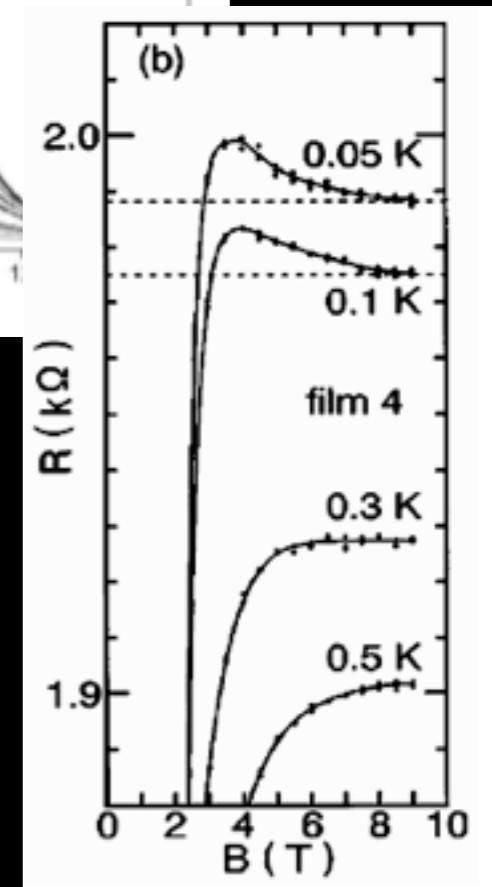


Baturina et al, '02

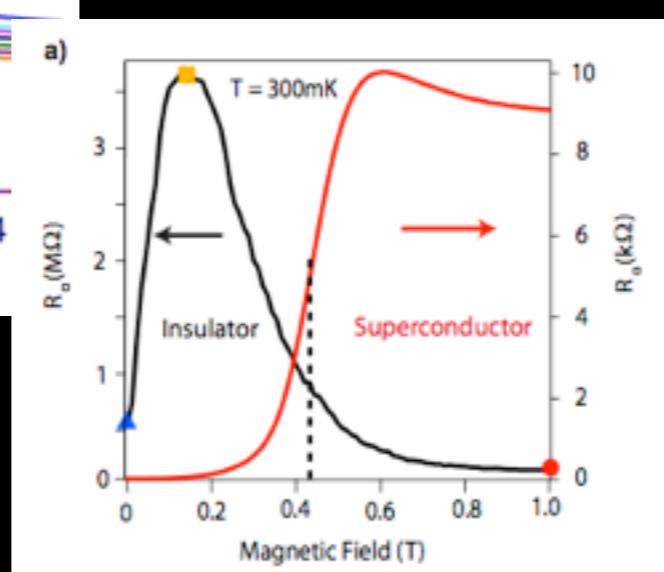


Gantmakher et al, '98

Steiner et al, '04

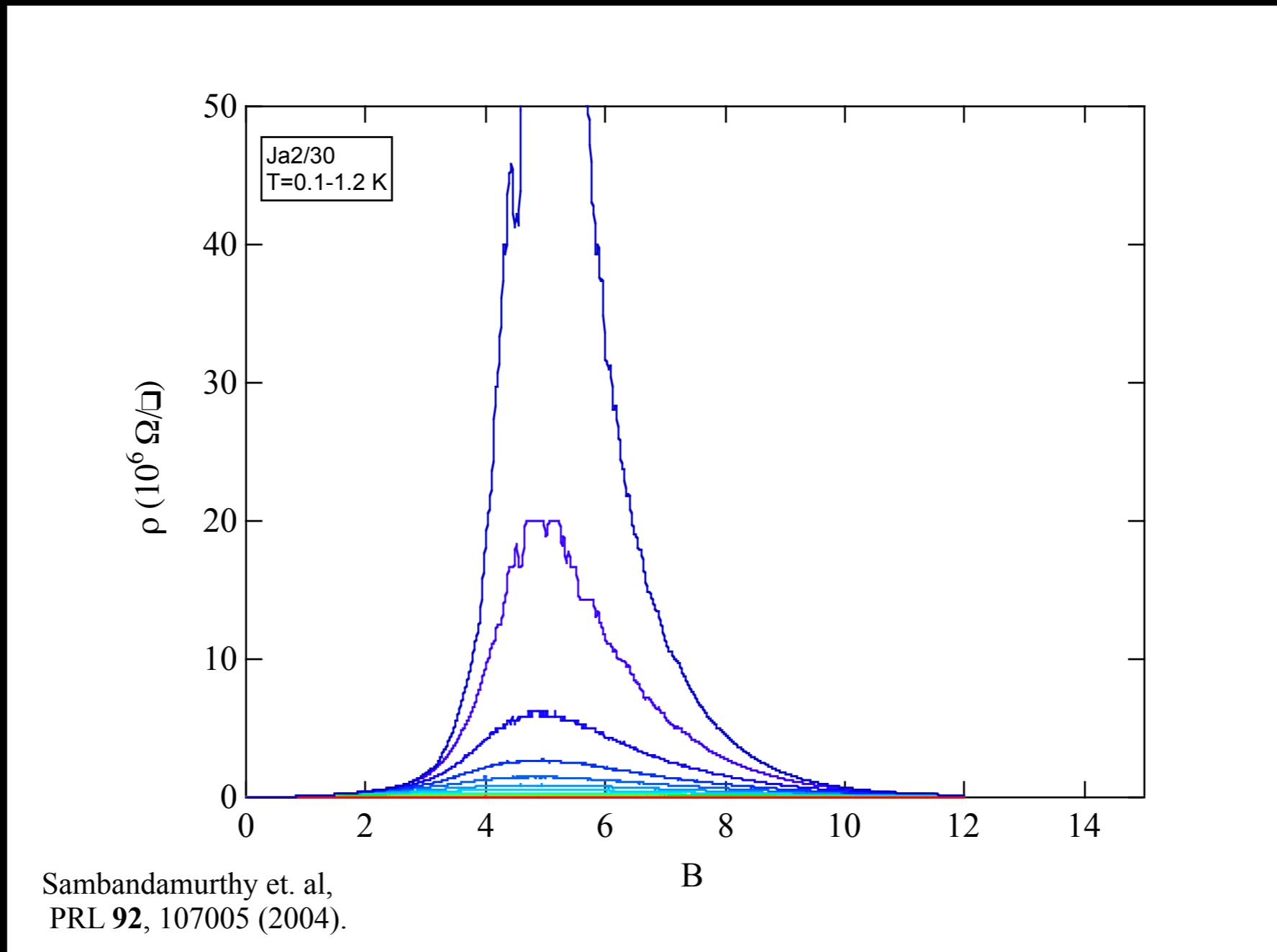


Okuma et al, '98

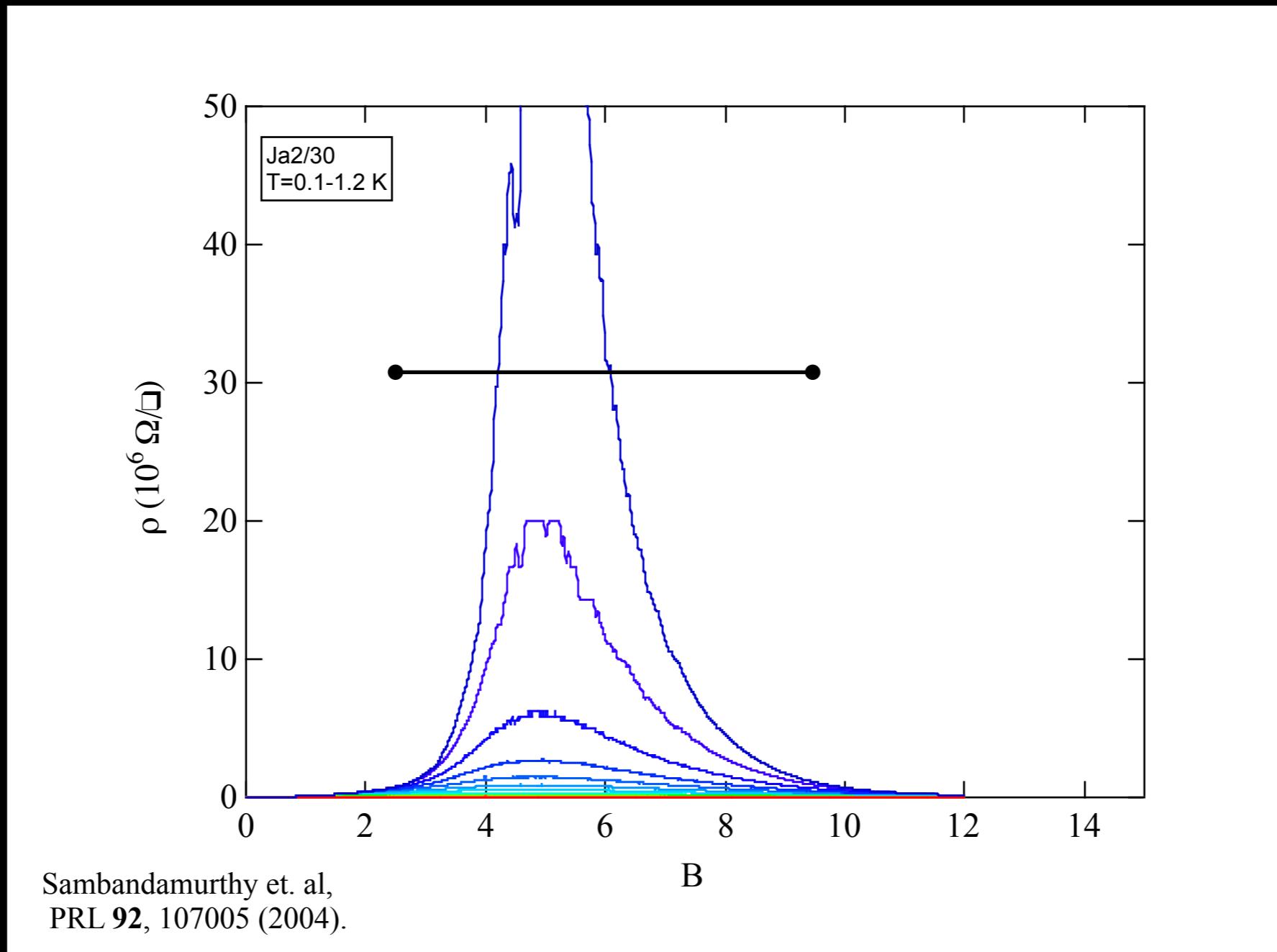


Allain et al, '12

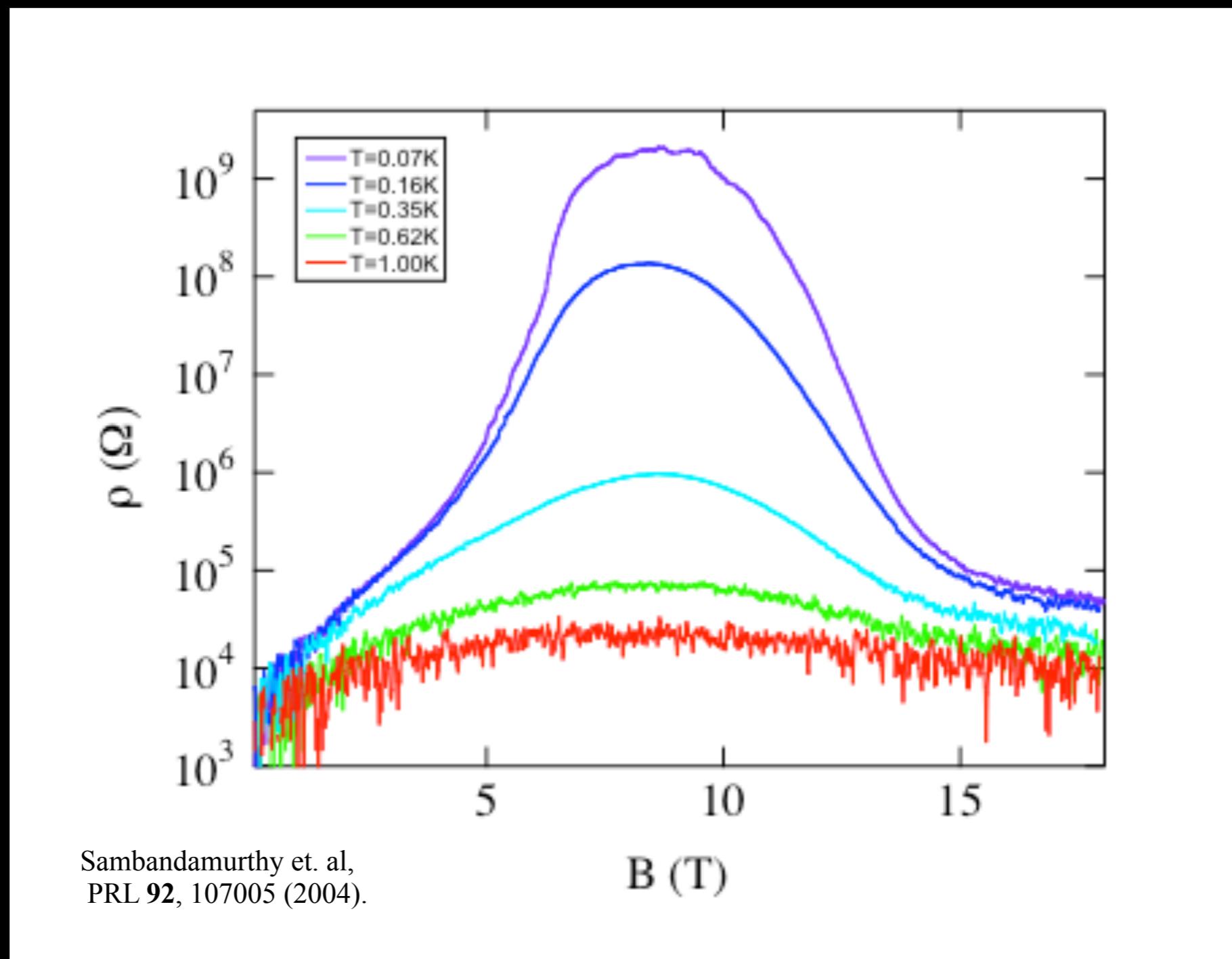
Finite range in B



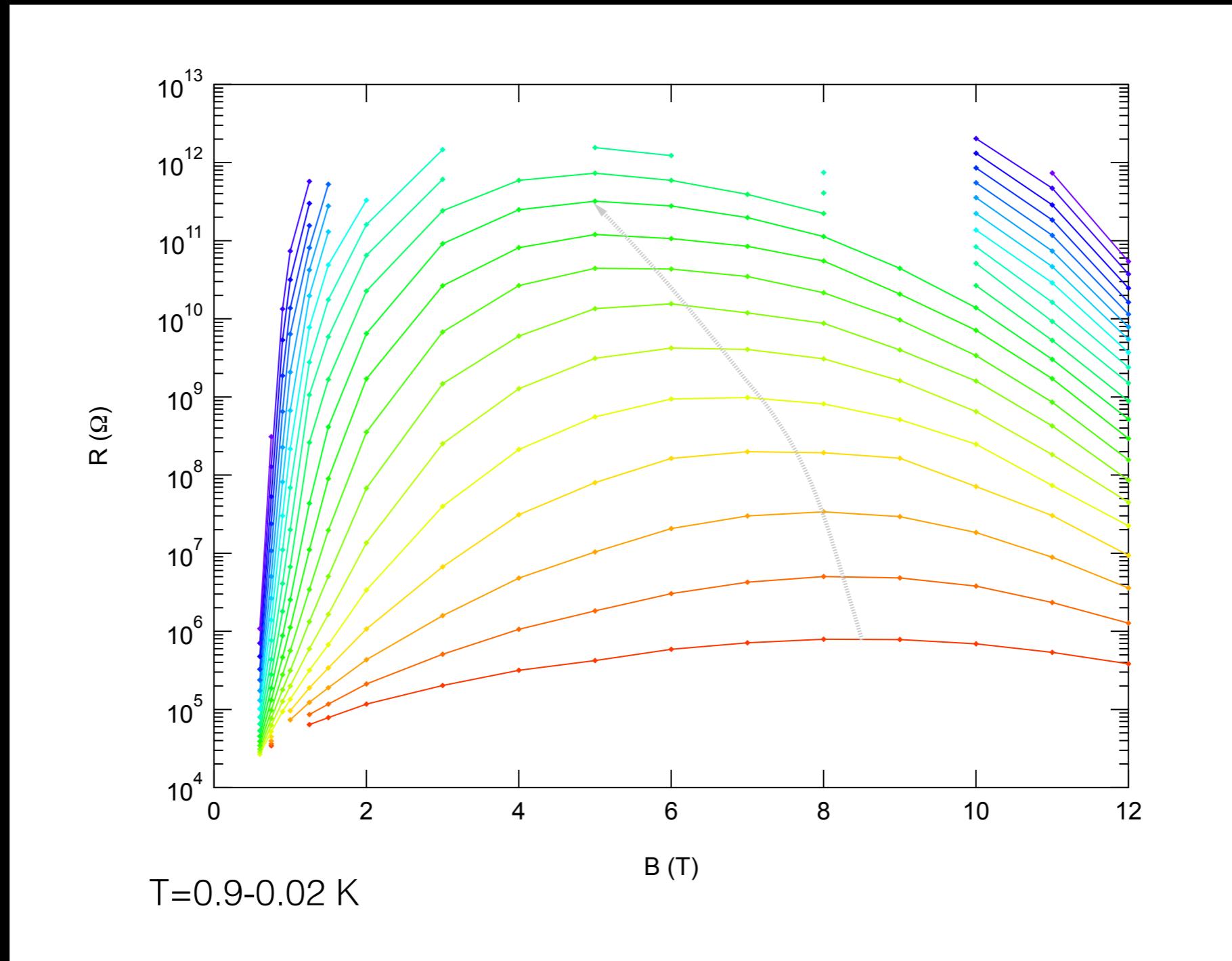
Finite range in B



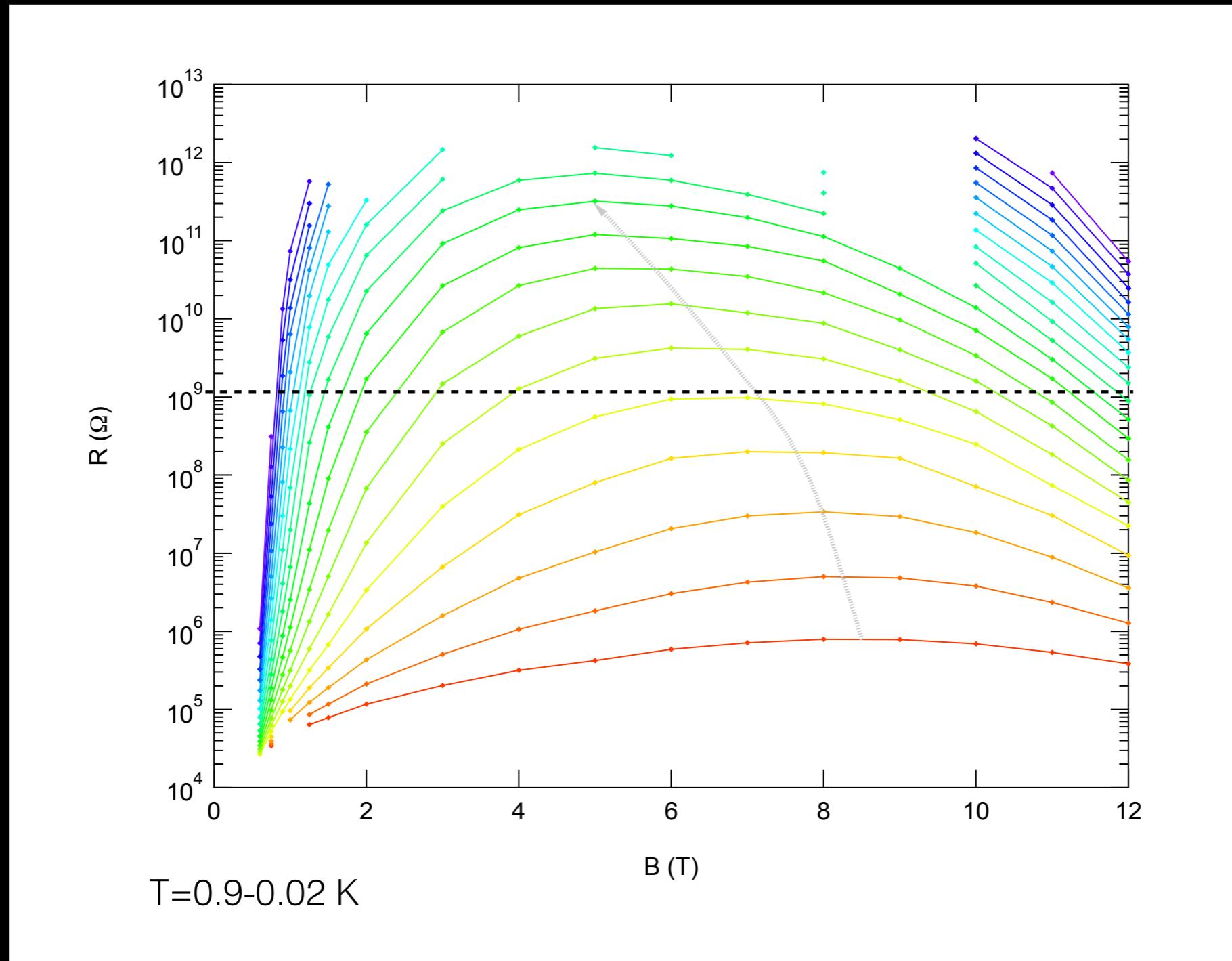
MR Peak

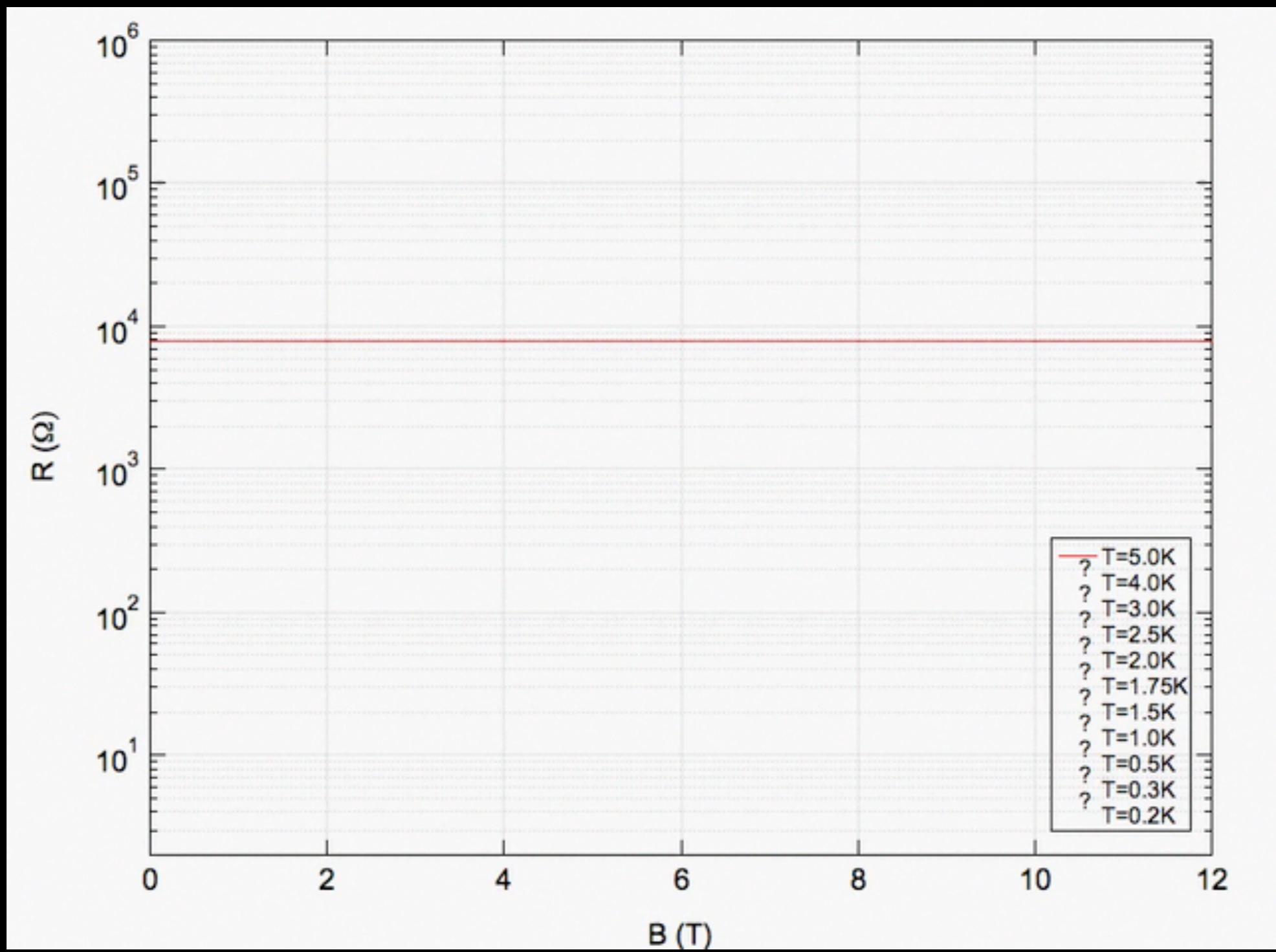


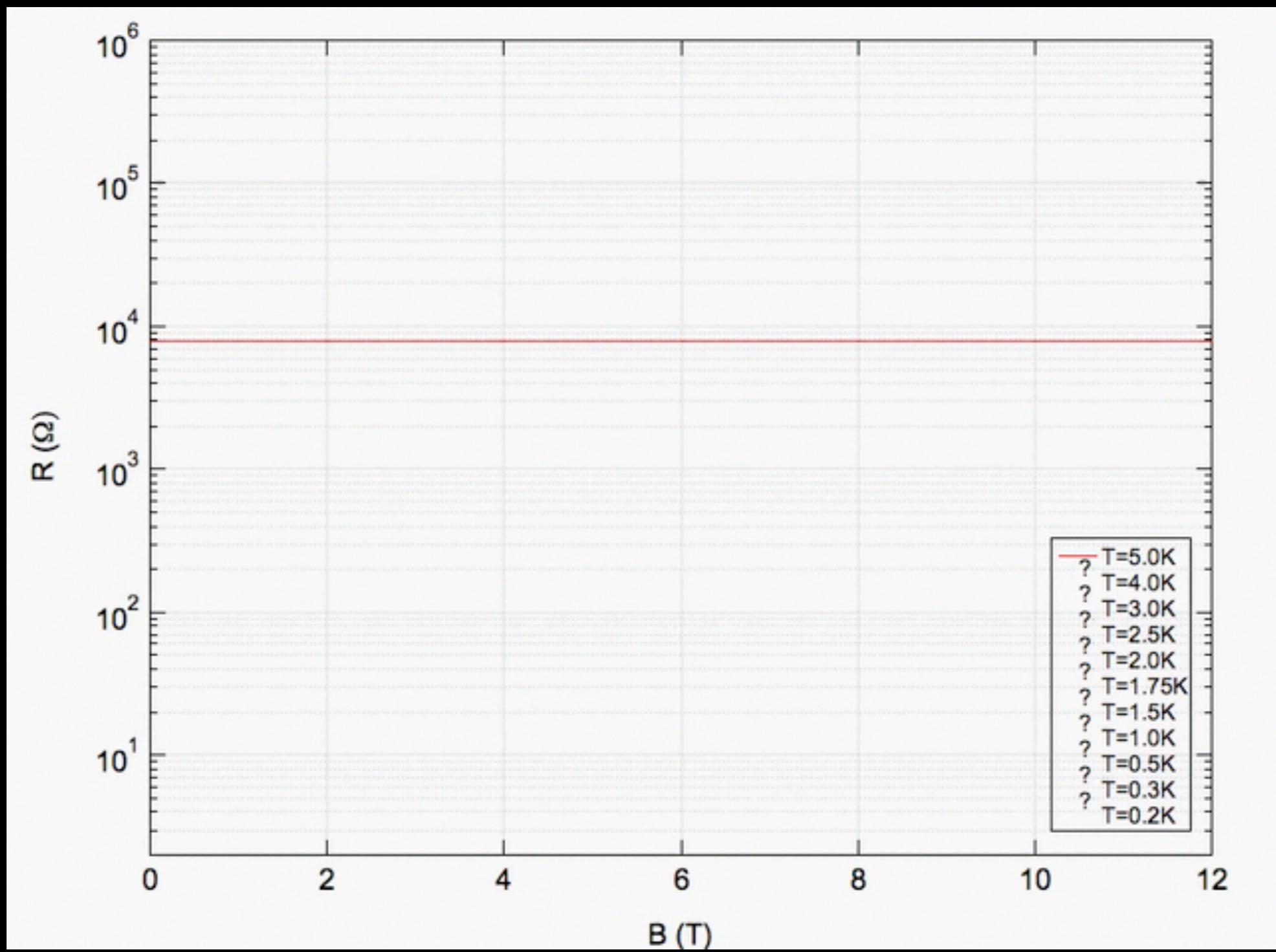
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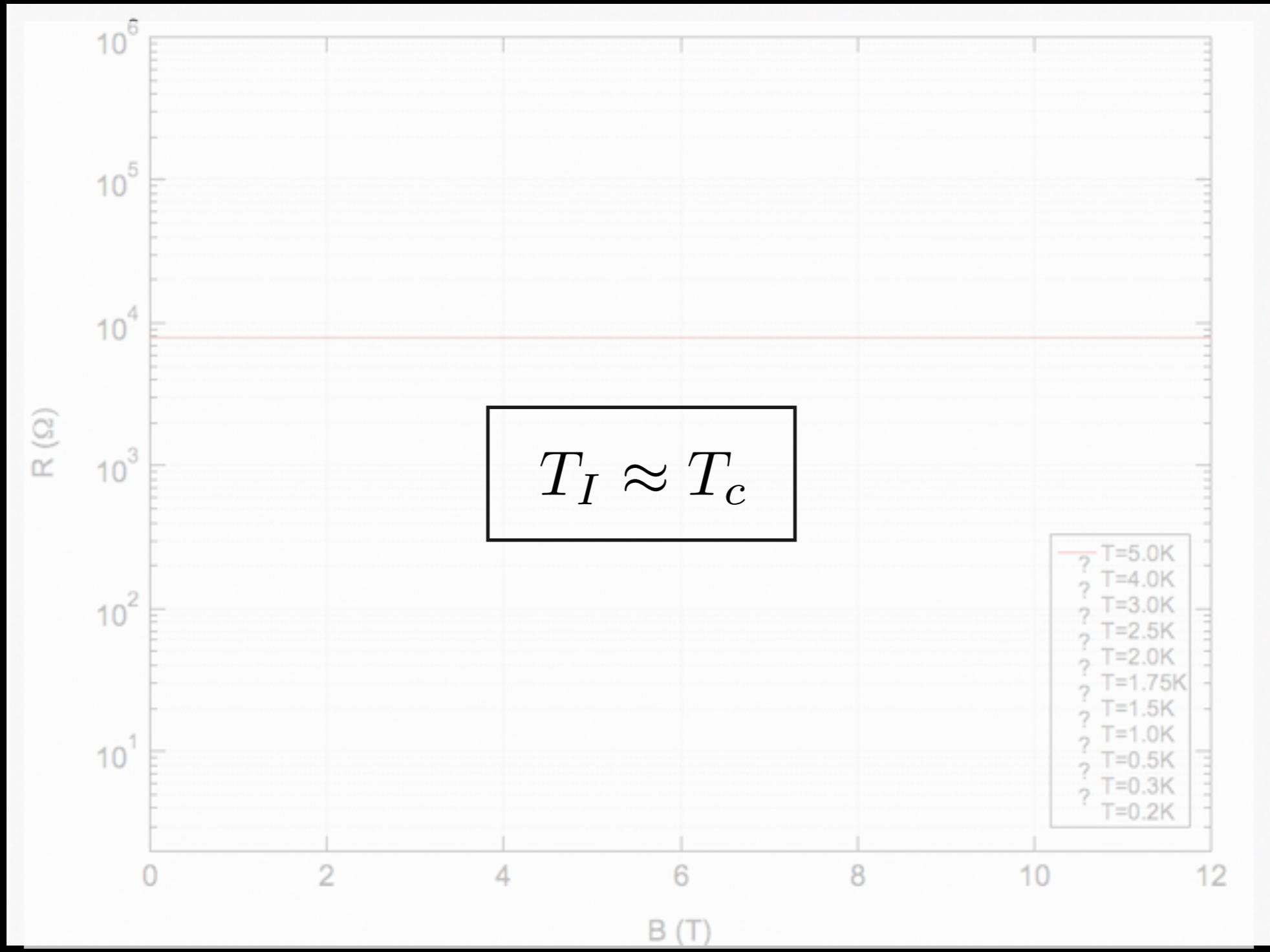


MR Peak









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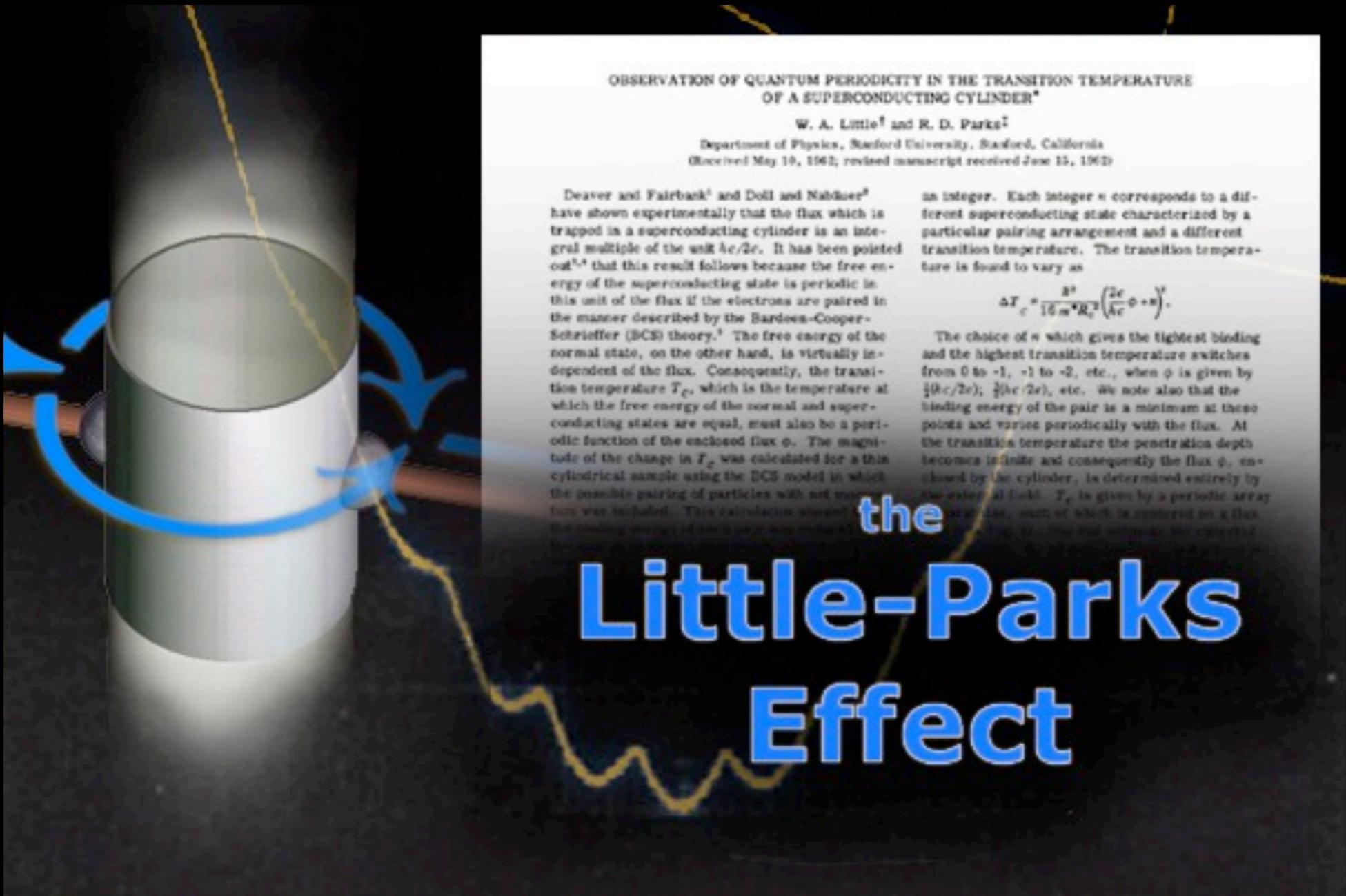
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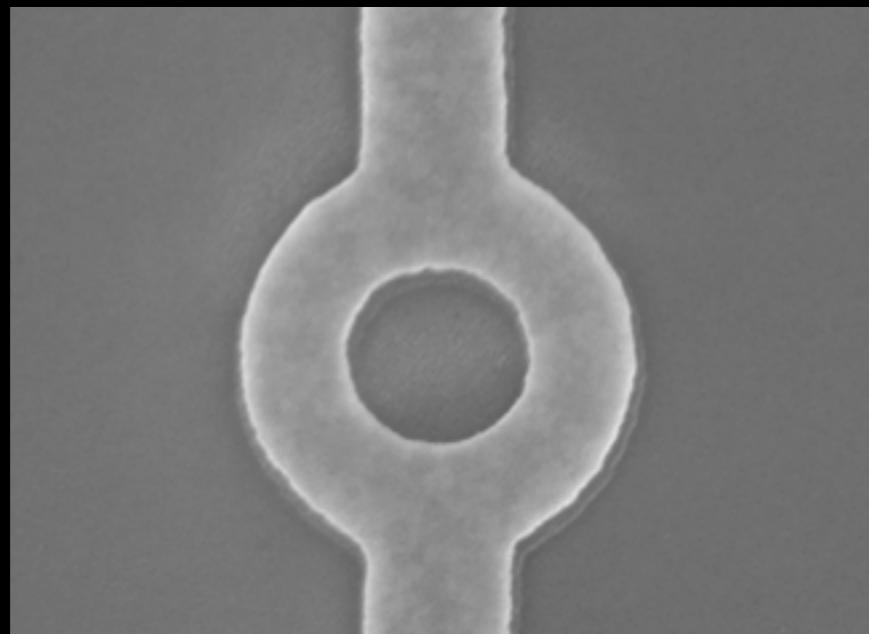
S. Syzranov et al., Phys. Rev. Lett. **108**, 256601 (2012)



the Little-Parks Effect

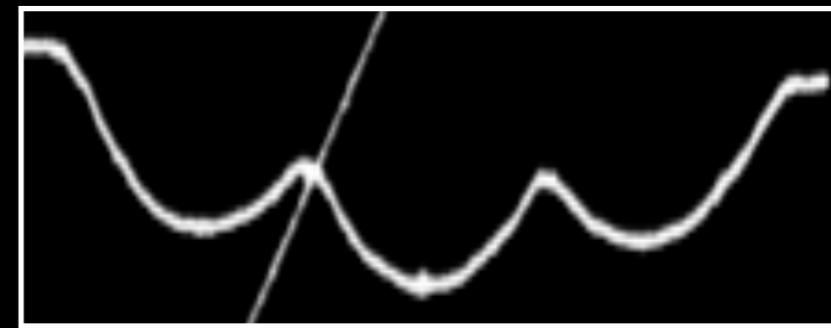
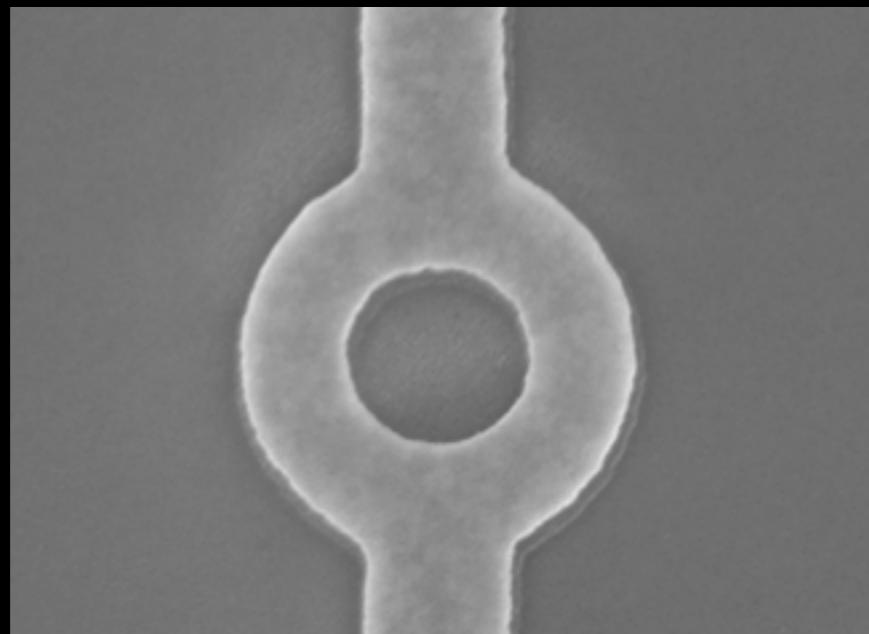
Magnetic-flux quantization

The Little-Parks Effect



Phys. Rev. Lett. 9, 9 (1962)

The Little-Parks Effect



Phys. Rev. Lett. 9, 9 (1962)

Superconducting Pair Correlations in an Amorphous Insulating Nanohoneycomb Film

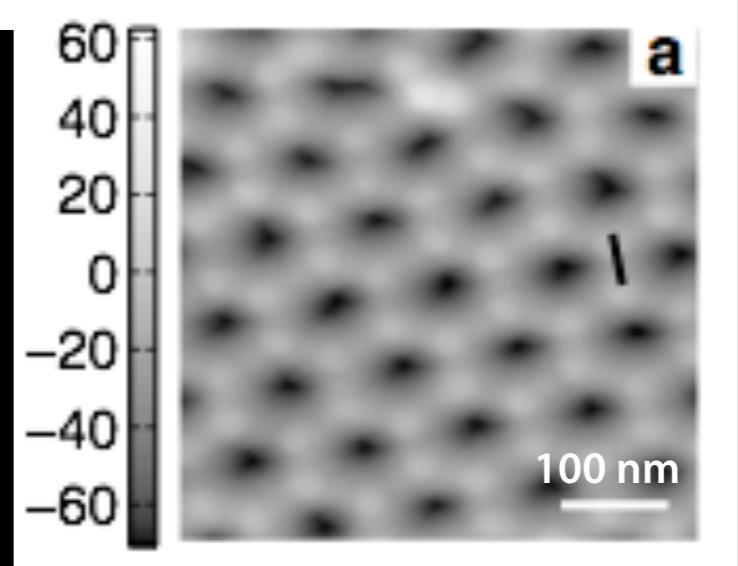
M. D. Stewart Jr.,¹ Aijun Yin,² J. M. Xu,^{1,2} James M. Valles Jr.^{1*}

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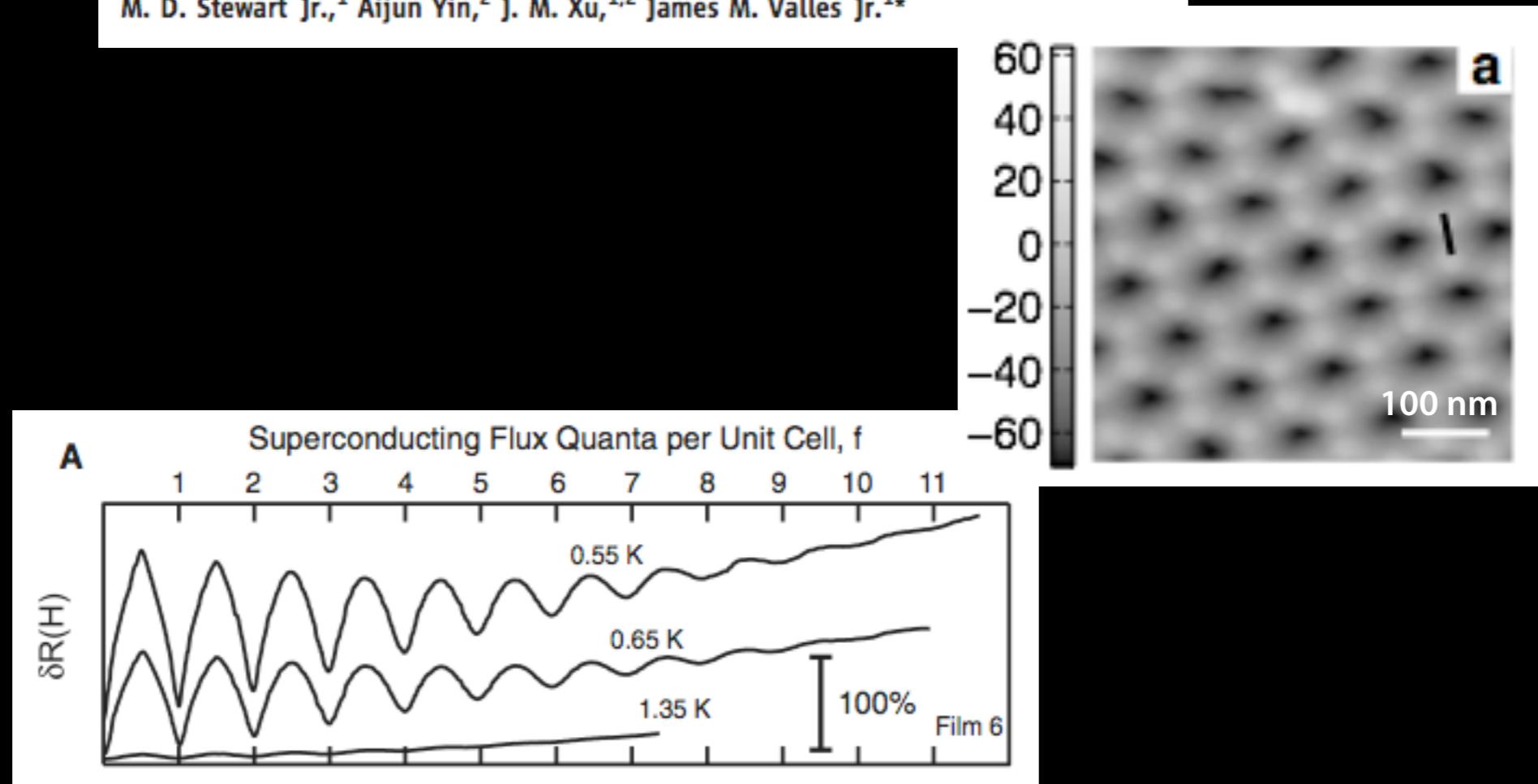
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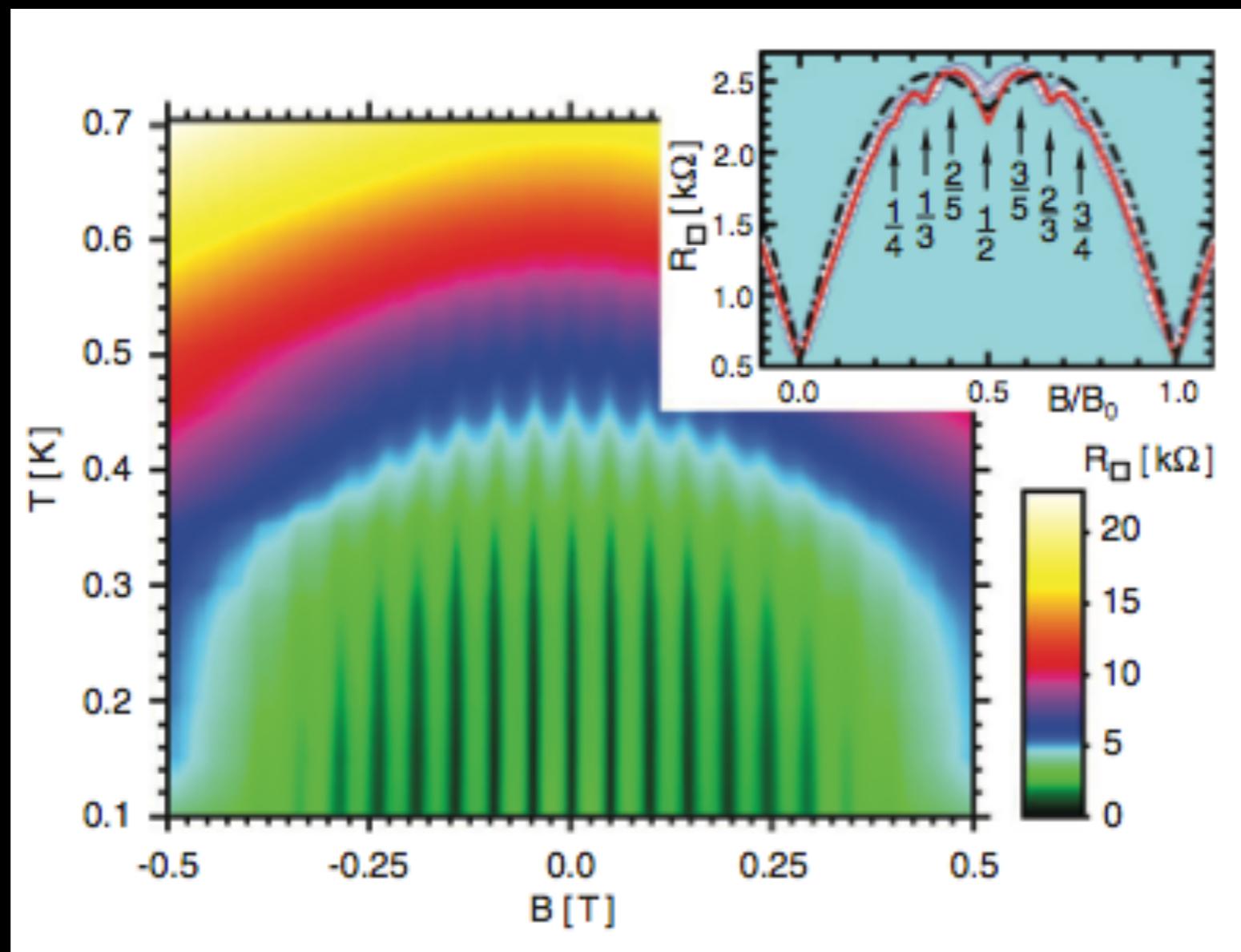
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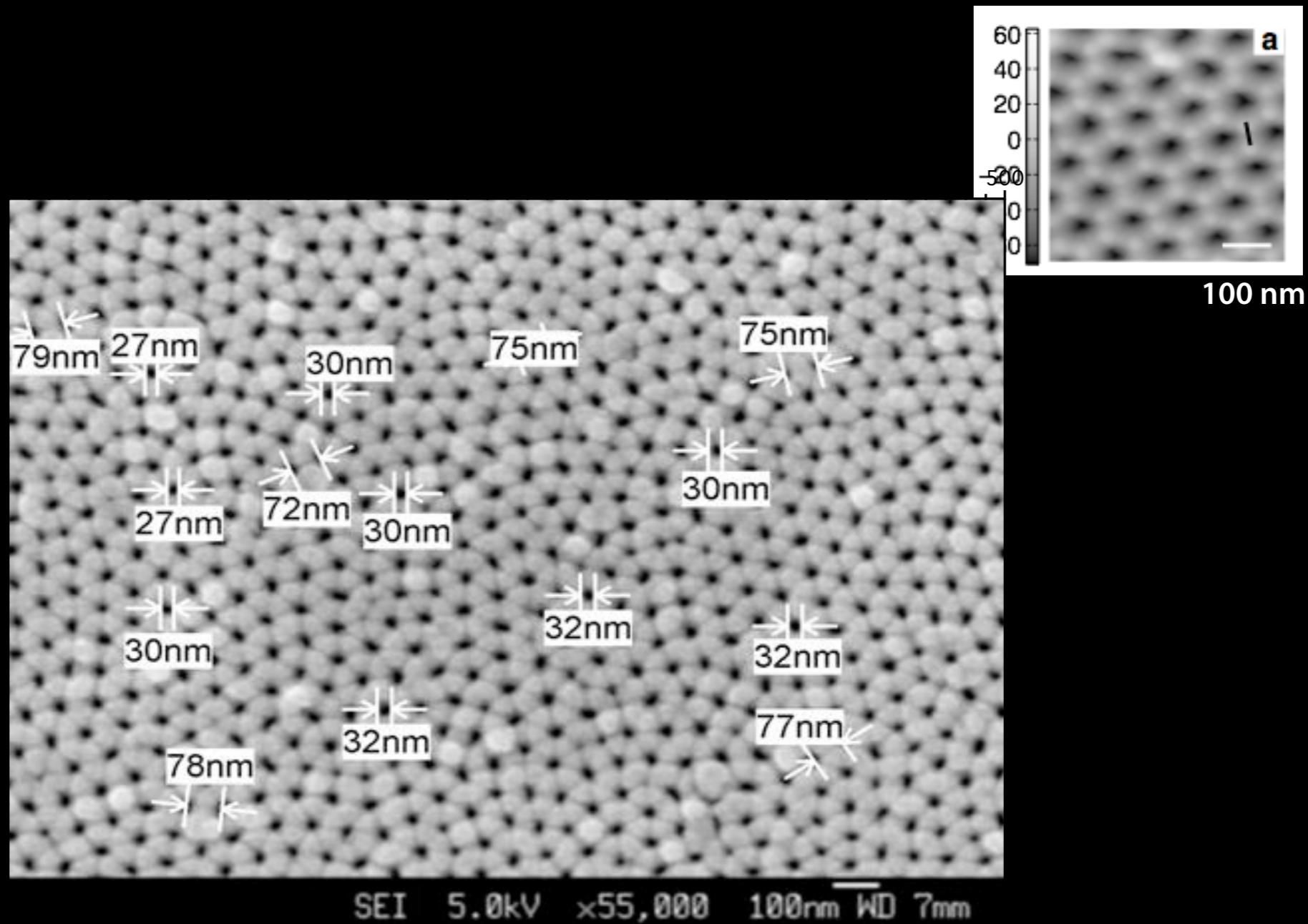


Nanopattern-stimulated superconductor-insulator transition in thin TiN films

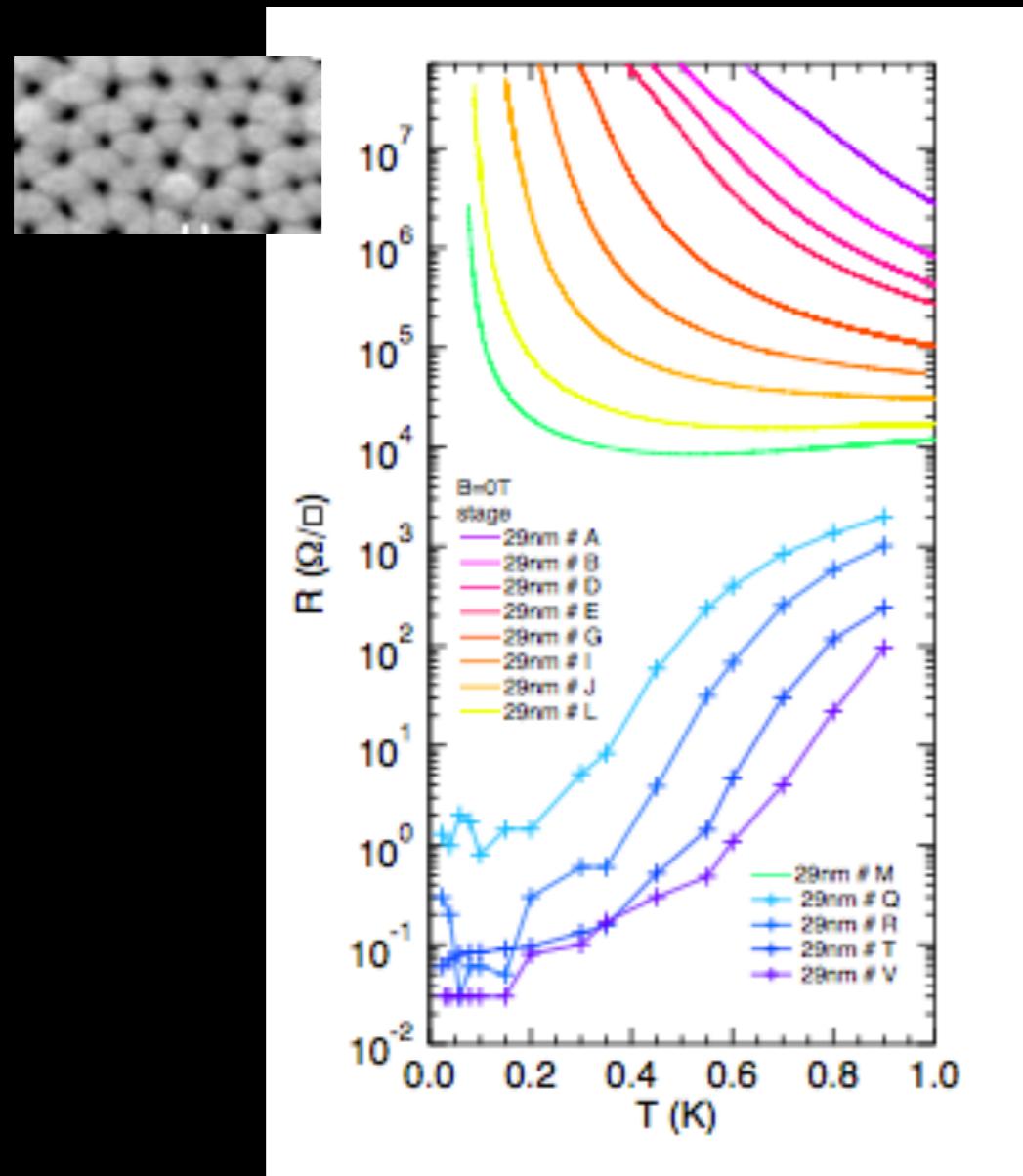
T. I. BATURINA^{1,2(a)}, V. M. VINOKUR², A. YU. MIRONOV¹, N. M. CHTCHELKATCHEV^{2,3,4}, D. A. NASIMOV¹
and A. V. LATYSHEV¹



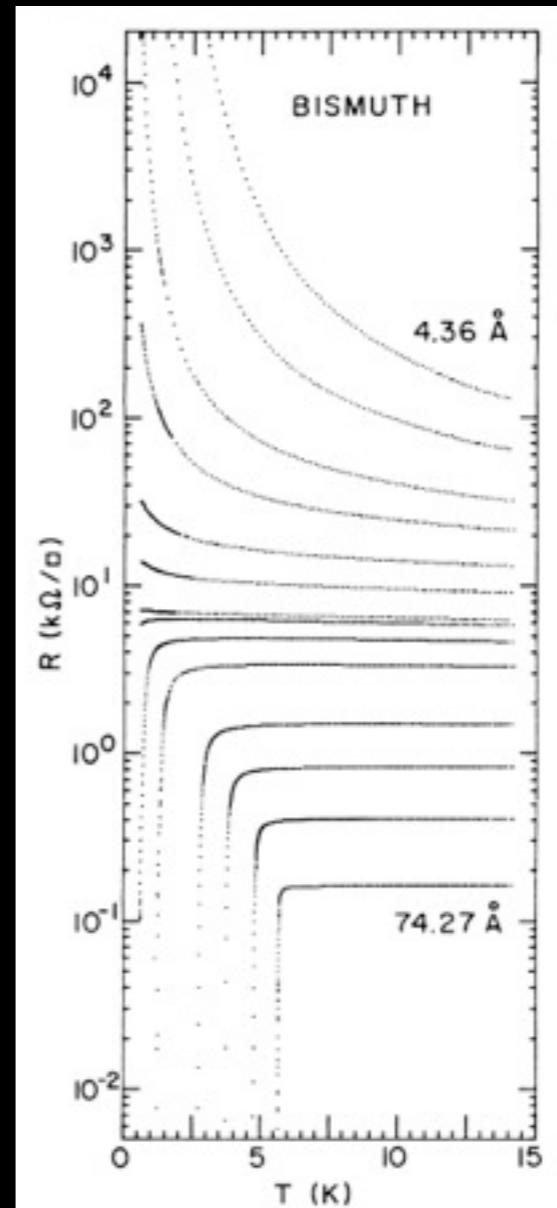
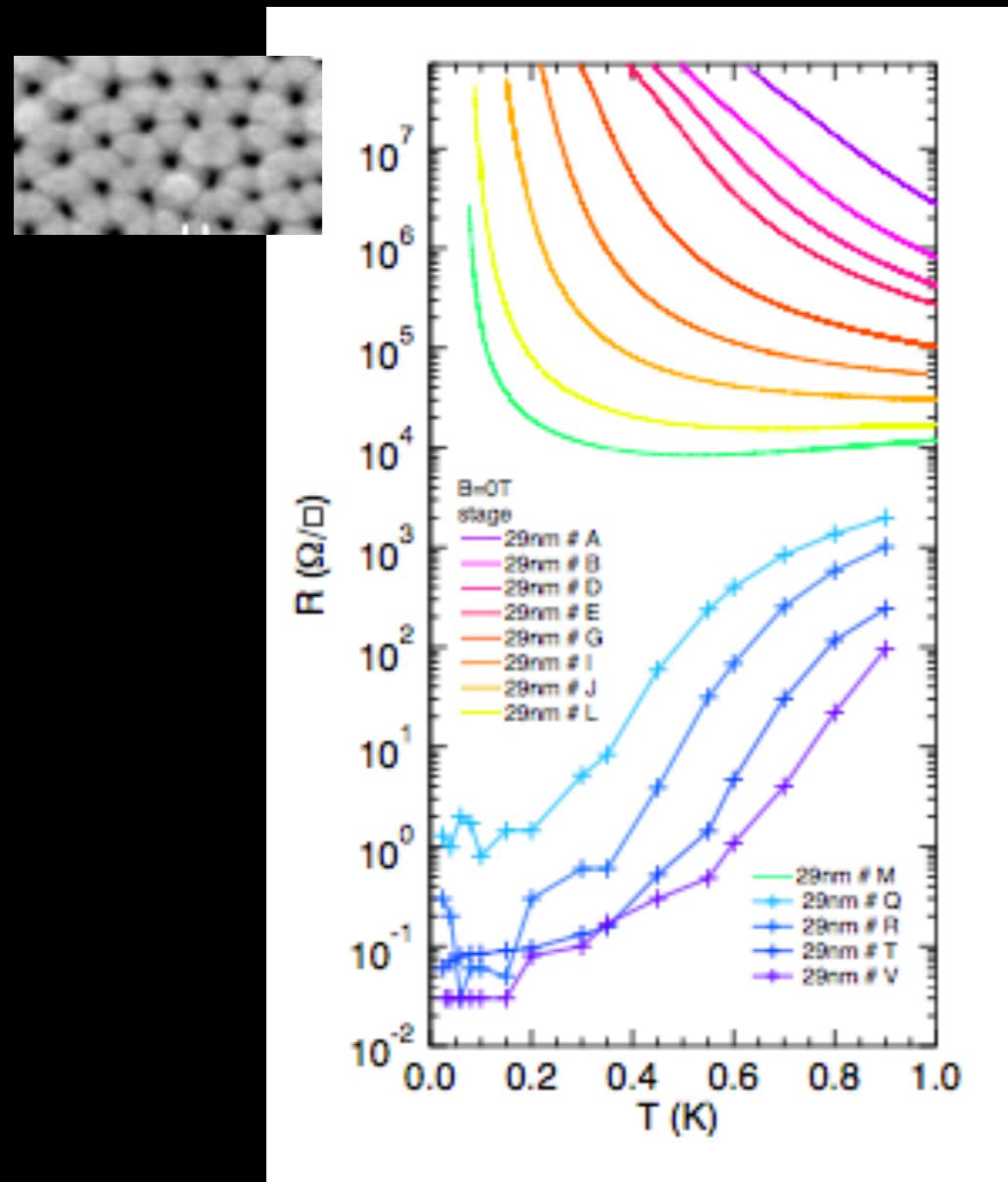
Our substrate



Disorder-driven SIT

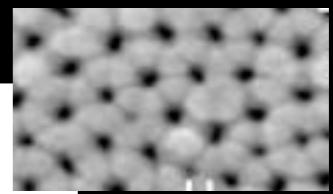
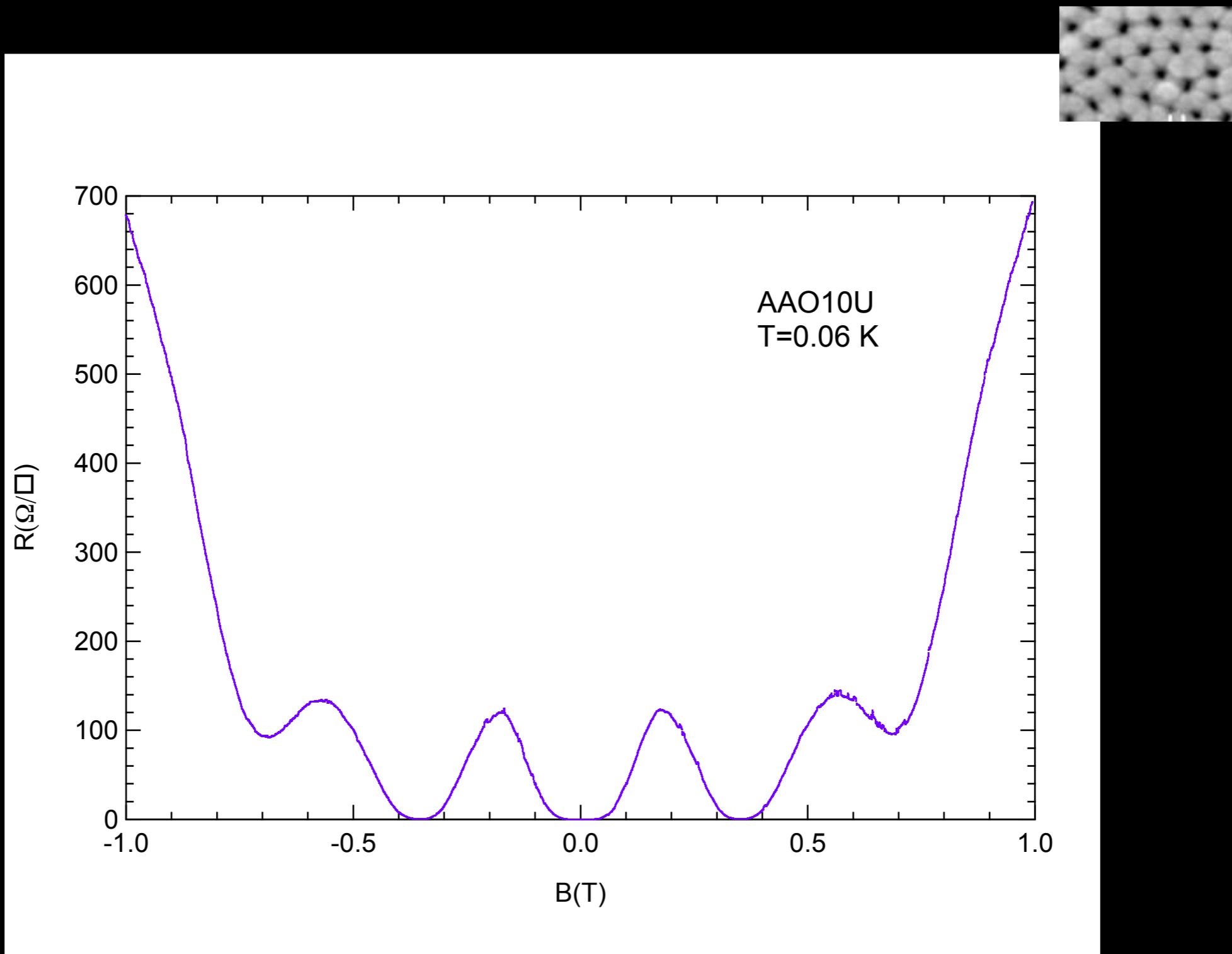


Disorder-driven SIT

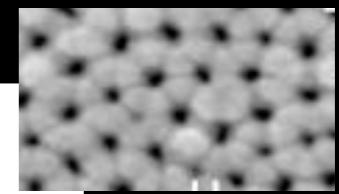
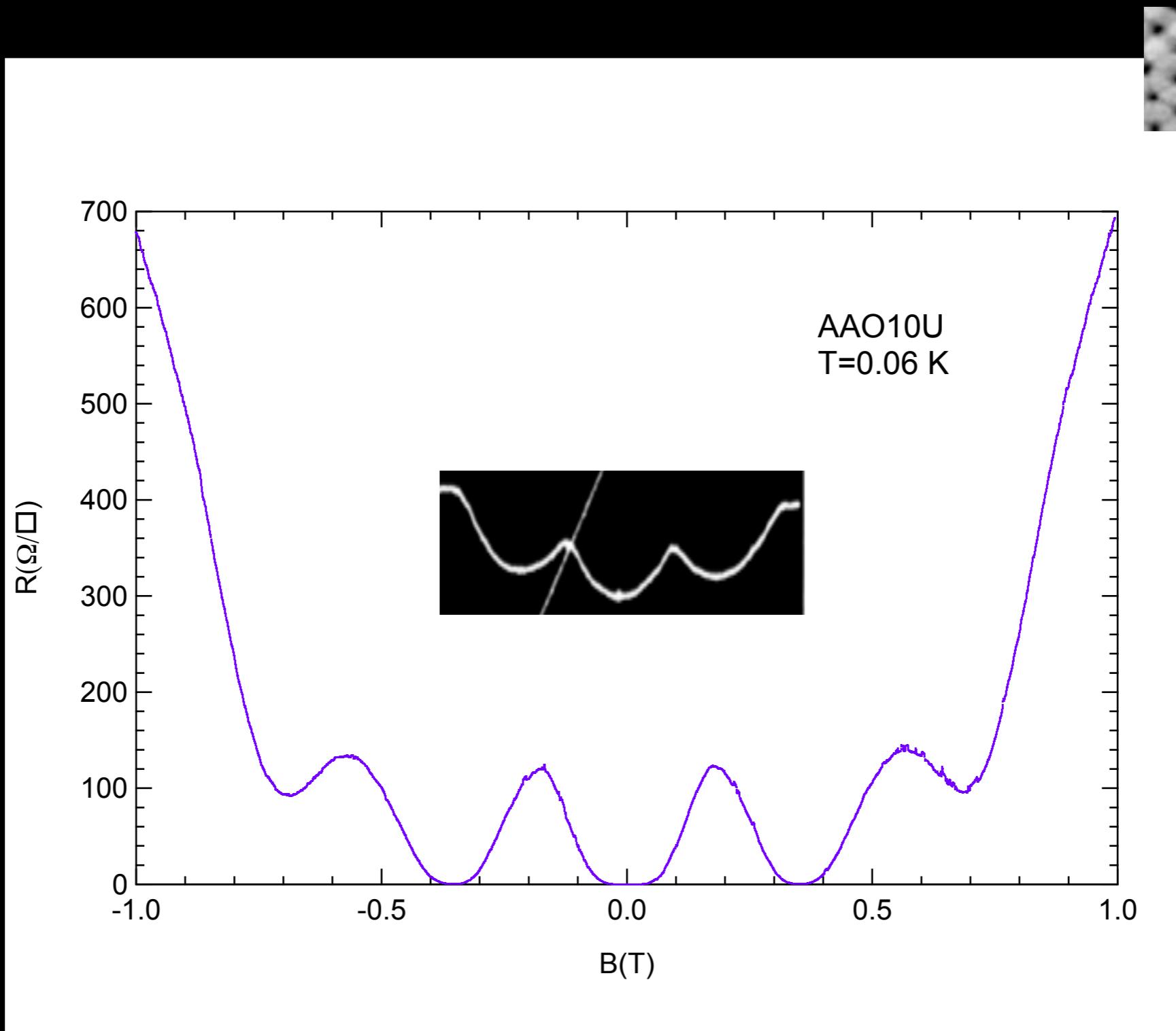


Superconducting samples

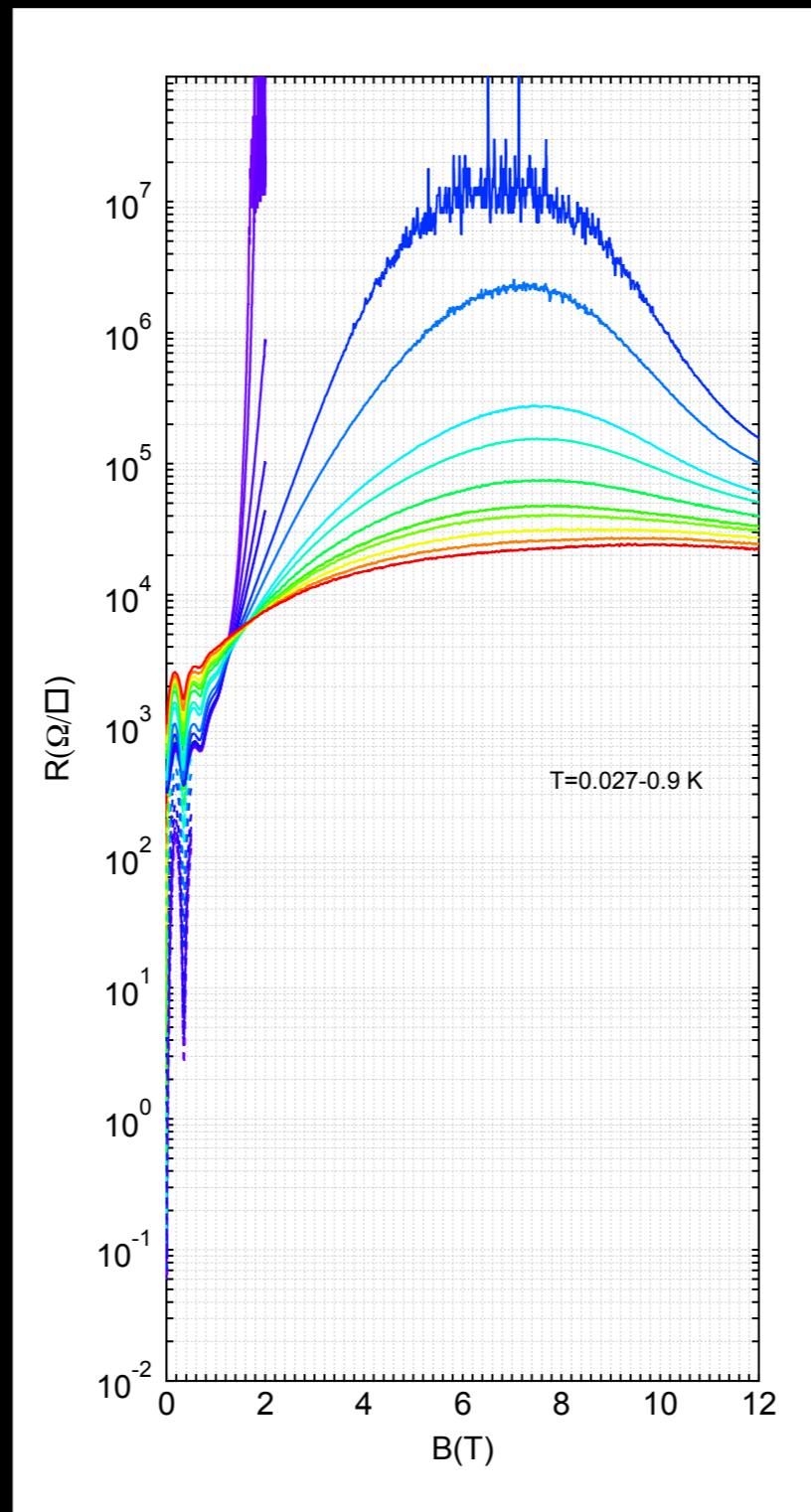
Superconducting samples



Superconducting samples

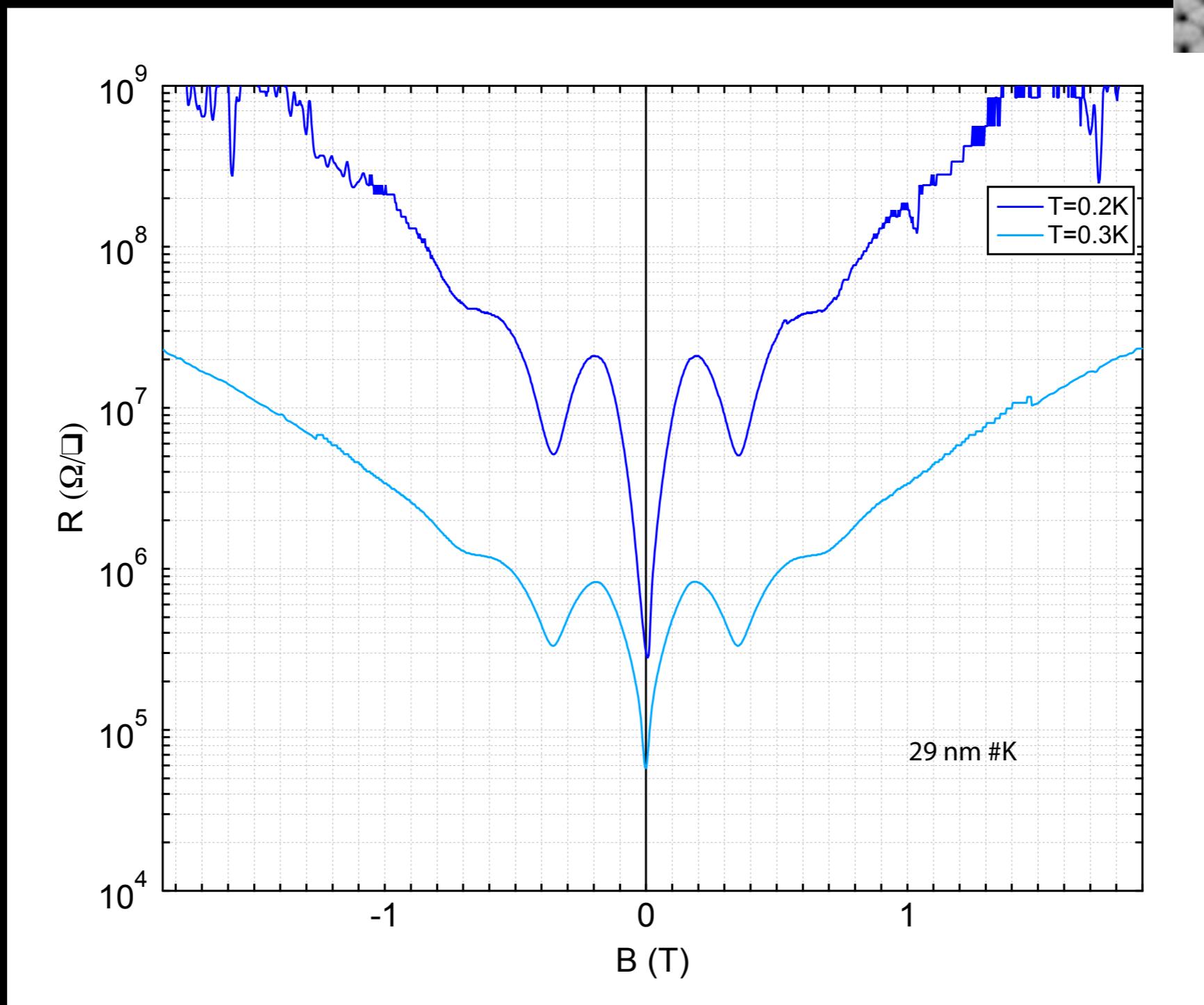
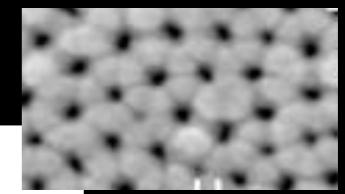


Similar high-B behavior

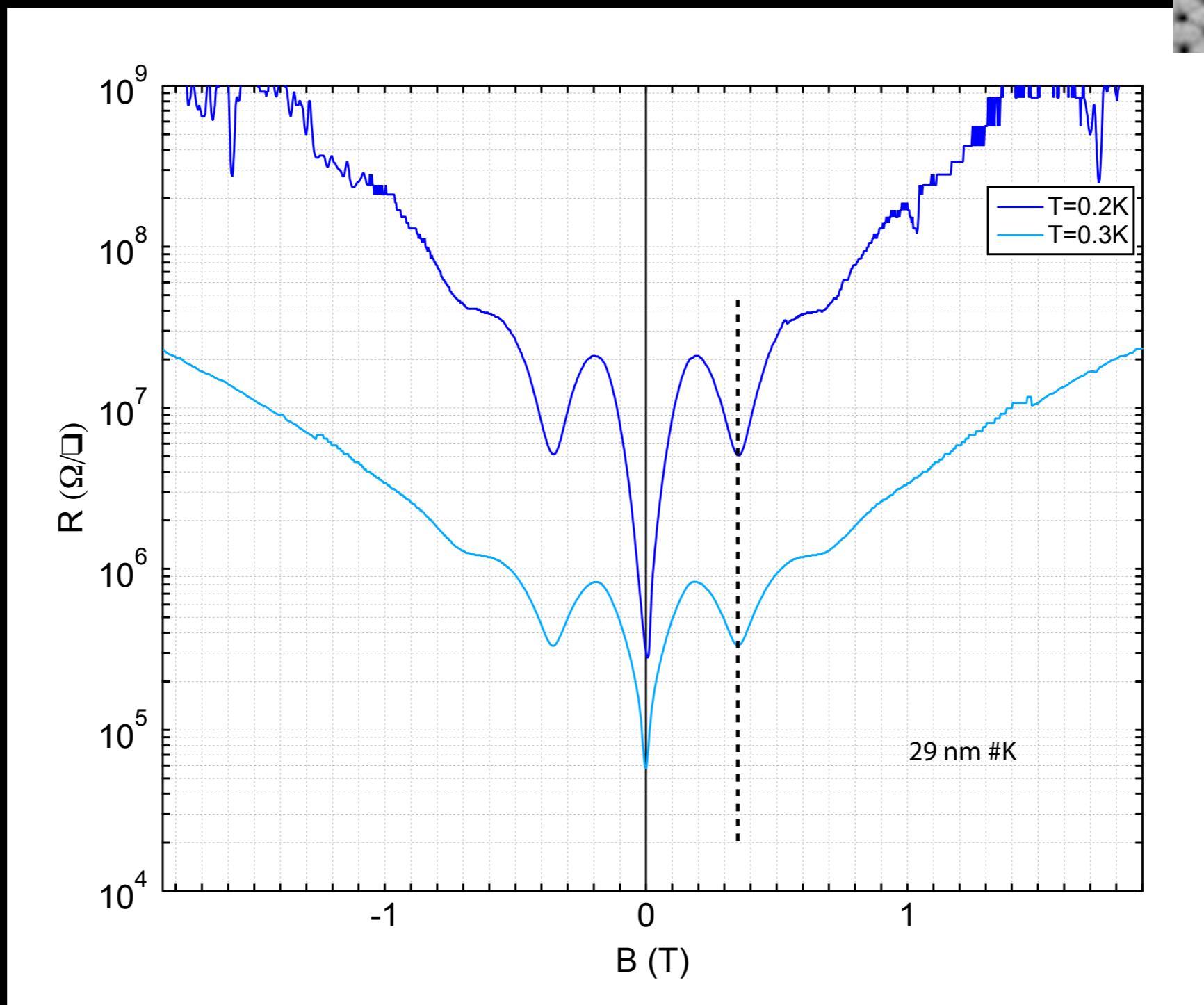
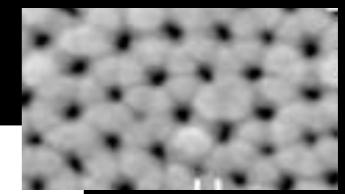


Insulating samples

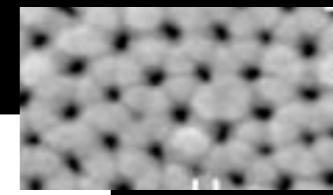
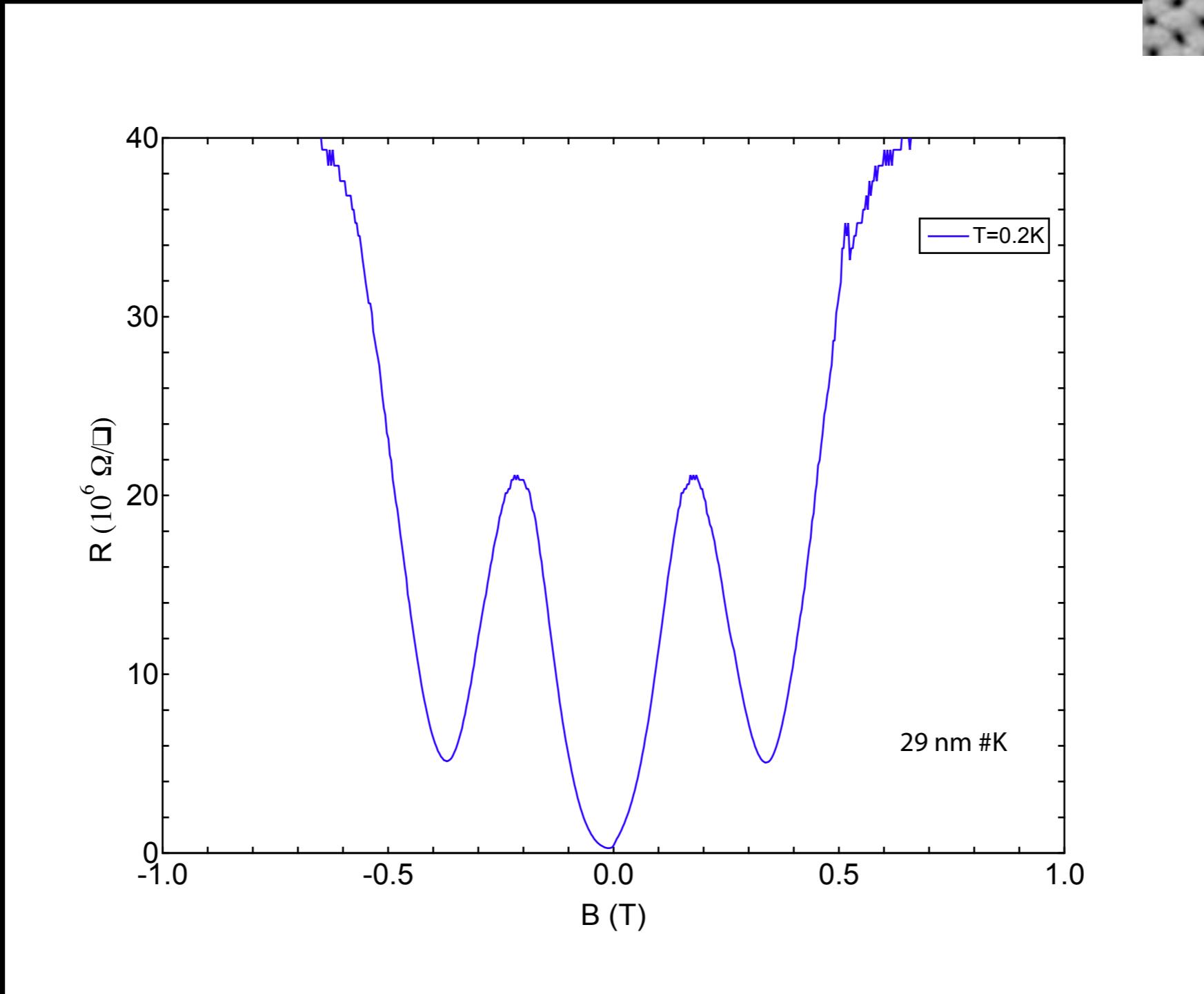
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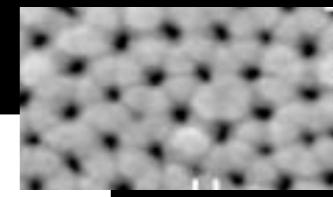
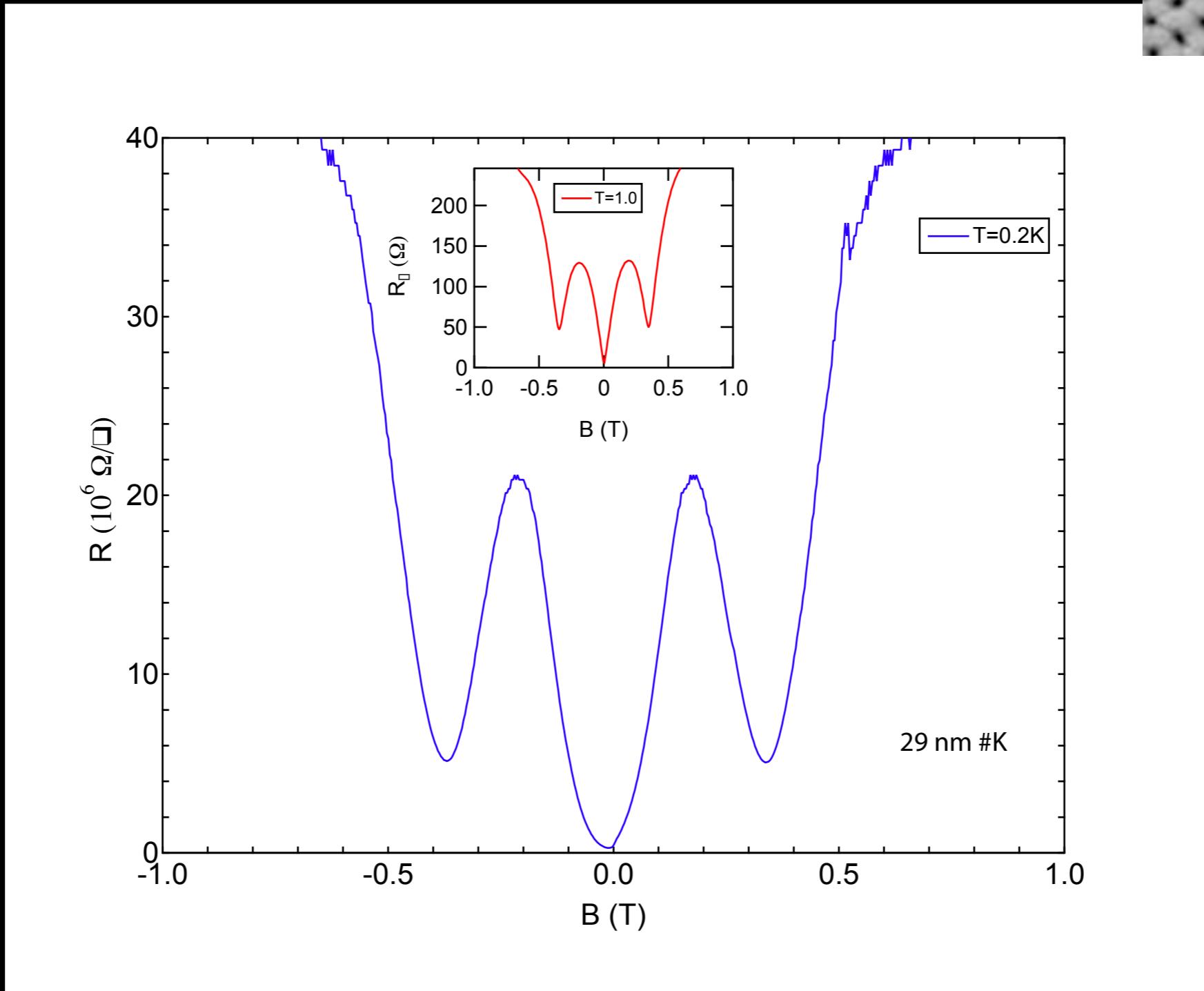
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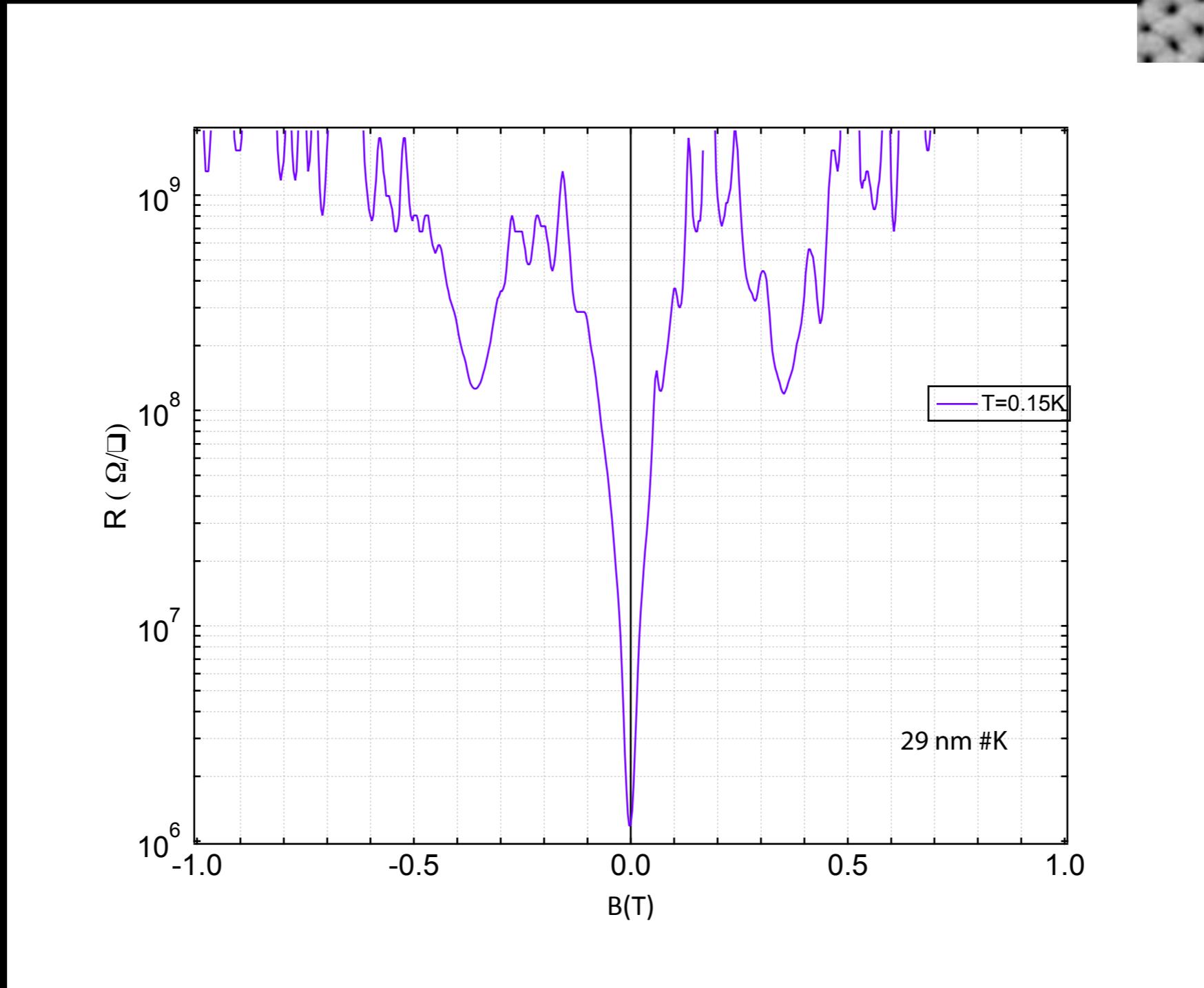
Linear scale



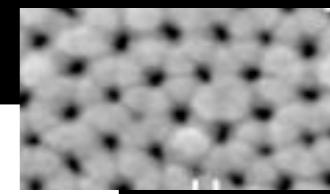
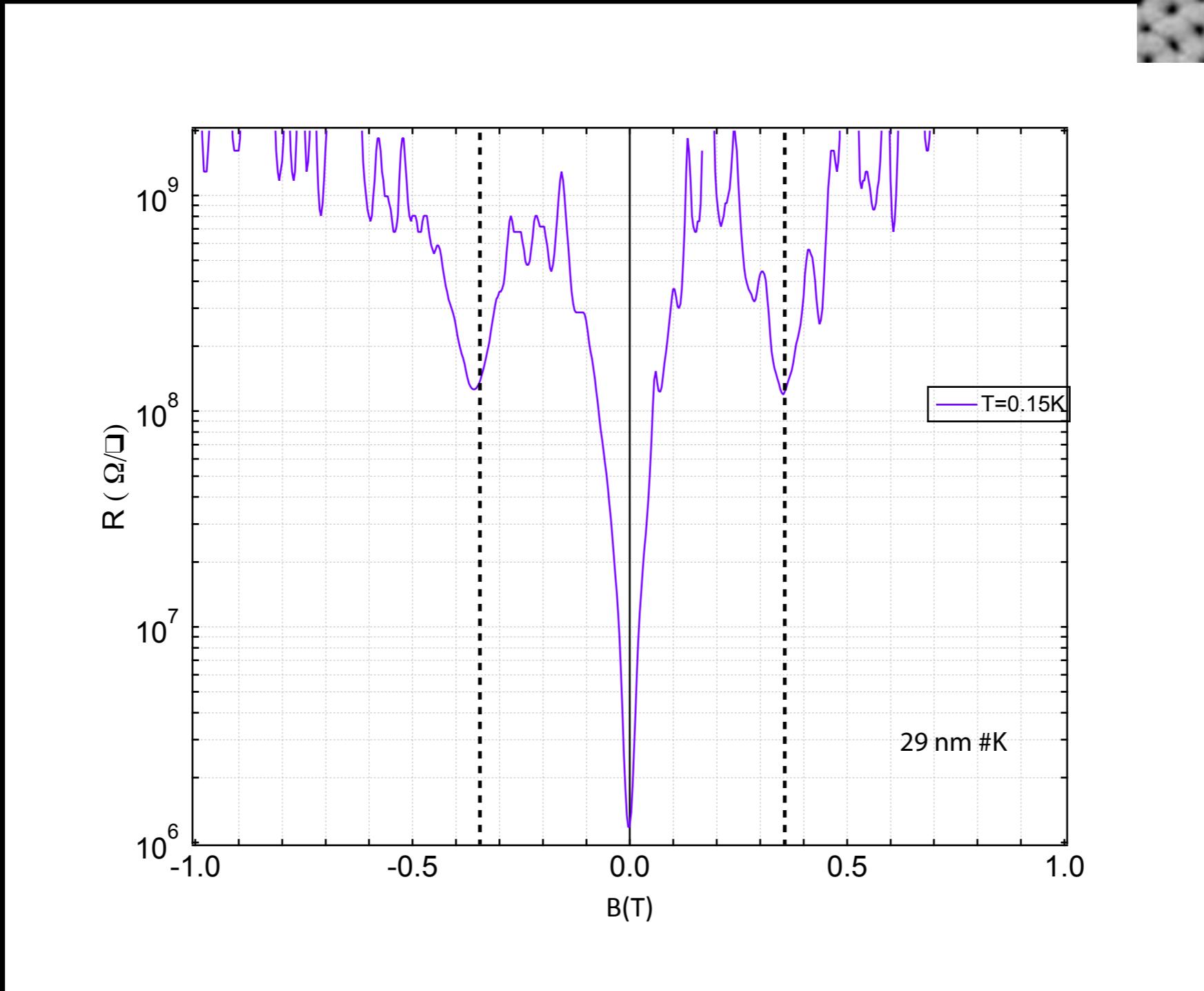
Linear scale



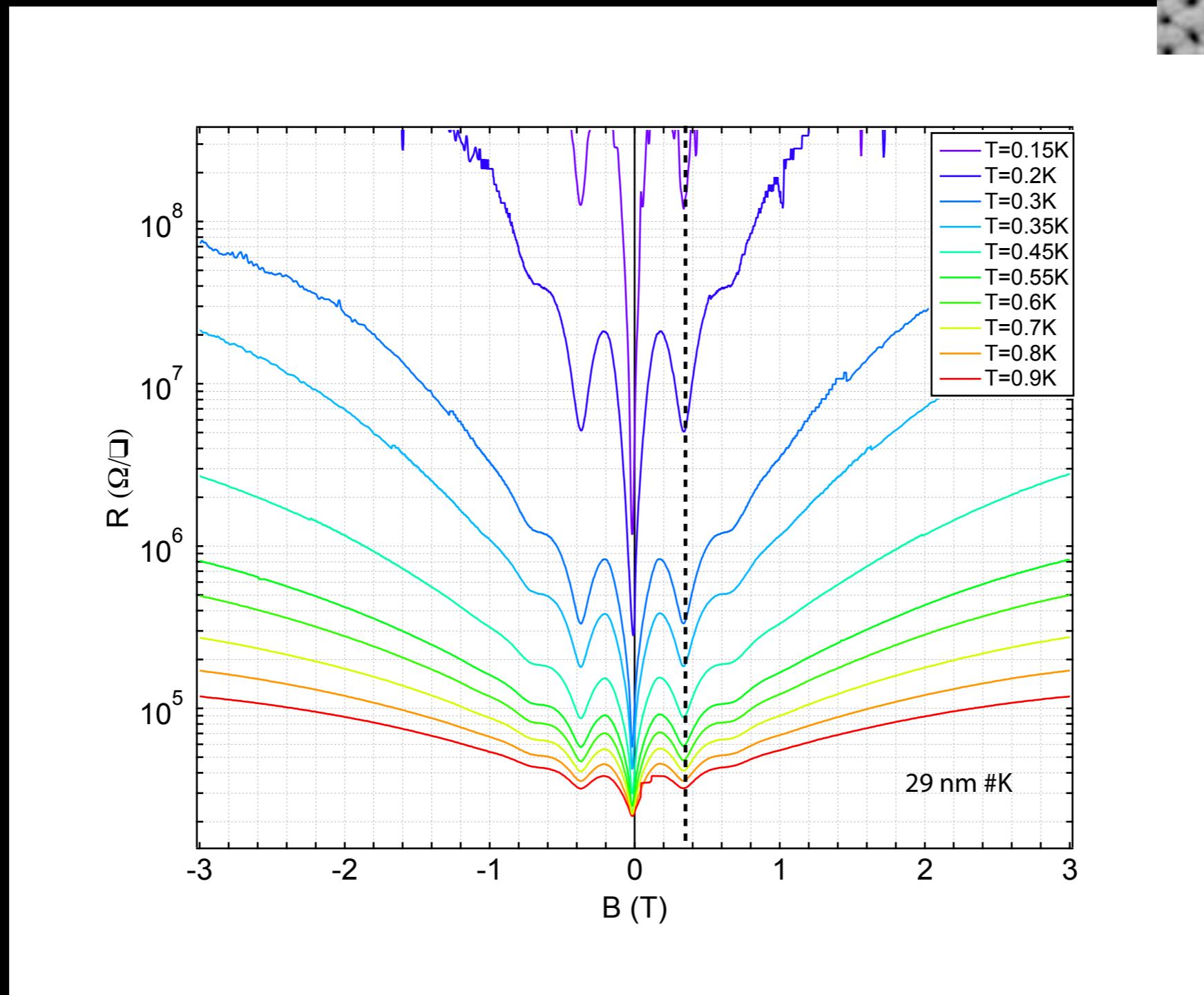
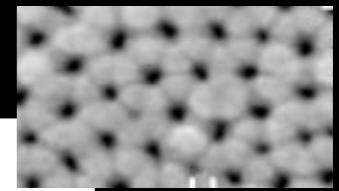
Really insulating!



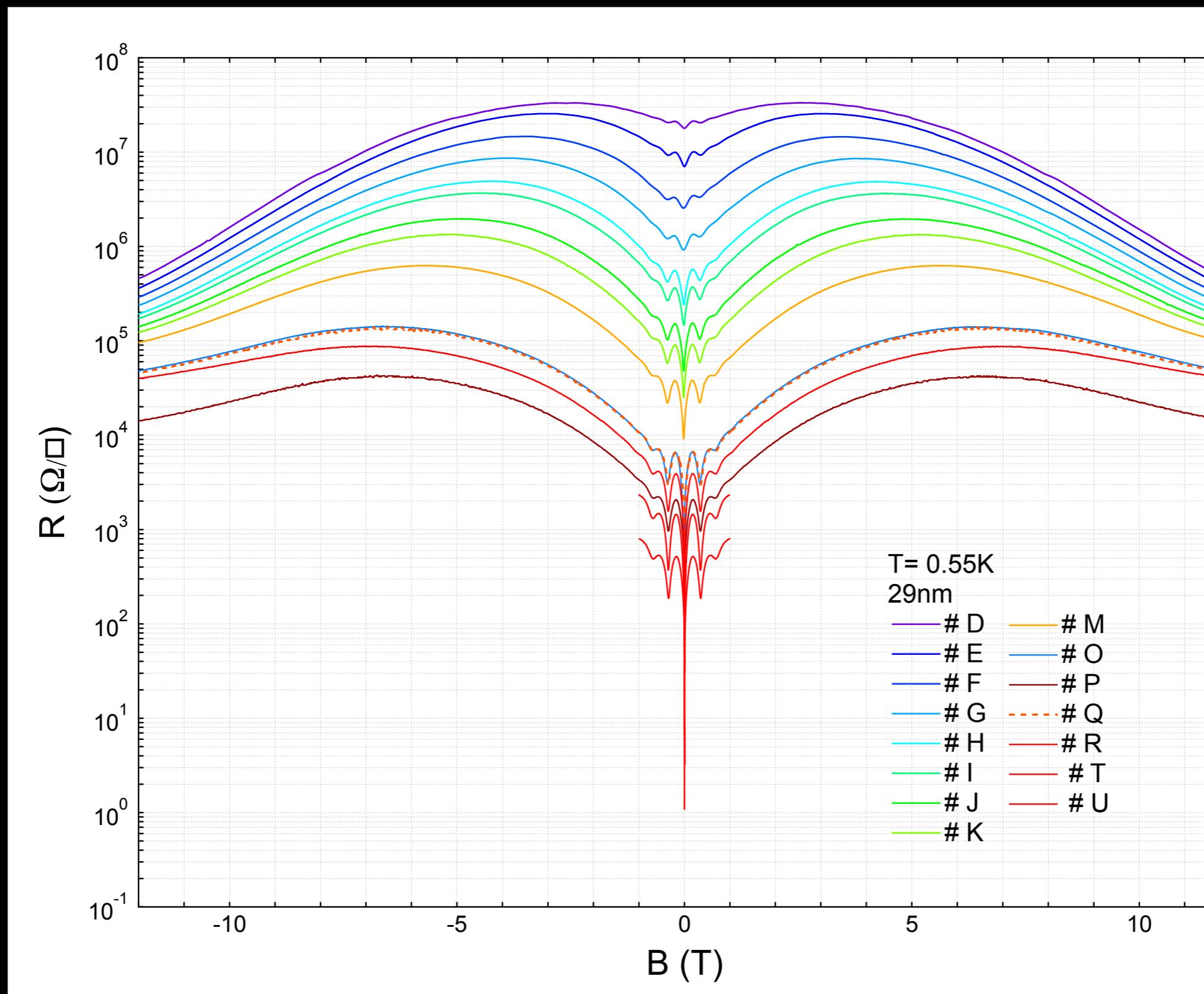
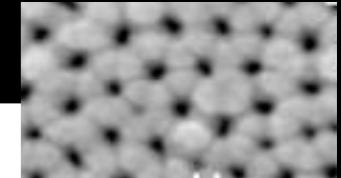
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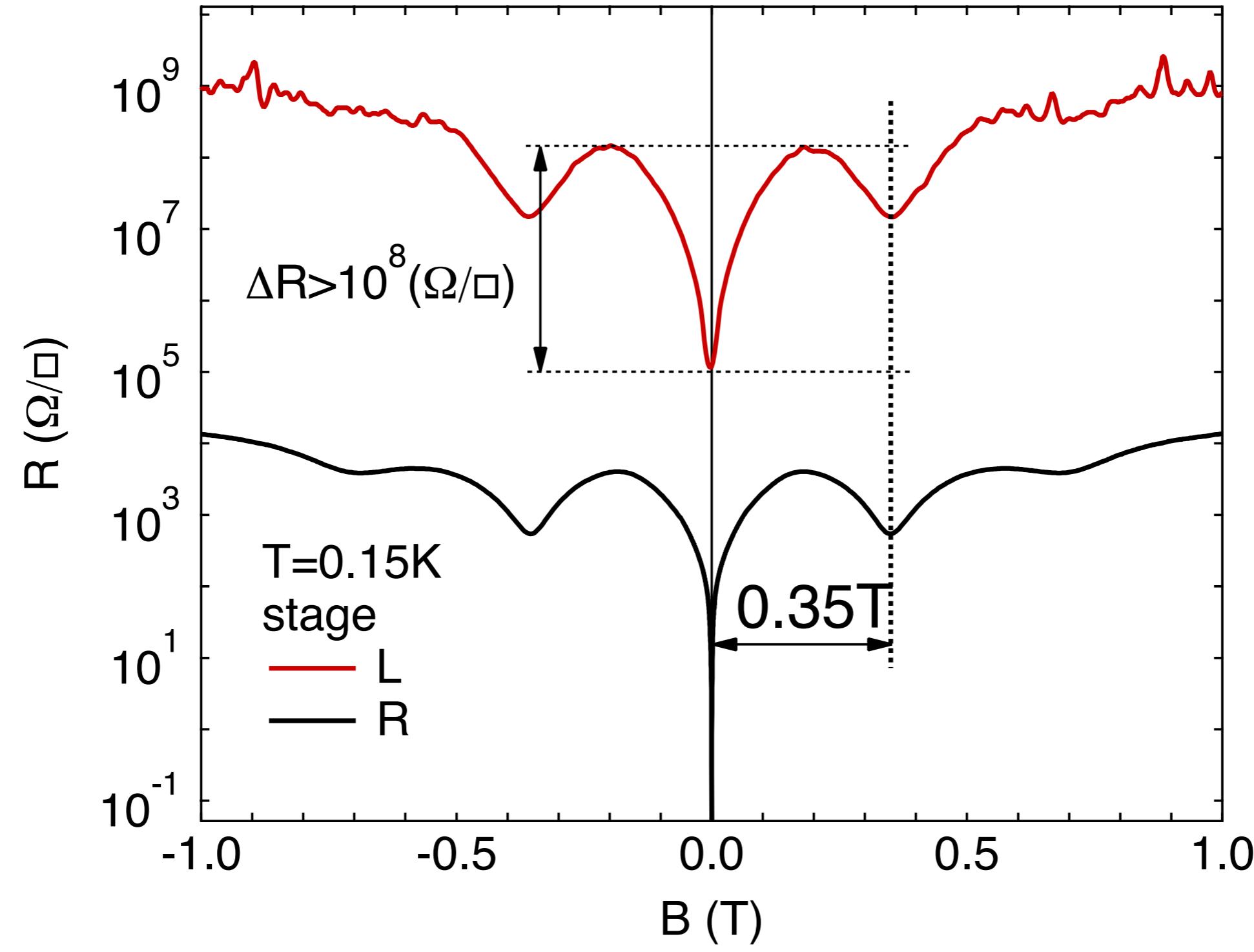


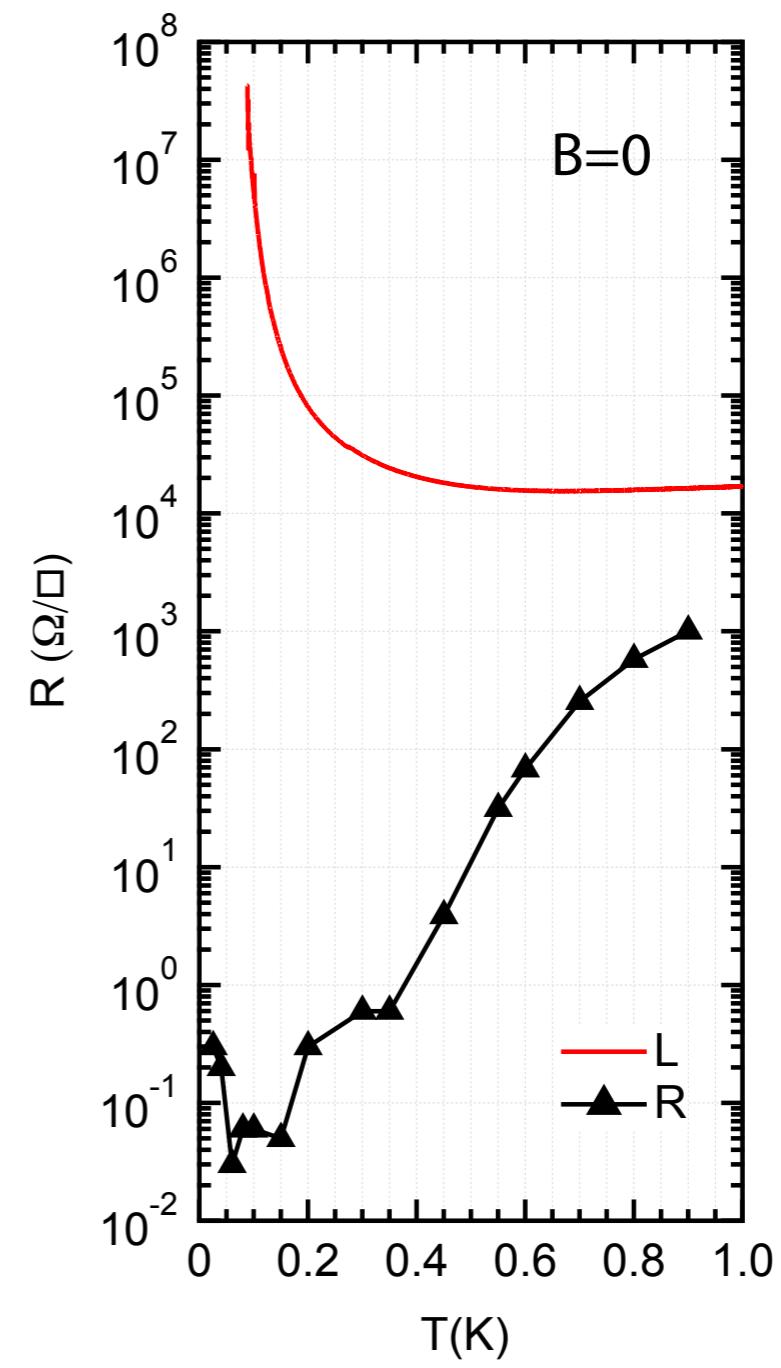
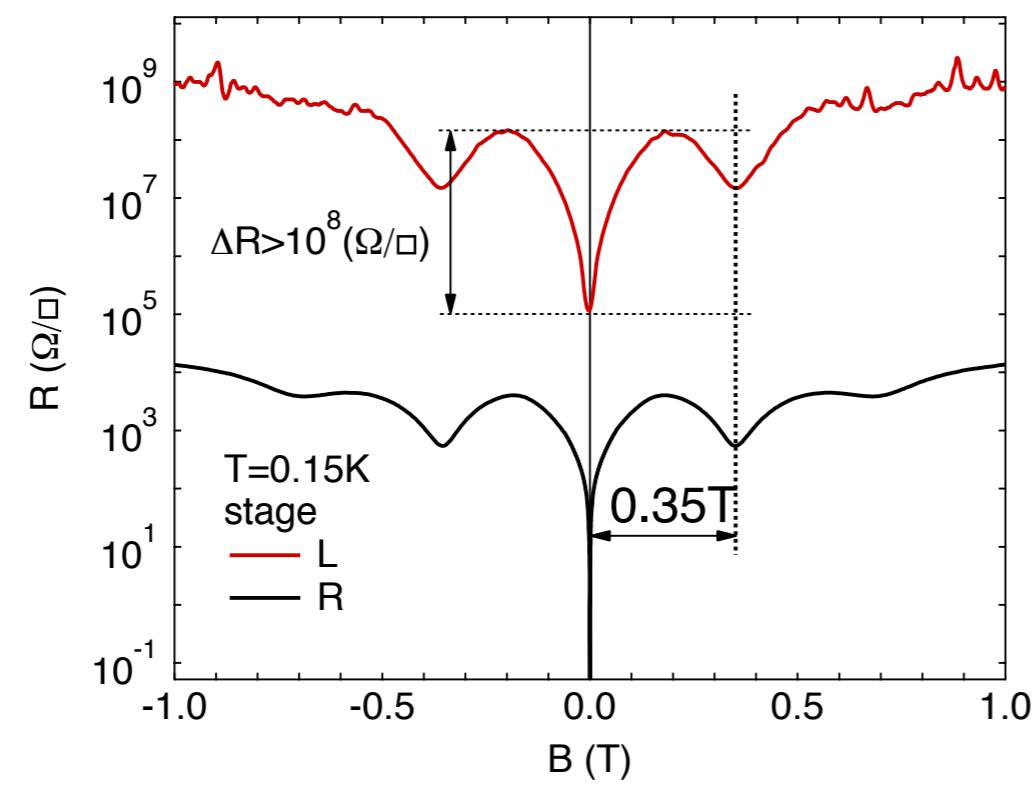
Temperature dependence

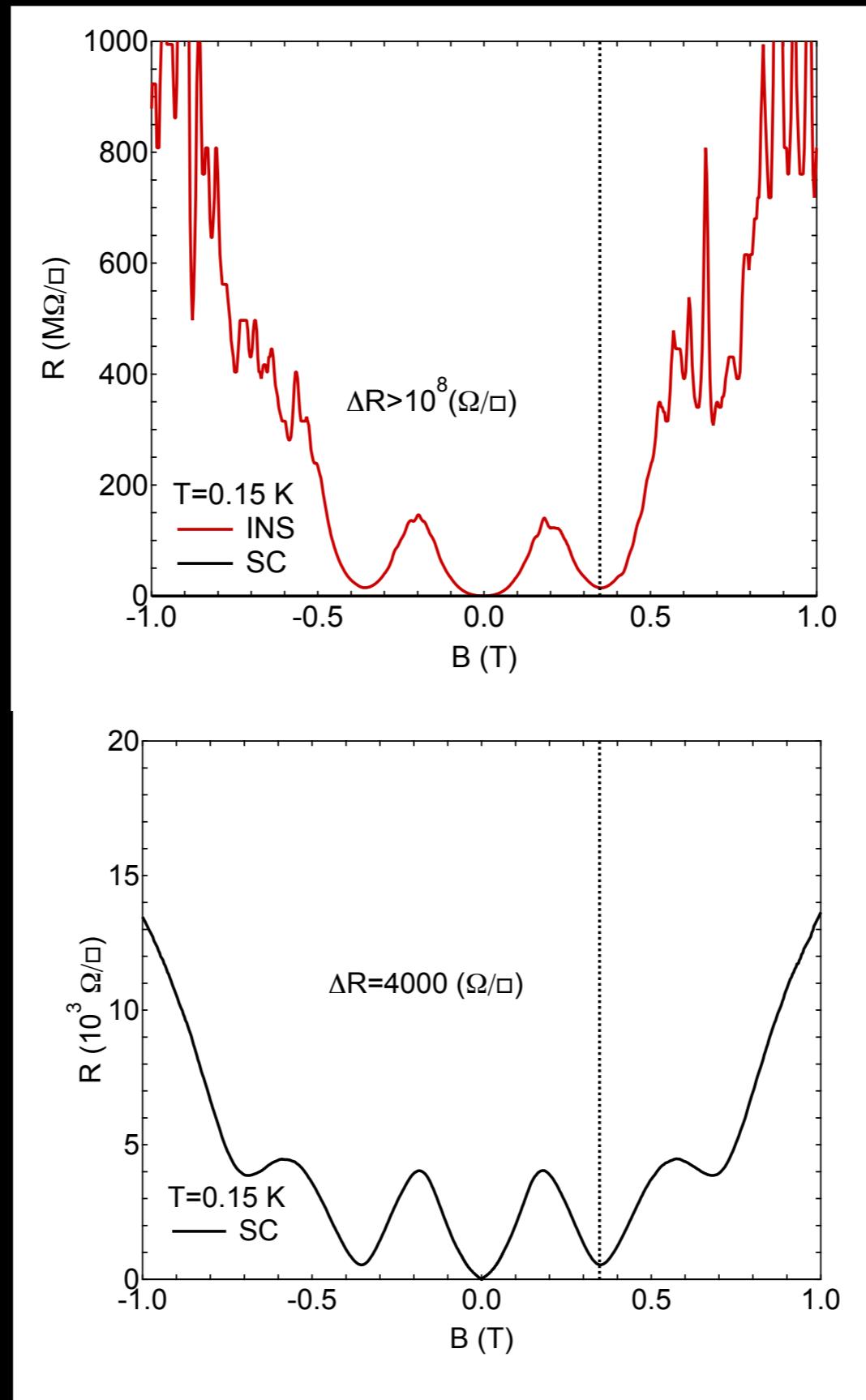


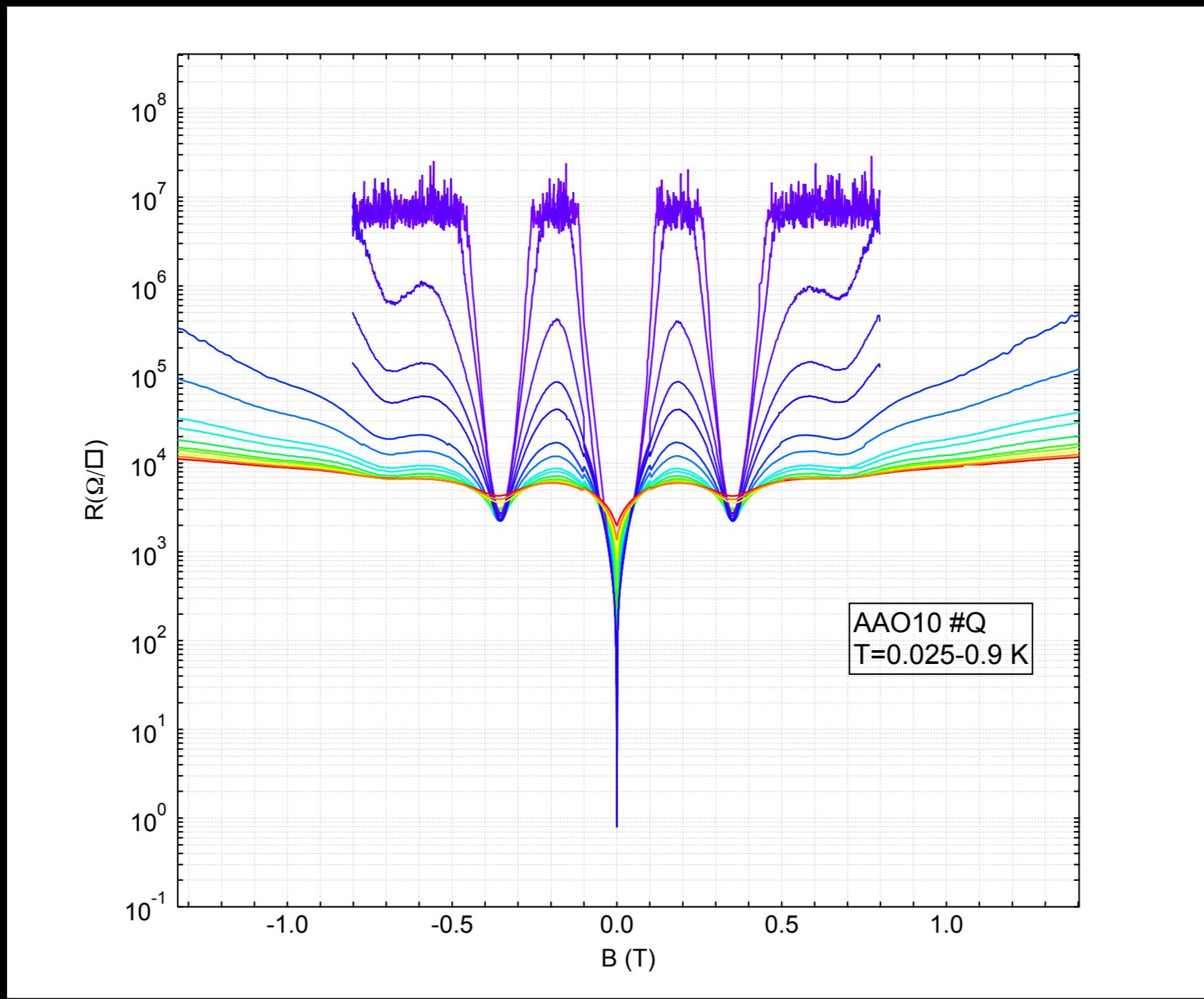
All together now:

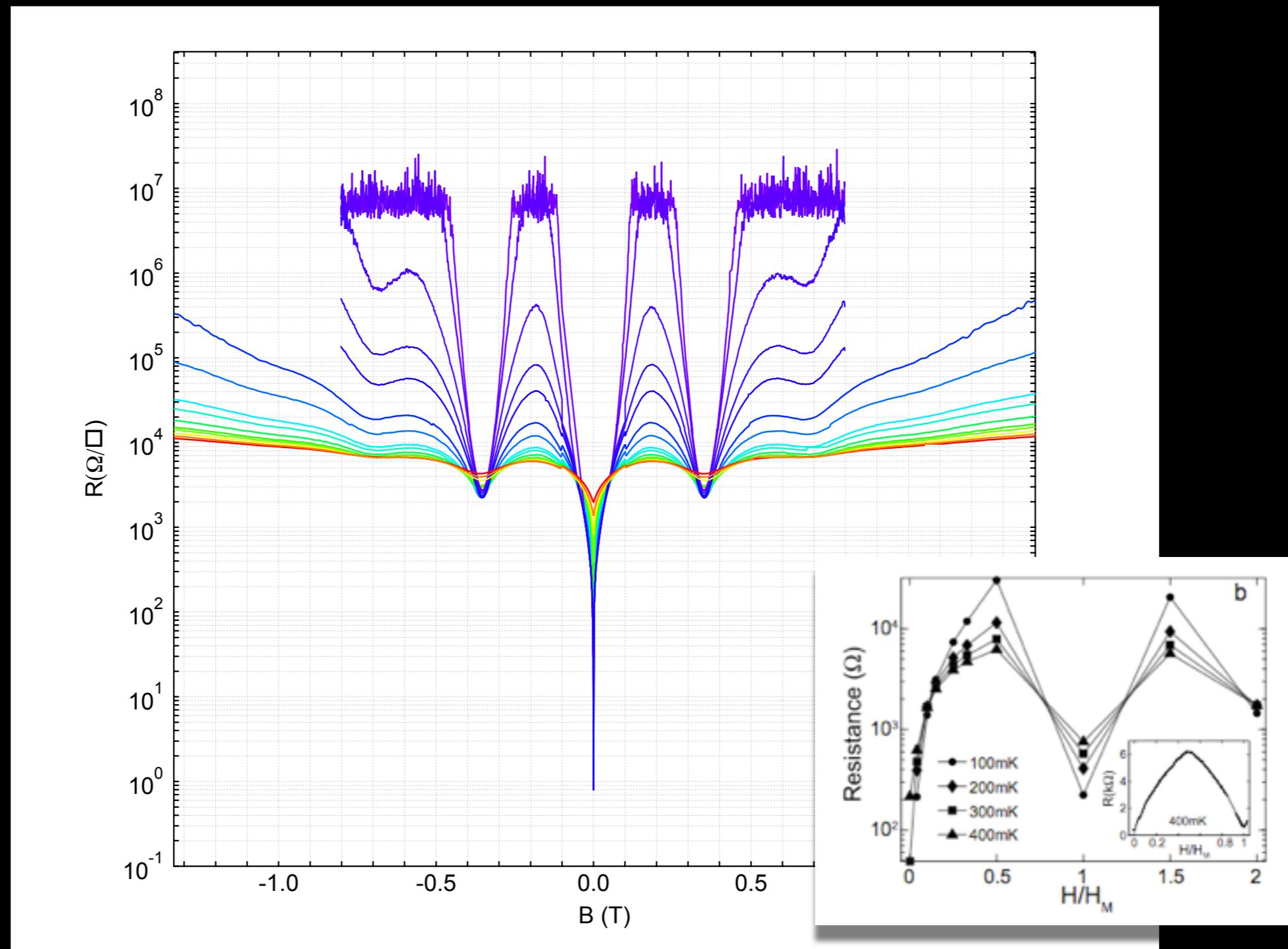




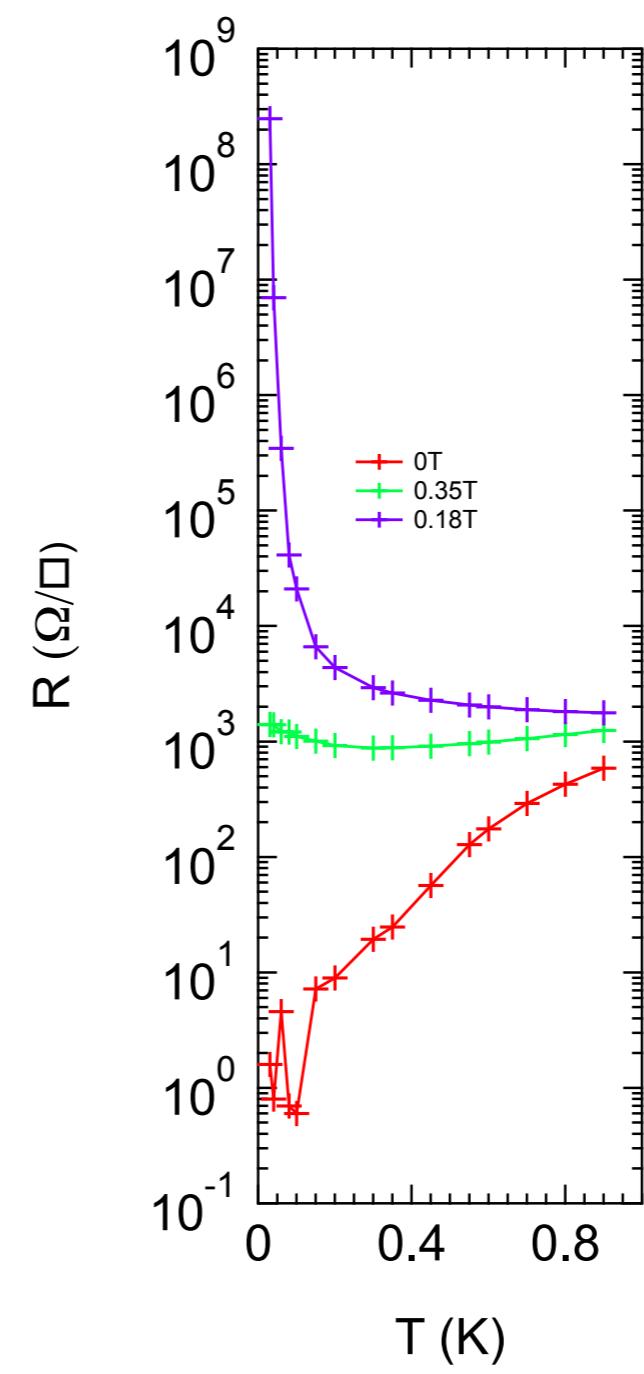








Stewart et al, (2008)



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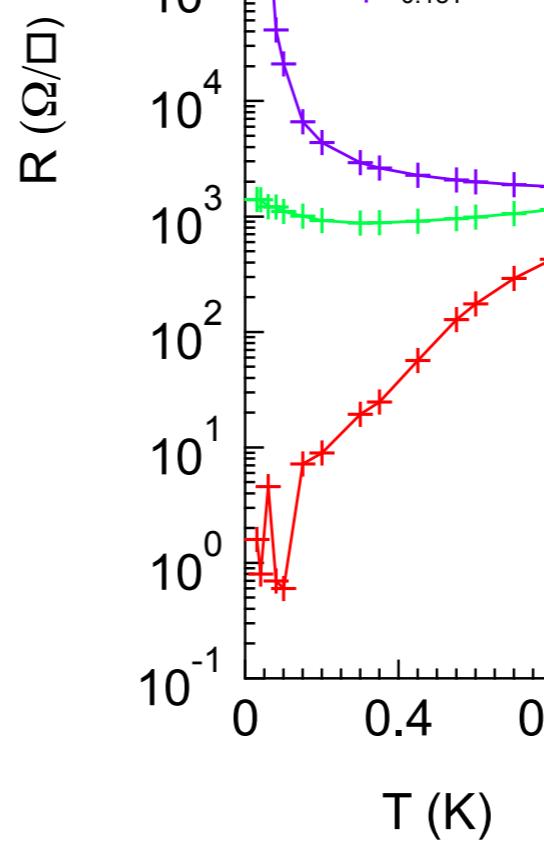
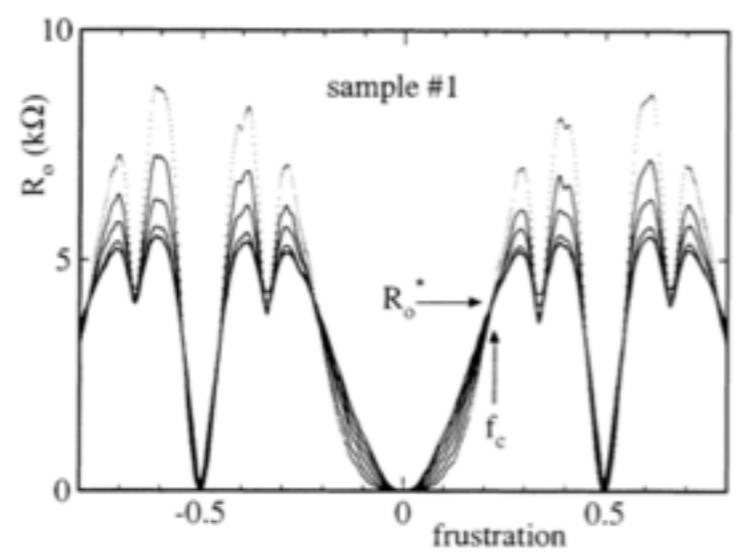
PHYSICAL REVIEW LETTERS

16 NOVEMBER 1992

Field-Induced Superconductor-to-Insulator Transitions in Josephson-Junction Arrays

H. S. J. van der Zant,^(a) F. C. Fritschy, W. J. Elion, L. J. Geerligs,^(b) and J. E. Mooij

Department of Applied Physics, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands
(Received 31 July 1991; revised manuscript received 6 August 1992)



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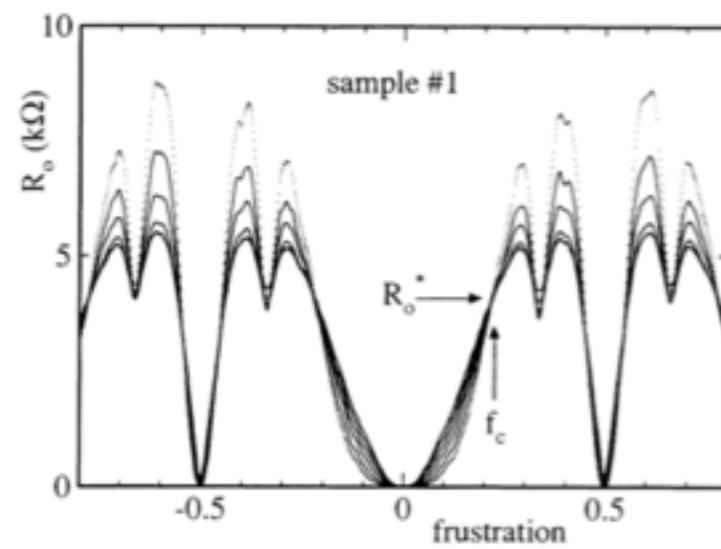
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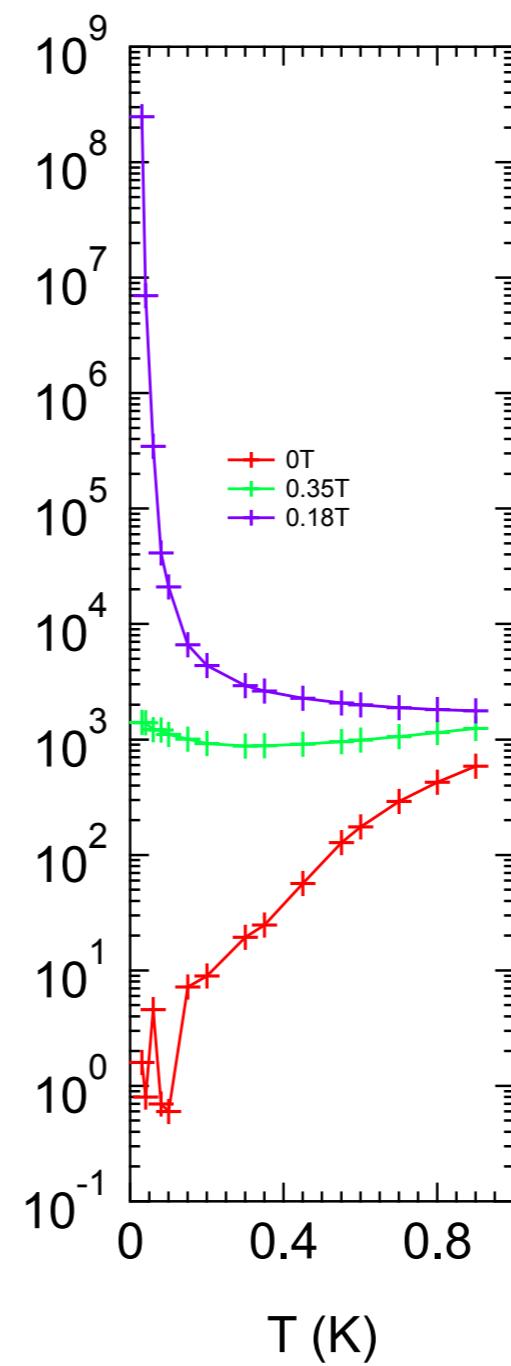
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Department of Applied Physics, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands
(Received 31 July 1991; revised manuscript received 6 August 1992)

JJ Arrays



R (Ω/\square)



Unconventional insulator

Unconventional insulator

Non-conventional insulator

Unconventional insulator
Non-conventional insulator
Aconventional insulator

Unconventional insulator
Non-conventional insulator
Aconventional insulator
Iconventional insulator

Unconventional insulator

Non-conventional insulator

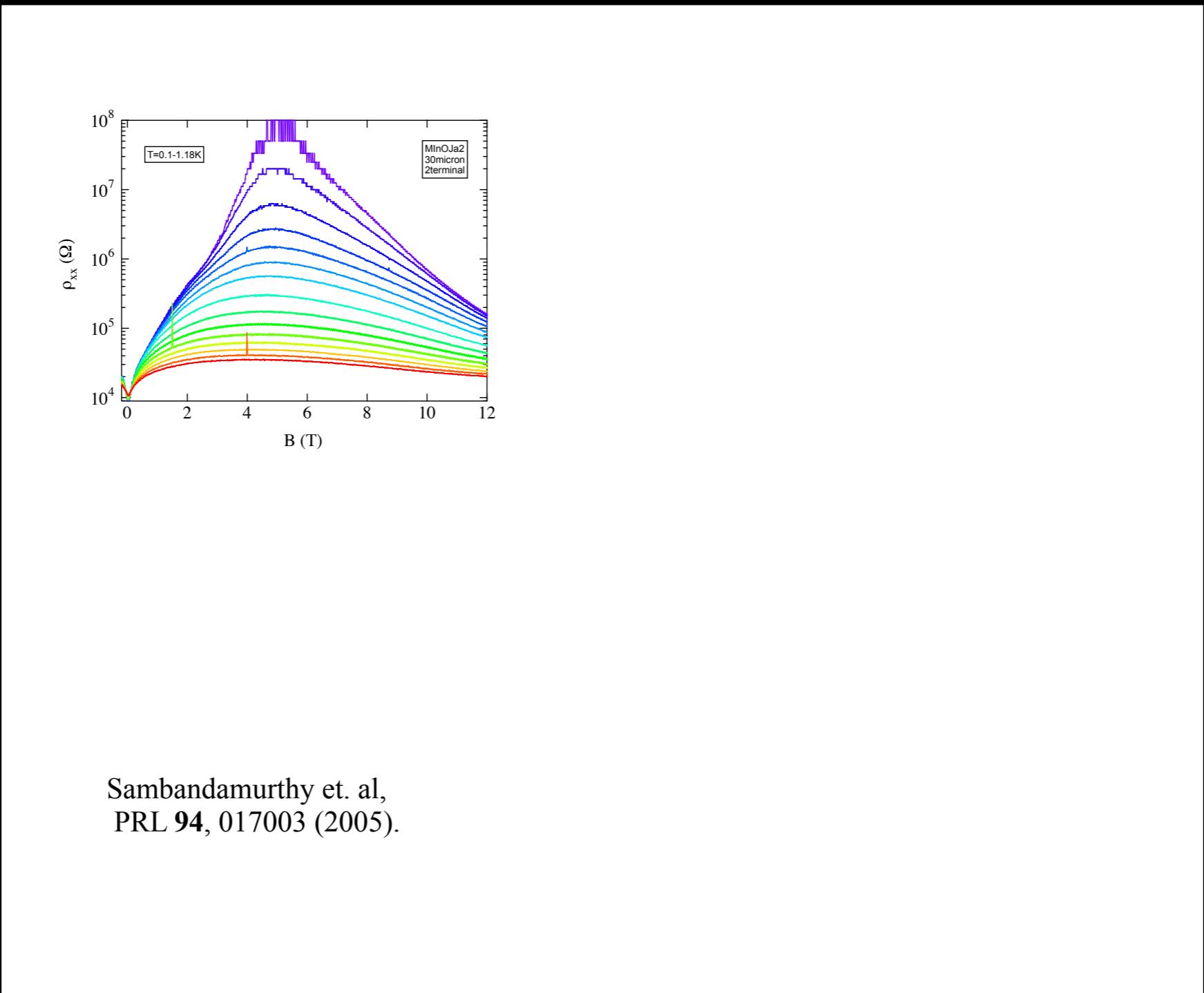
Aconventional insulator

Iconventional insulator

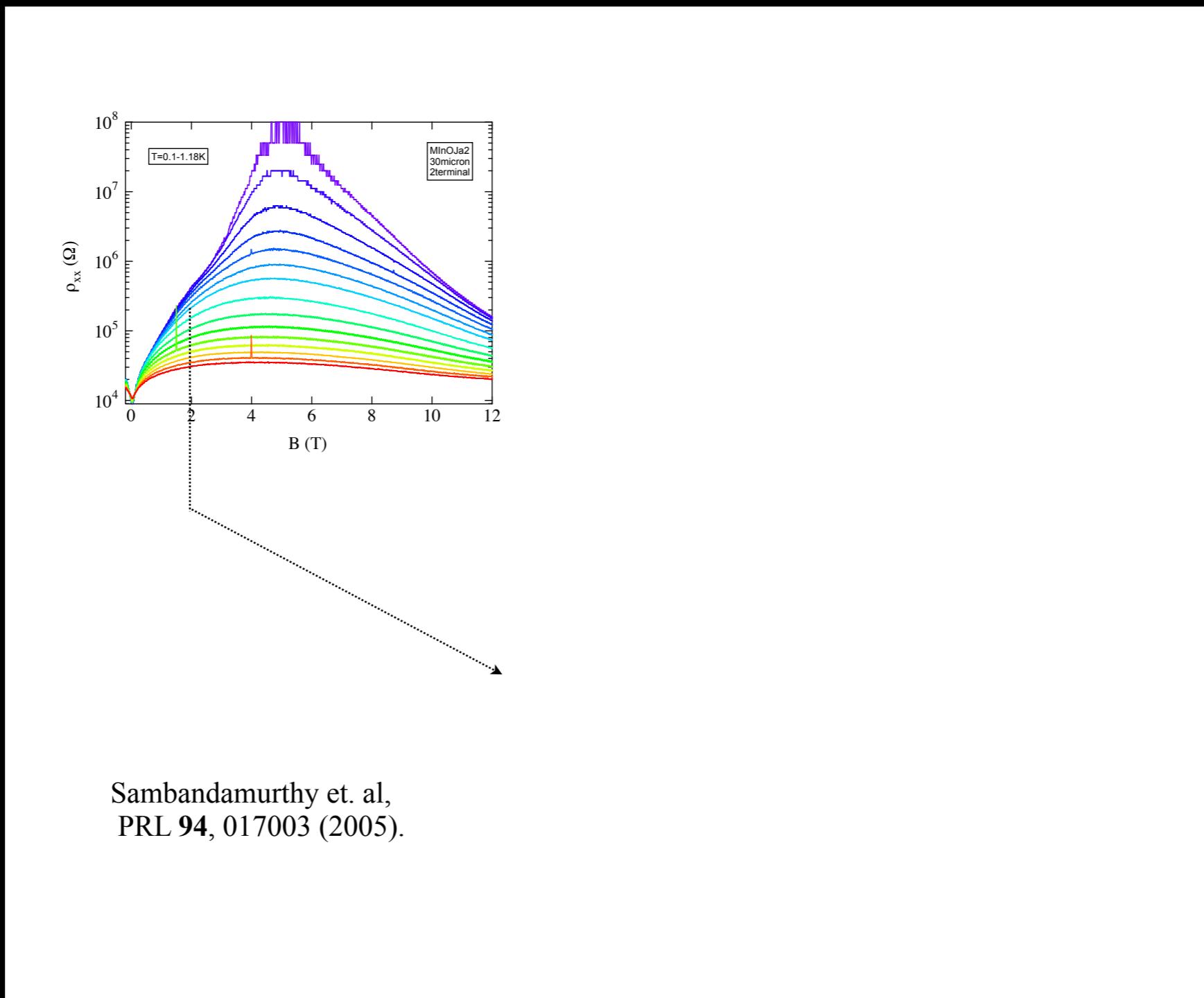
Disconventional insulator

Current-voltage characteristics

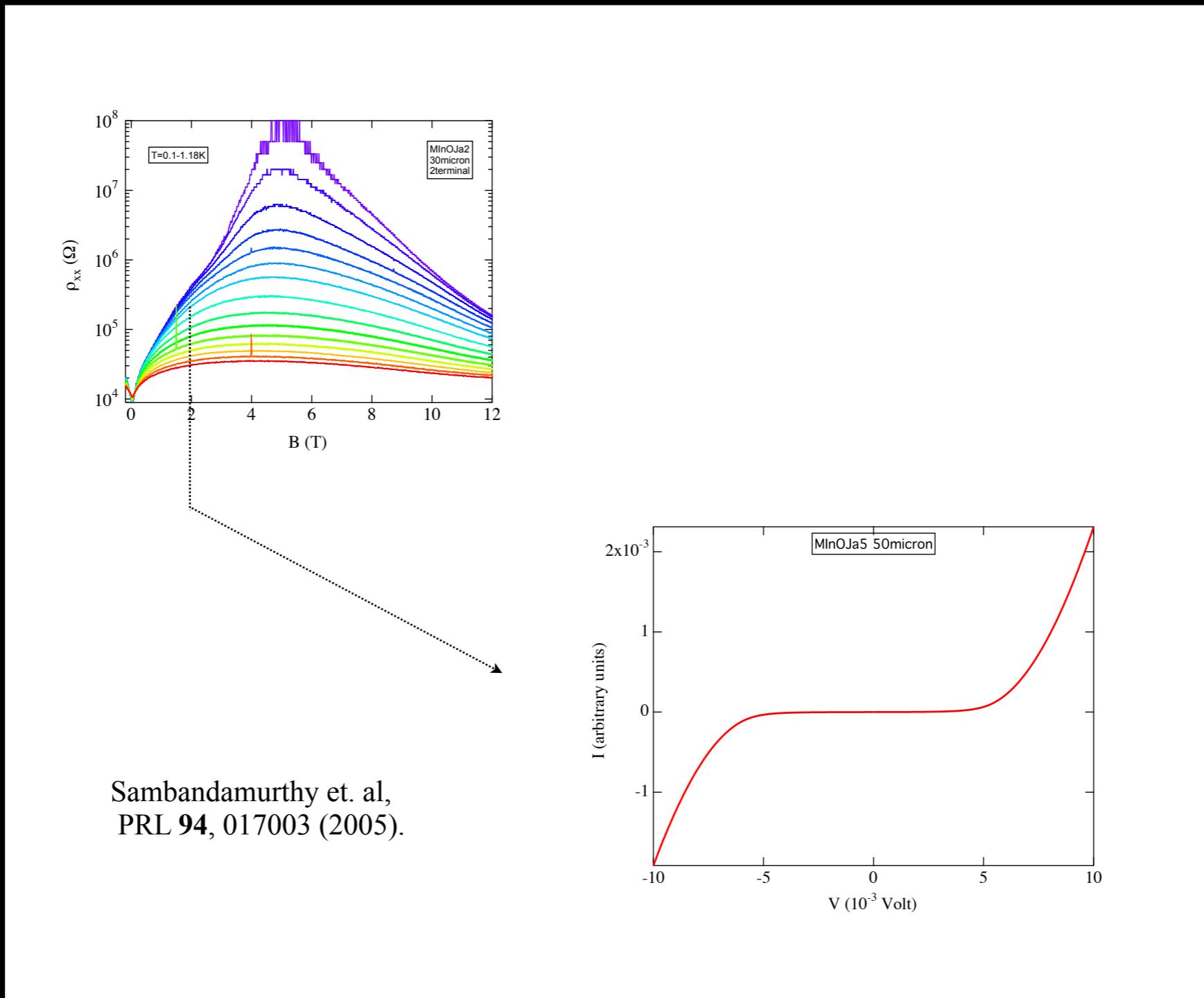
Current-voltage characteristics



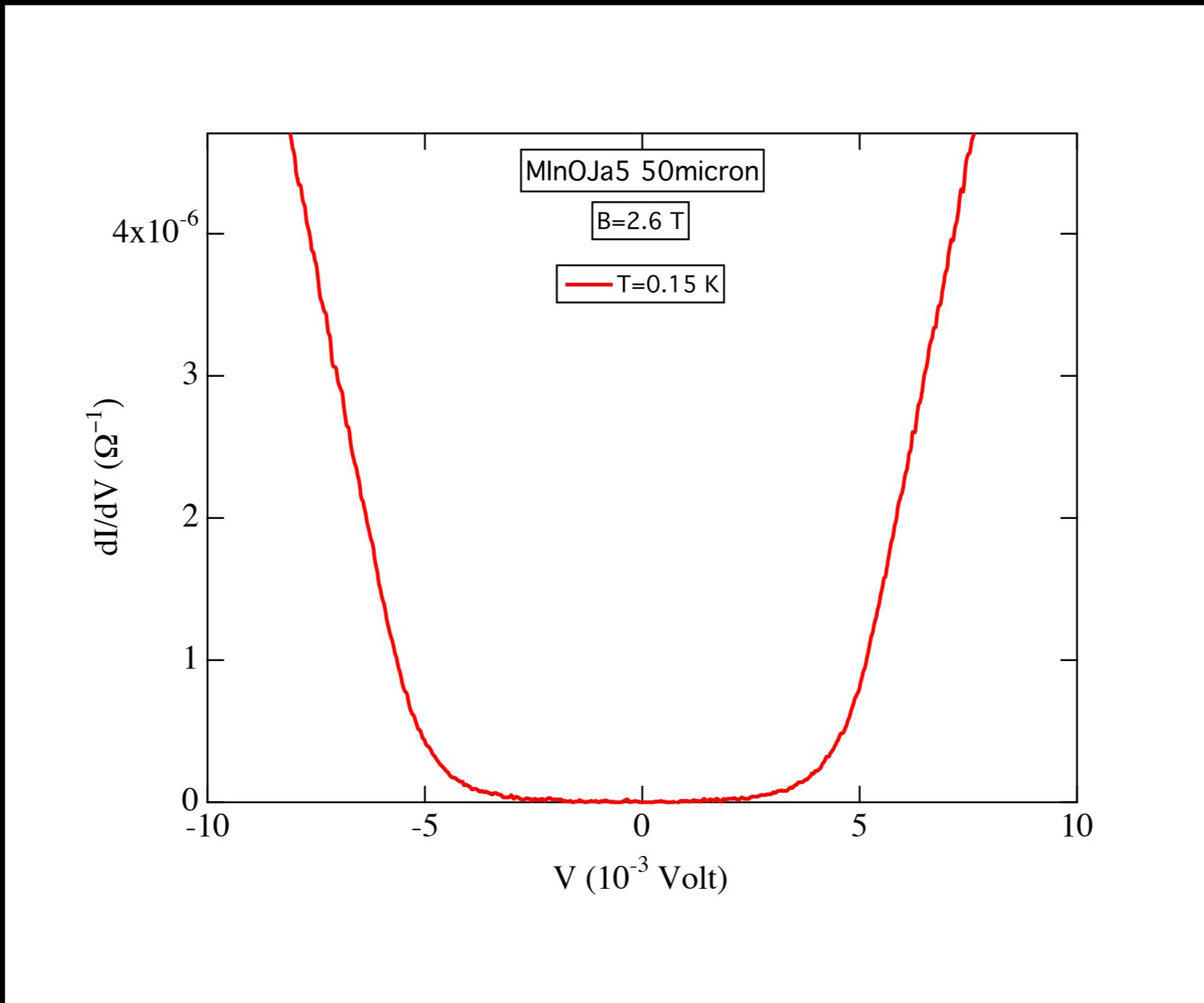
Current-voltage characteristics



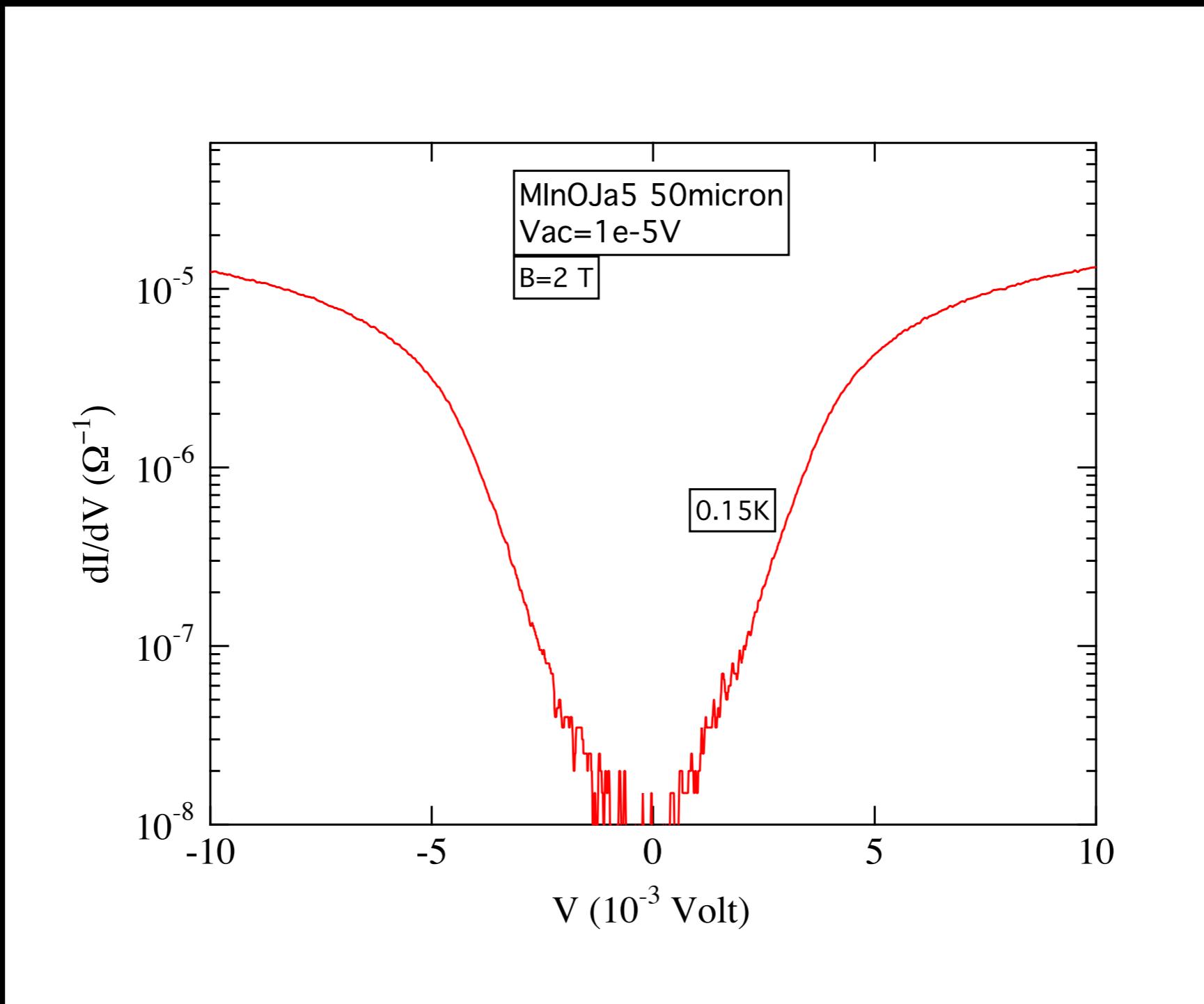
Current-voltage characteristics



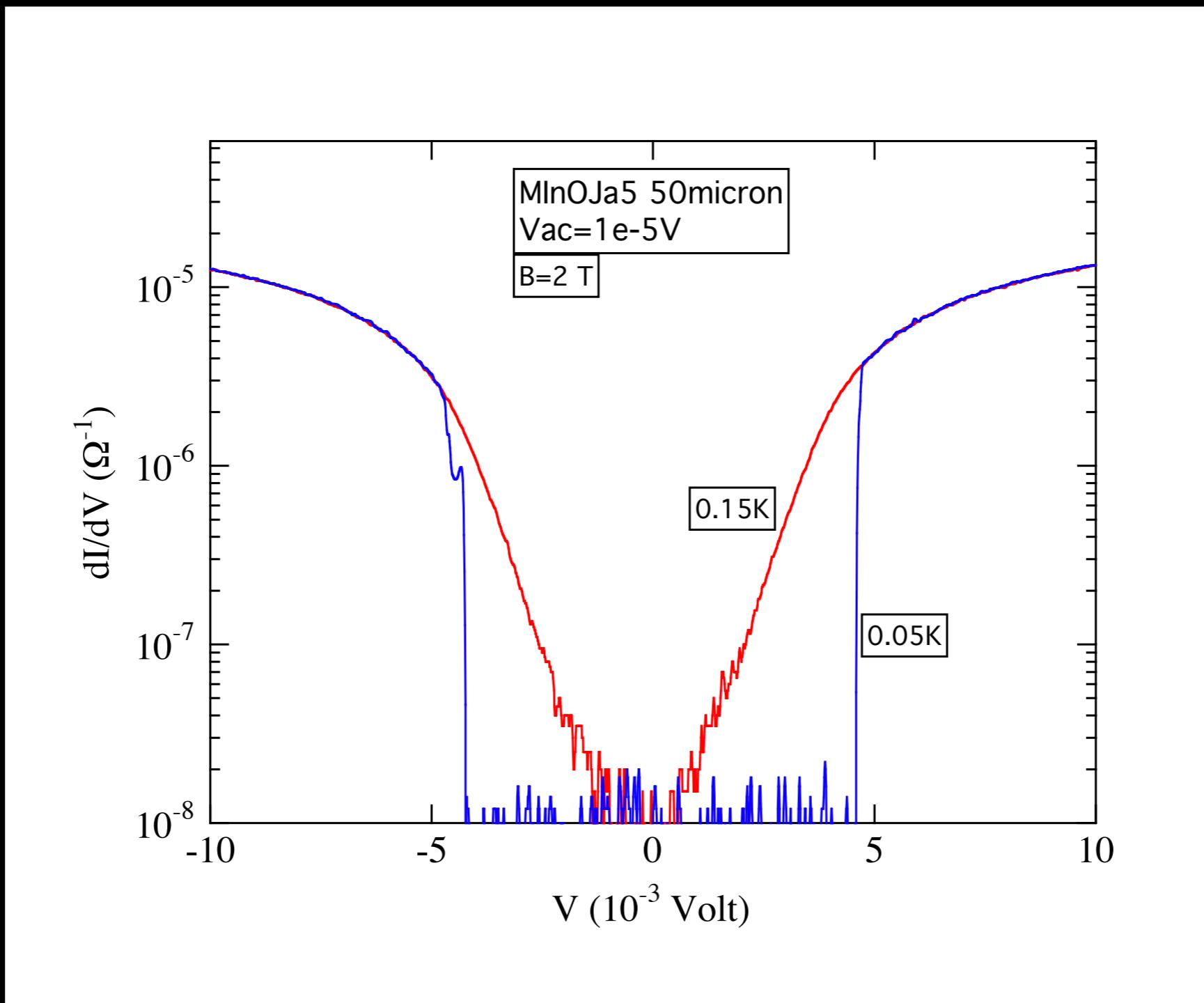
Highly non-linear



Highly non-linear



Transition to abrupt I-V



Current-voltage characteristics

PRL 94, 017003 (2005)

PHYSICAL REVIEW LETTERS

week ending
14 JANUARY 2005

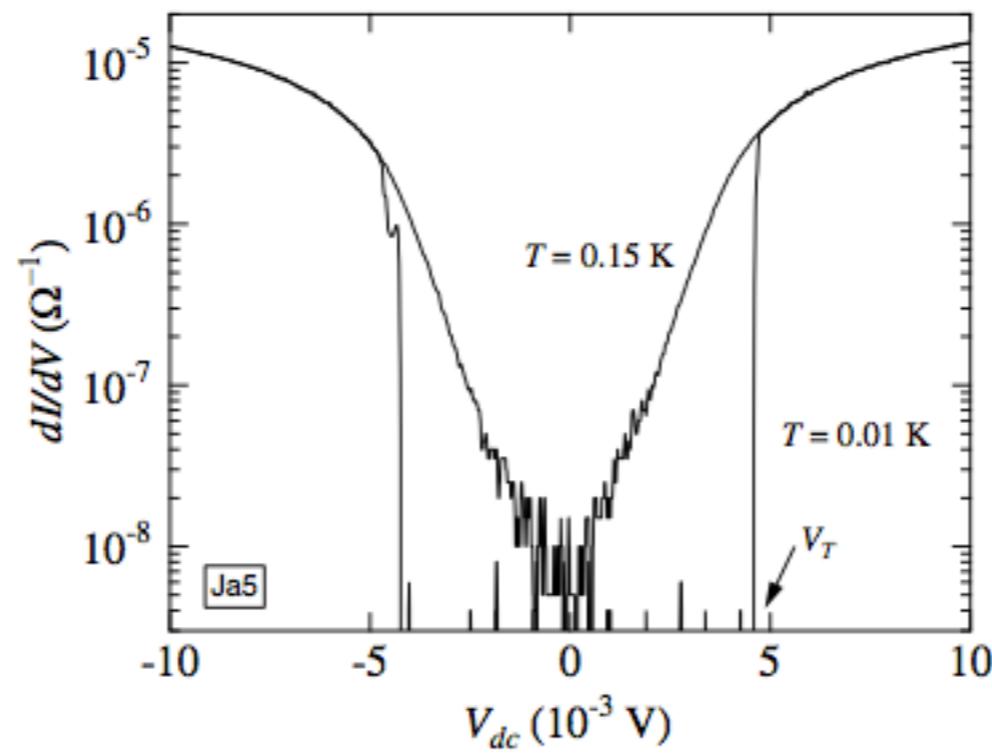
Experimental Evidence for a Collective Insulating State in Two-Dimensional Superconductors

G. Sambandamurthy,¹ L. W. Engel,² A. Johansson,¹ E. Peled,¹ and D. Shahar¹

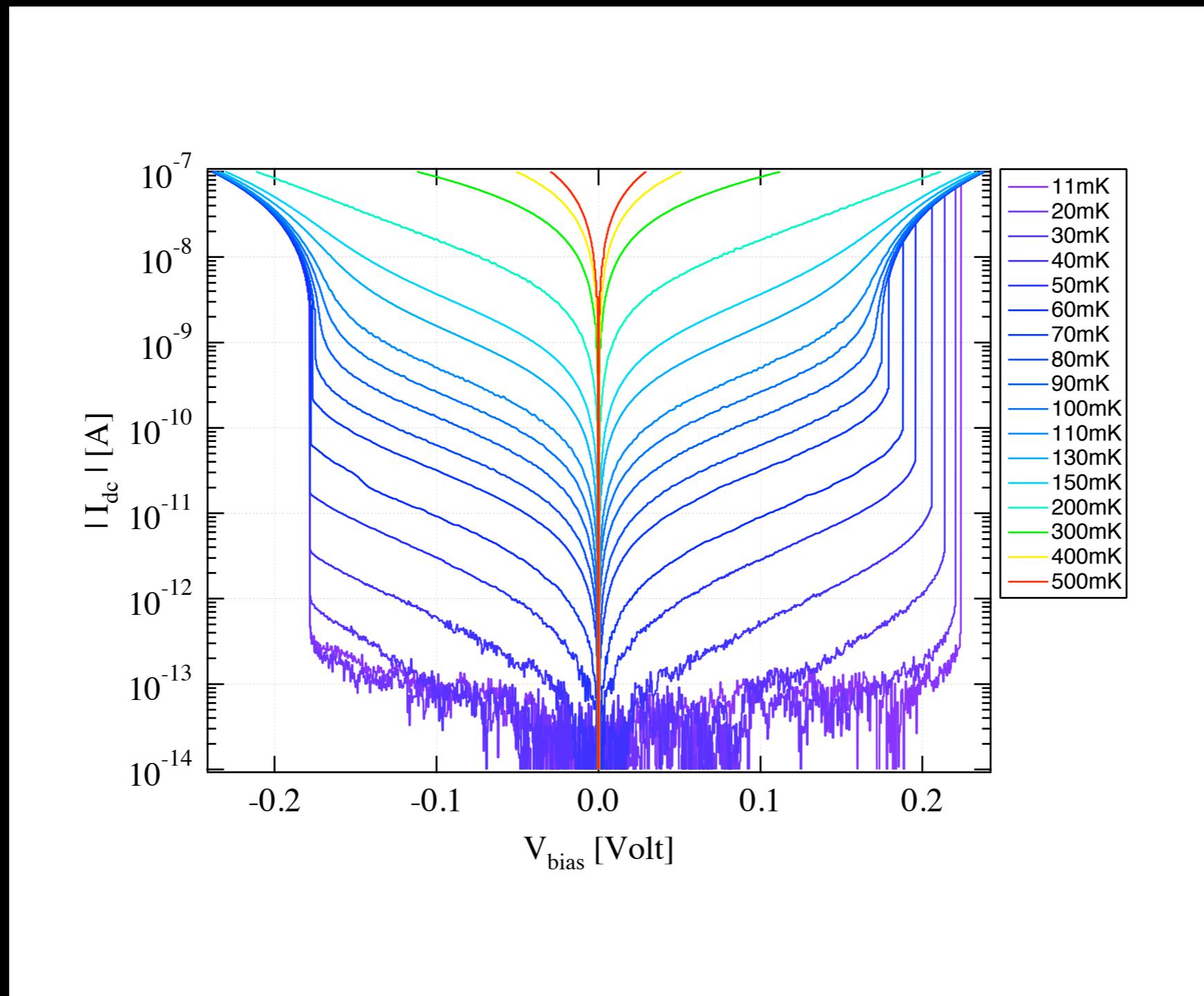
¹*Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel,*

²*National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida 32306, USA*

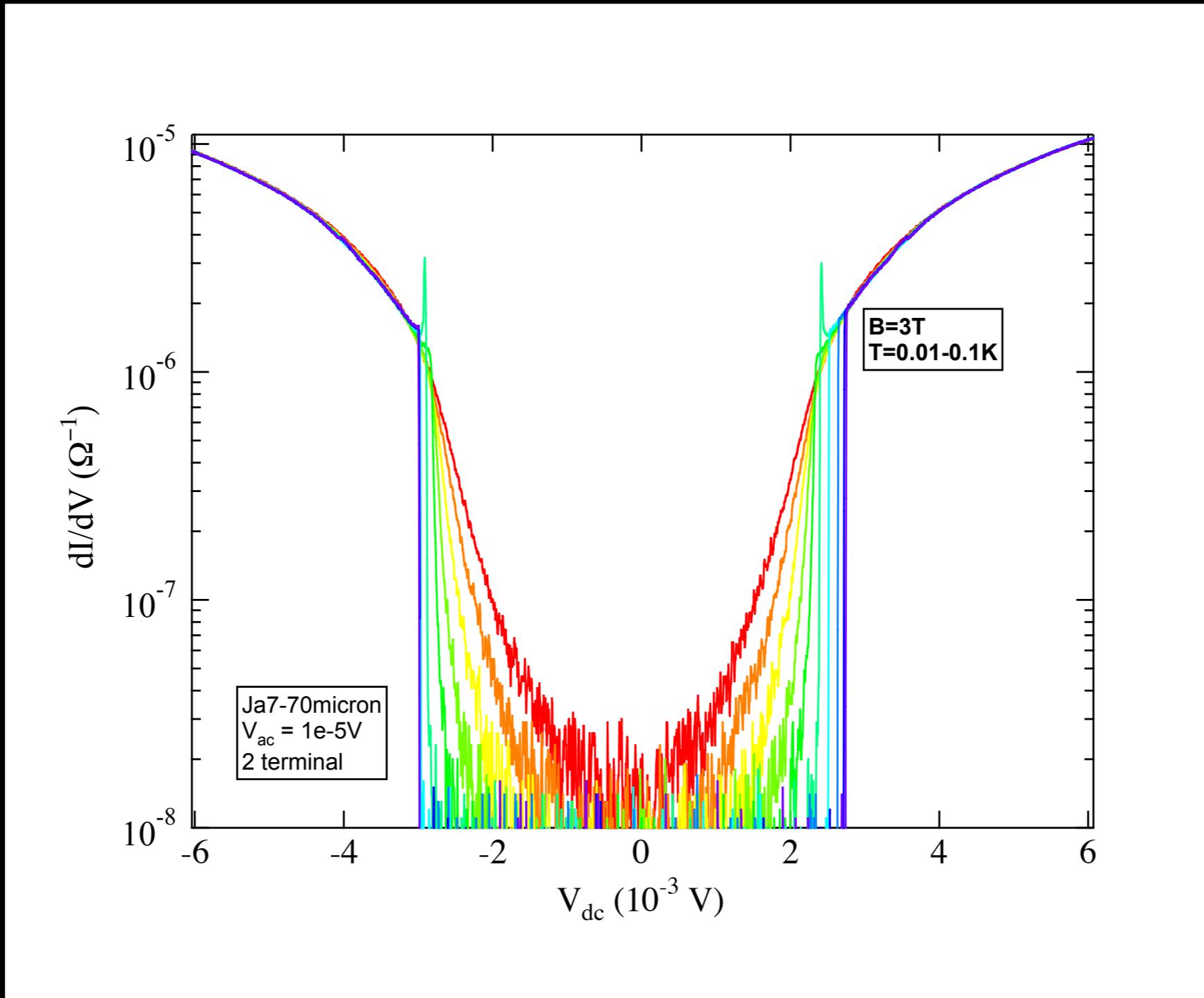
(Received 18 March 2004; published 12 January 2005)



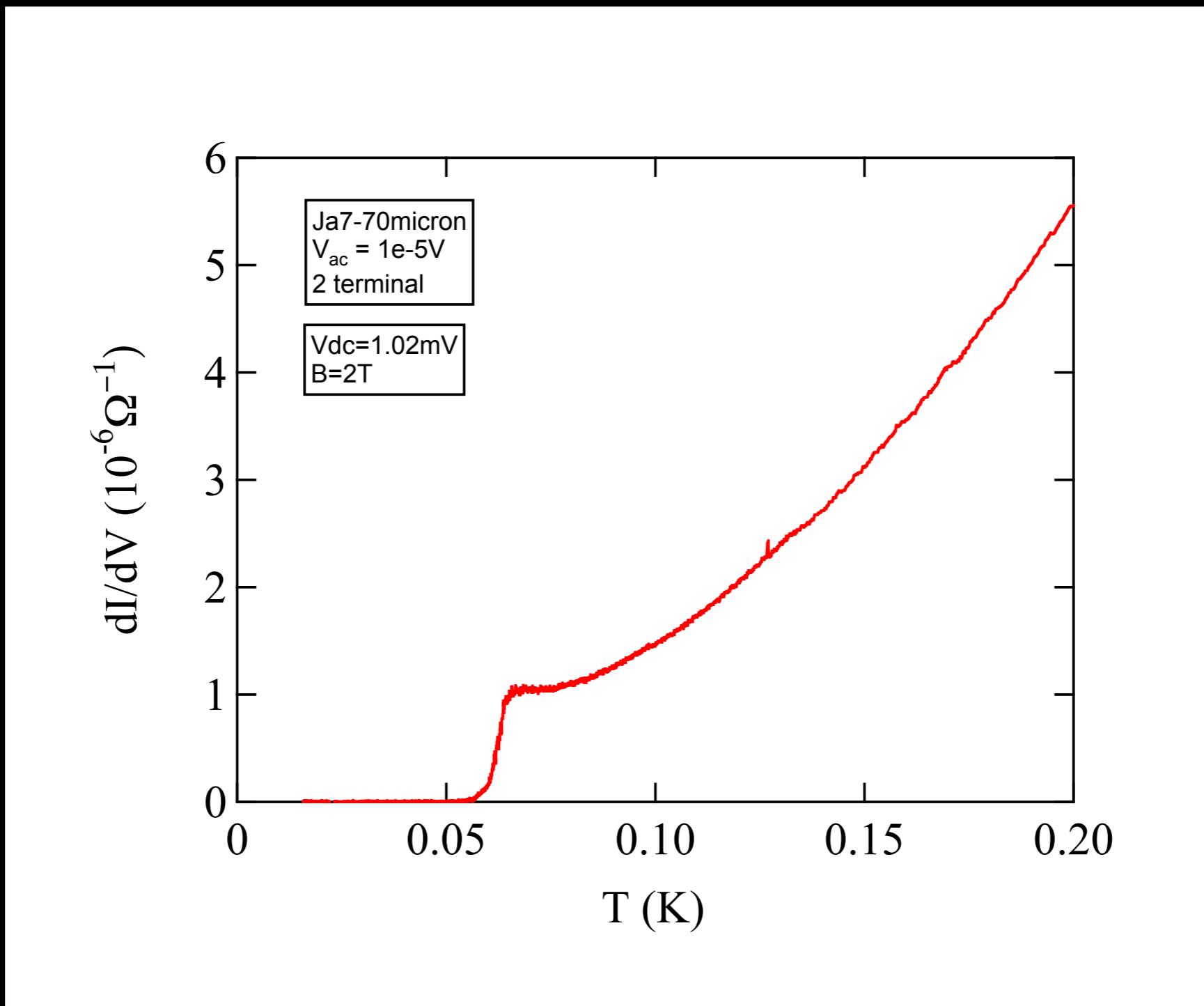
I-V



More temperatures



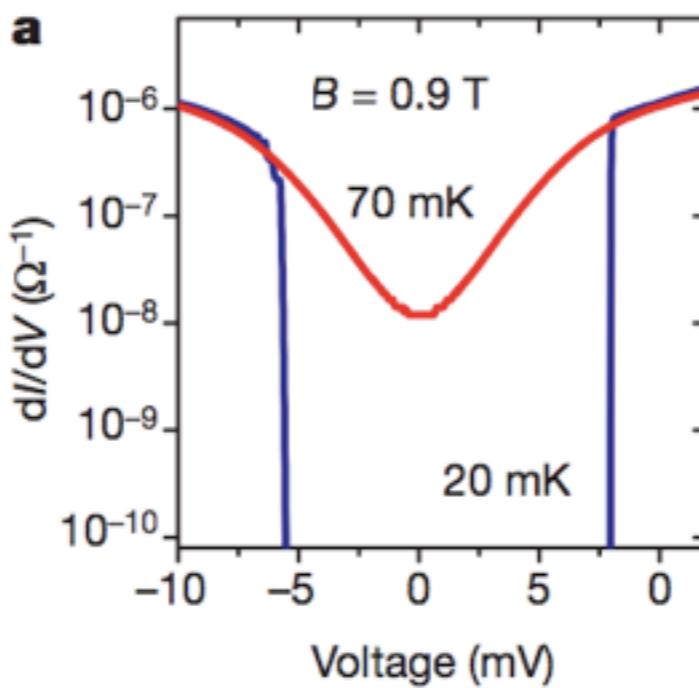
Superinsulator...



Another material!

Vinokur *et al.*, NATURE | Vol 452 | 3 April 2008

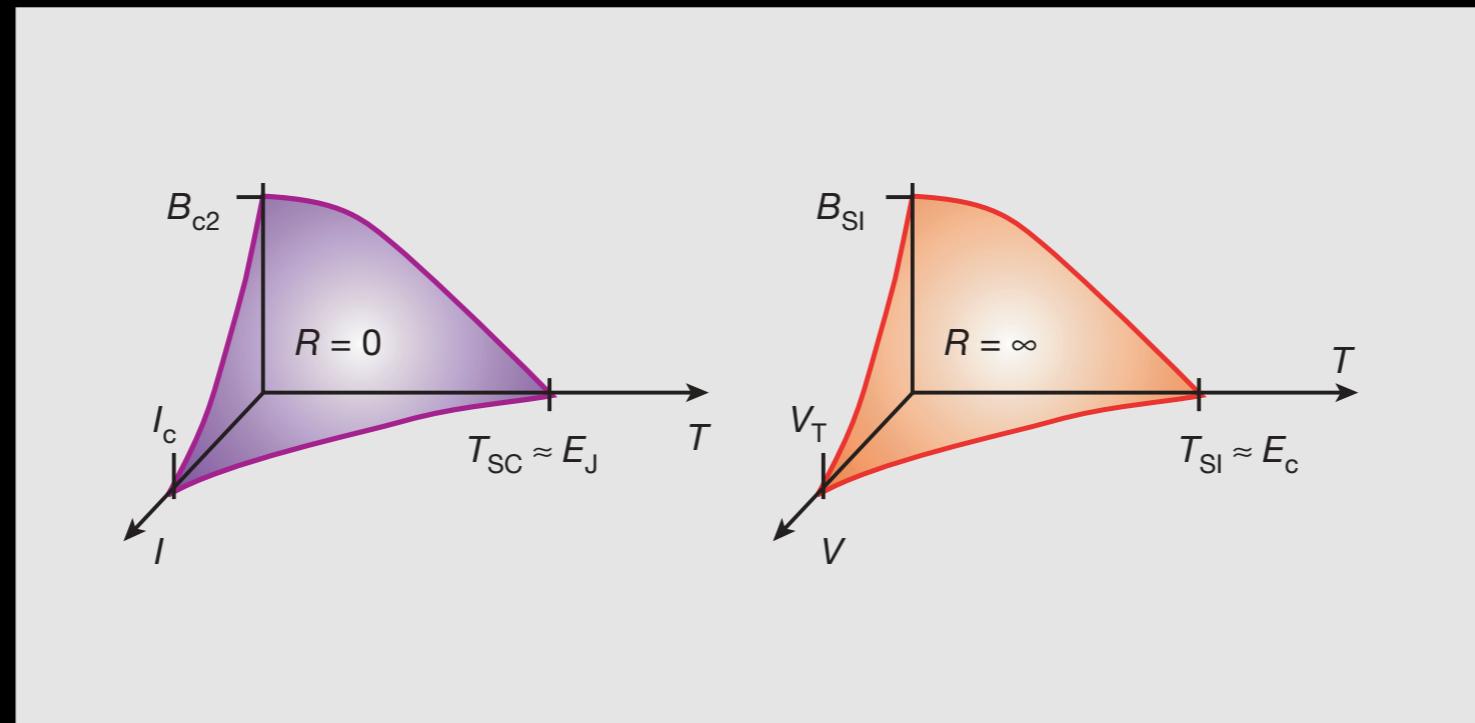
TiN

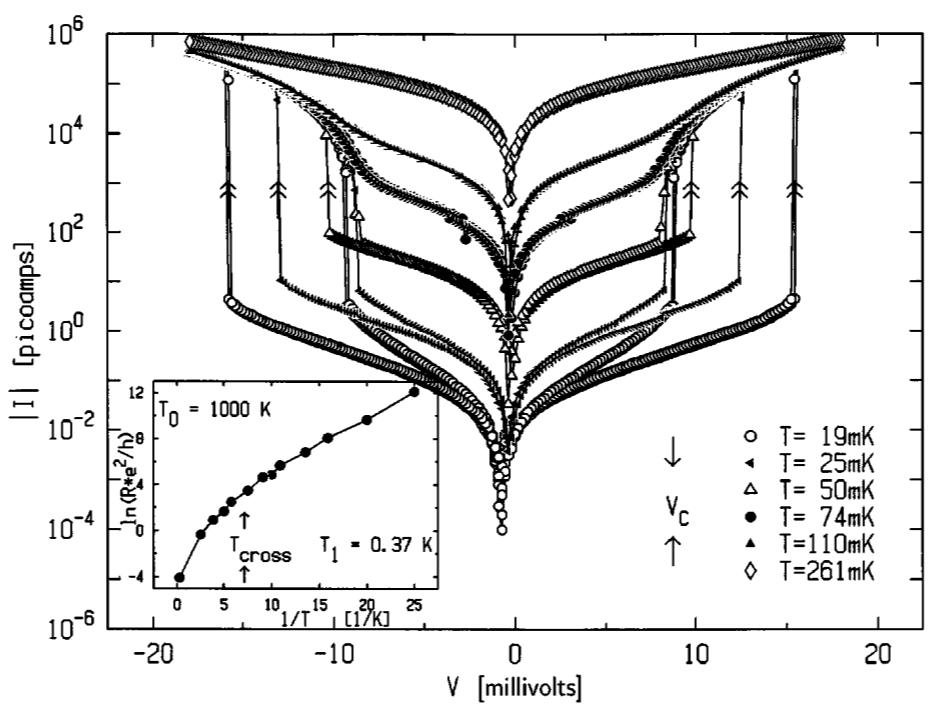


Superinsulator and quantum synchronization

Vinokur et al., NATURE | Vol 452 | 3 April 2008

Duality





Ladieu, Sanquer, and Bouchaud, 1996
 $\text{a:Y}_x\text{Si}_{1-x}$

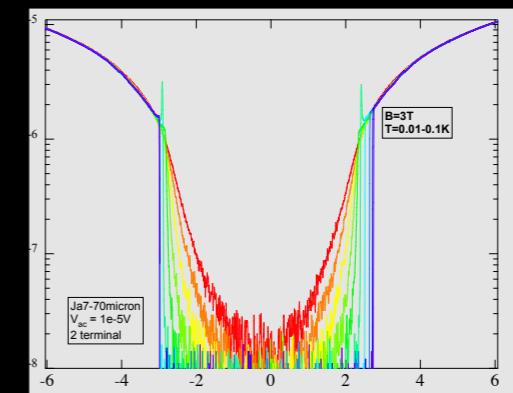
Jumps in current-voltage characteristics in disordered films

Phys. Rev. Lett. 102, 176803 (2009)

B.L. Altshuler, V.E. Kravtsov, I.V. Lerner, I.L. Aleiner

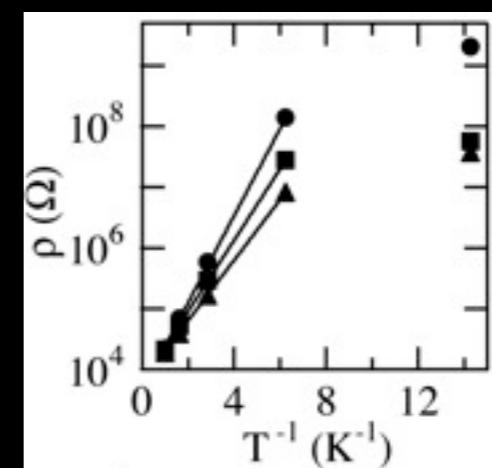
1. I-V is linear

(Apparent non-linearity from electron heating)



2. $R(T)$ is a fast function

$$\rho(T) = \rho_0 e^{T_I/T}$$



Jumps in current-voltage characteristics in disordered films

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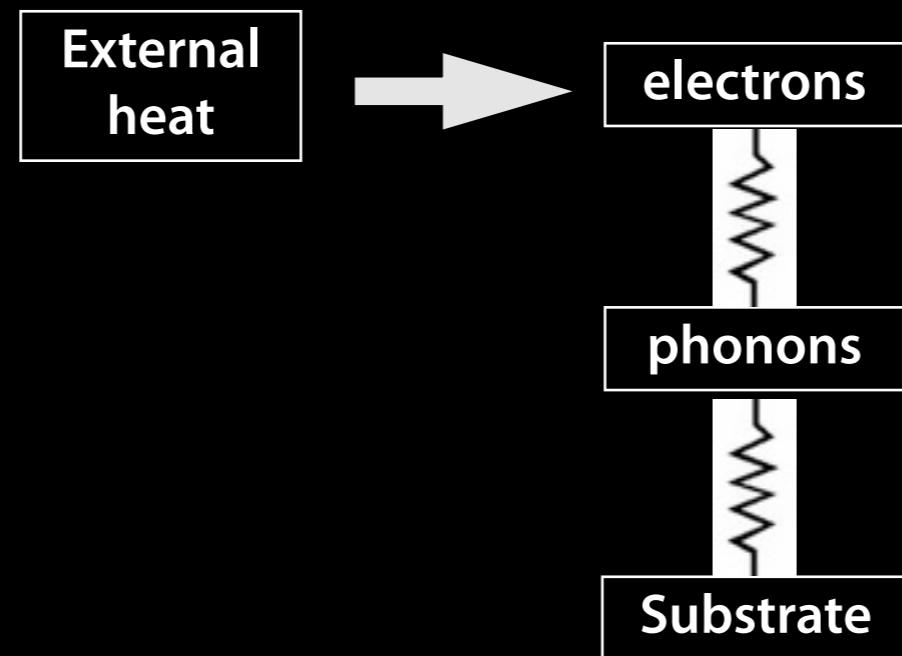
Heat balance equation:

Jumps in current-voltage characteristics in disordered films

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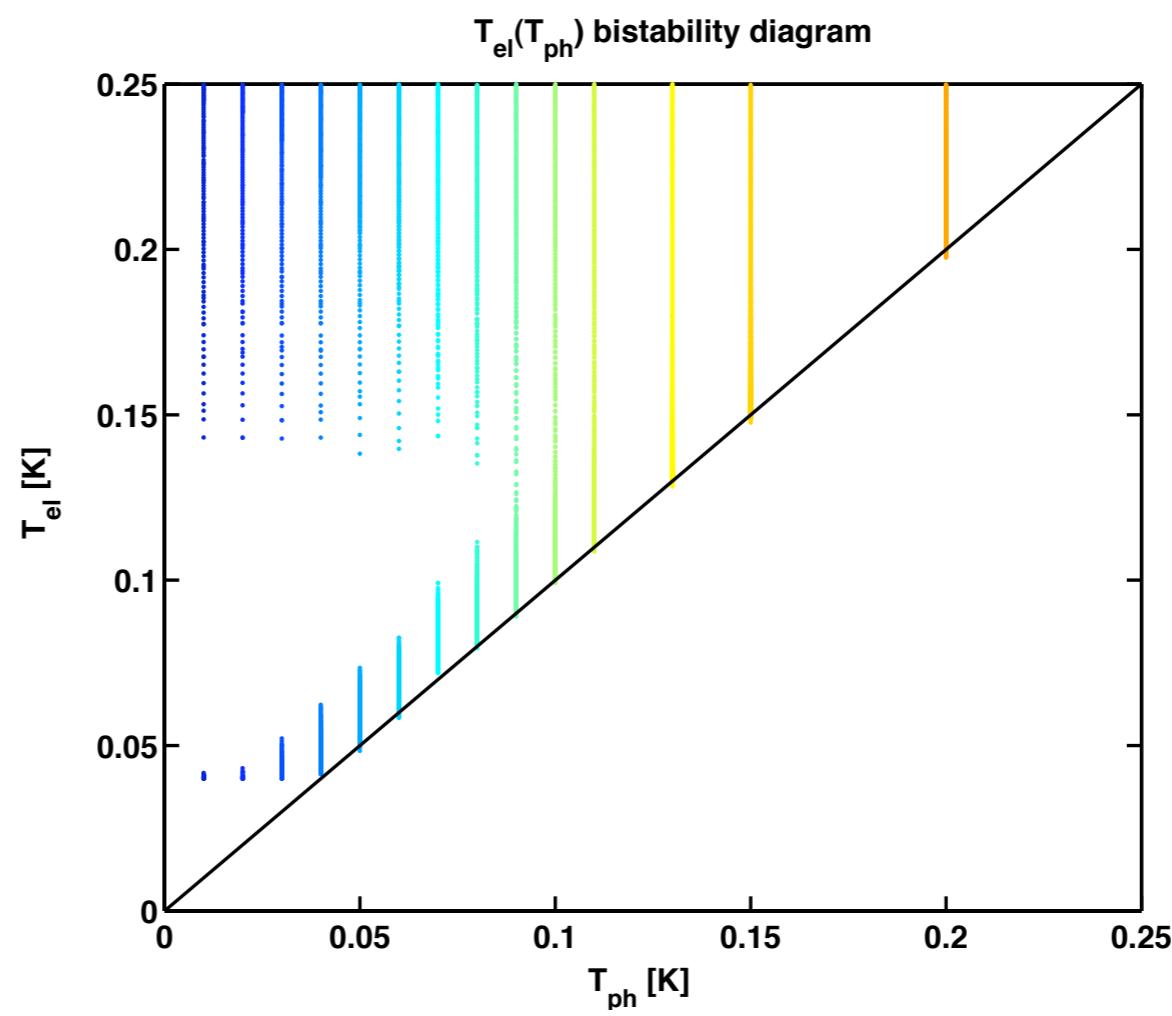
Phys. Rev. Lett. 102, 176803 (2009)

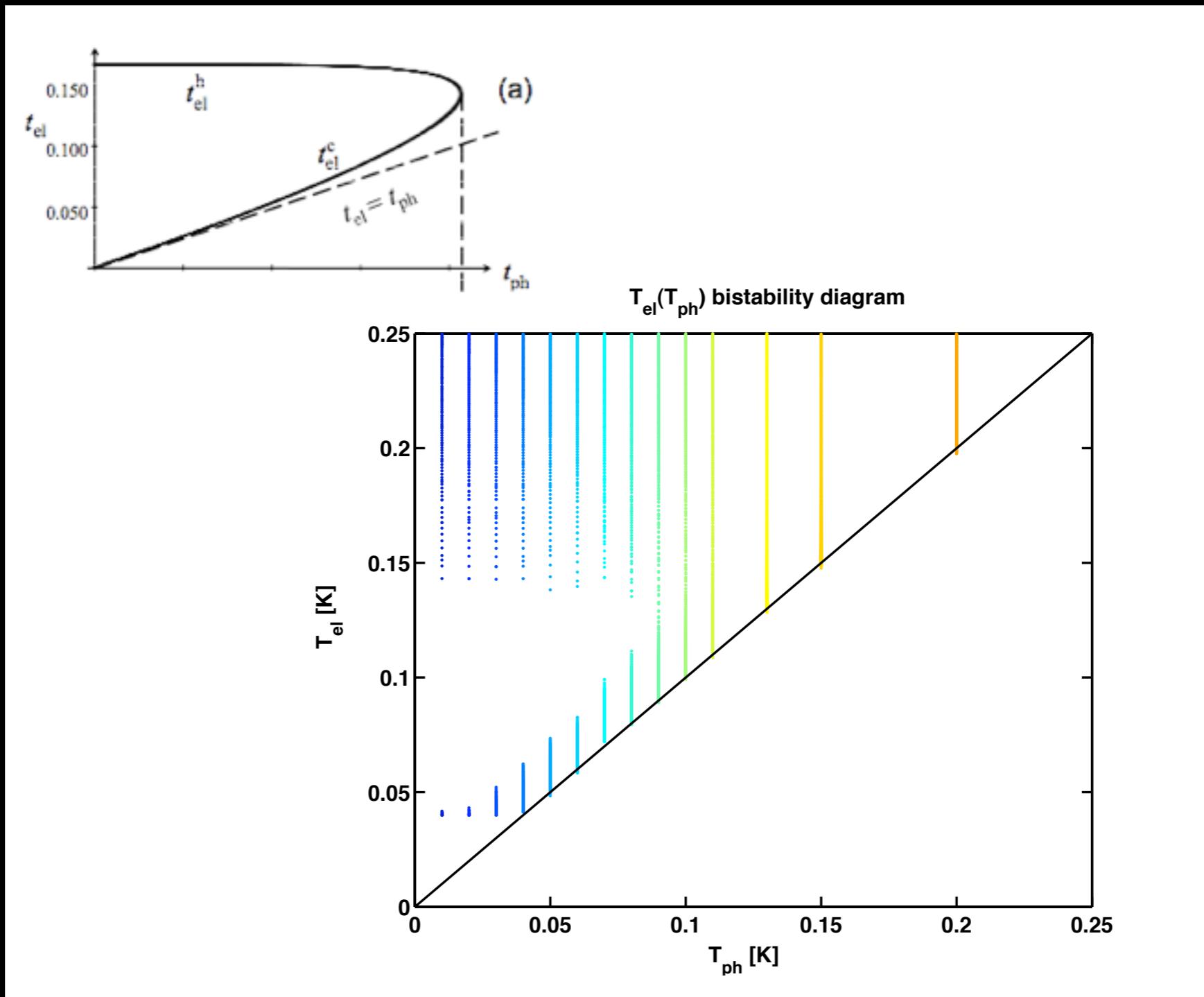
B.L. Altshuler, V.E. Kravtsov, I.V. Lerner, I.L. Aleiner

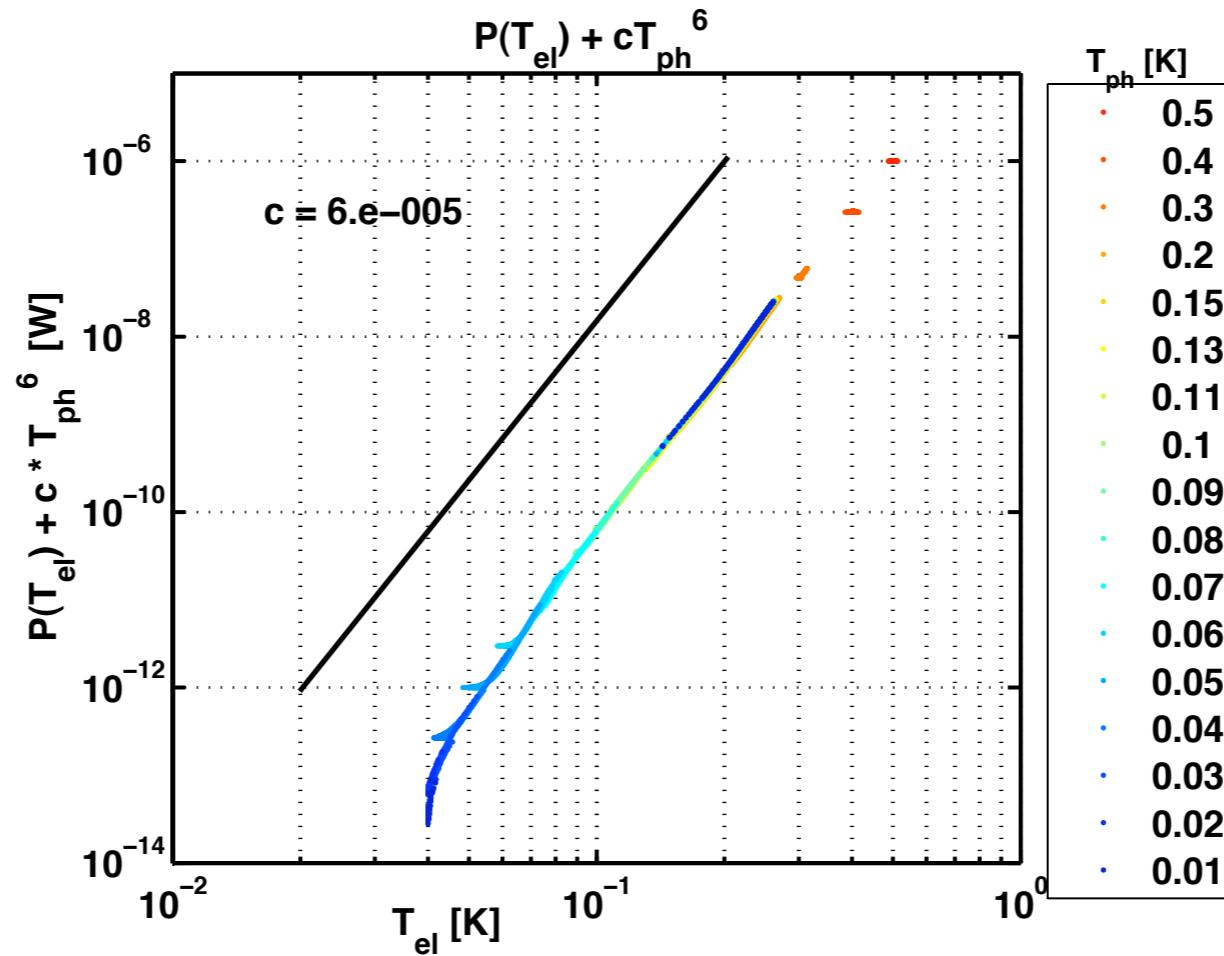
Heat balance equation:

$$\frac{V^2}{R(T_{el})} = \frac{\epsilon(T_{ph})}{\tau_{e-ph}(T_{ph})} - \frac{\epsilon(T_{el})}{\tau_{e-ph}(T_{el})}$$

M. Ovadia et al, Phys. Rev. Lett. 102, 176802 (2009)







Possible experimental manifestations of the many-body localization

D. M. Basko,^{1,*} I. L. Aleiner,¹ and B. L. Altshuler^{1,2}

¹*Physics Department, Columbia University, New York, New York 10027, USA*

²*NEC-Laboratories America, Inc., 4 Independence Way, Princeton, New Jersey 08540, USA*

(Received 24 July 2007; published 23 August 2007; publisher error corrected 14 September 2007)

Recently, it was predicted that if all one-electron states in a noninteracting disordered system are localized, the interaction between electrons in the absence of coupling to phonons leads to a finite-temperature metal-insulator transition. Here, we show that even in the presence of a weak coupling to phonons the transition manifests itself (i) in the nonlinear conduction, leading to a bistable I - V curve, and (ii) by a dramatic enhancement of the nonequilibrium current noise near the transition.

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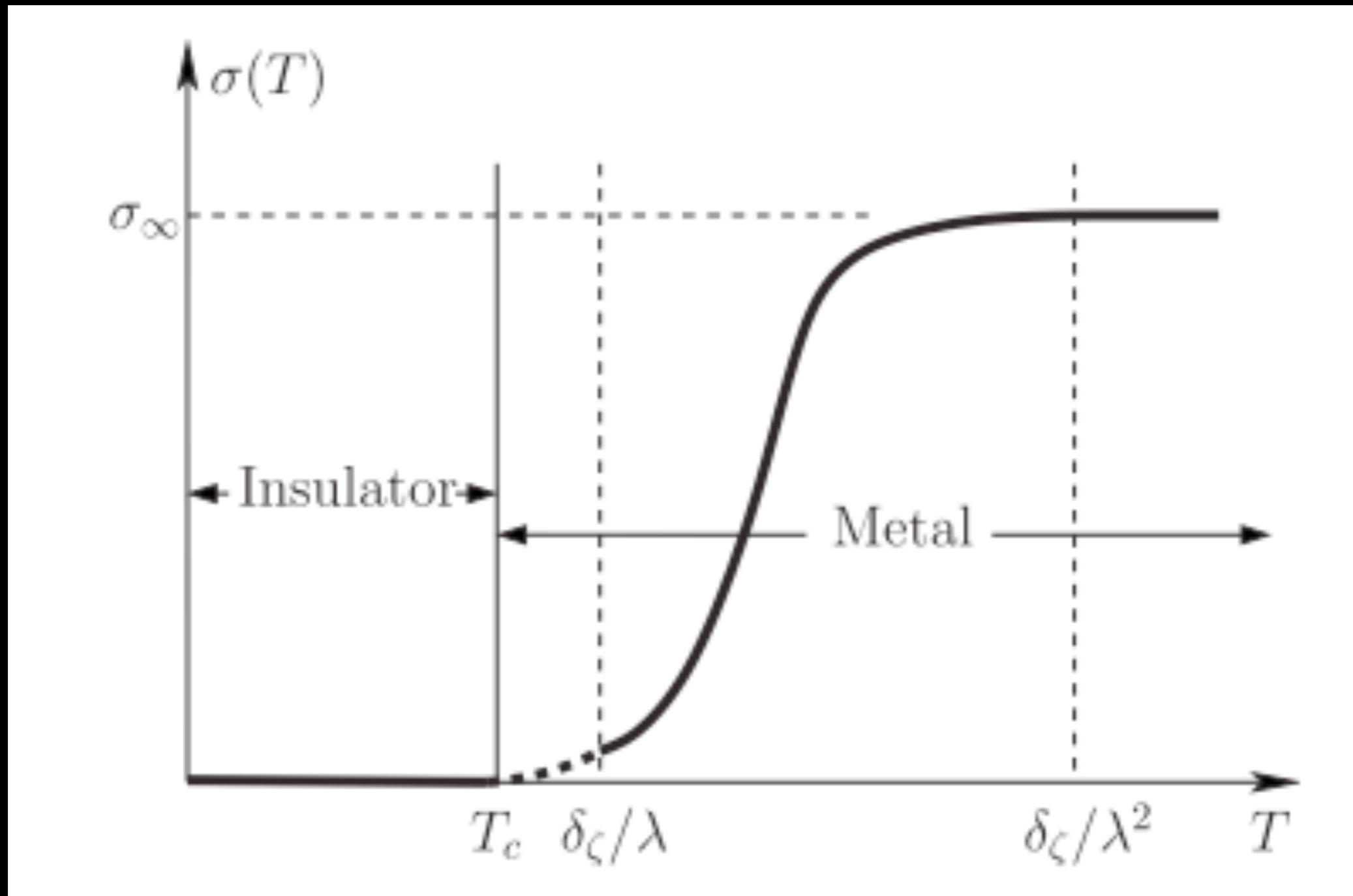
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Temperature dependence

Hyperactivated Resistance in TiN Films on the Insulating Side of the Disorder-Driven Superconductor-Insulator Transition[¶]

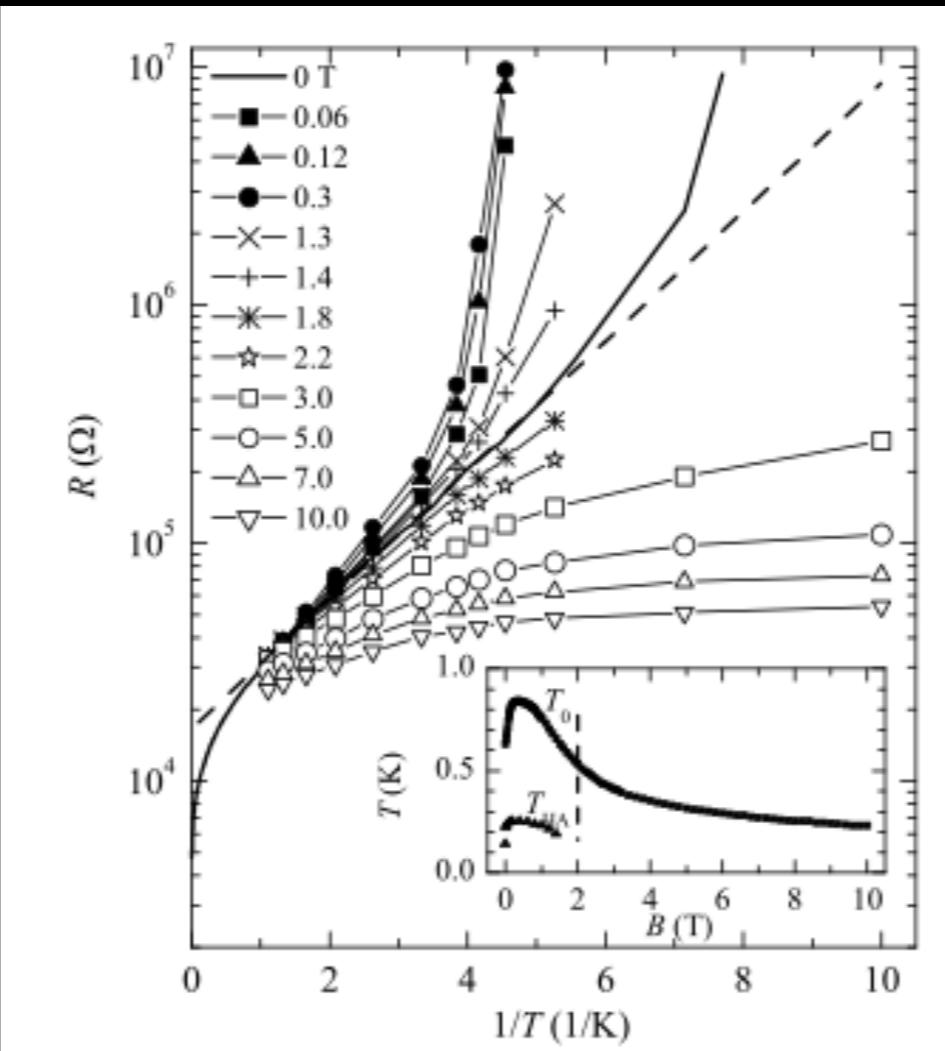
T. I. Baturina^a, A. Yu. Mironov^a, V. M. Vinokur^b, M. R. Baklanov^c, and C. Strunk^d

^a Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow Region 142432, Russia

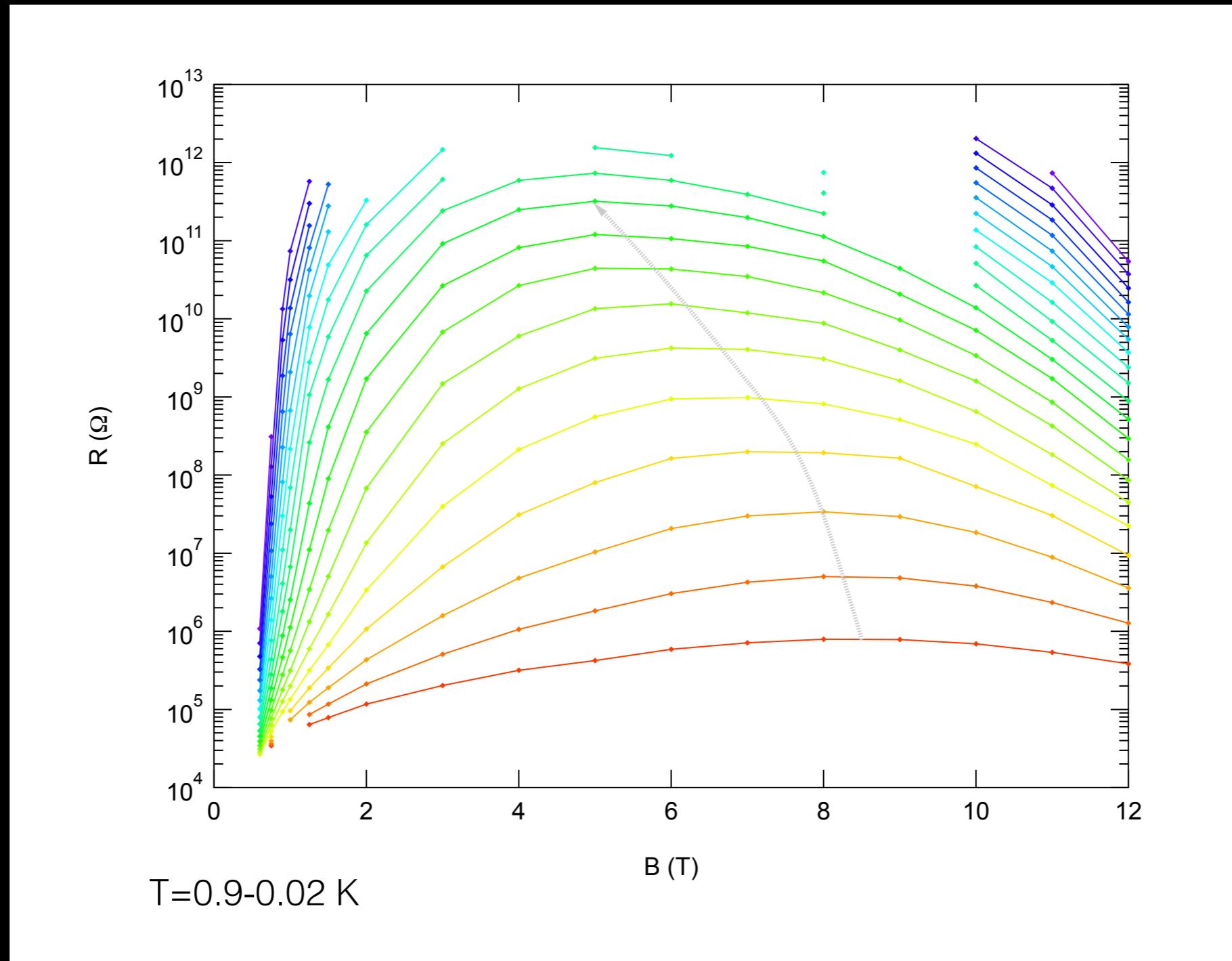
^b Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

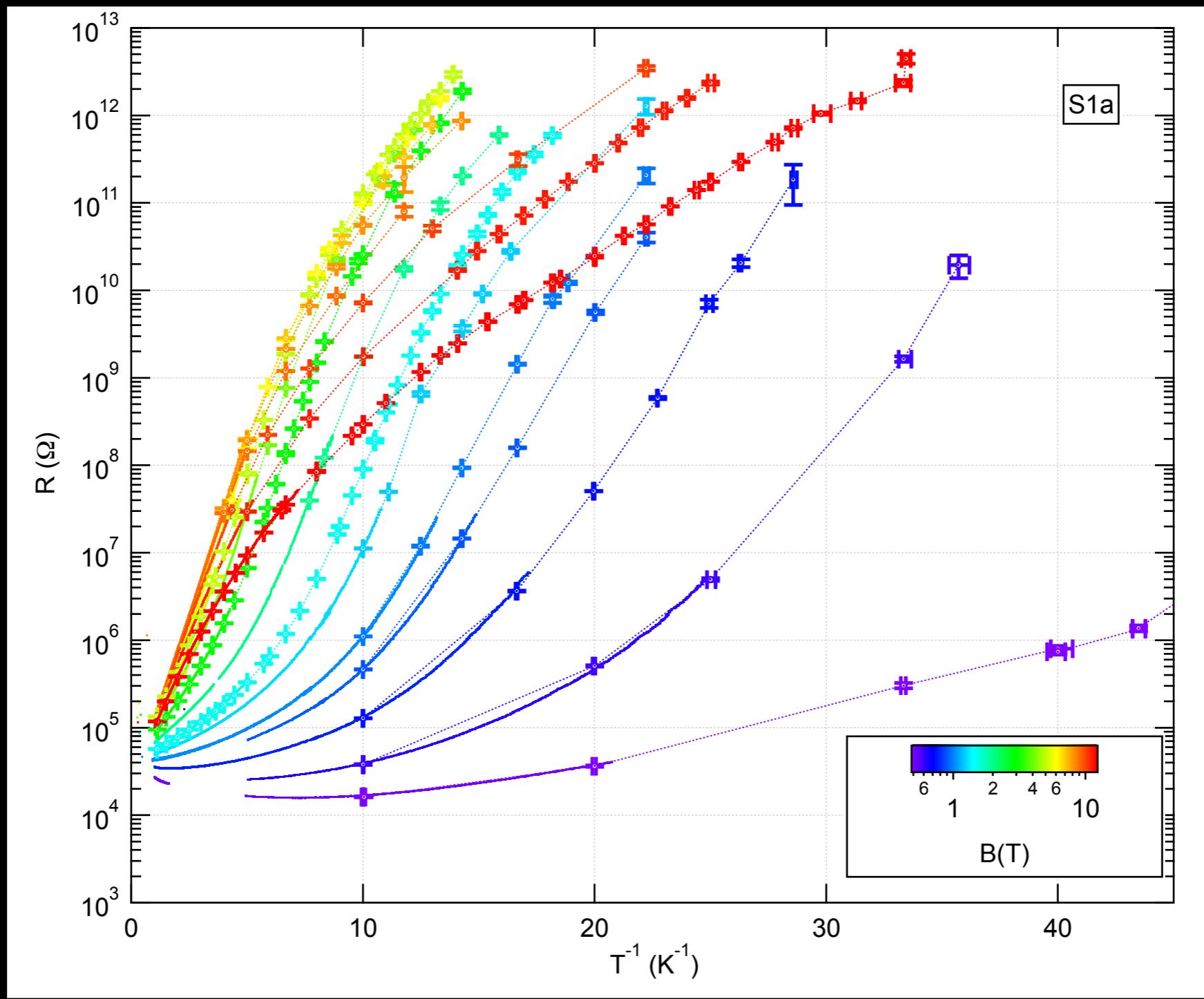
^c Institute of Applied Physics, Russian Academy of Sciences, Gor'kiy, Nizhny Novgorod 603900, Russia

^d Institut für Festkörperforschung, Forschungszentrum Jülich, D-5242 Jülich, Germany

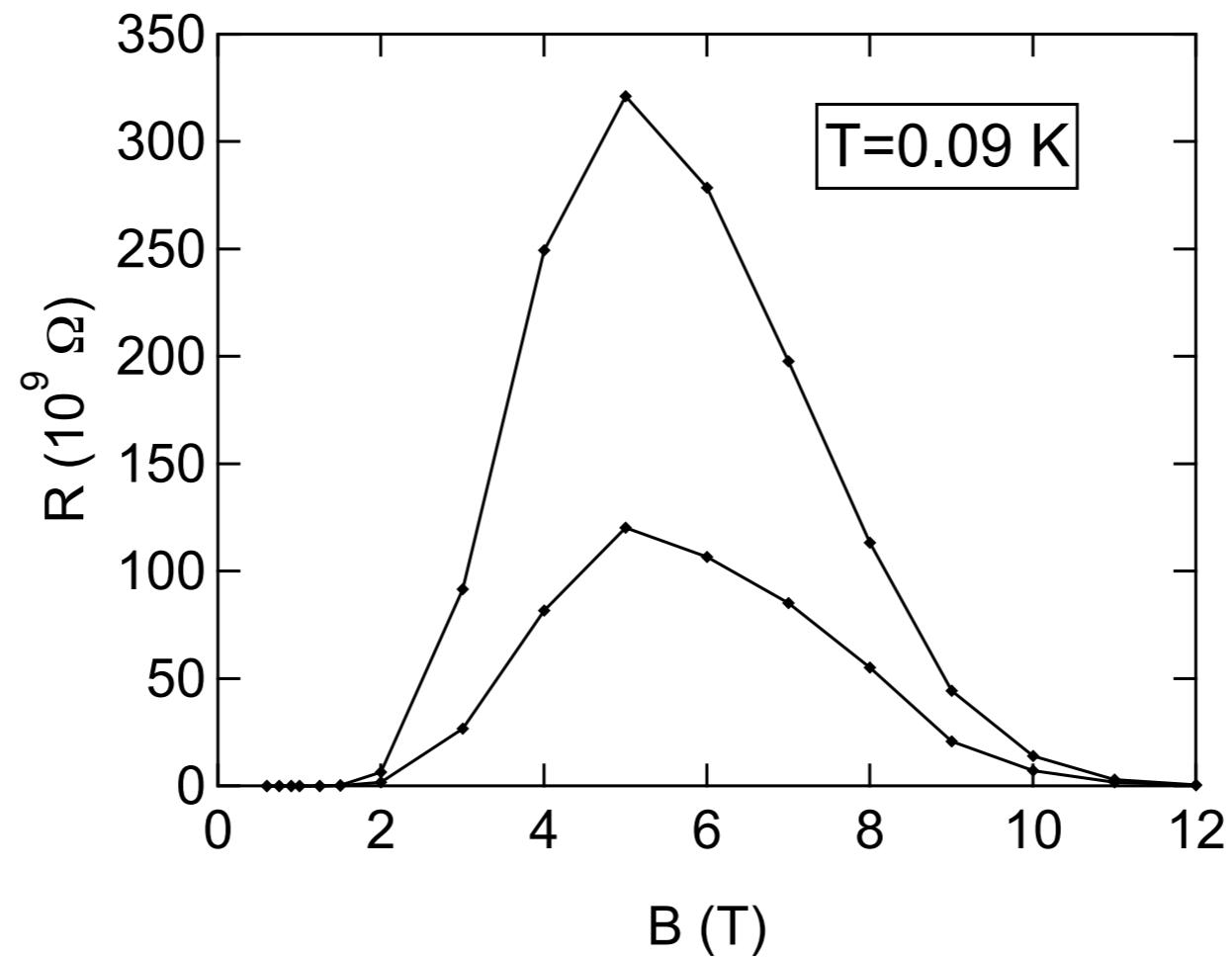


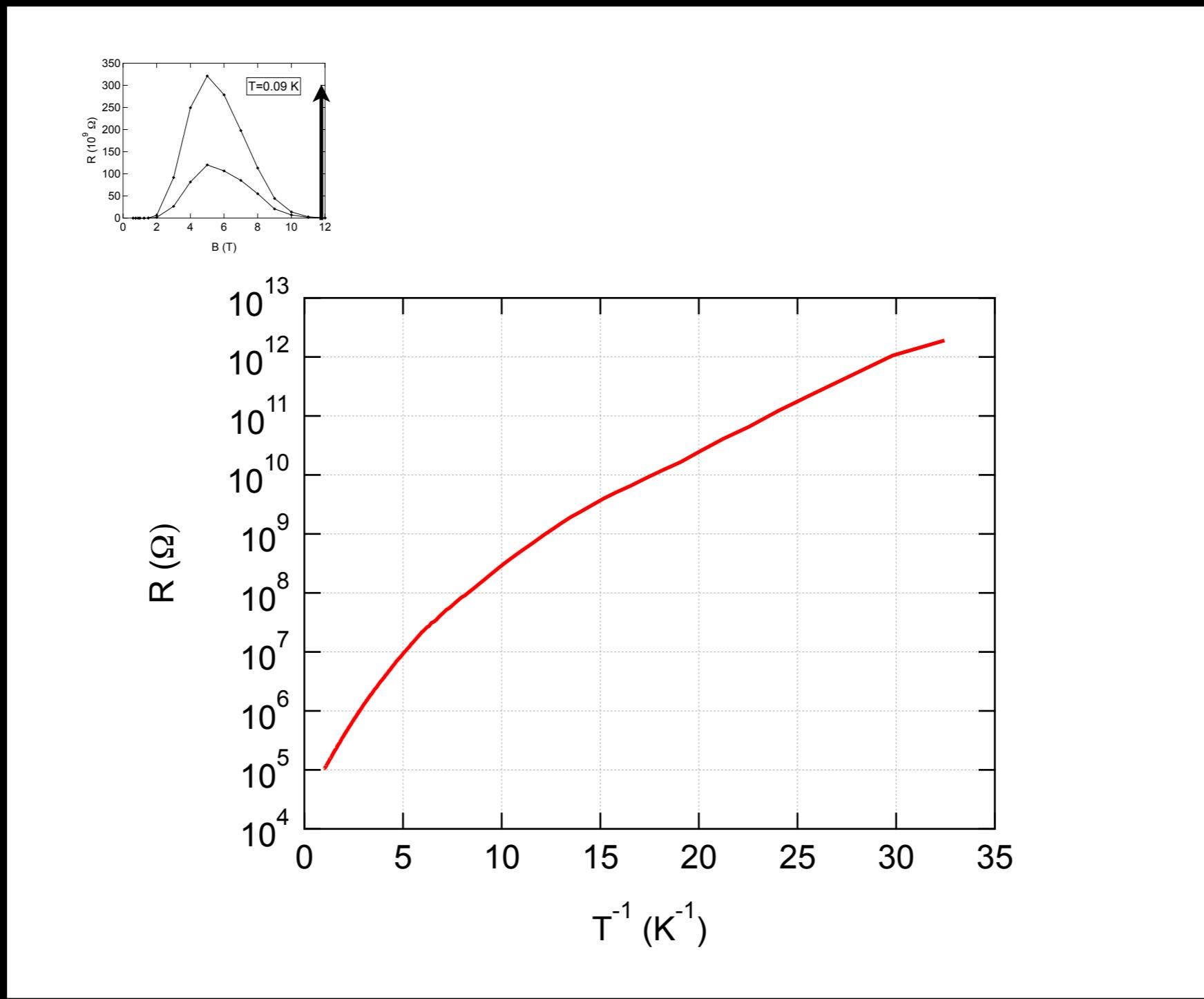
MR Peak

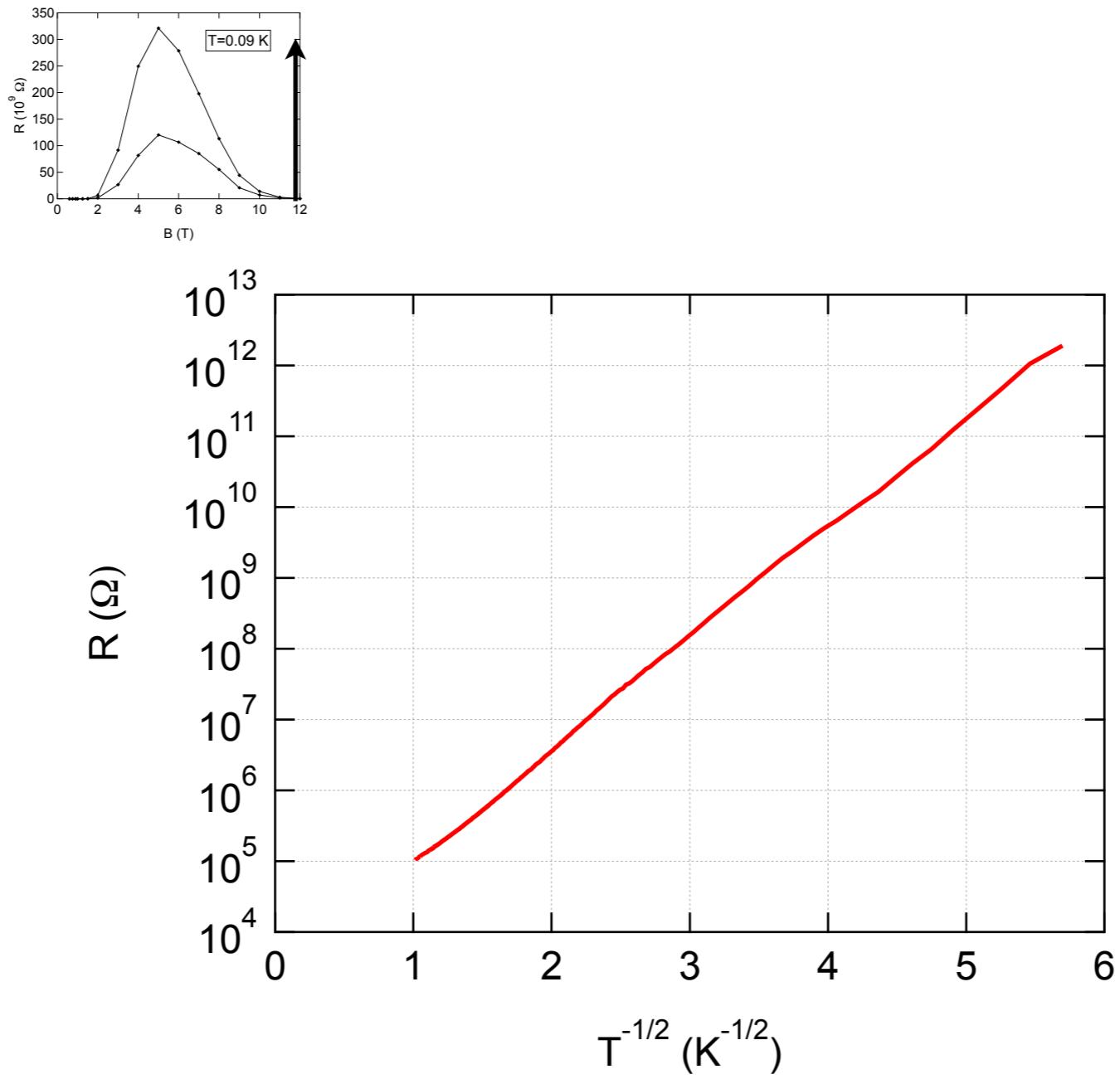


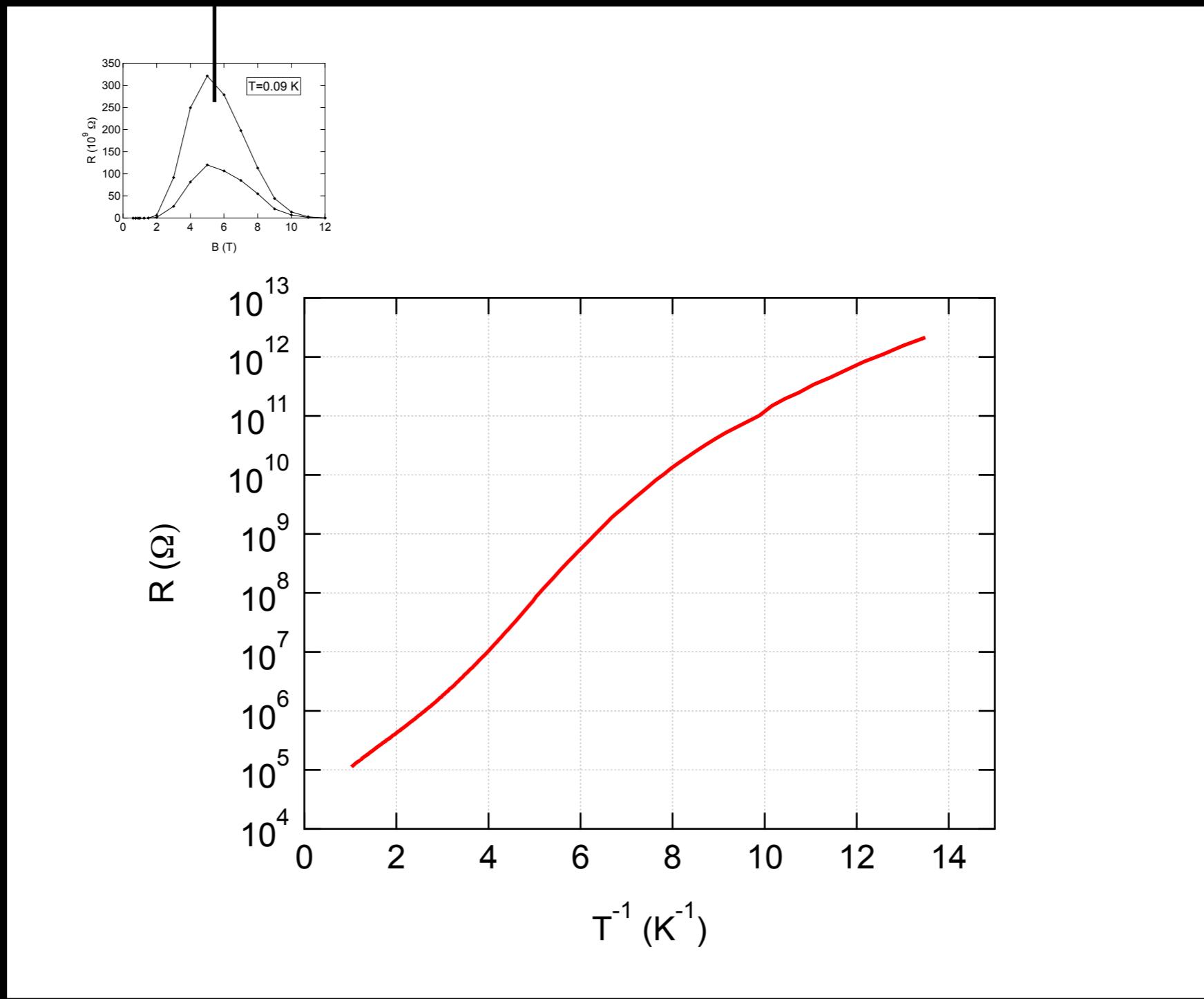


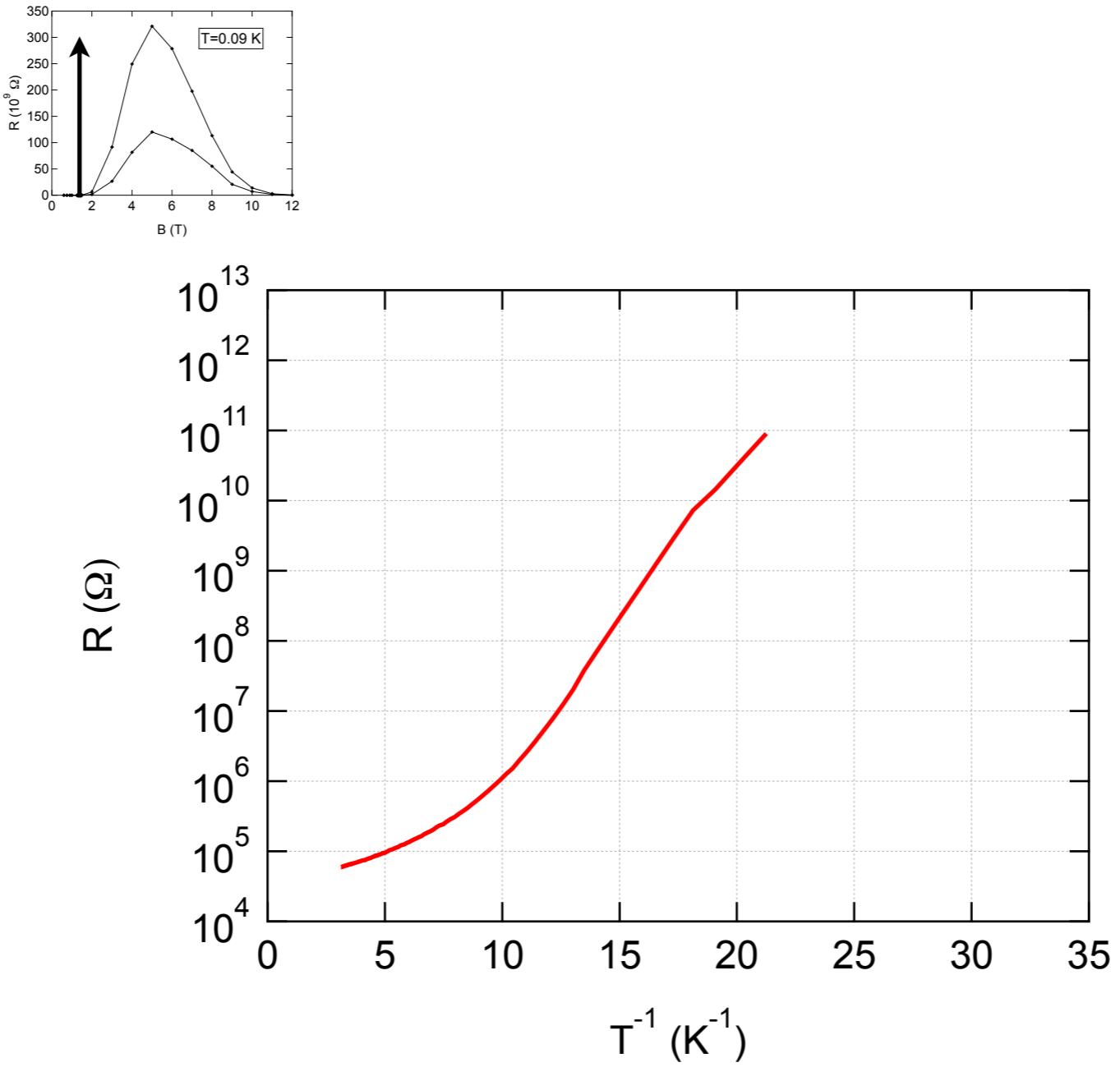
Magnetoresistance peak

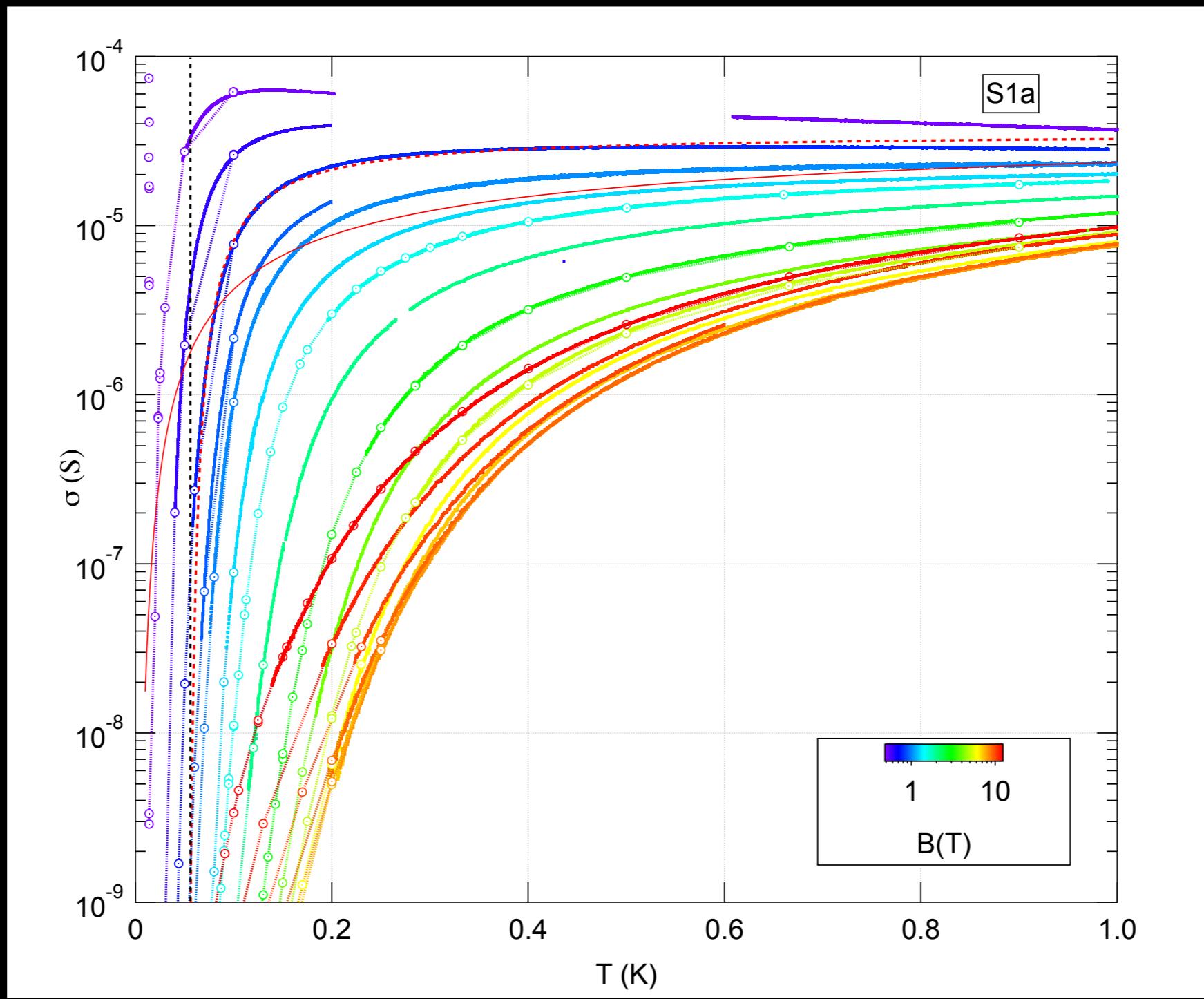


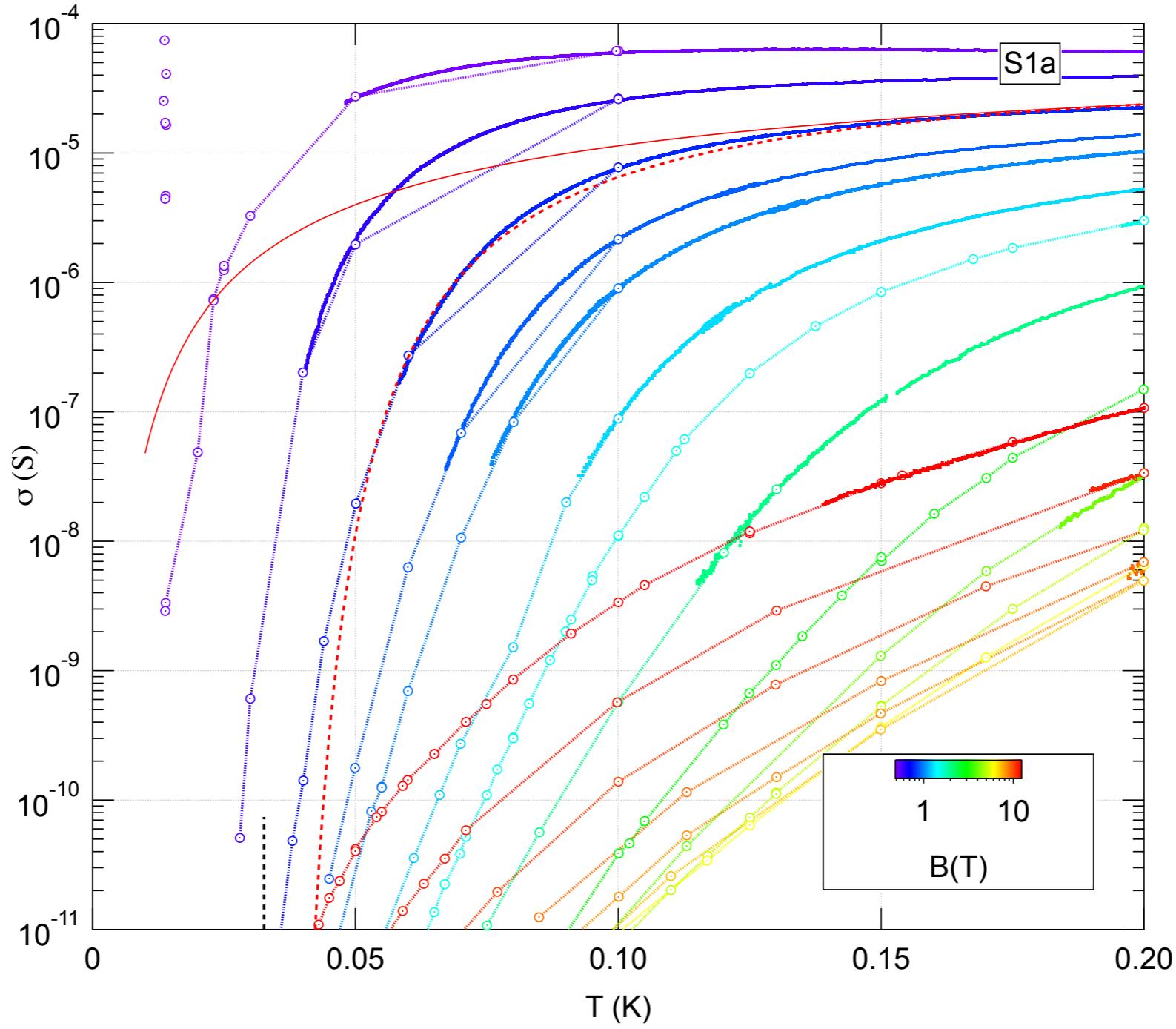




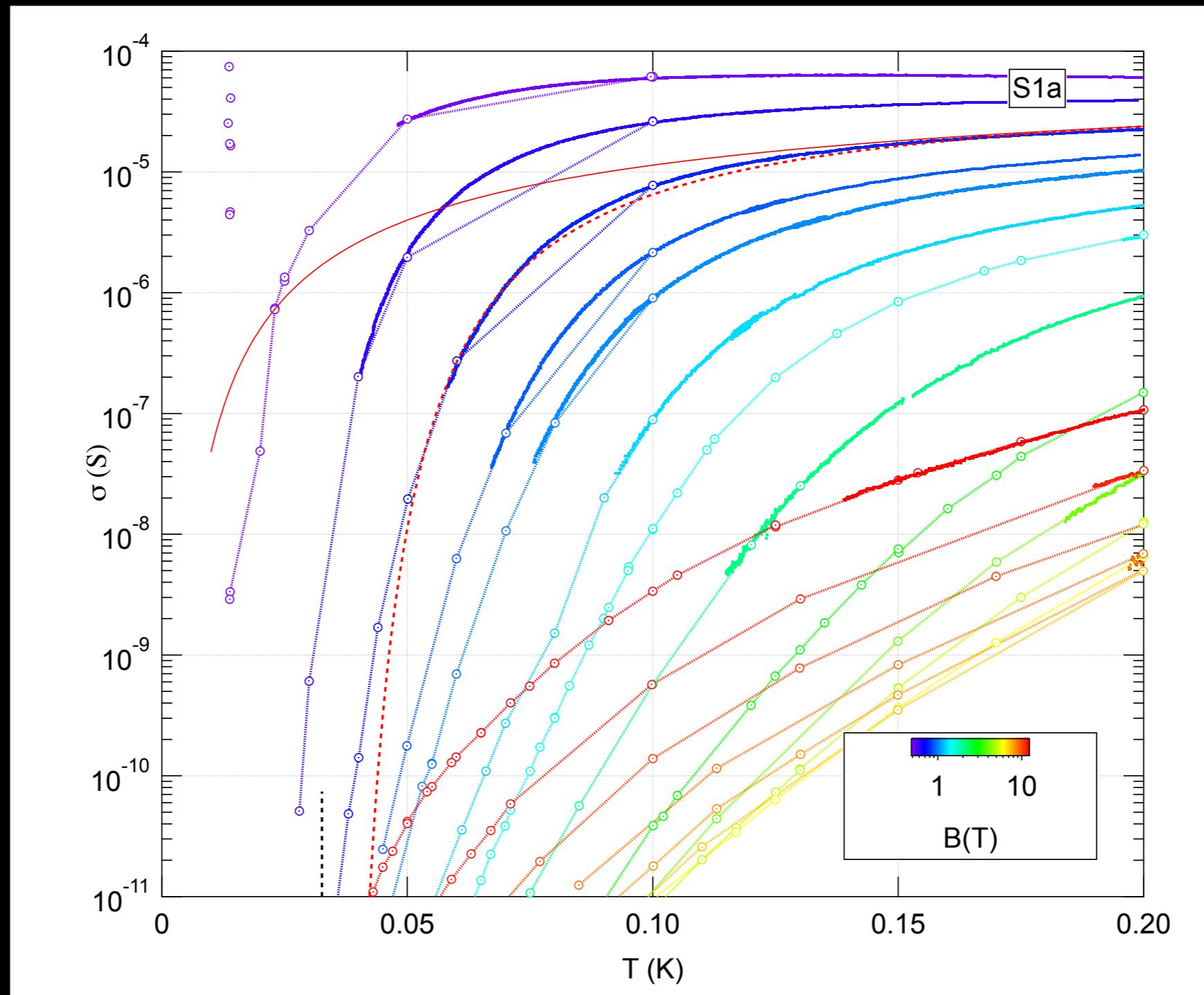


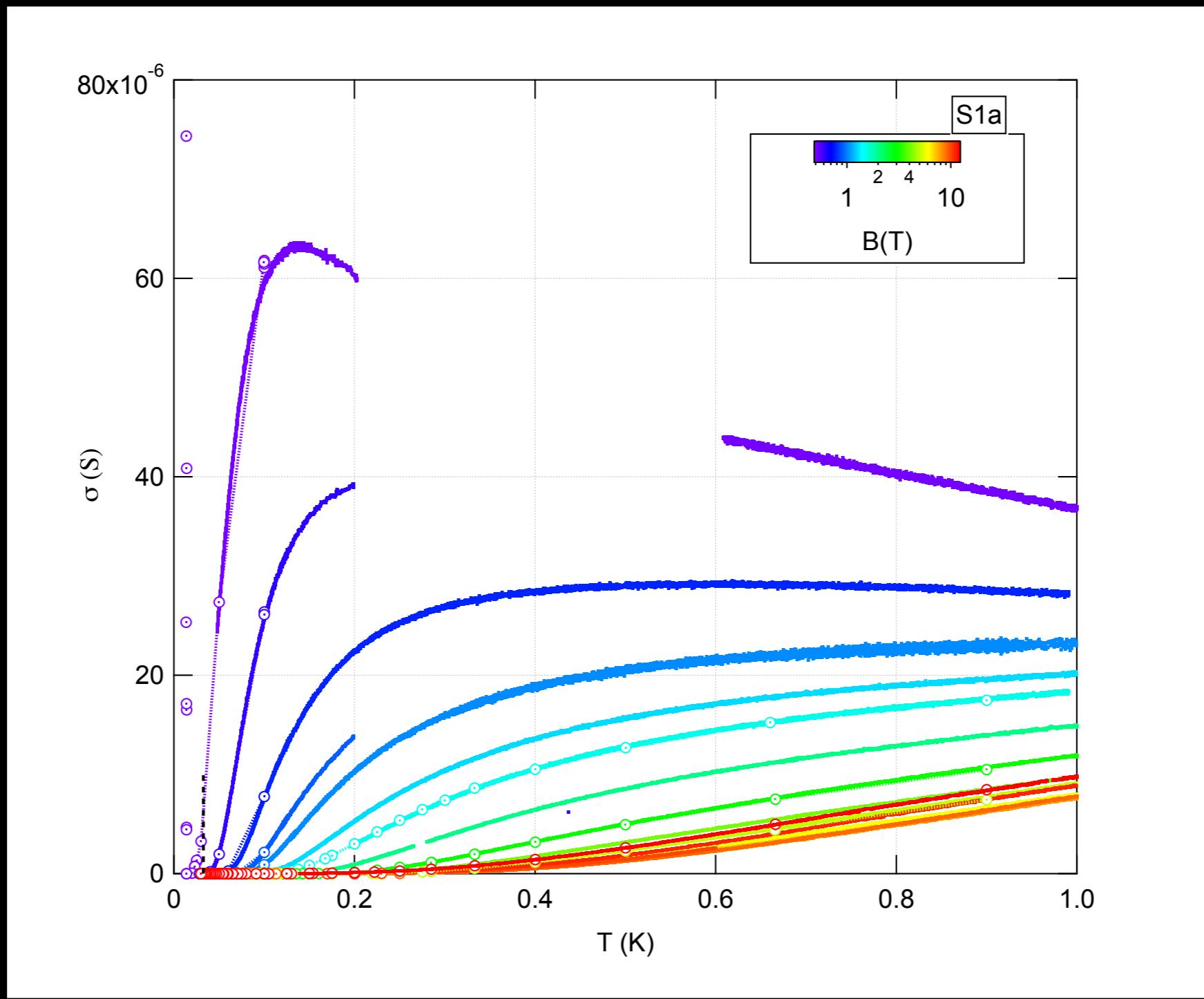




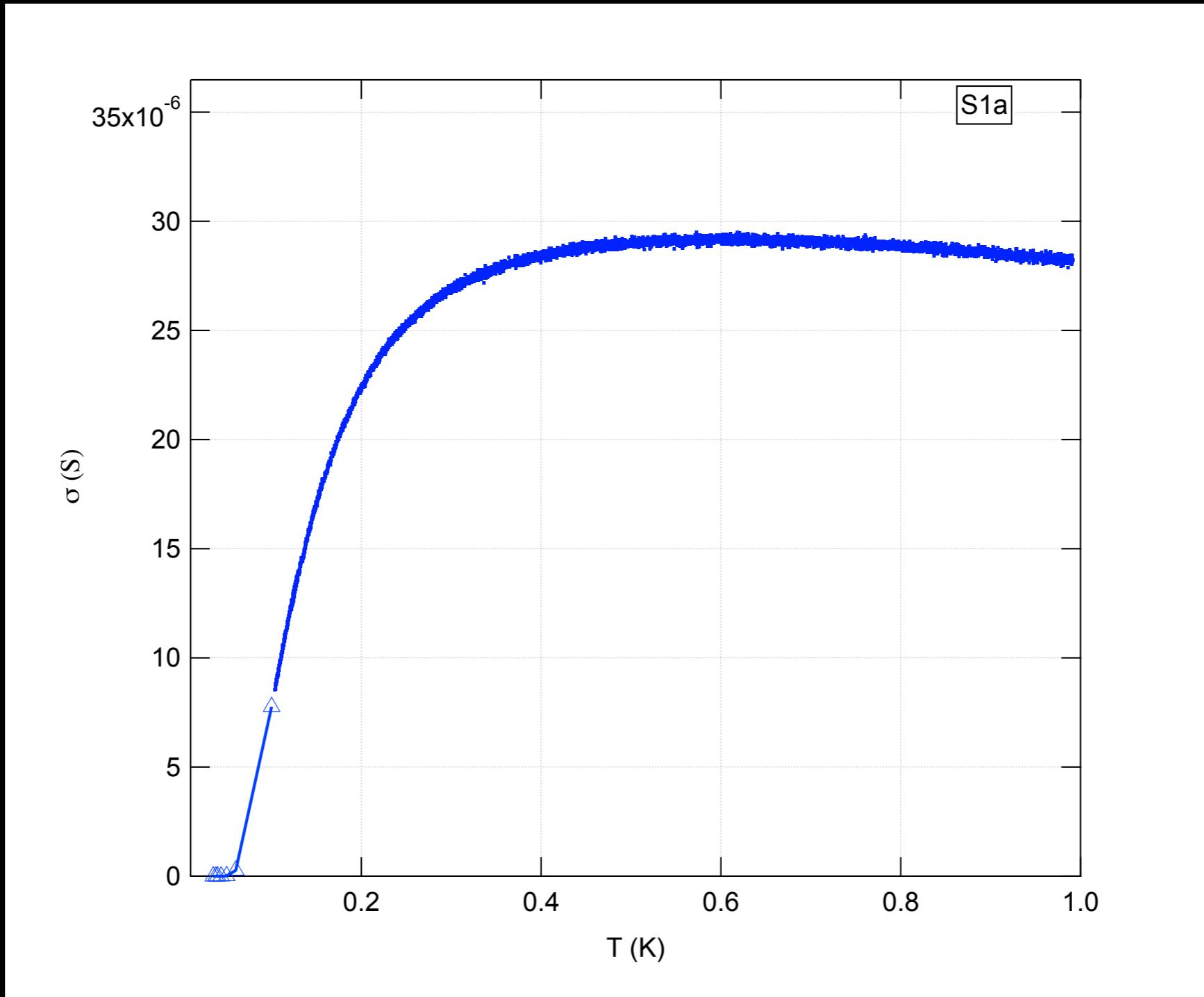


$$\sigma = \sigma_0 \exp[T_0/T - T^*]$$

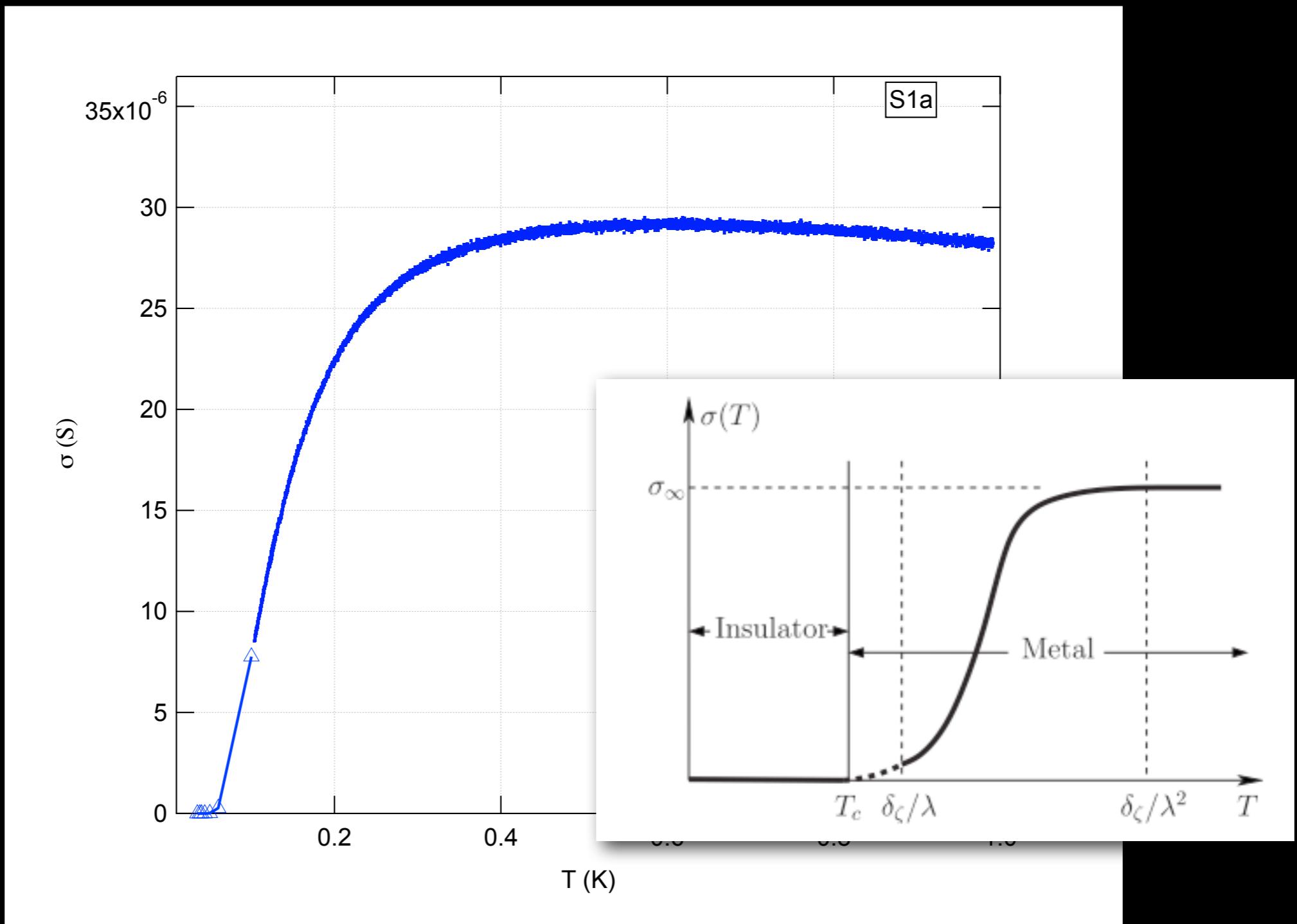


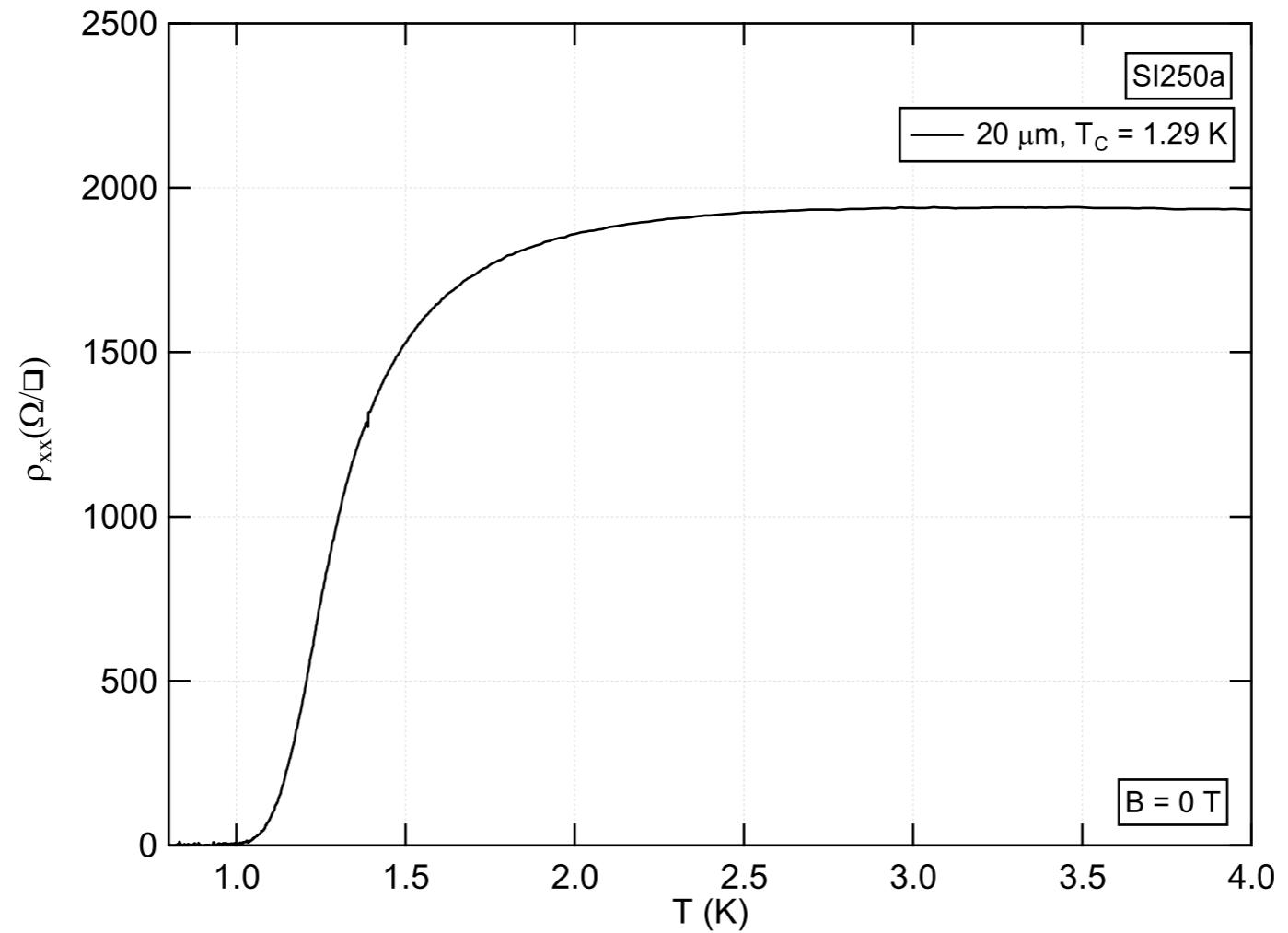


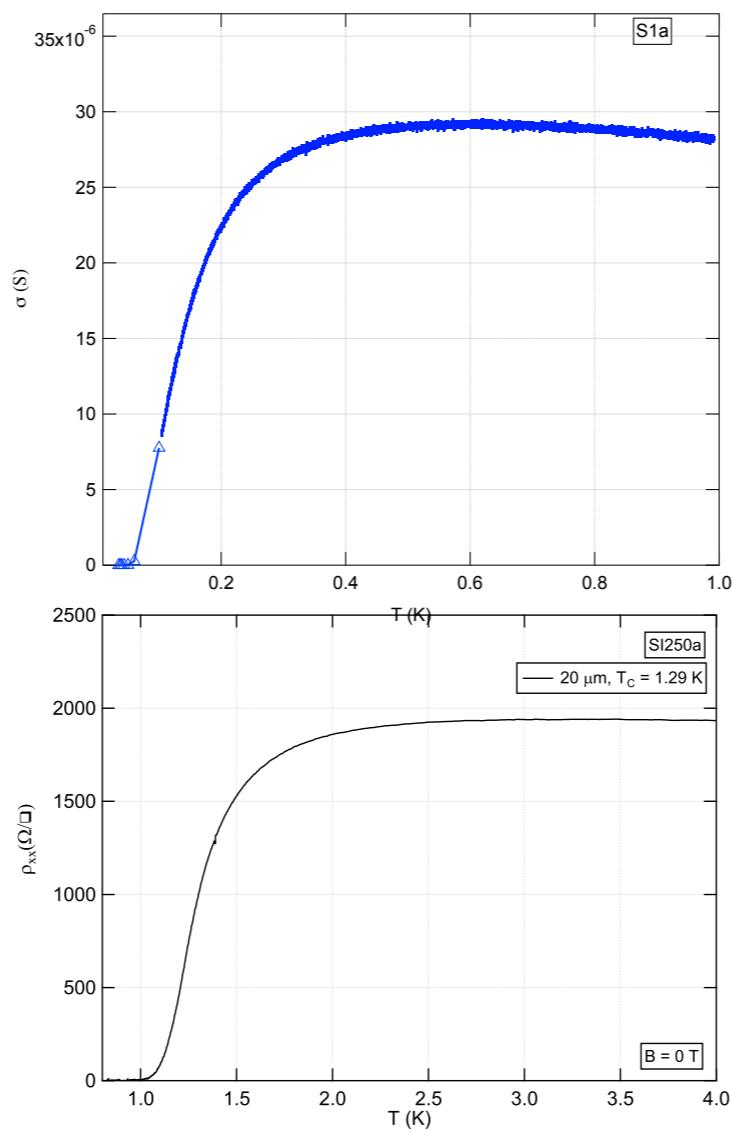
Ohmic response



Ohmic response







Thank you.