Team 5 Journal Club Presentation: "Electron-Phonon Decoupling in Disordered Insulators"

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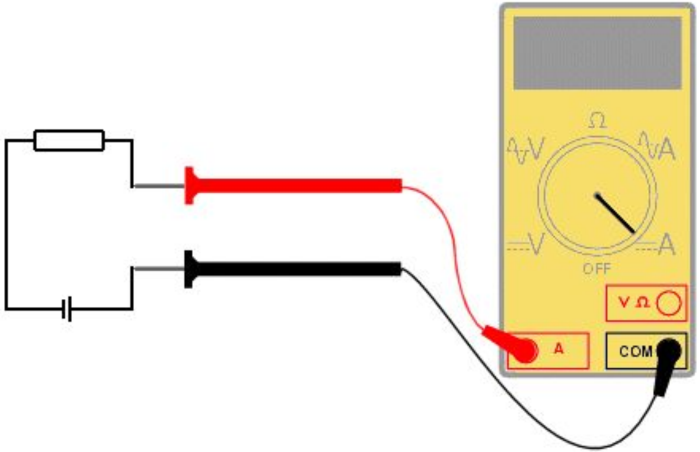


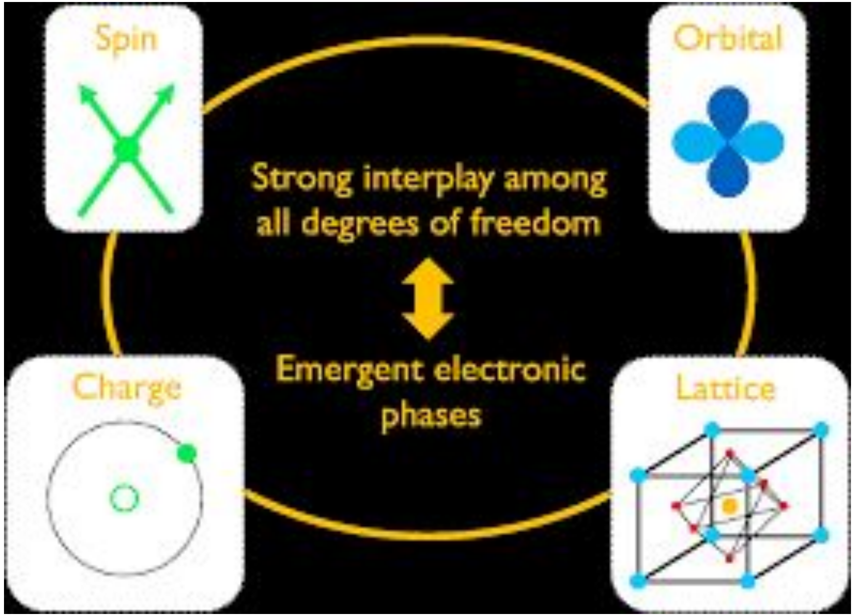
M. Ovadia, B. Sacépé, and D. Shahar, Phys. Rev. Lett., **102**, 176802 (2009)

Main Idea: Electron Overheating

- Material of interest: disordered superconductors into the insulating phase.
- Phenomenon: Large jumps in current as a function of voltage.
- They conclude that it shows the electrons are decoupled from the phonon bath, in the insulating state.
- Theory: the proposed explanation is that the large jumps are due to a overheating of electrons resulting from bistability.
  - There is a companion theory paper (by different authors, but it seems that the two groups were working in collaboration)
  - *Jumps in Current-Voltage Characteristics in Disordered Films* by Altshuler, Kravtsov, Lerner, and Aleiner, PRL 2009.

The Superconductor-Insulator Transition

- Name of the game: competing degrees of freedom
- Superconductor-insulator transition: superconductivity quenched with increasing B-field [1]
- Microscopic picture for this insulating phase

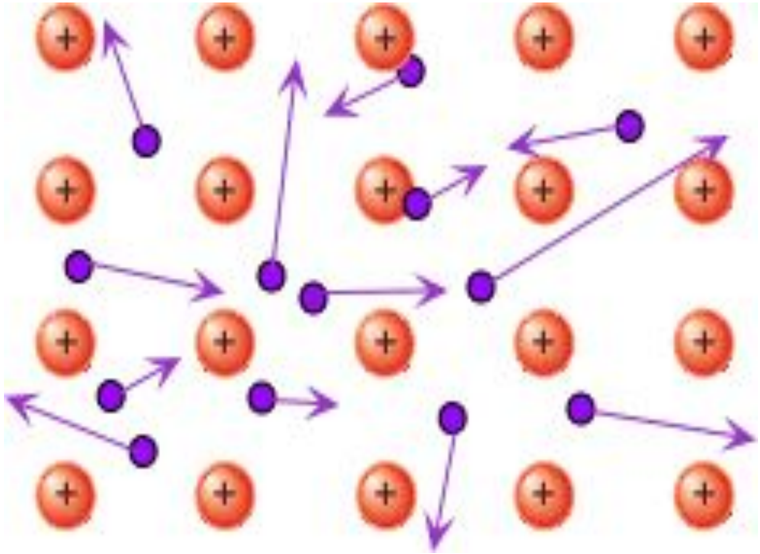


Schematic of competing degrees of freedom in condensed matter

[1] Allen M. Goldman and Nina Markovic, Phys. Today, **51**, 11 (1998).

Electron-Phonon Interactions

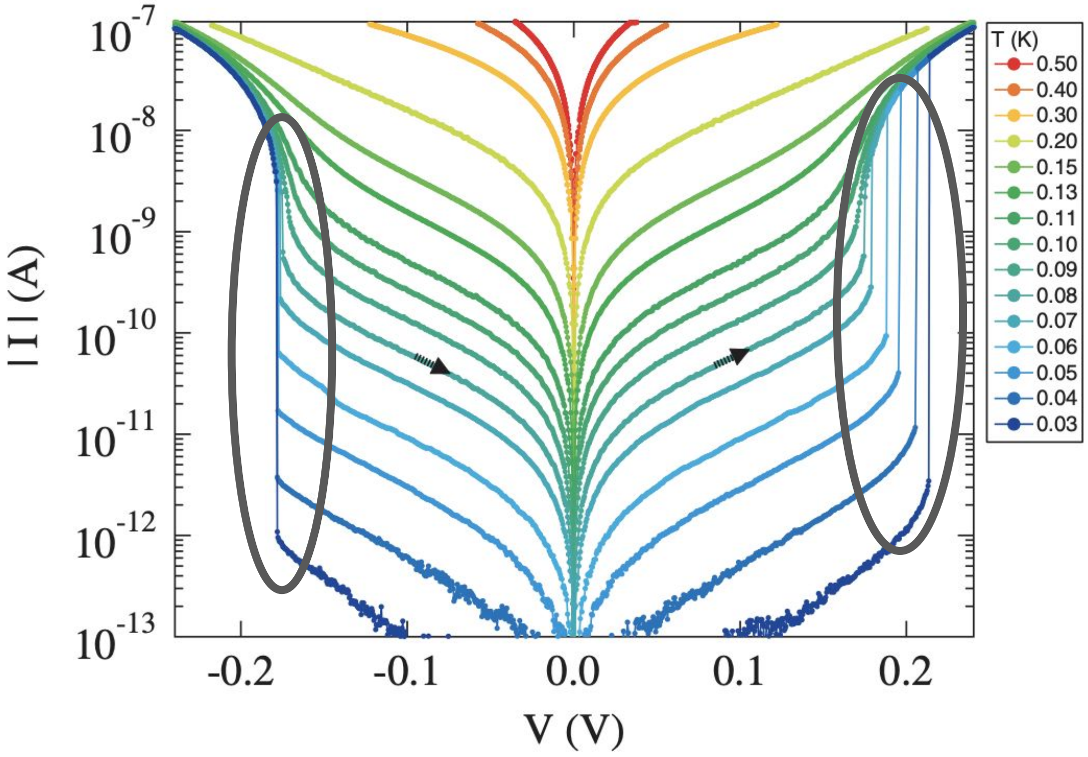
- Specifically, they look into the electrons and lattice (phonons) in disordered materials
- <u>Argument:</u> electrons vastly overheat relative to lattice in this phase
- <u>Evidence:</u> experimental current-voltage behavior for 30-nm thick InO_x films at B = 11 T



Simplified schematic of electronic and lattice degrees of freedom

Current Jumps Indicate Electron Overheating

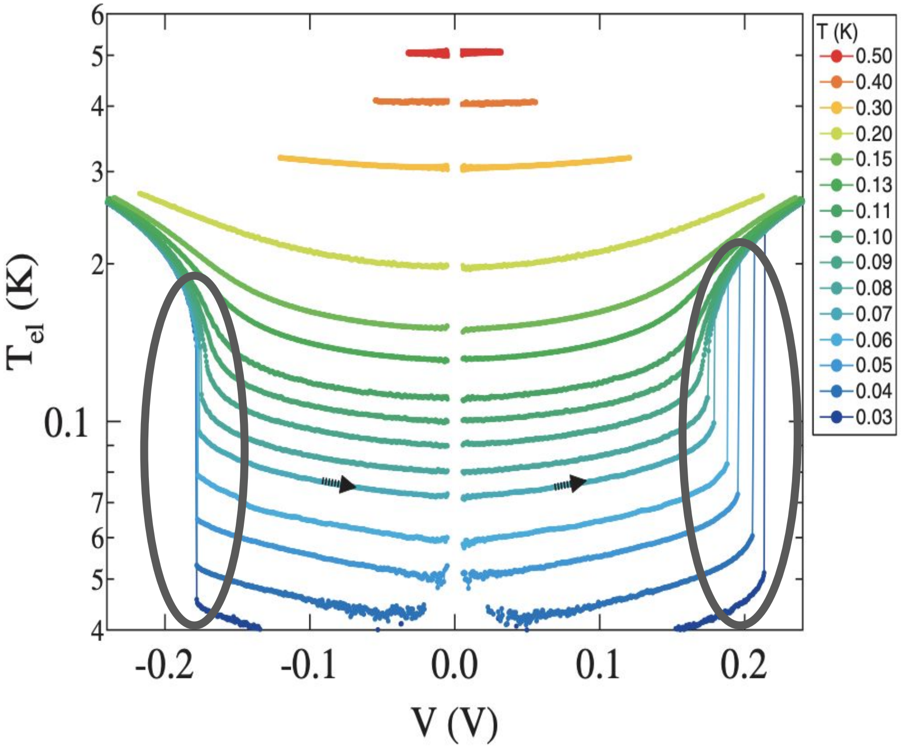
- Notice jumps of curves and asymmetry of sides



Plot of current magnitude vs. voltage at varying temperatures.

Electronic Temperatures Inferred

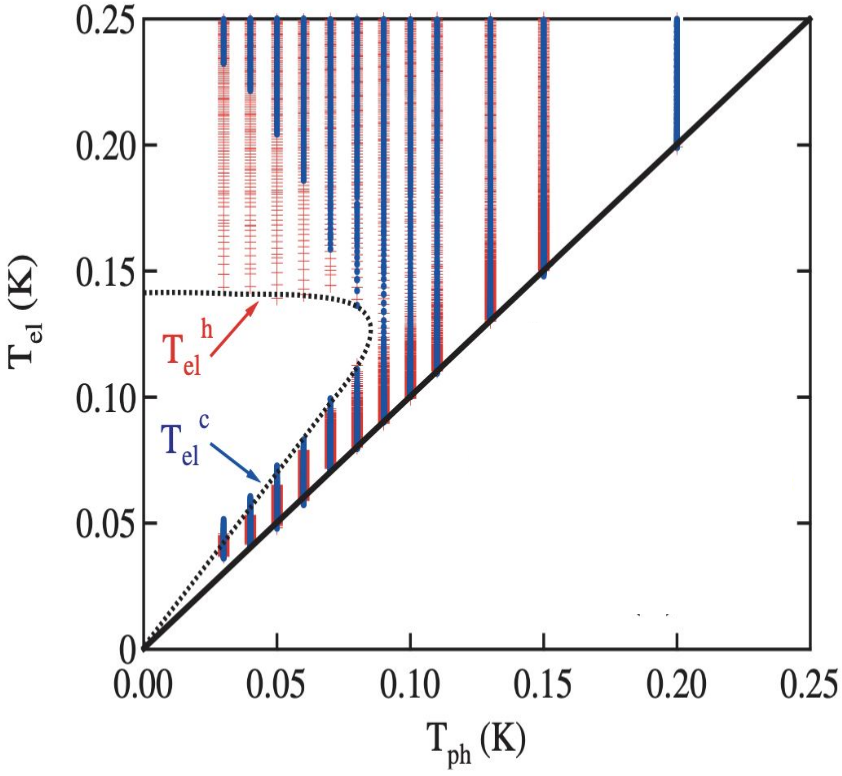
- Electronic temperature (T_{el}) derived from current-voltage
- Suggests T_{el} overheating



Plot of electronic temperature vs. voltage at varying temperatures

Excluded Electronic Temperatures

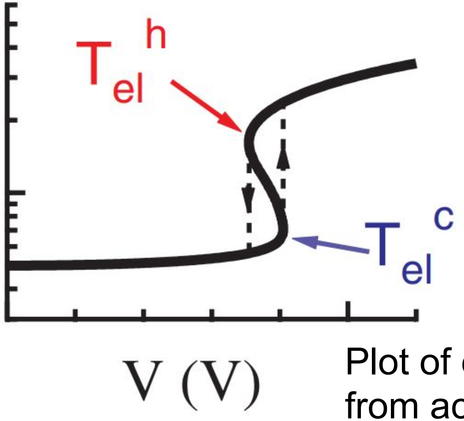
- Voltage sweeps on columns
- Notice excluded region of electronic temperatures on bottom left
- Staggering of jumps



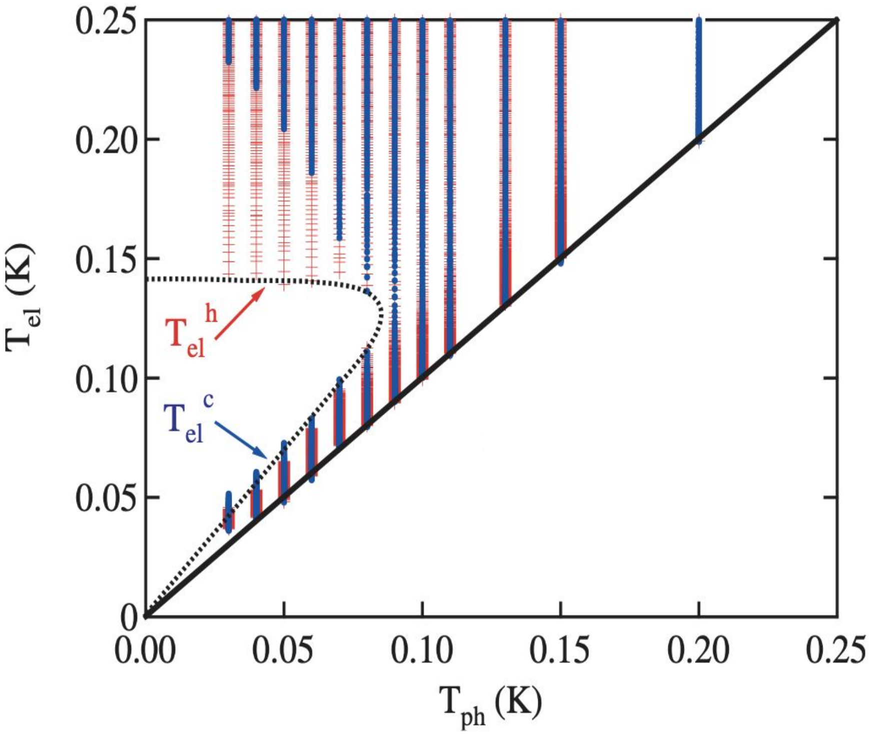
Plot of electronic temperature vs. phonon temperature with excluded region

Bi-Stabilities and Jumps

- T_{el} S-shape from theory
- Bi-stability results in jumps
- <u>Key Takeaway:</u> Insulating InO_x films decouple electrons and phonons

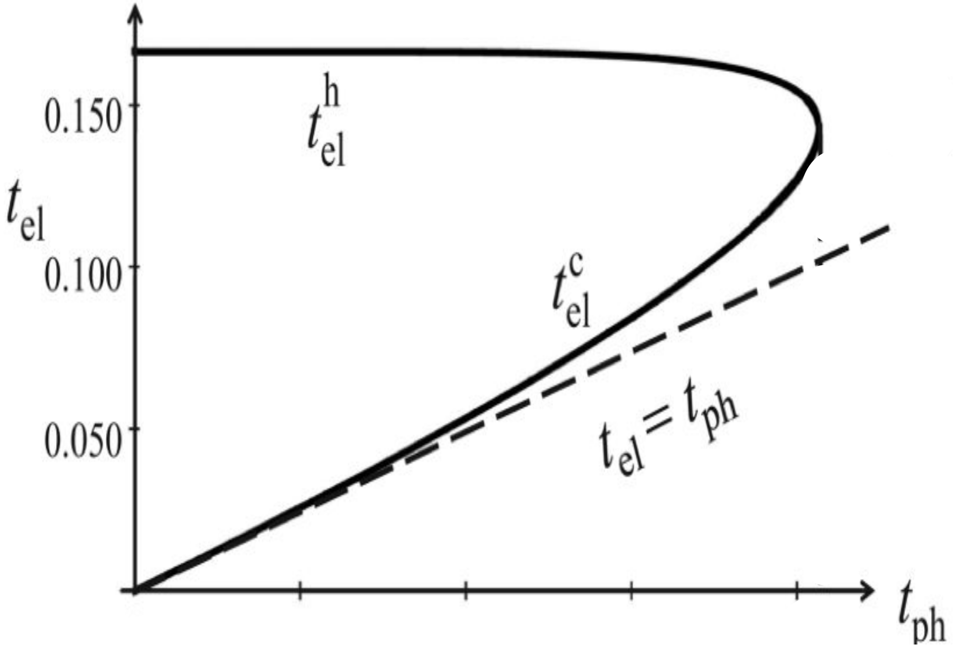


Plot of electronic temperature vs. voltage from accompanying theory



Similar Predictions in Previous Work

- Prior work established the superconductor-insulator transition with B [1]
- Excluded region in prior theoretical predictions for current-voltage behavior [2]
- Ref. [2] first demonstrated the bi-stability phenomenon



Theoretical plot of electronic temperature vs. phonon temperature in ref. [3]

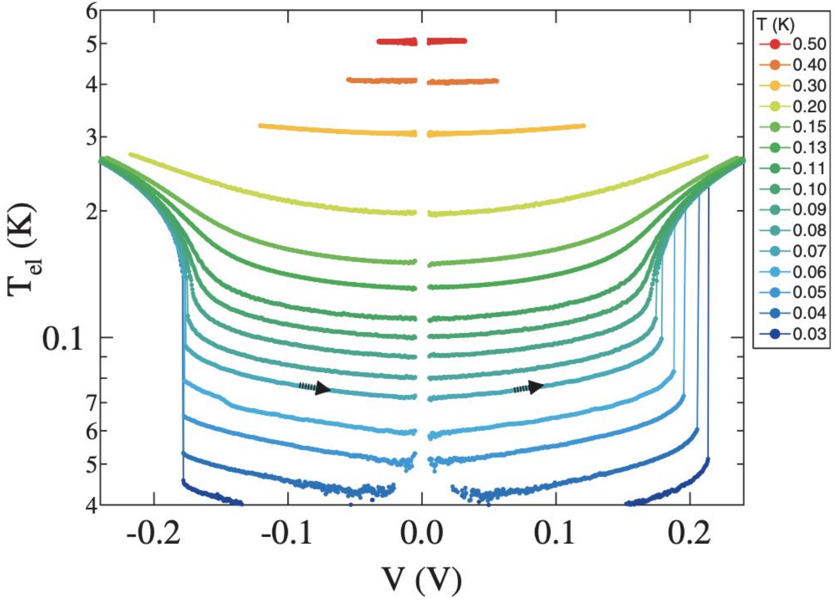
[1] Boris L. Altshuler, et al., Phys. Rev. Lett., **102**, 176803 (2009).
[2] G. Sambandamurthy, et al., Phys. Rev. Lett., **94**, 017003 (2005).

Scope

- The prominence of PRL assures the paper will be read by a diverse audience
  - No reasoning for why people other than Condensed Matter Physicists should be interested
  - No indication if the conditions in the experiment reflect anything outside the lab

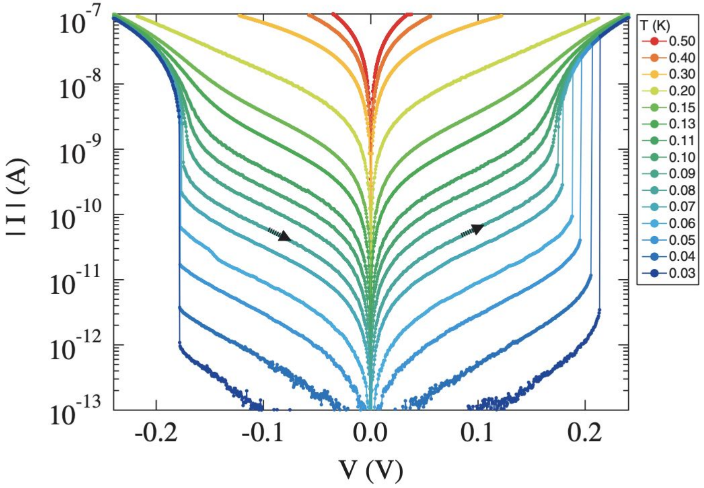
Lack of Errors

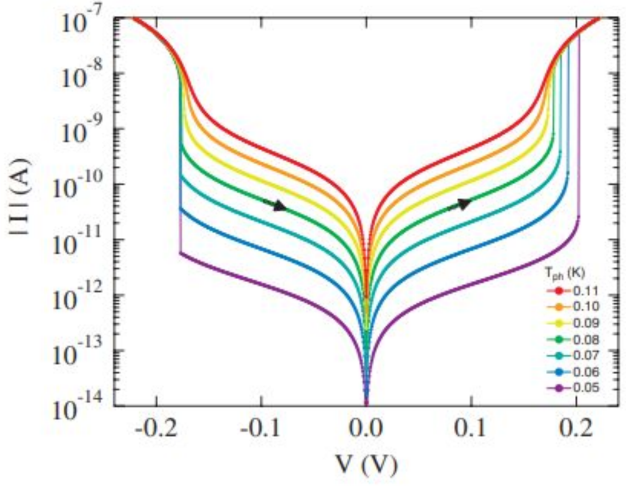
- No errors
  - In figures and text there are no error bars
  - Writers explain points near V = 0 are omitted due to excessive error



Experiment/Theory Comparison

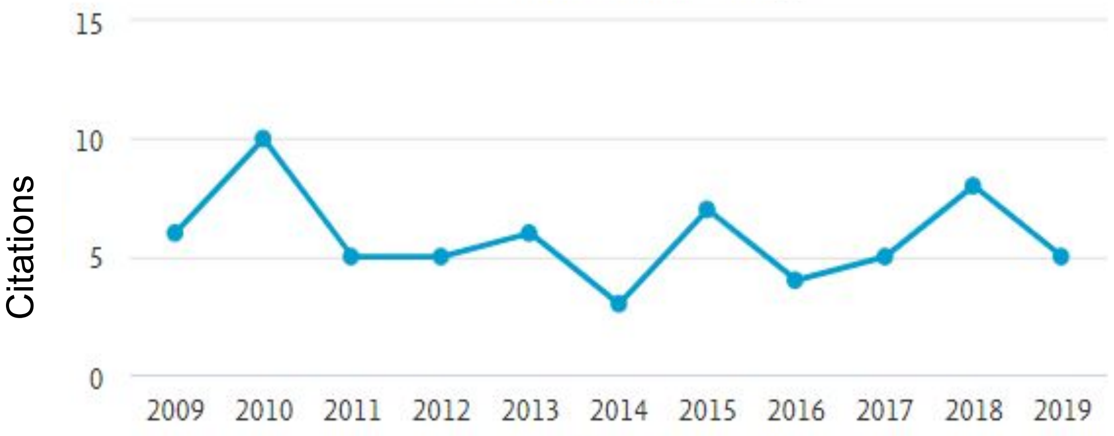
- Experiment (top) vs theory (bottom)
  - Isotherms seem to match very closely after close inspection, though presented poorly
  - A simple change in line colors could illustrate the match much better





Metrics

- 64 Citations in Scopus
  (88th percentile in Physics and Astronomy)
- 2.85 Field-Weighted Citation Impact
  (>1 means the document is more cited than expected)
- PRL highlights: “**Featured in Physics**” and “**Editors’ Suggestion**”
- Mentioned in Wikipedia as criticism of “Superinsulator”



Citations

Future research

- Many-body localization
- Superconductor-insulator transition

Top 3 citations

- “Universal dynamics and renormalization in many-body-localized systems” [1]
- “Superconductor-insulator quantum phase transition” [2]
- “Fractal superconductivity near localization threshold” [3]

[1] E. Altman and R. Vosk, *Annu. Rev. Condens. Matter Phys.*, **6**(1), 383-409 (2015)
[2] V.F. Gantmakher and V.T. Dolgopolov, *Physics-Uspekhi,* **53**(1), 1-49 (2010)
[3] M.V. Feigel'man, et al., *Annals of Physics,* **325**(7), 1390-1478 (2010)

Conclusions

- This work seems to represent a significant advance in understanding the unusual features of the insulating state of disordered superconductors.
- Opens the door to future theoretical work:
  - the results seem to show that electron transport is dependent only on the electron temperature,
  - need to identify a new phonon-independent mechanism to explain the insulating behavior.
- Experimental techniques seem to be mostly standard.

Recent progress (same team)

- **Inhomogeneous conduction state (2011)**
  - “Electric breakdown effect in the current-voltage characteristics of amorphous indium oxide thin films near the superconductor-insulator transition” [1]
- **Second-order phase transition (2016)**
  - **“**Nonequilibrium Second-Order Phase Transition in a Cooper-Pair Insulator” [2]
- **Directly measurement (2016)**
  - “Direct determination of the temperature of overheated electrons in an insulator” [3]
- **Quantum phase transitions (2017)**
  - **“**Instability of Insulators near Quantum Phase Transitions” [4]

[1] O. Cohen, et al., *Phys. Rev. B* **84**,100507 (2011)
[2] A. Doron, et al., *Phys. Rev. Lett*. **116**, 057001 (2016)
[3] T. Levinson, et al., *Phys. Rev. B* **94**, 174204 (2016)
[4] A. Doron, et al., *Phys. Rev. Lett*. **119**, 247001 (2017)