The Abdus Salam International Centre for Theoretical Physics
50th Anniversary 1964-2014

2583-8

Workshop on Coherent Phenomena in Disordered Optical Systems

26 - 30 May 2014

Non-equilibrium Dynamics in "Electron Glasses"

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Non-equilibrium dynamics in « electron glasses »

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A. Frydman, Tal Havdala
Bar Ilan University (Israel)

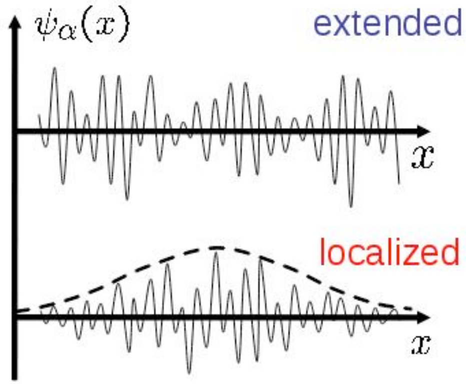
- Introduction
- *First period* : InO_x and granular Al prototypes
- *Second period* : thermal activation and new phenomena

Anderson localization of electrons

Disorder

1958 Anderson :

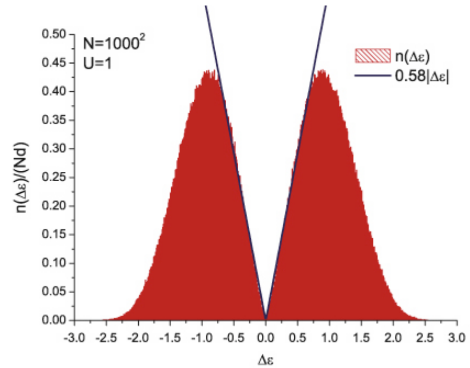
disorder localizes quantum states



Coulomb repulsion matters

1975 Efros, Shklovskii :

Coulomb repulsion adds constraints
on the arrangement of localized
electrons → coulomb gap



2006 Altshuler et al (Basko …)

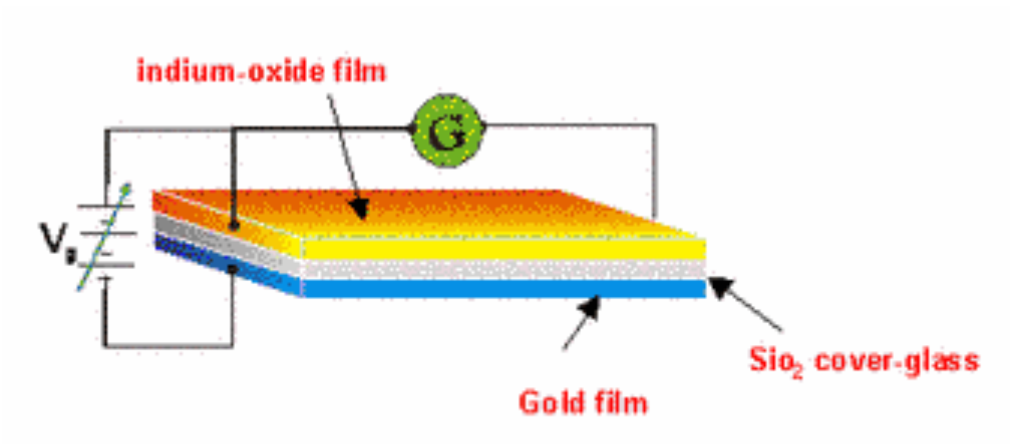
Many-body localization

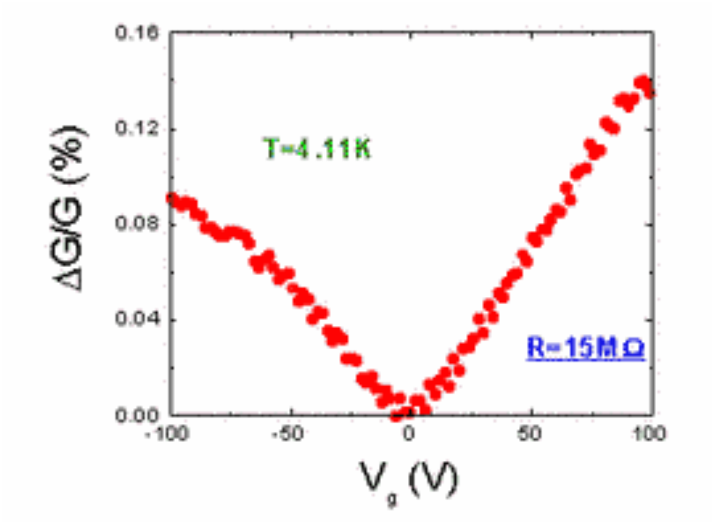
Electronic Coulomb glass ?

J. H. Davies, P. A. Lee and T. Rice (1982):

localized electrons + unscreened coulomb repulsion → highly correlated → new glass (finite T glass transition?)

Ben Chorin et Ovadyahu (1991): ***anomalous field effect and very slow relaxation of conductance in insulating indium oxide***

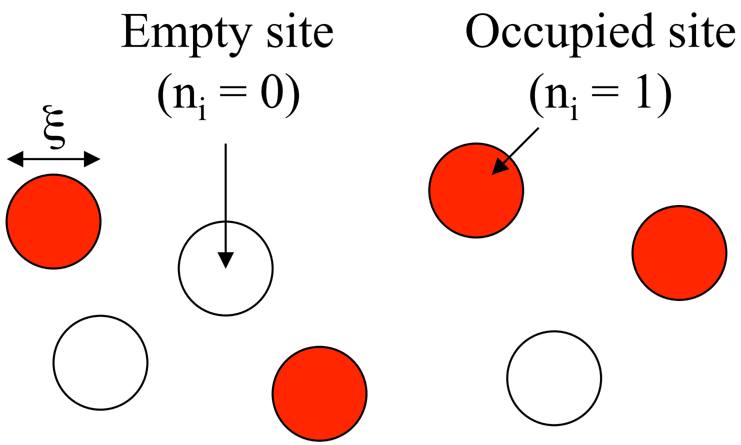


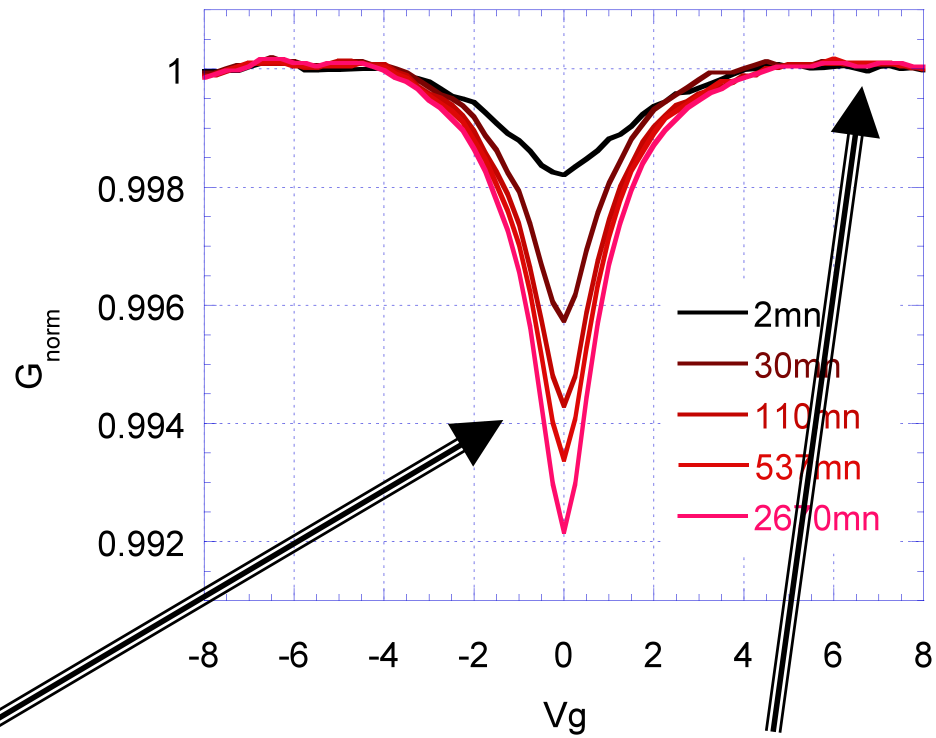


Manifestation of the electron (Coulomb ?) glass in indium oxide …

Electron Coulomb glass interpretation

Electron Coulomb glass model





<u>Fixed gate voltage Vg=0</u>:
system proceeds slowly to the equilibrium state (of minimum conductance)

After fast gate voltage change:
system in a highly excited state (higher conductance)

A few words on the theory side

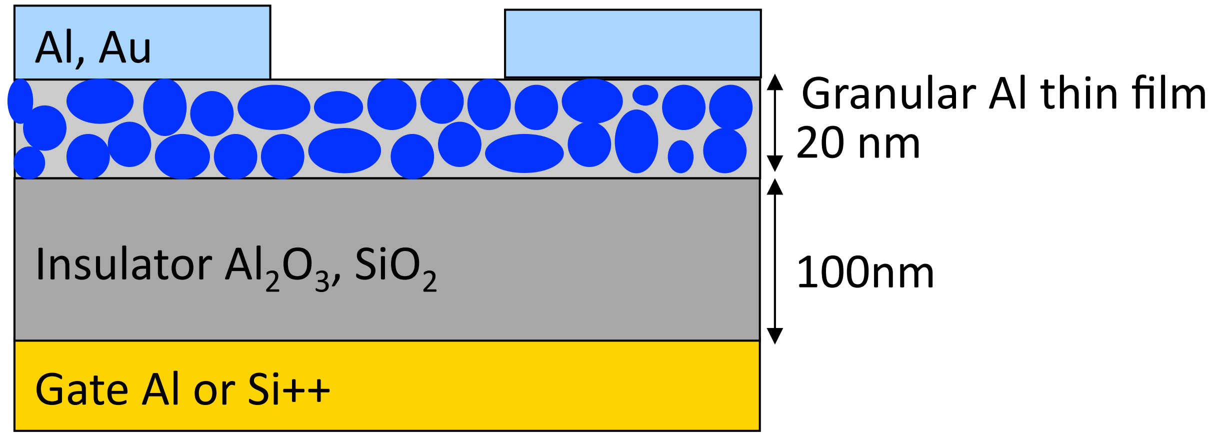
- Analytical approach (M. Muller et al., Dobrosavljevic et al.)

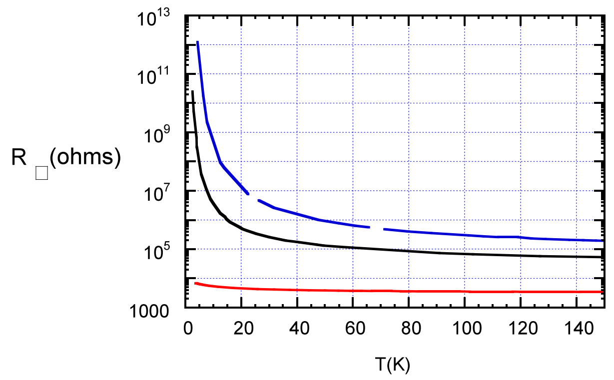
  - mean field → glass transition at T_g

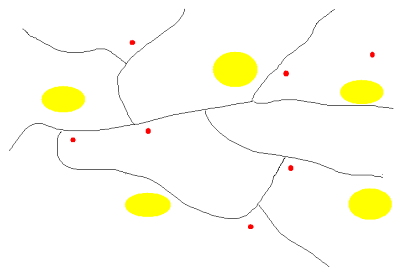
- Monte-Carlo simulations :
  - Coulomb repulsion slows down relaxation to equilibrium
  - during relaxation: diffusive carriers get localized, effective temperature decreases
  - no observation of T_g (on site disorder)
  - Limitations: not too low T, not « very » long times, classical limit (no quantum tunneling)

- *Introduction*
- *First period* : InO_x and granular Al prototypes
- *Second period* : thermal activation and new phenomena

Experiments on granular Al films





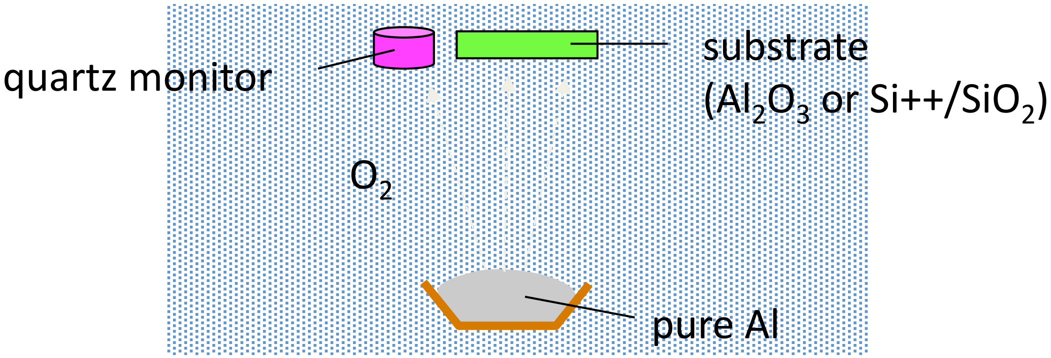


- Electrical conductance measurements

- Relaxation after excitation
    - to excite apply a gate field, a non ohmic bias, a higher temperature excursion, an E.M. radiation

Insulating granular Al films

Reactive evaporation : Al + O_2

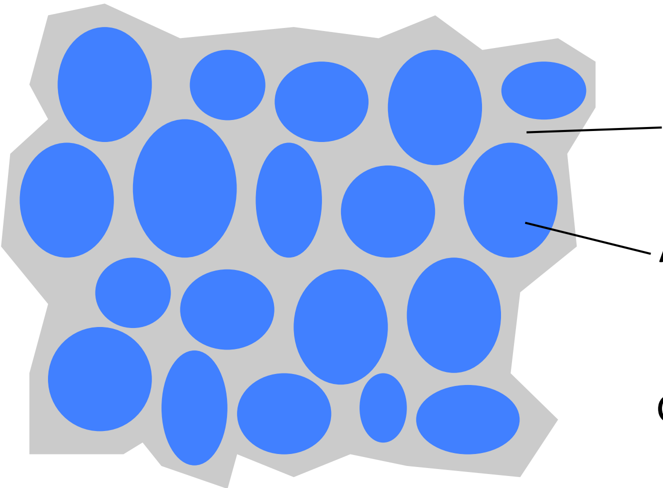


Parameters :

- O_2 ($p \cong 2 \times 10^{-5}$mbar)
- Al evaporation rate ≅ 2Å/s

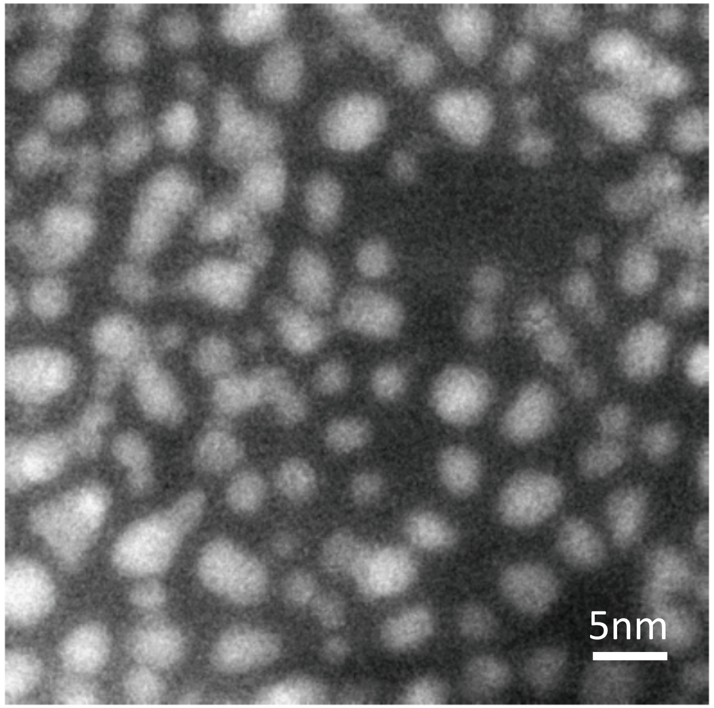
Structure of the films

Crystalline Al grains separated by an amorphous alumina tissue phase



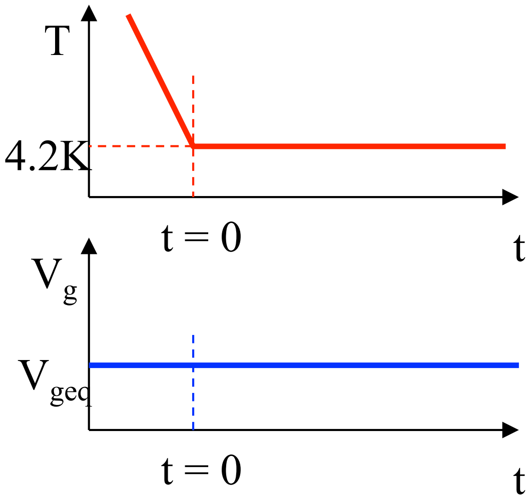
Grains size 2-4nm

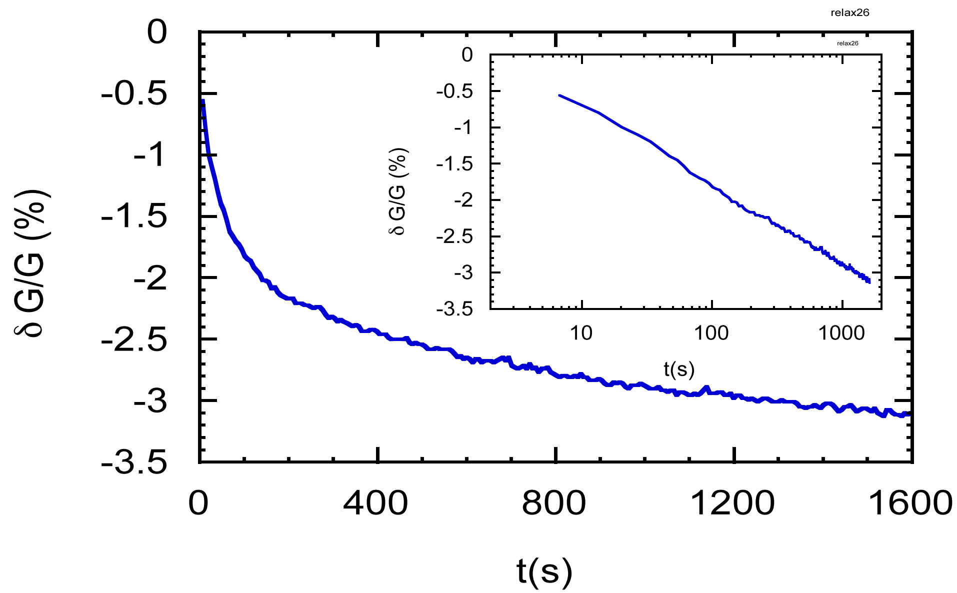
TEM picture

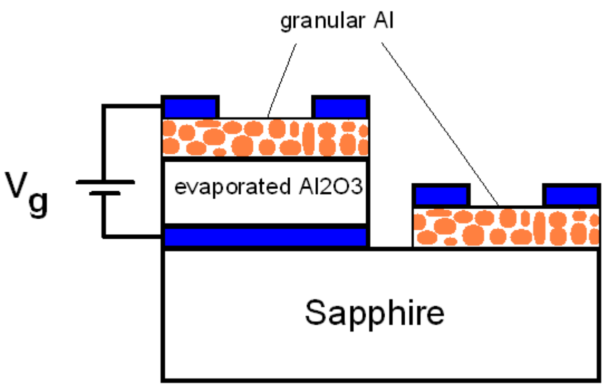


Out of equilibrium effects

Never ending slow conductance relaxation after a quench

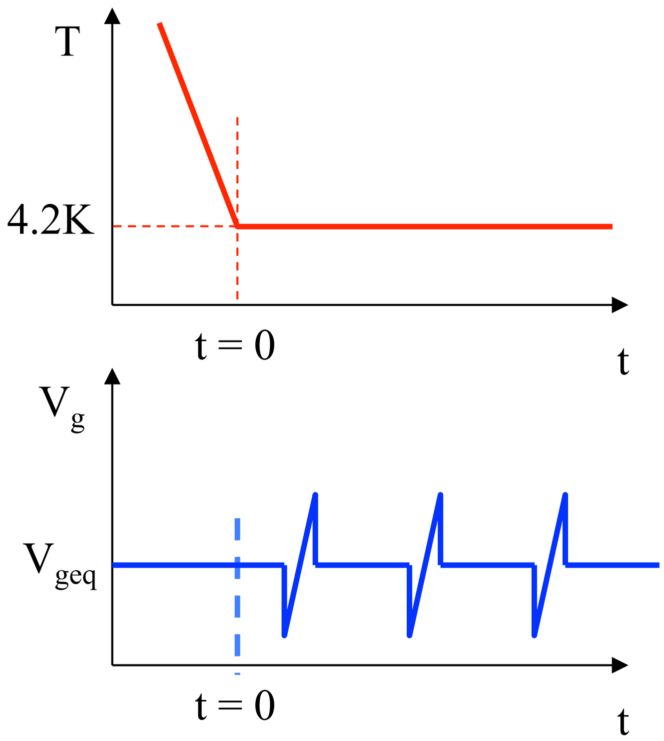




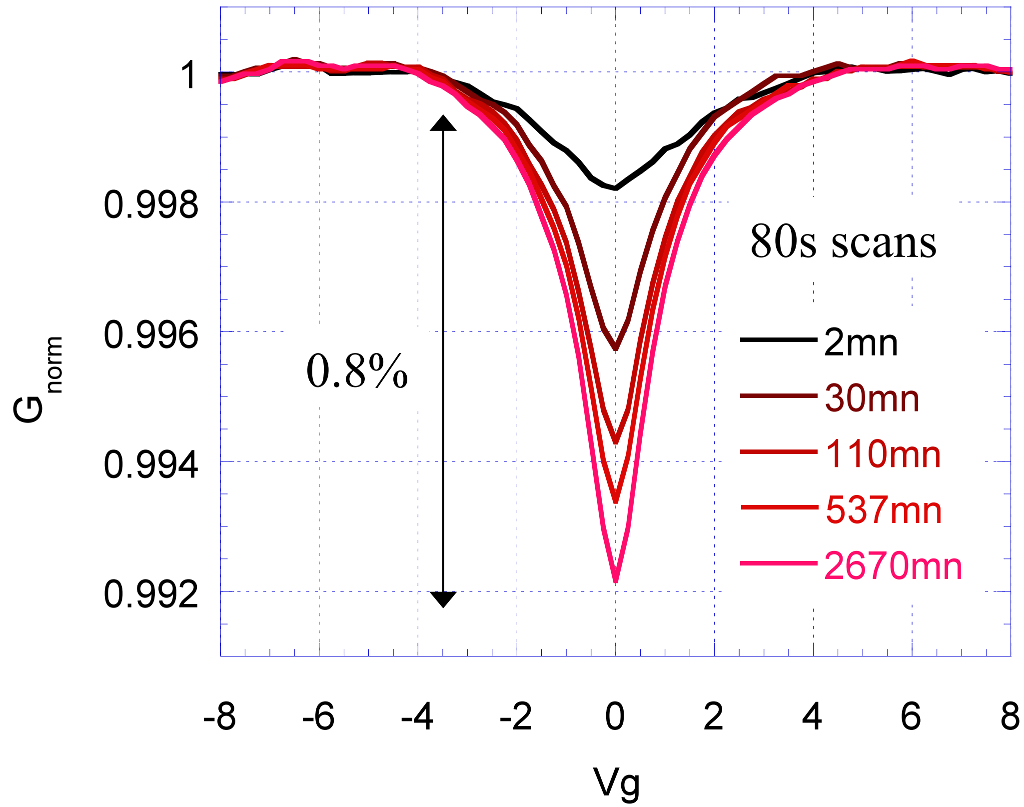


Out of equilibrium effects

G(t, V_g) after a quench at 4.2K



$R_\square$=30MΩ at 4.2K



- Field effect anomaly (the "cusp" or "dip")

-Amplitude grows like Ln(*t*)

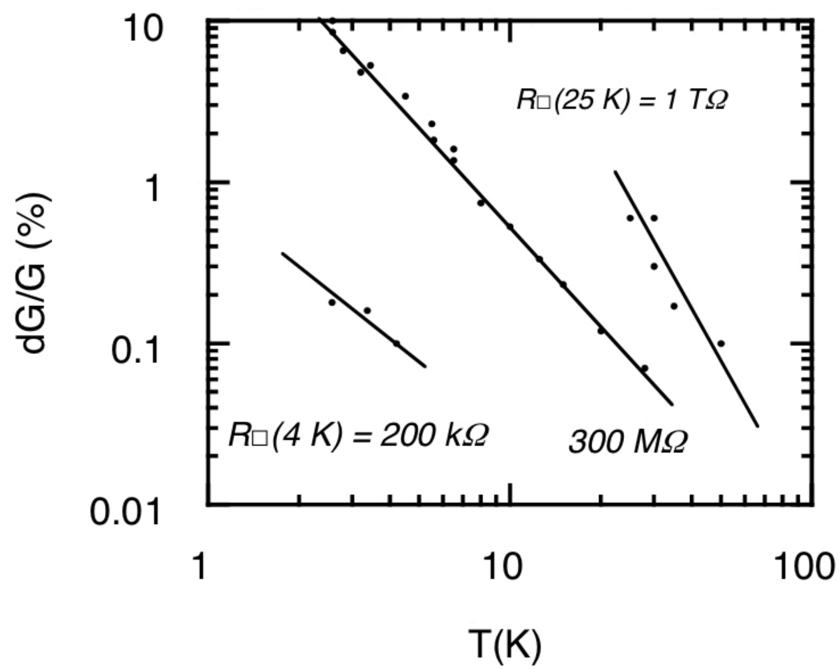
+ thermal memory

Is this a small effect ?

- the anomaly is always seen in gran Al insulating films

- it is most prominent (in %):

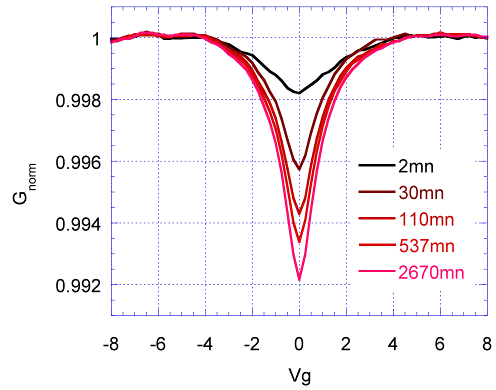
→ at low T (most measurements at 4K)
→ in more insulating samples
→ when measured fast



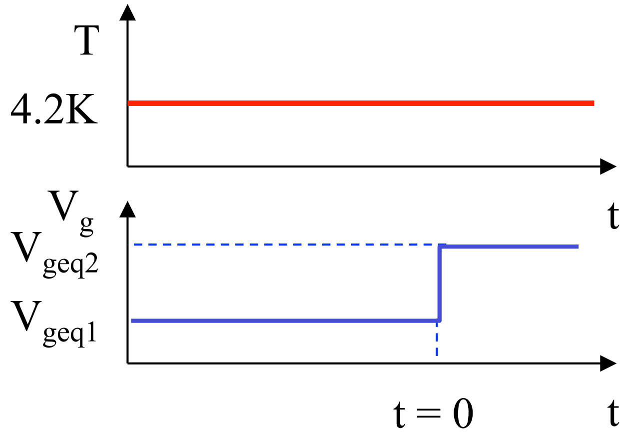
- for practical reasons we study samples were the anomaly is not so large (≤1%) but it can be a large effect (several tens of %)

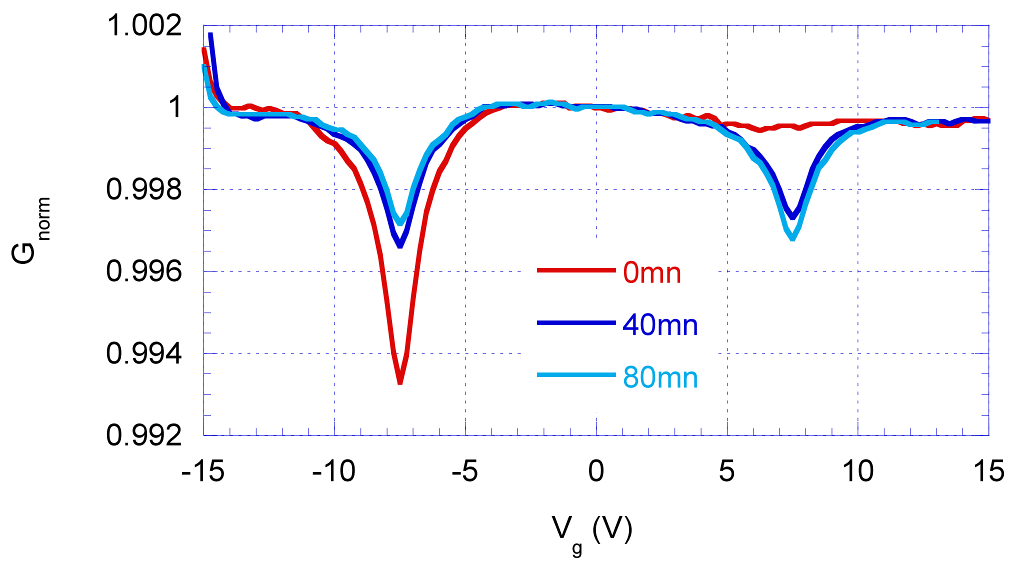
Cusp dynamics

Recall: after a cooling



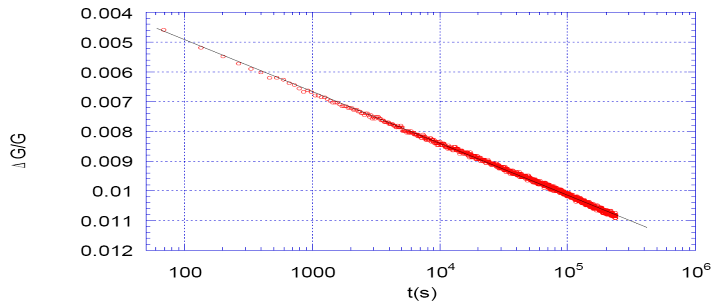
After a gate voltage change:





Formation of a new dip and erasure of the old one:

$\Rightarrow \Delta G \sim -\ln t$? but see later …

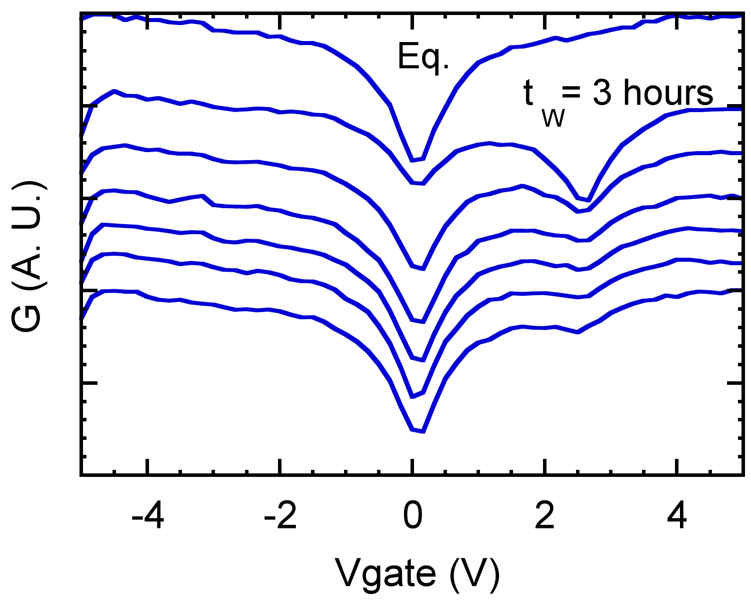


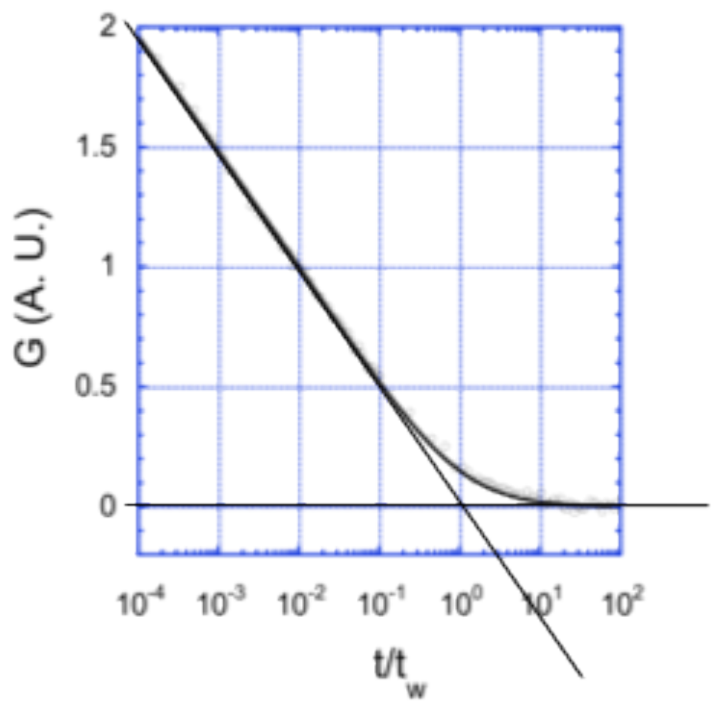
Is the dynamics activated ?

Is the dynamics accelerated when T is increased ? (it would explain why the dip becomes very faint)

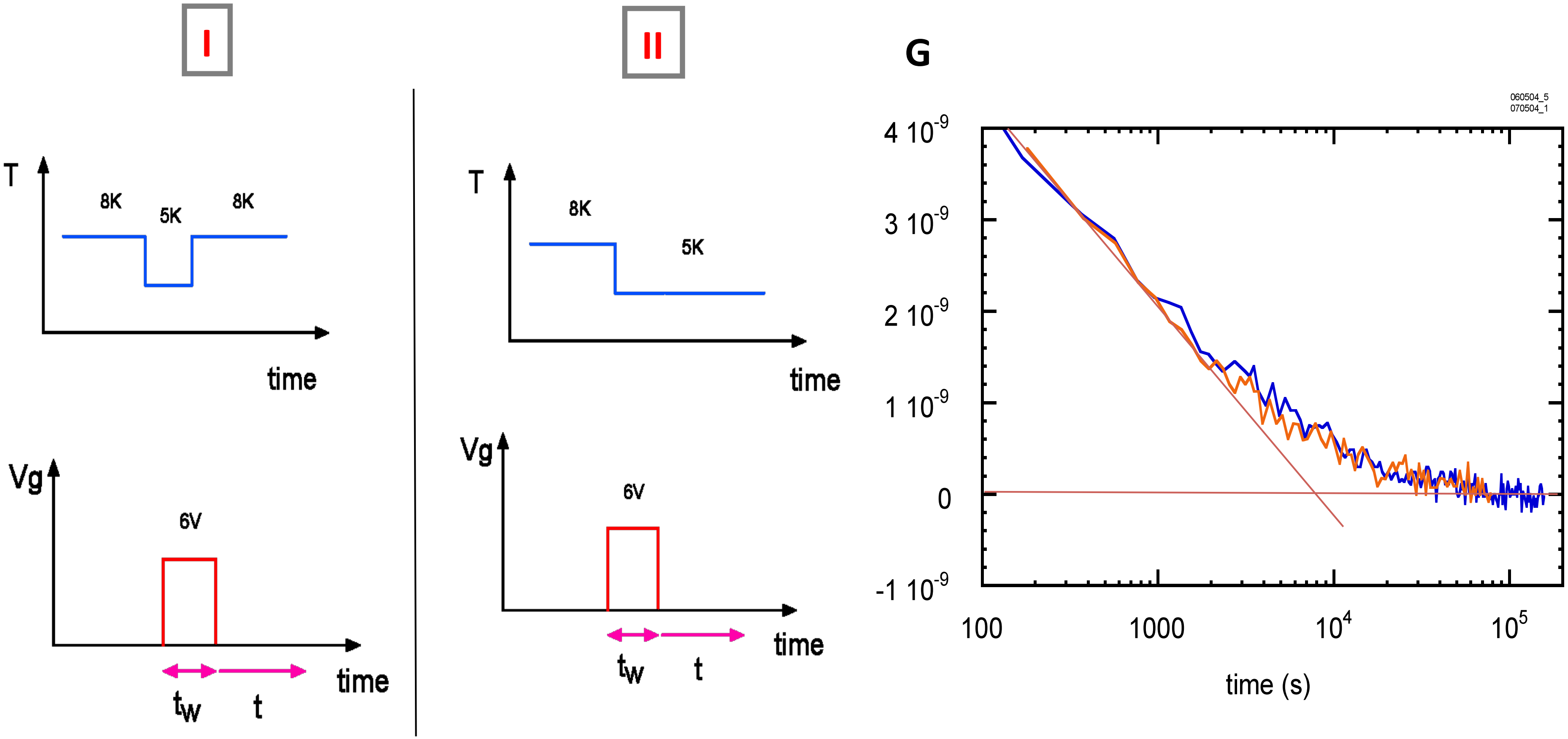
But how to detect a change of the dynamics if it has no characteristic time ?

→ look at the erasure time of a previously formed dip





Is the dynamics activated ?

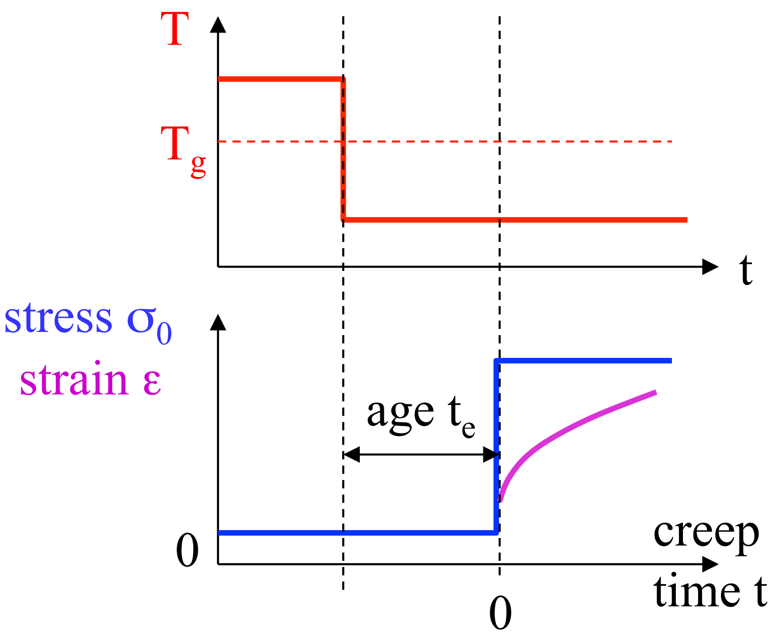


–> dynamics is not activated (in this T range)

If it is a glass … does it age ?

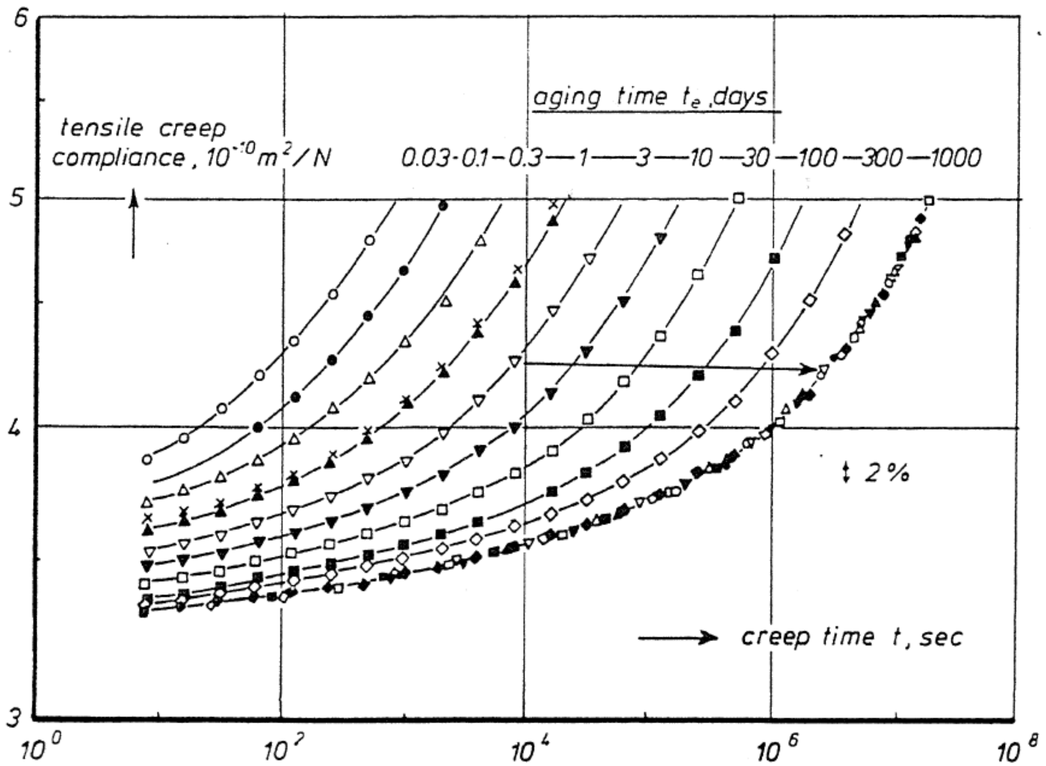
AGEING:

Ex: creep tests on polymers



The dynamics depends on time: the « older » the system, the slower the response to a stimulus !

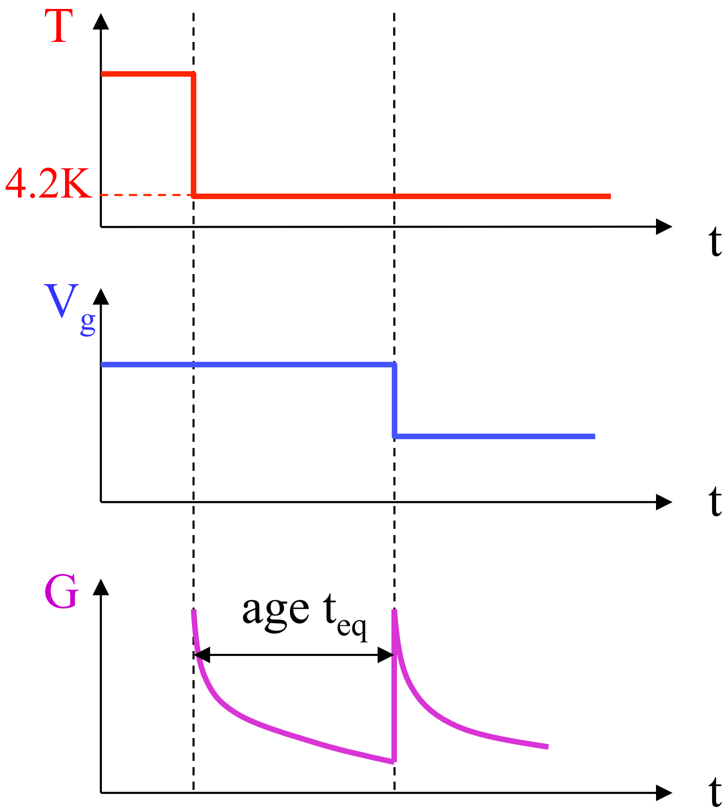
Creep compliance (t) = ε (t) / σ_0

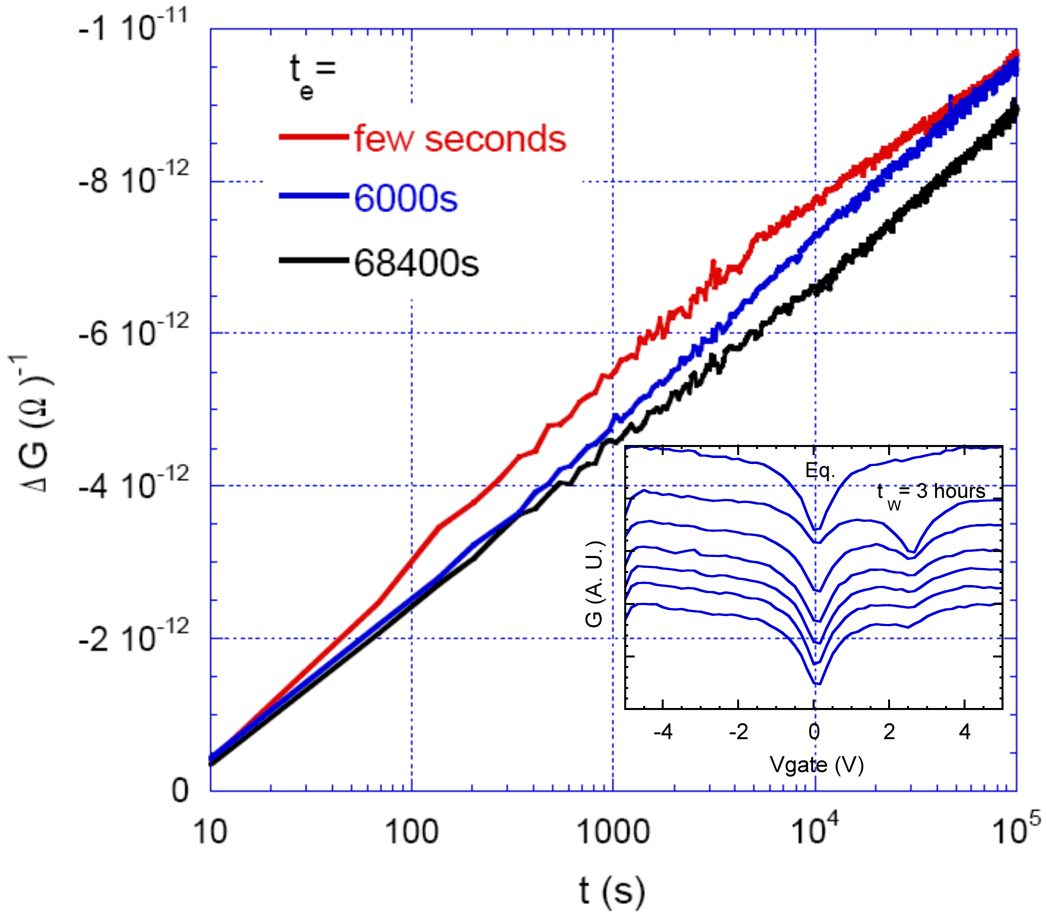


PVC quenched from 90°C to 40°C (T_g=80°C)

L.C.E Struik, 1978

Standard ageing protocol (1)





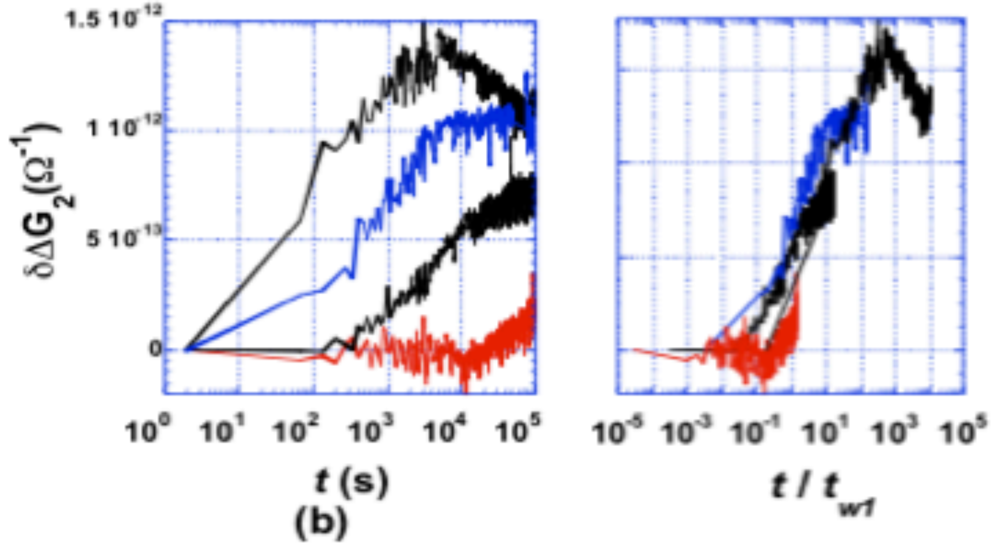
New dip growth: NOT like Ln(t) when t_{eq} NOT very large

(i.e. when system has not already aged !)

Standard ageing protocol

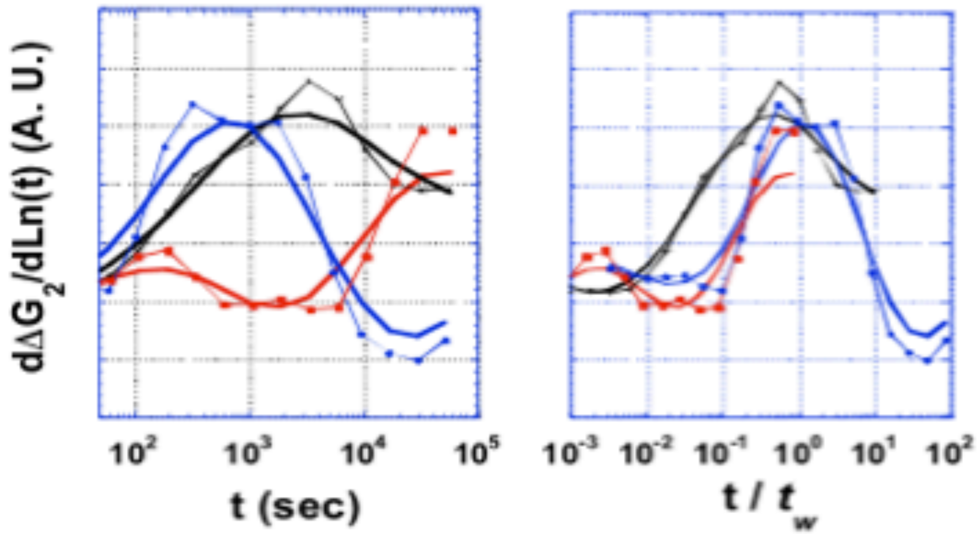
Departures from pure Ln(t) relaxation scale with t_{w1}

(b)



Effective relaxation time distribution $d\Delta G2/d\mathrm{Ln}(t)$ scales with t_{w1}

(c)

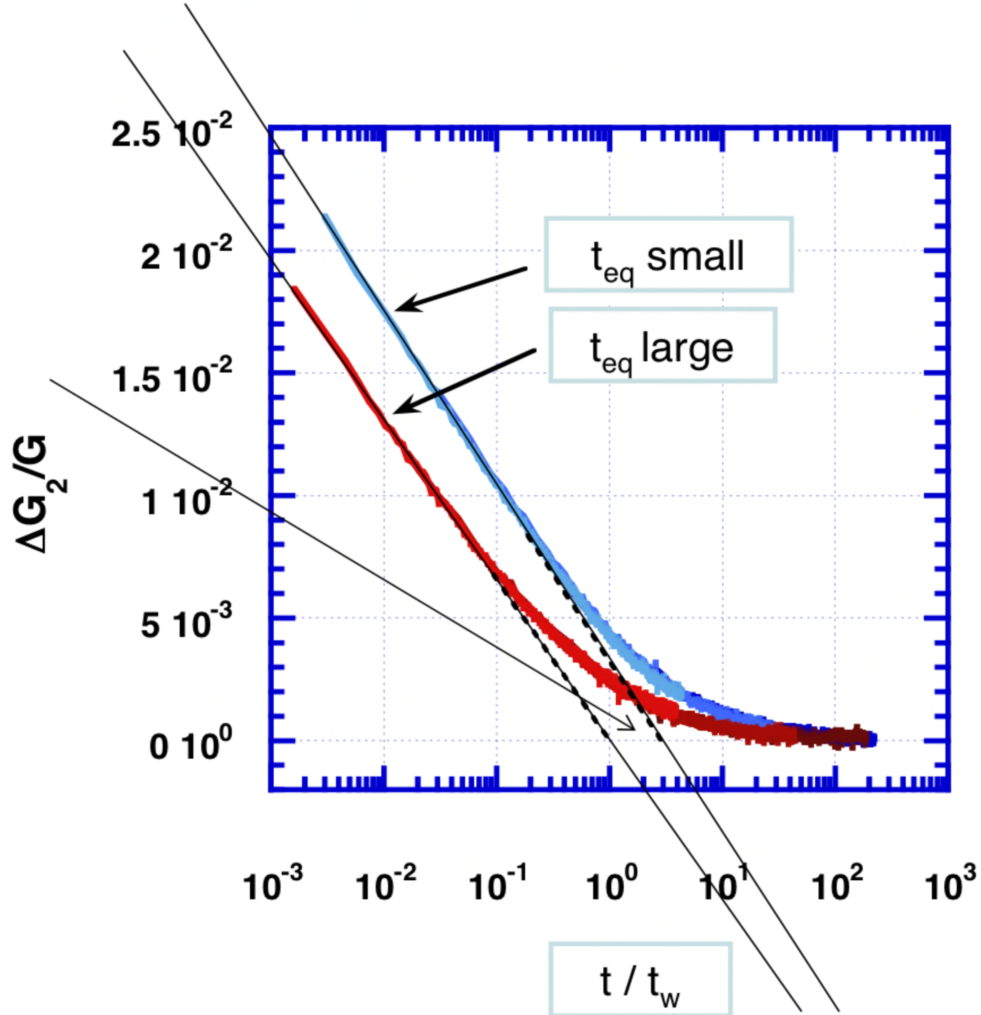


Ageing in the two dip protocol

Indeed when t_{eq} is small:

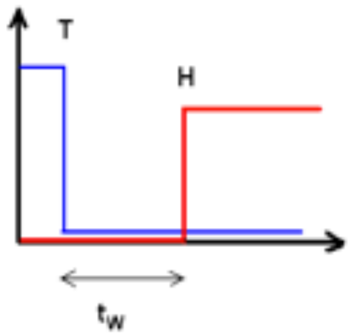
$t_{erasure} > t_w$

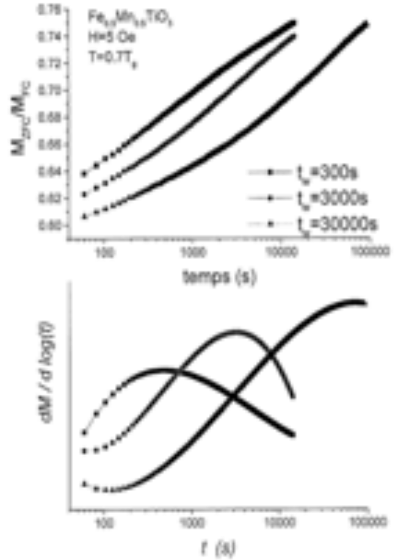
(here $t_{erasure} = 3\ t_w$)



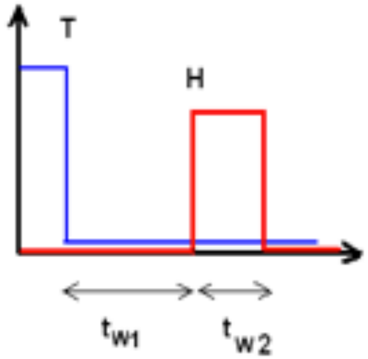
equivalent spin glasses protocols

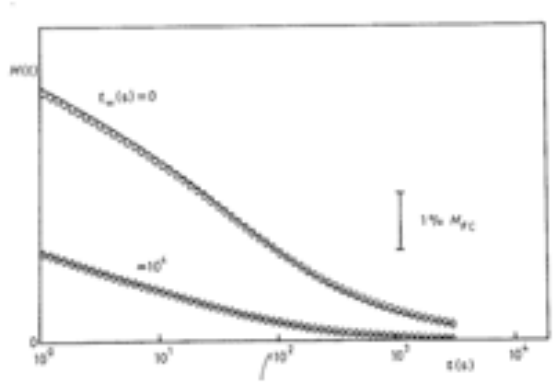
* Zero field cooled relaxation (ZFC):





* Isothermal remanent magnetization (IRM):





Universal behaviour ?

- Very strong similarity between *amorphous* InO_x and *granular* Aluminium

- Similar effects observed in :
  - In_2O_{3-x} , Tl_20_{3-x}
  - Granular Al
  - Ultra thin Pb, Bi films, thin Be films
  - Signs in icosahedral insulating quasicrystal i-AlPdRe
  - Discontinuous metal films Au, Ni, Ag, Al etc (?)

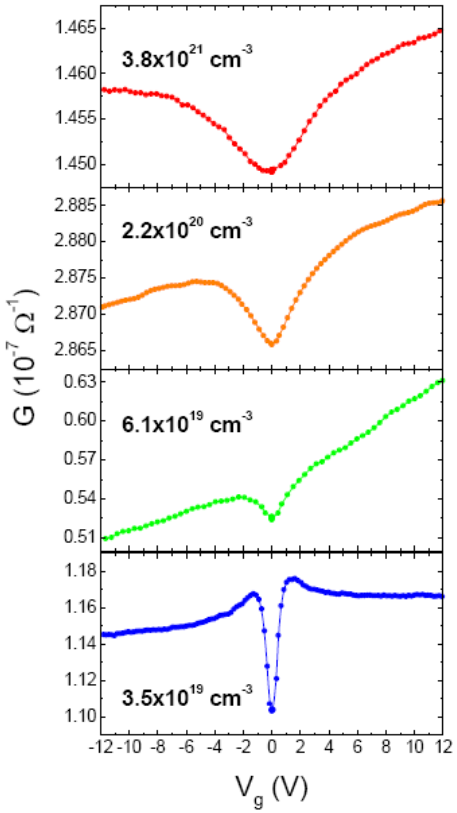
Universal behaviour ?

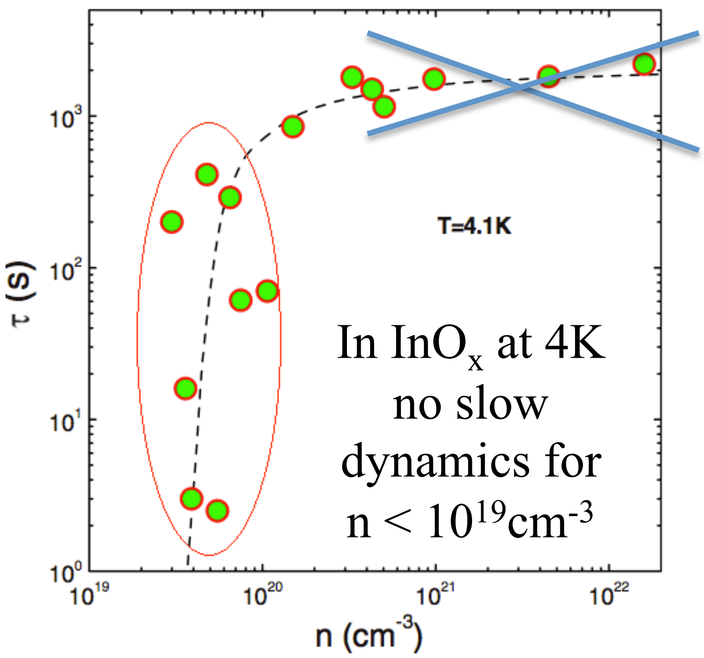
No similar phenomenology in doped semiconductors*, WHY ?

*But see Popovic et al.

Suggestion (*Ovadyahu, HUJ*):

« Because high enough carrier density (or number of carriers in a localization volume) is necessary »





- *Introduction*

- *First period : InO_x and granular Al prototypes*

- *Second period* : thermal activation and new phenomena

Why study other systems ?

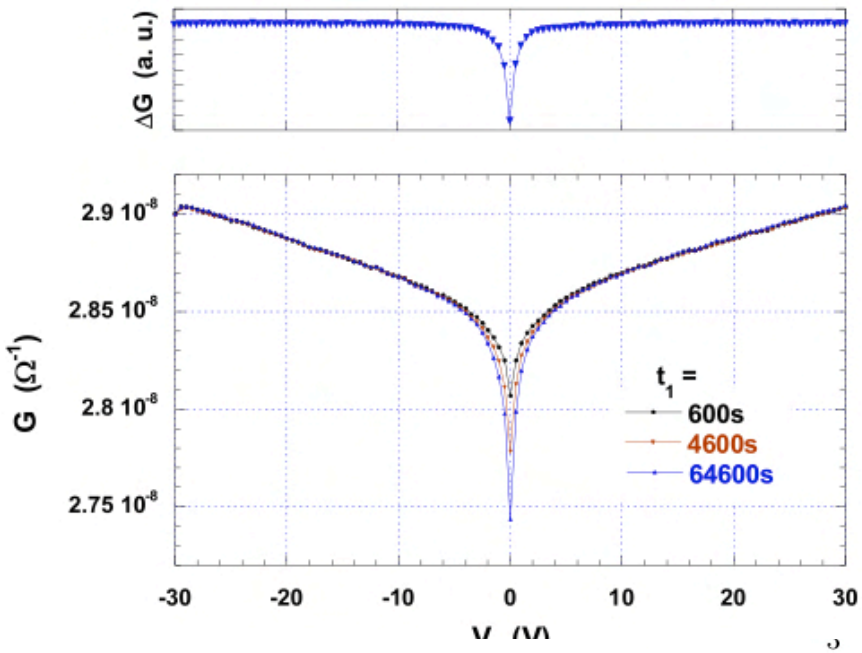
« … and the materials we've heard about in this conference (MoGe etc…) could also be good candidates ! » → *Study $Nb_{1-x}Si_x$*

Adkins et al (1984) :
discontinuous gold films :
- activated dynamics ?
- field effect seen at high T ?

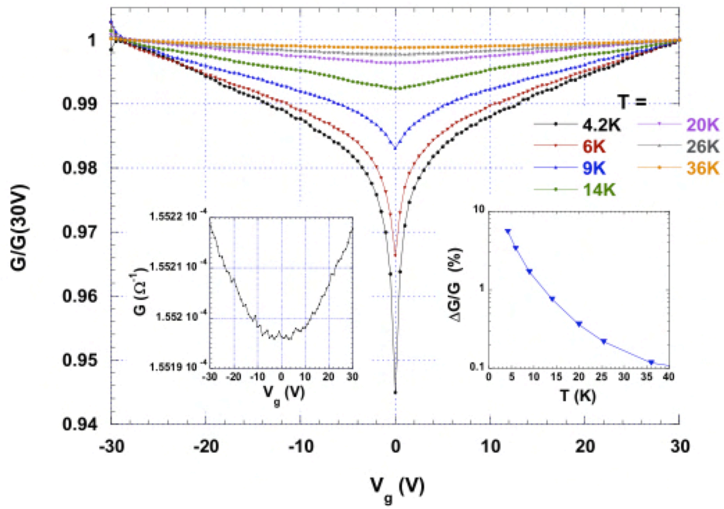
→ *Study discontinuous metals*

$Nb_{1-x}Si_x$

Growth of a field effect anomaly after a quench

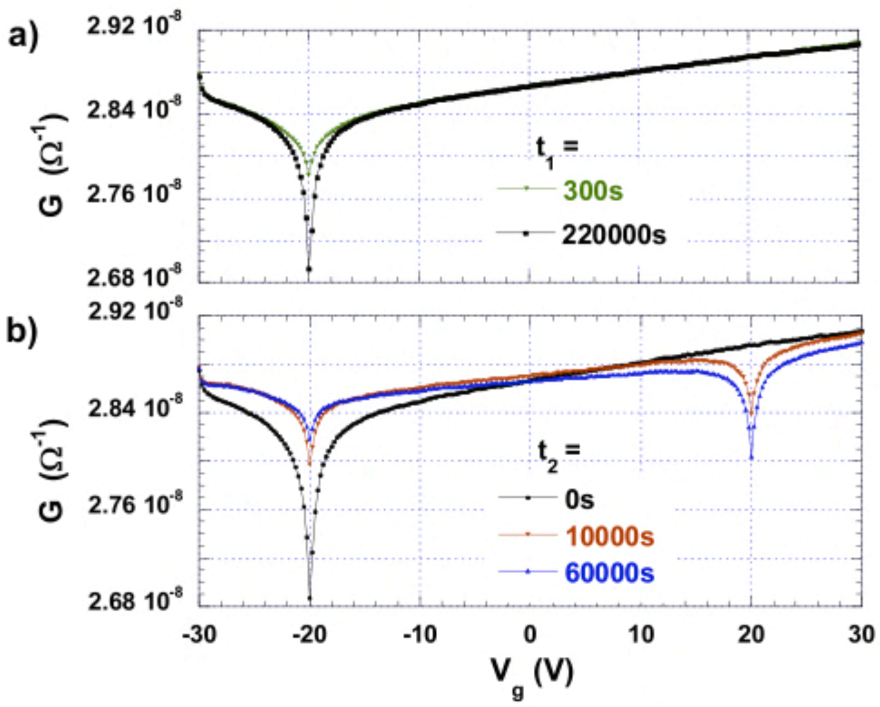


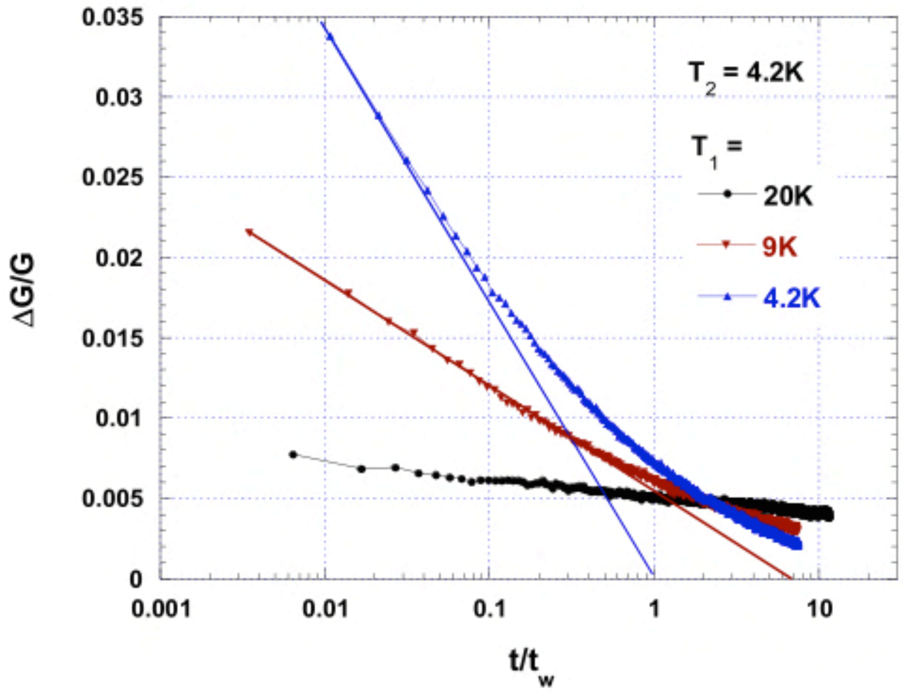
T dependence of the field effect anomaly



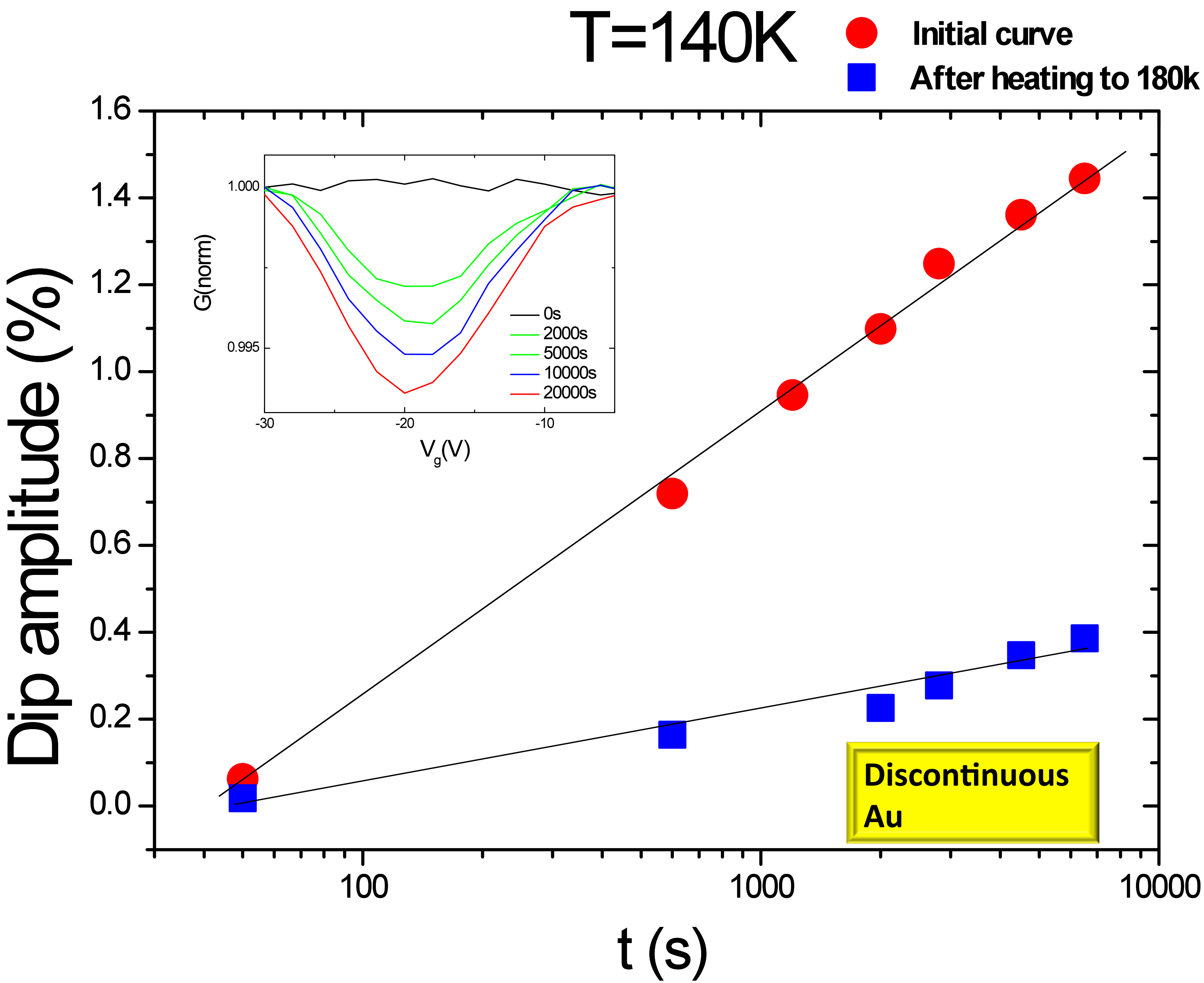
$Nb_{1-x}Si_x$

Demonstration of the T dependent dynamics :

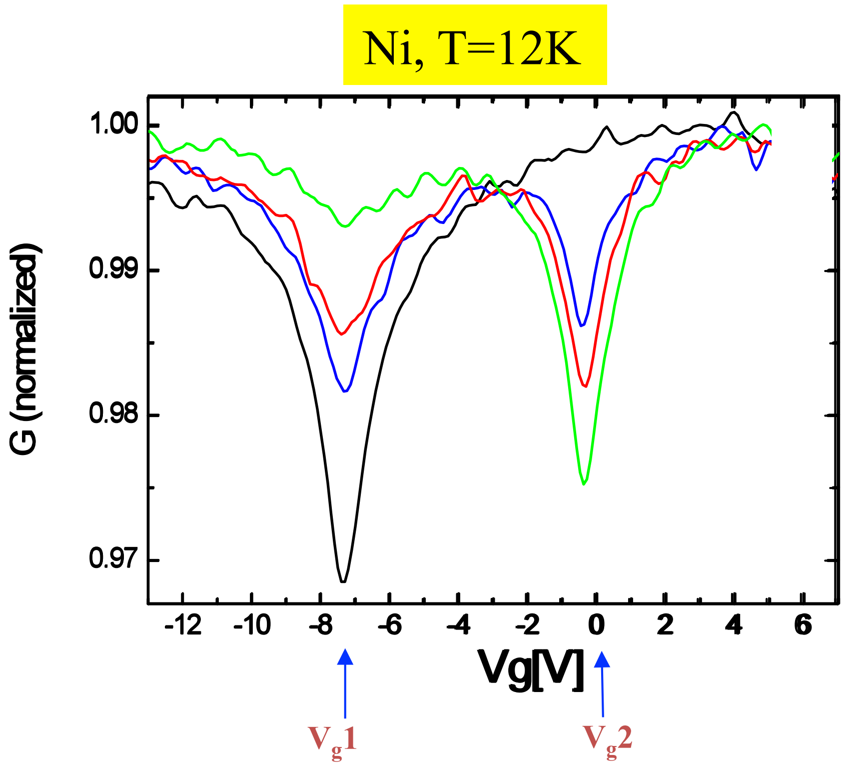


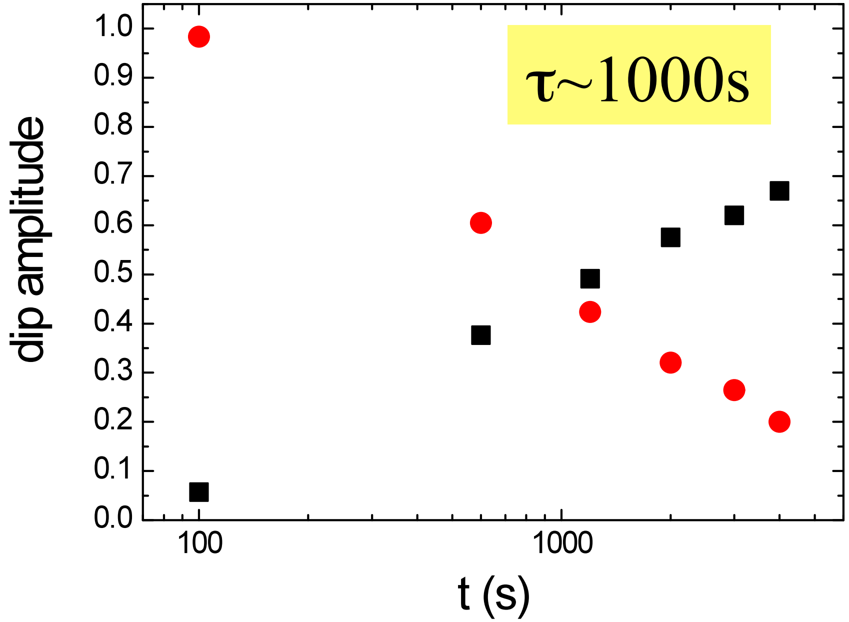


Discontinuous metals: activation



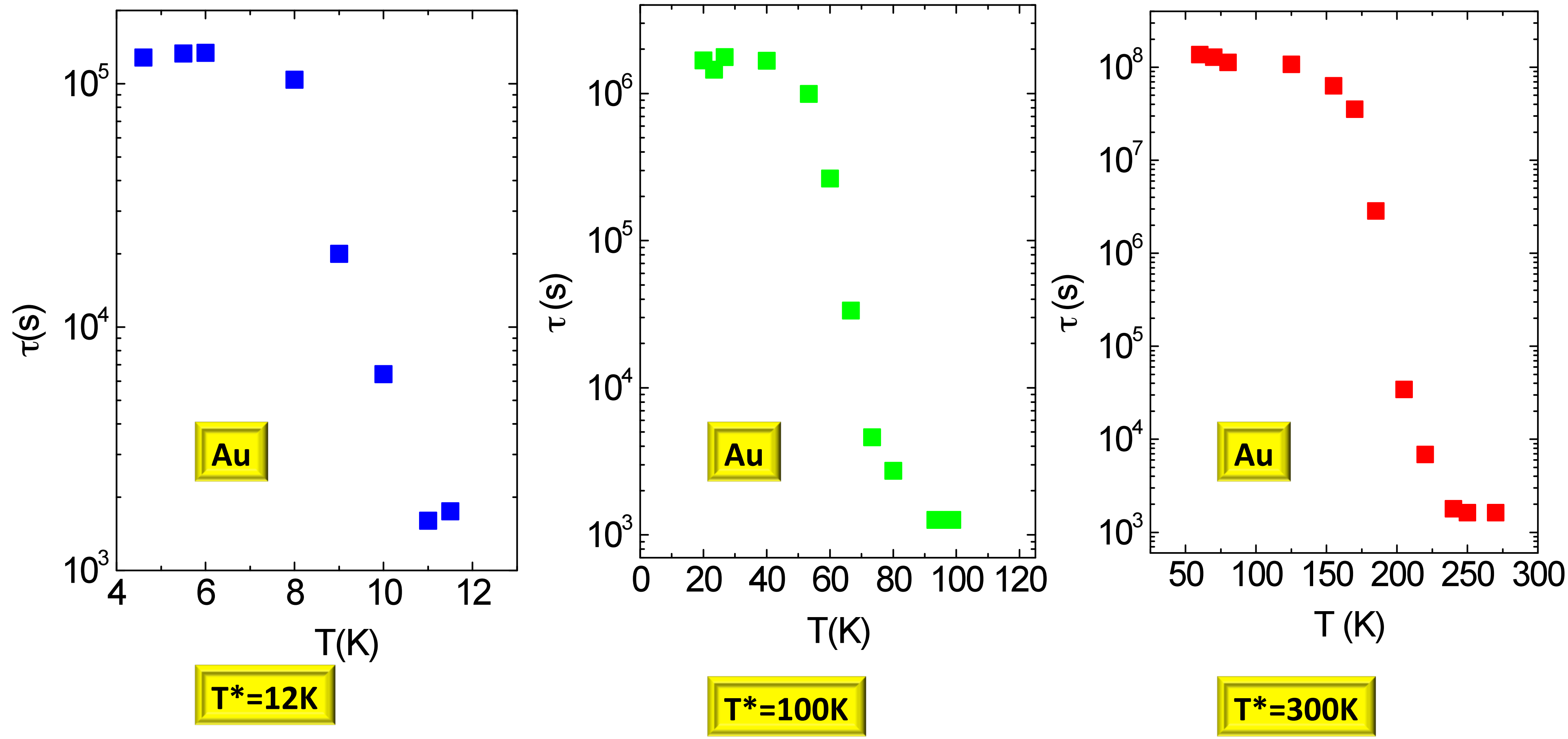
Discontinuous metals: activation



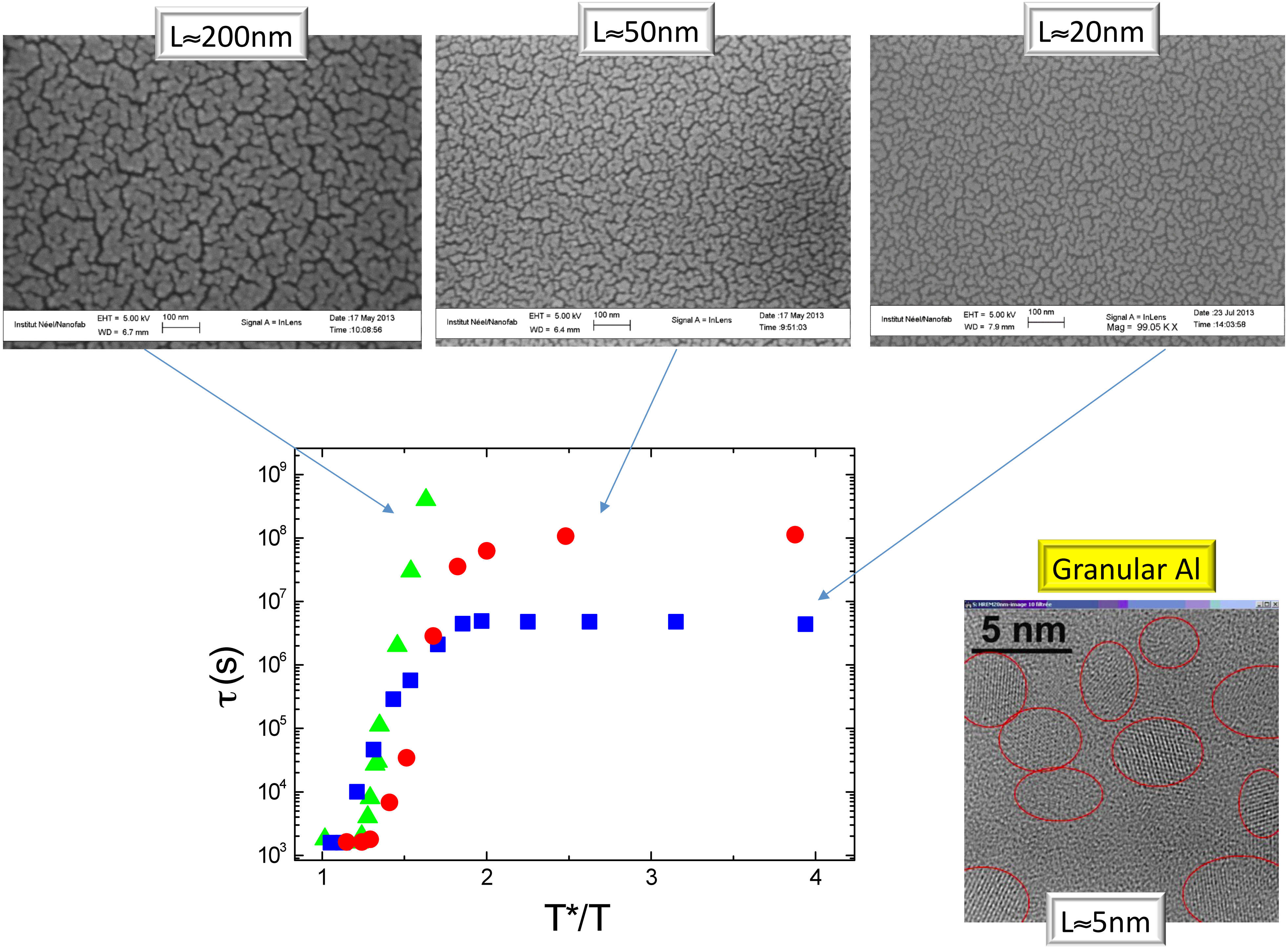


Recall: to determine the T dependence of the dynamics: V_{g1} at T* and Vg2 at T ≠ T* (here T<T*)

Discontinuous metals: activation



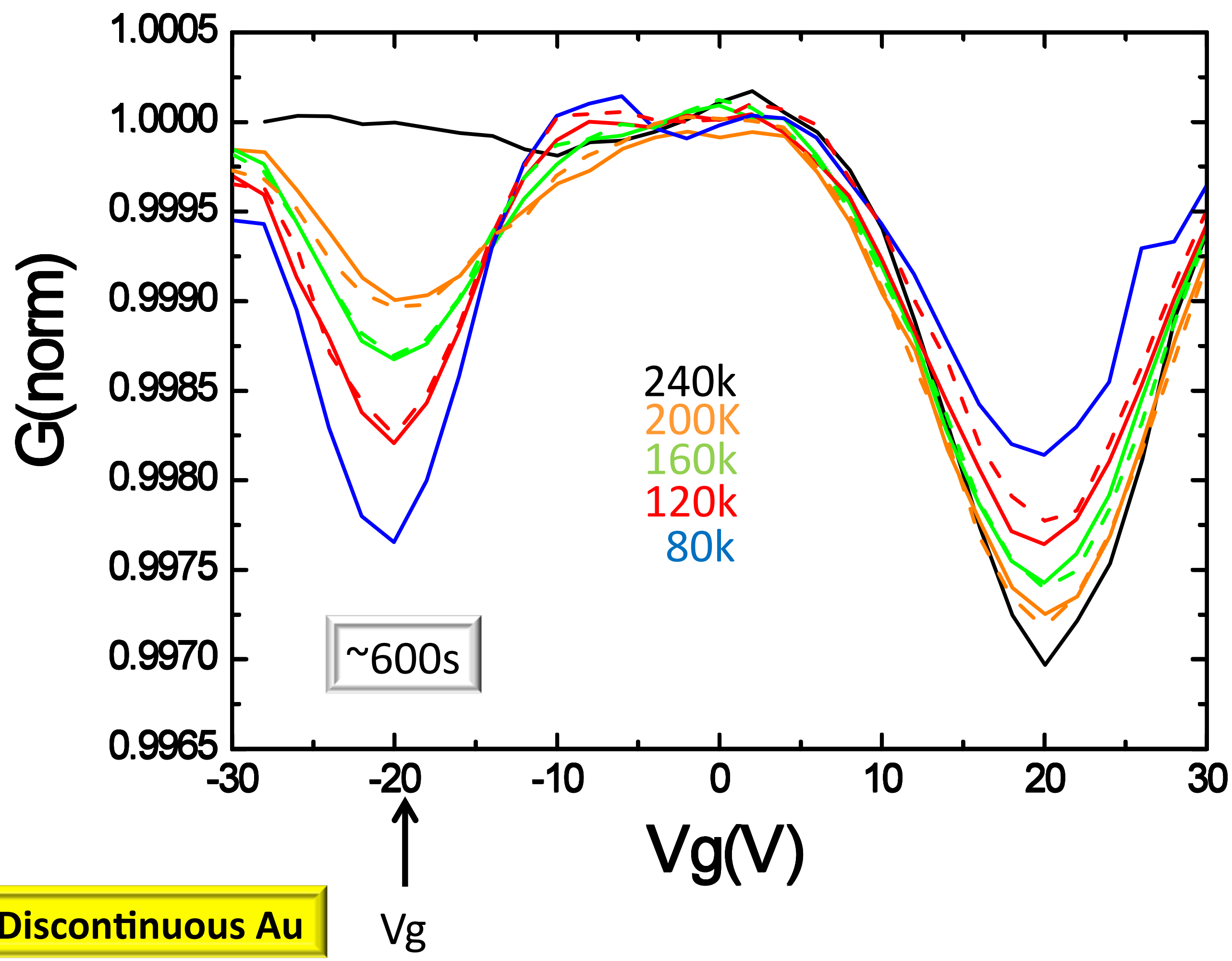
$$\tau = f\,(T^*/T)$$

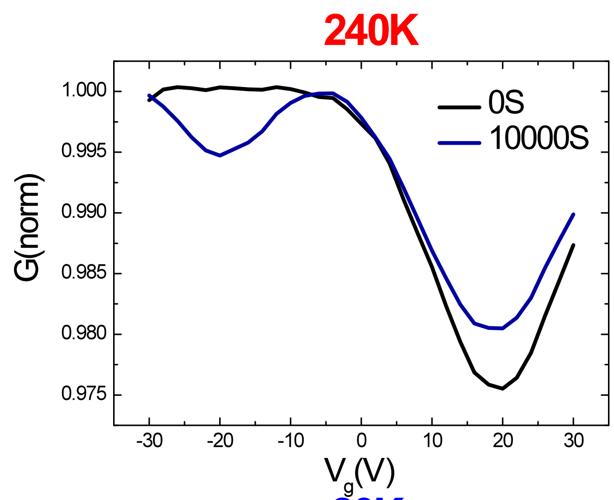


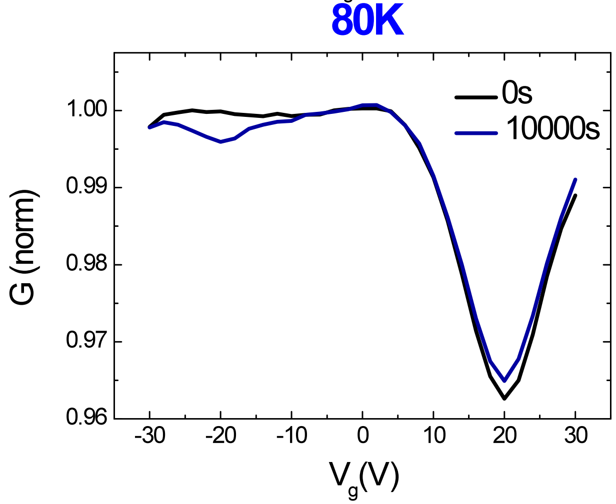
L≈200nm
Institut Néel/Nanofab
EHT = 5.00 kV
WD = 6.7 mm
100 nm
Signal A = InLens
Date :17 May 2013
Time :10:08:56
L≈50nm
Institut Néel/Nanofab
EHT = 5.00 kV
WD = 6.4 mm
100 nm
Signal A = InLens
Date :17 May 2013
Time :9:51:03
L≈20nm
Institut Néel/Nanofab
EHT = 5.00 kV
WD = 7.9 mm
100 nm
Signal A = InLens
Mag = 99.05 K X
Date :23 Jul 2013
Time :14:03:58
10^9
10^8
10^7
10^6
10^5
10^4
10^3
τ (s)
1
2
3
4
T*/T
Granular Al
5 nm
L≈5nm

Discontinuous metals: cooling effect !

+ thermal history memory

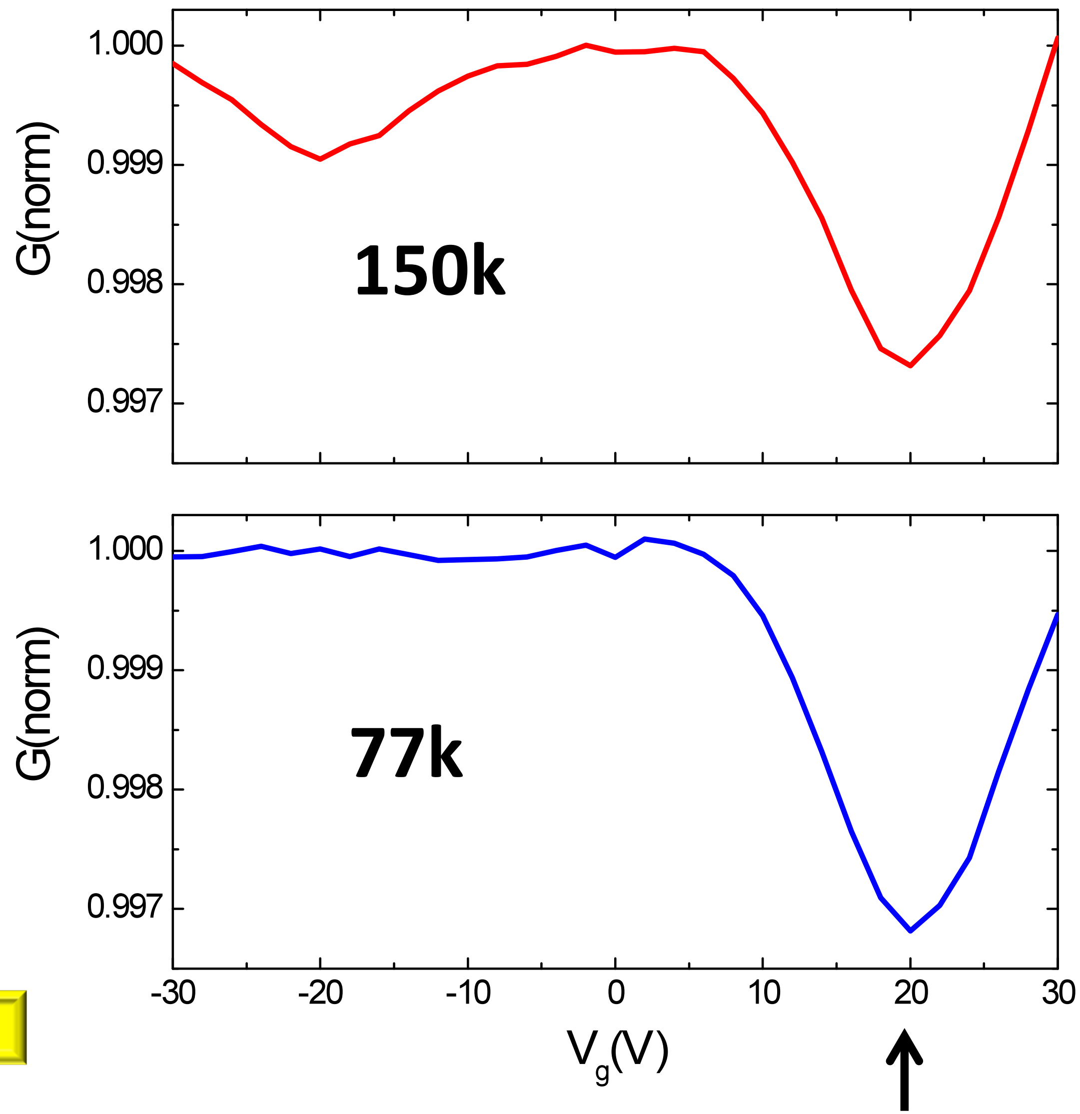






Discontinuous Au

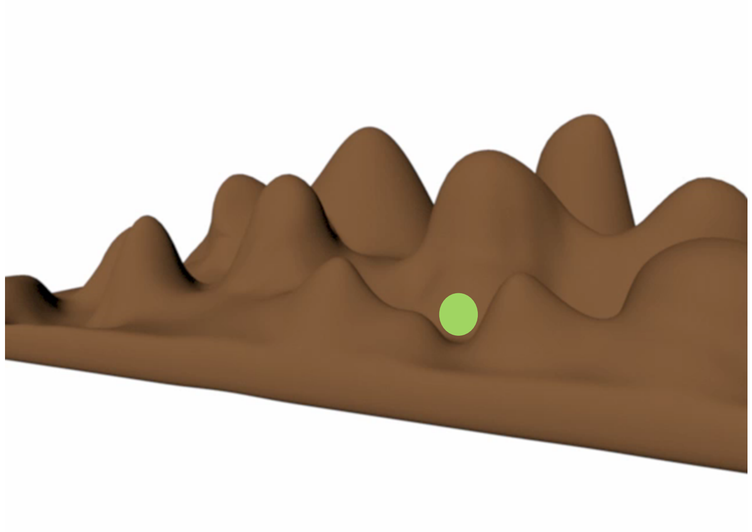
Discontinuous metals: cooling effect

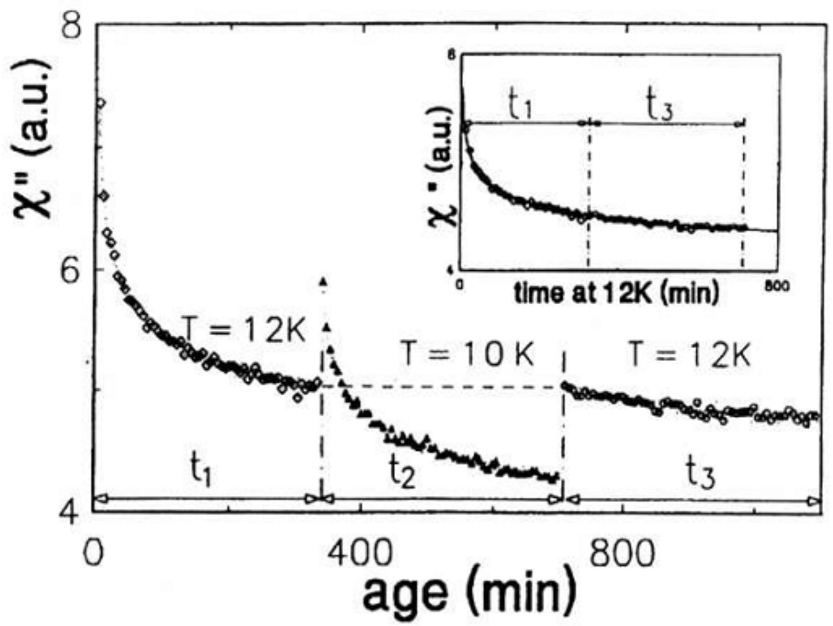


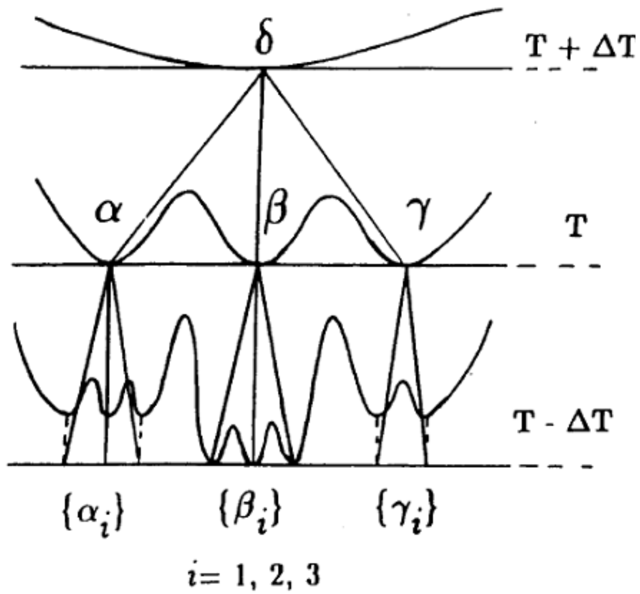
Discontinuous Au

Discontinuous metals: Temperature chaos ?

System's configuration space :







references

- Papers by :
  - Z. Ovadyahu and coll. (Jerusalem University)
  - J. Delahaye and T. Grenet (Grenoble, France)
  - A. Frydman et al. (Bar Ilan Univ., Israel)

An (almost) up-to-date review in the book:

The Electron Glass (M. Pollak, M. Ortuno and A. Frydman)

Cambridge University Press (2013)