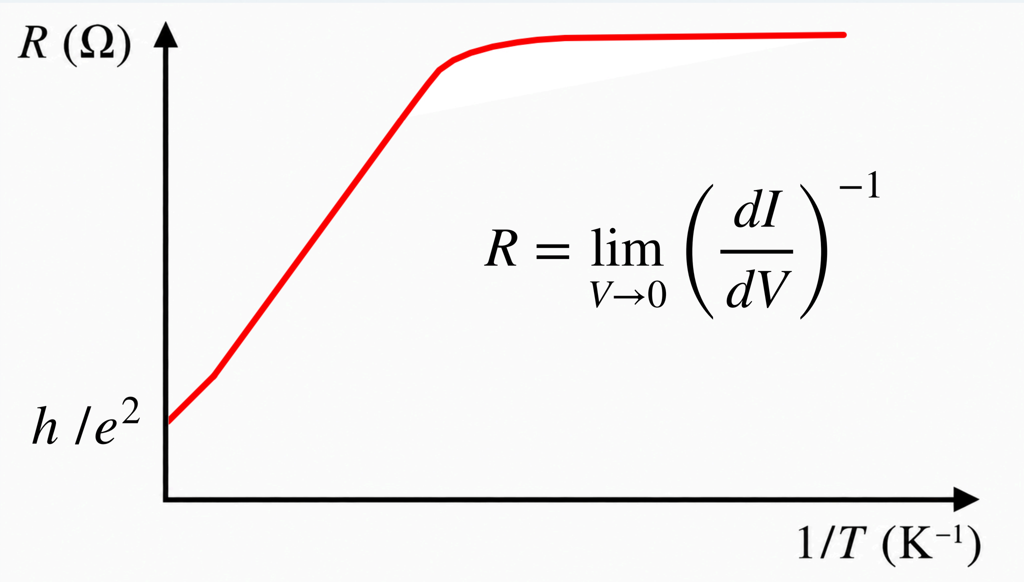
What Can Disordered Semiconductors Teach Us About The 2D Superconductor-Insulator Transition?

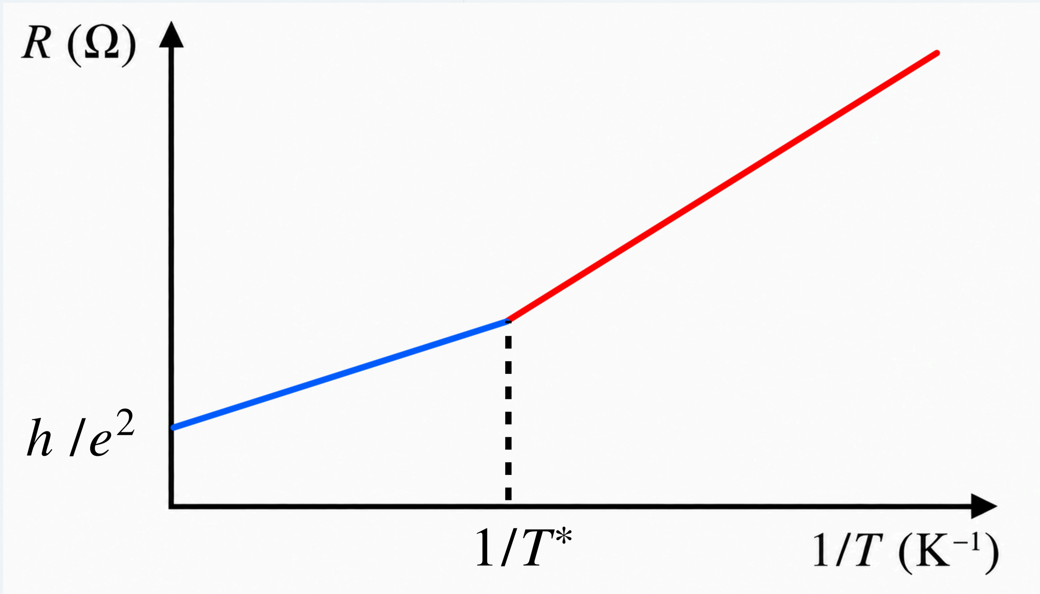
J. Gough, M. Ortuño, G. Auton, S. N. Holmes, H. Liu, M. Pepper
jonathan.gough.18@ucl.ac.uk

Transport In Thin Samples With A Large Localization Length

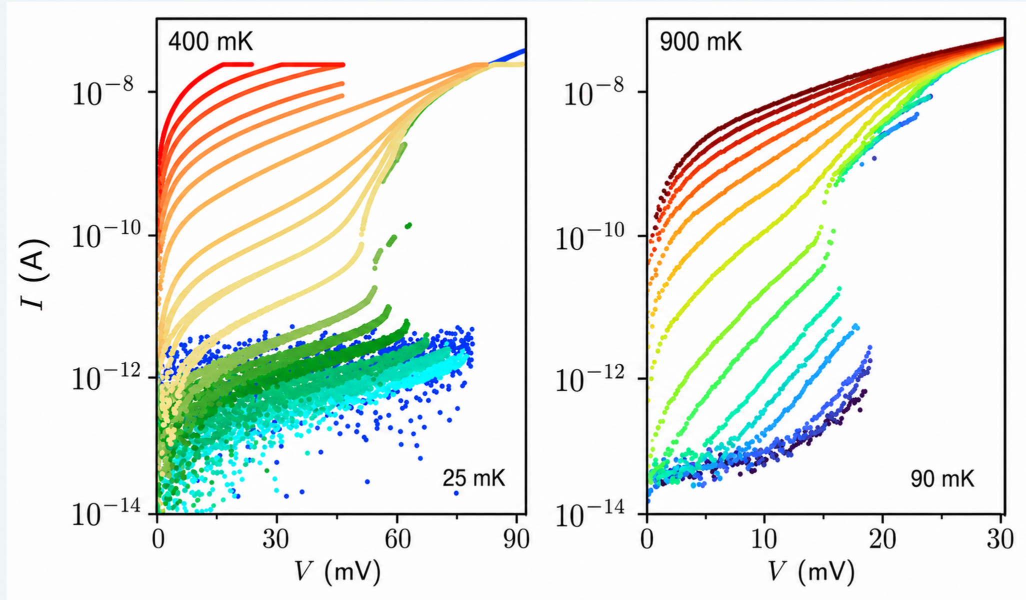
No Variable Range Hopping (Resistance Saturation)



Activation Energy Increases Below a Critical Temperature T^*



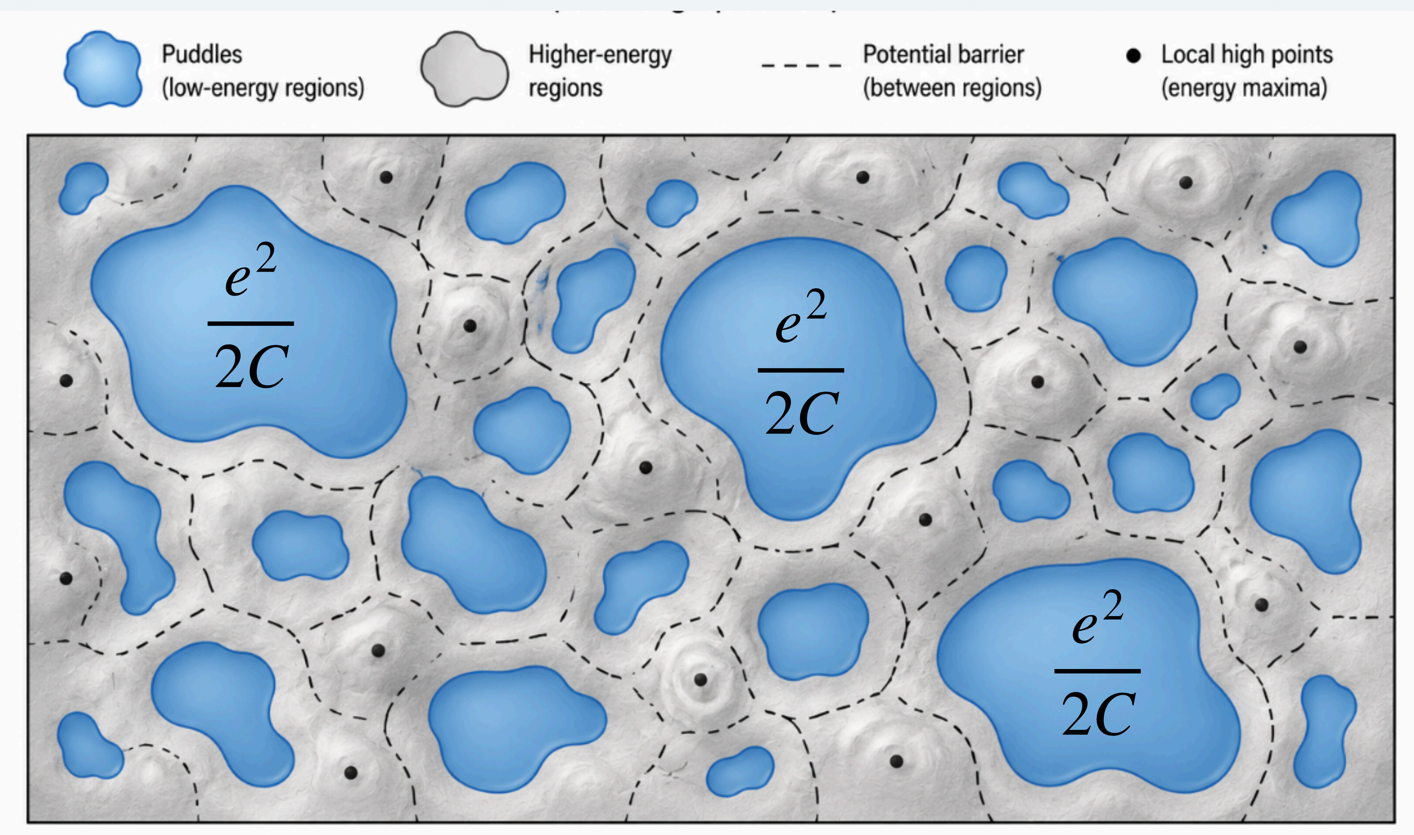
Voltage Induced Breakdown with Hysteretic Current Jumps



Shared transport signatures observed in many disordered superconductors on the insulating side of the 2DSIT [1] [2] [3]

Explanation

Continuous films but effective granularity due to fluctuations in disorder



Coulomb blockade dominates transport

$$E_c = \frac{e^2}{2C} \qquad \ln\left(\frac{V}{I}\right) \approx \frac{E_c}{k_b T_e}$$

- Pseudo-grains can support local superconductivity at $T_e < T^*$.
- Weak electron-phonon coupling leads to Joule heating.
- At a critical voltage a positive feedback loop leads to a bistability in $T_e(V)$.
- Saturation occurs due to a systematic background heating power P_0.

$$T_e = \left(T_\gamma^{\beta} + \frac{IV + P_0}{g_{e\gamma}}\right)^{\frac{1}{\beta}}$$

[4]

- System becomes more rigid at $T < T^*$ (Coulomb Glass-like or Wigner-like). [5]
- At a critical voltage, electrons move collectively to establish a gapless conduction channel. [6]
- Saturation occurs due to quantum tunnelling.

$$I \propto \left(V - V^*(T_e)\right)^{\zeta}$$

$$\frac{V^*(T_e)}{V^*(0)} \approx 1 - 2b\frac{T_e}{T_0}$$

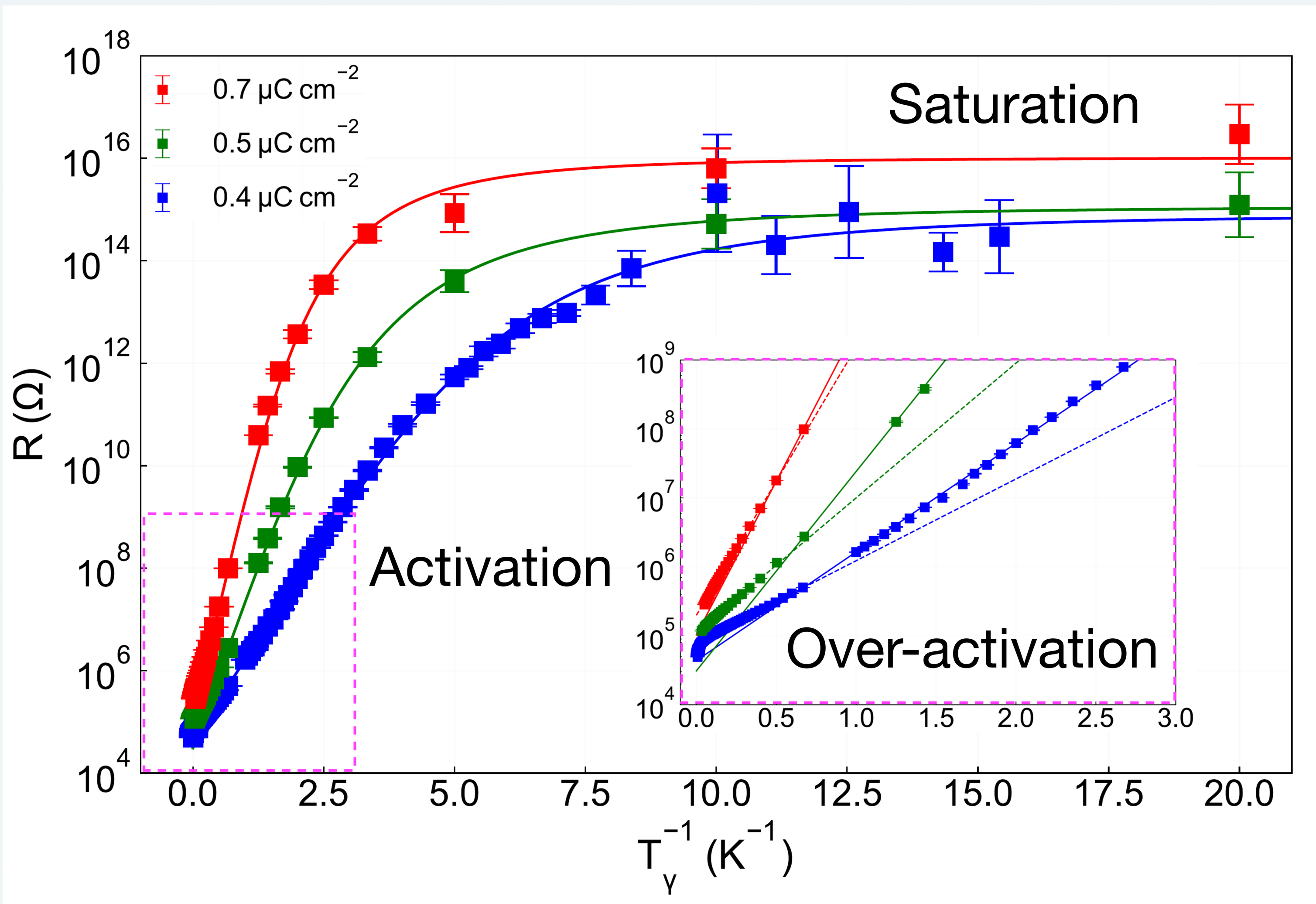
[1] To et al. Phys. Rev. Res. 8, 023360 (2026).
[2] Humbert, V. et al. Nat. Commun. 12, 6733 (2021).
[3] Ovadia, M. et al. D. Phys. Rev. Lett. 102, 176802 (2009).
[4] Altshuler, B. L. et al. Phys. Rev. Lett. 102, 176803 (2009).
[5] Munyan, S. et al. Phys. Rev. X 14, 041037 (2024).
[6] Middleton, et al, N. S. Phys. Rev. Lett. 71, 3198 (1993).
[7] Holmes, S. N. et al. J. Phys. D: Appl. Phys. 55, 46LT01 (2022).

Disordered InSb

100 nm InSb thin films grown by MBE.

Disorder introduced by controlled exposure to a Ne FIB. [7]

Samples measured by two terminal DC with high output impedance voltage source and Electrometer at lattice temperatures between 300 K and 25 mK.

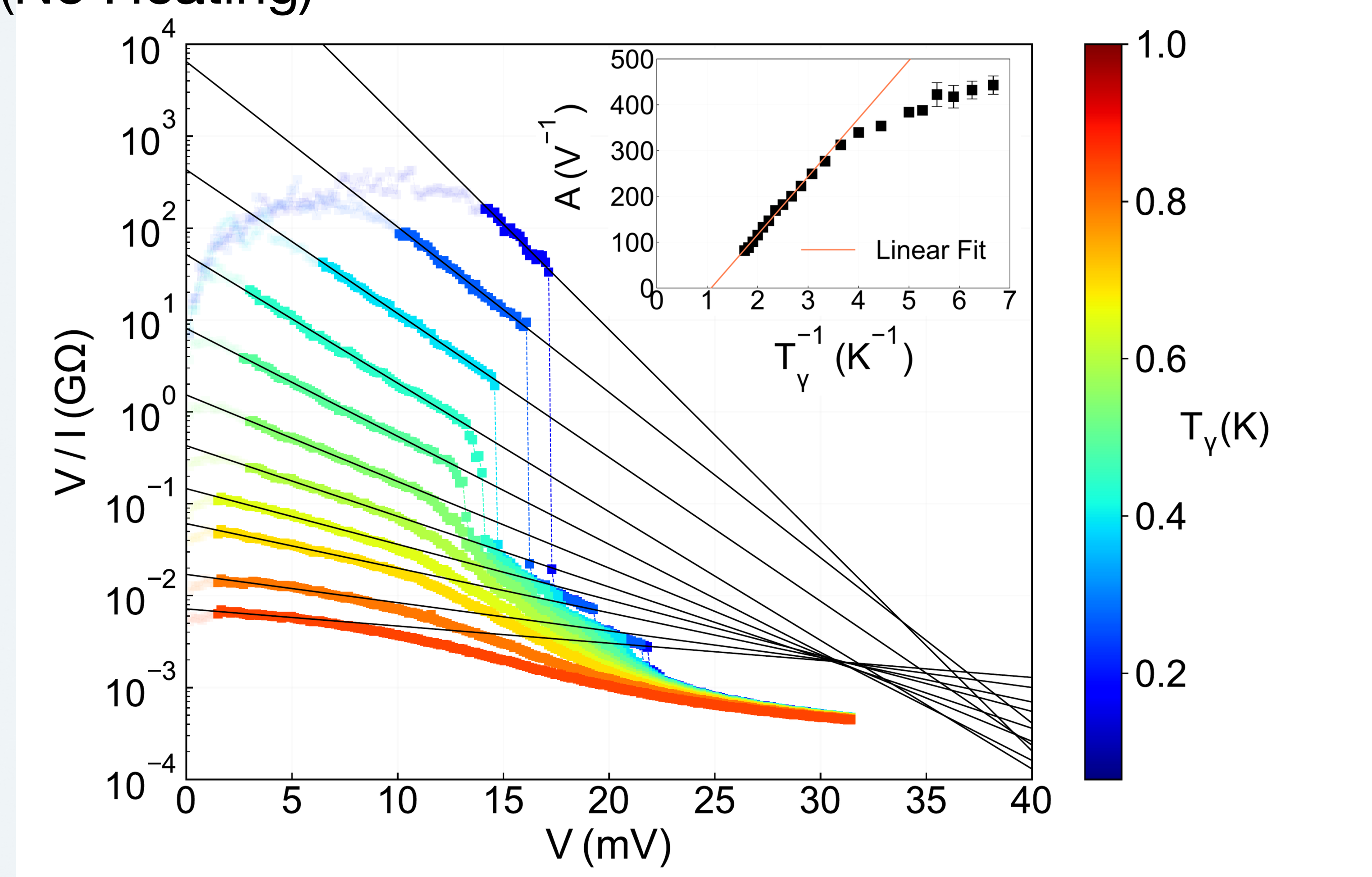


Takeaway 1:

Increasing activation energy below $T < T^*$ can occur without residual superconductivity.

Linear Field Enhanced Hopping (No Heating)

$$\ln\left(\frac{V}{I}\right) \approx \frac{T_0 - \alpha V}{T_e}$$



Voltage Induced Breakdown

Takeaway 2:

Heating does not occur at $V < V^*$ as $\ln(V/I)$ does not bend with applied V.

Takeaway 3:

The average hopping length can be extracted using the linear field enhanced hopping model. Its magnitude is consistent with hopping between pseudo-grains

UCL
UNIVERSIDAD DE MURCIA
LCN LONDON CENTRE FOR NANOTECHNOLOGY
UKRI Engineering and Physical Sciences Research Council