Glassiness in insulating granular Al thin films

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OUTLINE

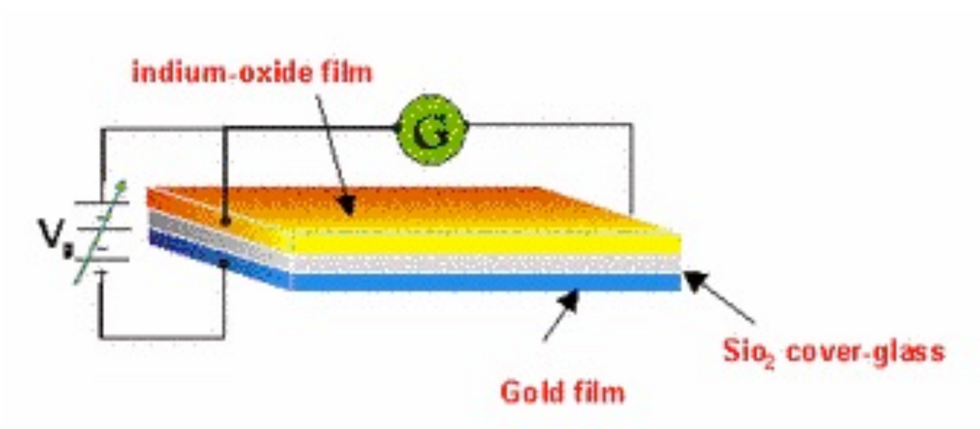
- how it started
- manifestations of « glassiness » in granular Al
- ageing
-questions

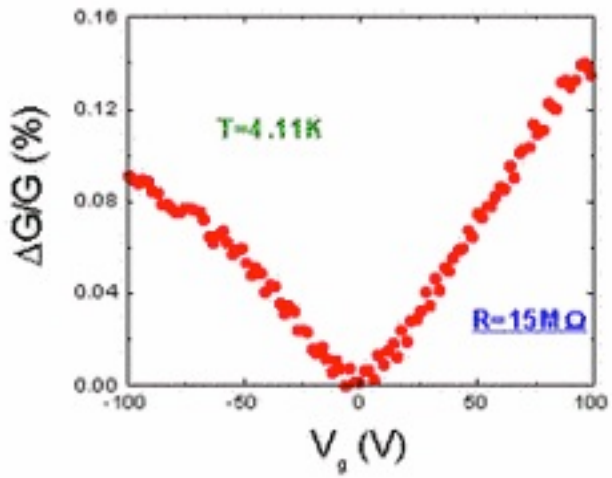
Electron Coulomb glass ?

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 …

Indium oxide … what else ?

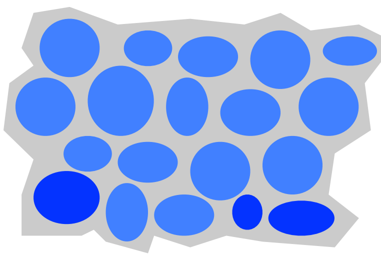
QUESTIONS:

- What is special with indium oxide ? Why no other system ?

- Standard doped semi-conductors: Ø

-What about granular metals ?

→ ***look for these effects in granular Al***



actually seen in: granular gold (Adkins et al., 1984)
ultrathin lead (Goldman et al. , 1997 and 2001)

OUTLINE

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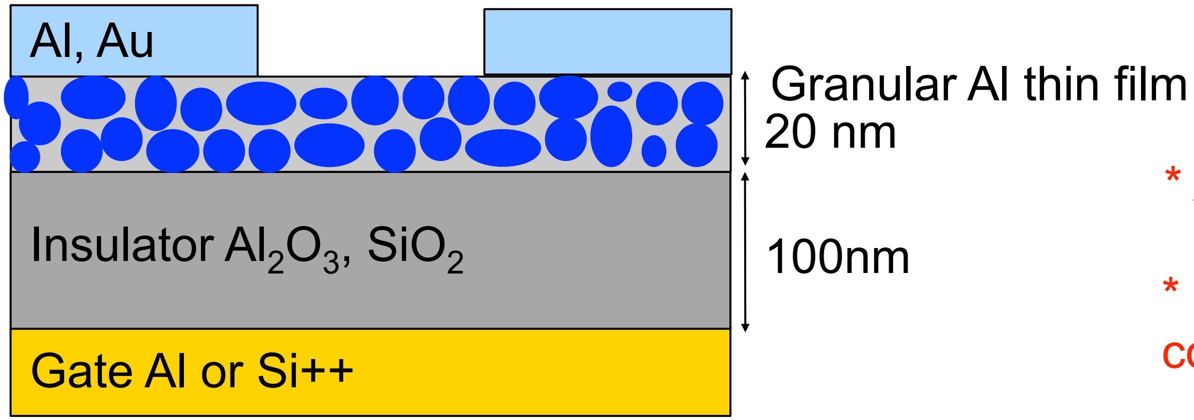
- manifestation of « glassiness » in granular AI
- ageing
- questions

Granular Aluminium samples

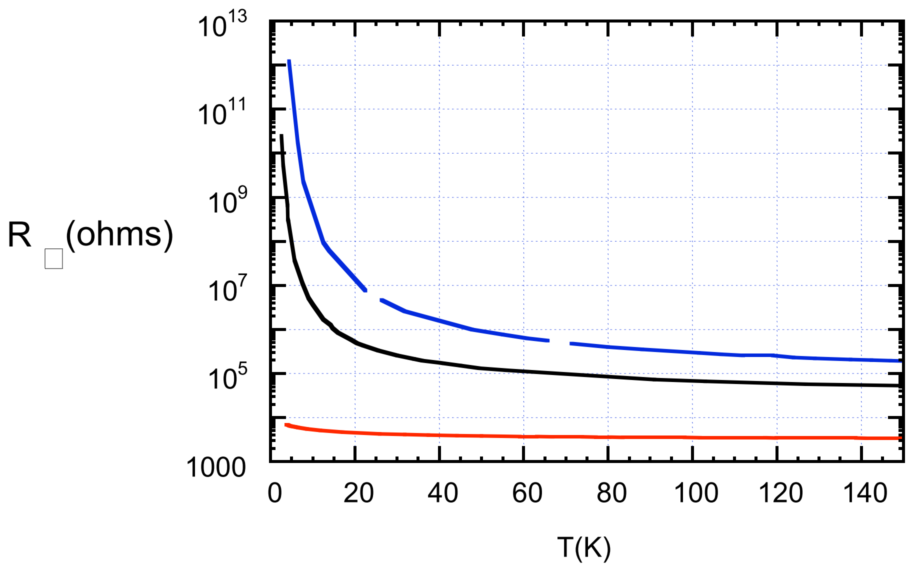


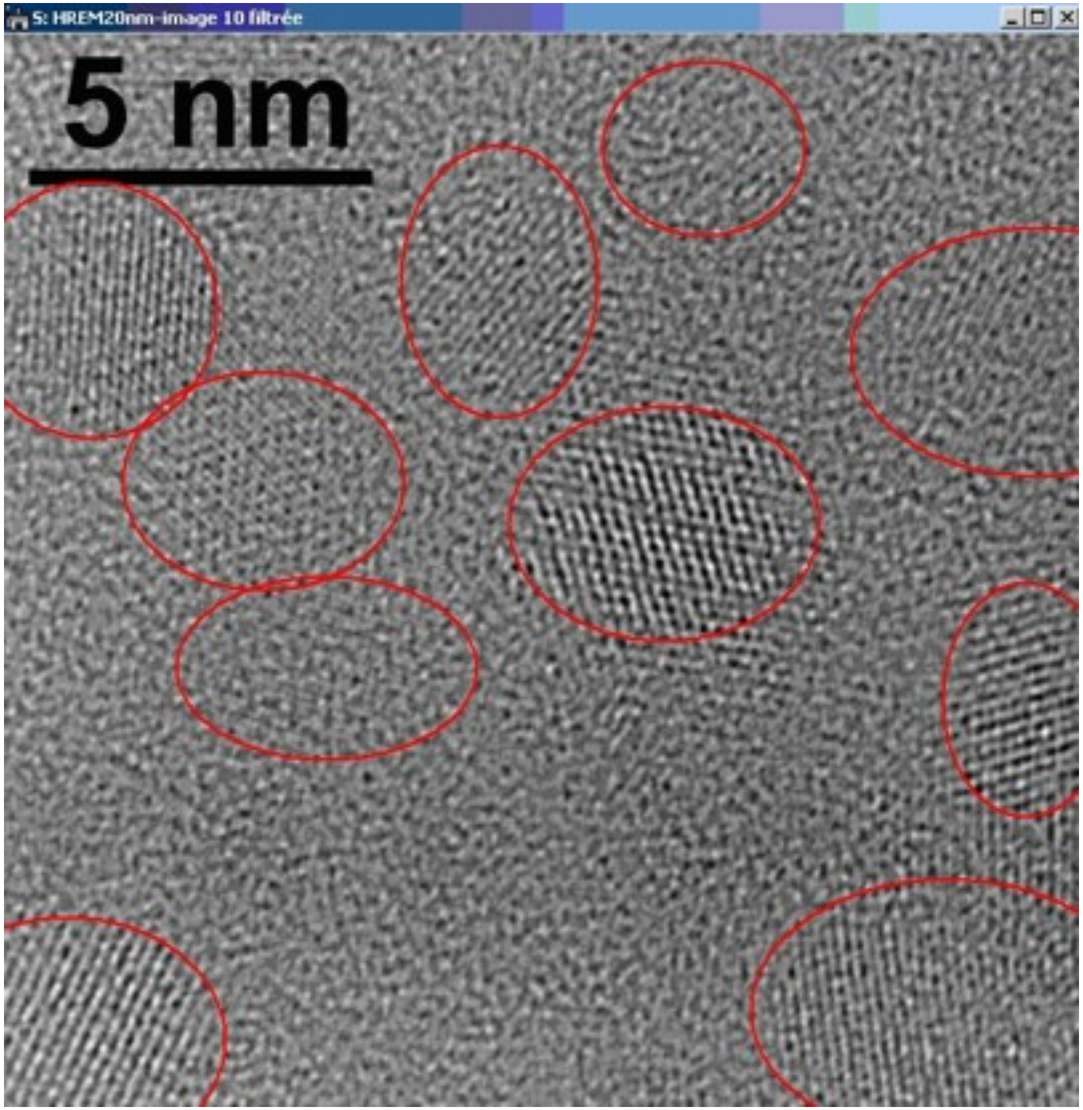
* Al evaporated in $P(O_2)$

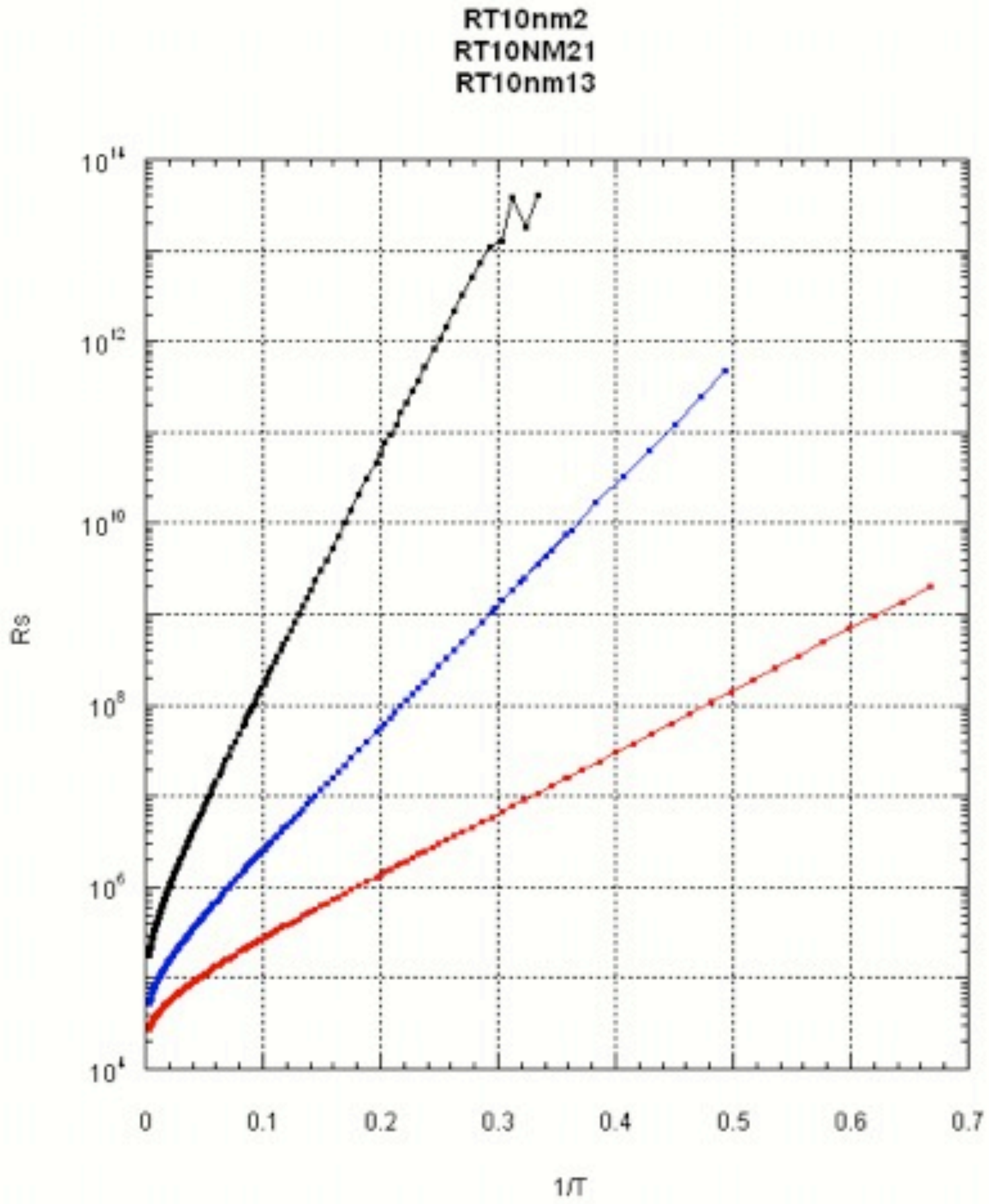
* nanometric Al grains covered by Al_2O_3

Study insulating films:

R/□ at 4K: 100 kΩ → 100 GΩ

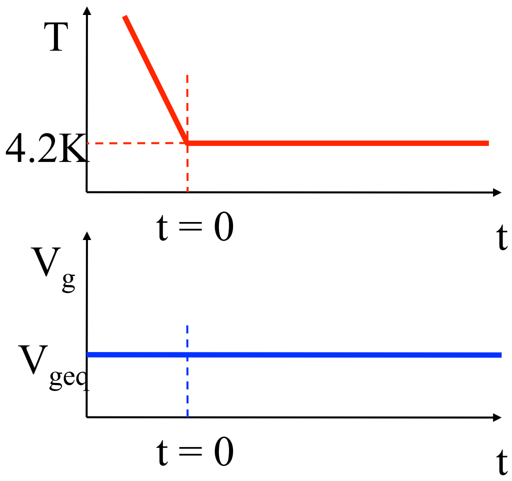


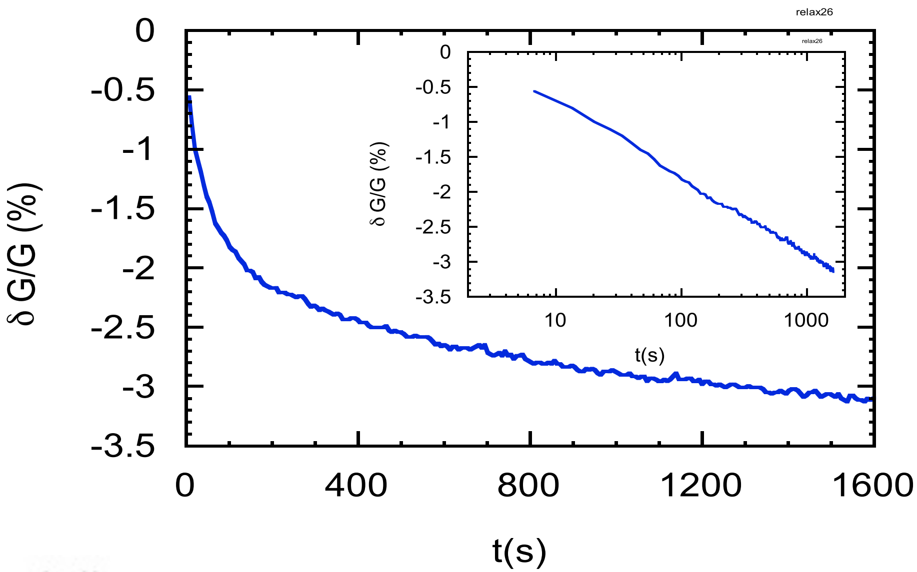

S: HREM20nm-image 10 filtrée
5 nm

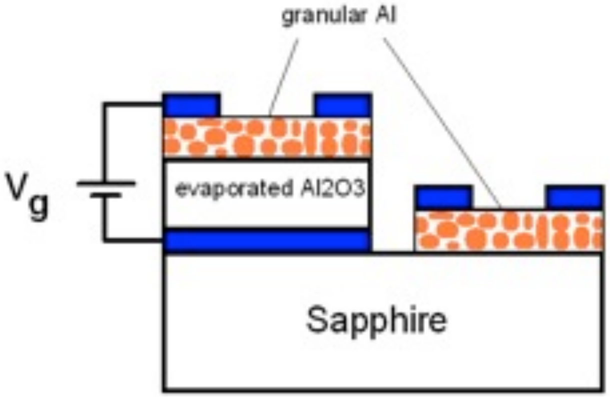

RT10nm2
RT10NM21
RT10nm13
Rs
1/T
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Out of equilibrium effects: slow relaxation

Never ending slow conductance relaxation after a quench

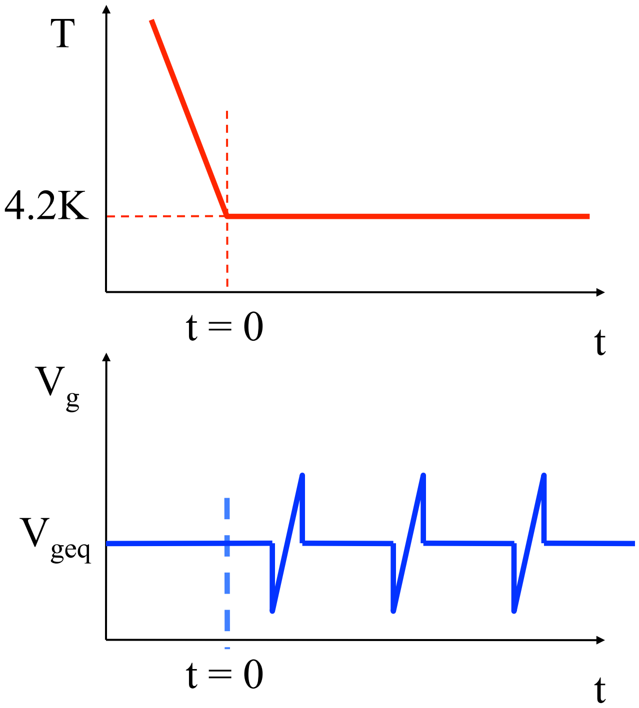


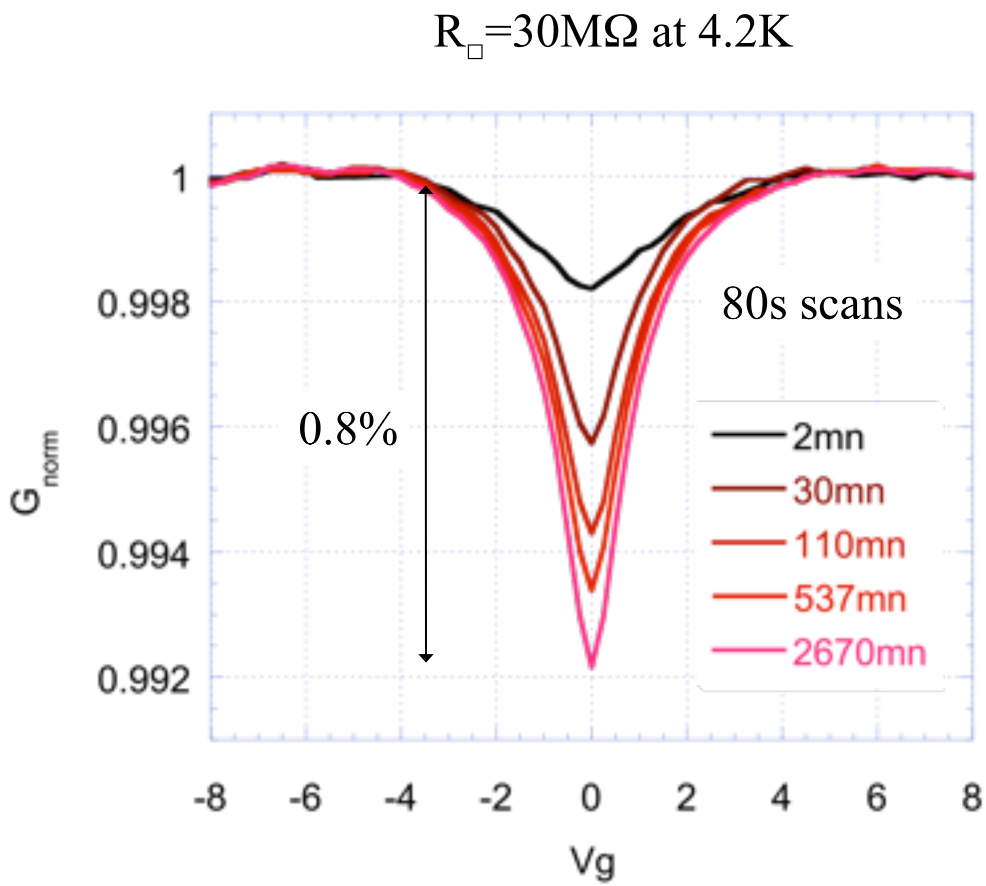




Out of equilibrium effects: field effect anomaly

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



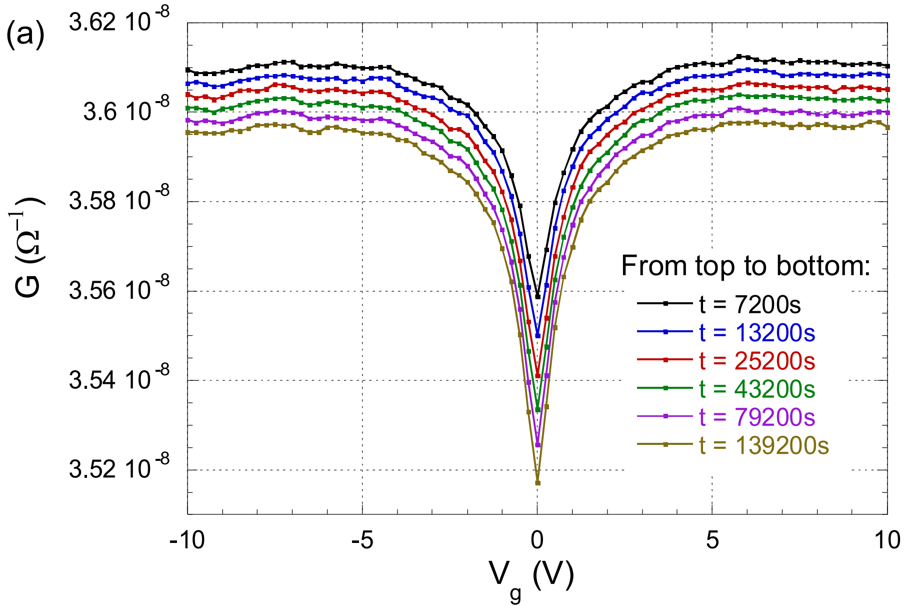


- Field effect anomaly (the “cusp” or “dip”)

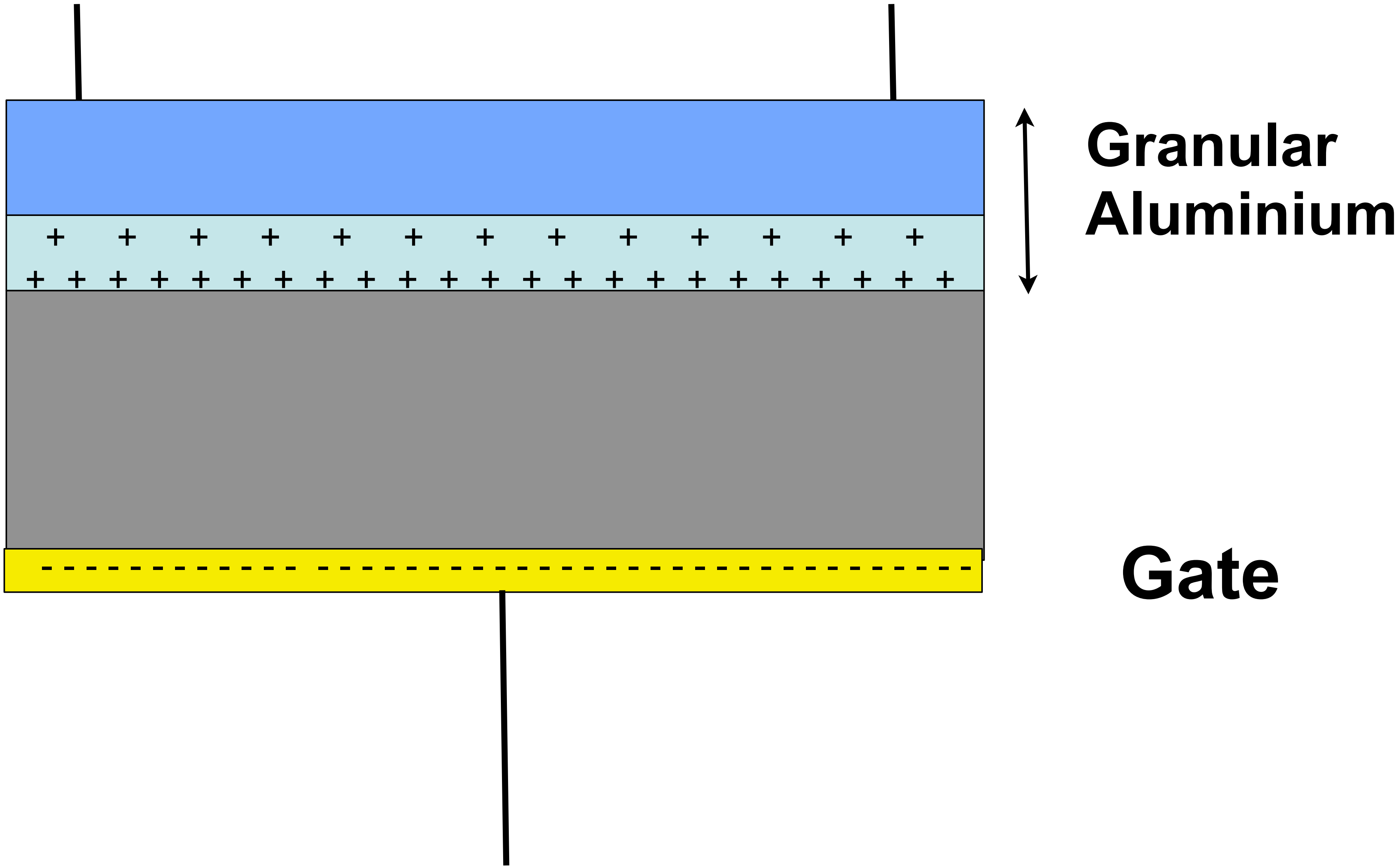
- Amplitude grows like Ln(*t*)

Out of equilibrium effects: thickness dependence

Baseline relaxation in «thick enough» samples:



- signature of a finite screening length (L_{screen} around 10 nm)


Granular
Aluminium
Gate

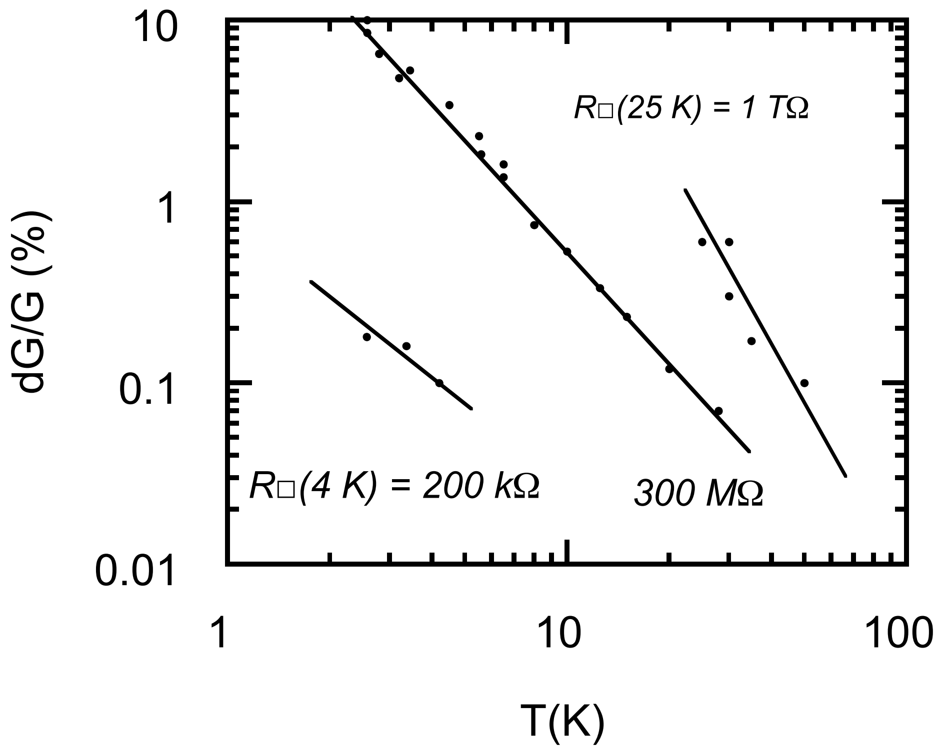
When do we see this anomaly ?

- the anomaly is always seen in insulating films

- it is most prominent (in %):

  → at low T (most measurements at 4K)

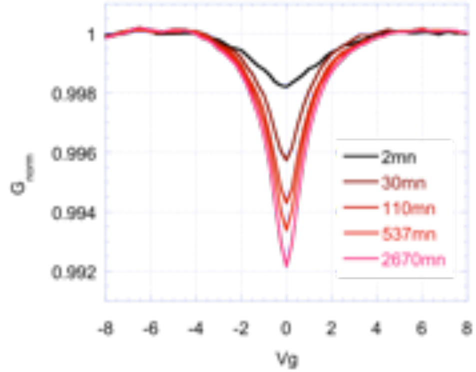
  → in more insulating samples



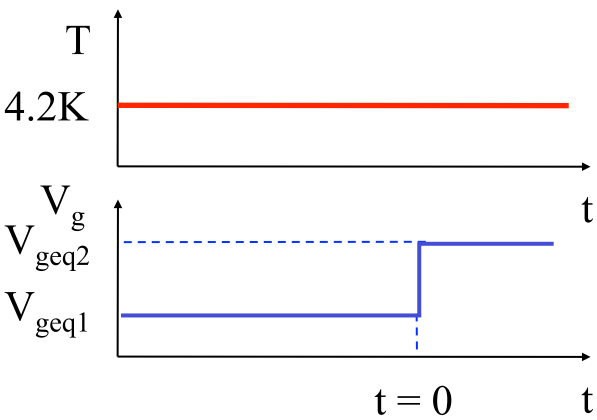
- for practical reasons we study samples were the anomaly is not so large (≤1%) but it can be a large effect (more than 10%)

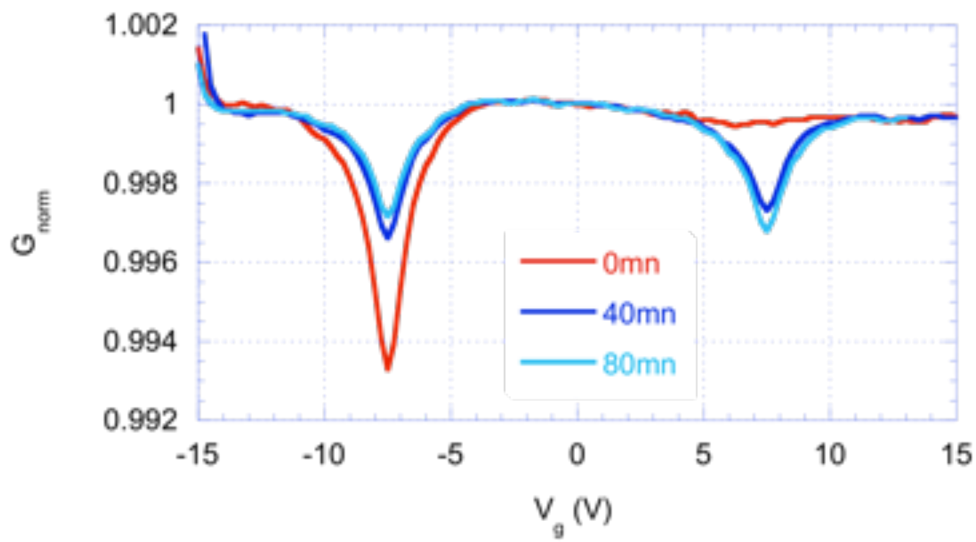
Cusp dynamics

Recall: after a cooling



After a gate voltage change:



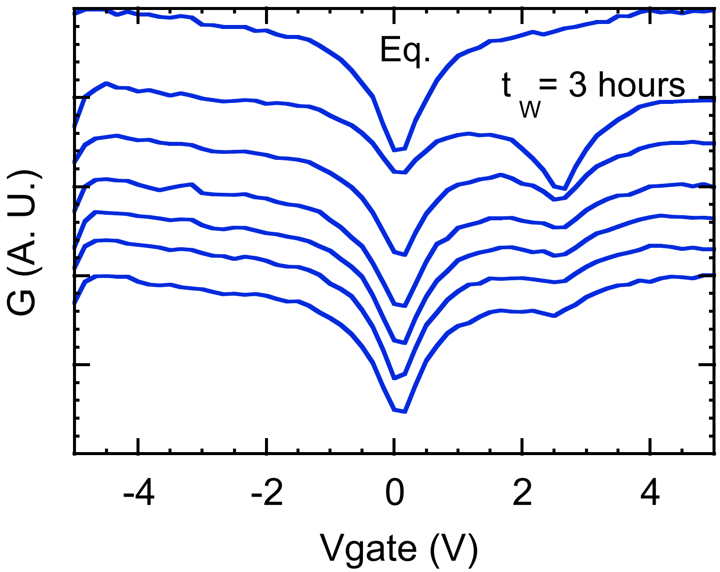


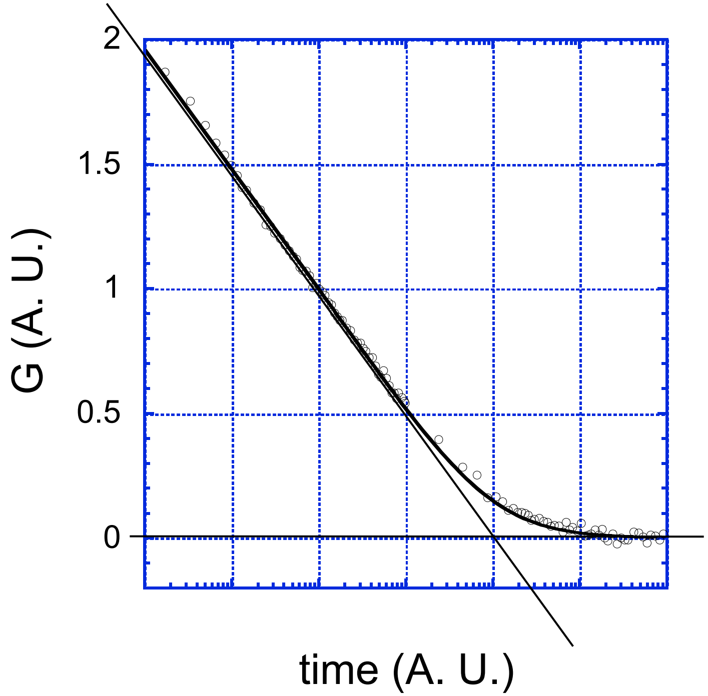
Is the dynamics activated ?

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 ?

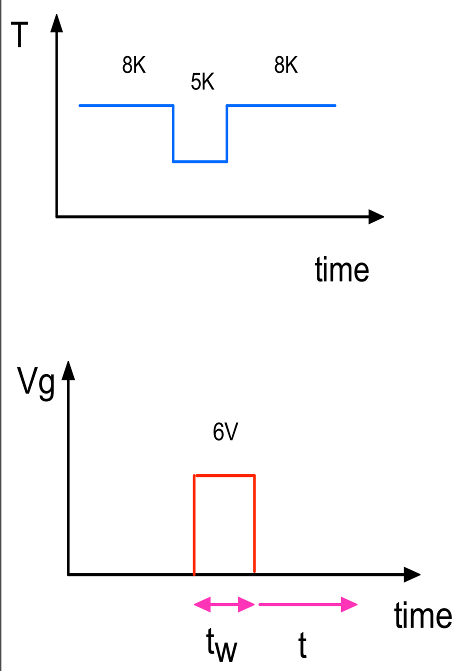
→ look at the erasure time of a previously formed dip



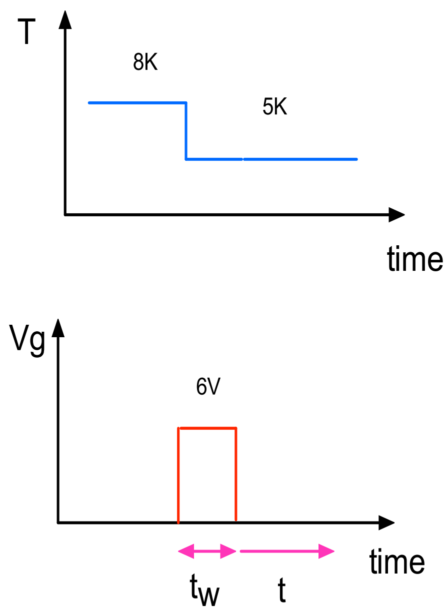


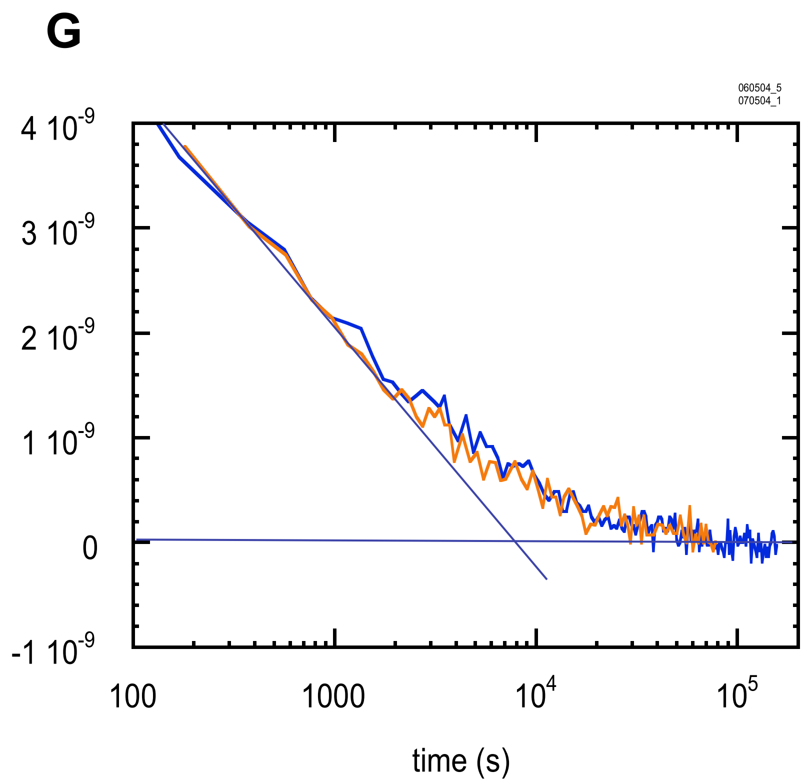
Is the dynamics activated ?

I



II





⇒ dynamics is not activated

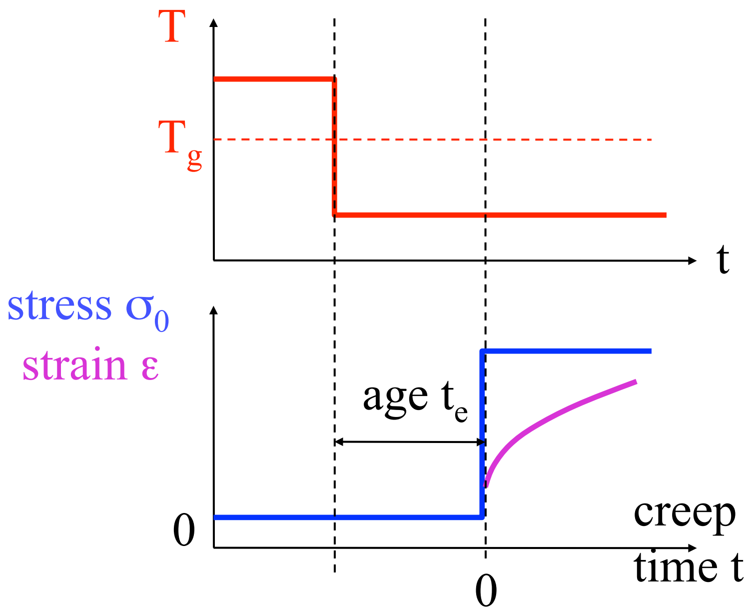
OUTLINE

- how it started
- some aspects of the « glassiness » in granular Al
- ageing
- questions

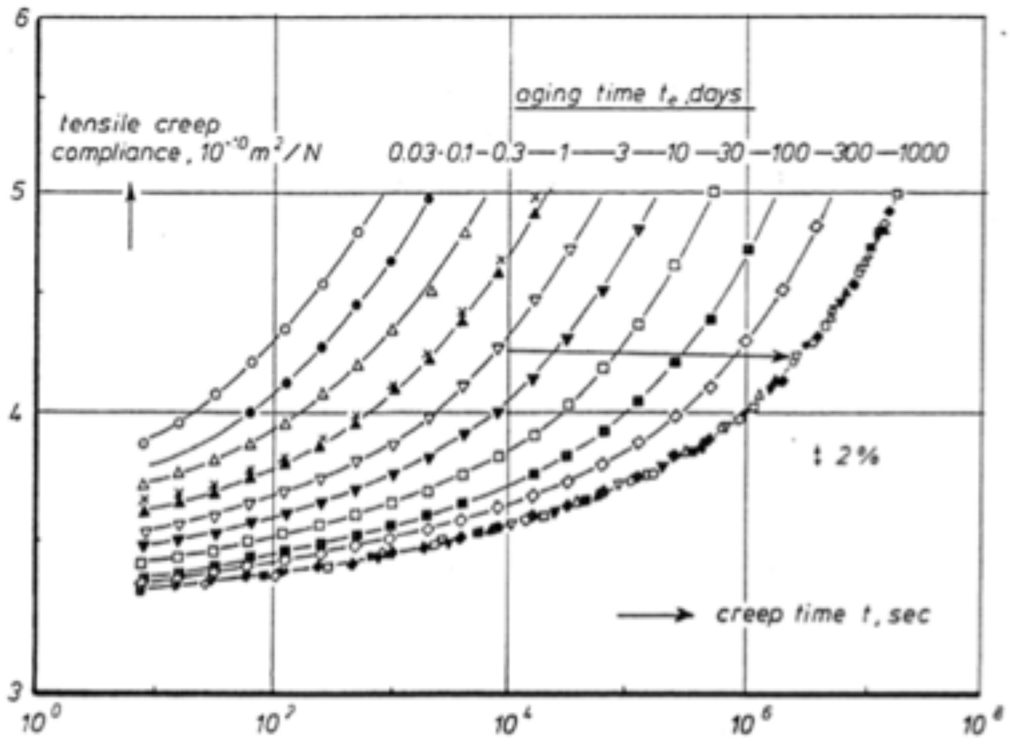
If it is a glass … does it age ?

AGEING:

Ex: creep tests on polymers



Creep compliance (t) = ε (t) / σ_0



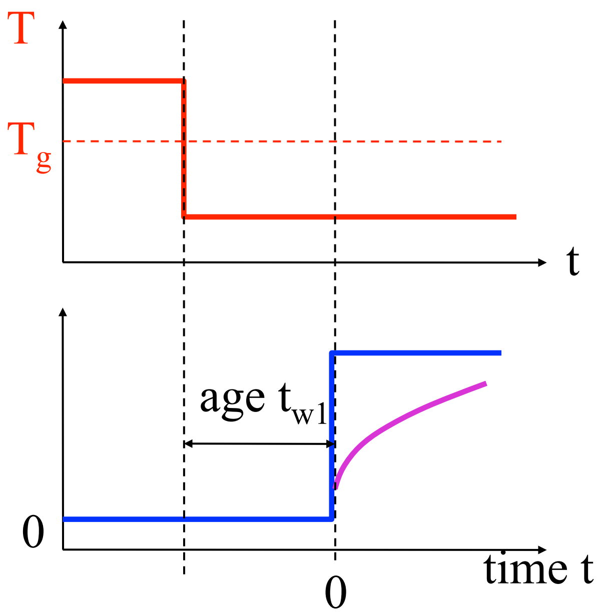
The dynamics depends on time: the « older » the system, the slower the response to a stimulus !

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

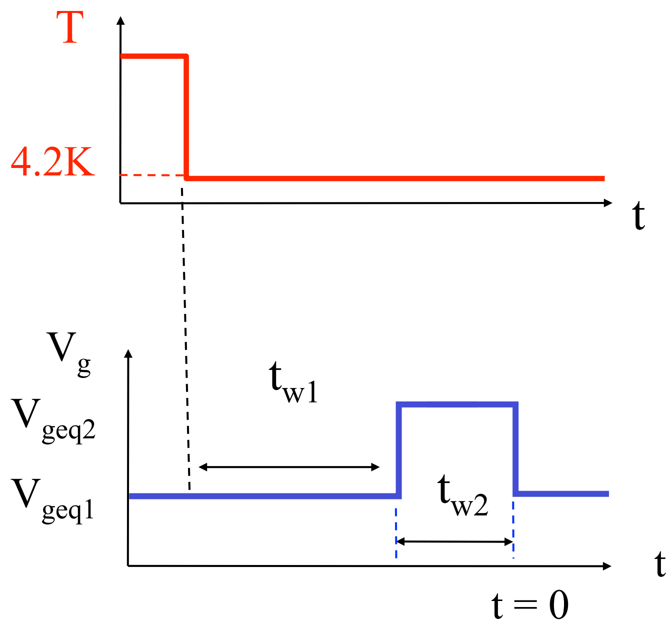
L.C.E Struik, 1978

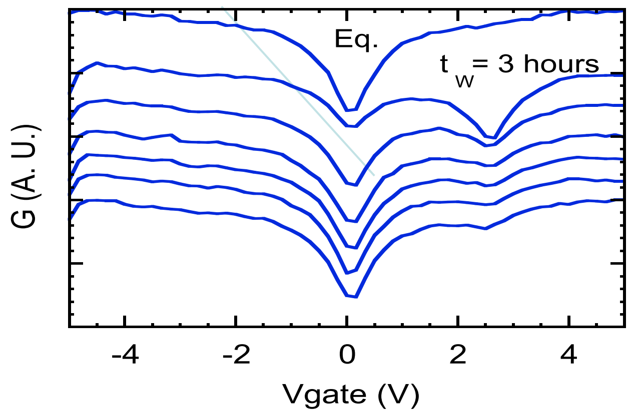
« ageing» and « Two dip » protocols

Standard « ageing » protocol



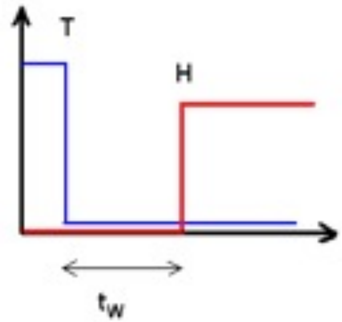
« Two dips » protocol

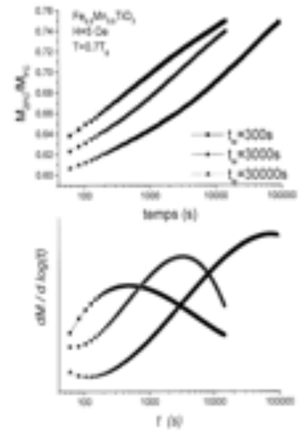




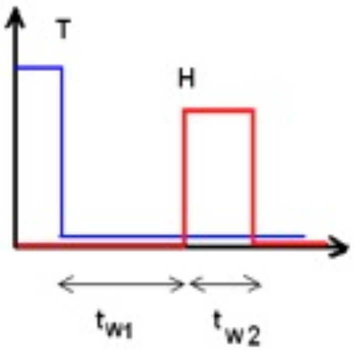
equivalent spin glasses protocols

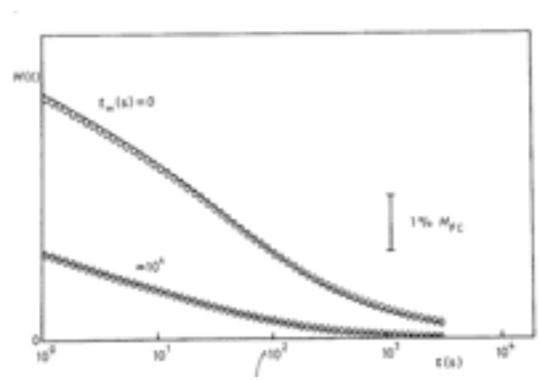
* Zero field cooled relaxation (ZFC):



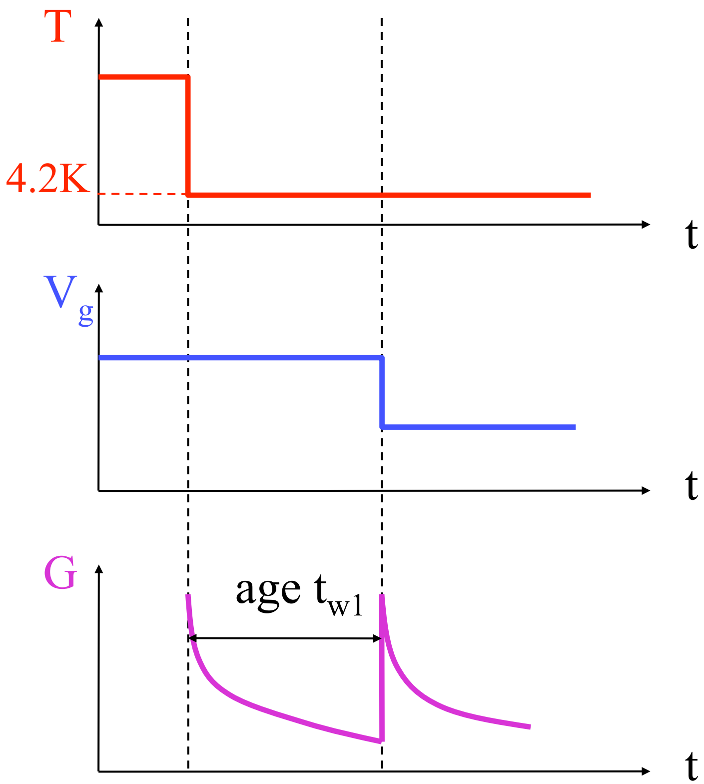


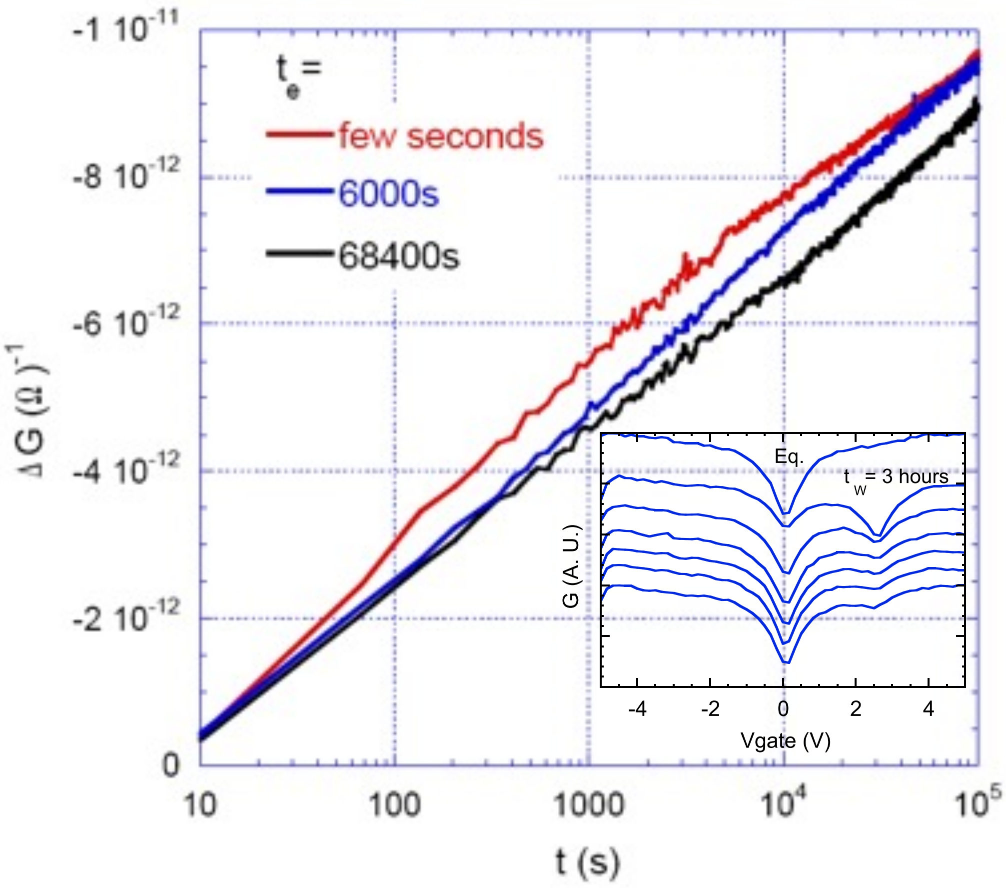
* Isothermal remanent magnetization (IRM):





Standard ageing protocol (1)

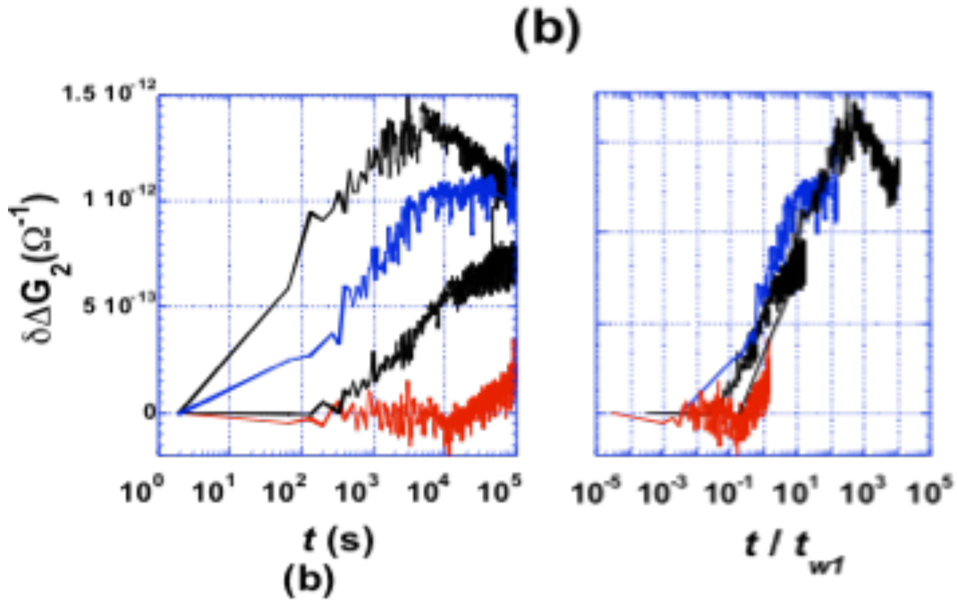




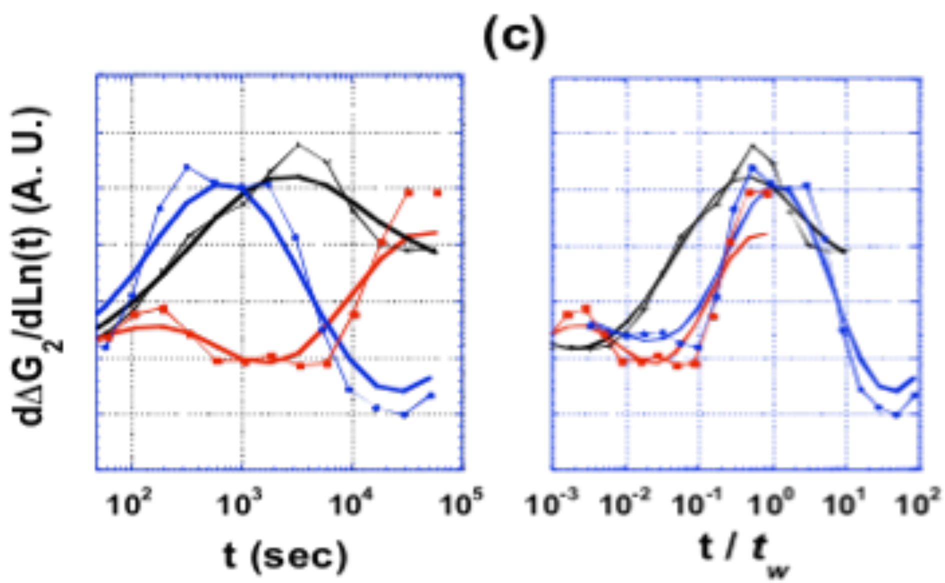
New dip growth: NOT like Ln(t)

Standard ageing protocol (2)

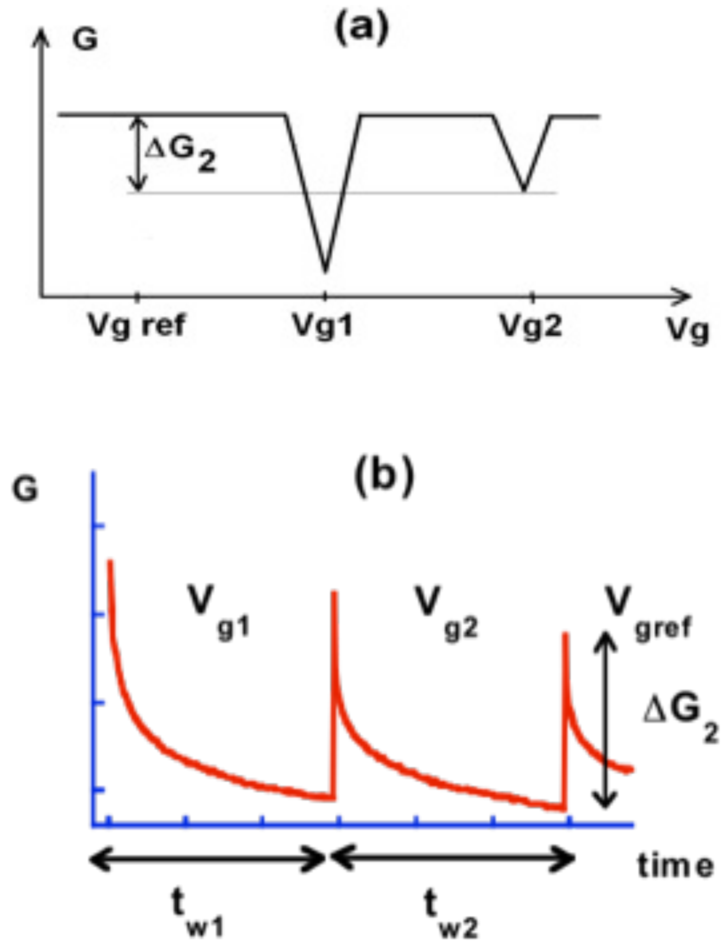
Departures from pure Ln(t) relaxation scale with t_{w1}

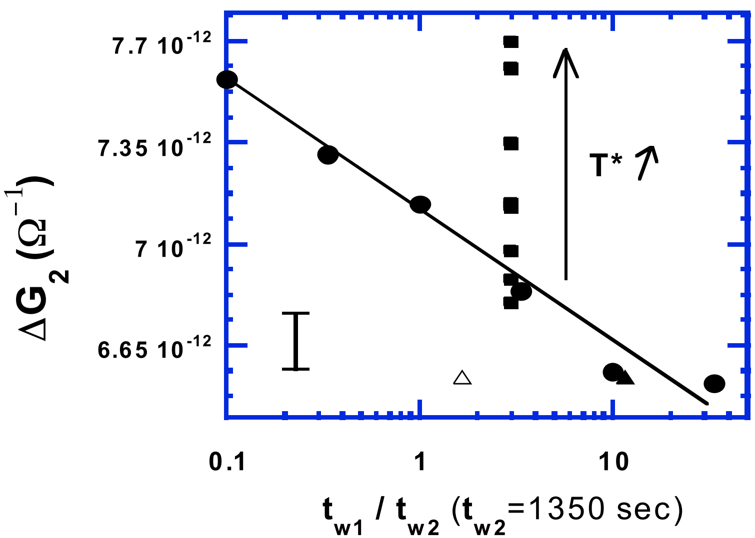


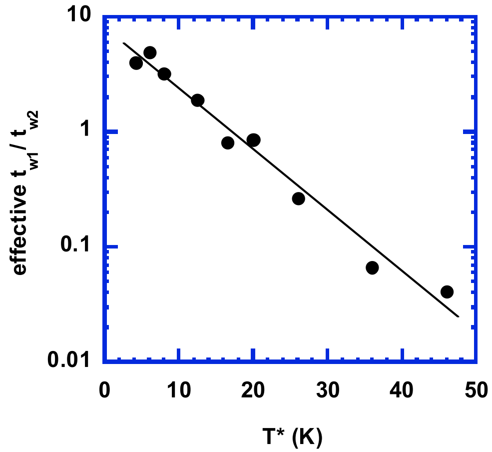
Effective relaxation time distribution $d\Delta G2/d\mathrm{Ln}(t)$ scales with t_{w1}



Rejuvenation by annealing

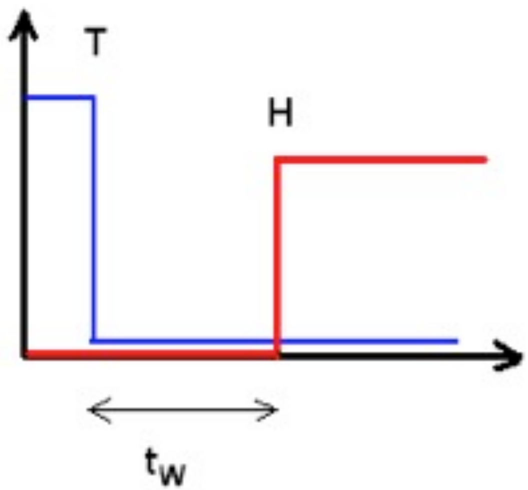




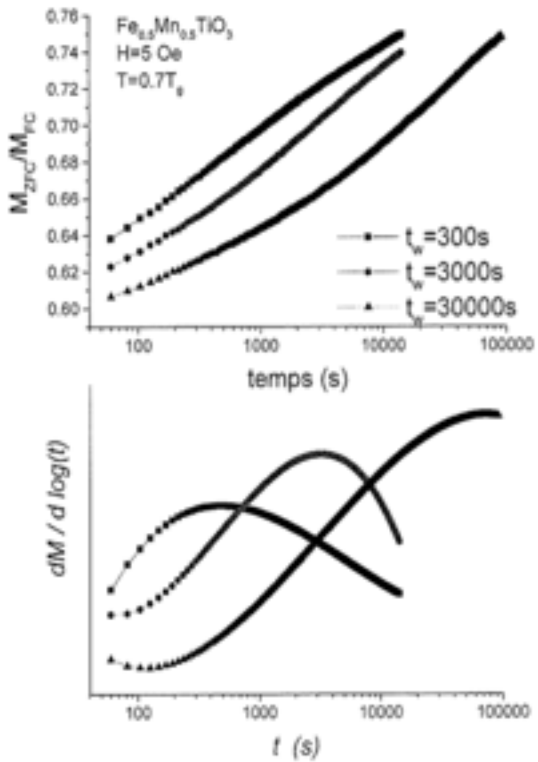


Example of spin glasses

Zero field cooling relaxation



Magnetization (t)

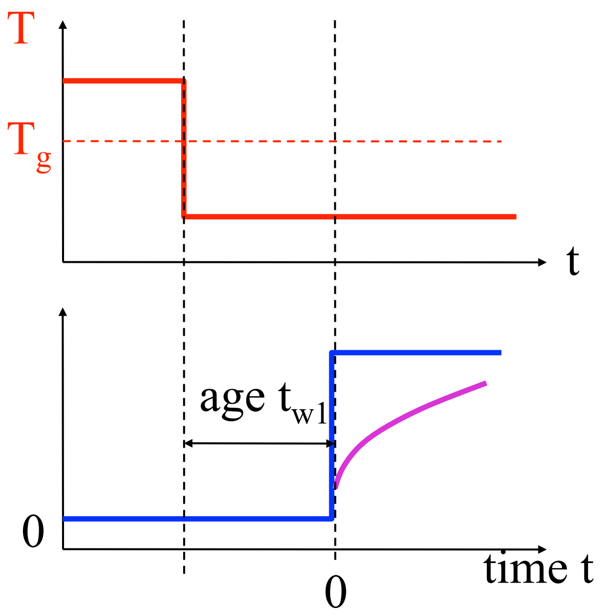


E. Vincent, 2006

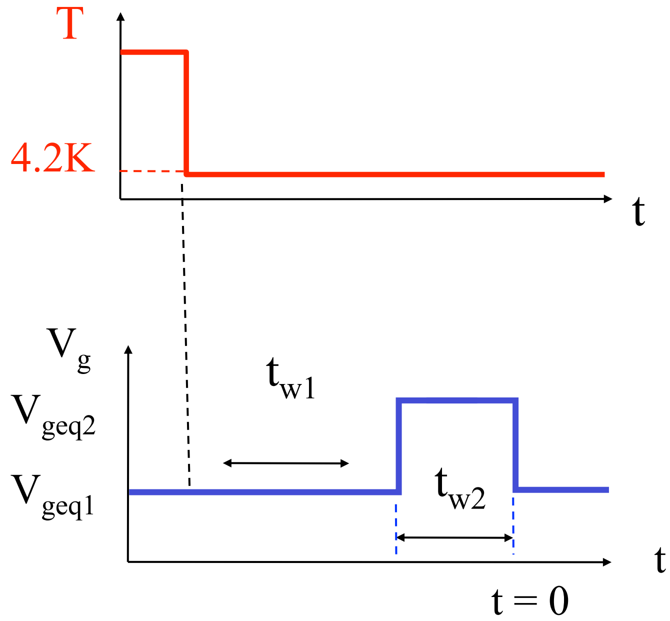
The age of the system is printed in its relaxation time distribution

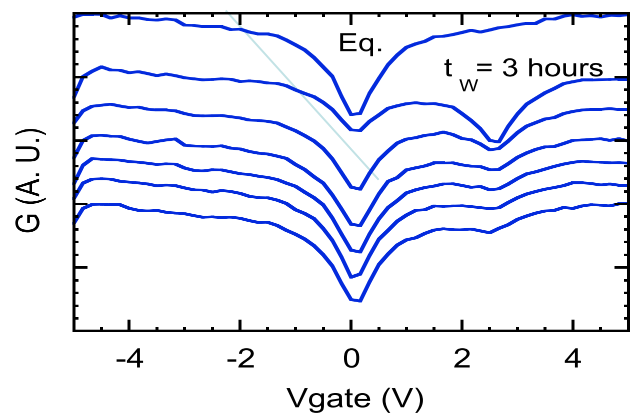
« ageing» and « Two dip » protocols

Standard « ageing » protocol



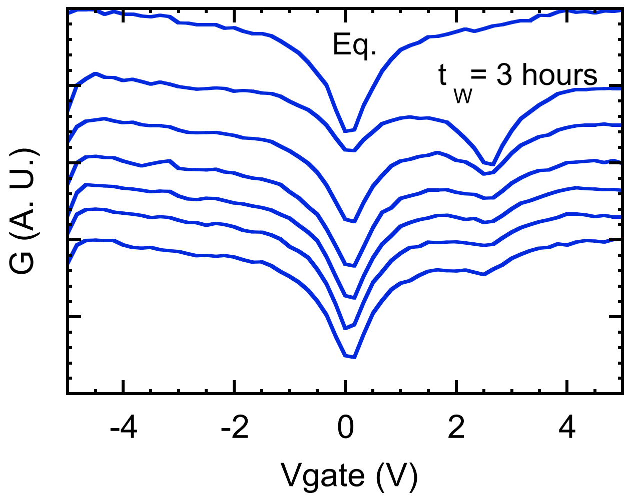
« Two dips » protocol

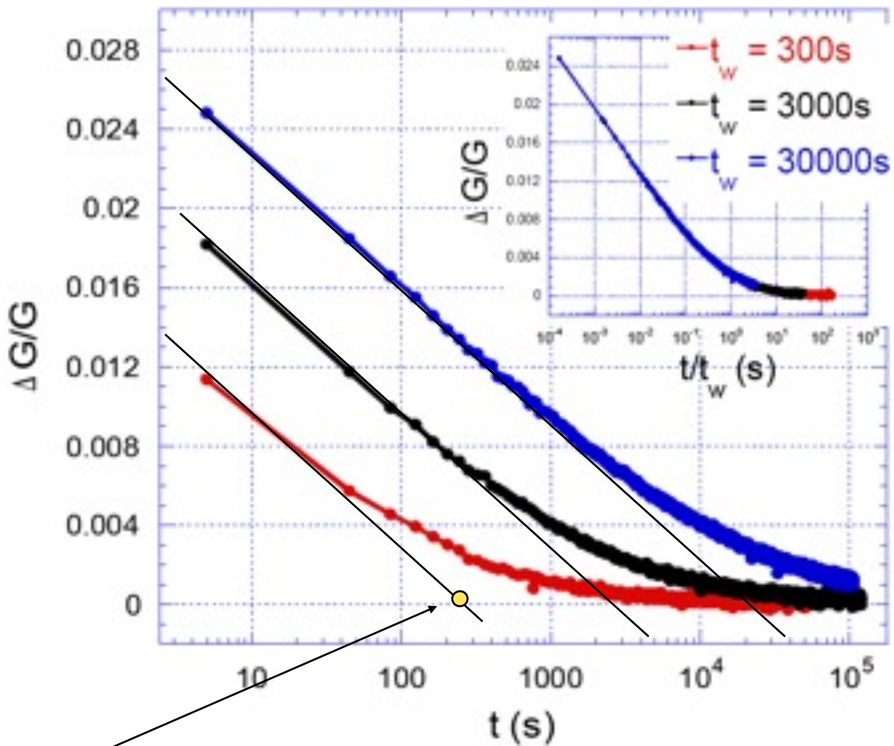




Two dip protocol: very «old» system

« Two dips » protocol



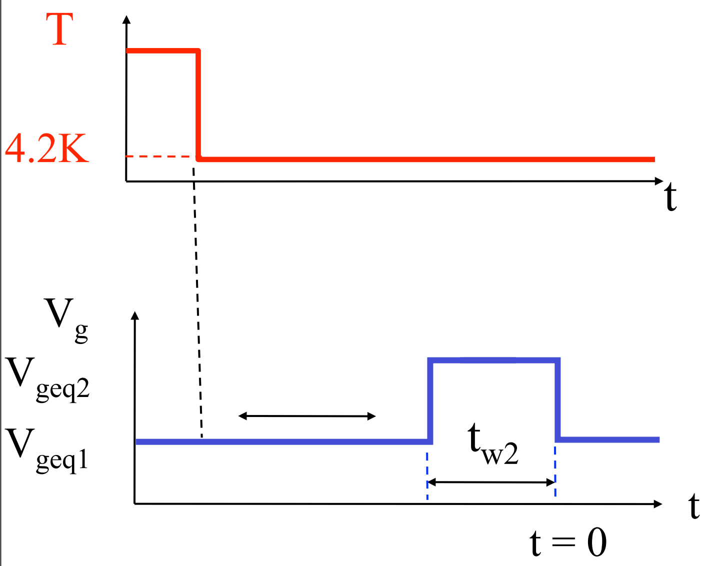


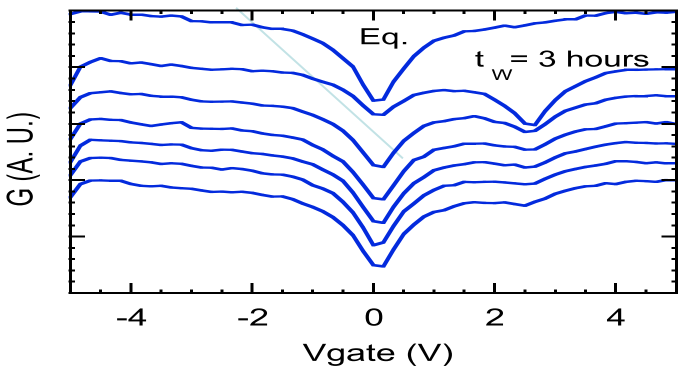
Erasure time

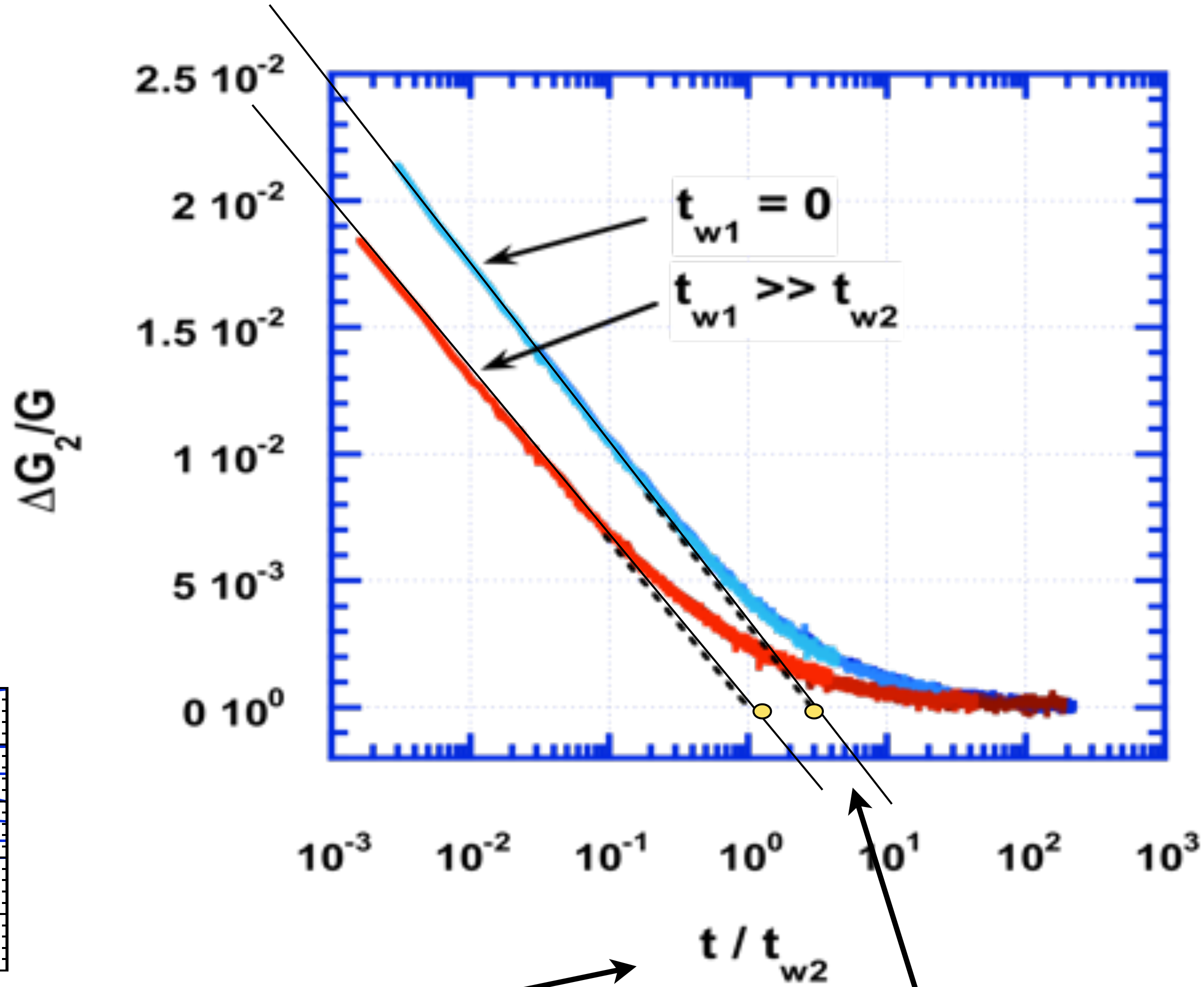
t/t_{w2} scaling

Two dip protocol: «young» (ageing) system

« Two dips » protocol







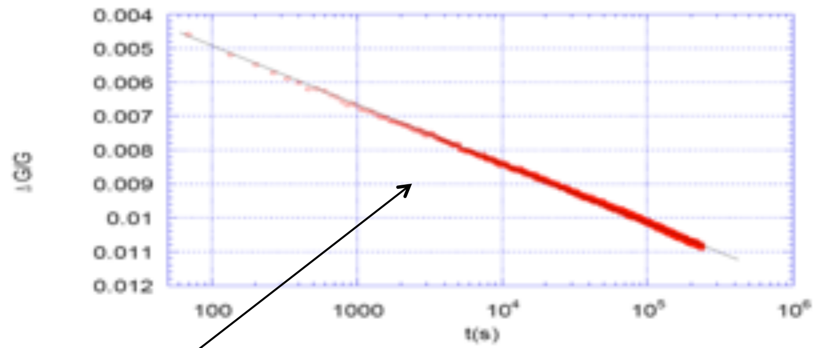
t/t_{w2} scaling:
memory of t_{w2}

value of $/t_{w2}$ erasure time:
memory of t_{w1}

A simple quantitative approach when $t_{w1} \gg t_{w2}$

A simple model can reproduce the data:

-collection of independant reversible « degrees of freedom »
- additive effect on G
- tunnel → $Ln(\tau_i)$ has a broad (flat) distribution

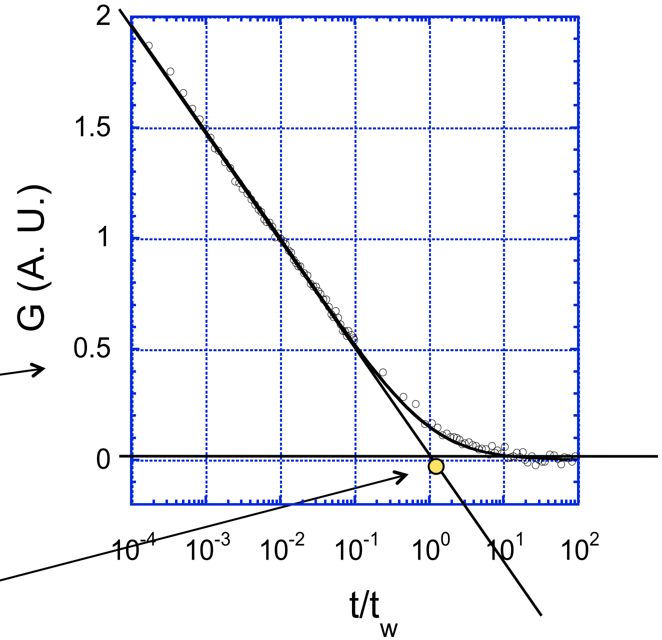


Then:

$$writing: \quad \Delta G(t < t_w) = -\Delta G_0 \sum_i (1 - \exp(-\frac{t}{\tau_i}))$$

$$erasure: \quad \Delta G(t > t_w) = \Delta G_0 \sum_i (1 - \exp(-\frac{t_w}{\tau_i})) \exp(-\frac{t - t_w}{\tau_i})$$

$$\Delta G(t > t_w) = -\Delta G_0 Ln(1 - \frac{t_w}{t})$$



erasure time

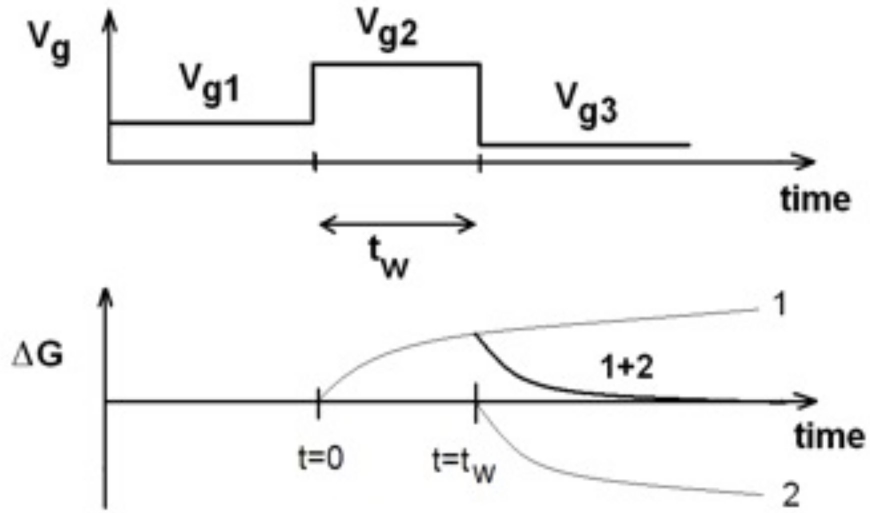
«Superposition principle»

erasure :

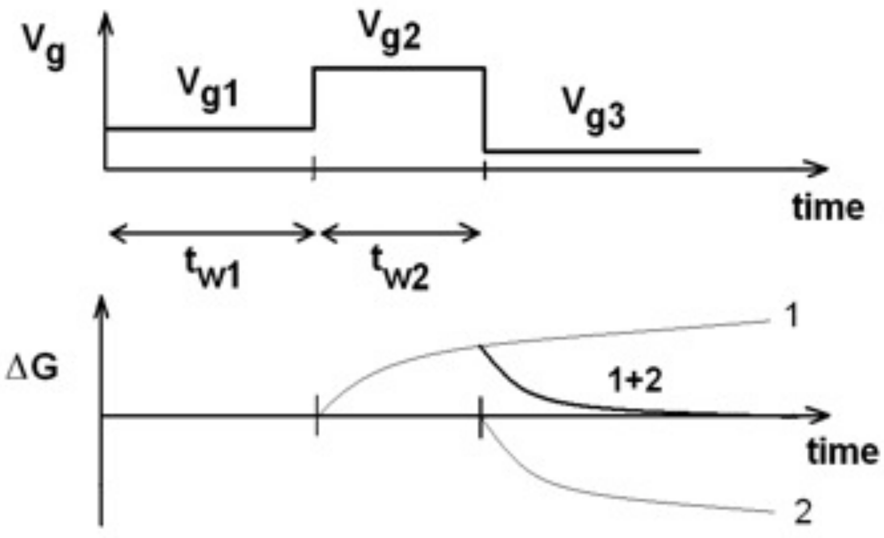
$$\Delta G(t > t_w) = \Delta G_0 \sum_i (1 - \exp(-\frac{t_w}{\tau_i}))\exp(-\frac{t - t_w}{\tau_i})$$

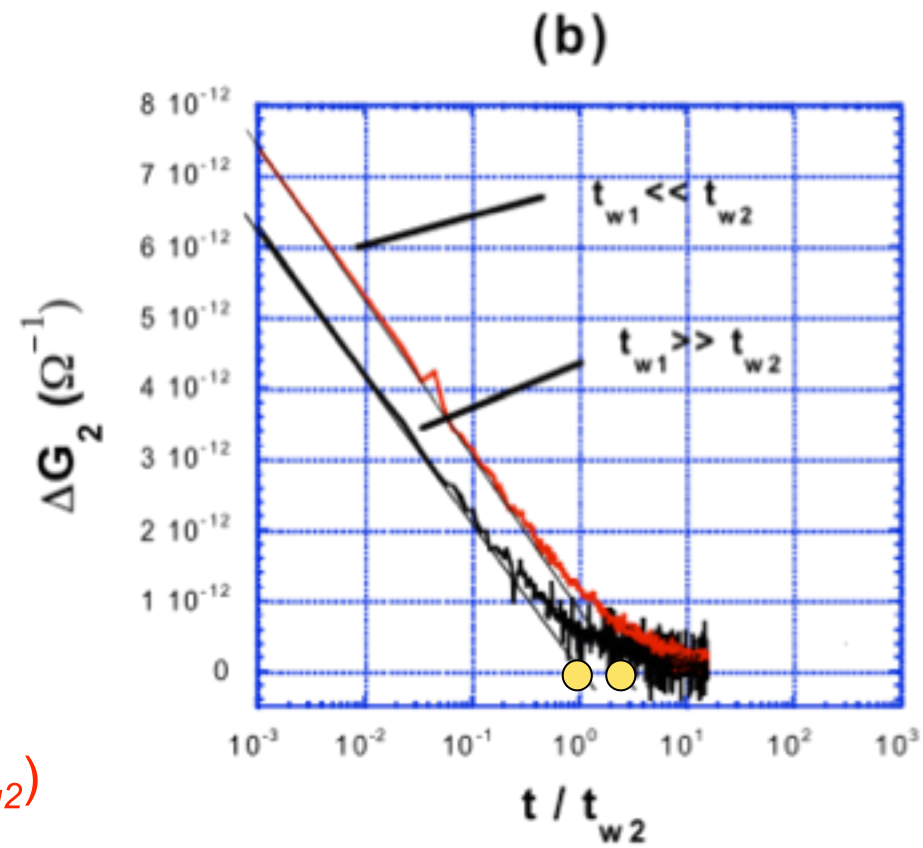
$$\Delta G(t > t_w) = \Delta G_0 \sum_i (1 - \exp(-\frac{t}{\tau_i})) - (1 - \exp(-\frac{t - t_w}{\tau_i}))$$

$$\Delta G(t > t_w) = \Delta G_0 (Ln(t) - Ln(t - t_w))$$



«Superposition principle»





Application of the principle for $G(V_g=V_{g2})$

A simple quantitative approach of ageing

-collection of independant reversible « degrees of freedom »

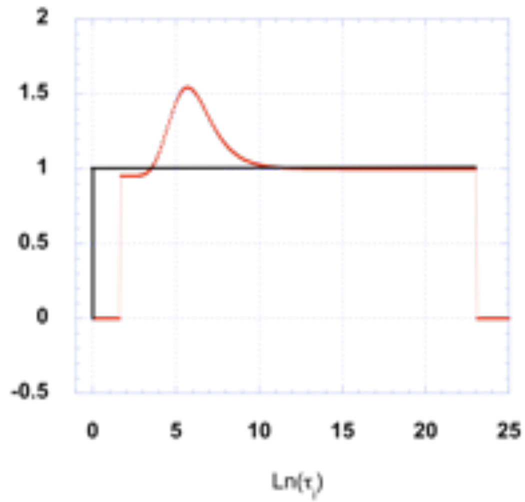
- additive effect on G

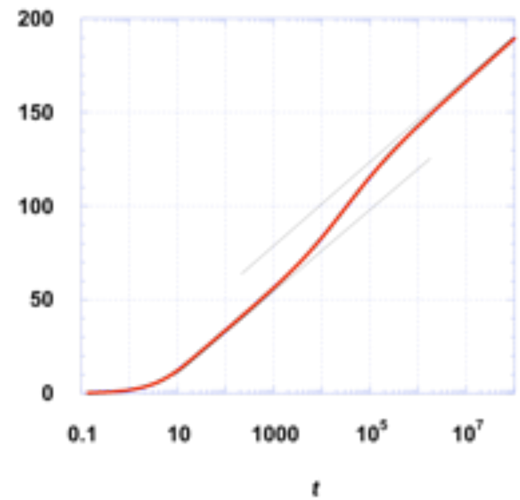
- Ln(τ_i) has a broad (flat) distribution

- $\tau_{i\rightarrow} \neq \tau_{i\leftarrow}$

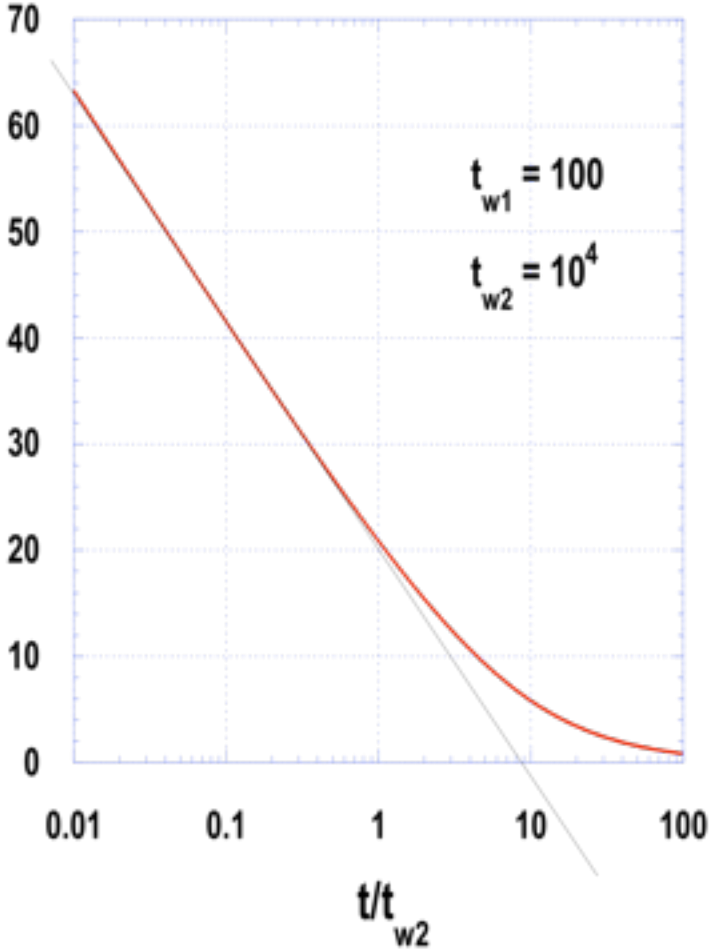
Suppose:

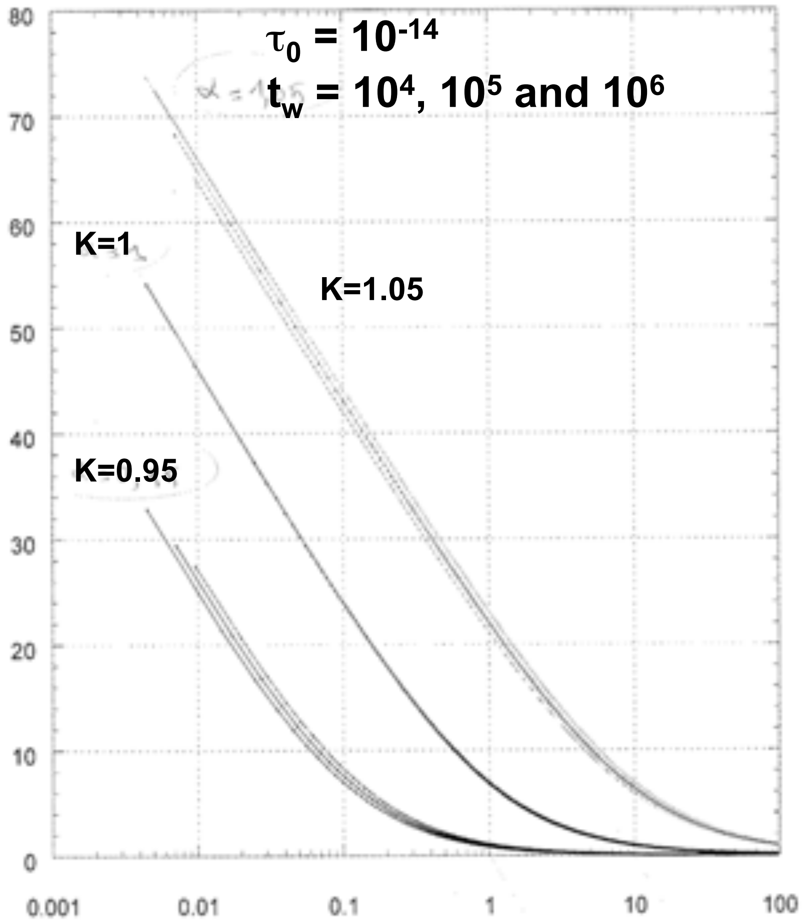
$\tau_{i\leftarrow} = \tau_0 \exp(\xi_i)$ and $\tau_{i\leftarrow} = \tau_0 \exp(k * \xi_i)$





A simple quantitative approach of ageing





OUTLINE

- how it started
- some aspects of the « glassiness » in granular Al
- is ageing present ? (is it a glass?)
- questions

Is this glass purely electronic ?

- competing « extrinsic » (non electronic) scenarios can be envisaged (slow atomic or ionic processes influencing the conductance)

- are there indications in favor of the coulomb electron glass ?

- 1) in Indium oxide: effect of carrier concentration (varied by changing oxygen concentration)

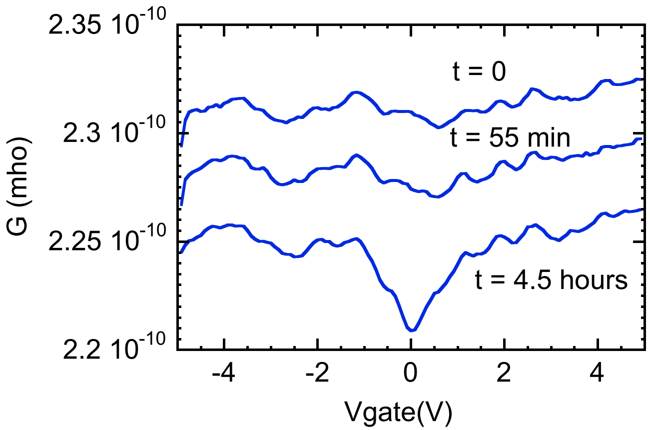
  * systematic effect of carrier concentration on the field effect anomaly width

  * the dynamics is also influenced by the carrier concentration (fast erasure of a formed field effect anomaly by a high enough Vg change)

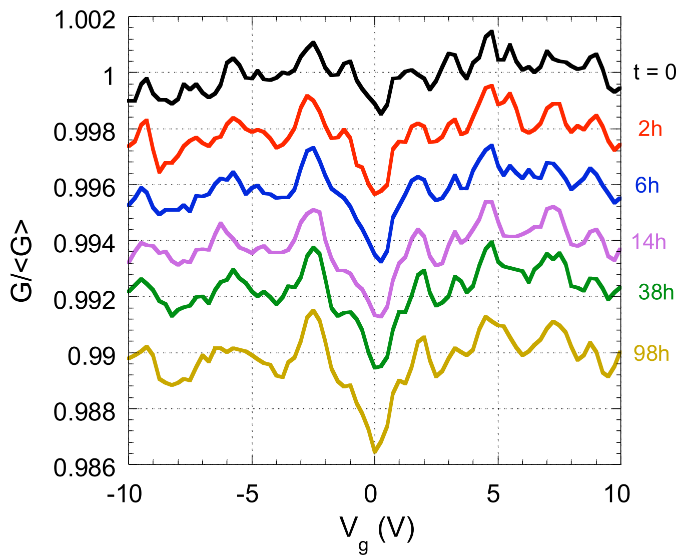
Is this glass purely electronic ?

- 2) <u>slow relaxation in mesoscopic samples :</u>

Size: 30 * 30 μm²



50*40 (mm)²



- mesoscopic fluctuations (fluctuations of percolation path as a function of V_g) and the cusp coexist

- both seem to have very different time scales (disorder seems totally frozen) → may be consistent with electron glass (cusp slow relaxation not due to disorder (atoms) relaxation)

Is this glass purely electronic ?

- 3) systematics in other materials:

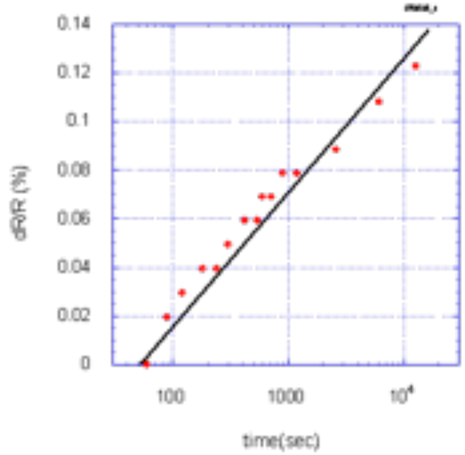
Up to now:

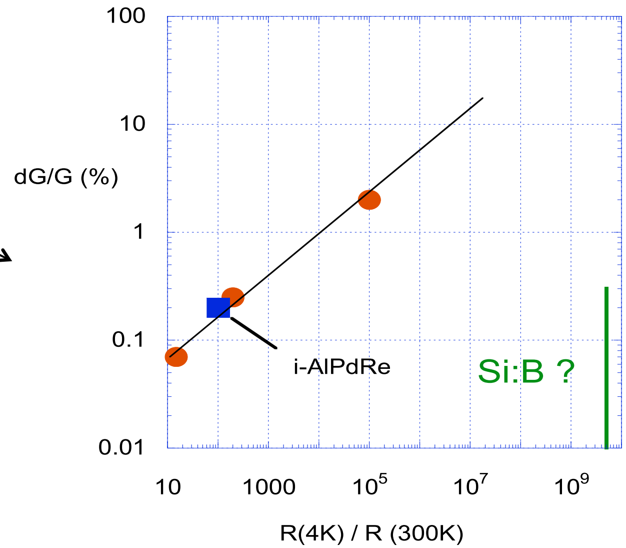
- studied in: indium oxide, granular aluminium

- seen in: granular gold, ultra thin Pb on a-Ge

- being studied in Ni films (without oxide, strong effect of magnetic field on the dynamics, Aviad Frydman)

- maybe present in icosahedral insulating quasicrystal i-AlPdRe





What do these materials have in common ?

Only expected in insulating samples ?

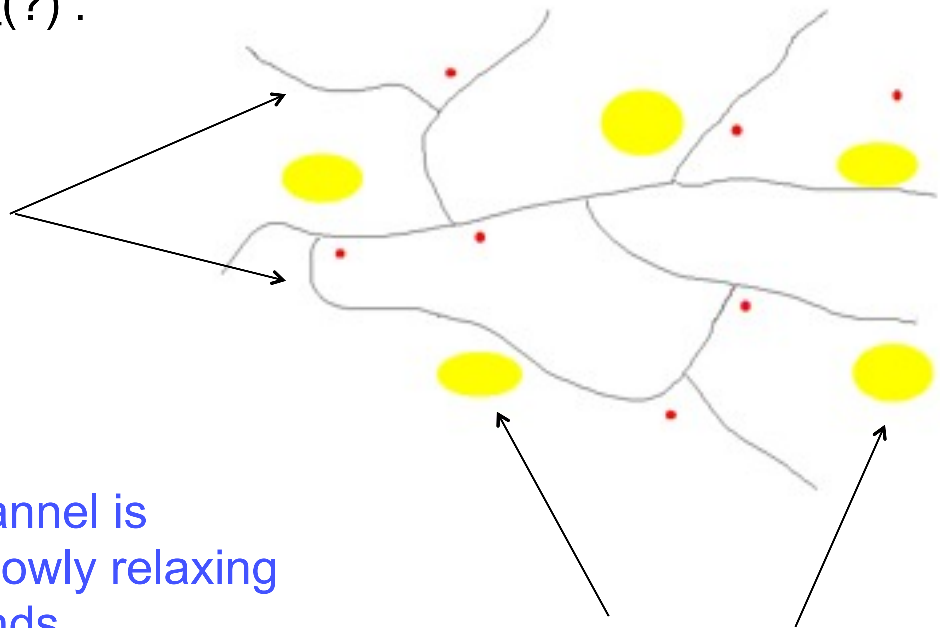
Apparent paradoxes:

- thermal memory of cusp but not of « back-ground » conductance

- very slow relaxations even for weakly (and metallic?) insulating samples

Consistent picture (?) :

Conduction path
(percolation):
« fast » electrons

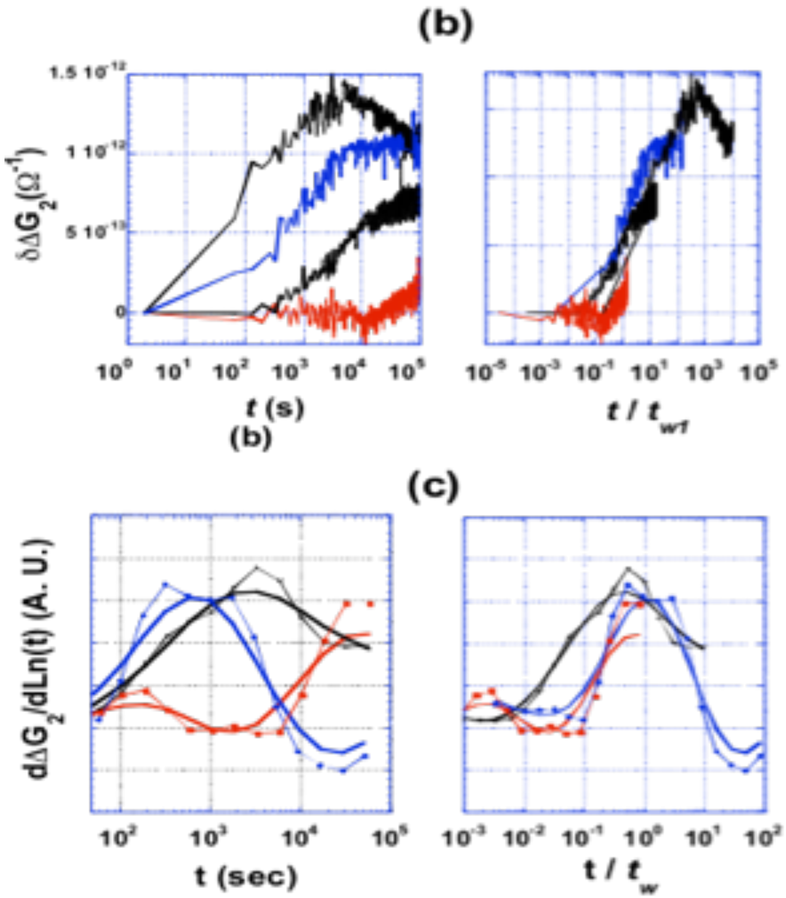


The conducting channel is
influenced by the slowly relaxing
coulomb glass islands

Islands of coulomb glass
« slow » electrons

Understanding the dynamics ?

- mechanism / significance of the ageing behaviour ?
(indication for the importance of correlations ?)



What we need:

theoretical predictions*

*that can be tested experimentally