A New View of the SIT

Idan Tamir

Weizmann Institute of Science

Collaborators - A. Doron, T. Levinson, M. Ovadia, B. Sacépé and D. Shahar

International Workshop

“Strongly disordered and inhomogeneous superconductivity”

Grenoble (France), 21-22 November 2016

CPTGA Centre de Physique Théorique Grenoble-Alpes

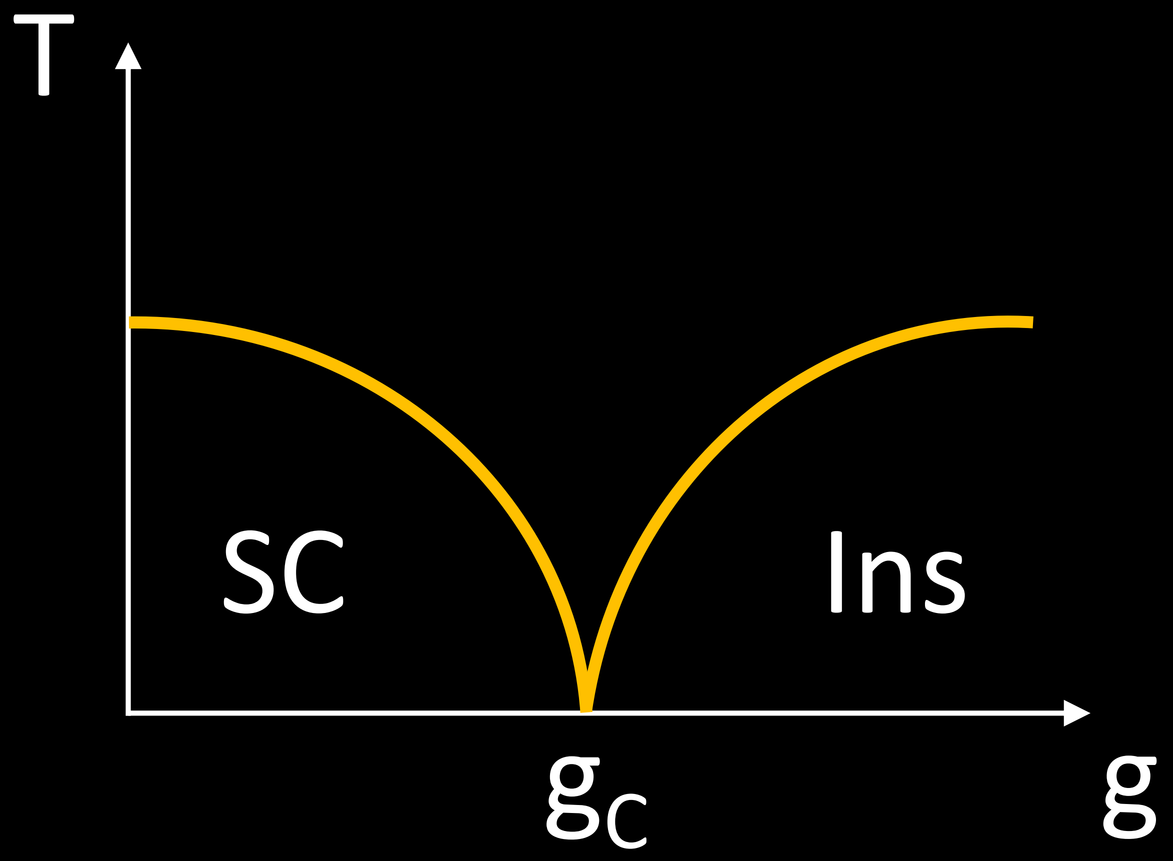
UNIVERSITÉ Grenoble Alpes

cnrs

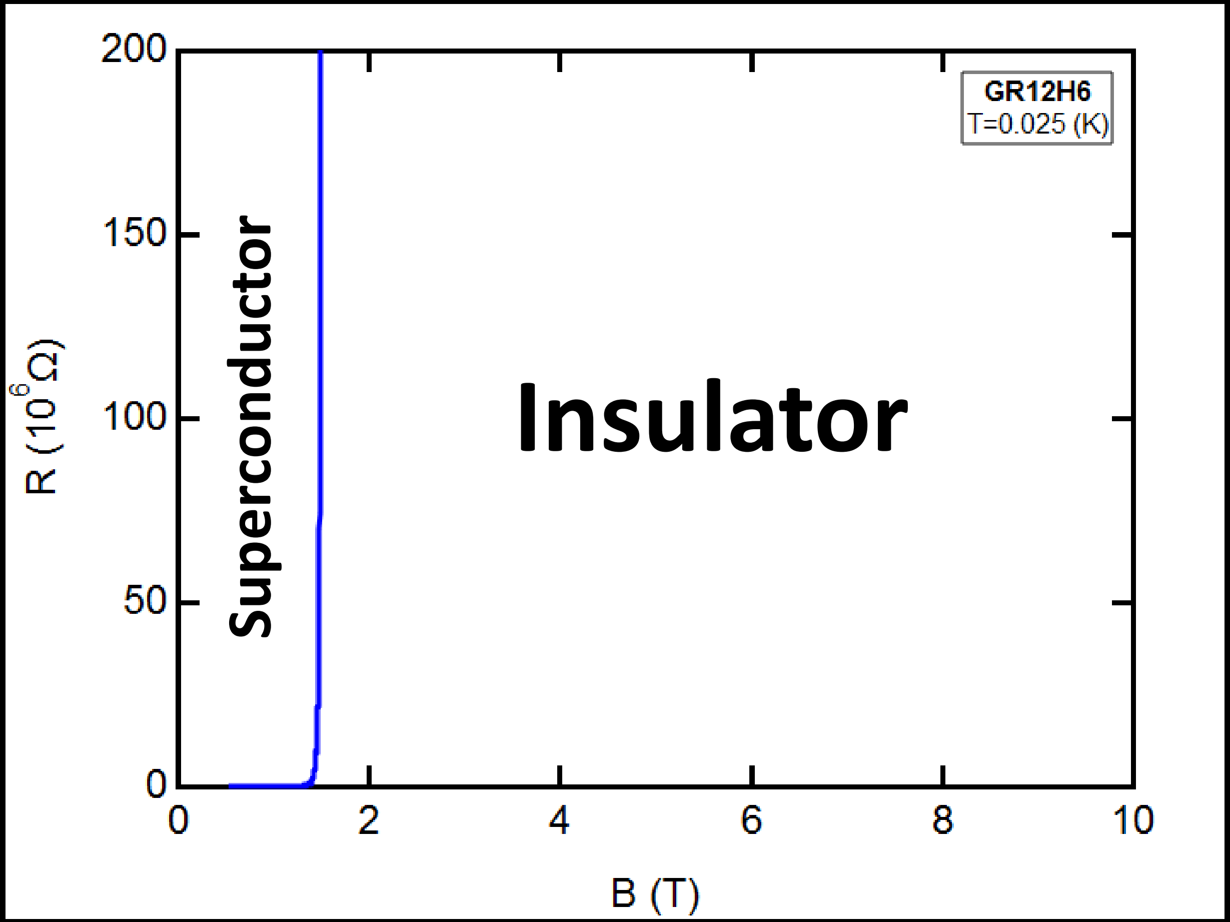
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE

Superconductor-Insulator Transition
(SIT)

Quantum Phase Transition

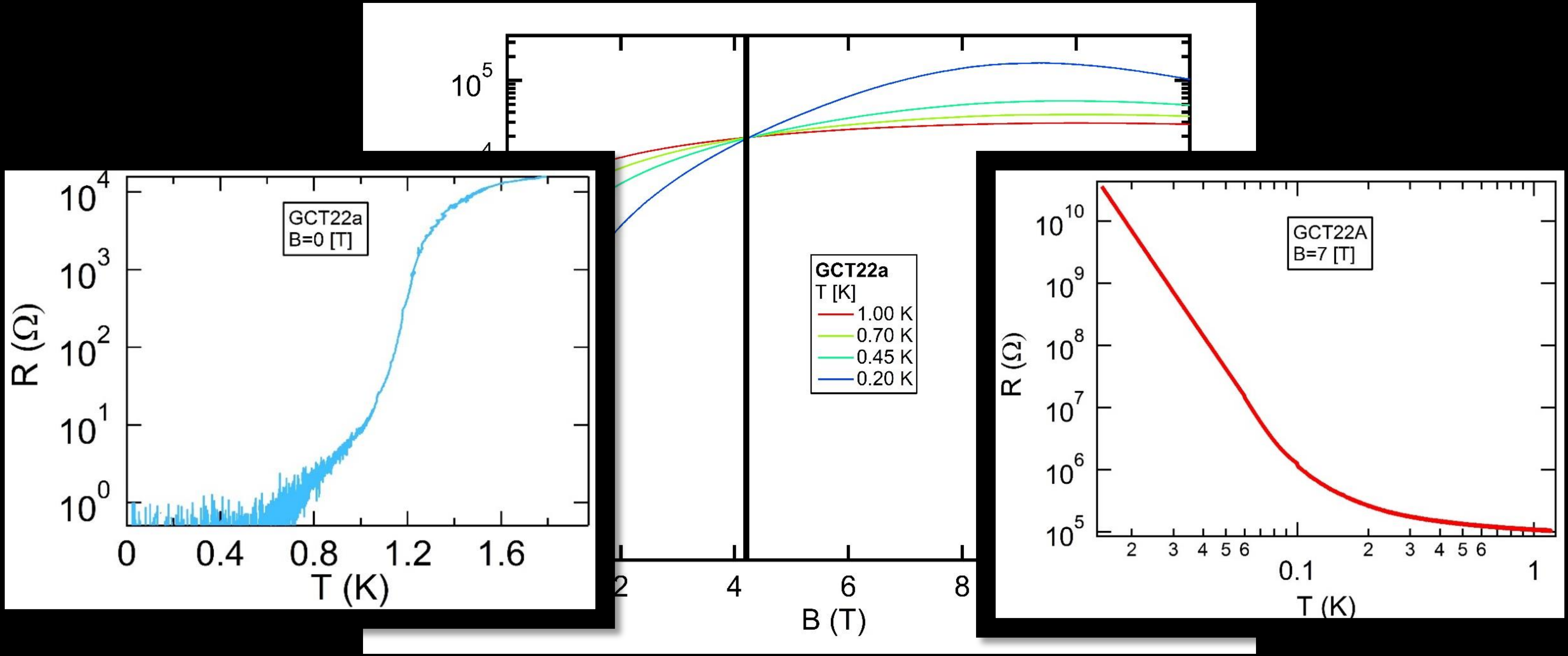


Quite Sharp.



GR12H6
T=0.025 (K)
Superconductor
Insulator
R (10^6 Ω)
B (T)
200
150
100
50
0
0
2
4
6
8
10

B Driven SIT in a:InO

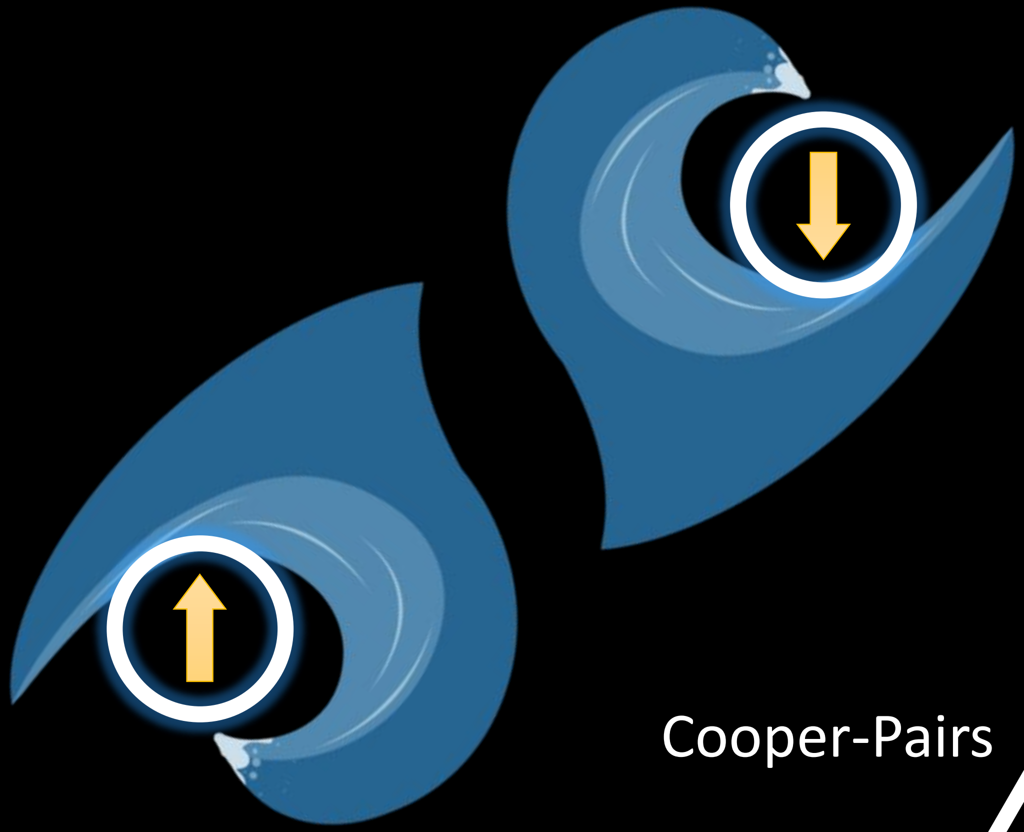


Cooper-Pair Insulator

CPI – Supporting Theoretical Arguments

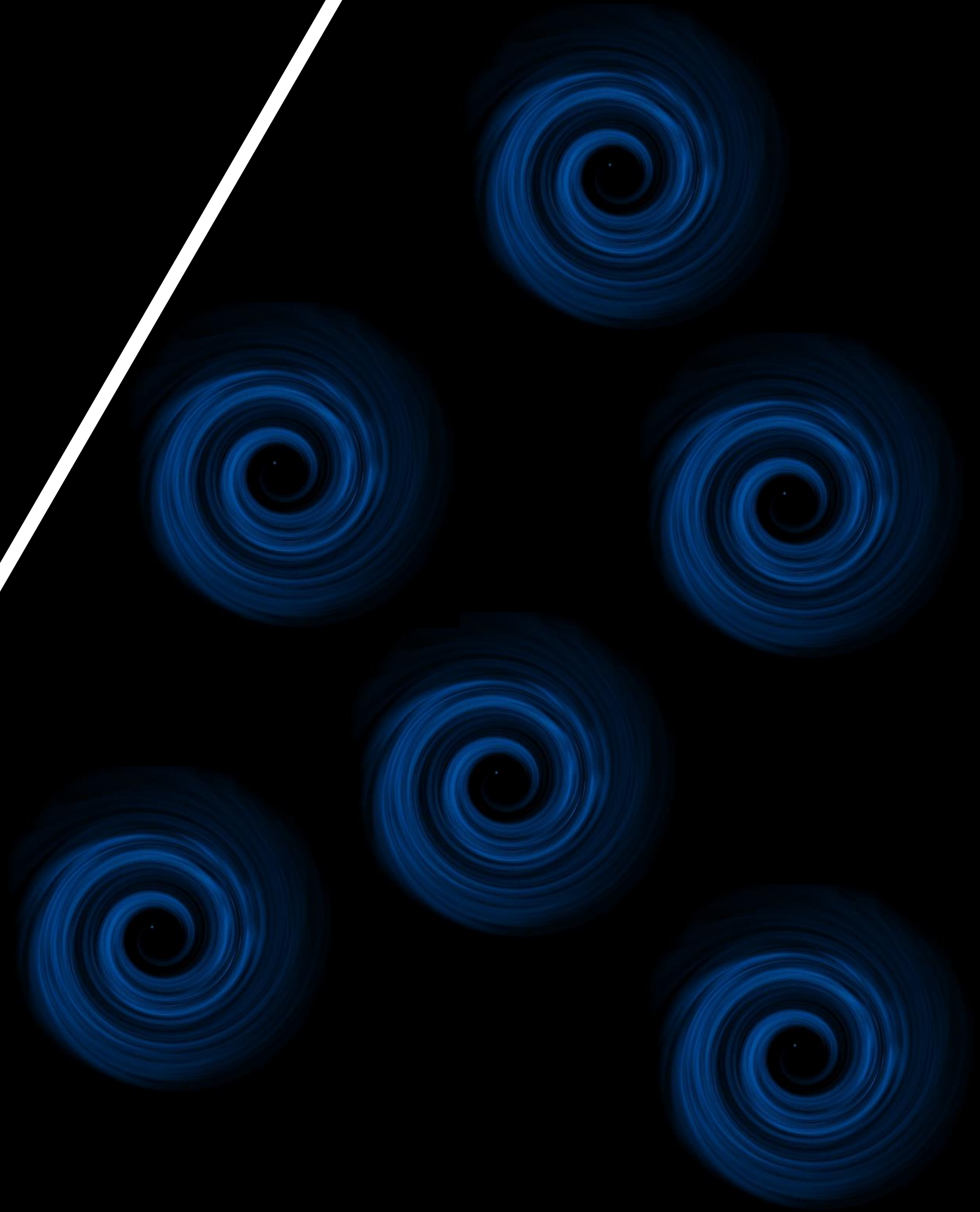
- M. P. A. Fisher, Phys. Rev. Lett. 65, 923 (1990)
- V. M. Galitski et al, Phys. Rev. Lett. 95, 077002 (2005)
- Dubi, Meir and Avishai, NATURE | Vol 449 | (2007)
- M. V. Feigel’man et al, Phys. Rev. Lett. 98, 027001 (2007)
- Vinokur et al., NATURE | Vol 452 | 3 April (2008)
- D. Meidan and Y. Oreg, Phys. Rev. B 79, 214515 (2009)
- Müller and Shklovskii, Phys. Rev. B 79, 134504 (2009)
- Pokrovsky, Falco and Nattermann, Phys. Rev. Lett. 105, 267001 (2010)
- K. Bouadim, Y.L. Loh, M. Randeria, and N. Trivedi, Nature Physics 7, 889 (2011)
- Lages and Shepelyansky, Eur. Phys. J. B81, 2, (2011)
- S. Syzranov et al., Phys. Rev. Lett. 108, 256601 (2012)
- Burmistrov et al, PRB (2015)
- ...

Duality



Cooper-Pairs

Vortices



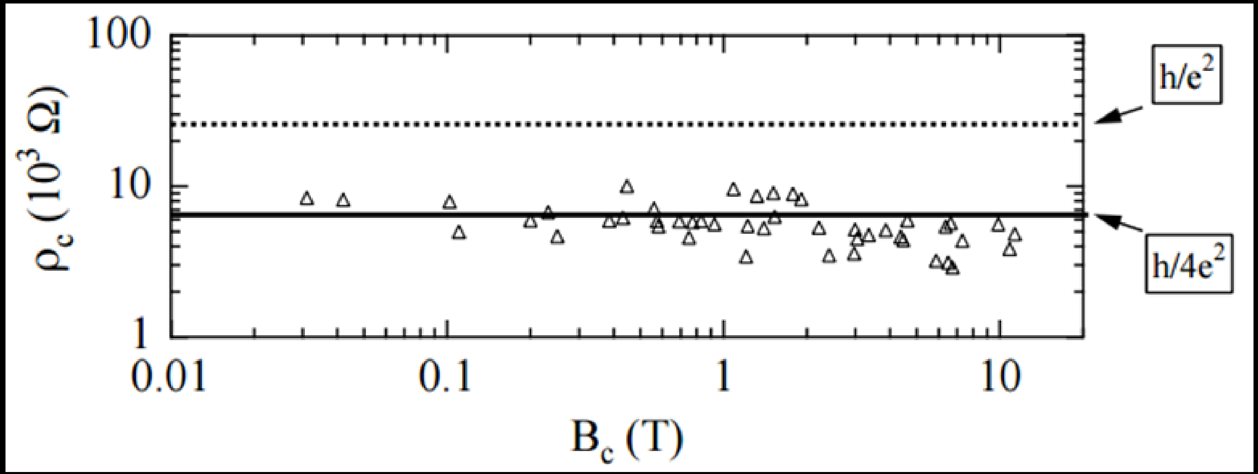
M. P. A. Fisher, Quantum phase transitions in disordered two-dimensional superconductors, Phys. Rev. Lett. 65, 923 (1990)

In JJA: Fazio, R. & Schön, G. Charge and vortex dynamics in arrays of tunnel junctions. Phys. Rev. B 43, 5307–5320 (1991).

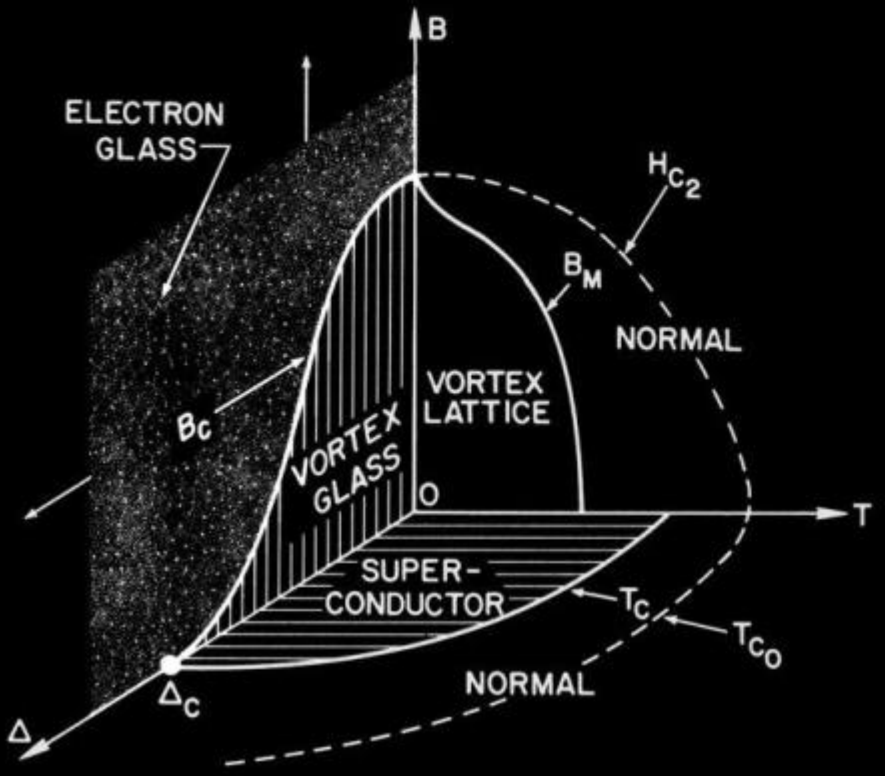
Vortex–Charge Duality-Symmetry

$$I \leftrightarrow V$$

$$\sigma = {}^{I}\!/_{V} \leftrightarrow \rho = {}^{V}\!/_{I}$$



Phase Diagram



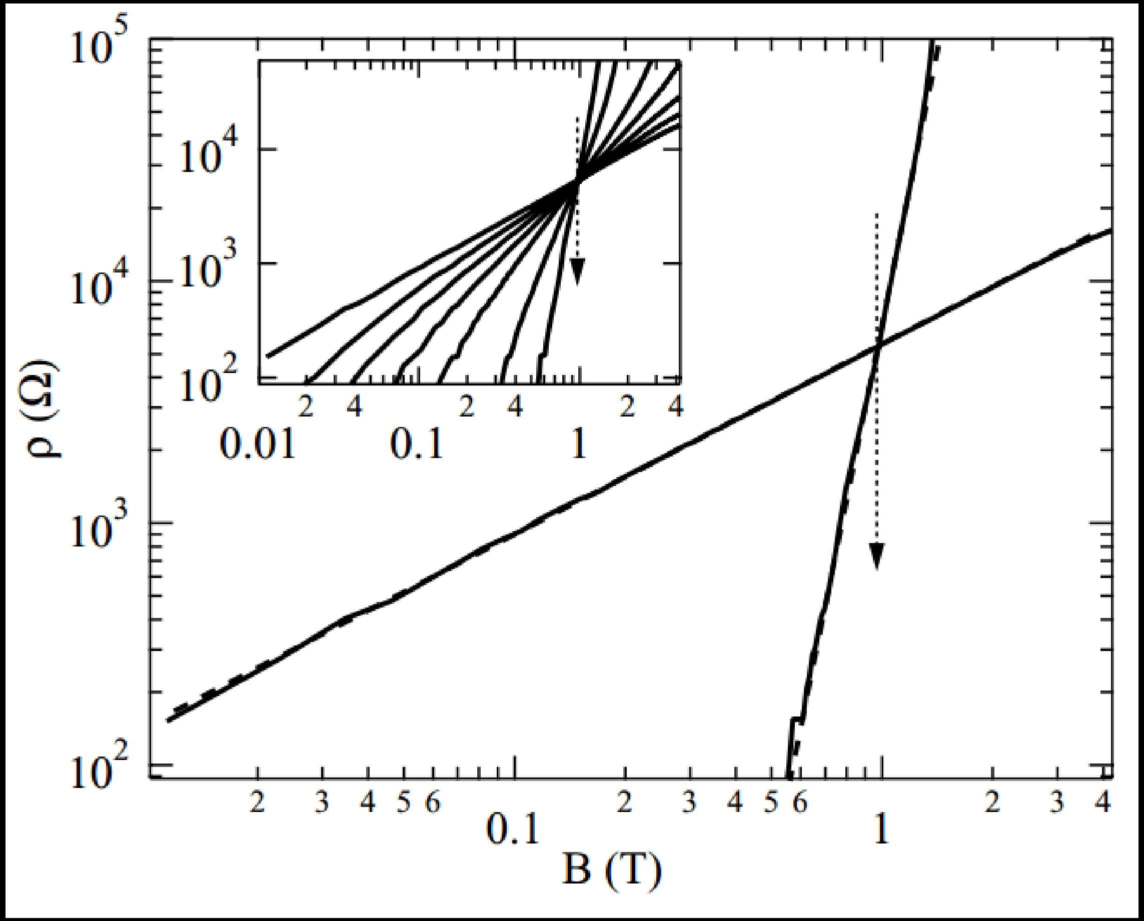
$T \neq 0$ → activation (pining) energy

$$U = \frac{1}{2} T_C \log \frac{B_C}{B}$$

Expected power law resistivity

M. P. A. Fisher, Quantum phase transitions in disordered two-dimensional superconductors, Phys. Rev. Lett. 65, 923 (1990)

Measured Power law resistivity across SIT

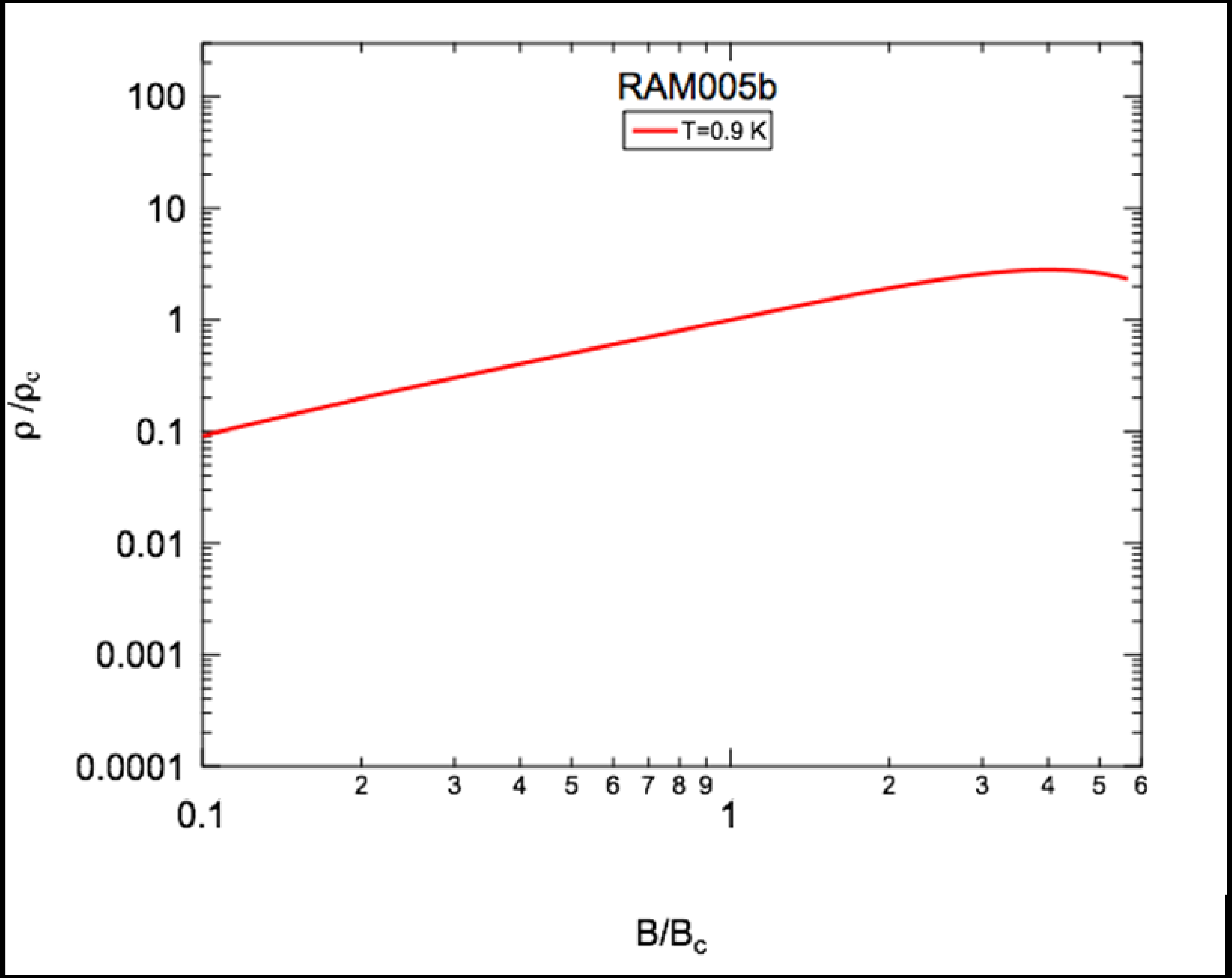


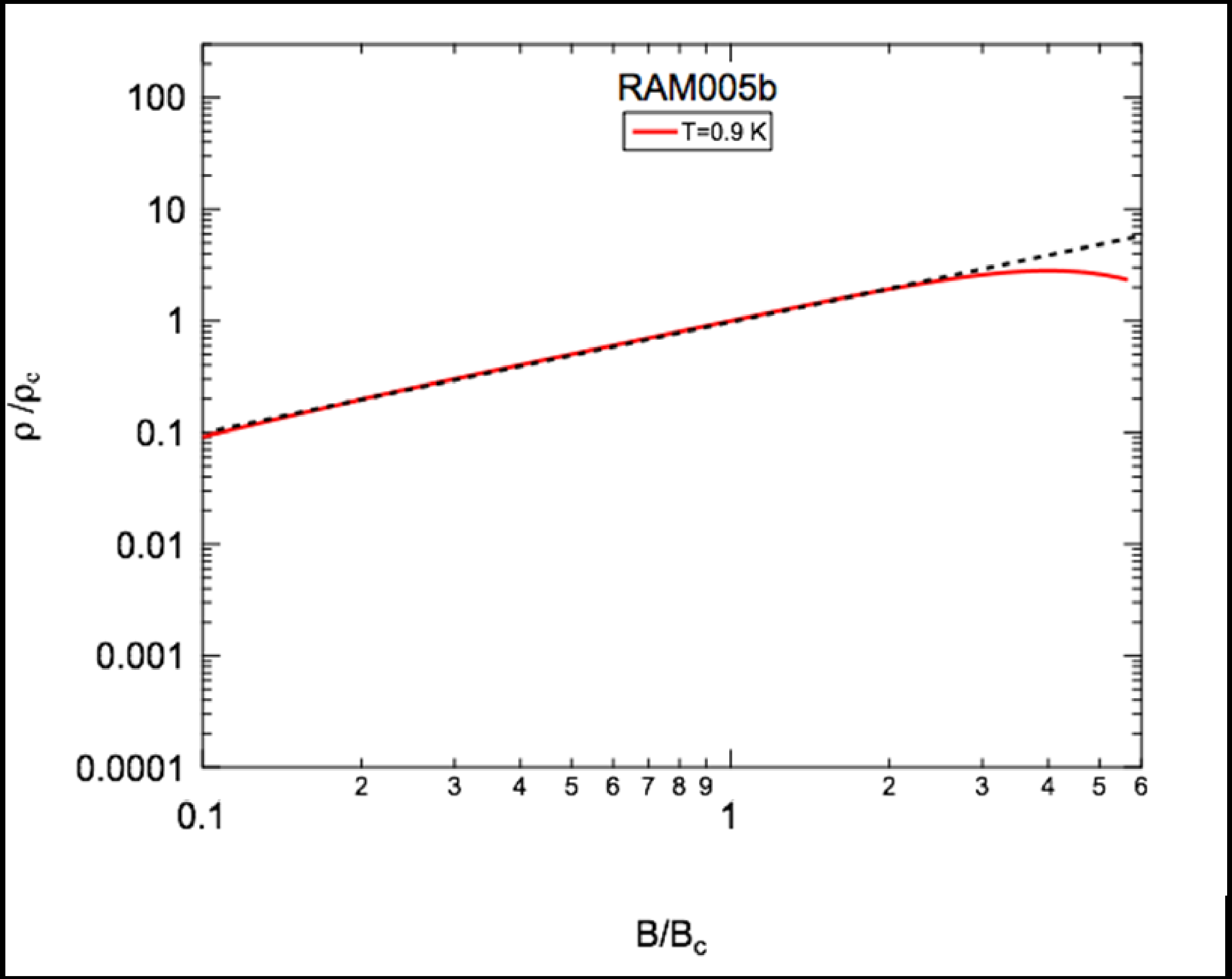
$$\rho(B,T) = \rho_C \left(\frac{B}{B_C}\right)^{T_0/2T}$$

Sambandamurthy, G; Johansson, A; Peled, E; Shahar, D; Bjornsson, Pg; Moler, Ka (2006). Power Law Resistivity Behavior in 2d Superconductors Across the Magnetic Field-Tuned Superconductor-Insulator Transition. Europhysics Letters. 75:611-617.

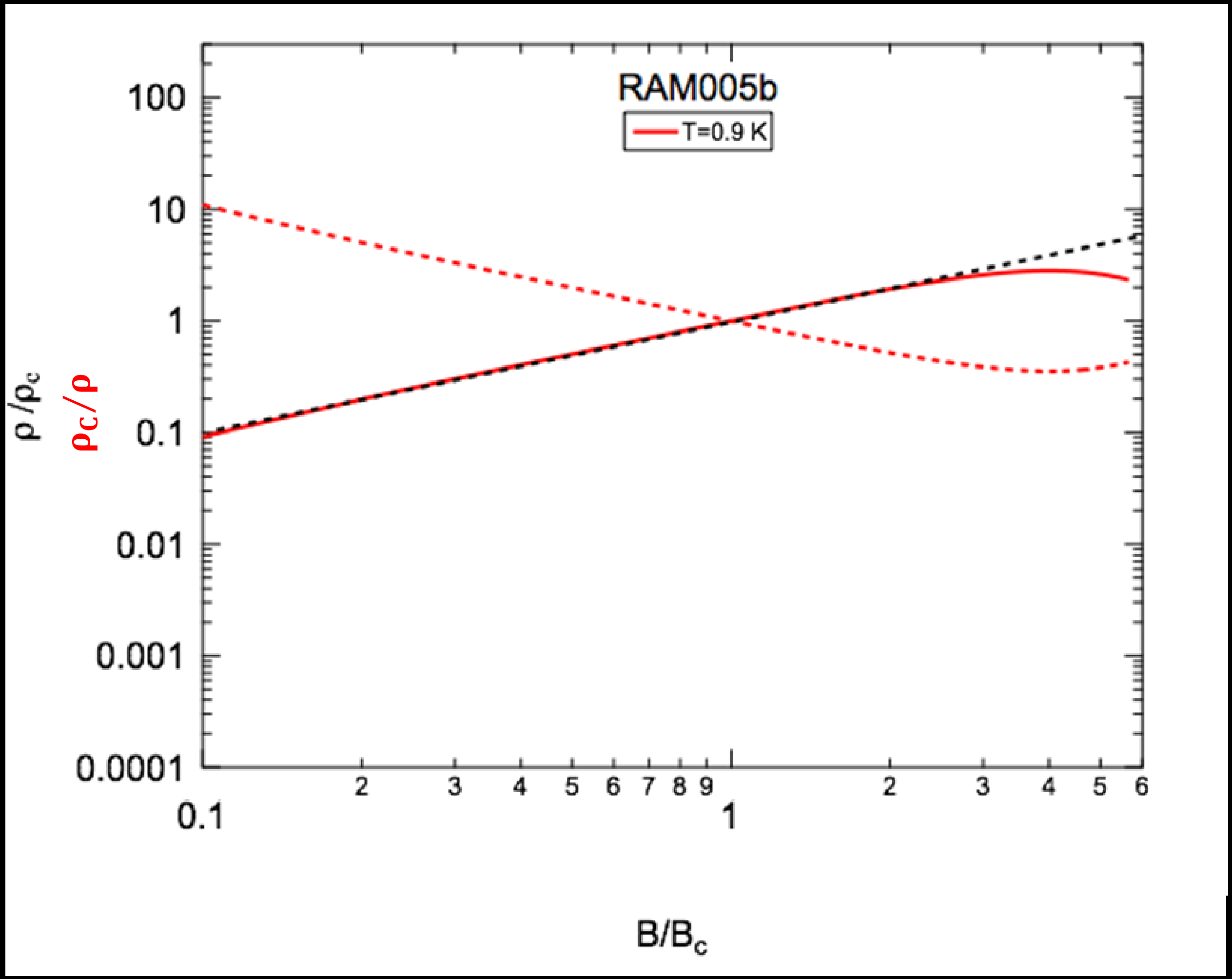
Duality Symmetry

$$\rho \leftrightarrow \sigma$$

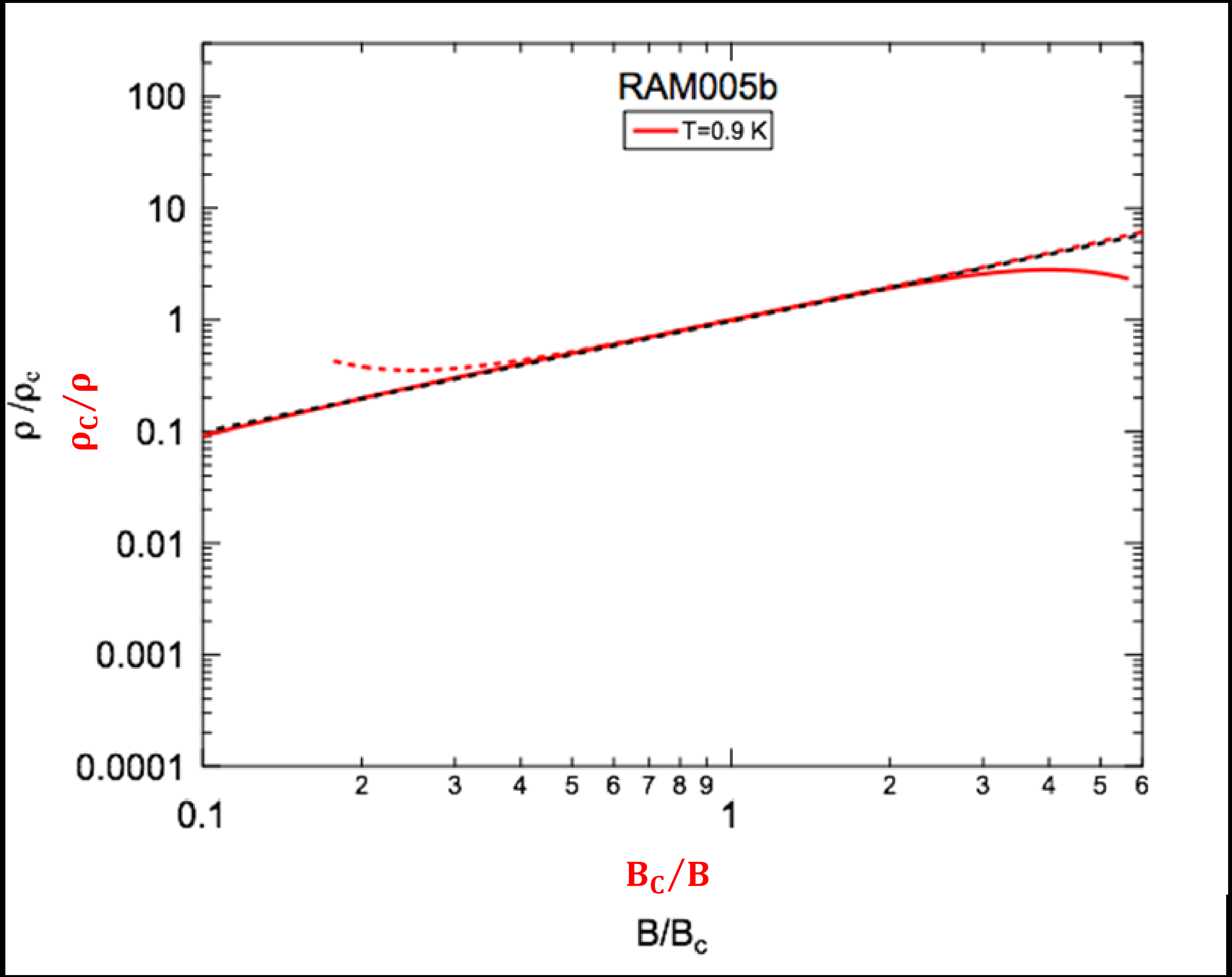

RAM005b
T=0.9 K
ρ /ρc
B/Bc
100
10
1
0.1
0.01
0.001
0.0001
0.1
1
2
3
4
5
6
7
8
9



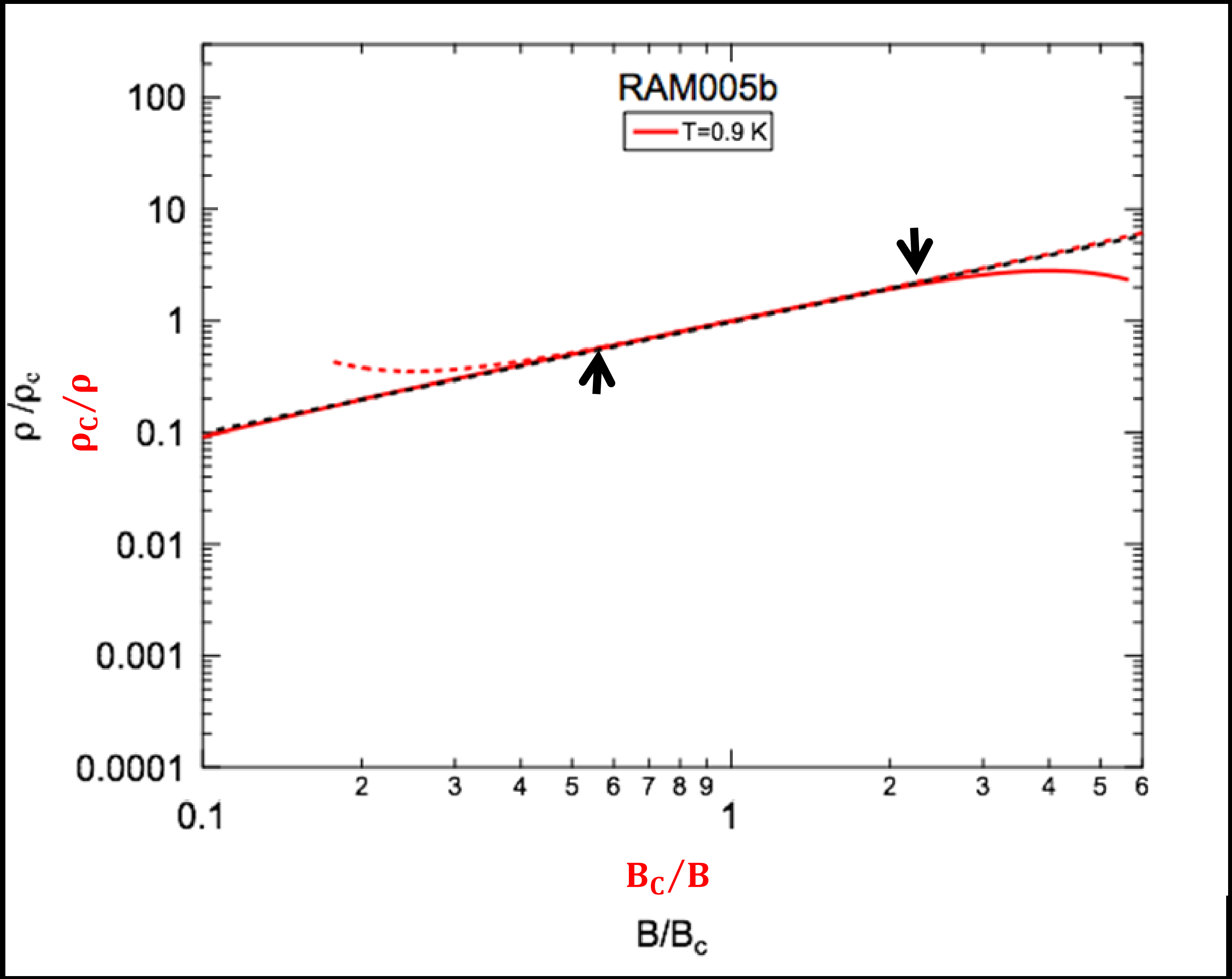
$$\frac{\rho(B,T)}{\rho_C} = \left(\frac{B}{B_C}\right)^{T_0/2T}$$



$$\frac{\rho(B,T)}{\rho_C} = \left(\frac{B}{B_C}\right)^{T_0/2T} \Rightarrow \frac{\rho_C}{\rho(B,T)}$$

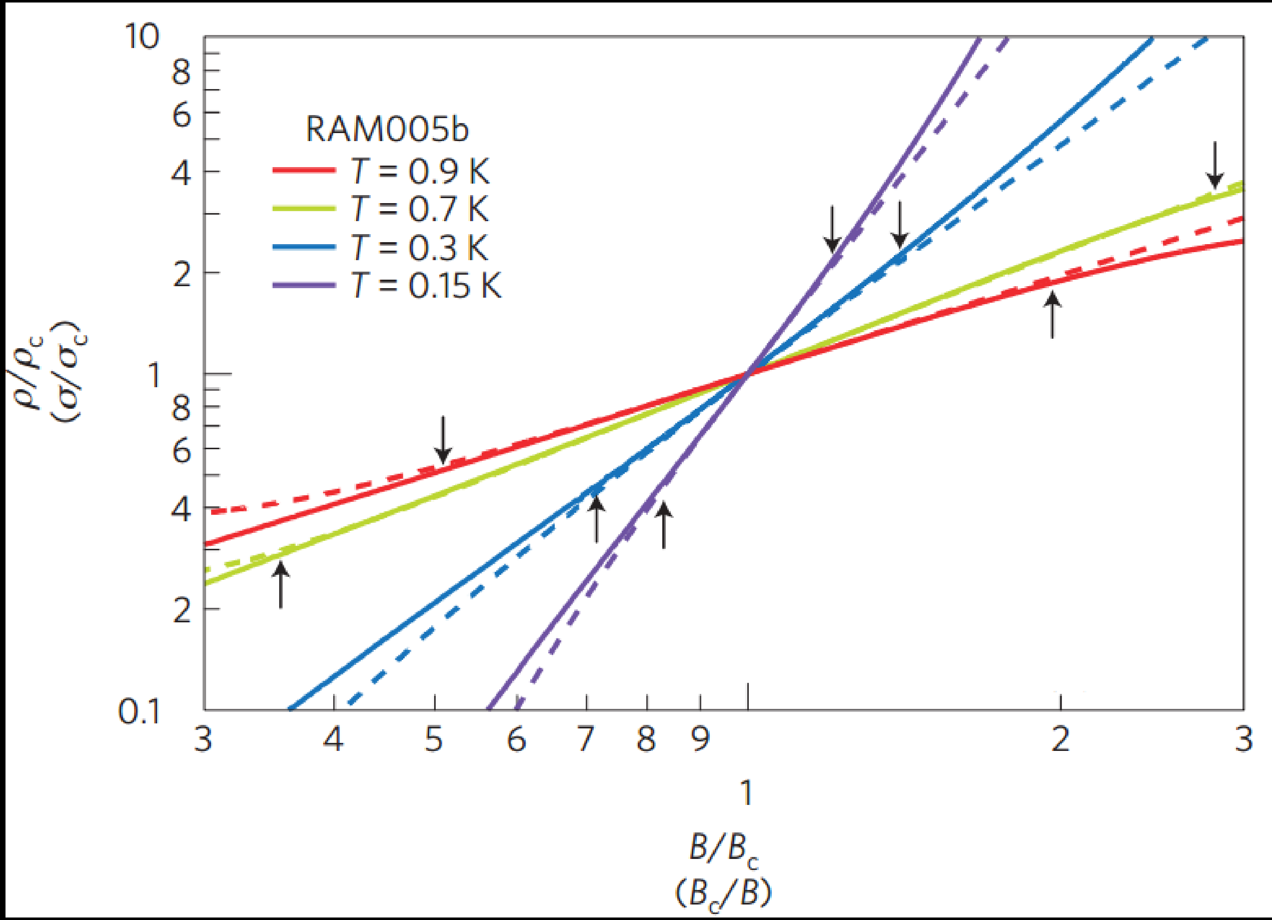


$$\frac{\rho(B,T)}{\rho_C} = \left(\frac{B}{B_C}\right)^{T_0/2T} \Rightarrow \frac{\rho_C}{\rho(B,T)} = \left(\frac{B_C}{B}\right)^{T_0/2T}$$



$$\rho(B_{SC}) = \sigma(B_{Ins})$$

Duality symmetry

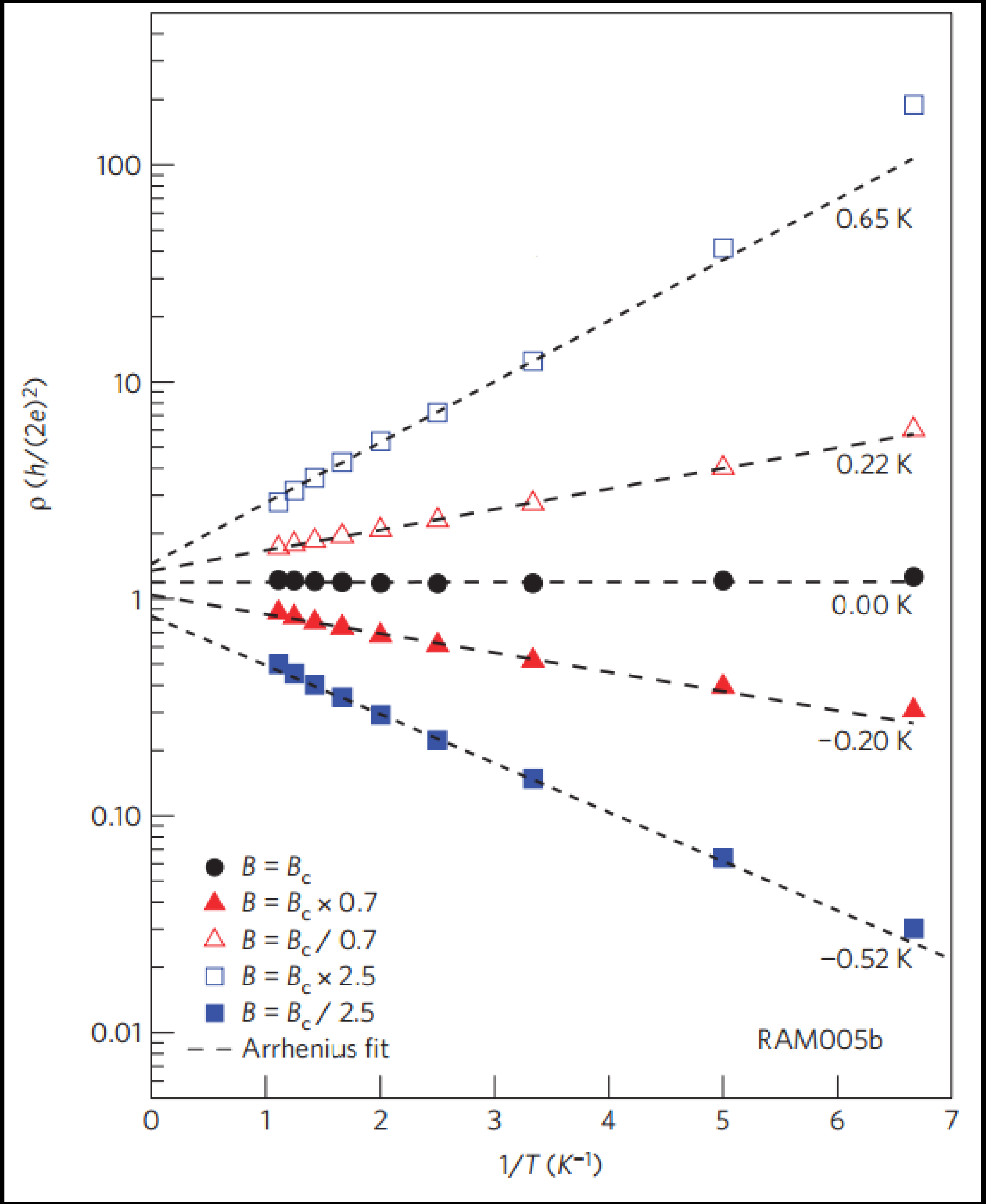


Ovadia, M; Kalok, D; Sacepe, B; Shahar, D (2013). Duality Symmetry and Its Breakdown in the Vicinity of the Superconductor-Insulator Transition. Nature Physics. 9:415-418.

Resistance Temperature Dependence

$$\rho(B,T) = \rho_C \times exp\left(\frac{E_0(B)}{k_B T}\right)$$

$E_0(B_{SC})$=-$E_0(B_{Ins})$



(very) Low Temperature

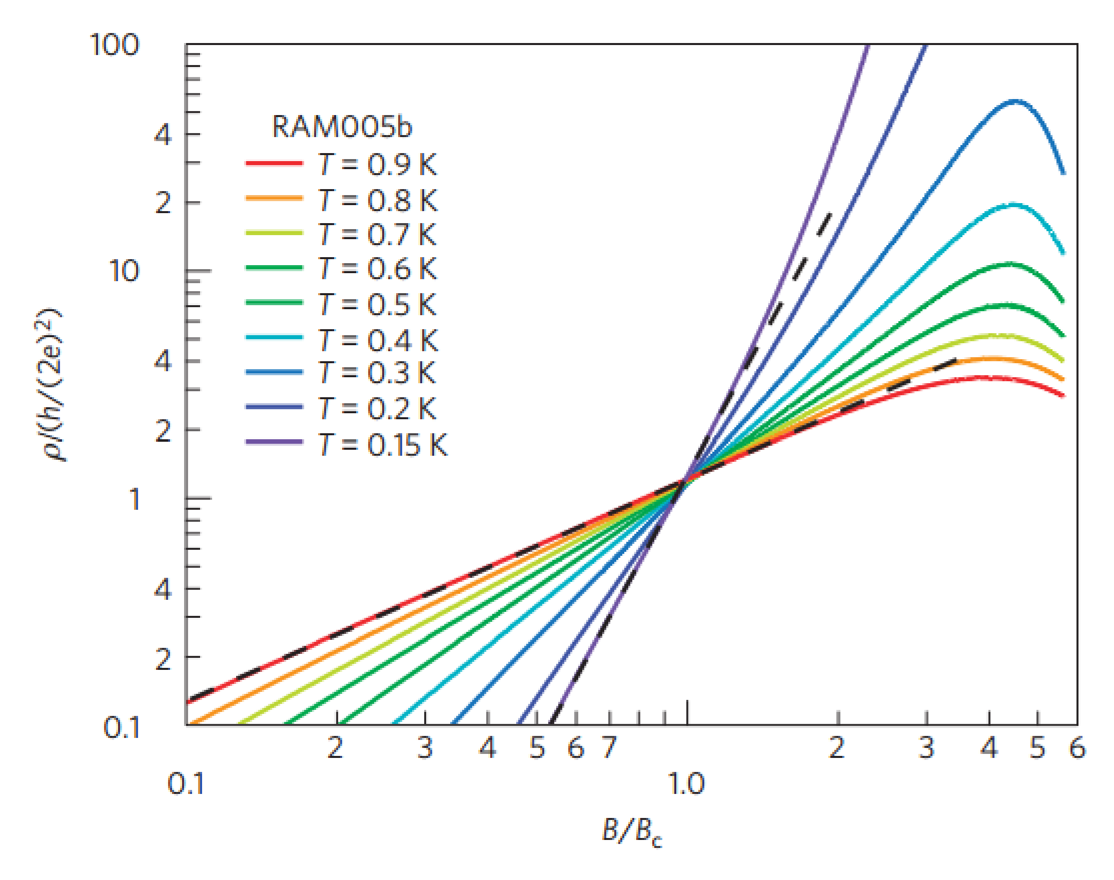
nature physics

LETTERS

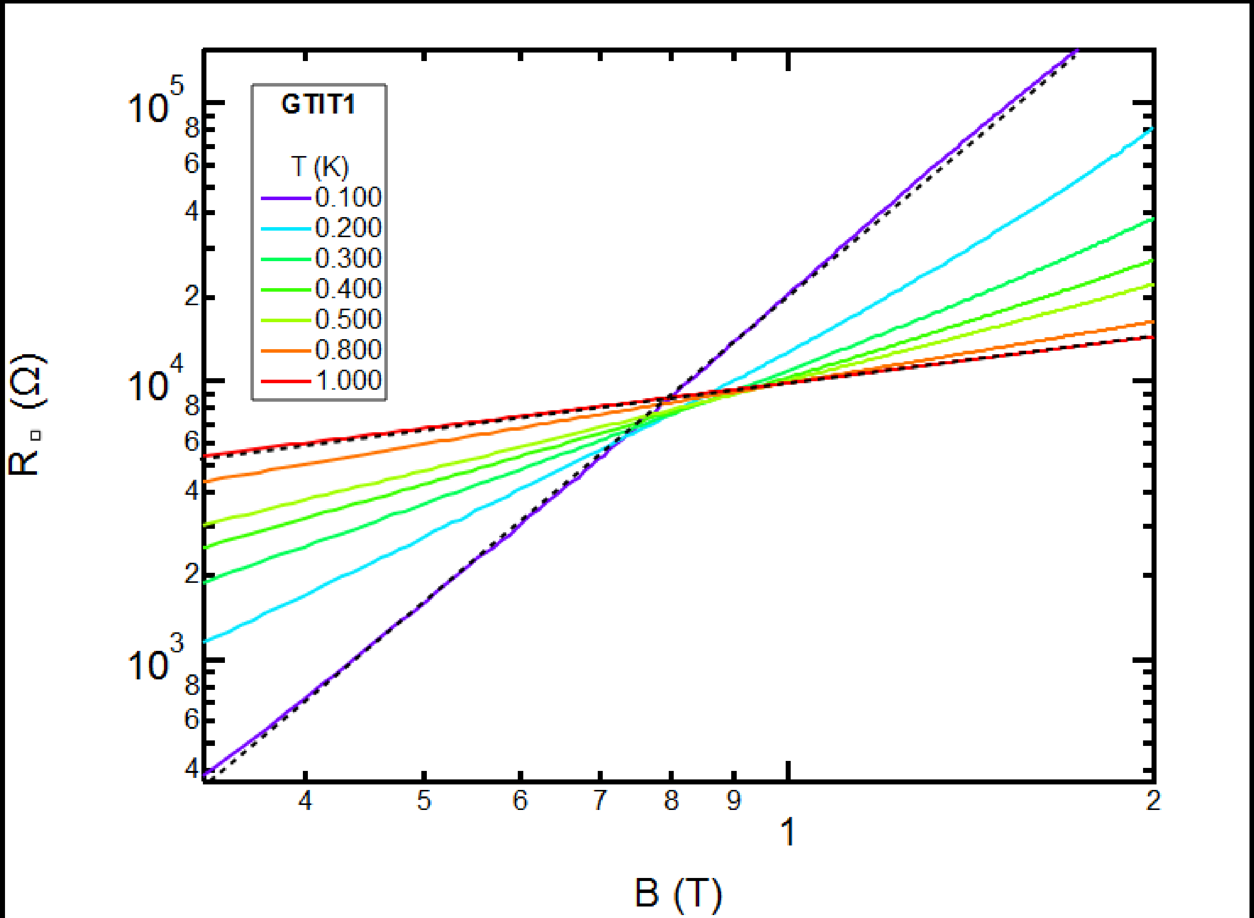
PUBLISHED ONLINE: 2 JUNE 2013 | DOI: 10.1038/NPHYS2636

Duality symmetry and its breakdown in the vicinity of the superconductor–insulator transition

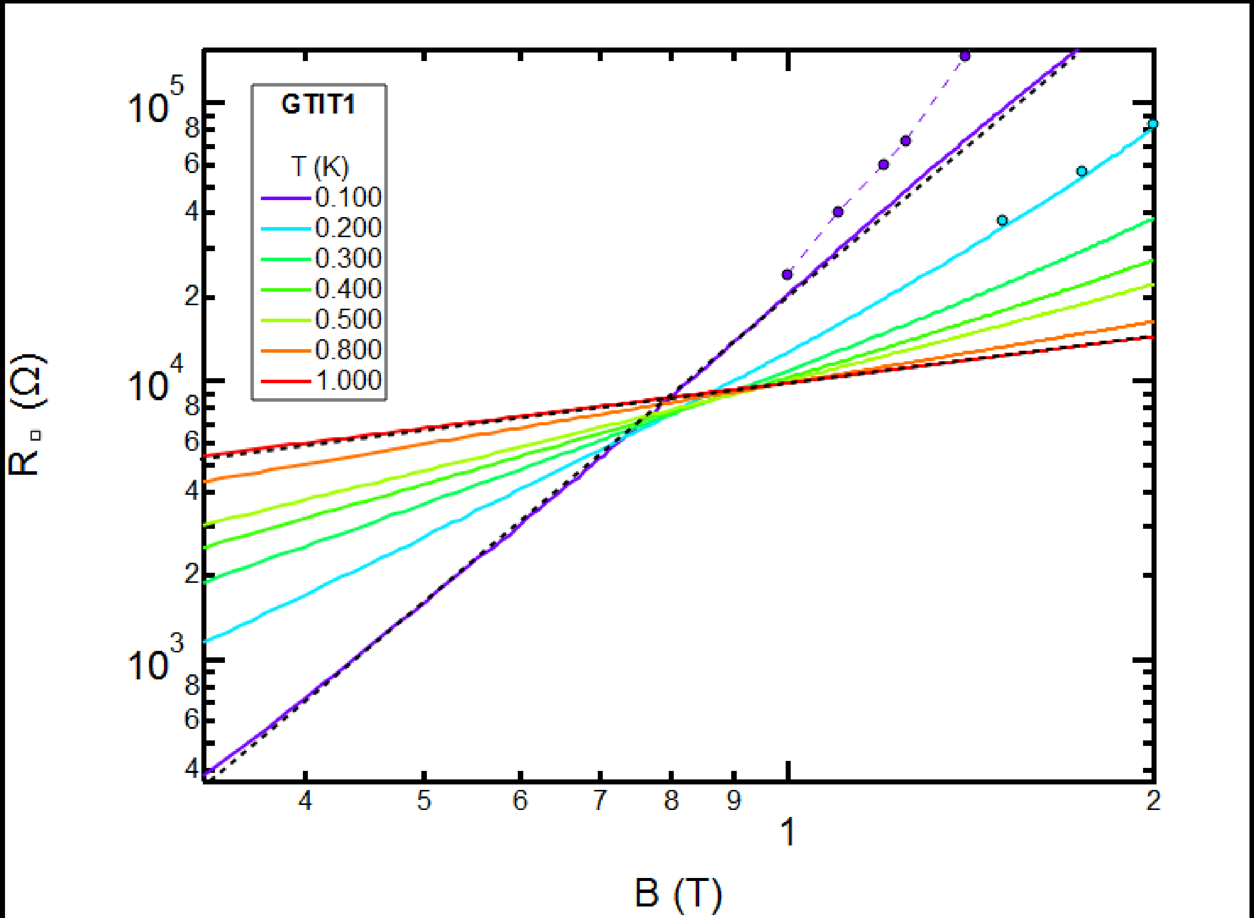
Maoz Ovadia, David Kalok*, Benjamin Sacépé† and Dan Shahar



Low Temperature Duality Breakdown



Low Temperature Duality Breakdown

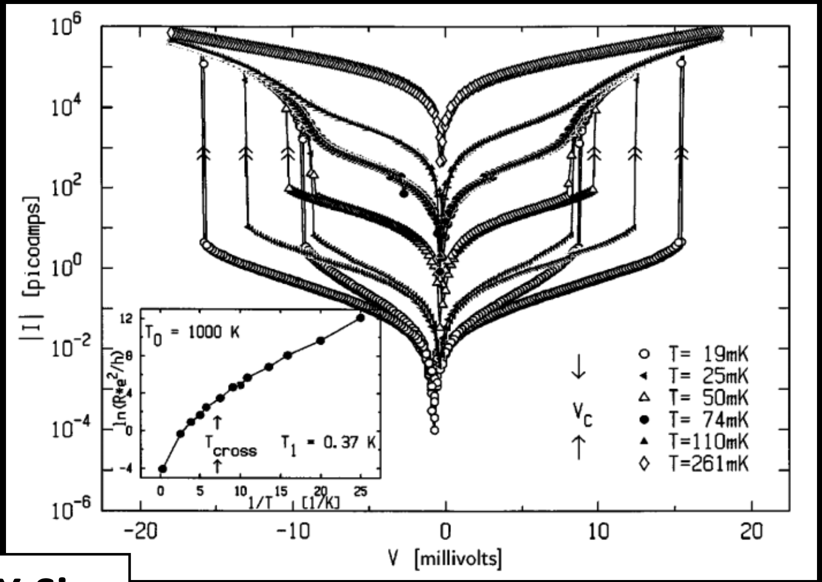


Properties of a CPI

- Exponential temperature dependence of the resistance

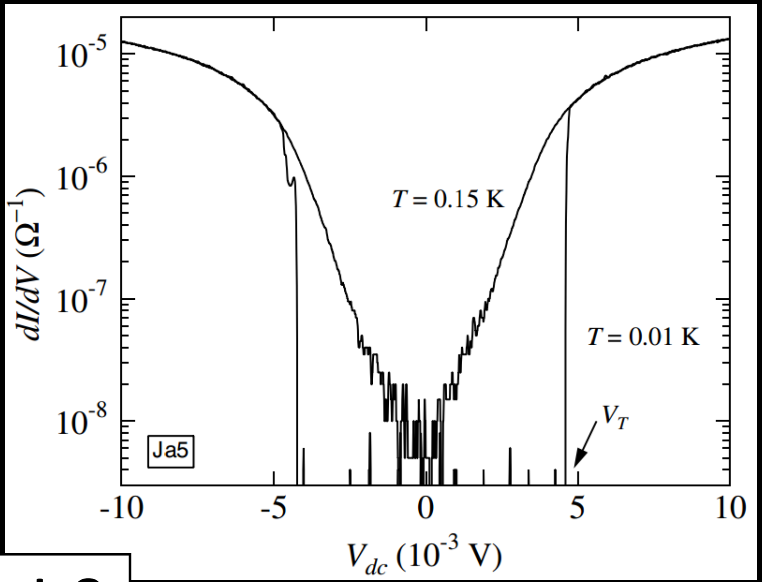
- Electrons are interacting and decoupled from phonons

Discontinuous Current-Voltage Characteristics in CPI's



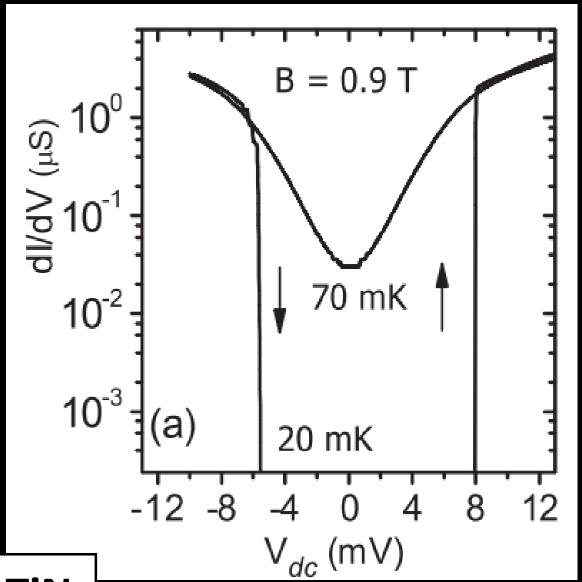
Y_xSi_{1-x}

F. Ladieu, M. Sanquer, and J. P. Bouchaud, Phys. Rev. B 53, 973 (1996).



a:InO

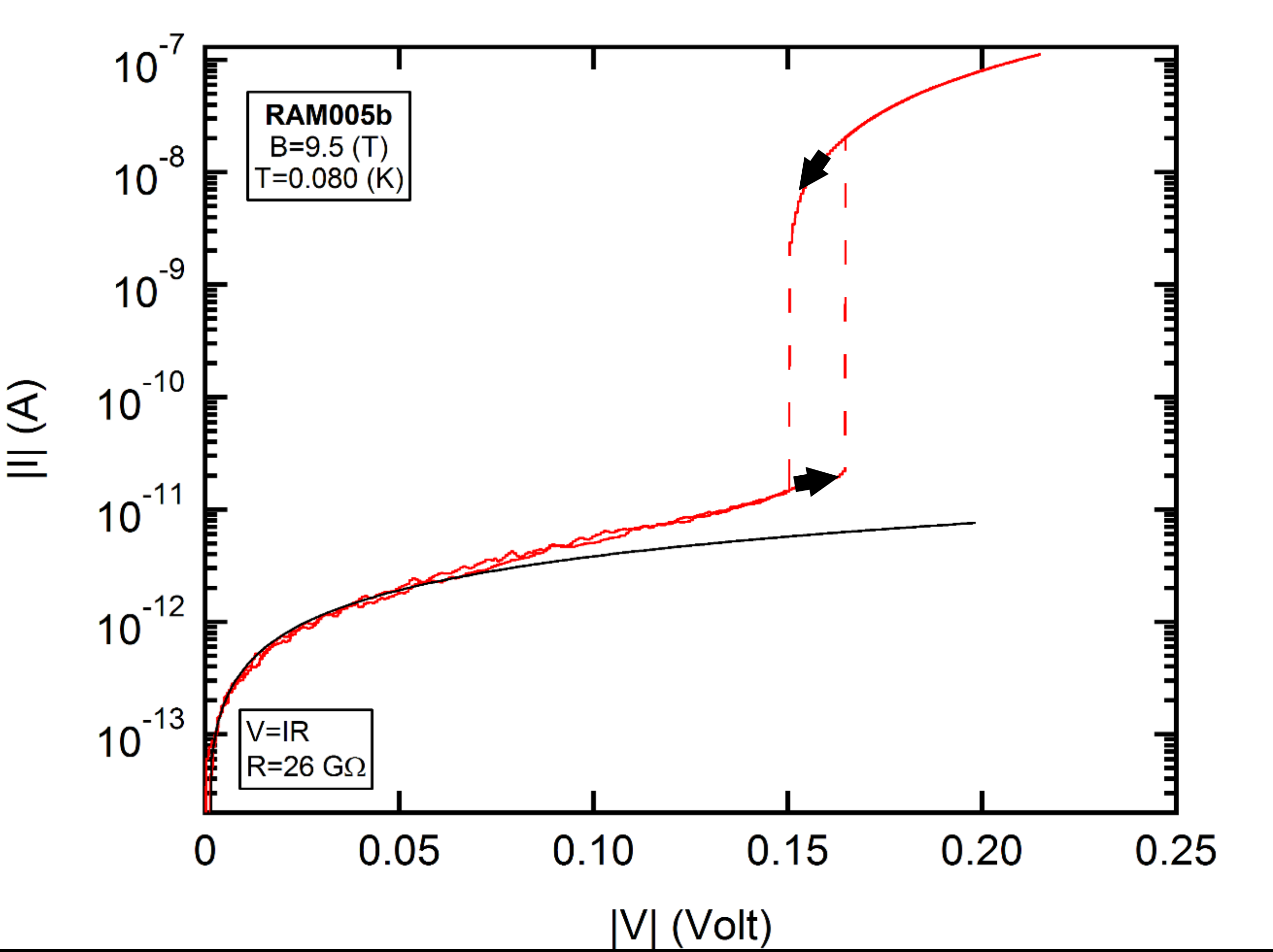
Sambandamurthy, G; Engel, L.w; Johansson, A; Peled, E; Shahar, D (2005). Experimental Evidence For a Collective Insulating State in Two-Dimensional Superconductors. Physical Review Letters. 94.



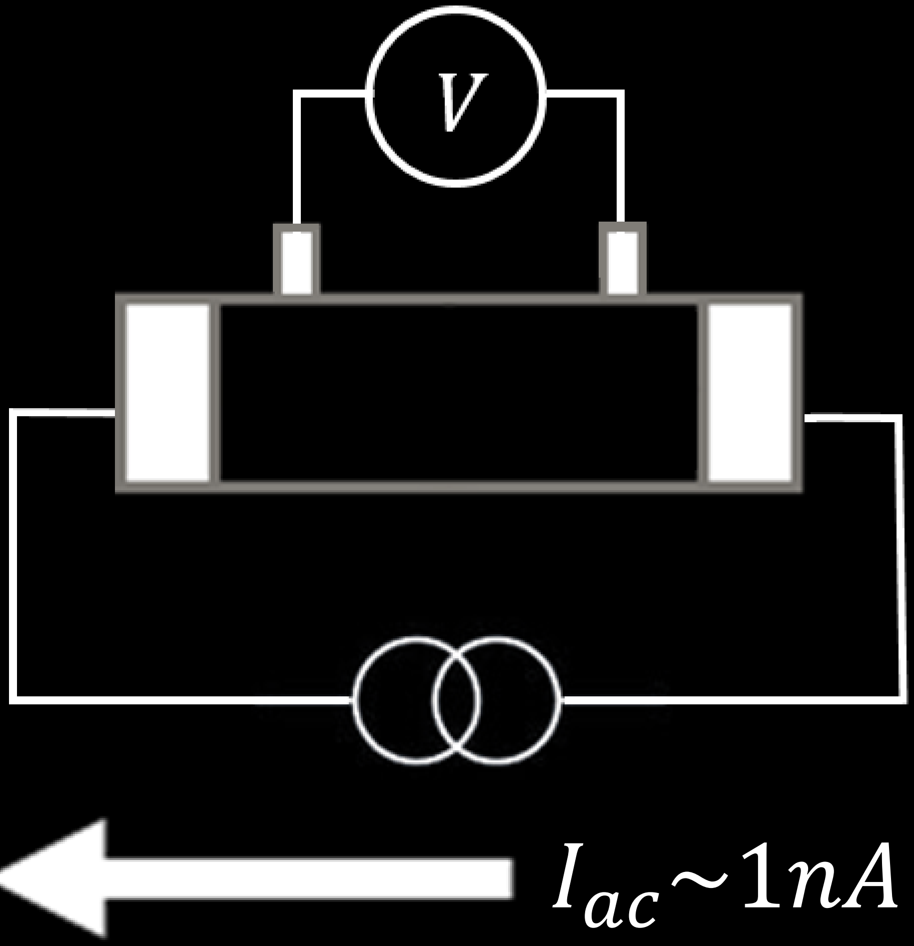
TiN

T. Baturina, A. Y. Mironov, V. Vinokur, M. Baklanov, and C. Strunk, Phys. Rev. Lett. 99, 257003 (2007)

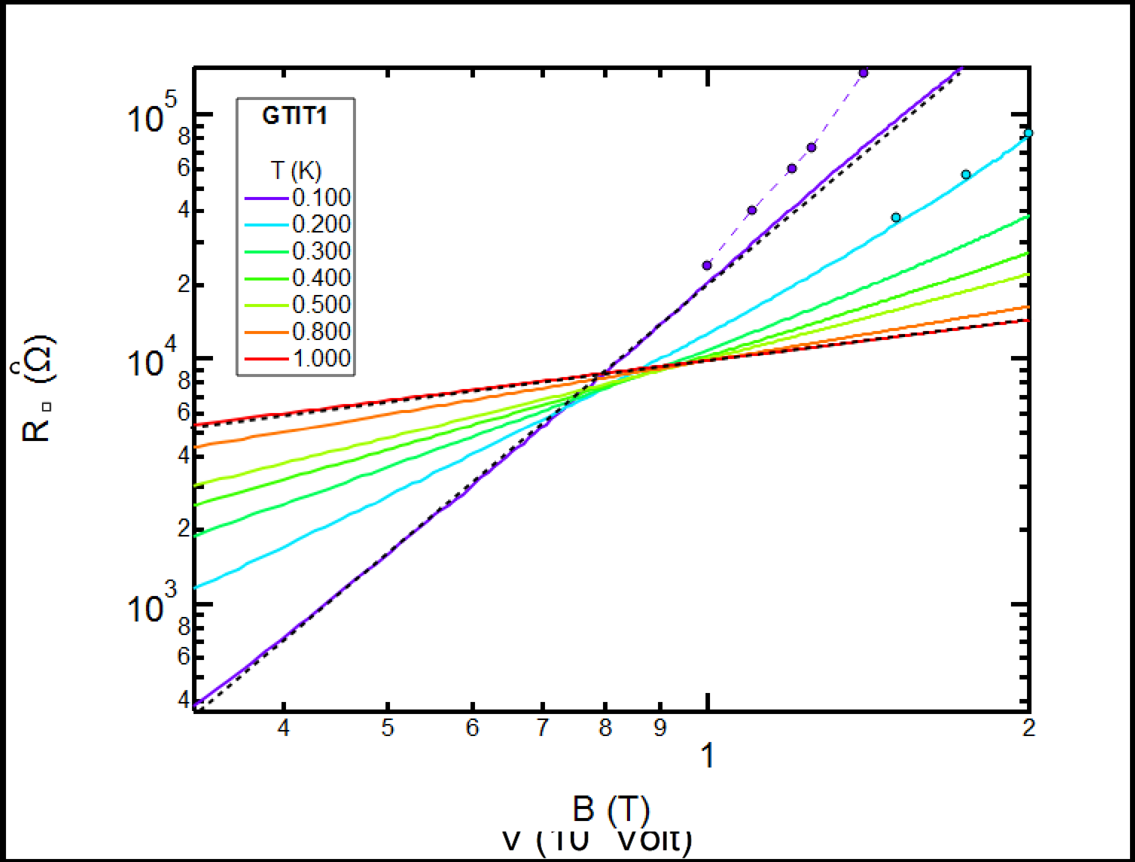
Current-Voltage Characteristics



4 Probe Measurement



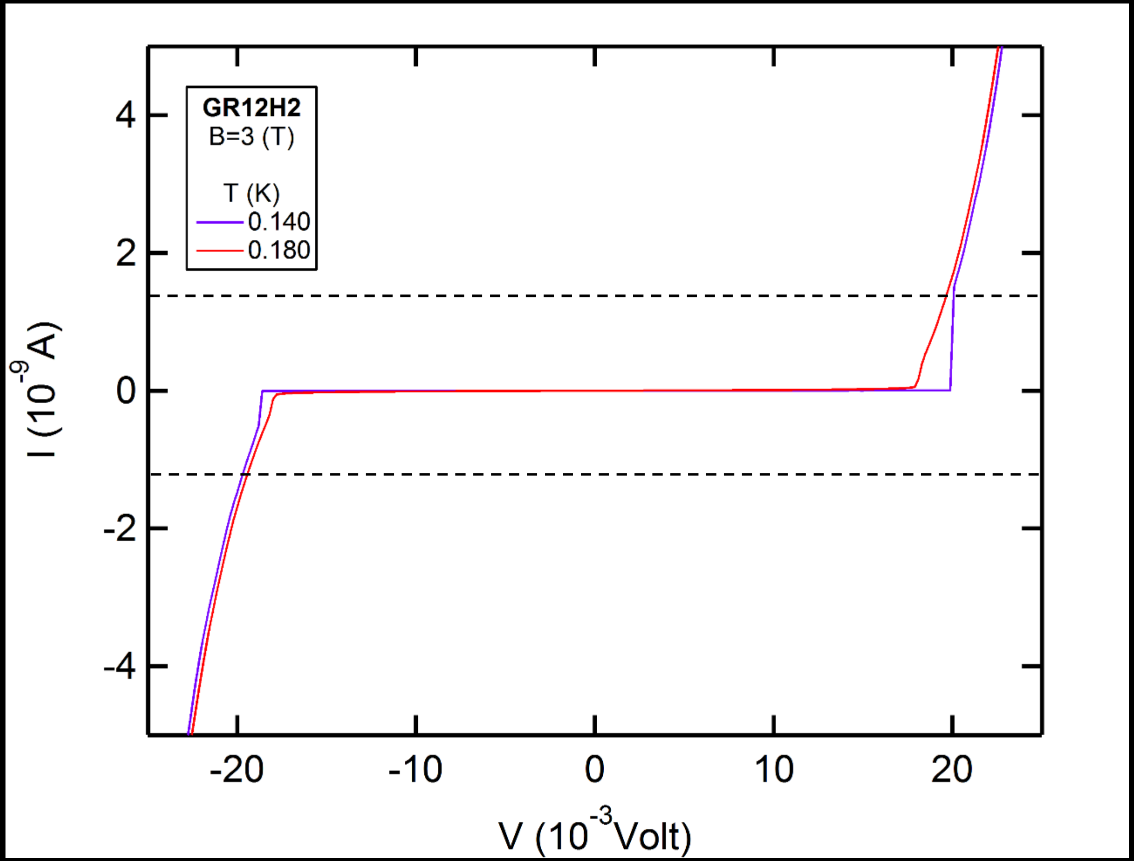
$I_{ac}{\sim}1nA$



Doron, A., Tamir, I., Levinson, T., Ovadia, M., Sacépé, B., & Shahar, D. (2016). Transport Catastrophe Near the Superconductor-Insulator Transition. *arXiv preprint arXiv:1606.06606*.

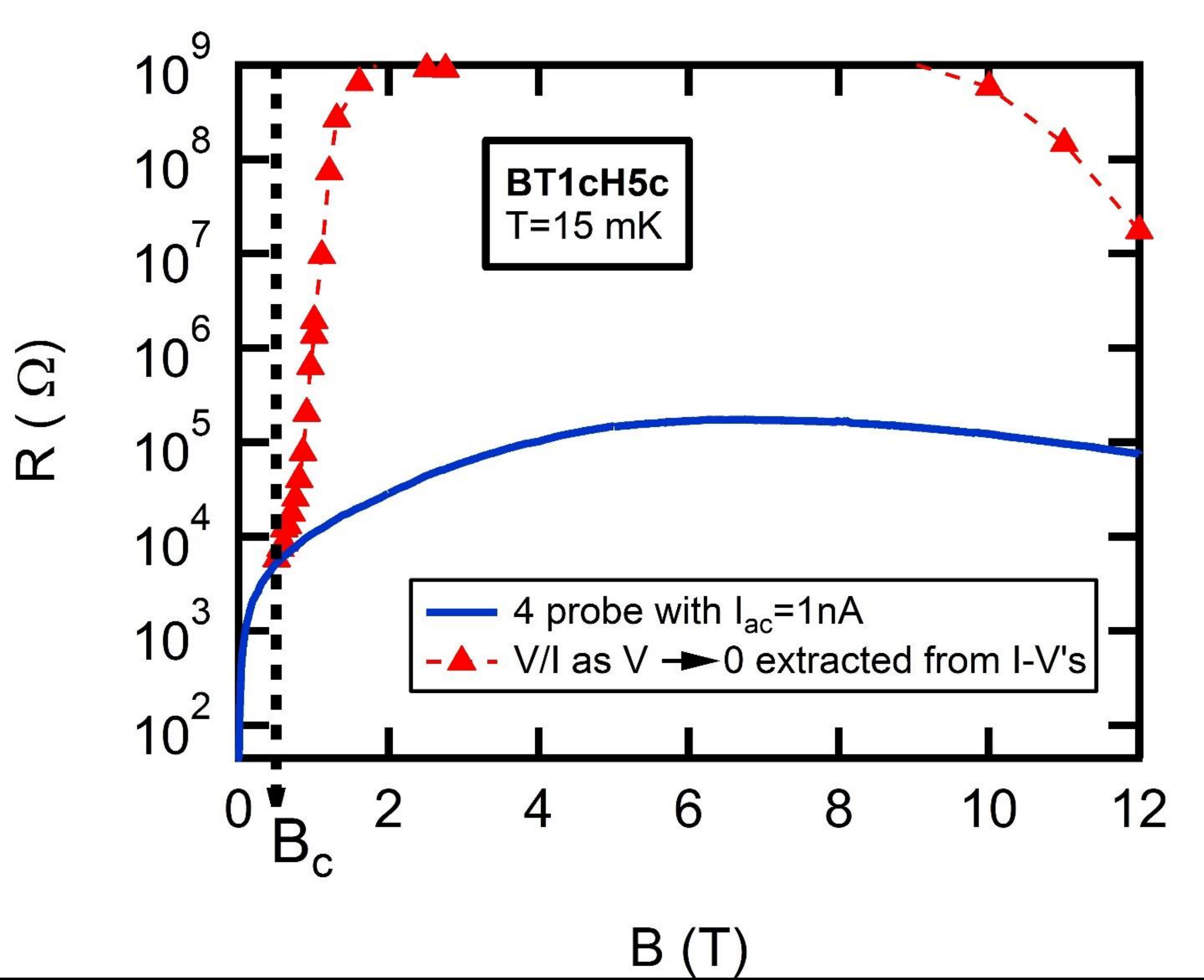
4 Probe Measurement

- $1\,nA$ is allowed → Sampling mostly the high current branch without knowing (high current branch is linear).
- $1nA$ is in the unstable region. Not clear what is measured.

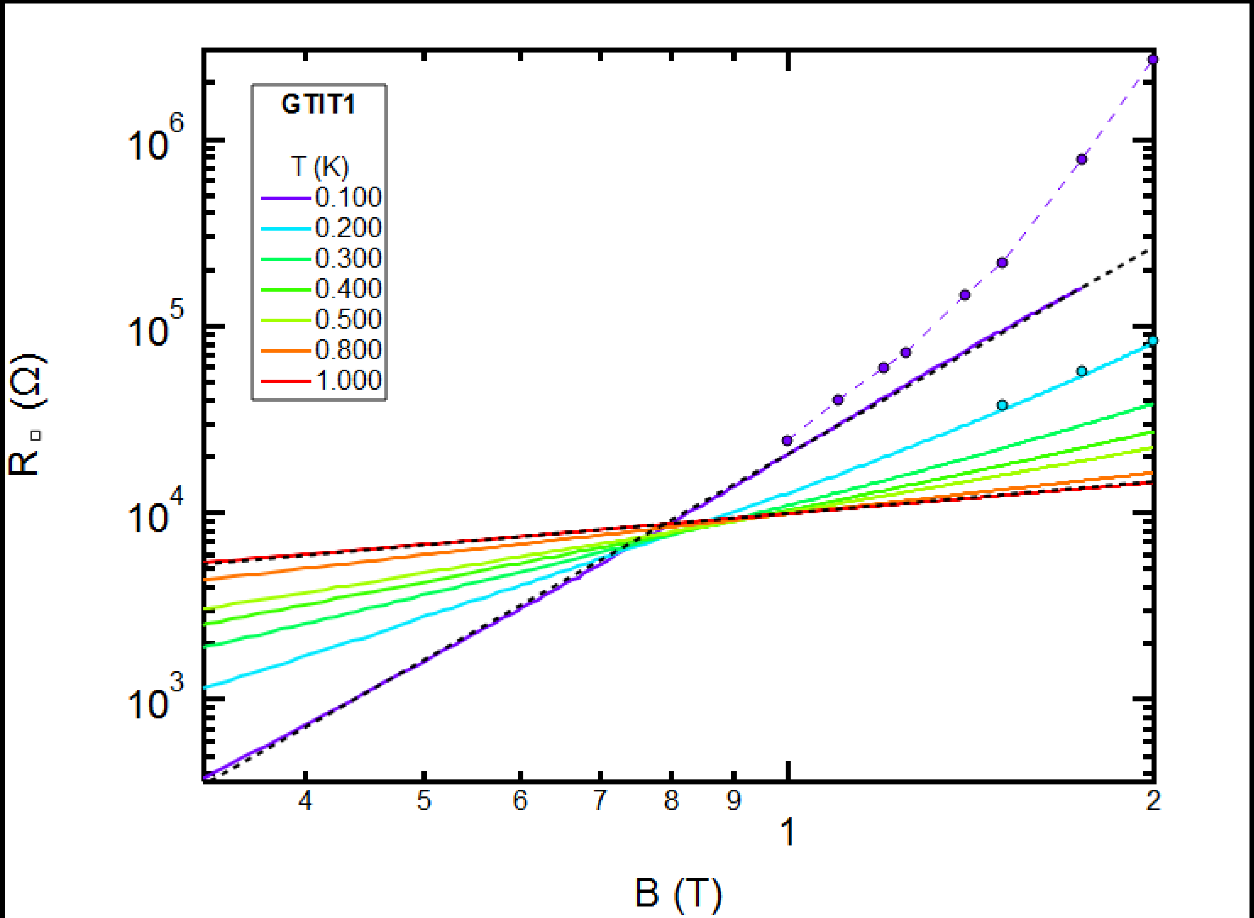


Doron, A., Tamir, I., Levinson, T., Ovadia, M., Sacépé, B., & Shahar, D. (2016). Transport Catastrophe Near the Superconductor-Insulator Transition. *arXiv preprint arXiv:1606.06606*.

4 Probe Catastrophe

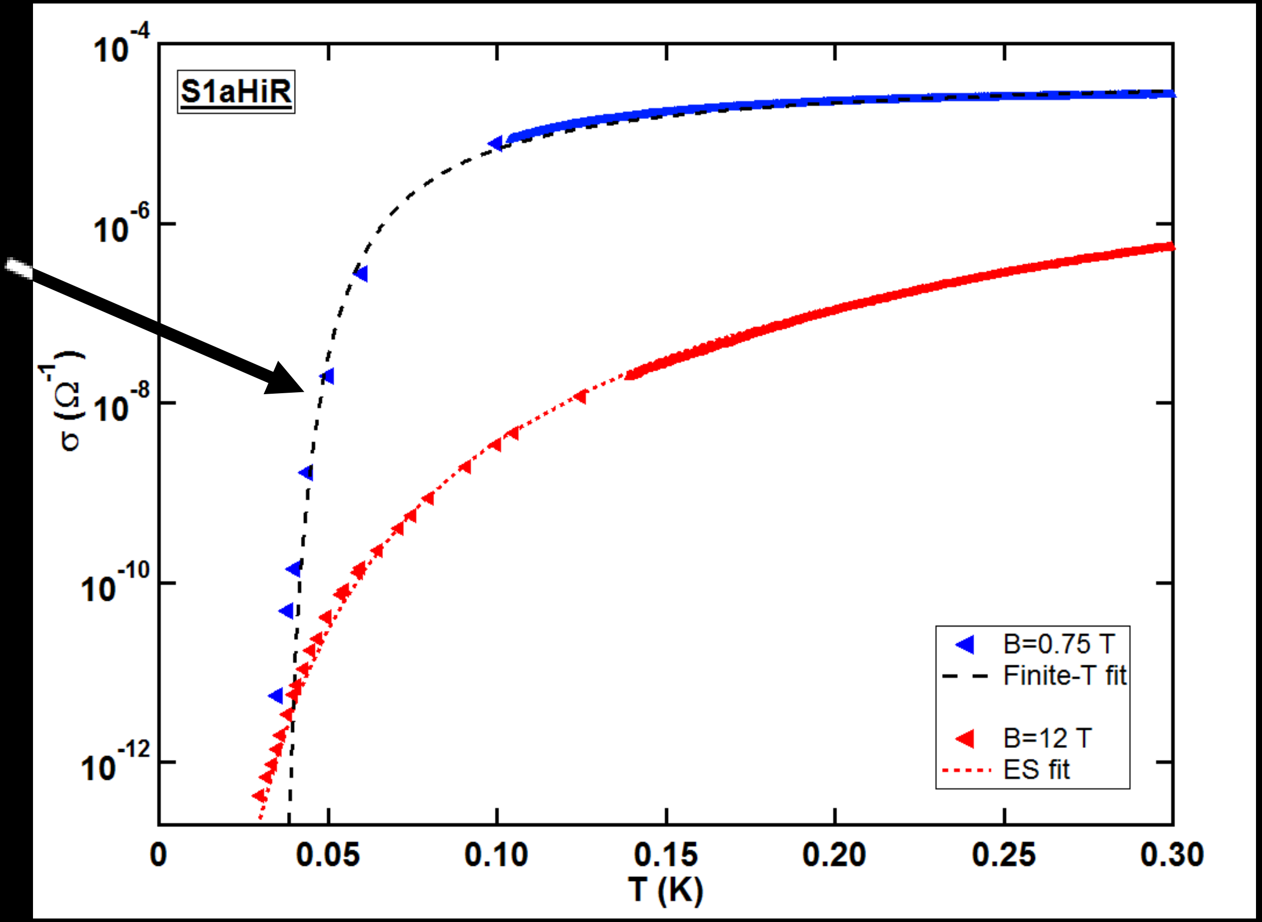


Low Temperature Duality Breakdown



Low Temperature Conductivity

$$\sigma(T) = \sigma_0 \times exp\left\{-\frac{T_0}{T - T^*}\right\}$$



Ovadia, M.; Kalok, D.; Tamir, I.; Mitra, S.; Sacepe, B.; Shahar, D. (2015). Evidence For a Finite-Temperature Insulator. Scientific Reports. 5:13503.

PHYSICAL REVIEW B **76**, 052203 (2007)

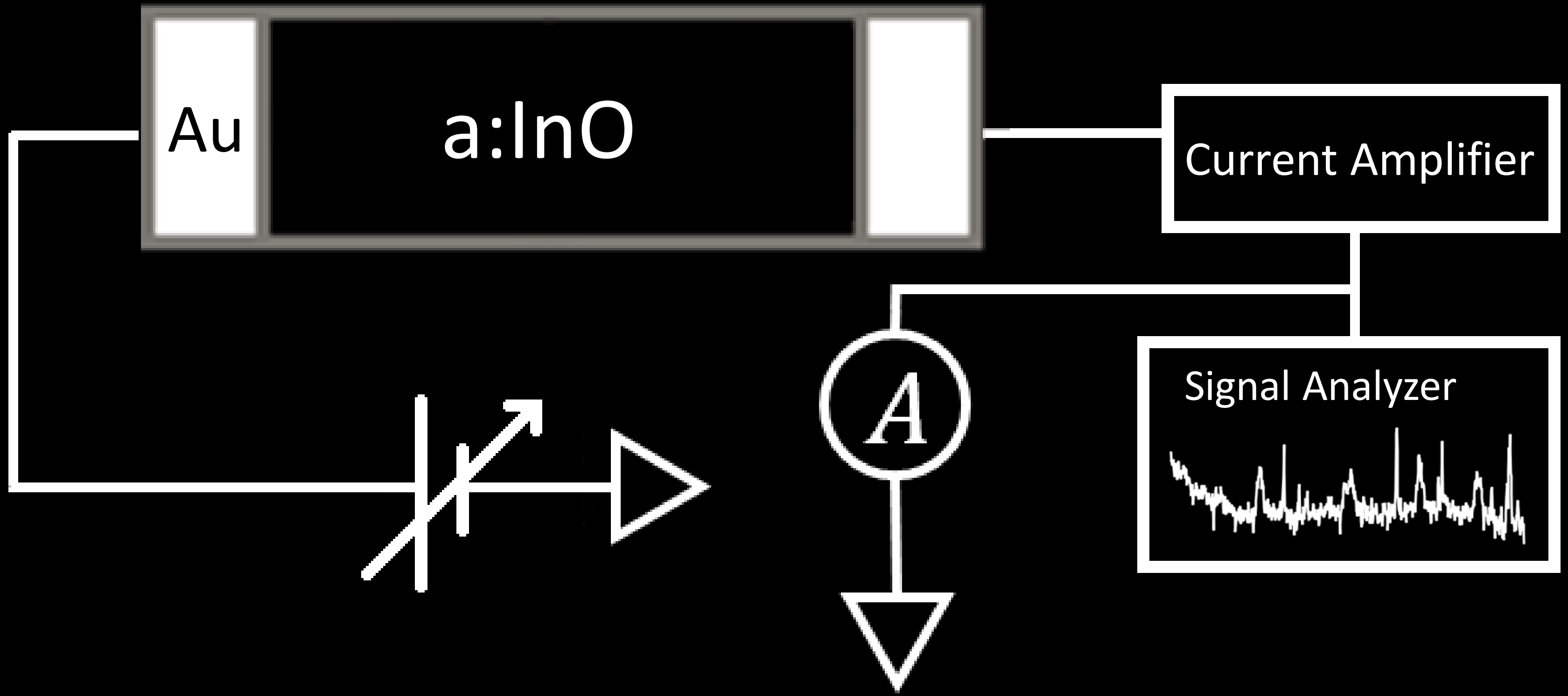
Possible experimental manifestations of the many-body localization

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)

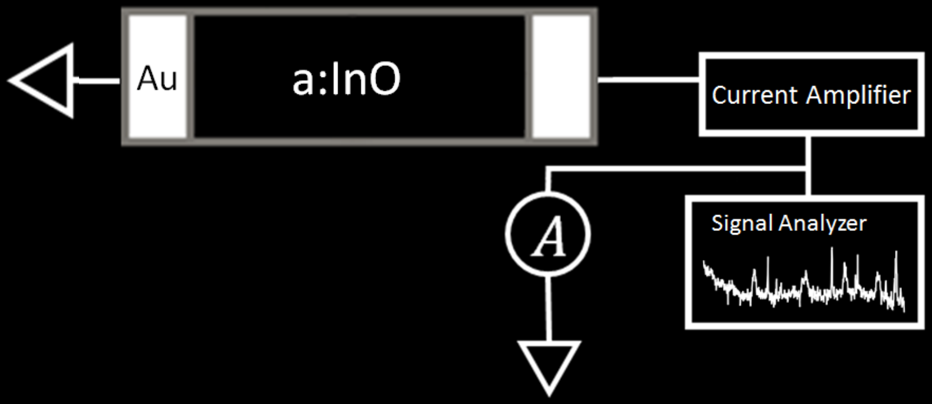
Recently, it was predicted that if all one-electron states in a noninteracting disordered system are localized, the interaction between electrons in the absence of coupling to phonons leads to a finite-temperature metal-insulator transition. Here, we show that even in the presence of a weak coupling 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.

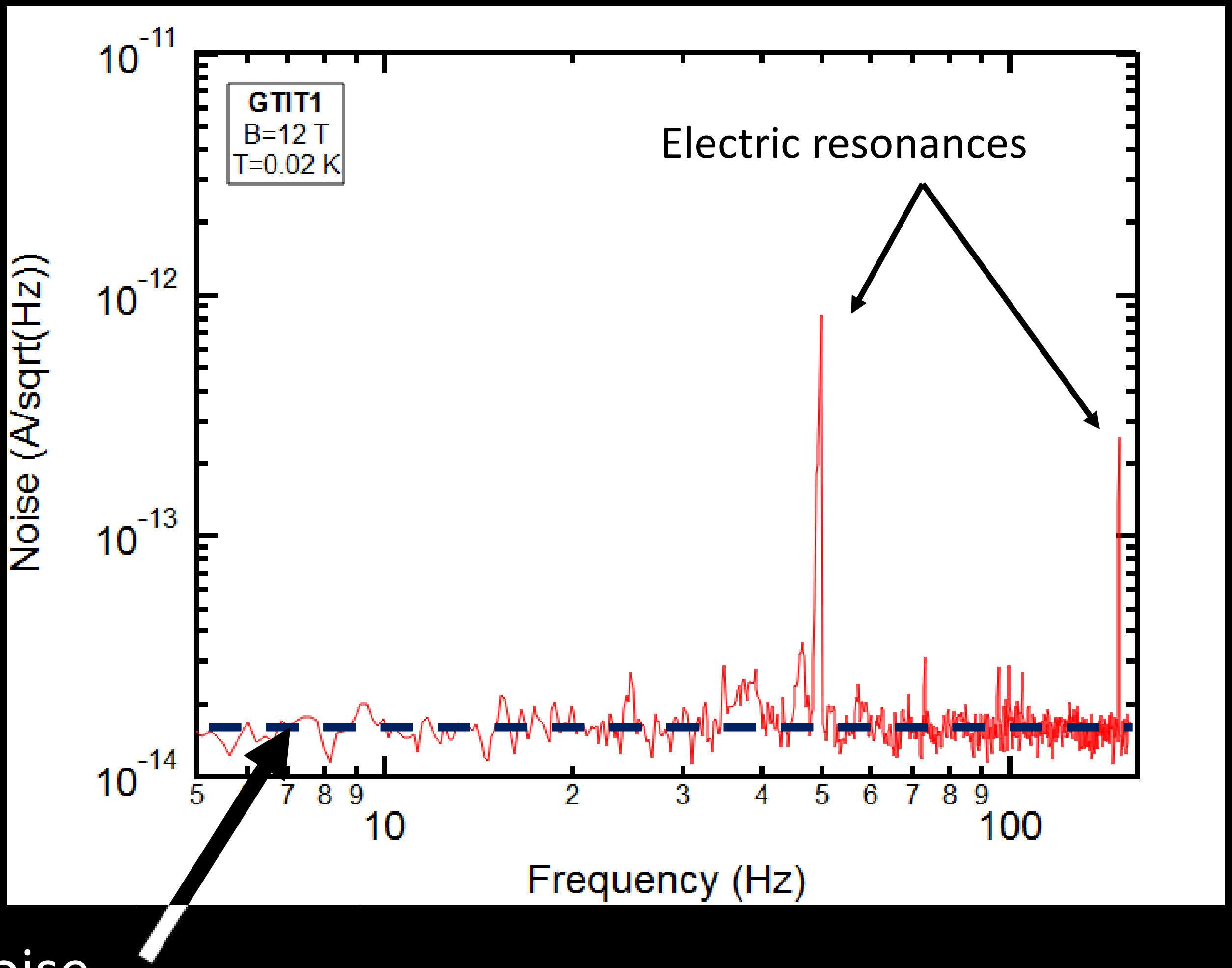
DOI: 10.1103/PhysRevB.76.052203 PACS number(s): 72.10.−d, 72.15.Rn, 72.20.Ee, 72.60.+g

Noise Measurement - Setup



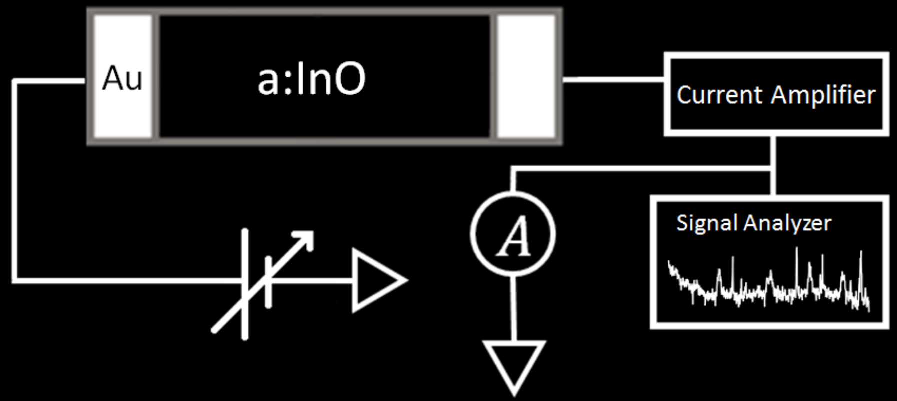
Noise Spectral Density – $V = 0$

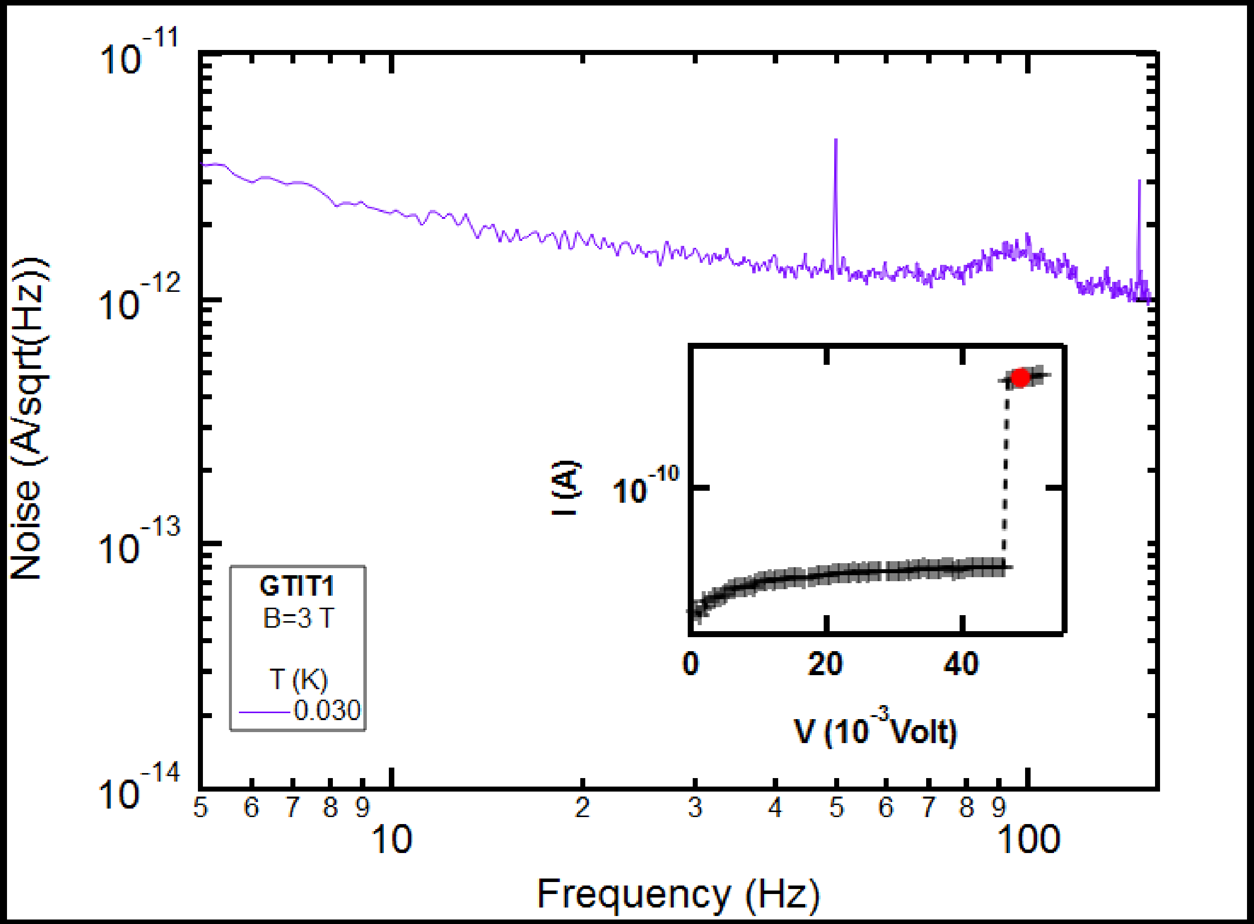




Amplifier baseline noise

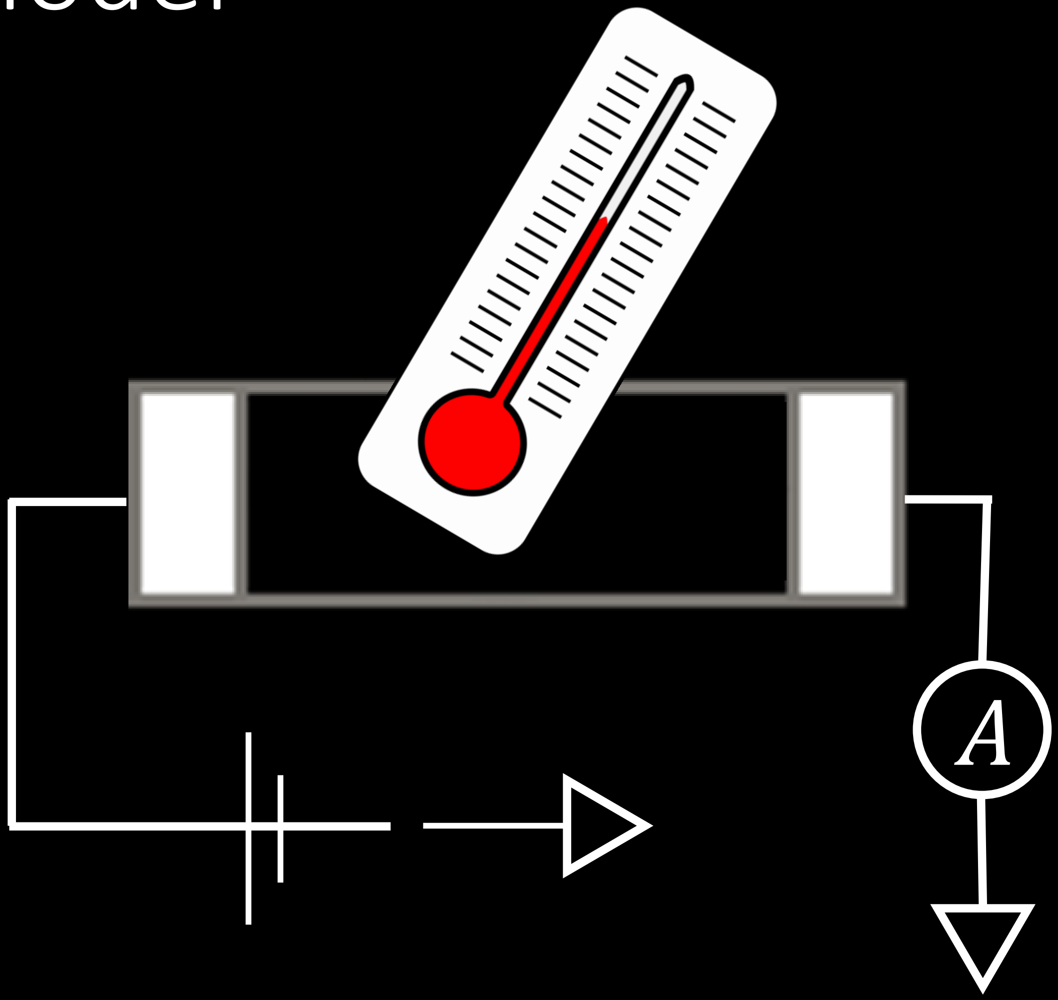
Noise Spectral Density – $V \neq 0$



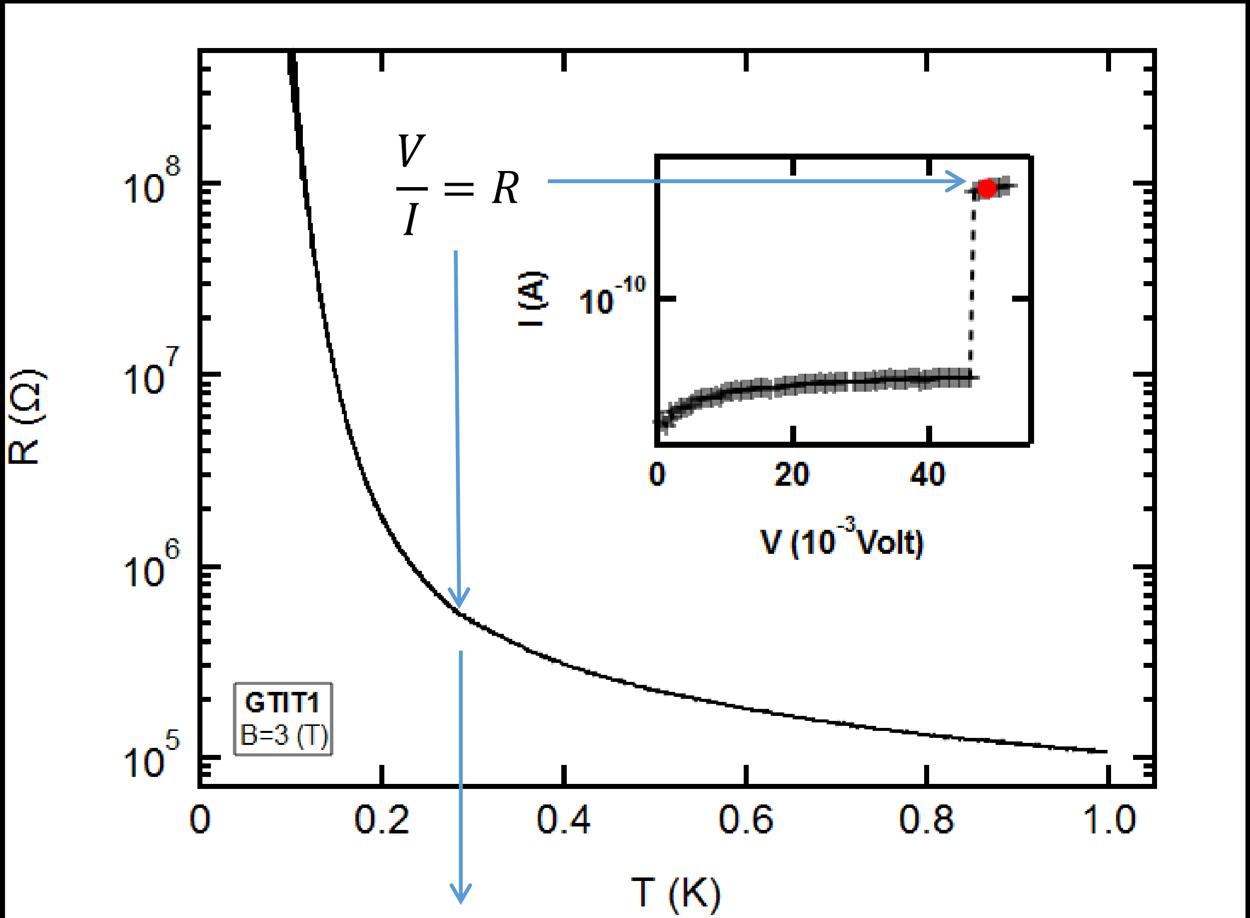


Noise Thermometry – Over-Heated electron Model

- Primary Thermometer
- Coupled directly to the electrons
- $Noise \propto \sqrt{\frac{4kT_{el}}{R}}$

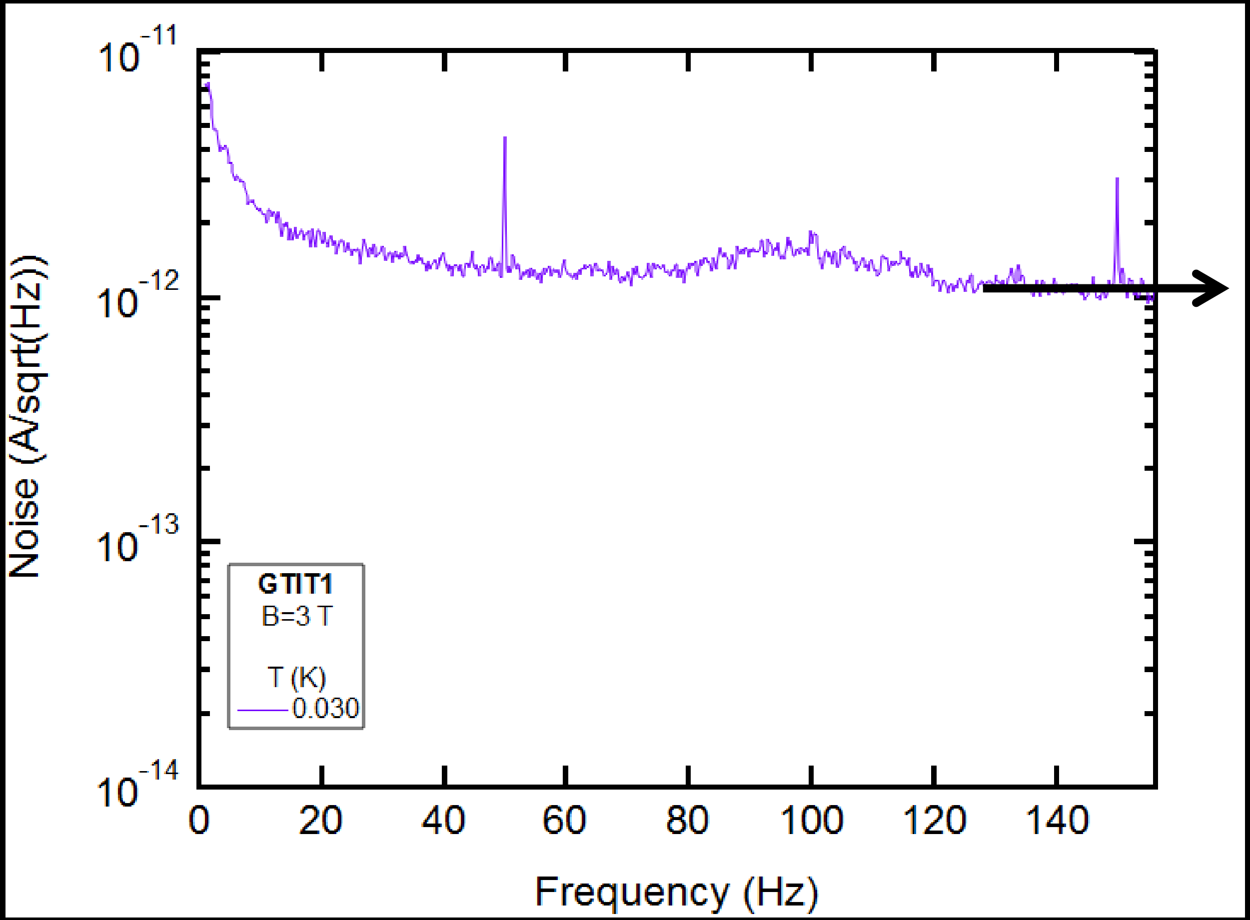


Over-Heated electron Model



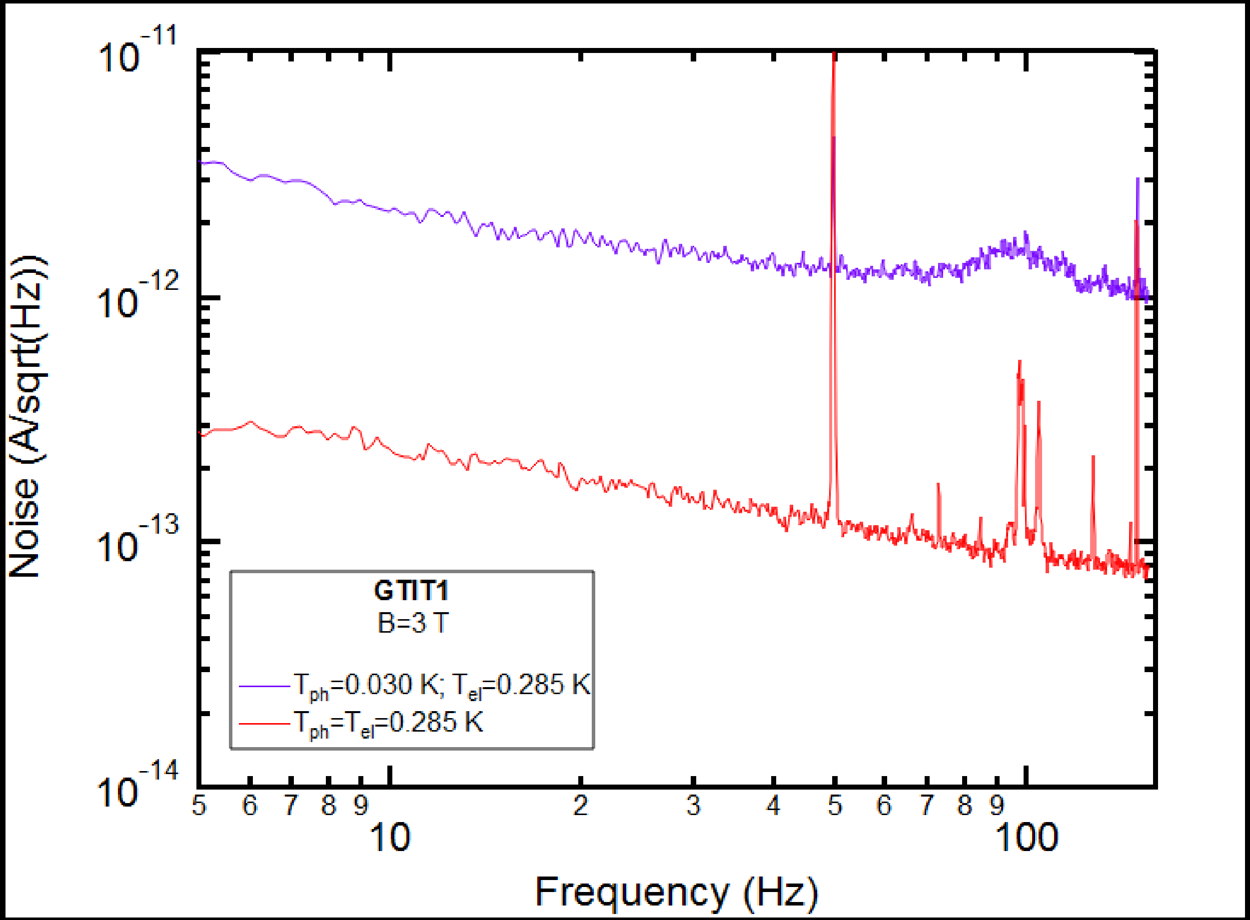
$T_{el} \sim 0.285\ K$

Noise Spectral Density – $V \neq 0$

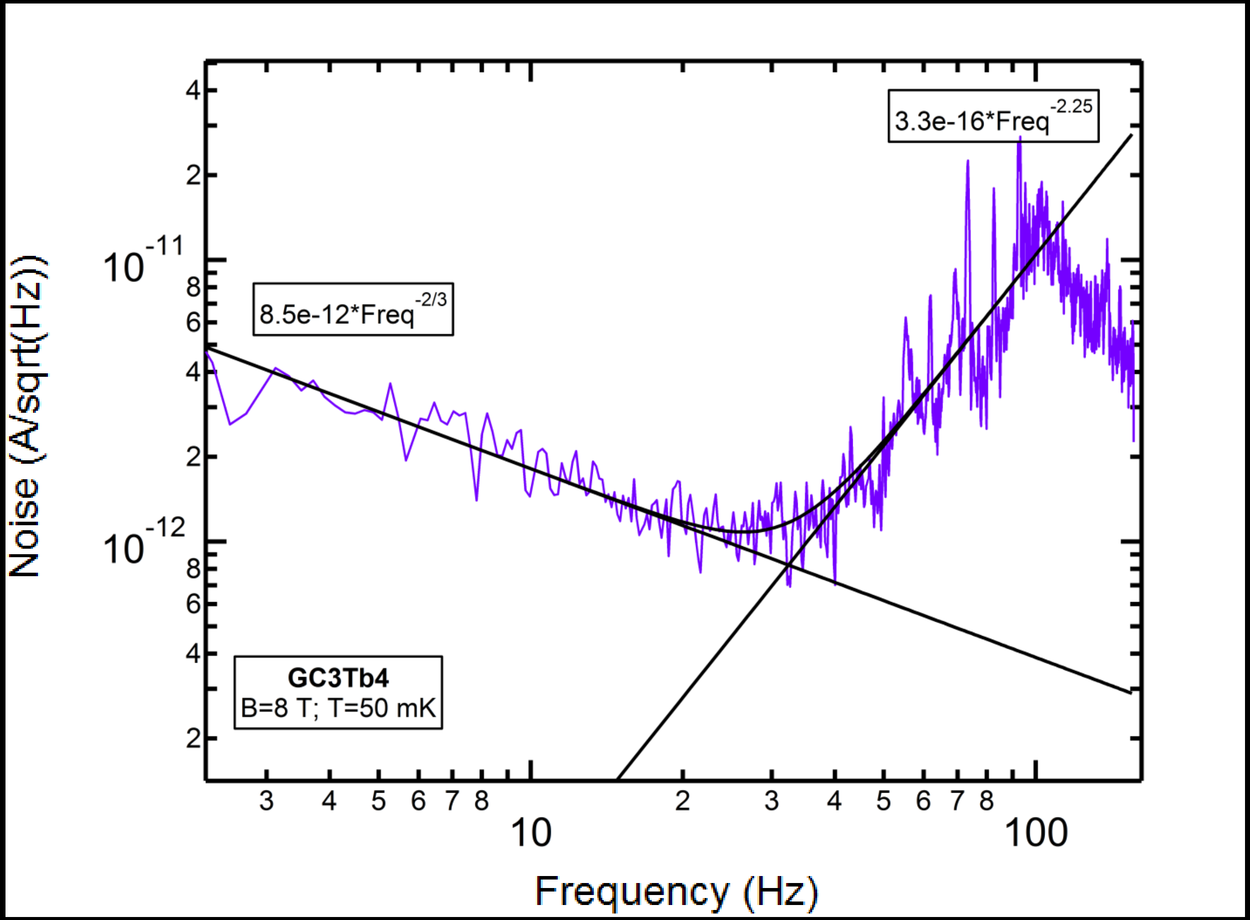


$T \sim 3000\ K$

Noise Spectral Density – $T_{el} = T_{ph}$

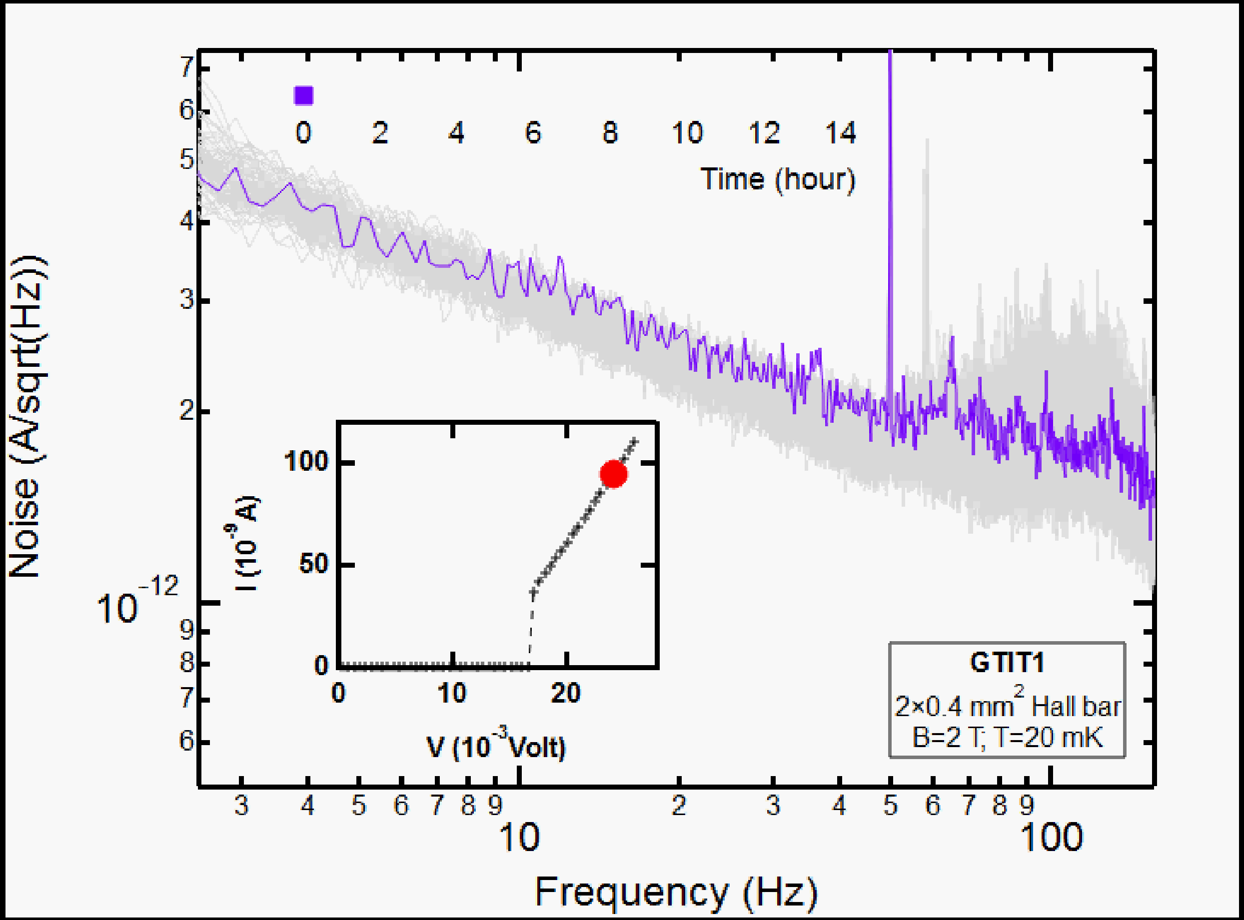


Noise Peak



Celasco, E., Celasco, M., & Eggenhöffner, R. (2007). Crackling noise peaks as signature of avalanche correlation. Journal of Applied Physics, 101(5), 054908.

Noise Peak – Time dependence



Low Temperature Summary

- Duality symmetry is broken
- Instability of the $I - V$ characteristics is observed
- Resistance (calculated from $I - V$'s) show strong temperature dependence, despite *e-ph* decoupling
- Large (time dependent) noise is observed as an applied V bias is introduced

Thank You!