Insulating Phases

Old-fashioned equilibrium systems extrapolated from non-zero T to T=0

S.A. Kivelson

KITP 2015

Localization at the Edge of 2D Topological Insulator by Kondo Impurities

Boris Altshuler, Stanford, Nov. 5, 2015

Kondo spins coupled to a chiral Luttinger Liquid

Altshuler, Aleiner, Yudson, Phys. Rev. Lett. **111**, 86401 (2013)
Yevtushenko, Wugalter, Yudson, Altshuler, arXiv:1505.04820

Are topologically protected edge states really topologically protected in "real" solids?

Many-body localization is certainly profound and new

Is it relevant to the properties of “real” materials?

Or is it always destroyed by phonon-induced VRH?

And even if so, are there phenomena for which such effects are weak enough that it is useful to think of “almost” MBL?

"I would like to mention that insulators,
i.e. conductors with resistance much larger than h/e^2
in which the resistance increases as the temperature decreases,
have never been studied in detail."

Best,
Boris

Boris Spivak that is

Moreover, when I asked him, Elihu Abrahams concurred

Why there is (probably) no such thing as an interacting Anderson insulator

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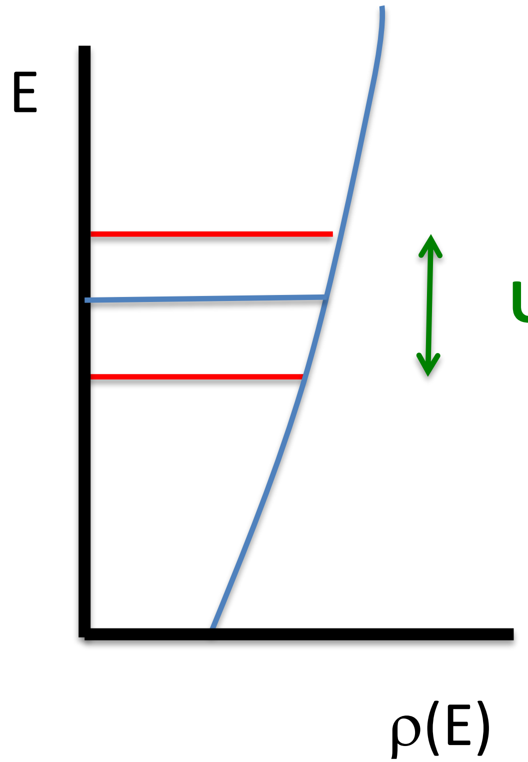
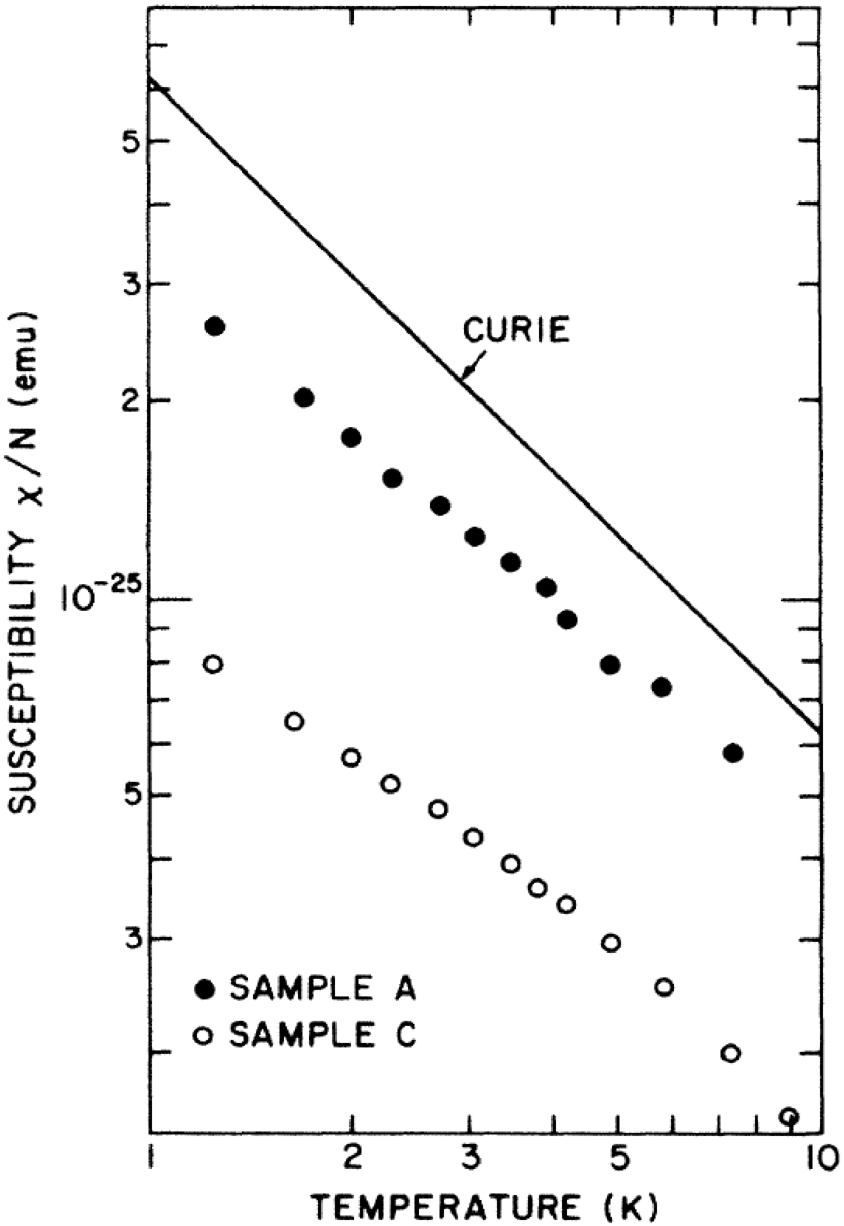
Effect of weak repulsive interactions:



$U^{eff} \sim U/\xi^d$

$n_{spin} \sim \rho(E_F)\, U^{eff}$

Probably leads to spin-glass or random singlet phase.



Here is the magnetic susceptibility of strongly insulating P doped Si

A) $n_P = 6.7 \times 10^{17}\ cm^{-3}$

B) $n_P = 2.4 \times 10^{18}\ cm^{-3}$

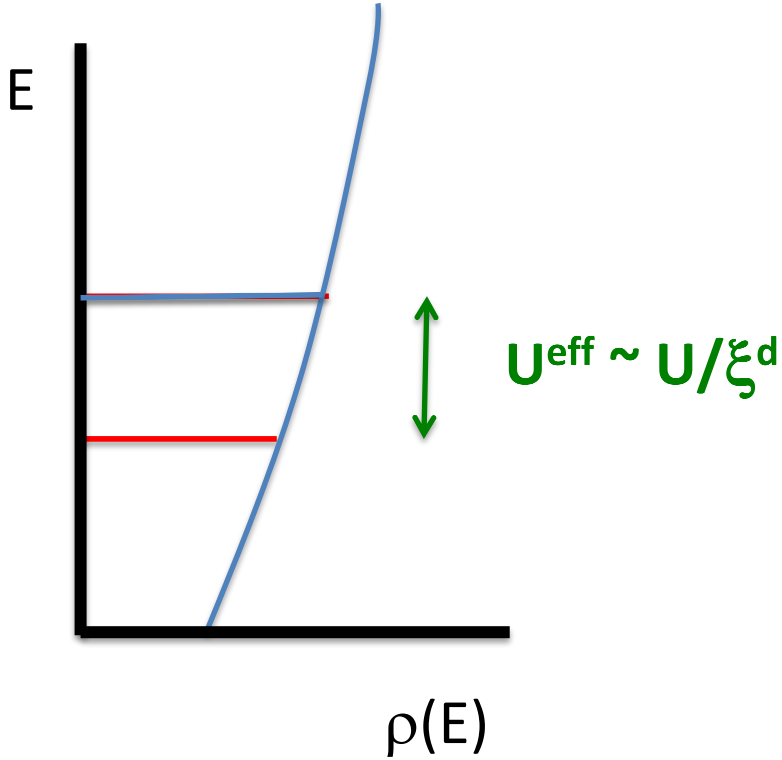
M.P. Sarachik *et al*
Phys. Rev. B **34**, 387 (1986).

(positive sign corresponds to paramagentism)

(An Anderson insulator would exhibit Pauli paramagnetism)

Why there is (probably) no such thing as an interacting Anderson insulator

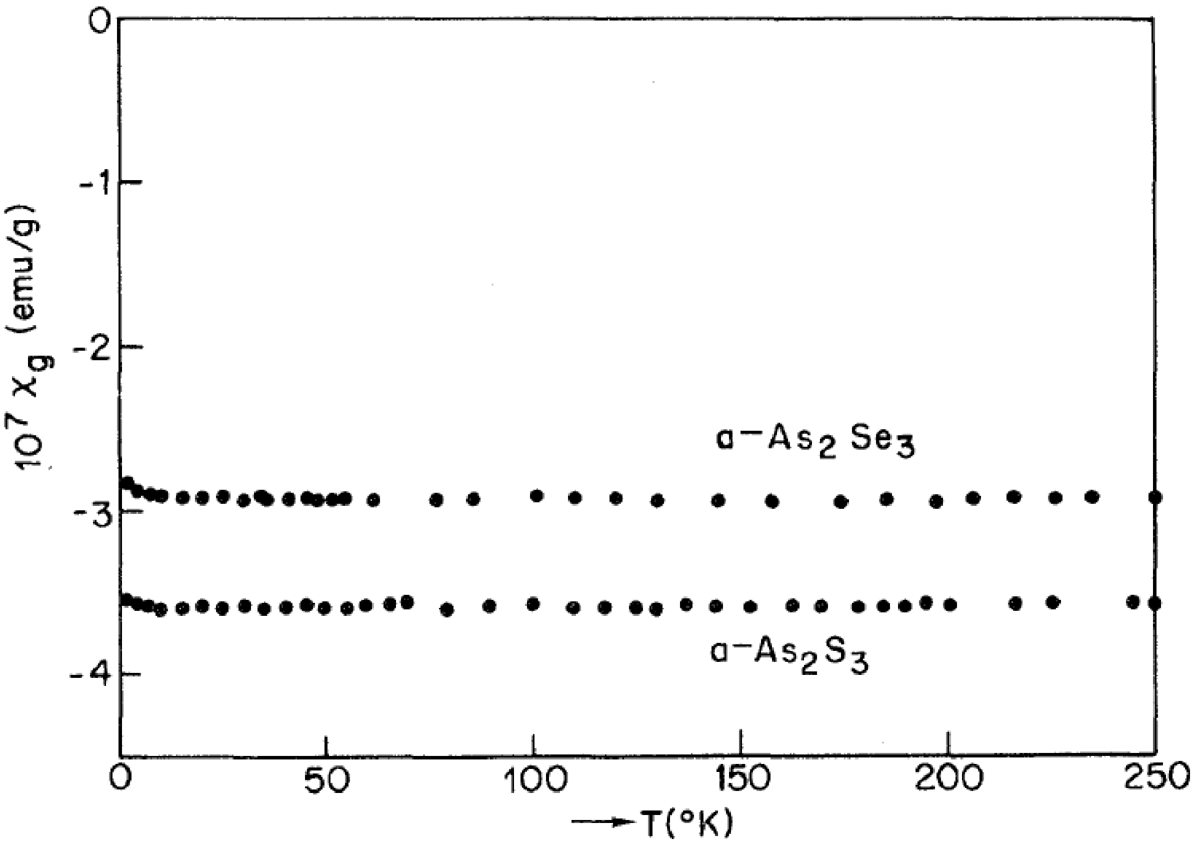
Effect of weak attractive interactions:



$\Delta_{spin} \sim \rho(E_F)\, U^{eff}$

"Anderson negative U centers"
spin-gap, but no charge gap

Magnetic susceptibility of amorphous chalcogenide glasses



Strongly insulating (conductivity is "activated")

Large optical gap

Diamagnetic

Pinning of Fermi energy indicates large density of states at Fermi energy (compressible)

Bosonic insulator – pairing without SC

Conjecture: For electrons with spin, effects of interactions in an Anderson insulator are never perturbative

Spin-orbit coupling probably does not affect this conclusion so long as Kramers degeneracy maintained

However, the presence of a Zeeman field may be a game changer.

Equilibration in a disordered insulator

Phonons and variable range hopping.

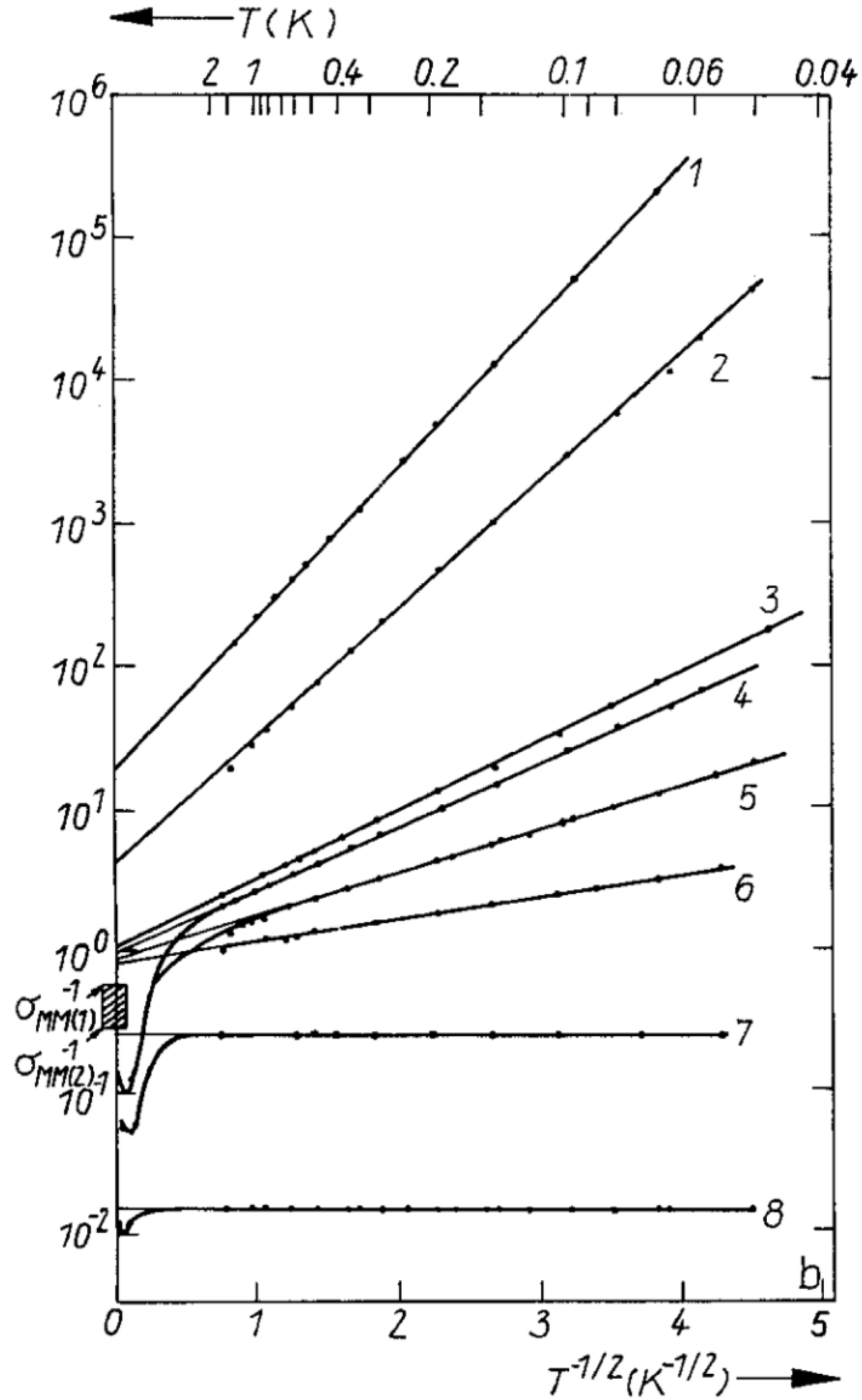
Variable-range-hopping (VRH) in neutron-transmuted doped GaAs

Rentzsch *et al*, Physica Status Solidi B **137**, 691 (1986).

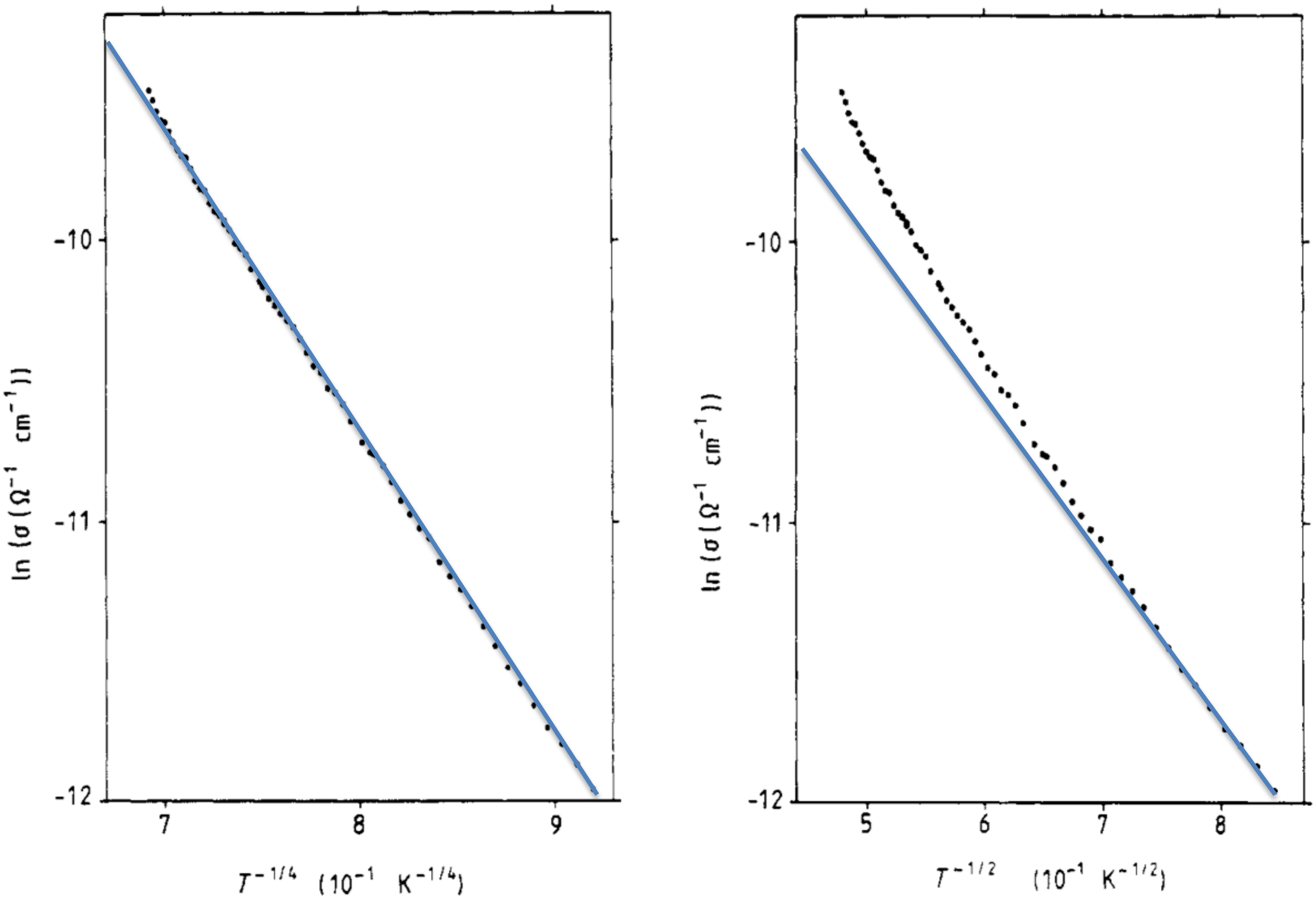
(y axis in Ohm-cm)

$$\rho(T) = \rho_0 \exp[(T_0/T)^\alpha]$$

$\alpha = 1$ "activated"
$\alpha = 1/(d+1)$ Mott VRH
$\alpha = 1/2$ Efros – Shklovski VRH

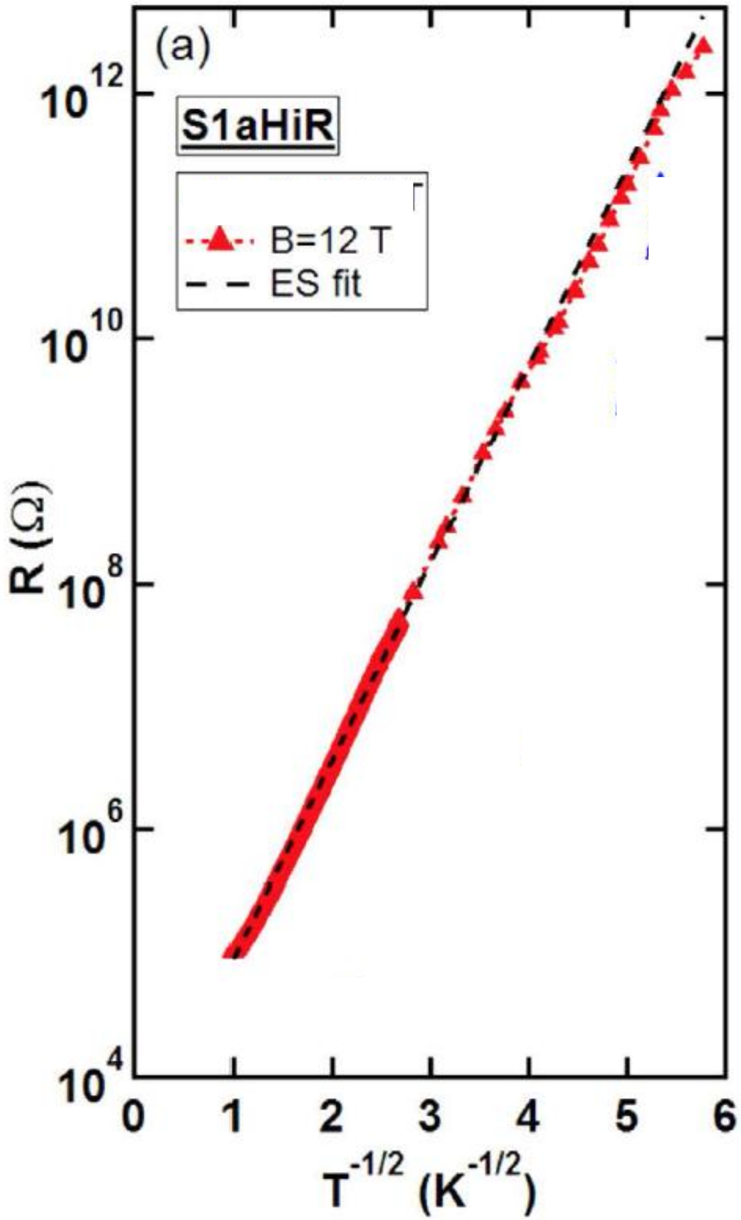


Compensated n-InP – M. Benzaguen *et al*, Journal of Phys. C: Solid State Phys. **18**, L1008 (1985)



InO Film for B > B_{SIT} ~ 0.5 T

M. Ovadia *et al*,
Scientific Reports **5**, 13503 (2015)



The “Hall insulator” in 2D, and its relation to the QHIT and the SIT

$$\sigma_{xx}(T) \to 0 \ \text{ and } \sigma_{xy} \to 0 \ \text{ as } \ T \to 0$$

$$\rho_{xx}(T) \to \infty \ \text{ and } \rho_{xy} \sim B/nec \ \text{ as } \ T \to 0$$

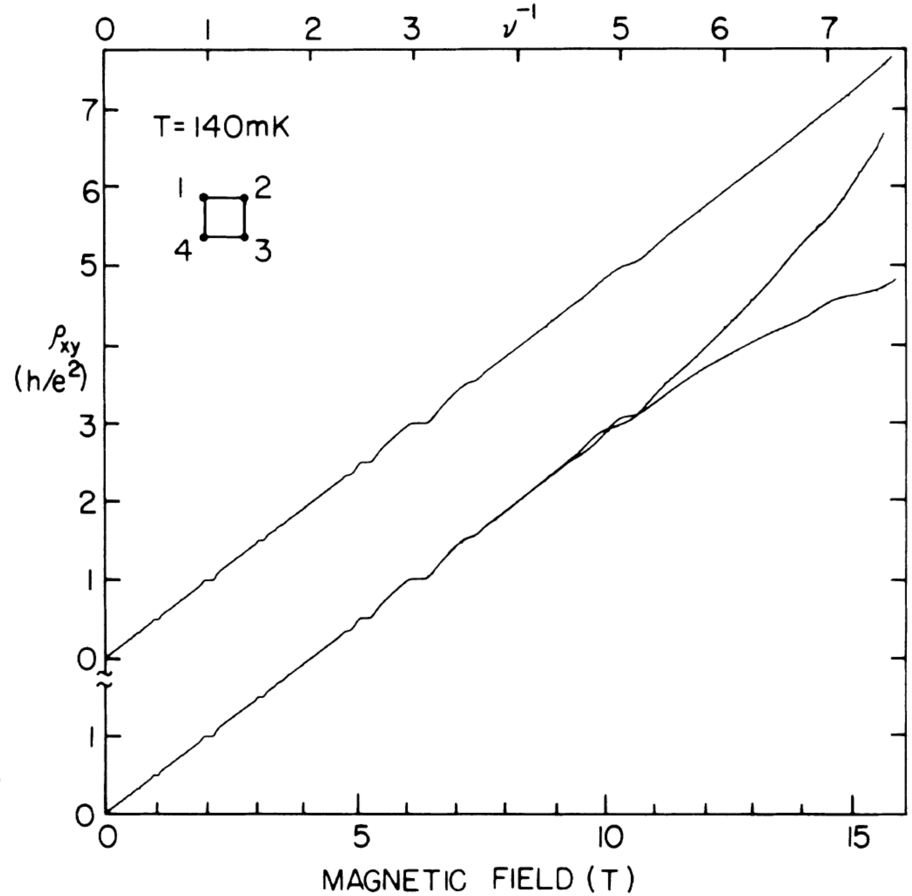
$$\rho_{xy} = \frac{-\sigma_{xy}}{[\sigma_{xx}]^2 + [\sigma_{xy}]^2} \to \text{const} \ \text{ if } \ \sigma_{xy} \sim [\sigma_{xx}]^2$$

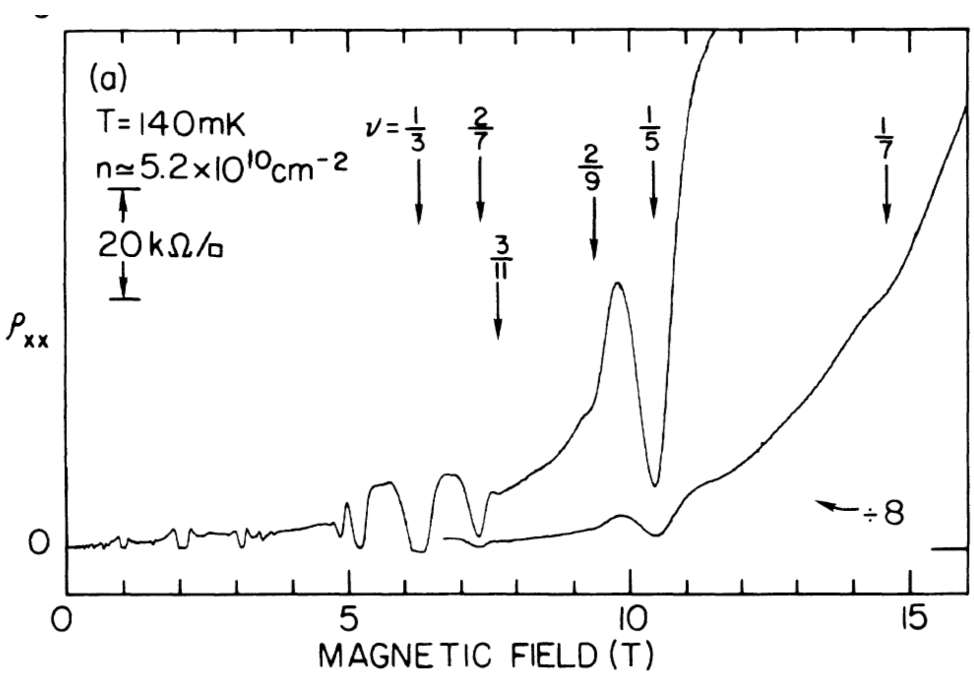
SAK, D.H. Lee, and S-C. Zhang, PRB **46**, 2223 (1992).

O.Entin-Wohman, A.G. Aronov, Y. Levinson, and Y. Imry, PRL **75**, 4094 (1995)
(Addressed in the context of VRH and the Holstein model)

High mobility GaAs/AlGaAs heterostructure

Goldman, Shayegan, Tsui
Phys. Rev. Lett. **61**,881 (1988)



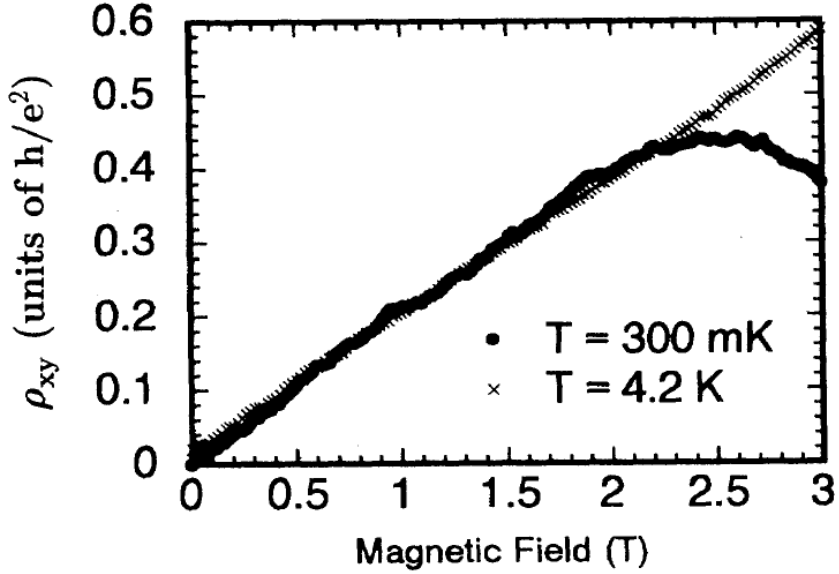


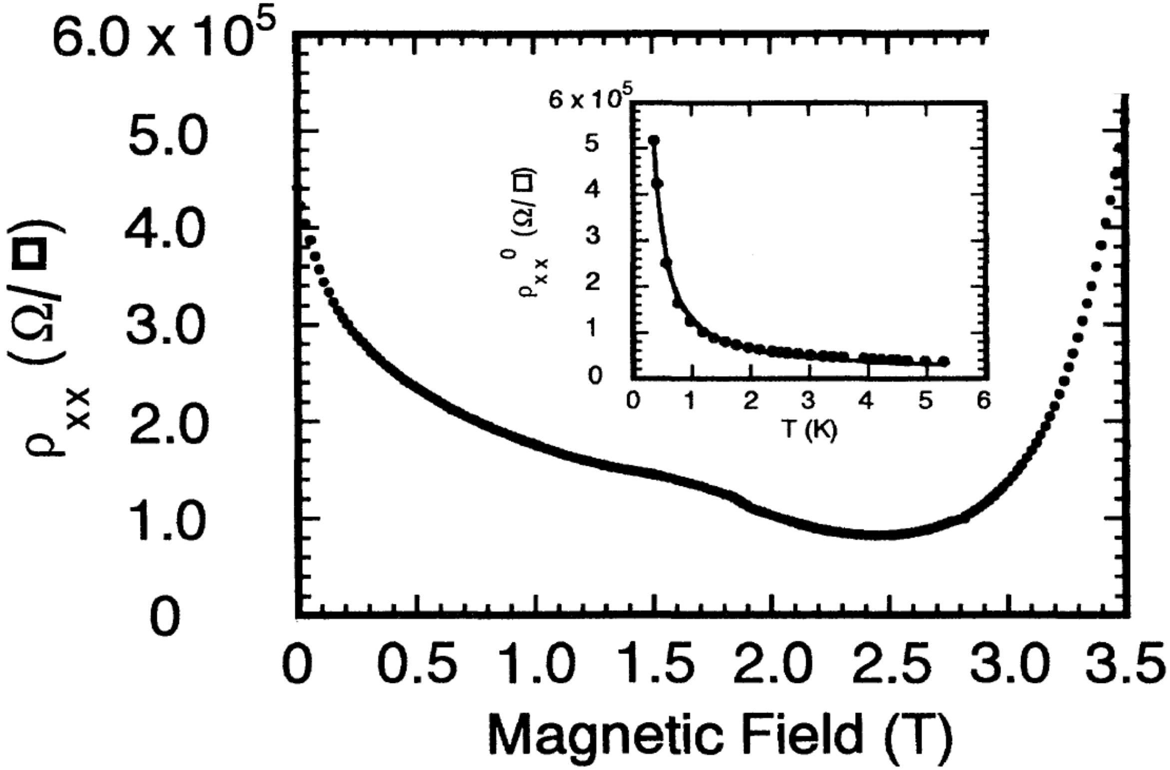
Von Klitzing constant
$R_K = h/e^2$
$= 25.12807557$ kΩ

Low Mobility GaAs/AlGaAs heterostructure

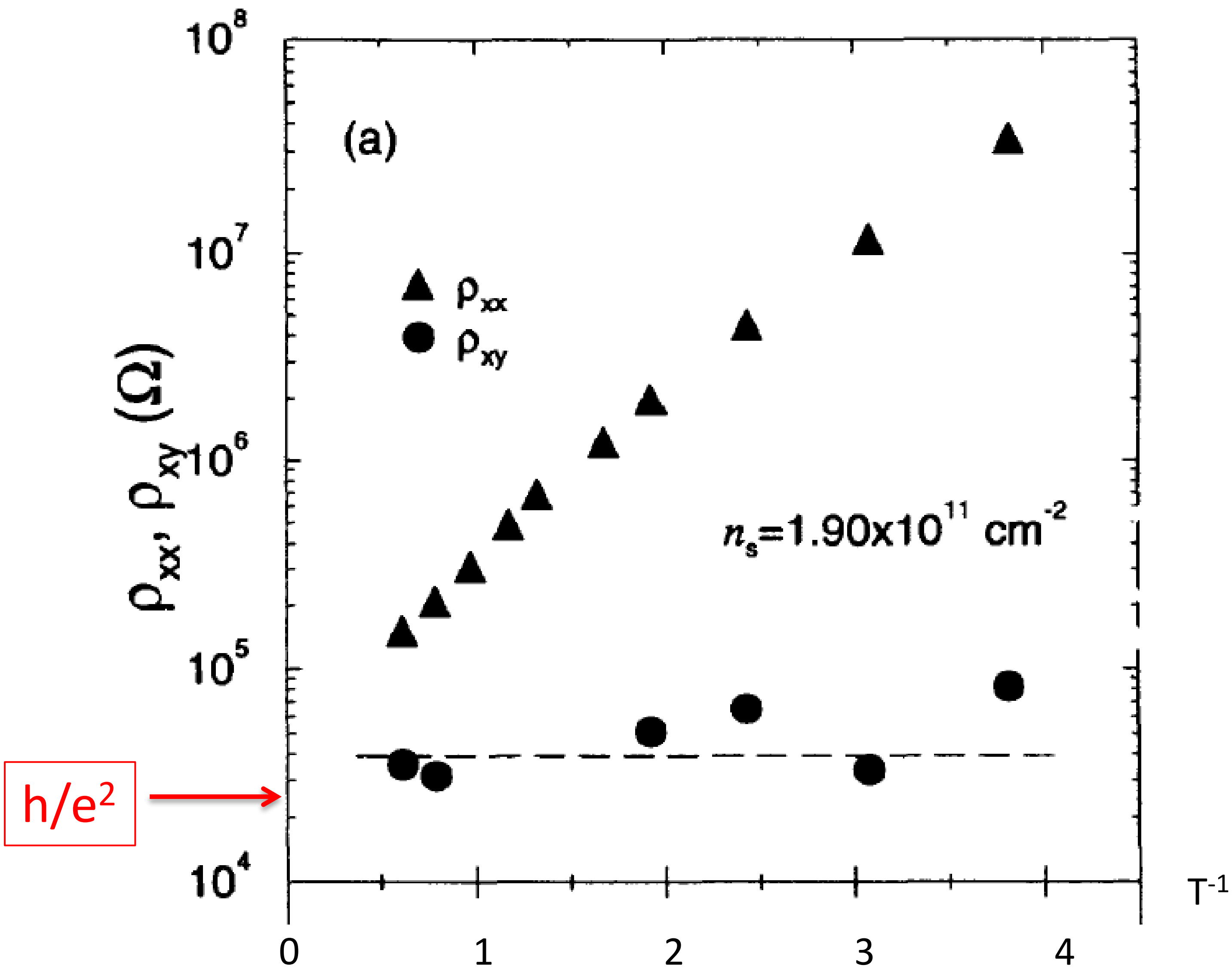
Johnson and Jiang,

Phys. Rev. B**48**, 2823 (1993)



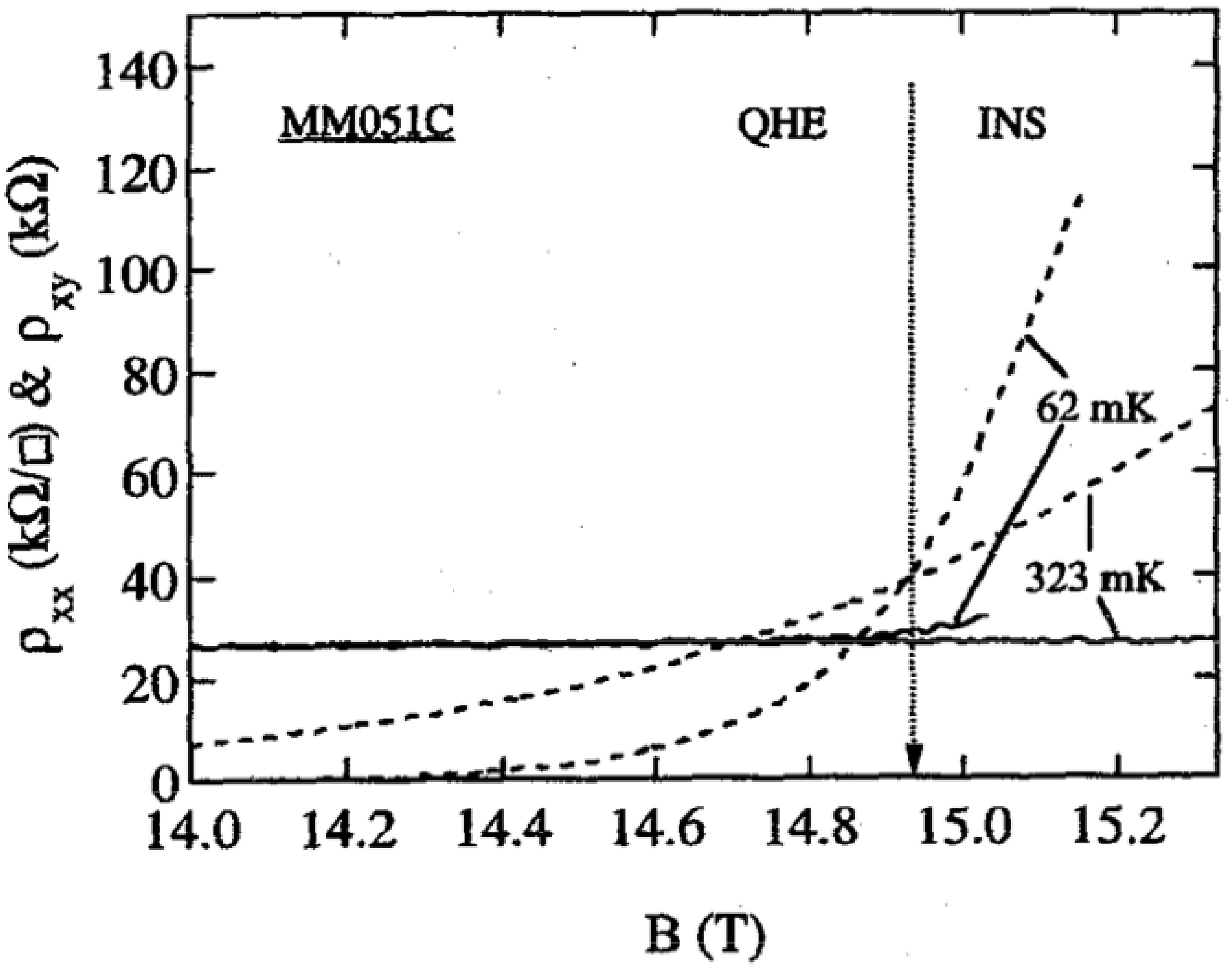


Si MOSFET with n=



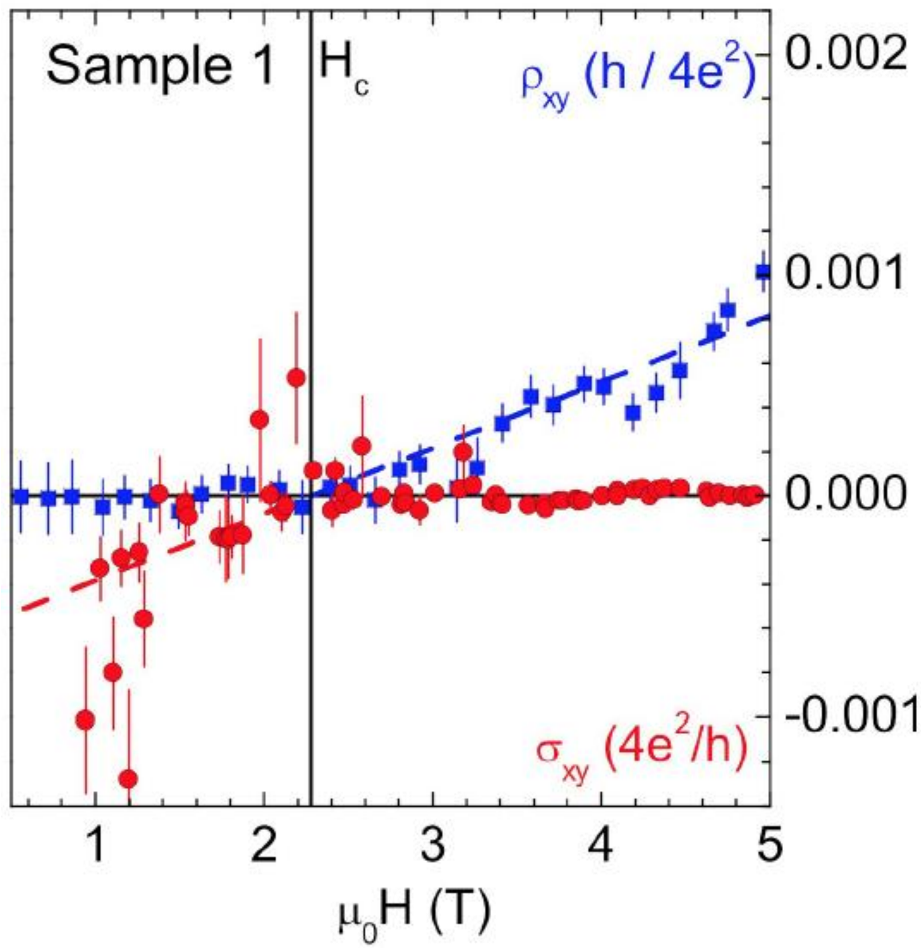
Hall insulator proximate to the QHIT

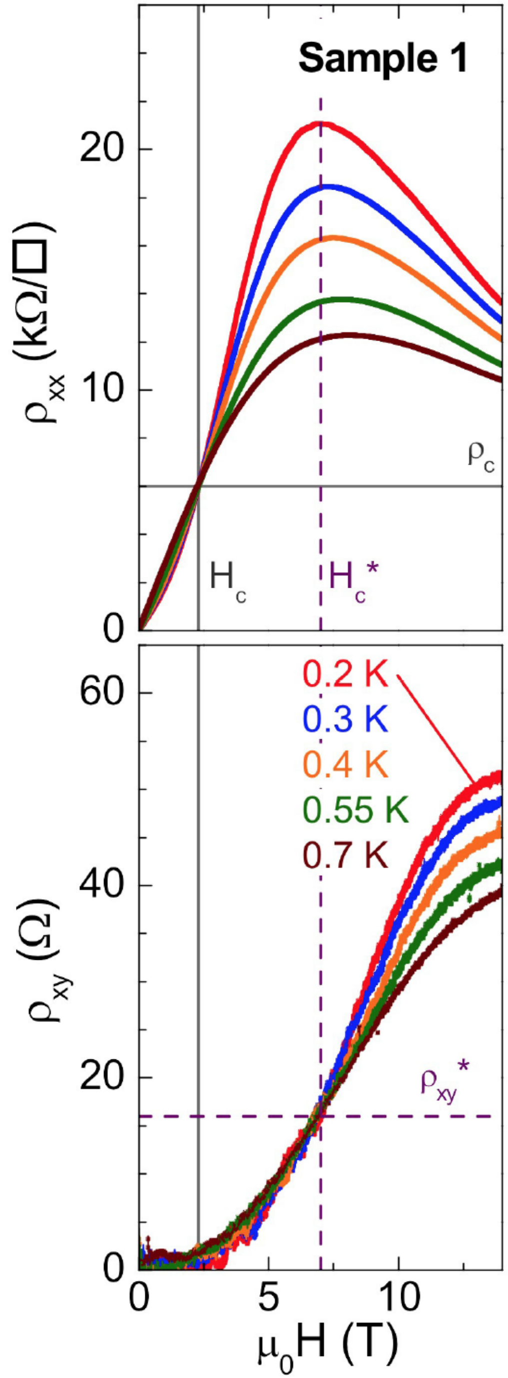
Shahar, Tsui, Shayegan, Cunningham, Shimshoni, and Sondhi, Solid State Commun. **102**, 817 (1997).



Hall Insulator close to the SIT in InO films with B_{SIT} ~ 3T

Breznay, Steiner, SAK, Kapitulnik arXiv 2015





Equilibration in a disordered insulator

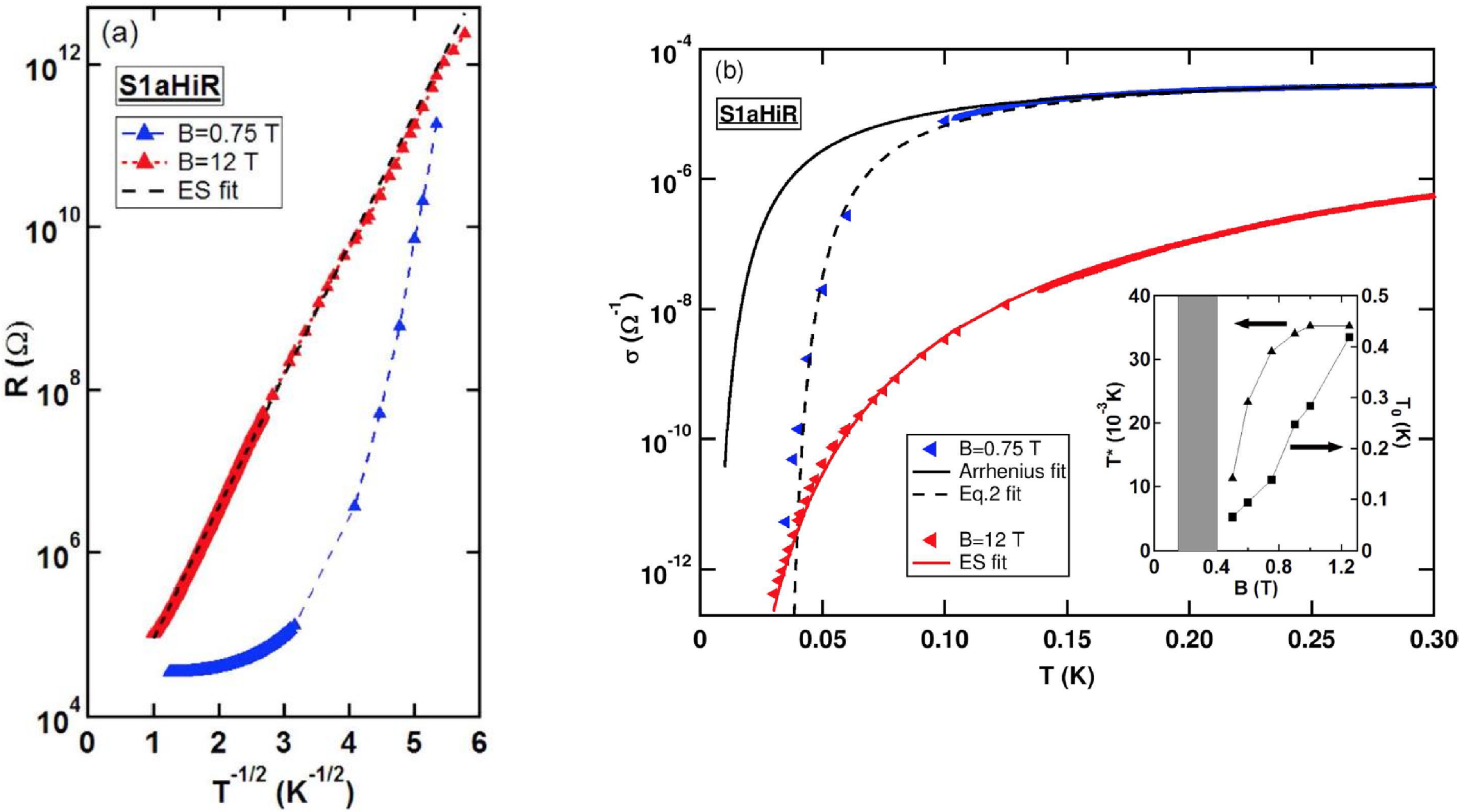
Phonons and variable range hopping.

But is there any evidence of a finite T “almost” transition
to an insulating state?

And if so, how
(given that we do not yet know how to measure the growth of entanglement)
can one distinguish many-body localized states
from “classical” glassy states?

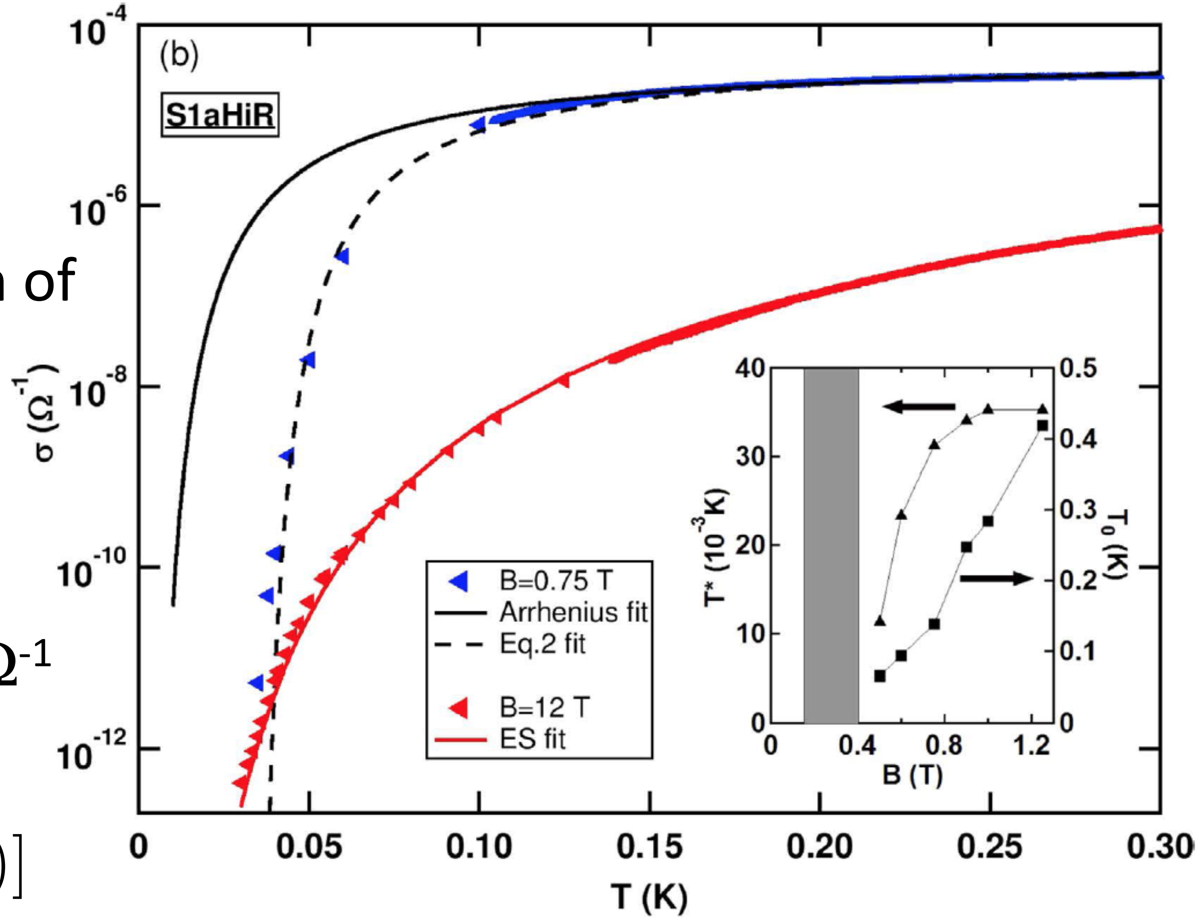
InO Film for B > B_{SIT} ~ 0.5 T

M. Ovadia *et al*, Scientific Reports **5**, 13503 (2015)



InO Film for B > B_{SIT} ~ 0.5 T

M. Ovadia *et al*, Scientific Reports **5**, 13503 (2015)



Superconducting quantum of conductance:

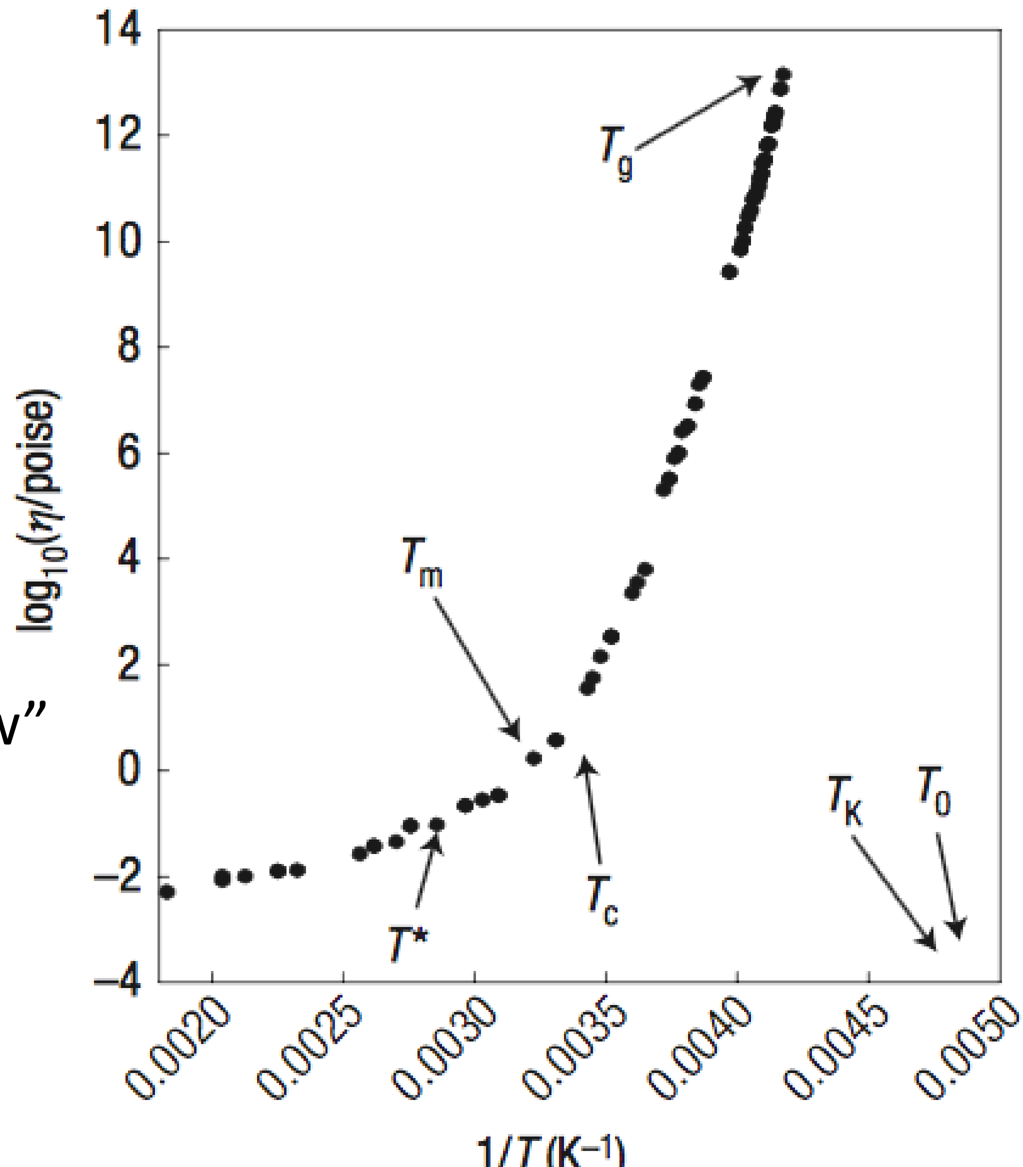
$\sigma_Q = (2e)^2/h$
$= 1.59184494207 \; 10^{-4} \; \Omega^{-1}$

$$\rho = \rho_0 \exp[T_0/(T - T^*)]$$

$$T_0 = 0.138K, \quad T^* = 0.031K, \quad T_{min} = 0.042K = [1.35]T^*$$

The Glass Transition in Supercooled Liquids

"In Search of a Theory of
Supercooled Liquids"
SAK and G. Tarjus
Nature Materials **7**, 831 (2008).



$$\eta(T) \sim \exp\left[DT_0/(T - T_0)\right]$$

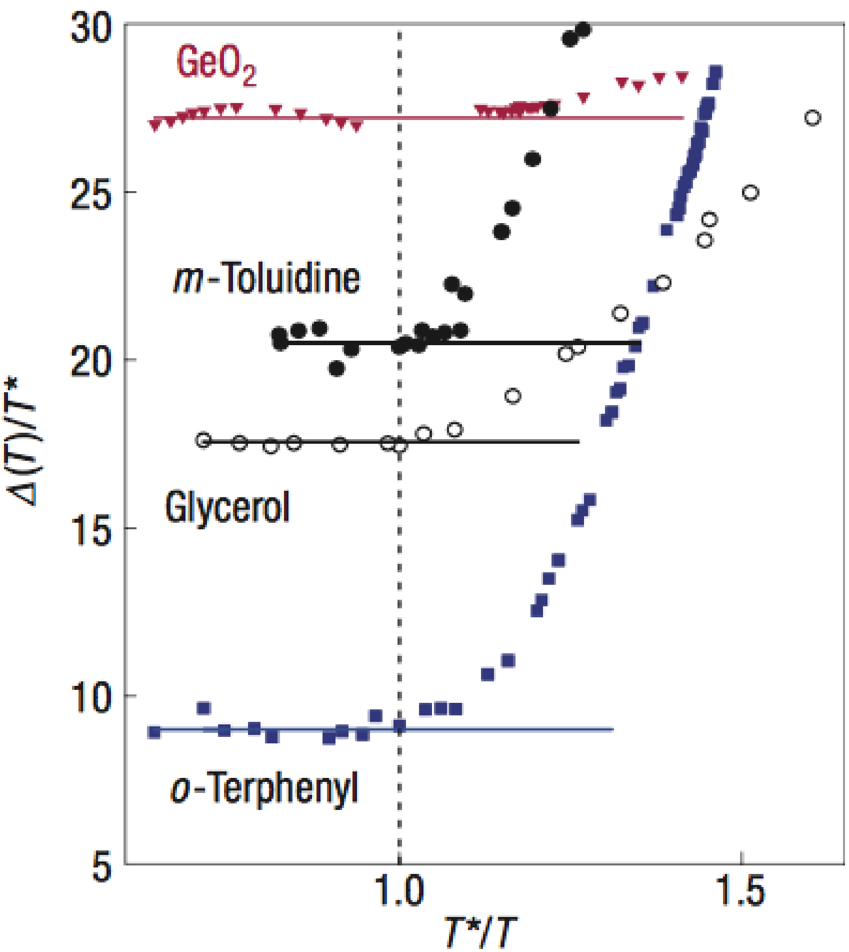
"Volger-Fulcher-Tammann Law"

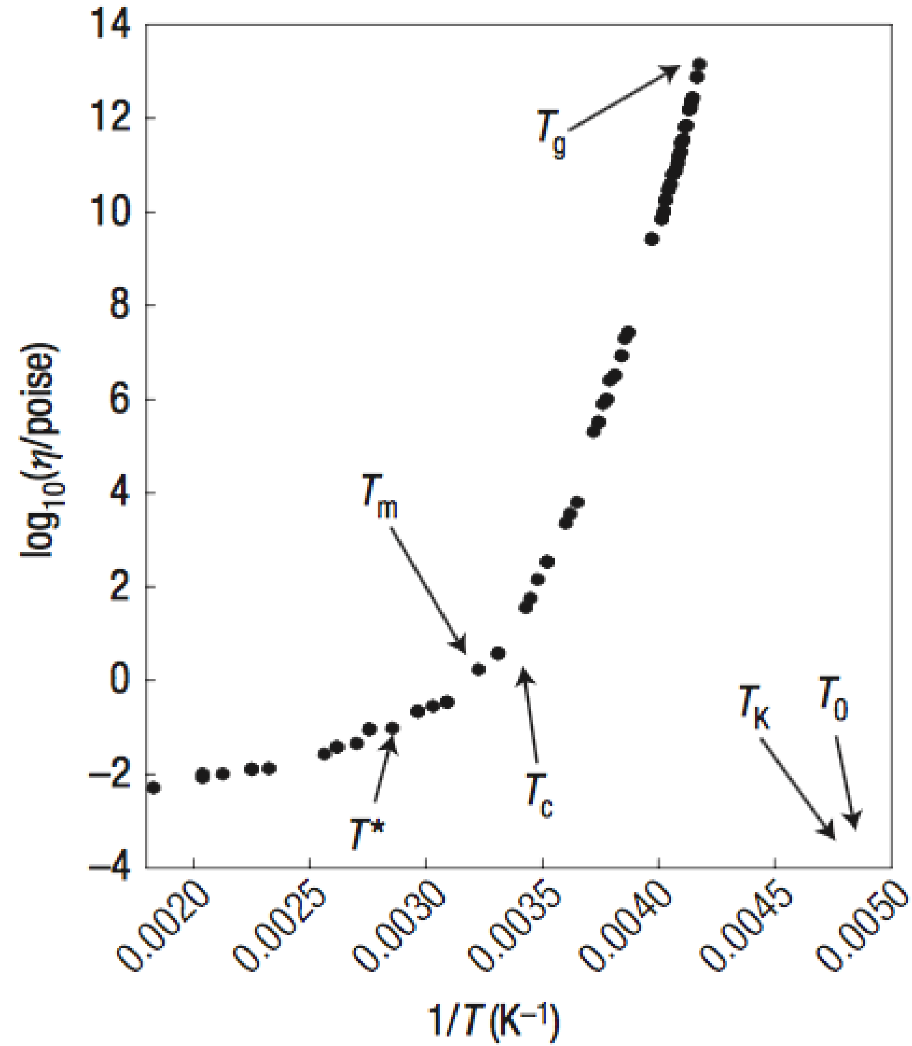
At T_g, typically $T > 1.2T_0$

$$\eta(T) = \eta_\infty \exp[\Delta(T)/T]$$

$$\Delta(T) \approx E_\infty + \Theta(T^* - T) E_1 (1 - T/T^*)^x$$

$$\text{with} \quad x \approx 8/3$$





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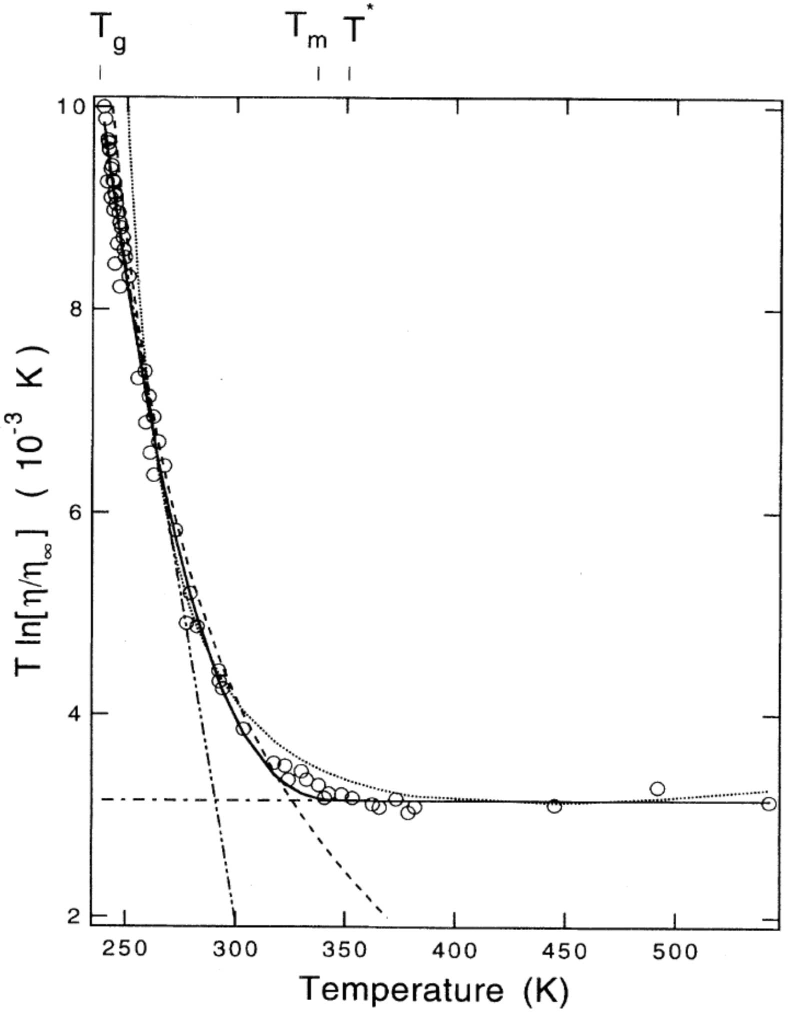
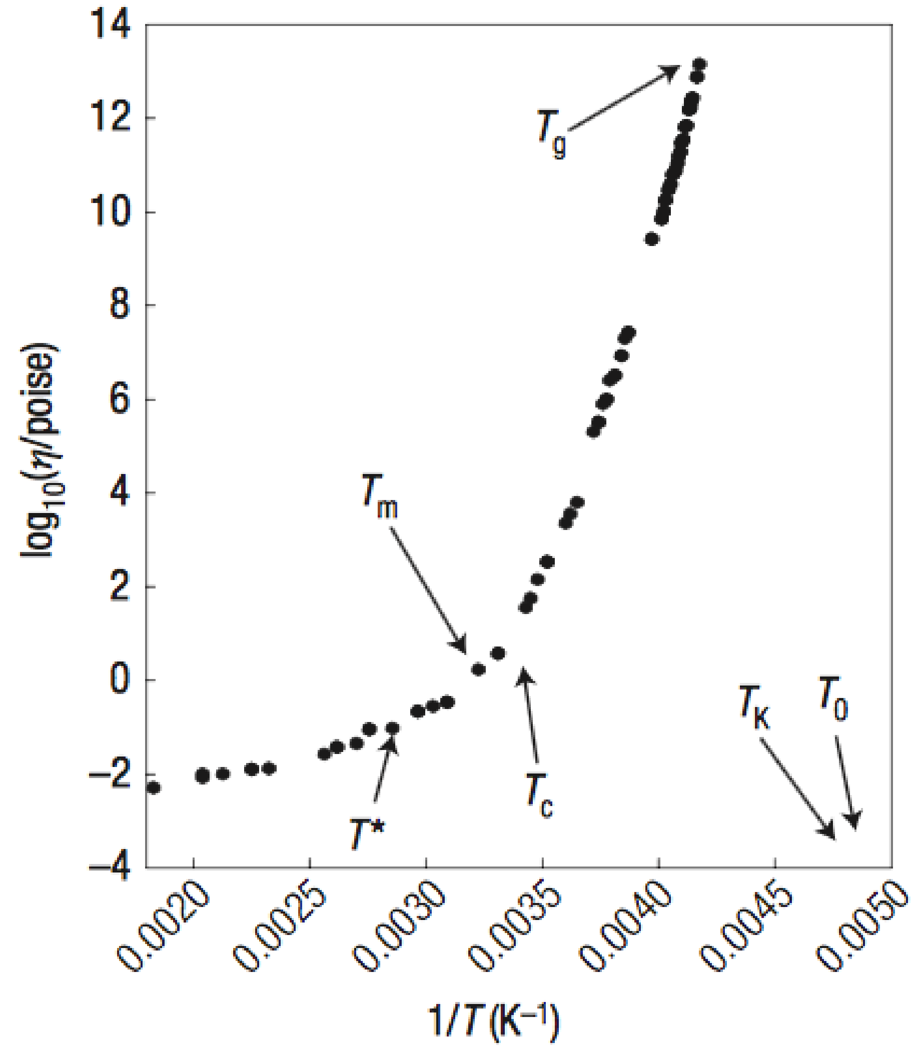
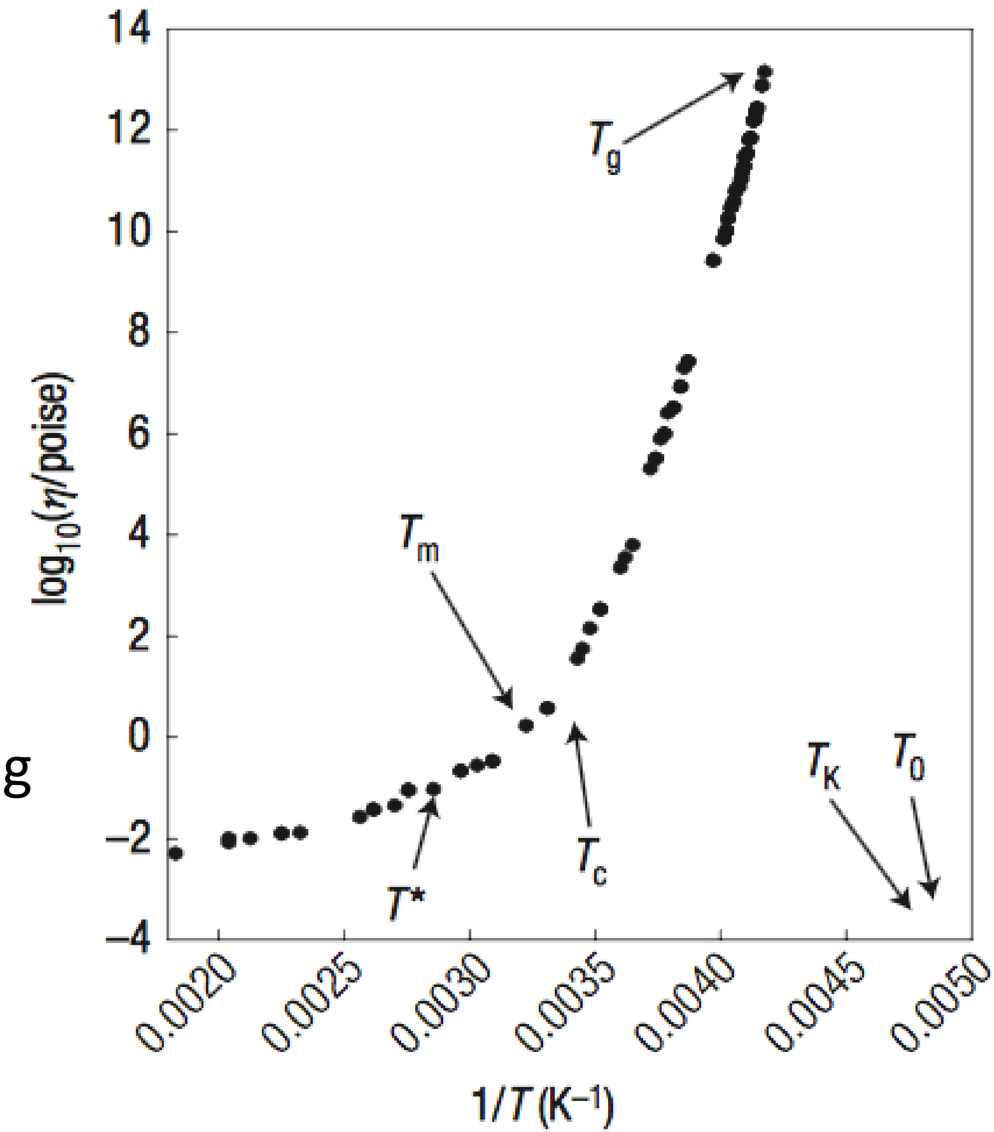




$$\eta(T) \sim \exp\left[DT_0/(T-T_0)\right]$$

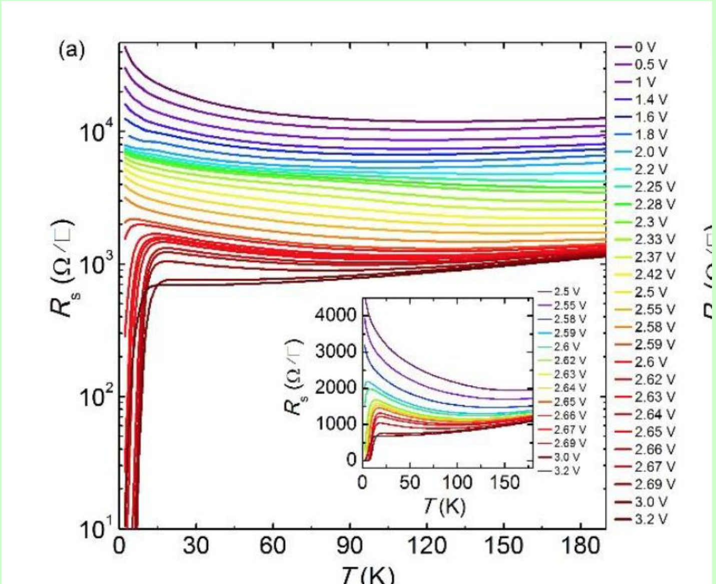
This is a purely classical phenomenon



There may or may not be an "ideal glass" transition at $T=T_0$

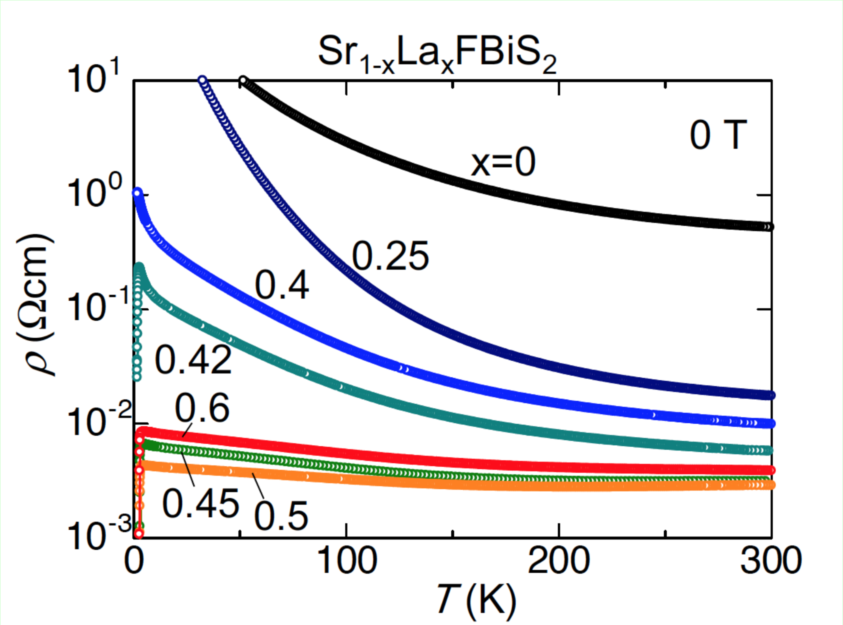
No doubt something resembling a classical glass transition in an electronic system would be exceedingly interesting itself.

In any case, this raises the issue of how to distinguish an "apparent" classical glass transition from an "almost" MBL

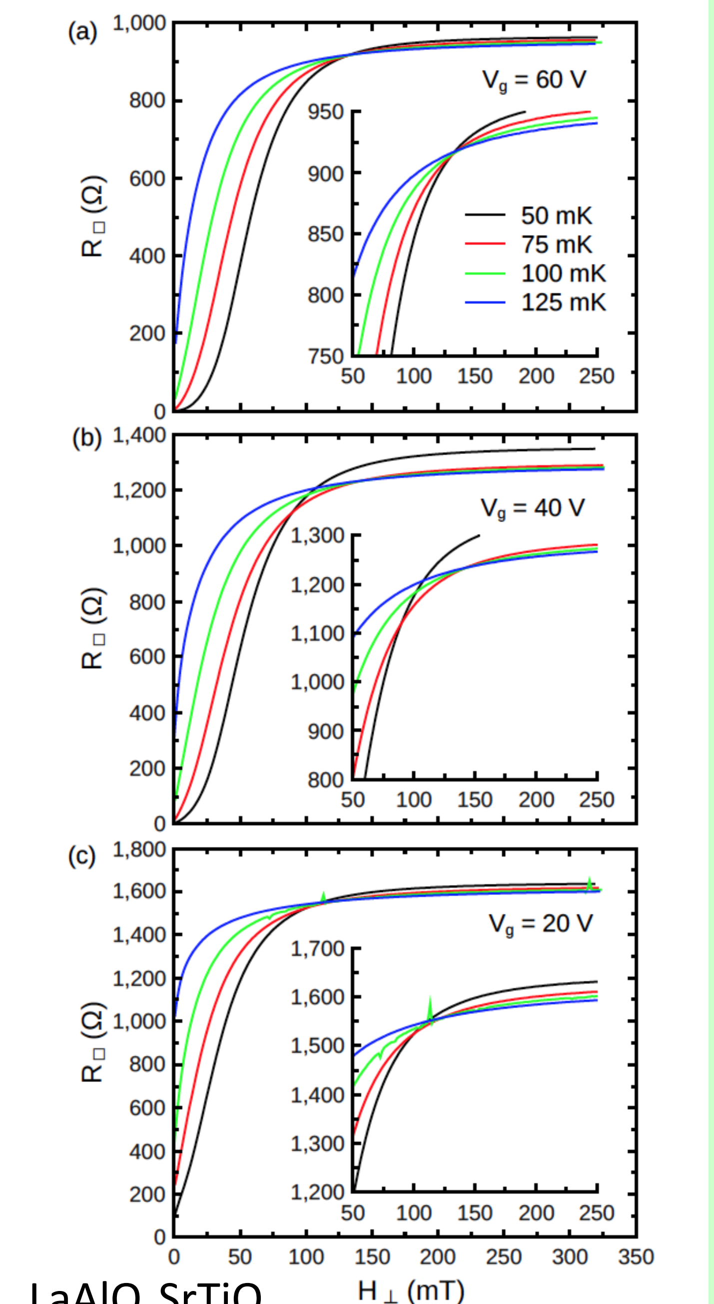


Gated electron-doped cuprate
arXiv:1507.01668

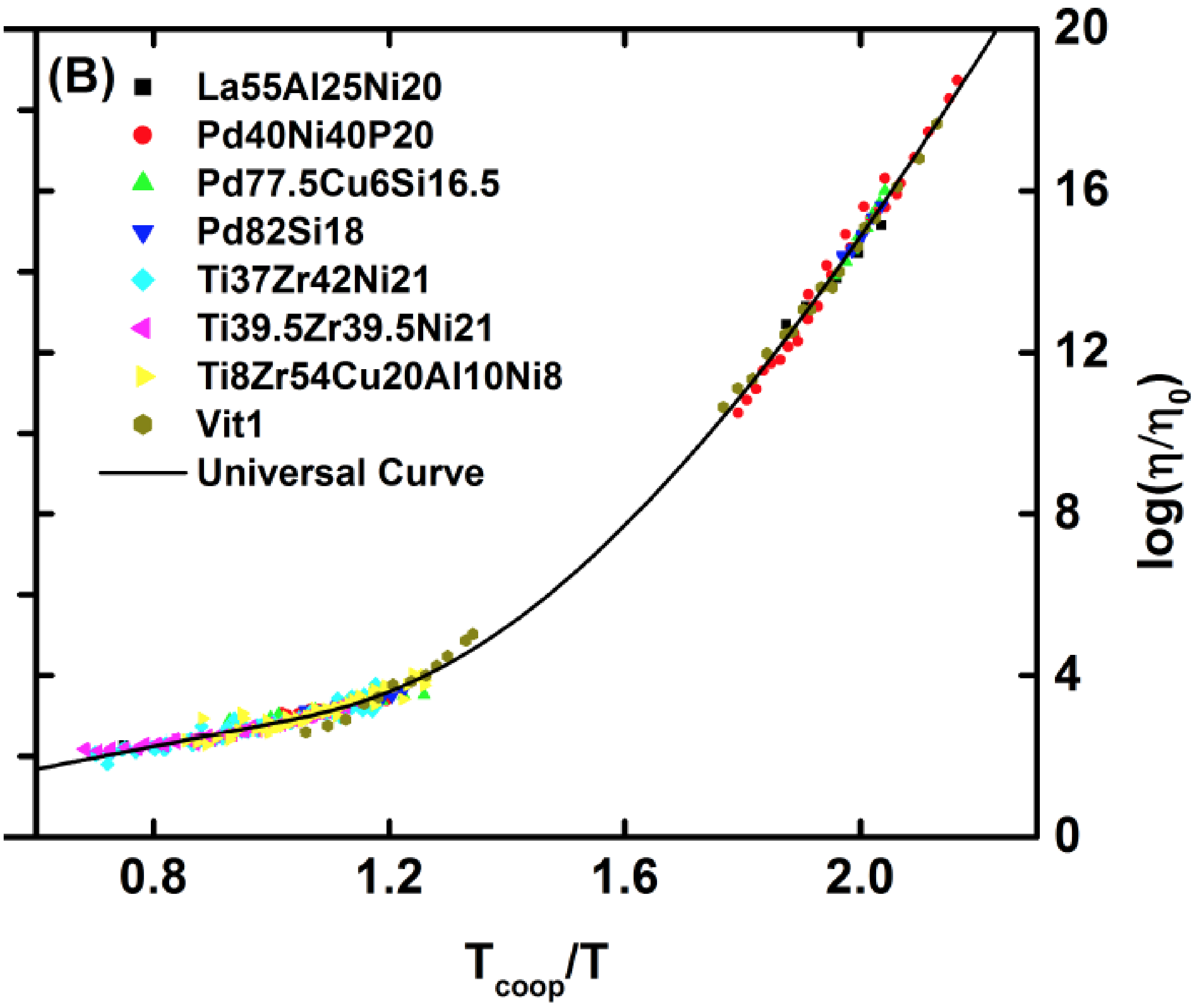
Thanks



arXiv:1311.5117



$LaAlO_3SrTiO_3$
arXiv1309.3612



M. Blodgett, T. Egami, Z. Nussinov, K. F. Kelton, ArXiv:1407.7558