EMERGENCE OF THE INSULATING PHASE IN THIN NB$_X$SI$_{1-X}$ FILMS CLOSE TO THE SIT

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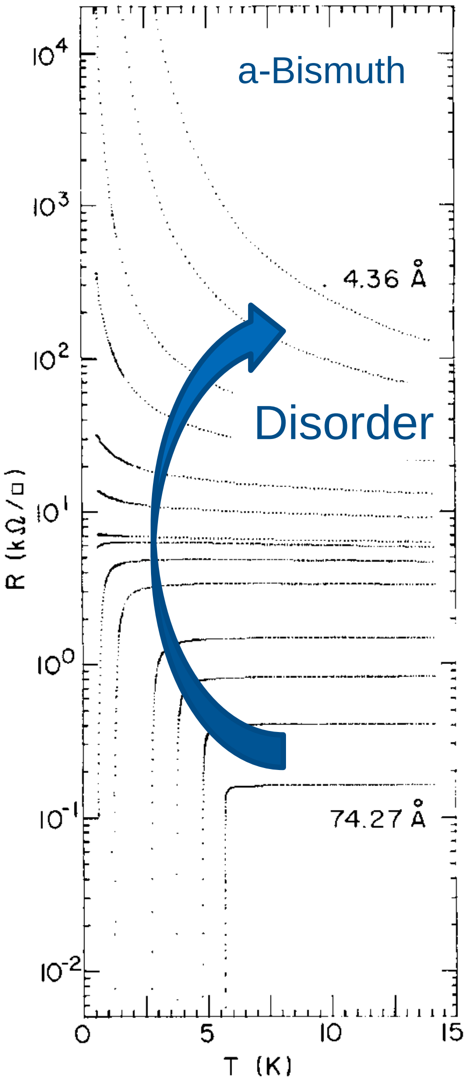
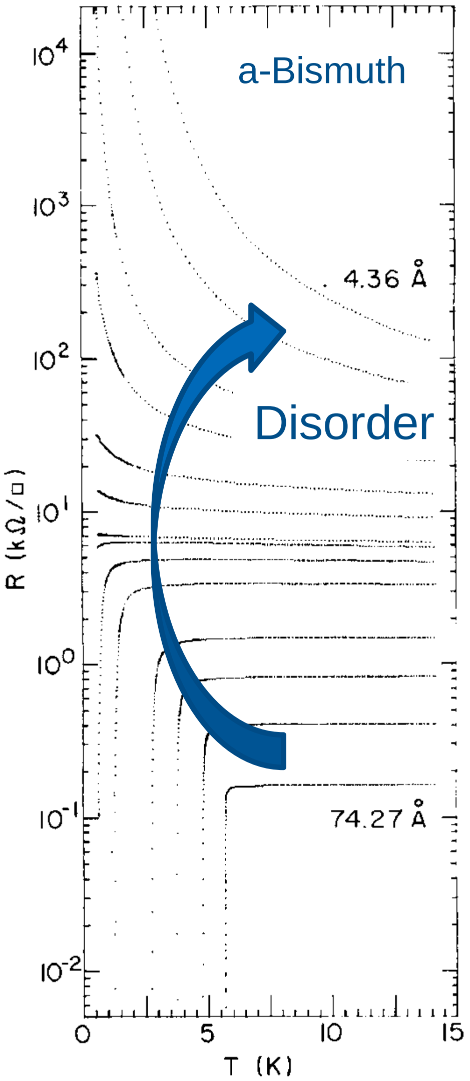
MOTIVATION



Haviland et al, *Phys. Rev. Lett.*, **62** 18 1989

MOTIVATION



Haviland et al, *Phys. Rev. Lett.*, **62** 18 1989

Disorder-induced SIT in 2D systems

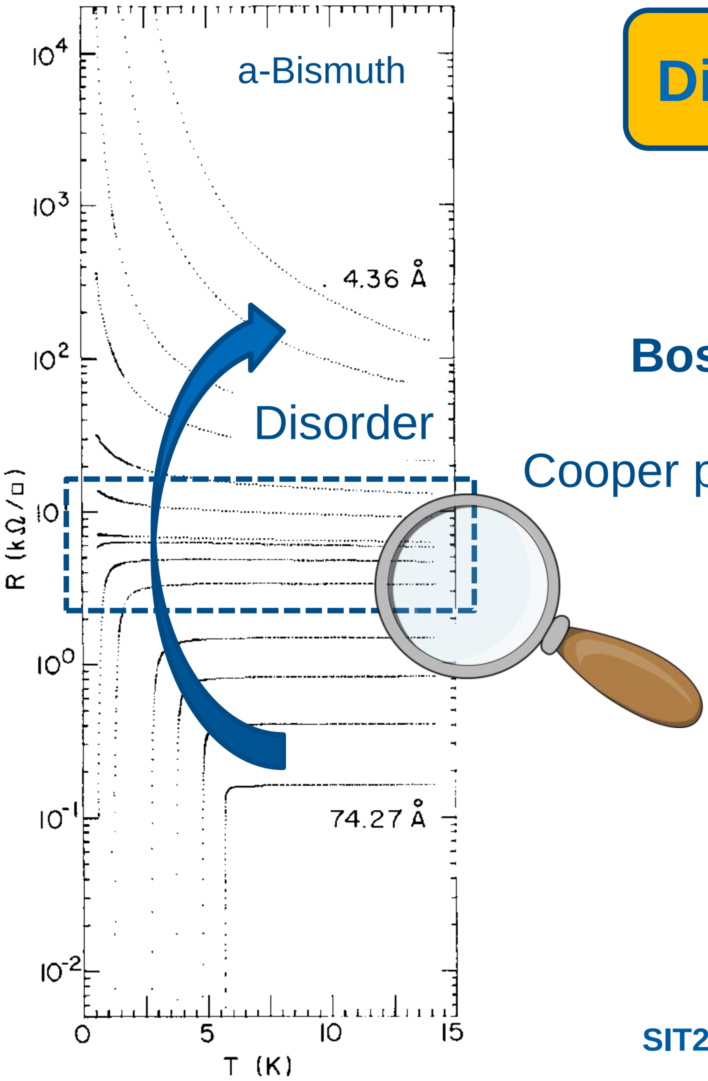
Bosonic scenarii

Cooper pairs in the insulator

Fermionic scenarii

NO Cooper pairs in the insulator

MOTIVATION



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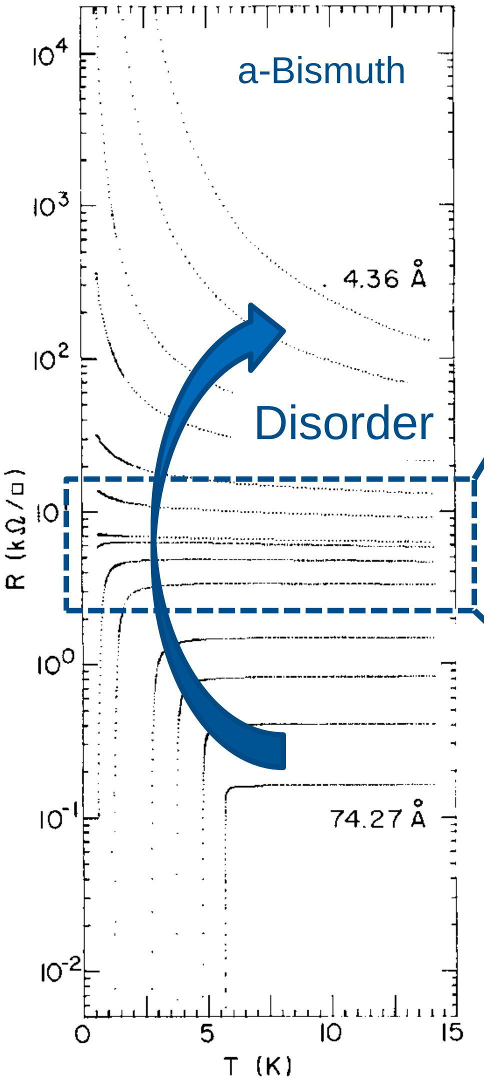
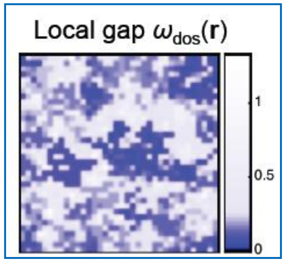
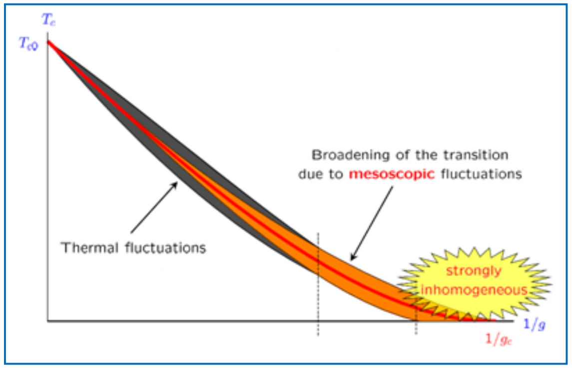




Bouadim et al., *Nat. Phys.*, **7** 884 2011

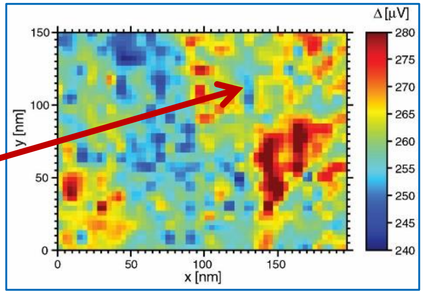
Zoom on the transition

? Homogeneous phase



Skvortsov et al., *PRL*, **95** 057002 2005

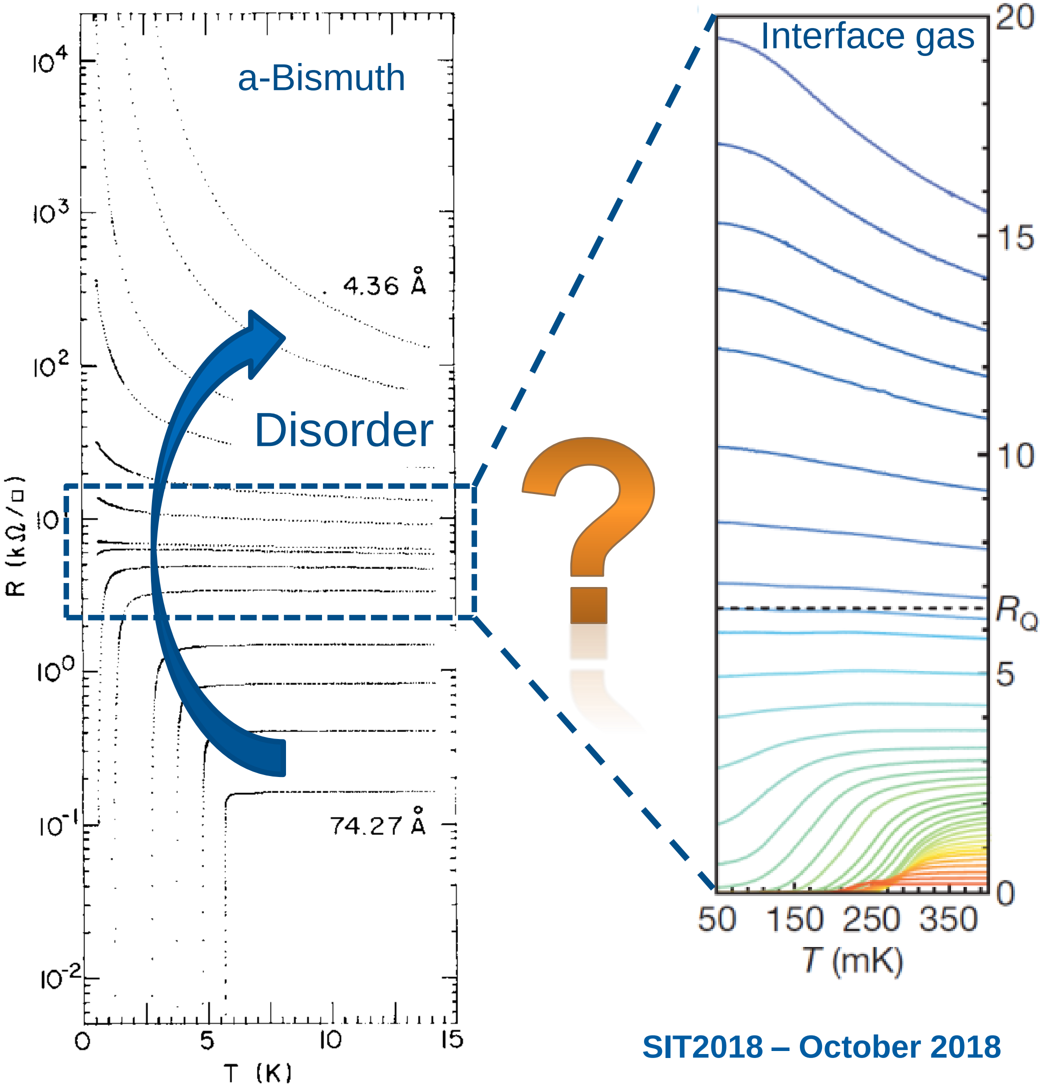
Inhomogeneous order parameter



Sacépé et al., *PRL*, **101** 157006 2008

MOTIVATION

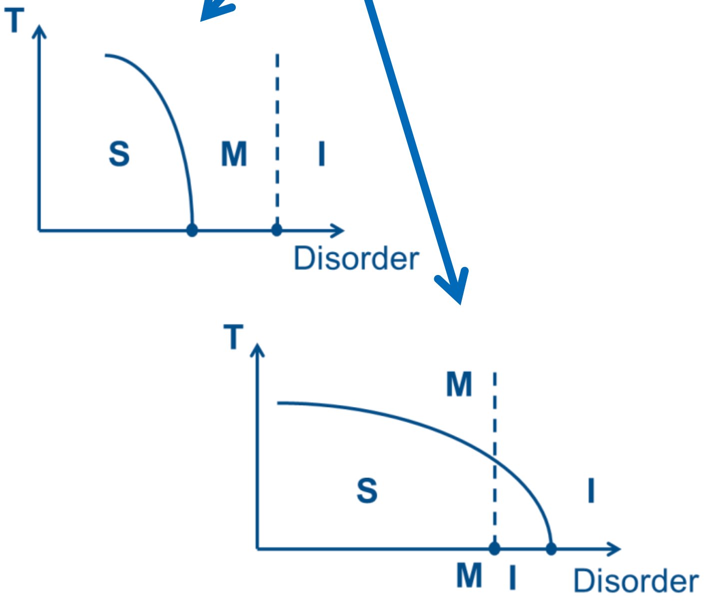
Haviland et al, *Phys. Rev. Lett.*, **62** 18 1989



Caviglia et al, *Nature*, **456** 6241 2008

Zoom on the transition

? Homogeneous phase
? Metallic states

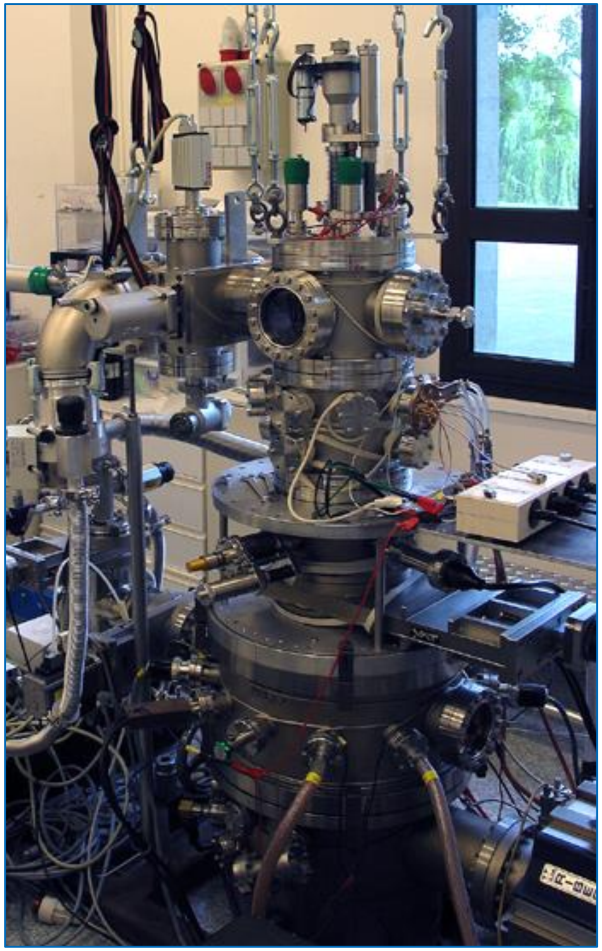


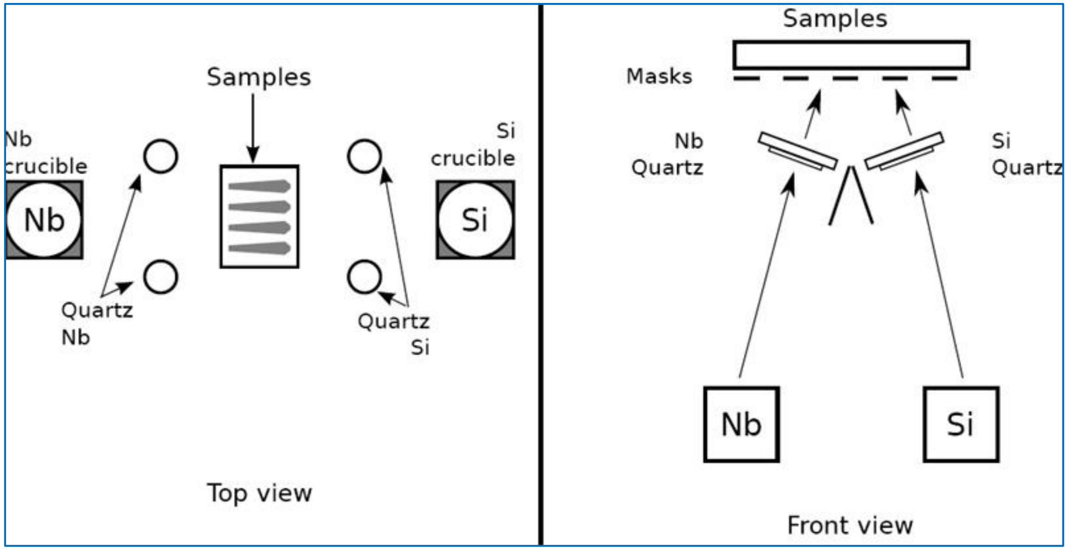
A-NBSI THIN FILMS

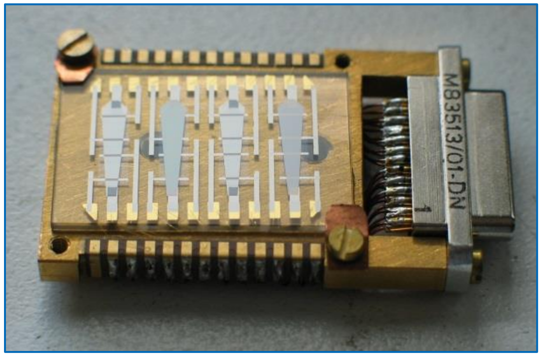
- System characterization
- 3 ways of tuning the disorder

NBSI THIN FILMS

Synthesis







NBSI THIN FILMS

General characteristics

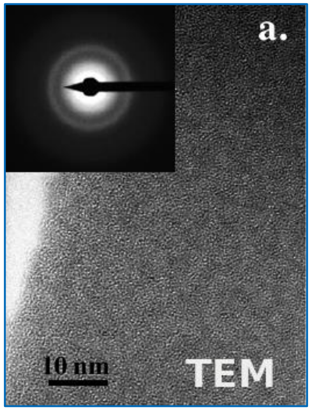
- **Morphology :**
  - Continuous down to 2.5 nm (at least)
  - Amorphous

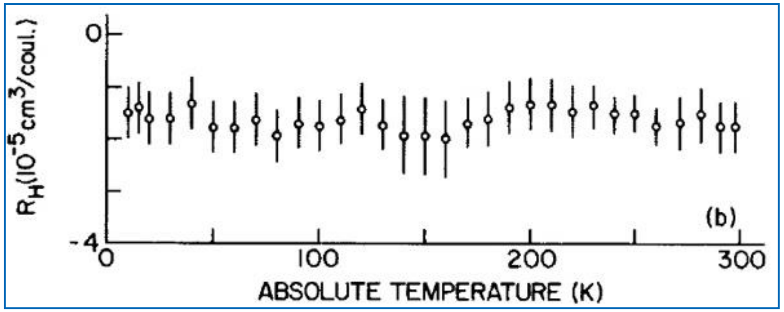
- **Mean free path** $l = 2.6\,\text{Å} \text{ to } 5\,\text{Å}$

- **Electronic density n ~** a few 10^{27} m^{-3}

- **Superconducting coherence length**
  ξ ~ 50 nm for T_c=1K

- **Heat treatment :**
  - No modification of n
  - No modification of the composition x





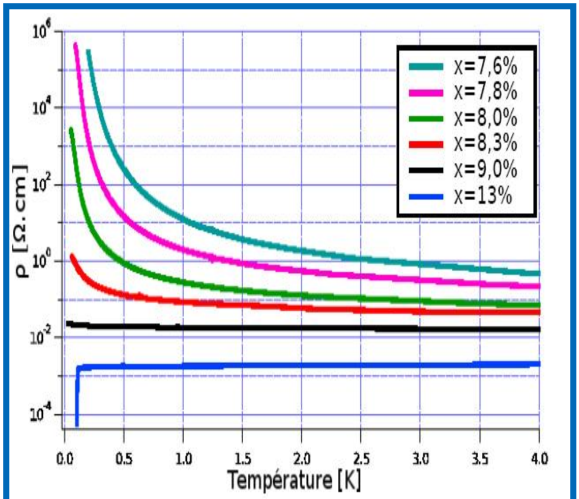
Nava et al., *J. Mat. Res.*, **1** 327 1986

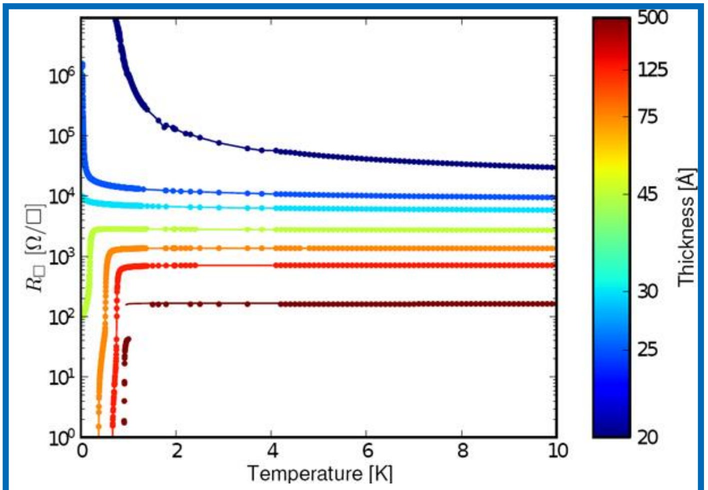
NBSI THIN FILMS

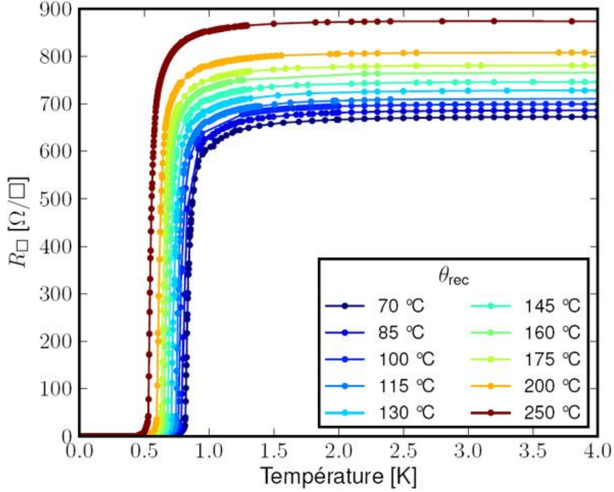
3 different disorder-induced SITs

Usual disorder parameter in 2D : $R_\square = \frac{\rho}{d_\perp} \propto \frac{1}{k_F l}$

Crauste et al. *PRB* **87** 144514 2013







x induced **Composition**

- 3D : d > 100 nm

$$\boxed{R_\square = \frac{1}{k_F l}}$$

$d_\perp$ induced **Thickness**

- 2D, 18%
- ξ ~ 50 nm

$$\boxed{R_\square = \frac{\rho}{d}}$$

θ_{anneal} induced **Heat treatment**

- d=12.5 nm, 18%

$$\boxed{R_\square = \frac{1}{k_F l}}$$

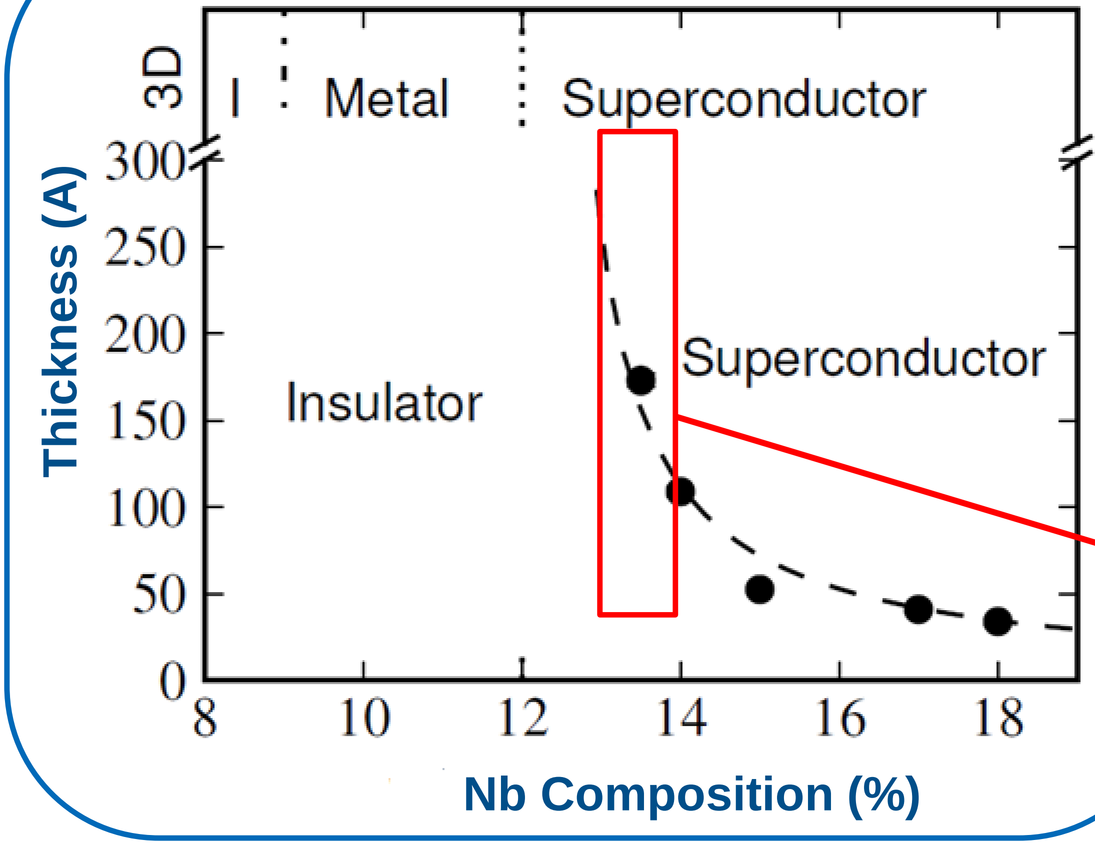
ONSET OF THE INSULATING REGIME IN NBSI FILMS

- 2 dissipative phases
- Analysis of conduction laws close to the MIT

SAMPLES

Near the SIT

Crauste *PRB* **90** 060203 2014

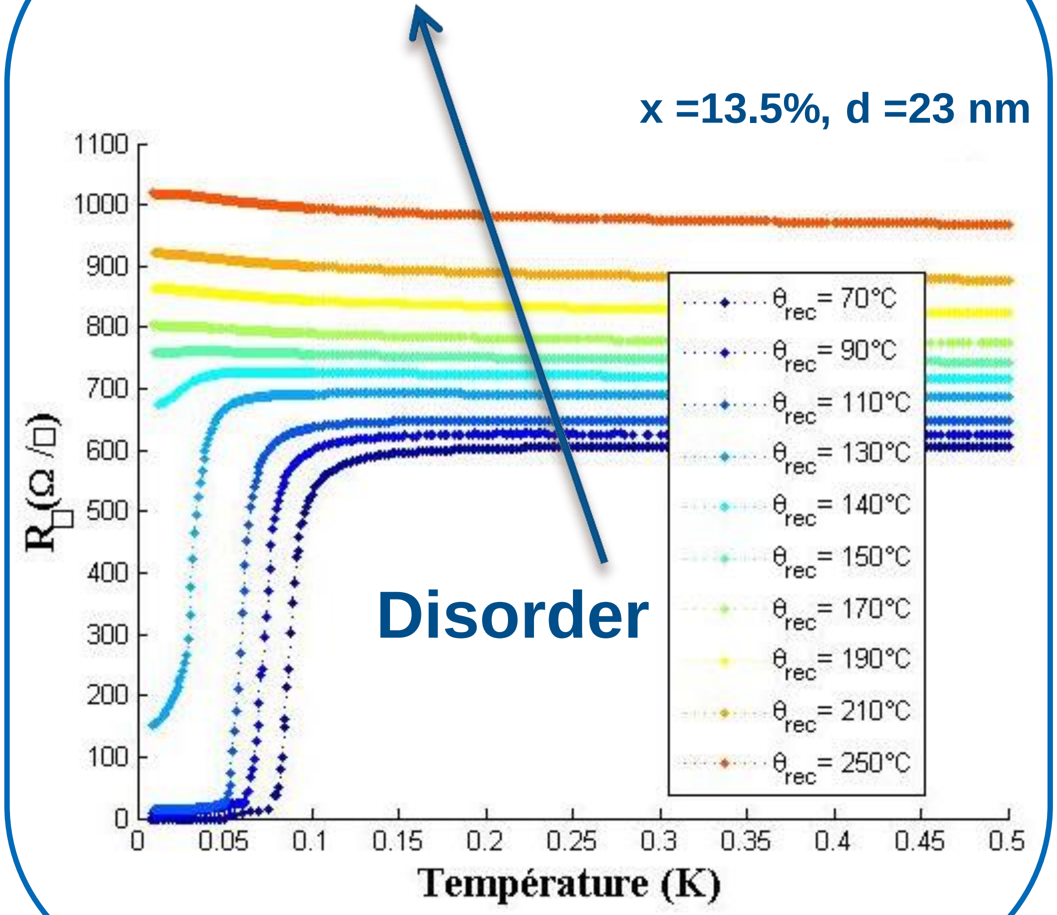


x= 13.5 %, $d_c \approx$ 18 nm

Films
with d= [3 , 35 nm]

FINE-TUNING THE DISORDER

2 dissipative phases!



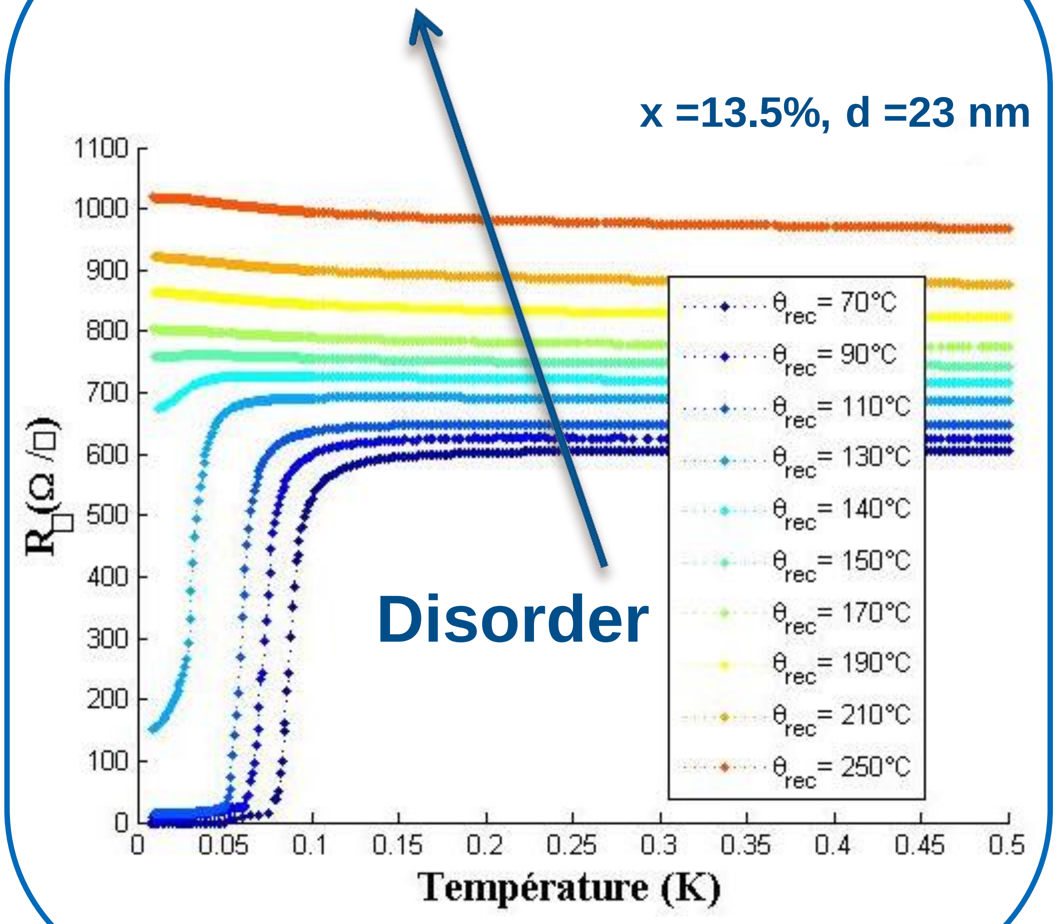
x =13.5%, d =23 nm

Disorder

Couëdo *Sc.Rep.* **6** 35834 2016

FINE-TUNING THE DISORDER

2 dissipative phases!

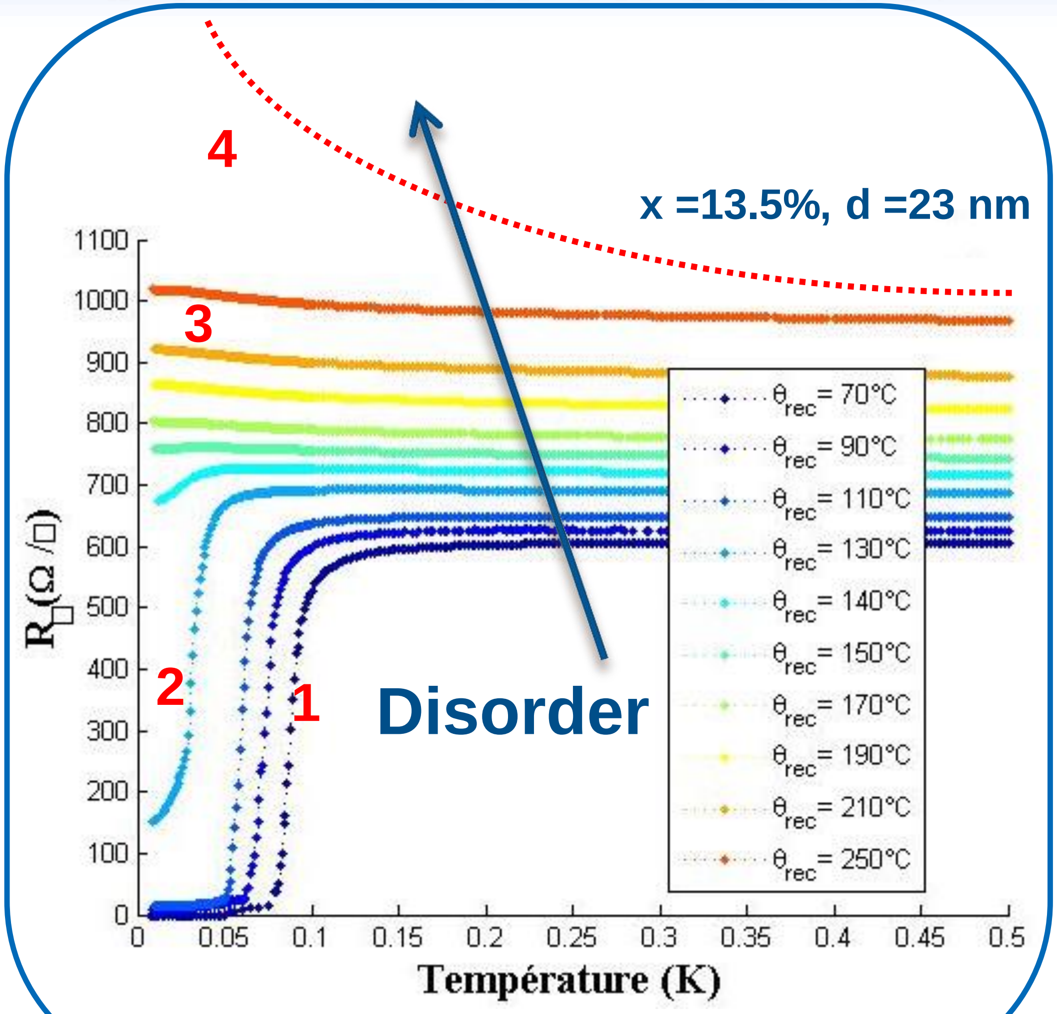


x =13.5%, d =23 nm

Disorder

Couëdo *Sc.Rep.* **6** 35834 2016

4 DISTINCT REGIMES



Couëdo *Sc.Rep.* **6** 35834 2016

At T⟶0

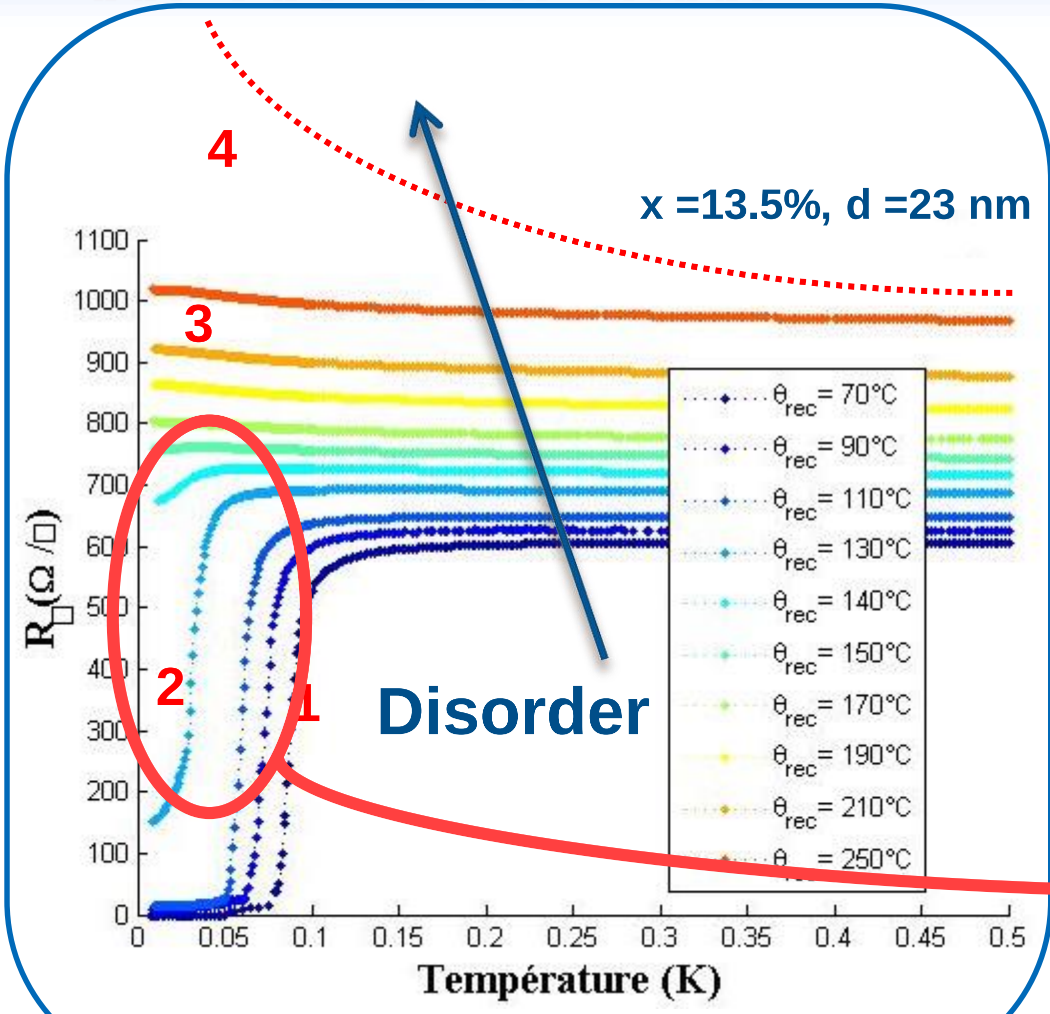
1 – Superconductor (R=0)
2 – **Metal 1**: Finite R & TCR > 0
3 – **Metal 2**: Finite R & TCR < 0
4 – Insulator

Disorder measured by :

$$R_{\square,N} = R_{\square}(4K)$$

METAL 1 REGIME

Inhomogeneities?

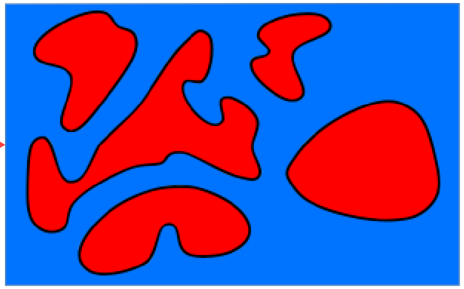


Couëdo *Sc.Rep.* **6** 35834 2016

1 – Superconductor (R=0)
2 – **Metal 1**: Finite R & TCR > 0
3 – **Metal 2**: Finite R & TCR < 0
4 – Insulator

Possible picture for Metal 1:

Superconducting puddles



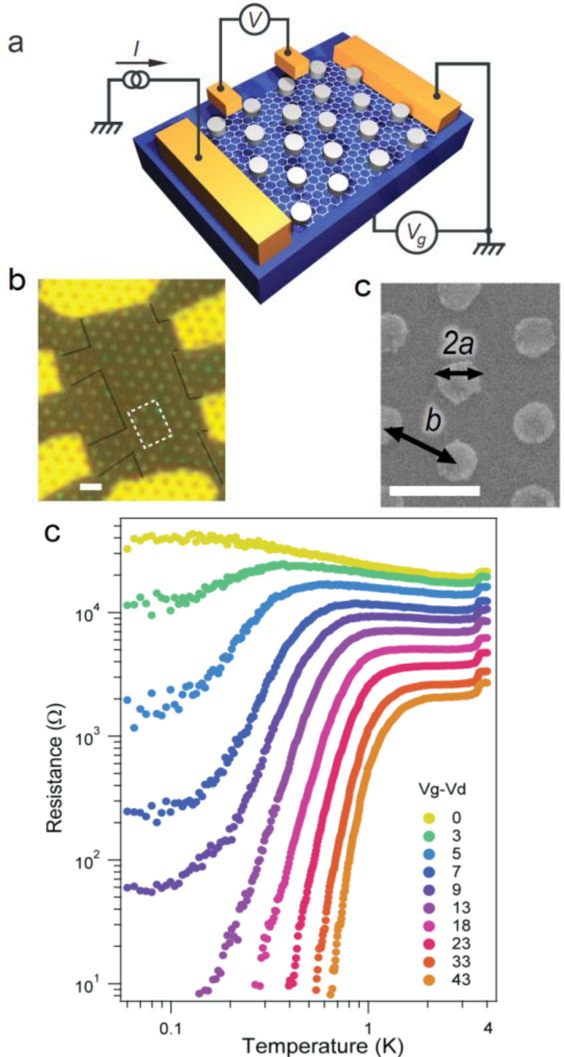
🟦 Non superconducting material
🟥 Superconductor

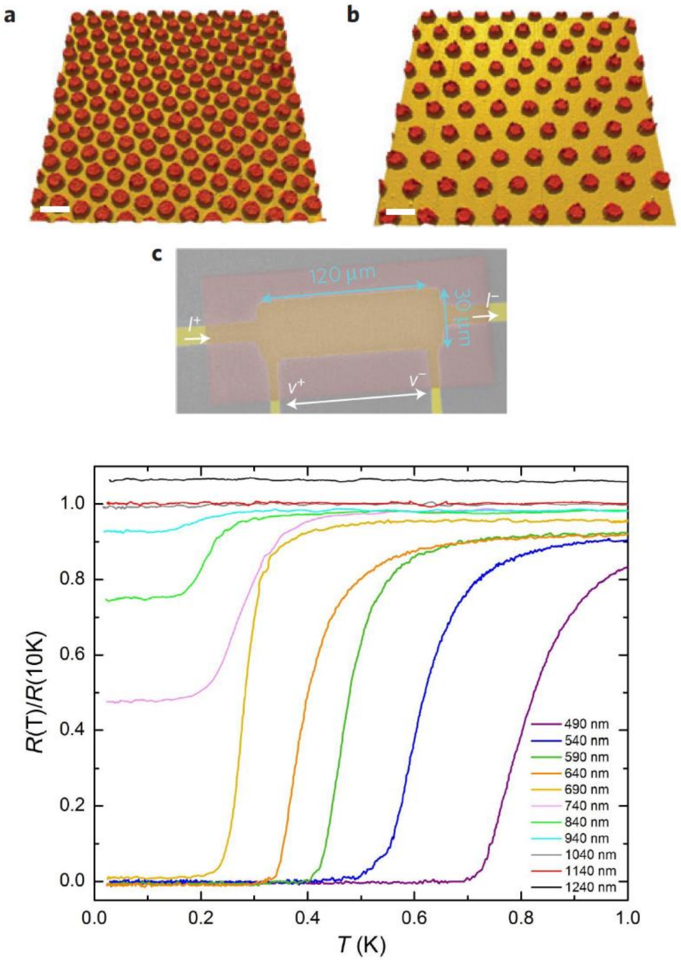
METAL 1 REGIME

Sn islands on Graphene

Nb islands on Au

Han et al. *Nat. Phys.* **10** 380 2014

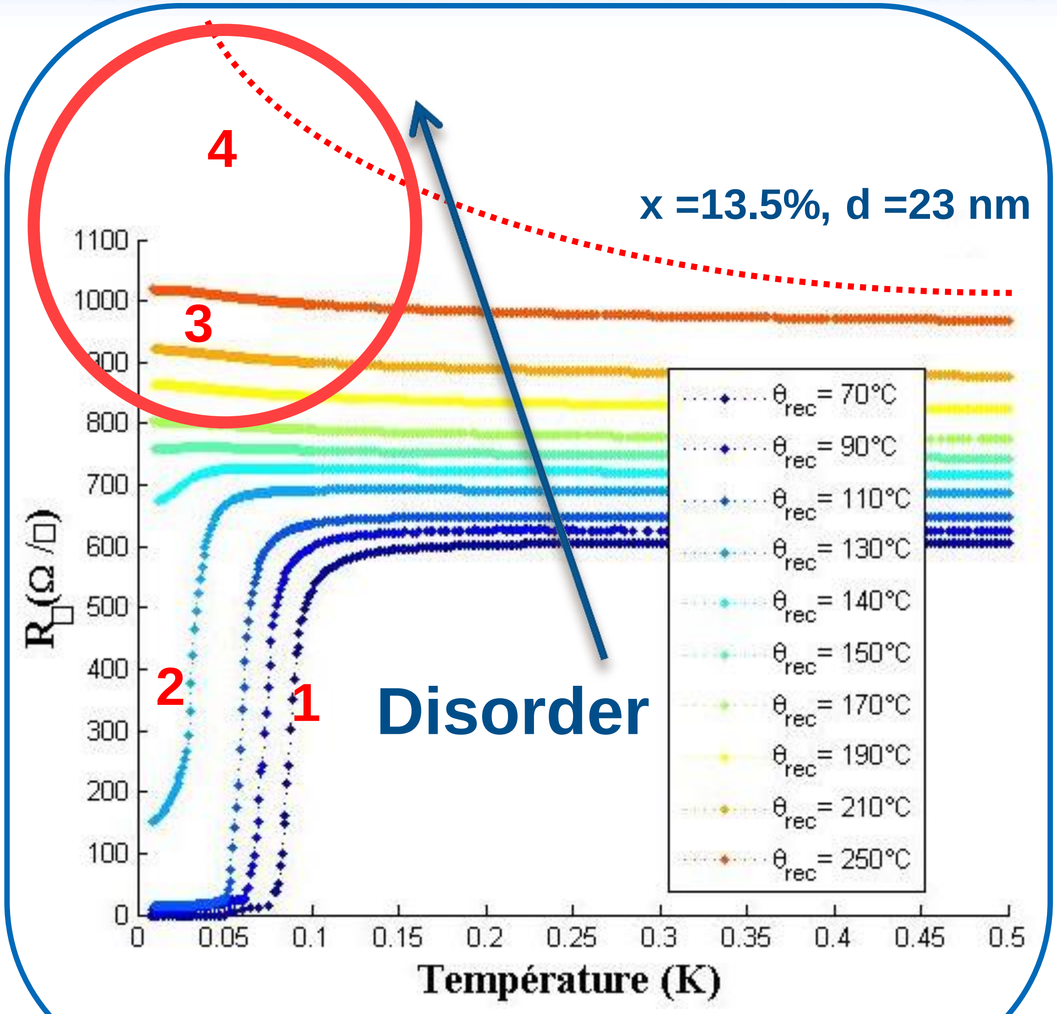




Eley et al. *ArXiv 1206.5999*

METAL-TO-INSULATOR TRANSITION

MIT?



Couëdo *Sc.Rep.* **6** 35834 2016

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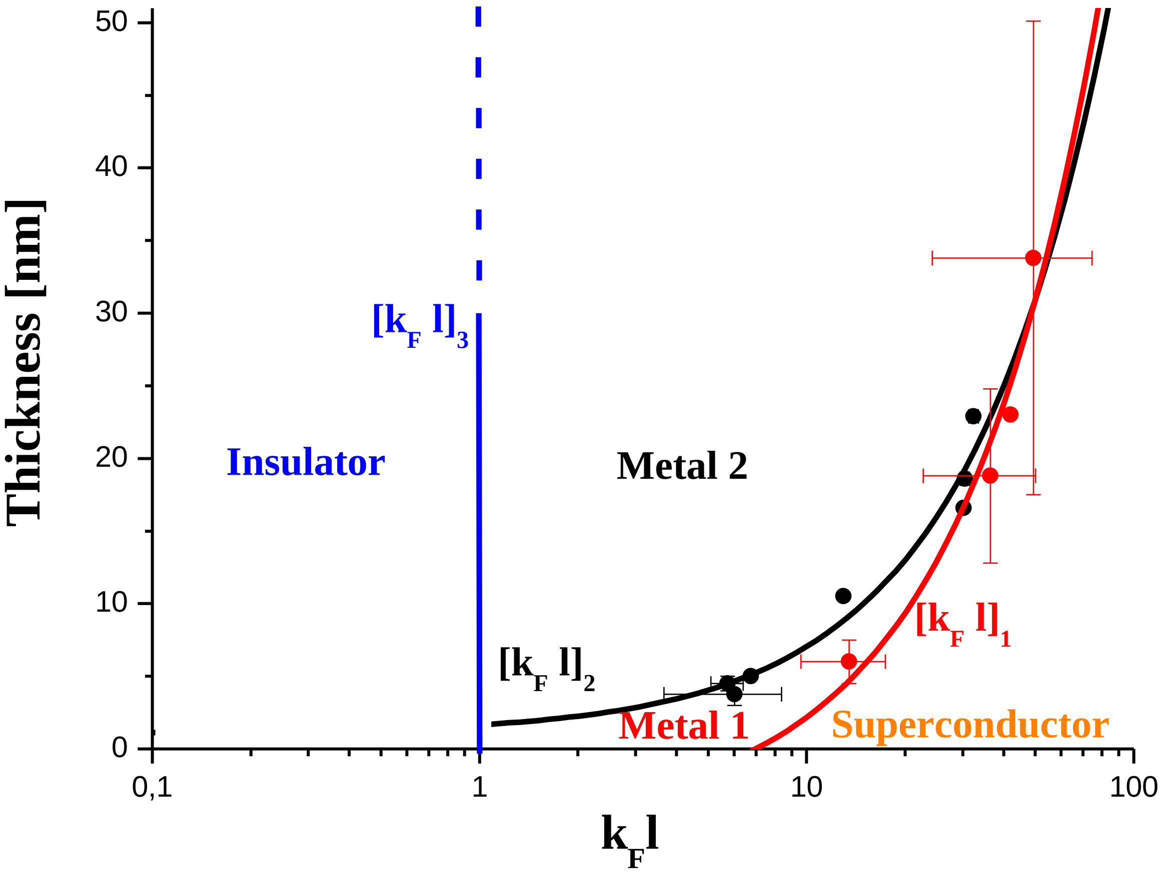
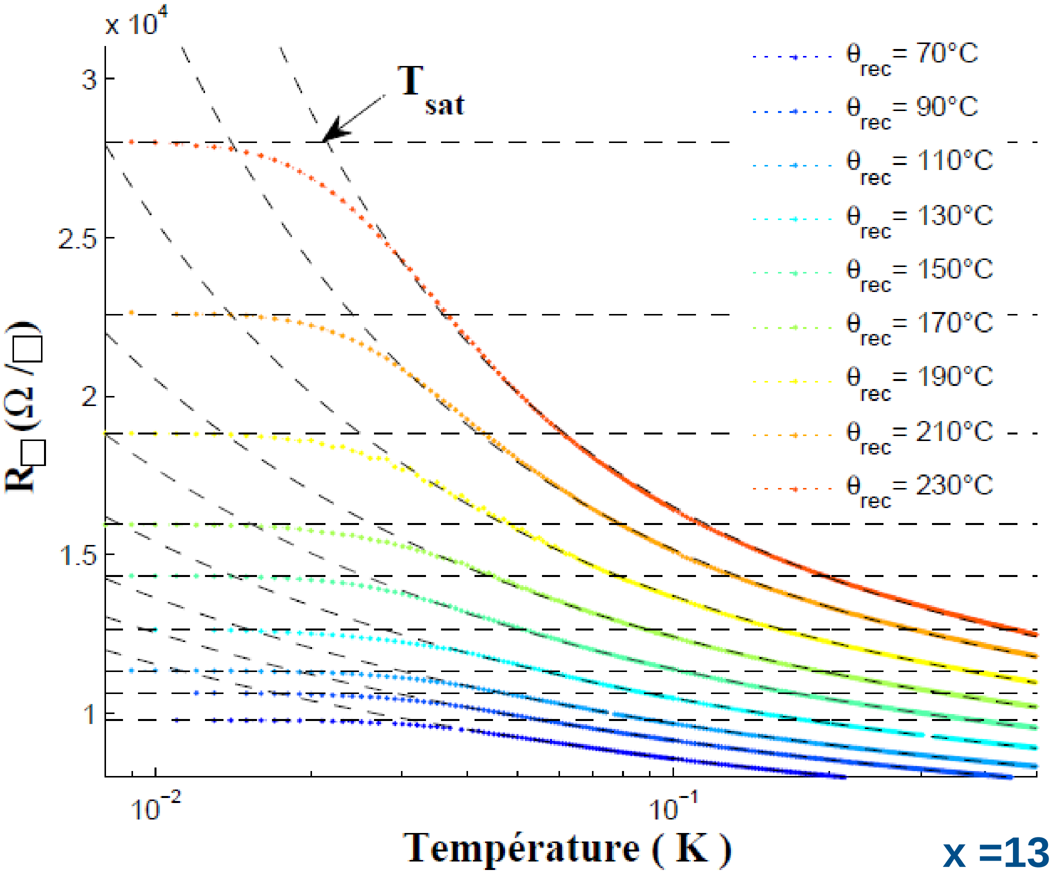
PHASE DIAGRAM



ONSET OF THE INSULATING REGIME

From the Metal 2 phase

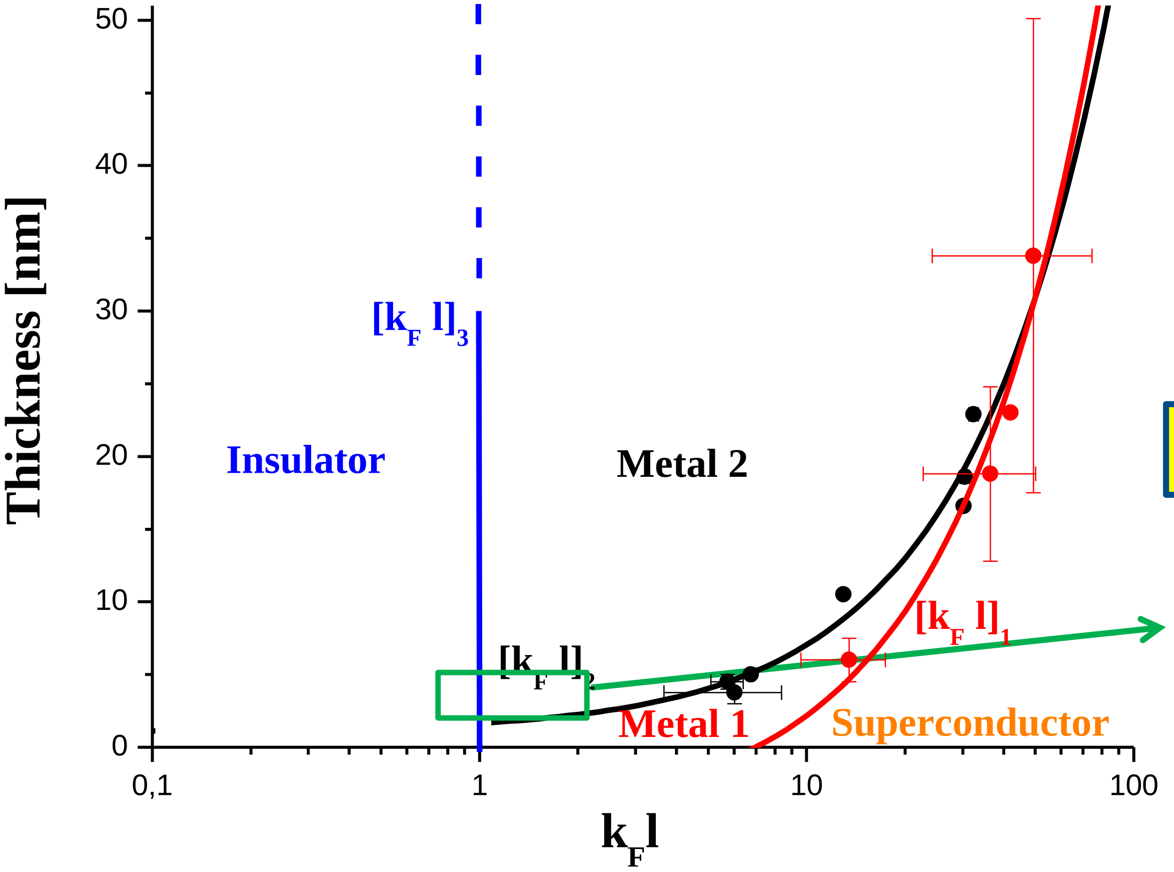


- **How does the « Metal 2 » phase evolve towards an insulating regime ?**
- **Are there any signature of localization in the « Metal 2 » regime ?**

x =13.5%, d = 5 nm

ONSET OF THE INSULATGING REGIME

Samples

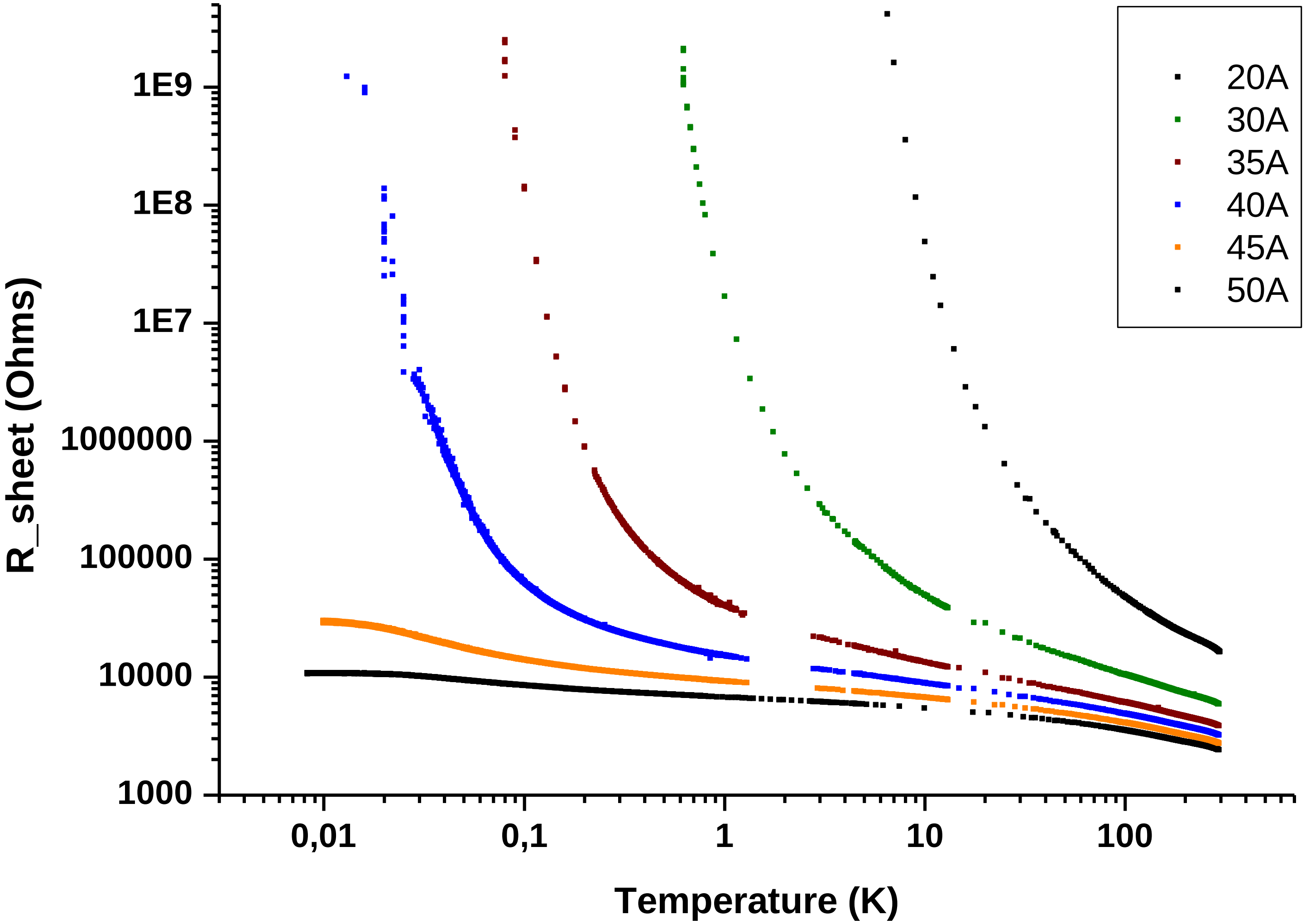


x= 13.5 %

6 Films with d= [2, 5 nm]

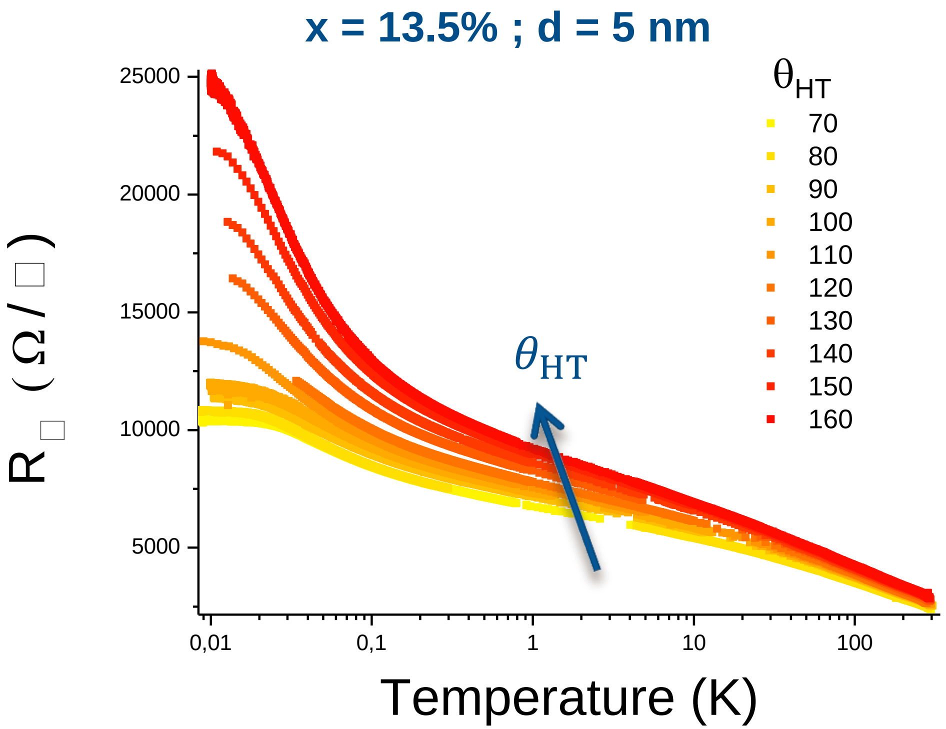
INSULATING REGIME

As-deposited samples



METAL 2 REGIME

Towards the « Metal 2 » - Insulator transition



A *single* sample with heat treatment

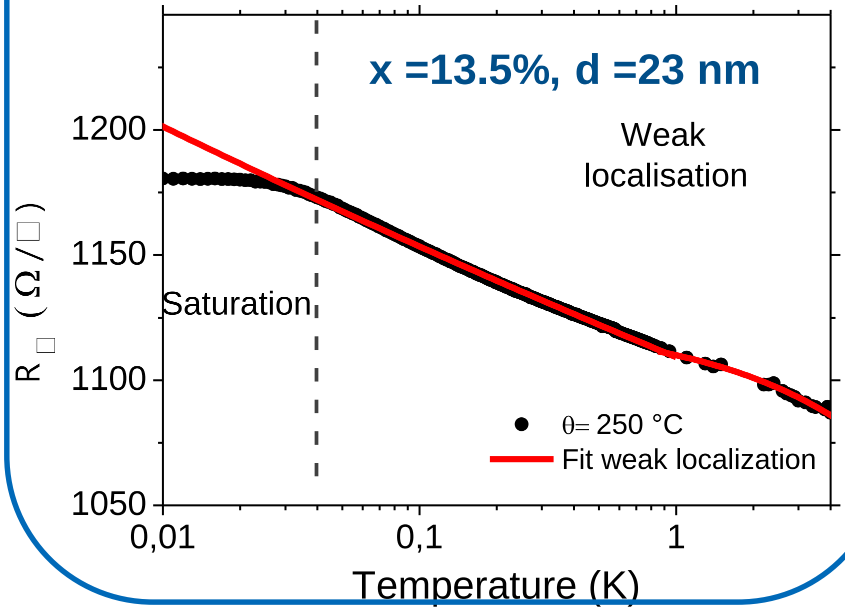
METAL 2 REGIME

2 distinct regimes

Disorder →

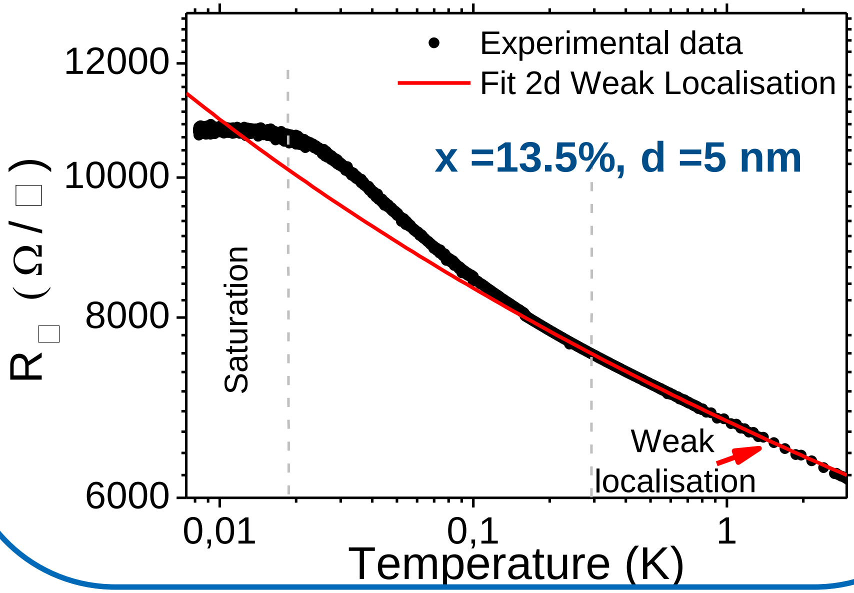
M2 far from MIT

- Weak localization
- Saturation of resisitivity at T->0



M2 close to MIT

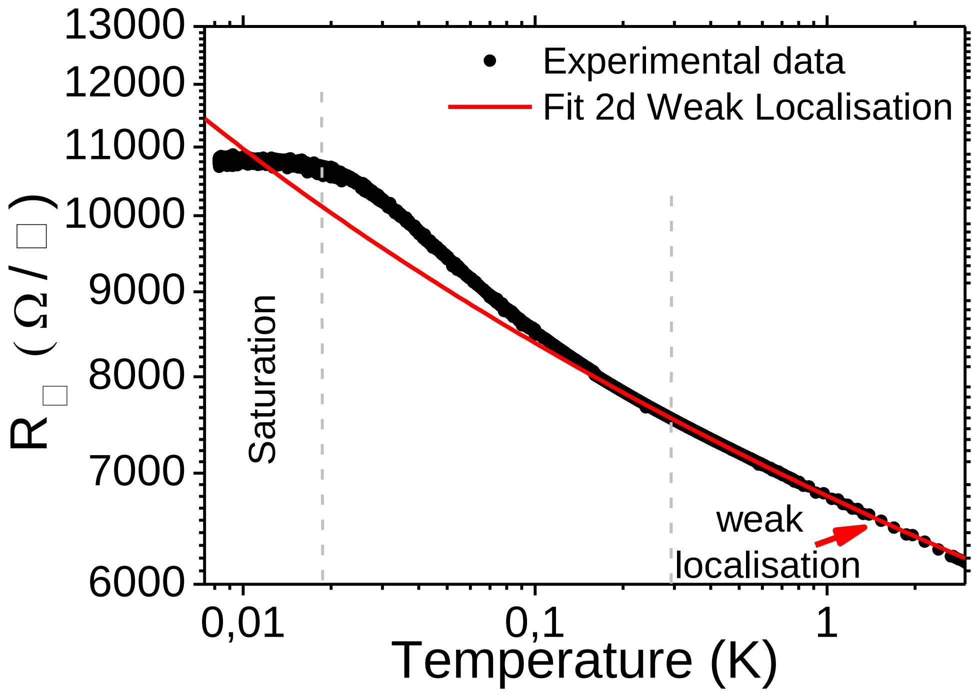
- Weak localization
- More insulating than weak localization
- Saturation of resisitivity at T->0



METAL 2 REGIME

Near the « Metal 2 » - Insulator transition

x = 13.5% ; d = 5 nm

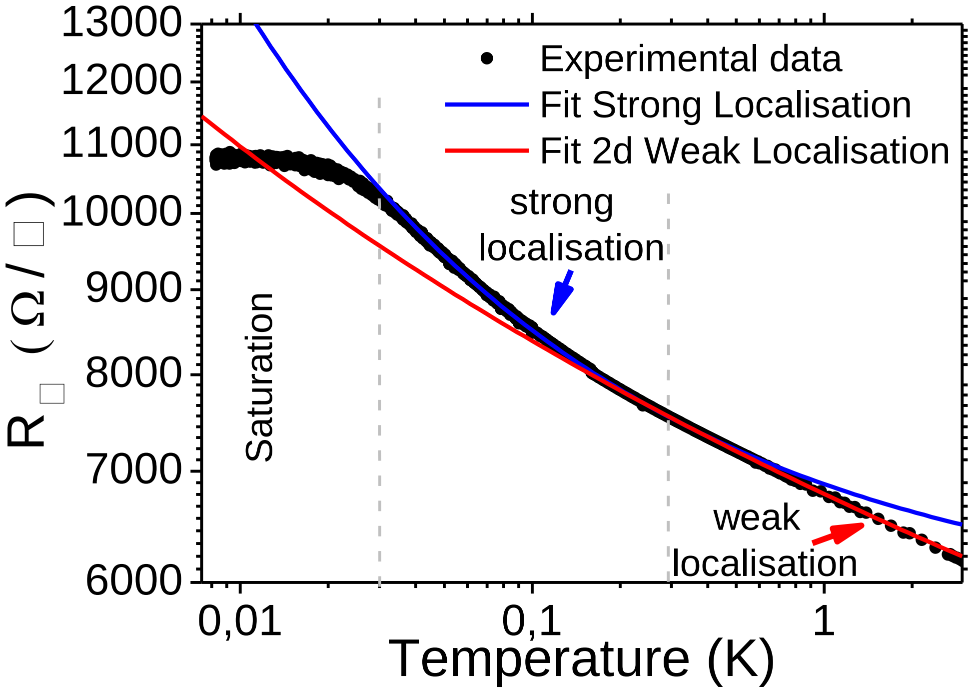


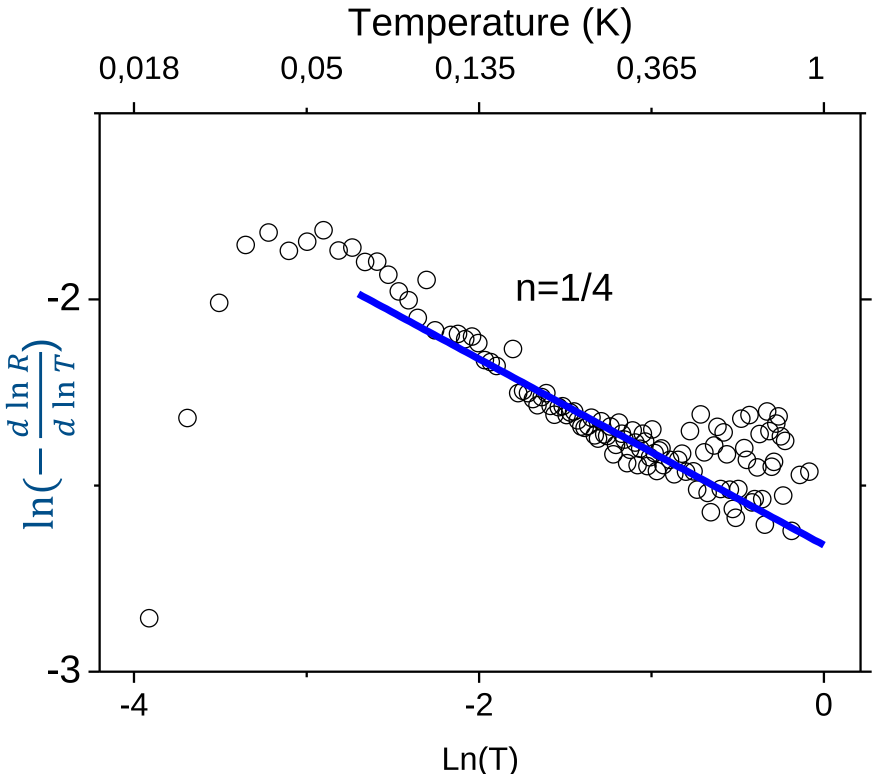
High temperature :
2D Weak Localization : $R \propto \ln(T)$

METAL 2 REGIME

Near the « Metal 2 » - Insulator transition

x = 13.5% ; d = 5 nm





Intermediate temperature:

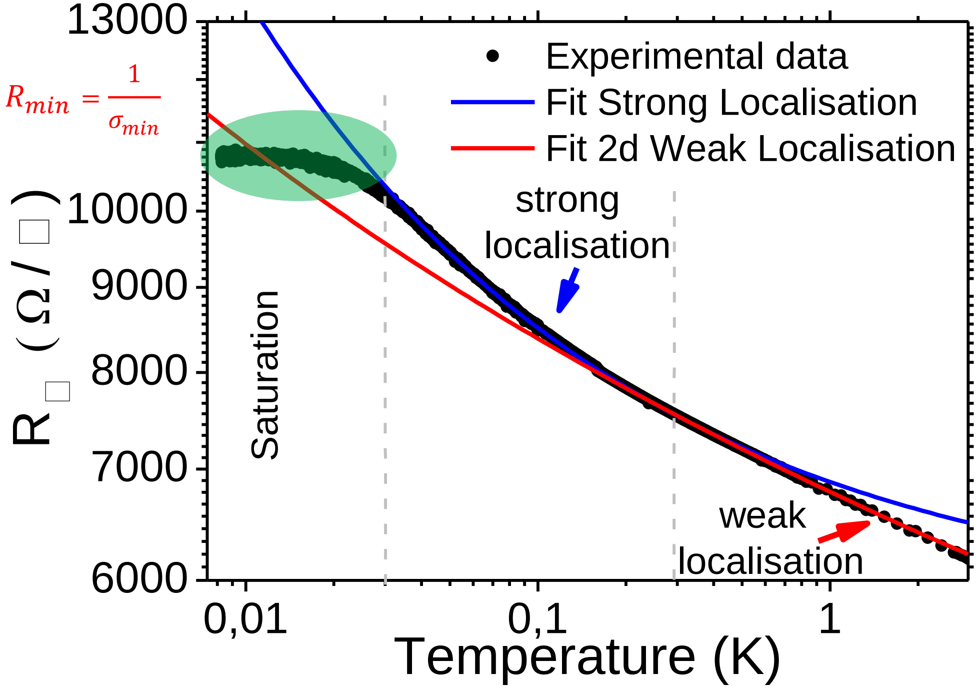
Exponential Law: $R \propto e^{\left(\frac{T_0}{T}\right)^n}$

Zabrodskii's plot:

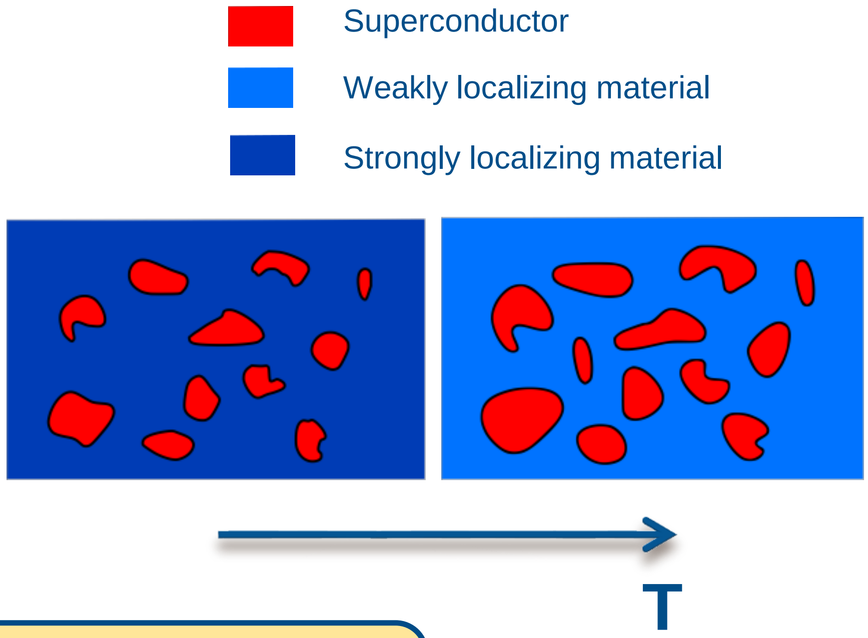
$$\ln\left(-\frac{dlnR}{dlnT}\right) \propto -nln(T)$$

METAL 2 REGIME

Near the « Metal 2 » - Insulator transition


x = 13.5% ; d = 5 nm

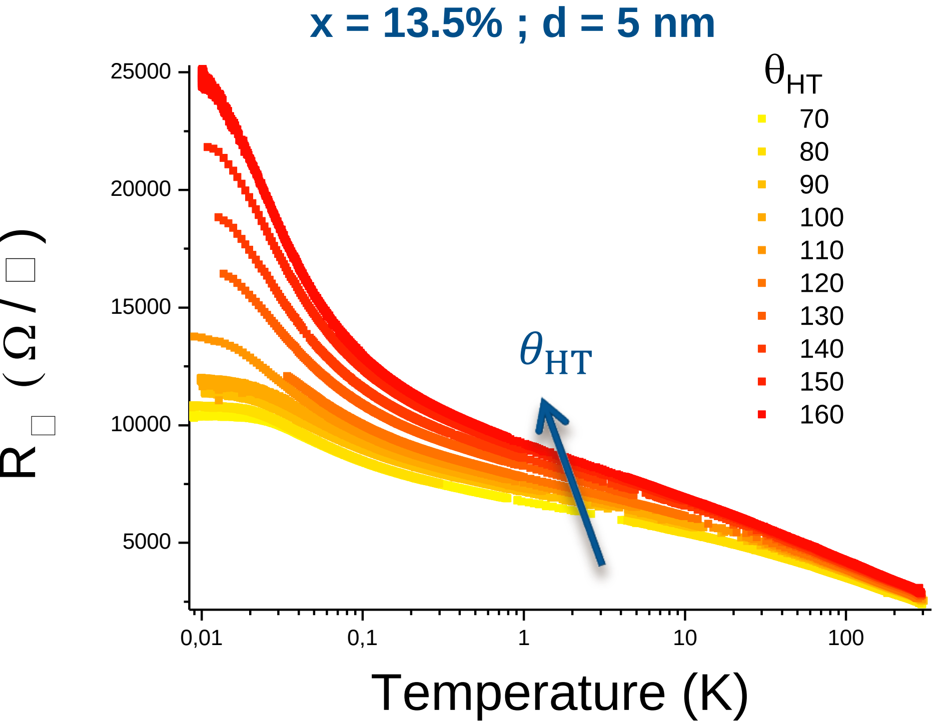
Superconducting puddles coupled by Josephson effect at low temperature

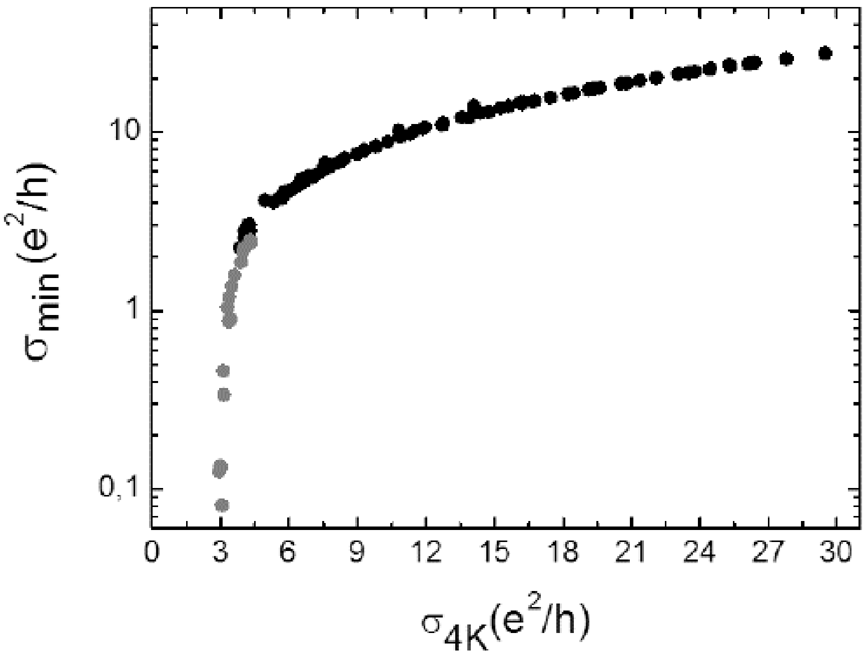


Lowest temperature:
Metallic ground state →Saturation of the resistance

METAL 2 REGIME

Crossing the « Metal 2 » - Insulator transition



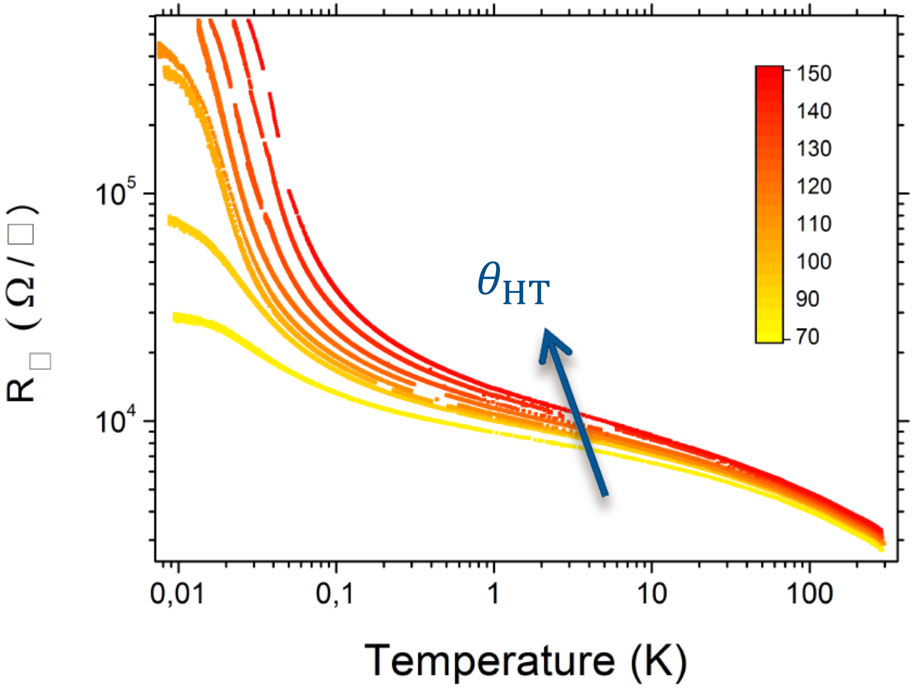


$\sigma_{min} = \sigma_{\square}(10mK)$ vanishes as disorder ↗

INSULATING REGIME

Crossing the « Metal 2 » - Insulator transition

x =13.5% ; d =4,5 nm

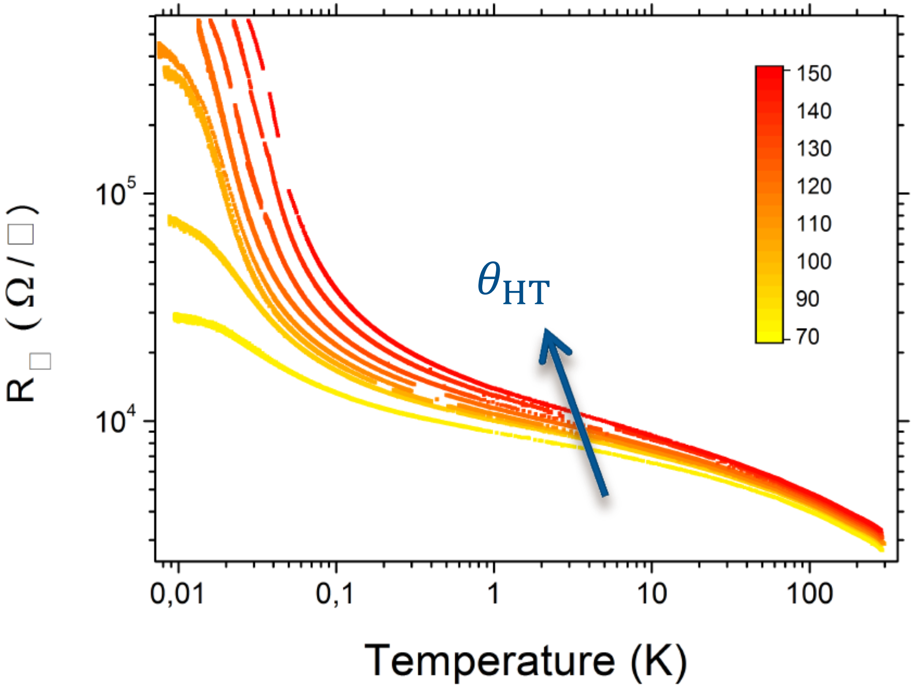


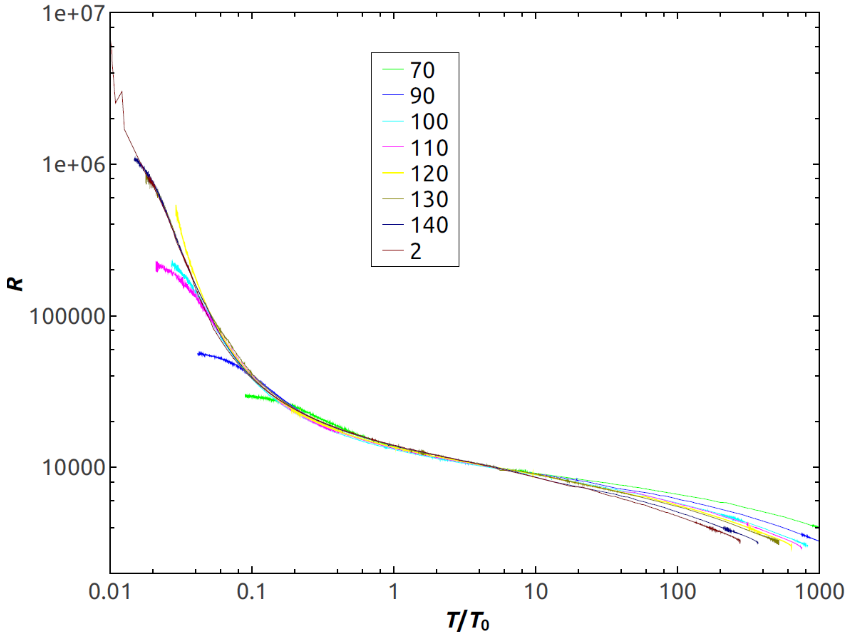
A *single* sample crossing the M2-I-T with heat treatment

INSULATING REGIME

Crossing the « Metal 2 » - Insulator transition

x =13.5% ; d =4,5 nm





Single parameter scaling works ⟶ see M. Ortuño's talk

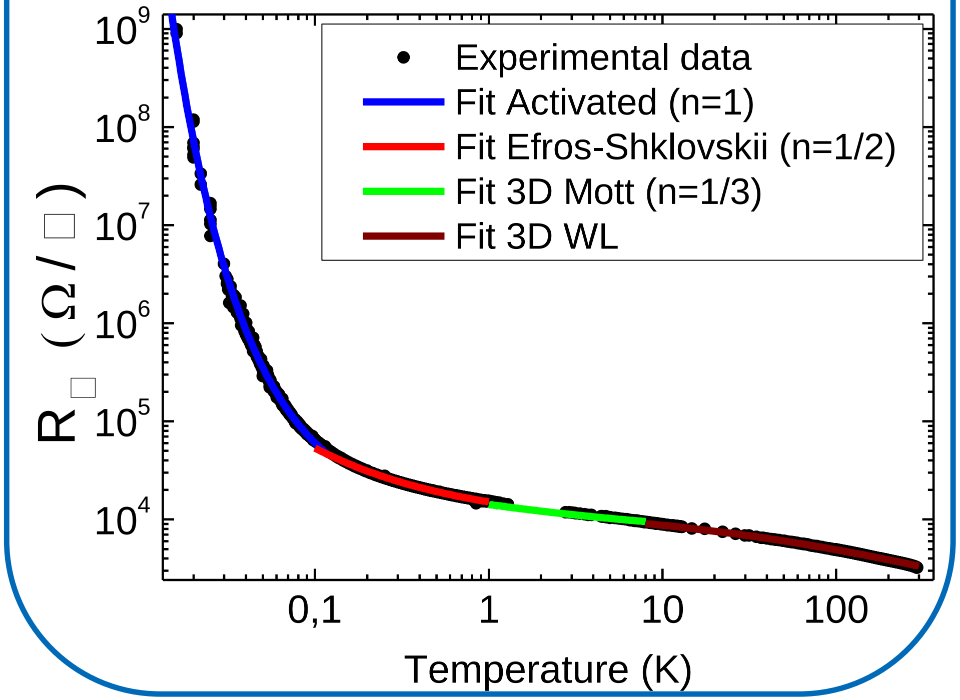
INSULATING REGIME

Different Localization Laws

$$R = R_0 e^{\left(\frac{T_0}{T}\right)^n}$$

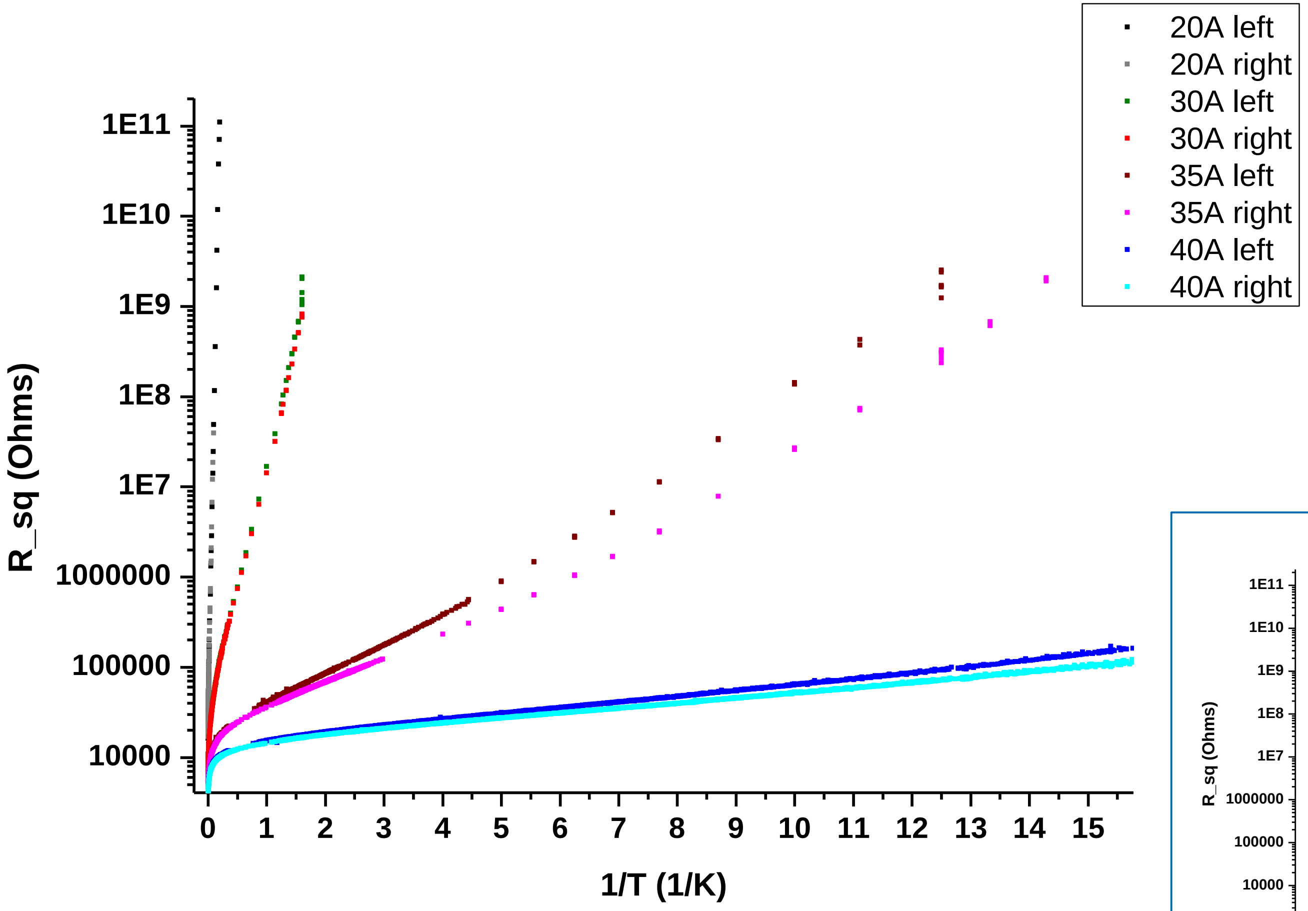
Insulator

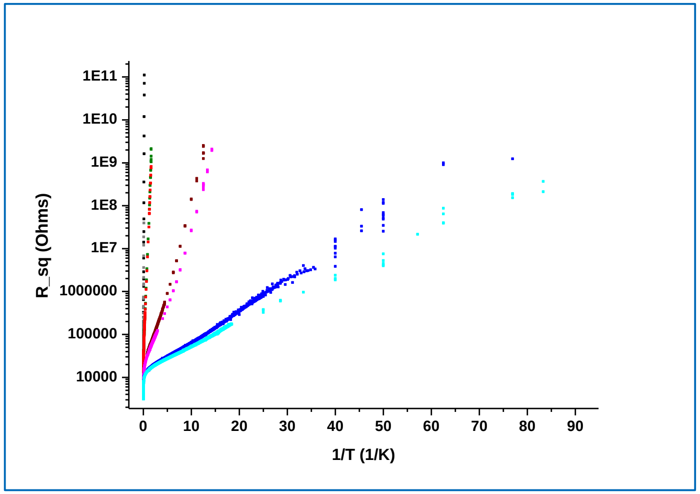
- 4 different regimes



INSULATING REGIME

Activated behavior at lowest temperatures

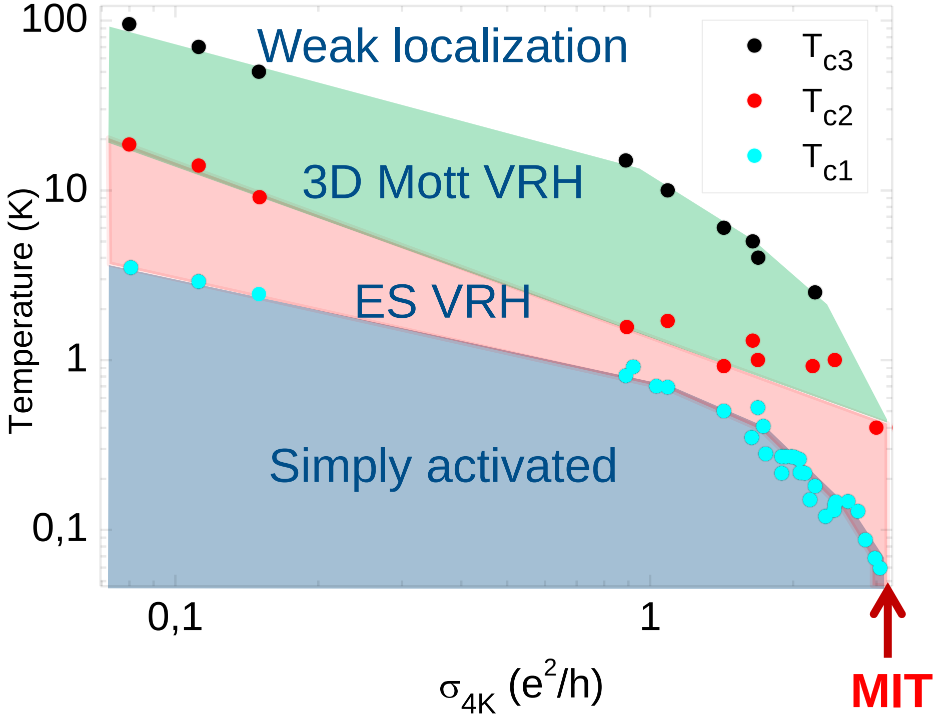




INSULATING REGIME

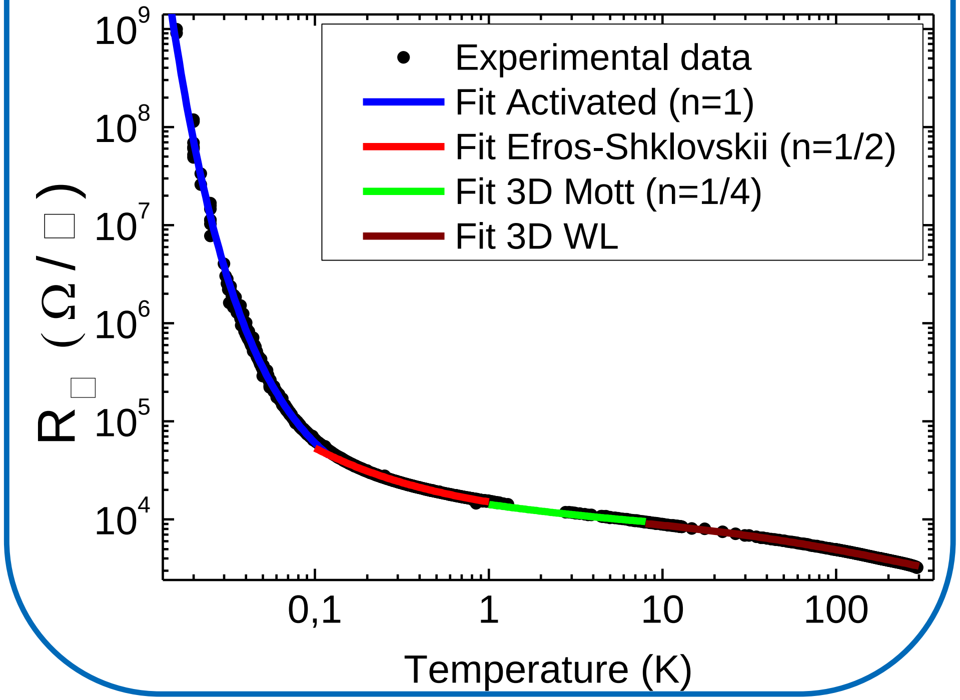
Different Localization Laws…

$$R = R_0 e^{\left(\frac{T_0}{T}\right)^n}$$



Insulator

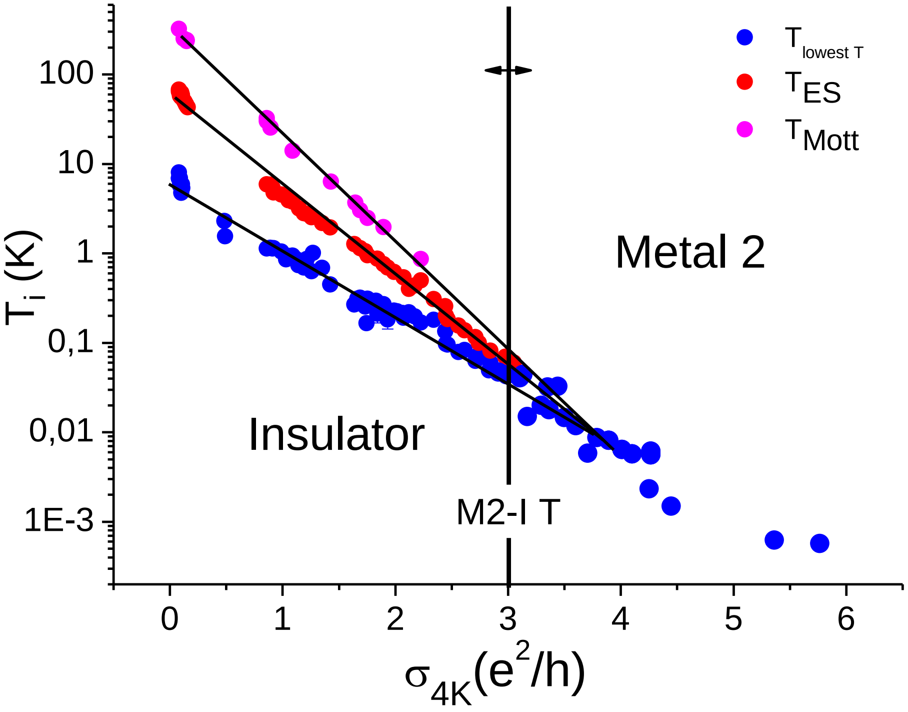
- 4 different regimes



INSULATING REGIME

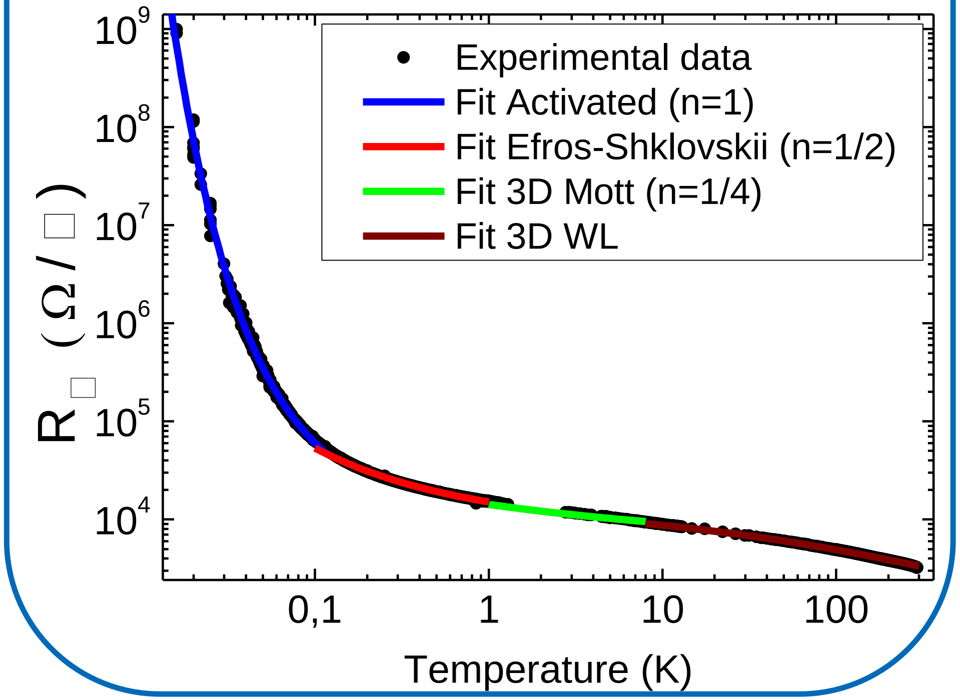
Different Localization Laws…

$$R = R_0 e^{\left(\frac{T_0}{T}\right)^n}$$



Insulator

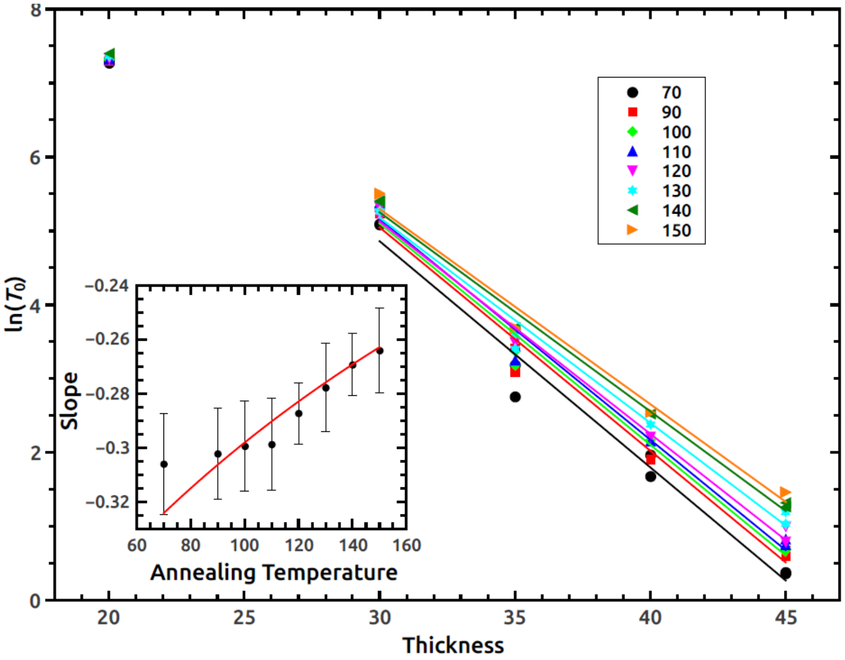
- 4 different regimes



INSULATING REGIME

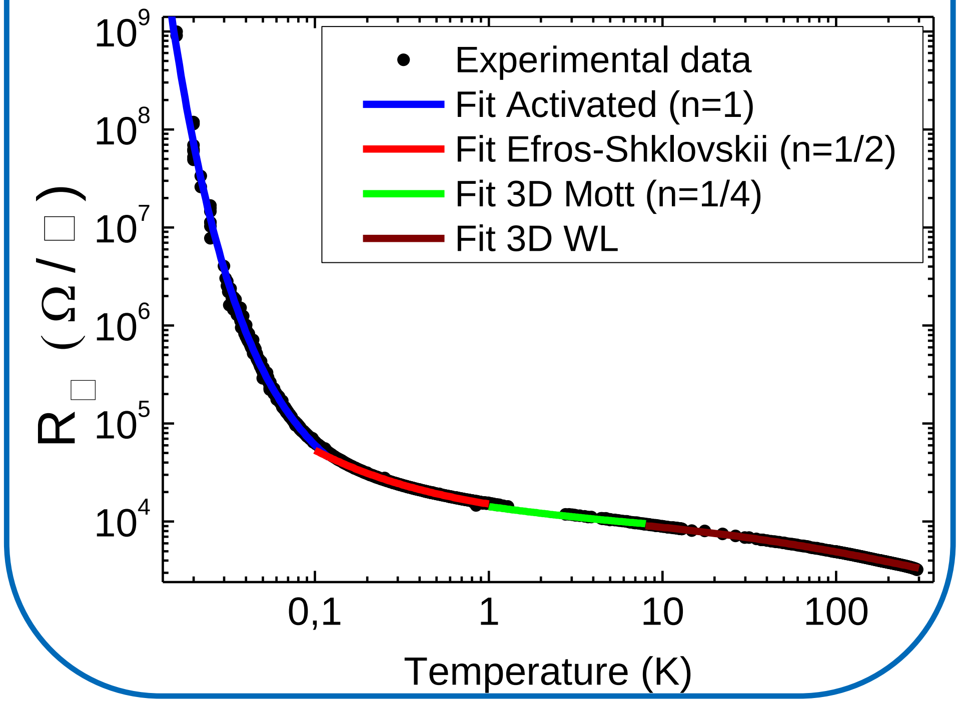
… or a diverging localization length?

$$R = R_0 e^{\left(\frac{T_0}{T}\right)^n}$$



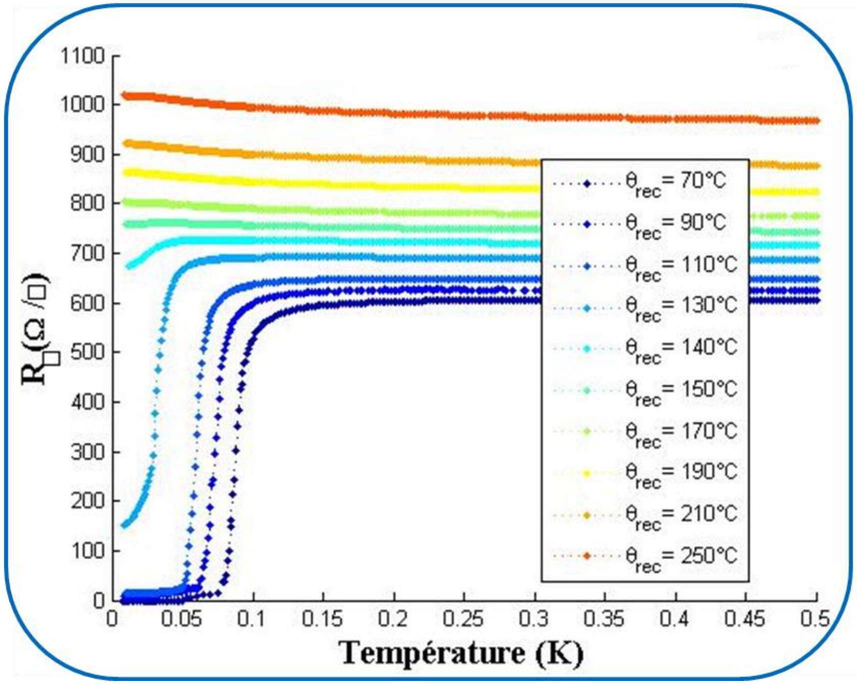
Insulator

- 4 different regimes

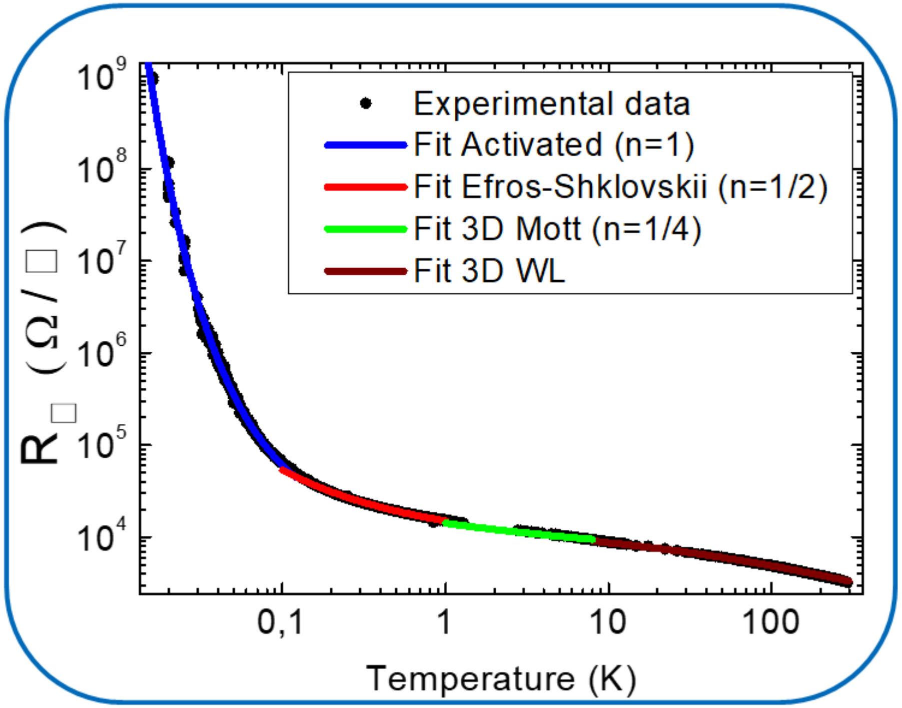


SUMMARY

- 2 dissipative phases observed close to the SIT



- Activated behavior in the insulating side



Wait for M. Ortuño's talk for the theory on the insulating side