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Glassiness in insulating granular aluminum thin films

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Glassiness in insulating granular Al thin films

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OUTLINE

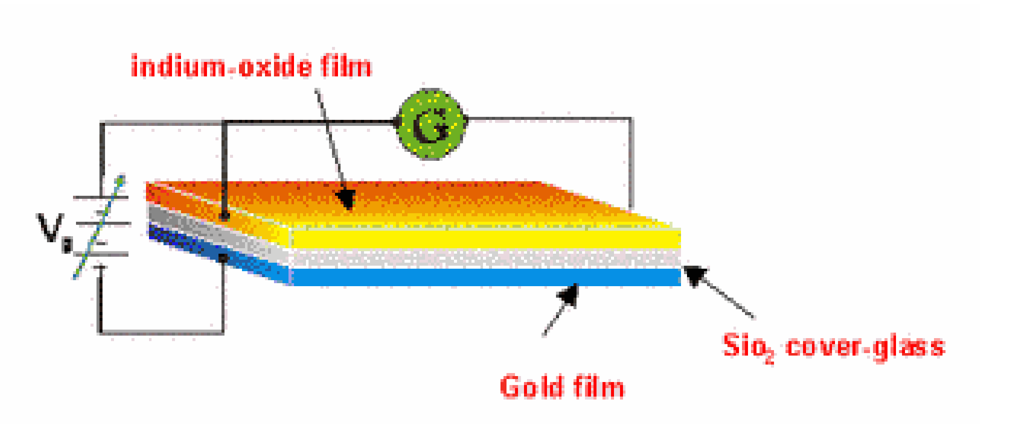
- how it started
- some aspects of the « glassiness » in granular Al
- is ageing present ? (is it a glass ?)
- is it an electron glass ?

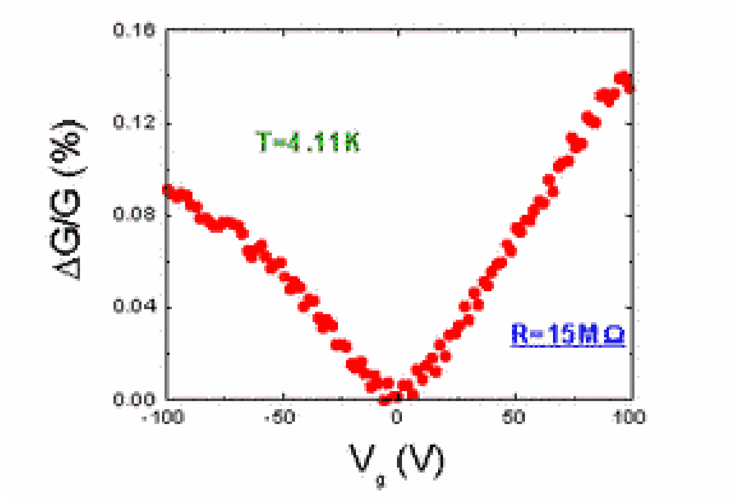
Electron Coulomb glass ?

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 …

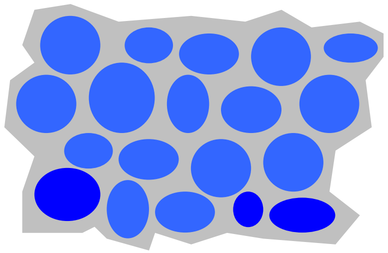
Indium oxide … what else ?

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)

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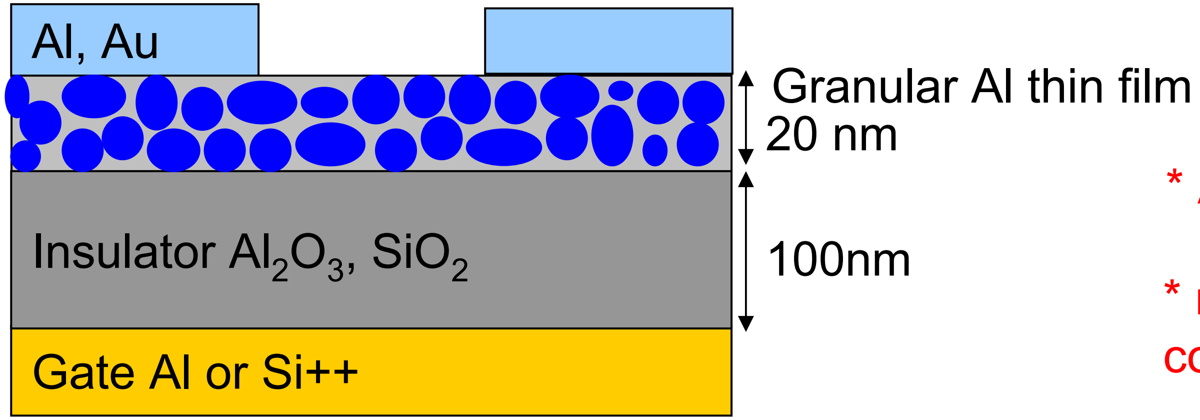
Granular Aluminium samples

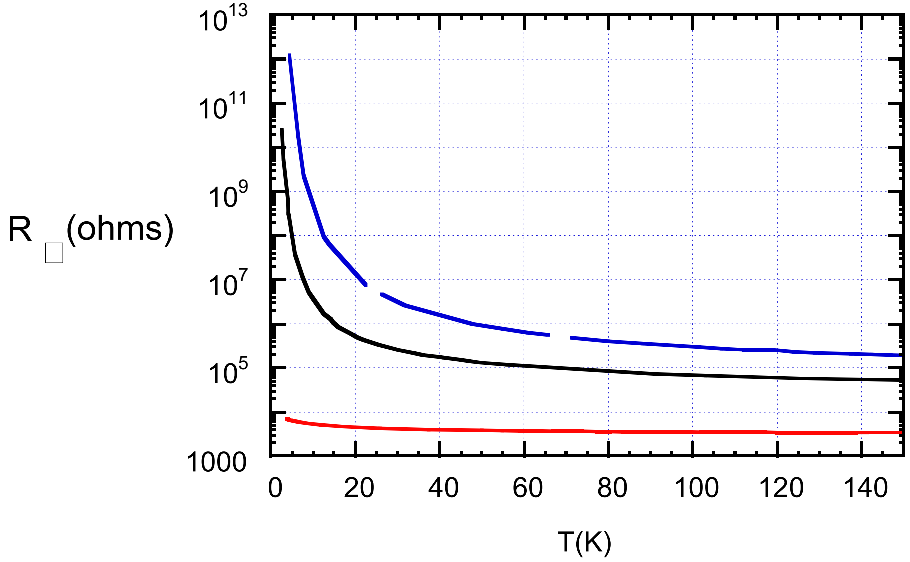


* Al evaporated in $P(O_2)$

* nanometric Al grains covered by Al_2O_3

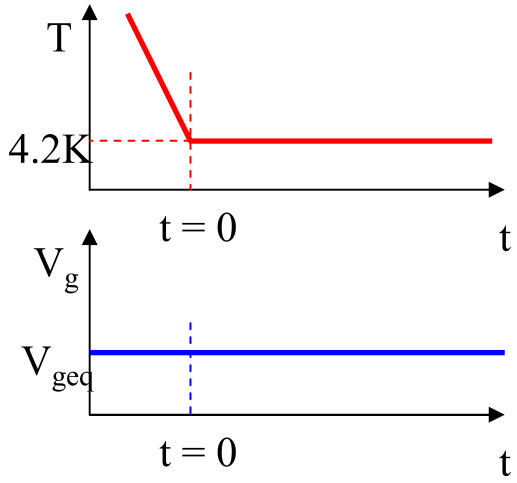
Study insulating films:

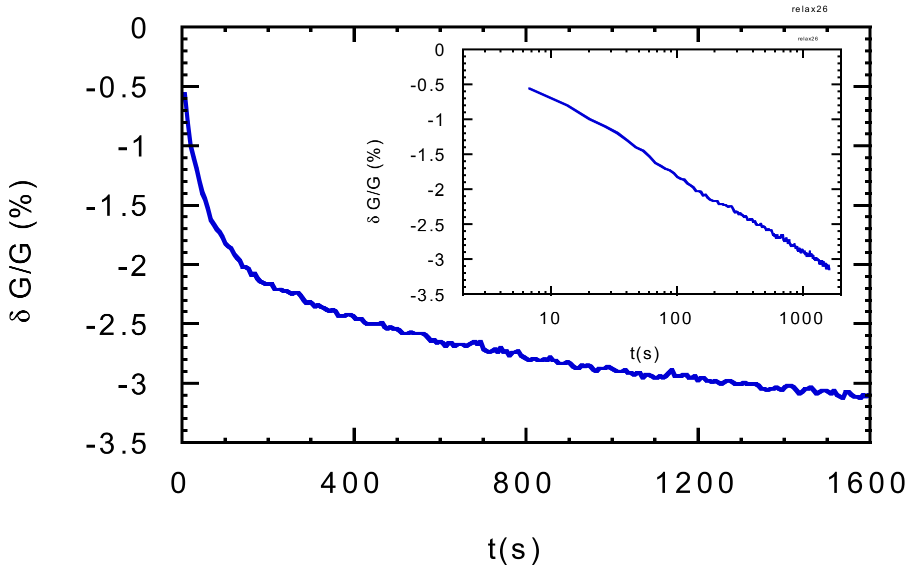
R/□ at 4K: 100 kΩ → 100 GΩ

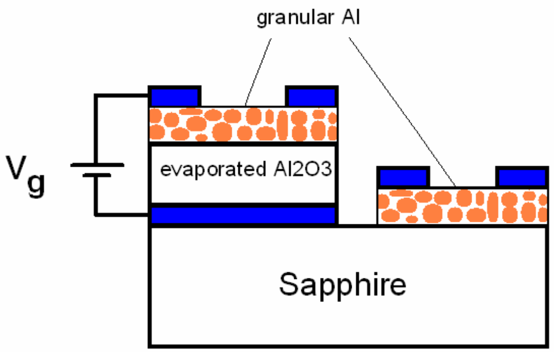


Out of equilibrium effects

Never ending slow conductance relaxation after a quench

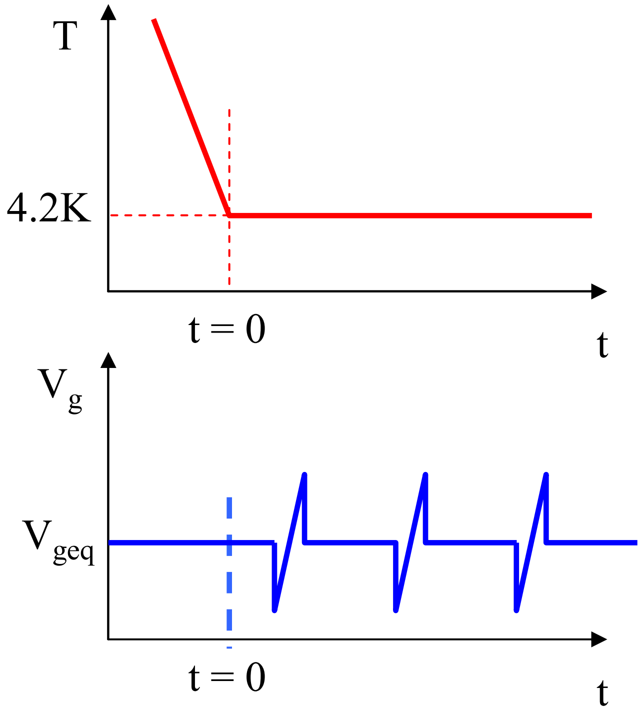




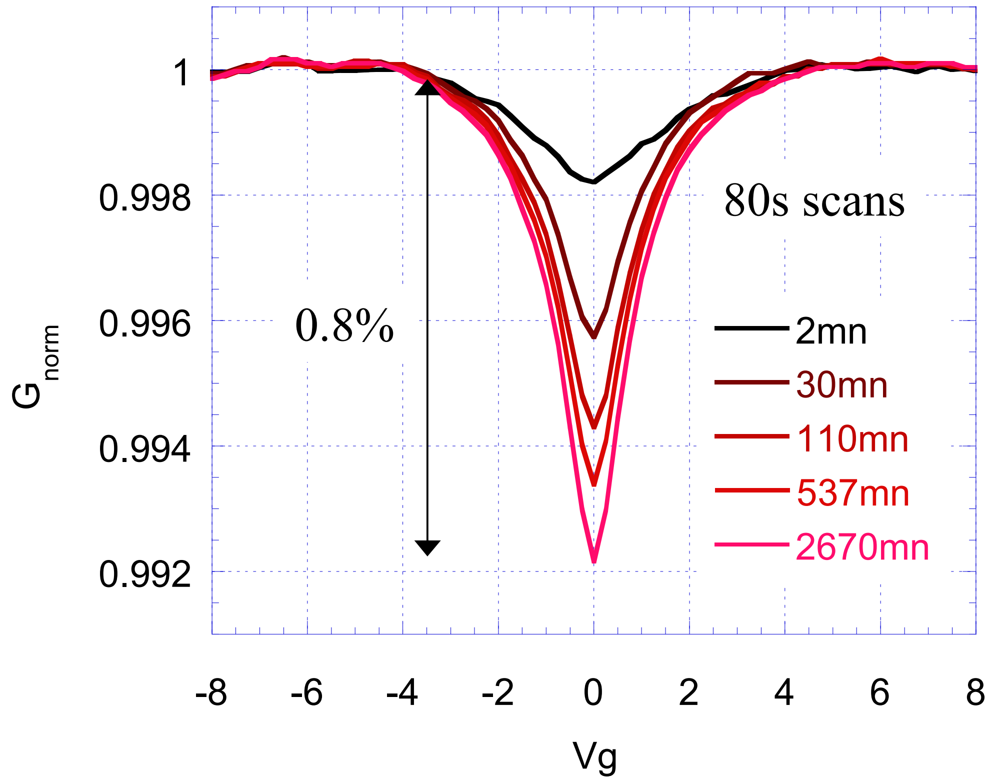


Out of equilibrium effects

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



$R_{\square}$=30MΩ at 4.2K



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

- Amplitude grows like Ln(*t*)

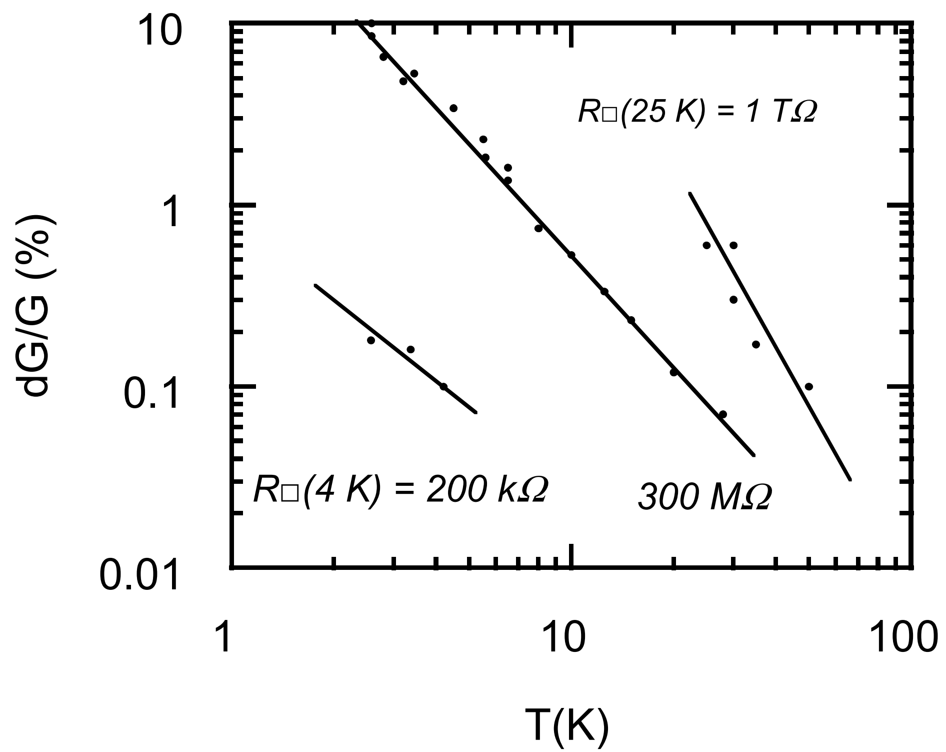
When do we see this anomaly ?

- the anomaly is always seen in insulating films

- it is most prominent (in %):

  → at low T (most measurements at 4K)

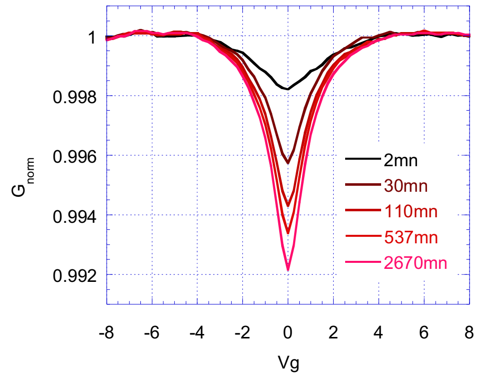
  → in more insulating samples



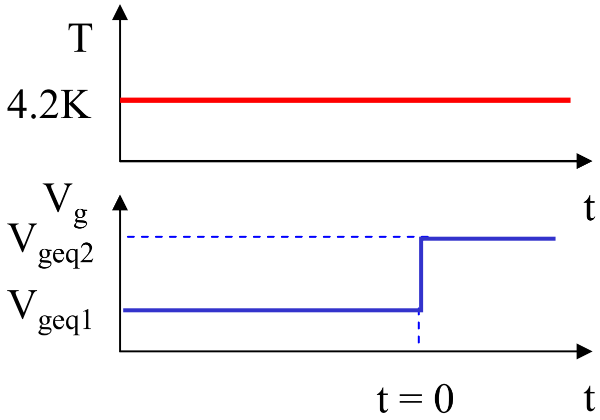
- for practical reasons we study samples were the anomaly is not so large (≤1%) but it can be a large effect

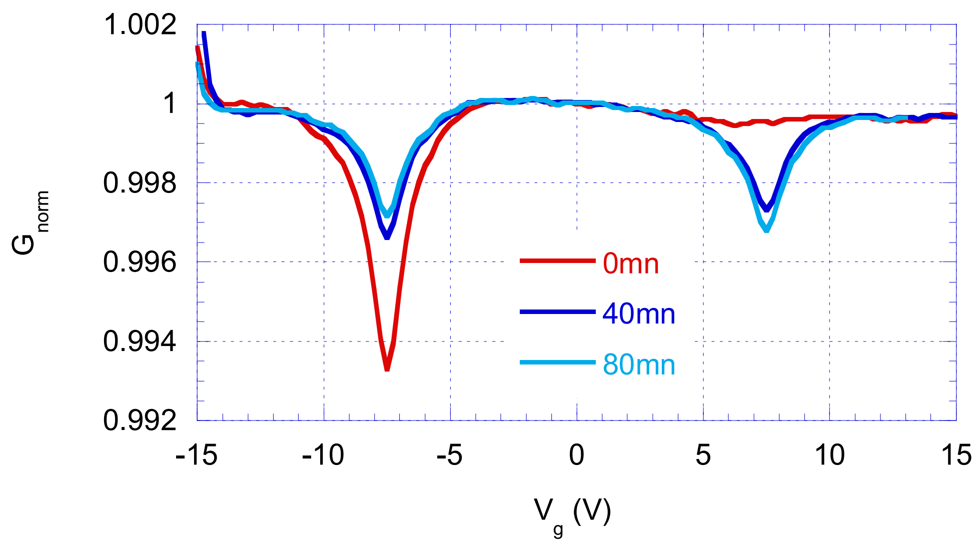
Cusp dynamics

Recall: after a cooling



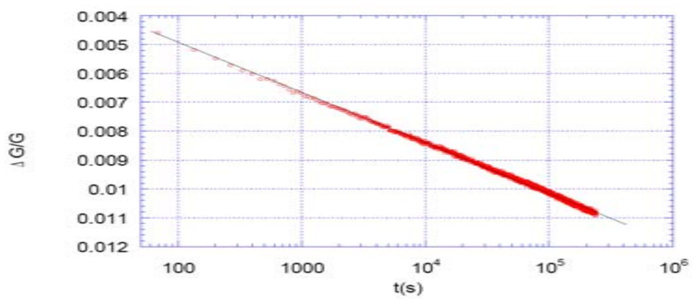
After a gate voltage change:





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

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

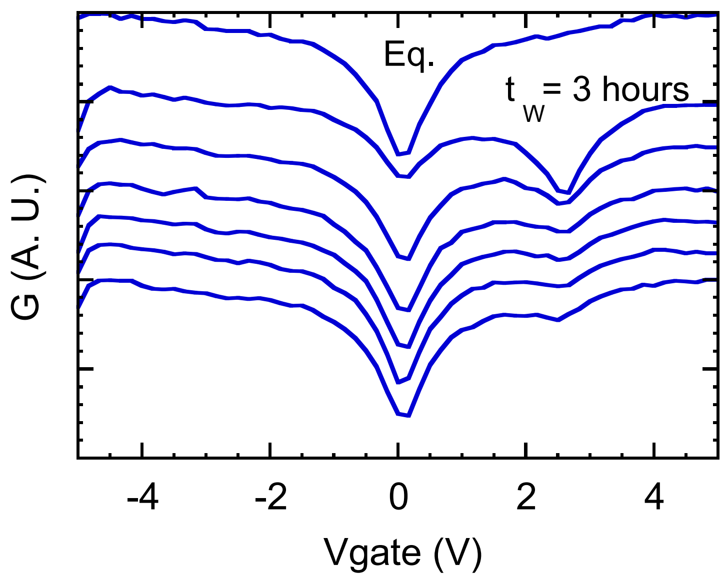


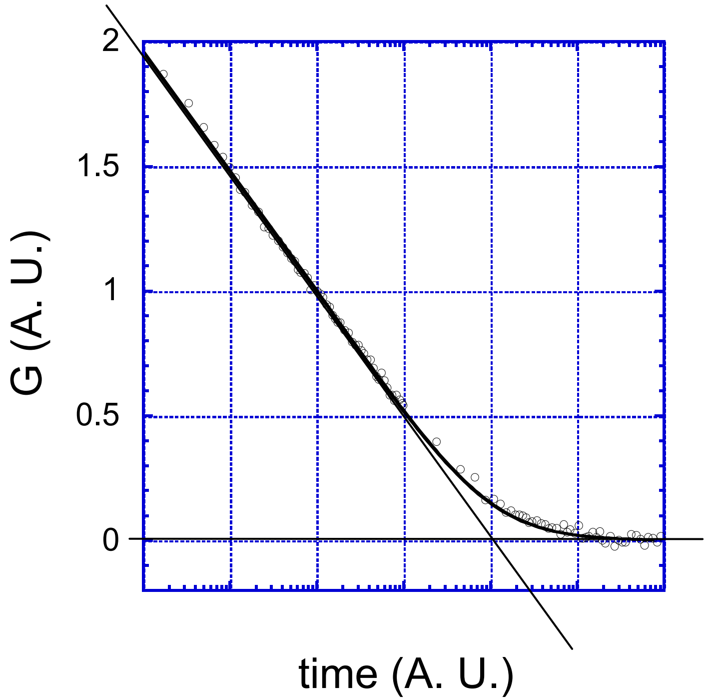
Is the dynamics activated ?

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

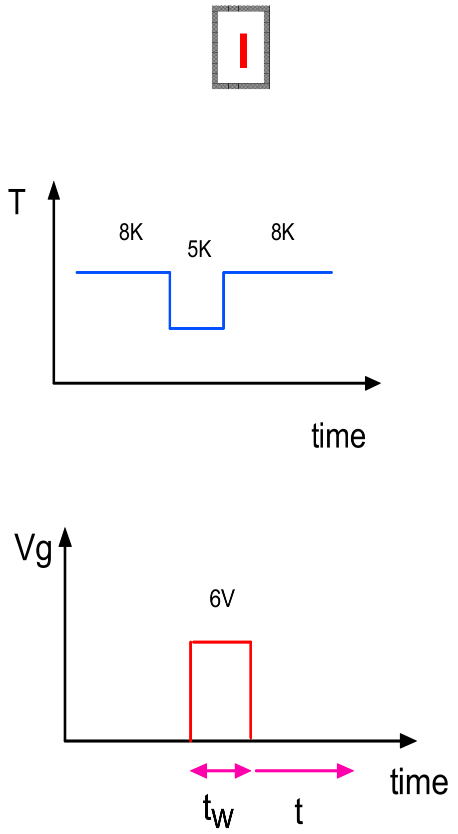
But how to detect a change of the dynamics if it has no characteristic time ?

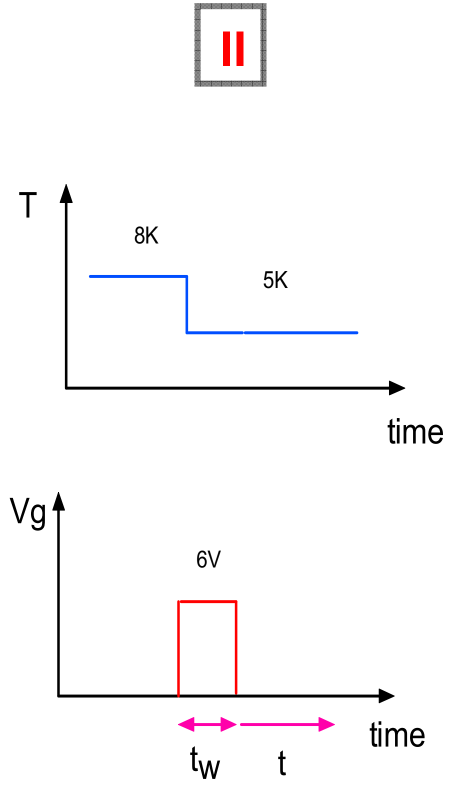
→ look at the erasure time of a previously formed dip

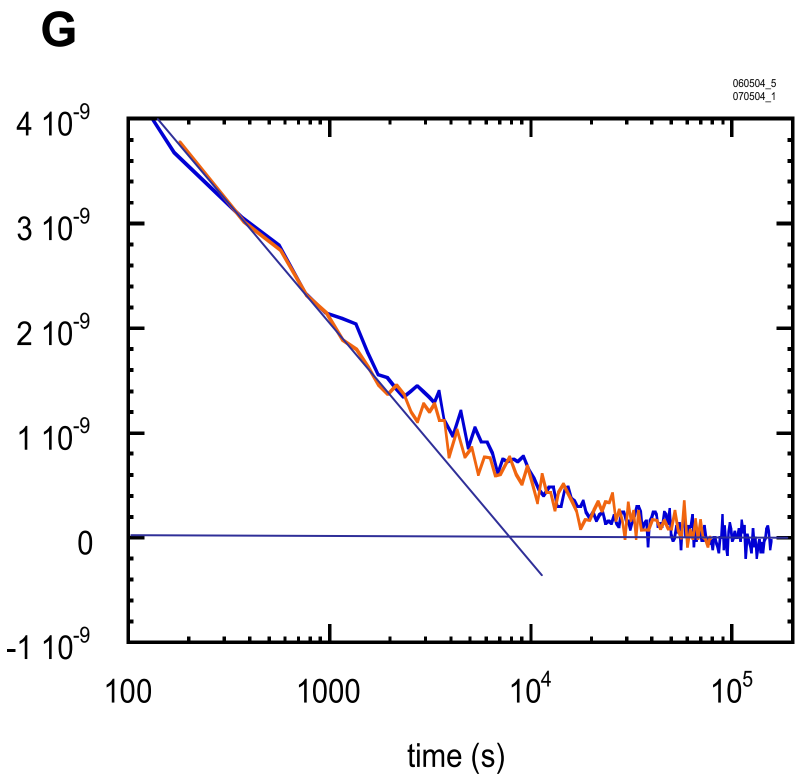




Is the dynamics activated ?



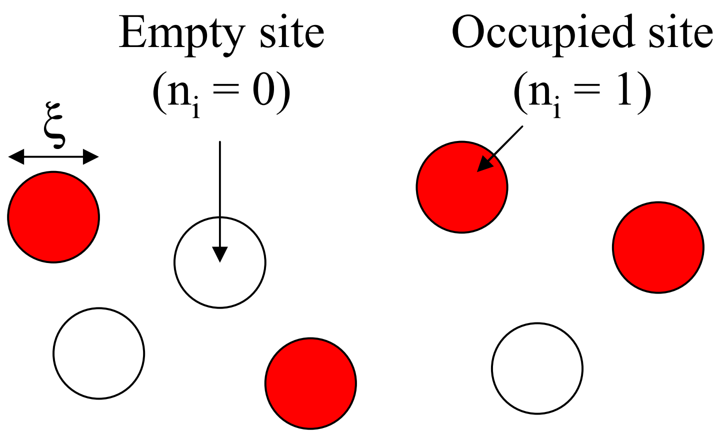


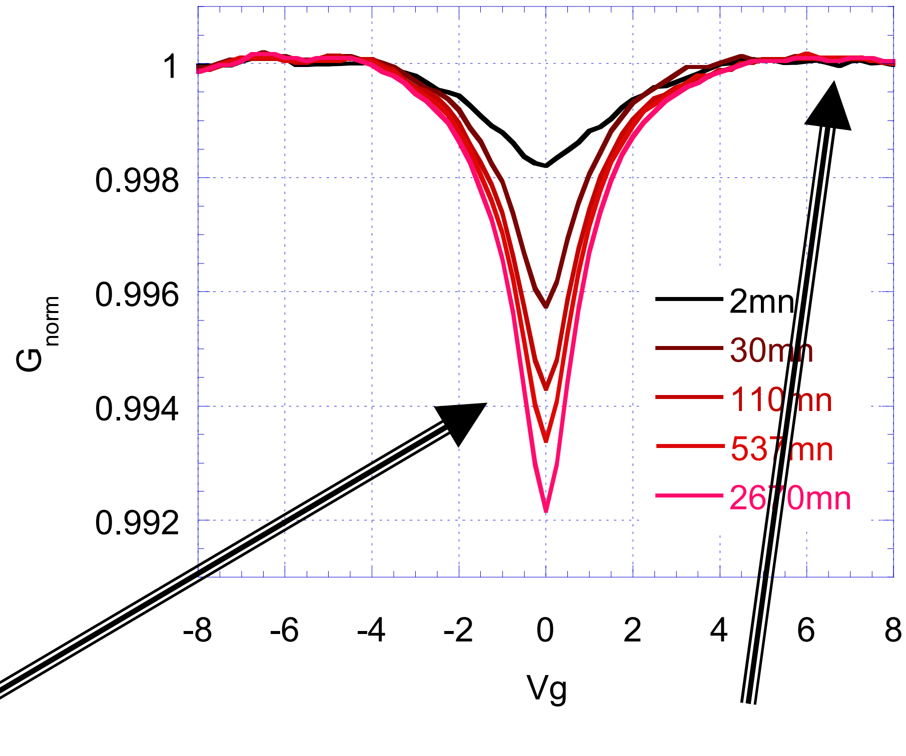


⇒ dynamics is not activated

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)

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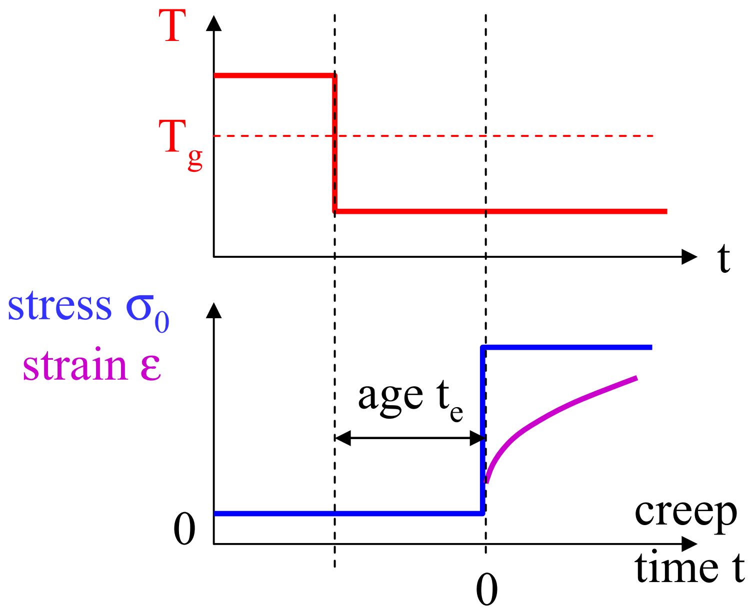
If it is a glass … does it age ?

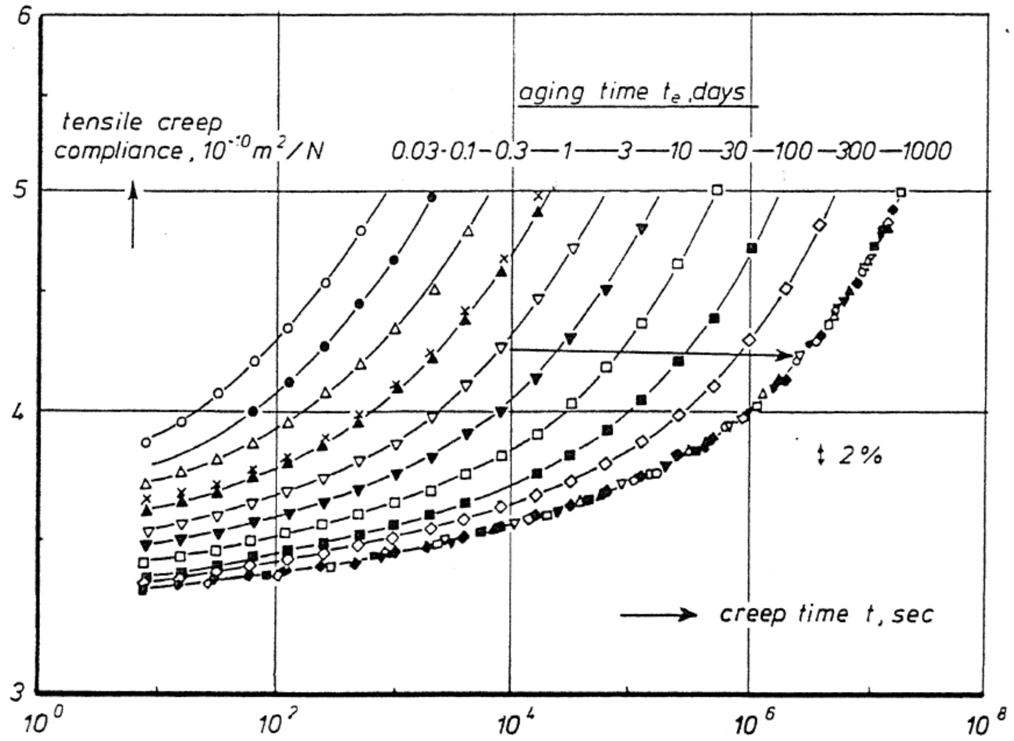
AGEING:

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

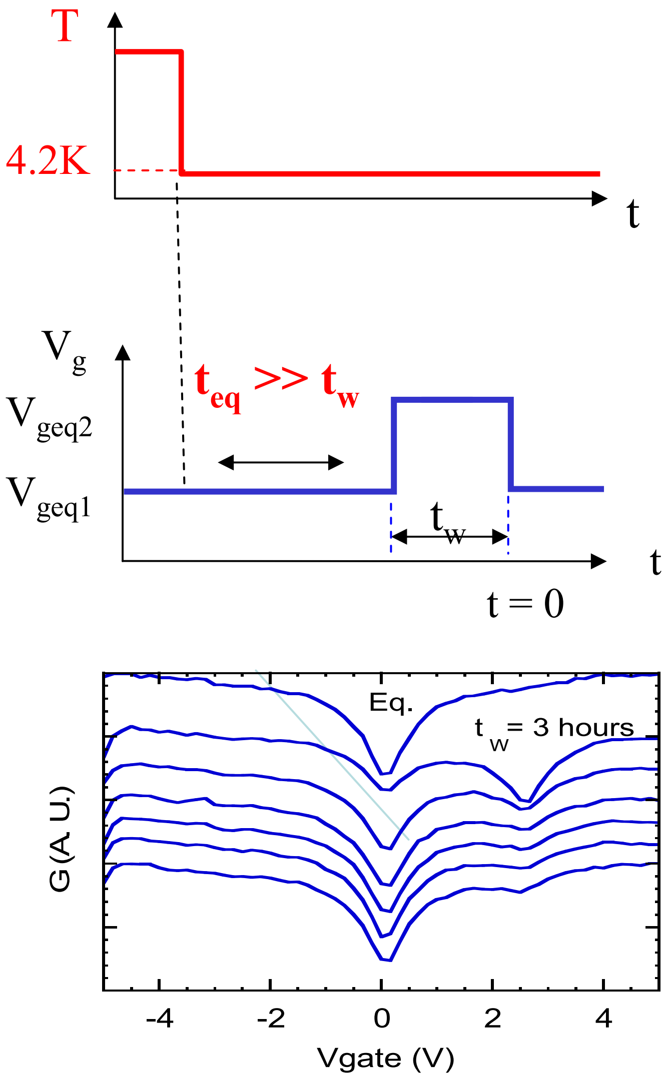


PVC quenched from 90°C to 40°C (T_g=80°C)

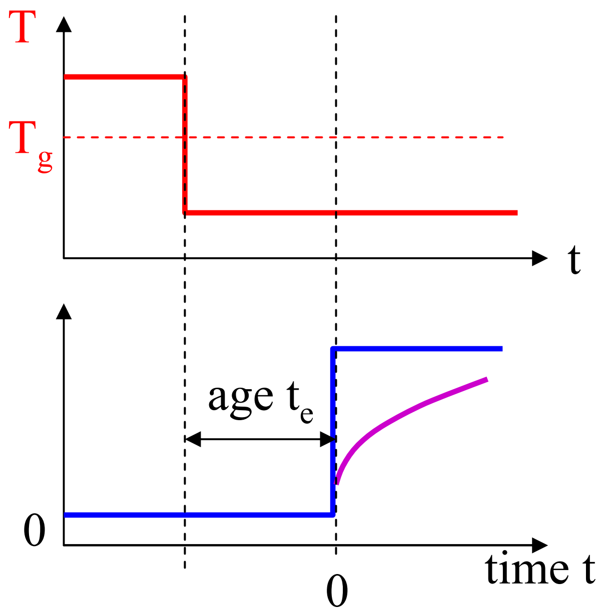
L.C.E Struik, 1978

« Two dip » versus « ageing protocol

« Two dips » protocol

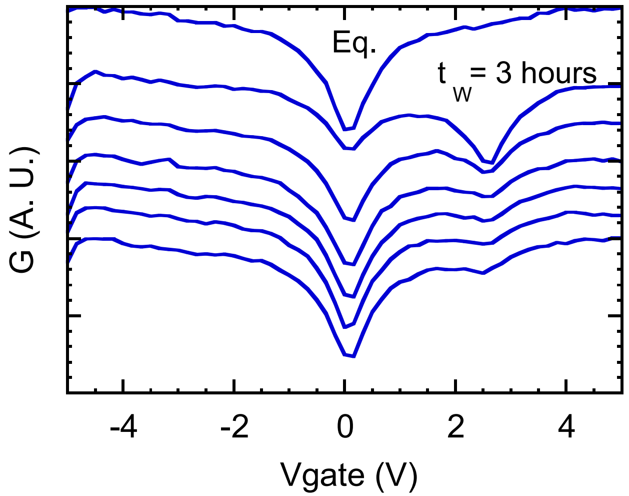


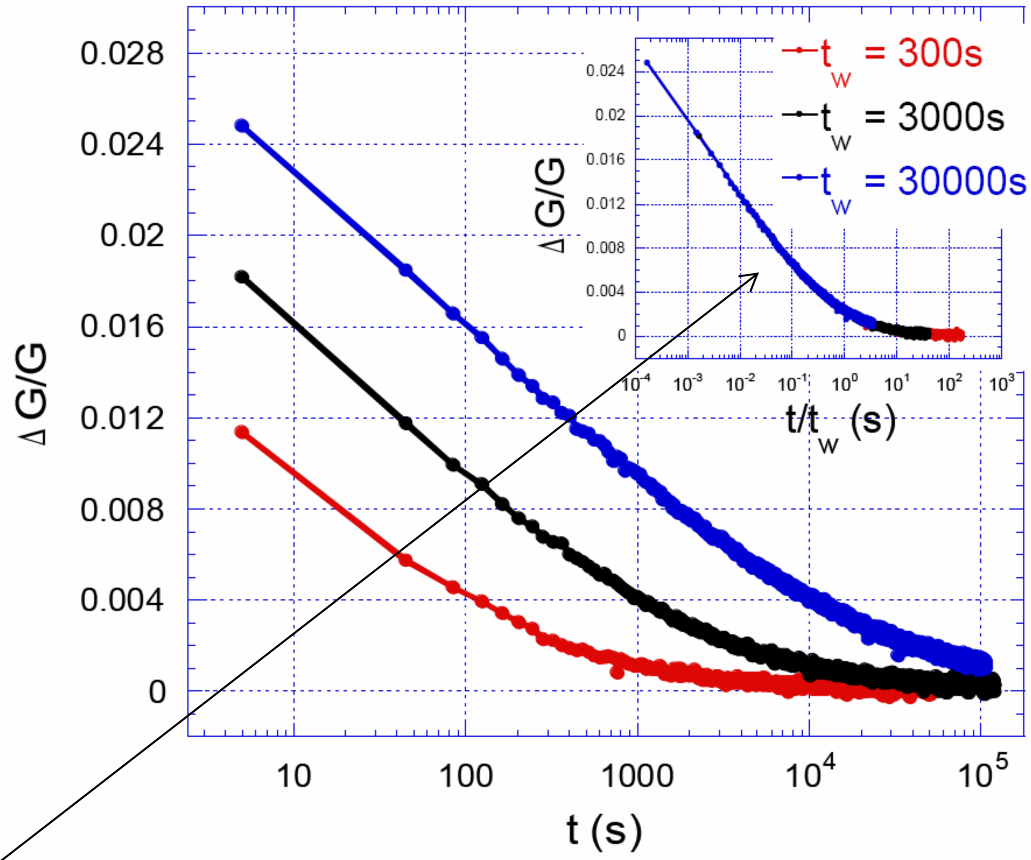
Standard « ageing » protocol



Two dip protocol: full « ageing » ?

« Two dips » protocol





t/t_w scaling =
« full ageing » ?

… it does not demonstrate ageing

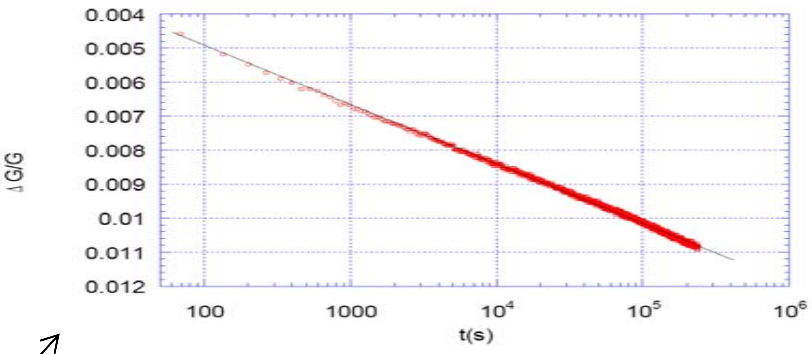
A simple model can reproduce the data:

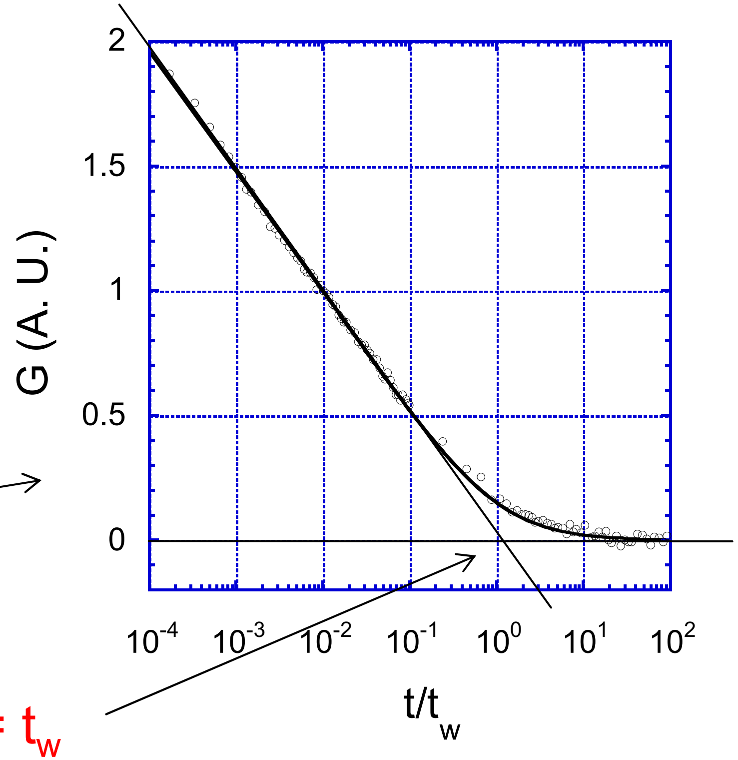
-collection of independant reversible « degrees of freedom » (e.g. polarisable TLS)
- additive effect on G
- tunnel → Ln(τ_i) has a broad (flat) distribution

Then:

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

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

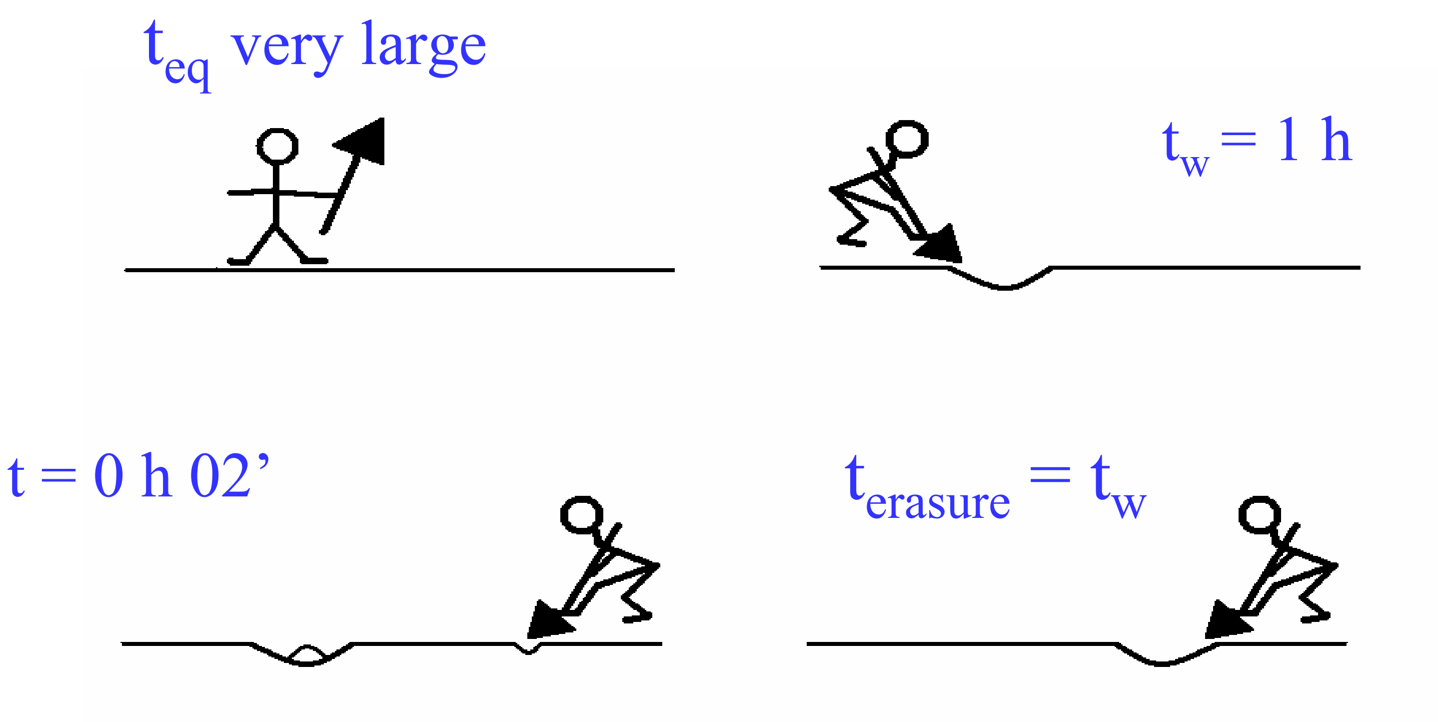




But this is NOT ageing !

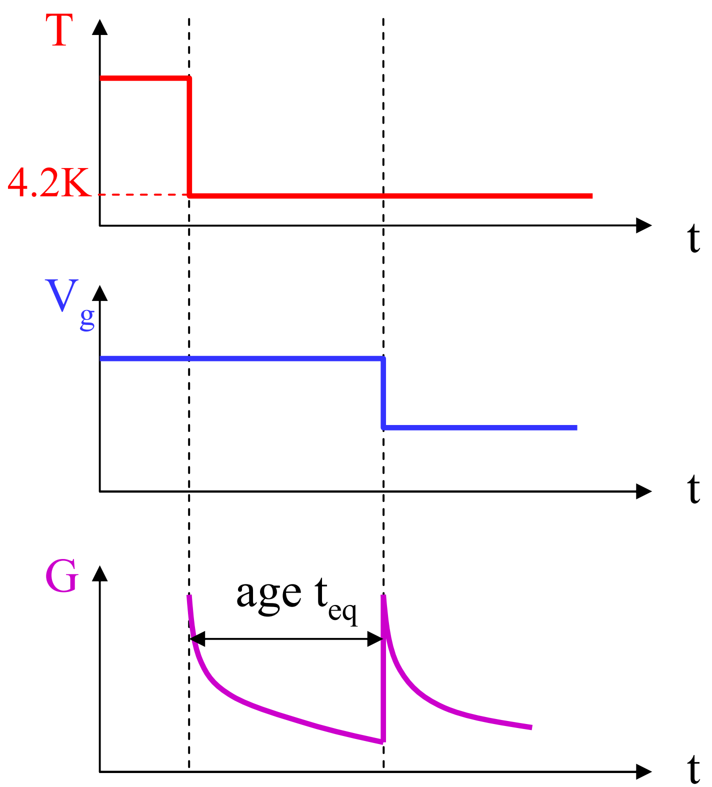
$t_{erasure} = t_w$

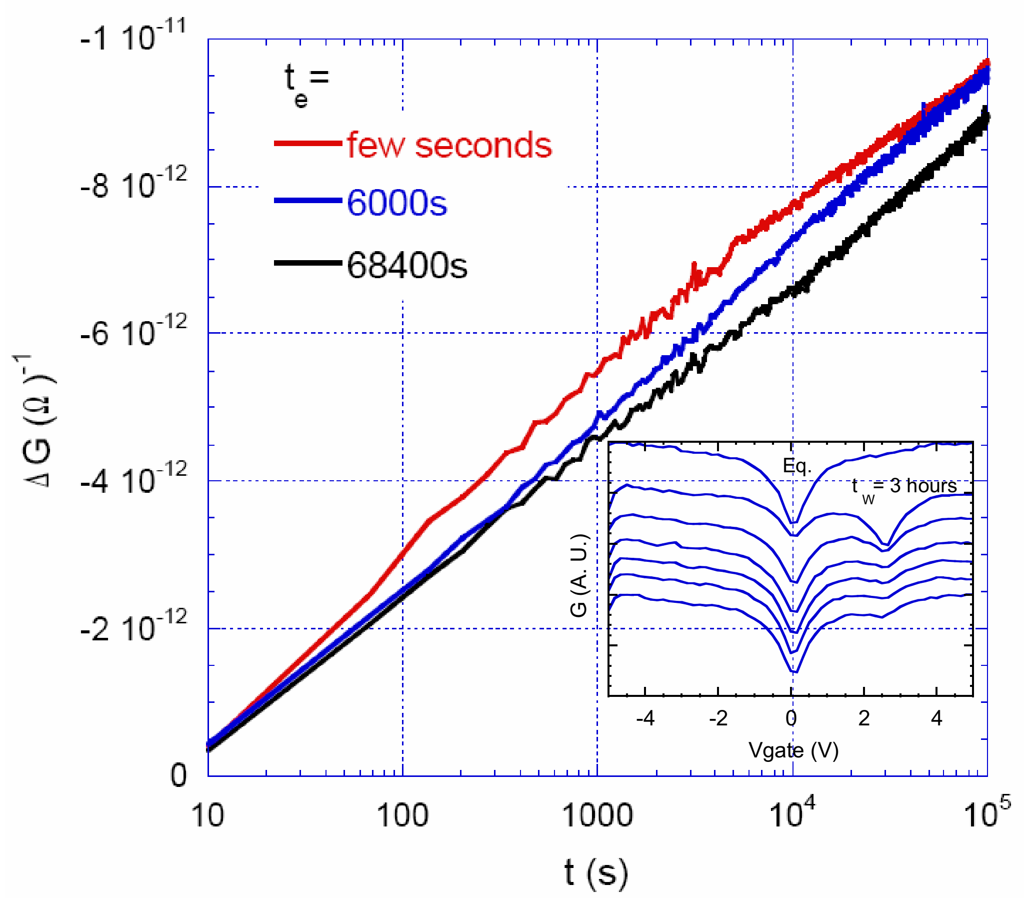
Picturial view of the « two dip » protocol



« full scaling » ↔ $t_{end} = t_w$: trivial effect !

Standard ageing protocol (1)

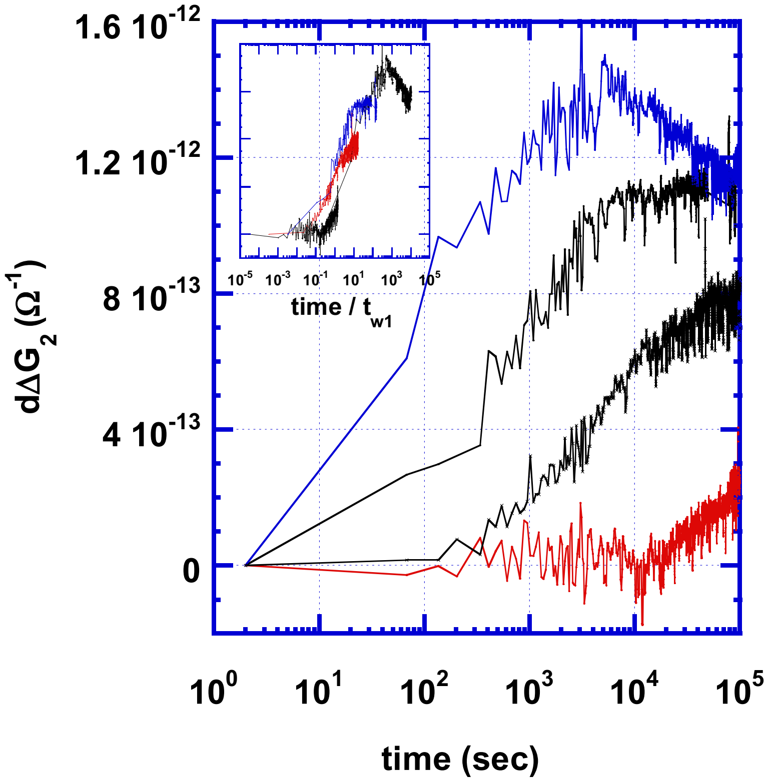




New dip growth: NOT like Ln(t) when t_{eq} NOT very large

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

Standard ageing protocol (2)



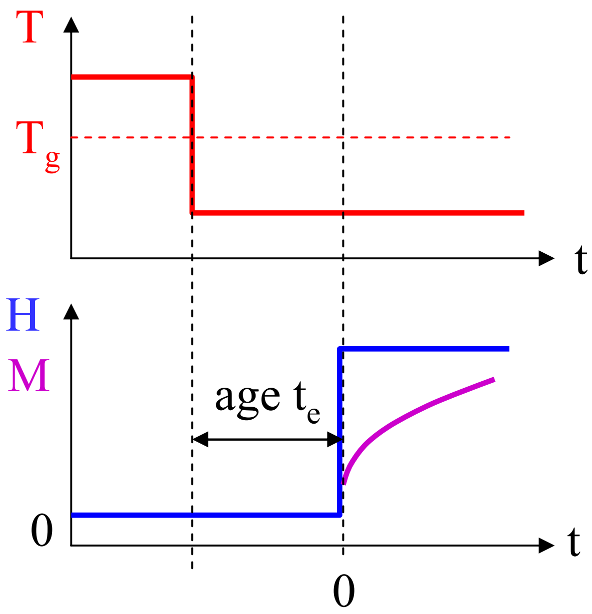
the departure from *Ln(t)* scales with t_{eq}

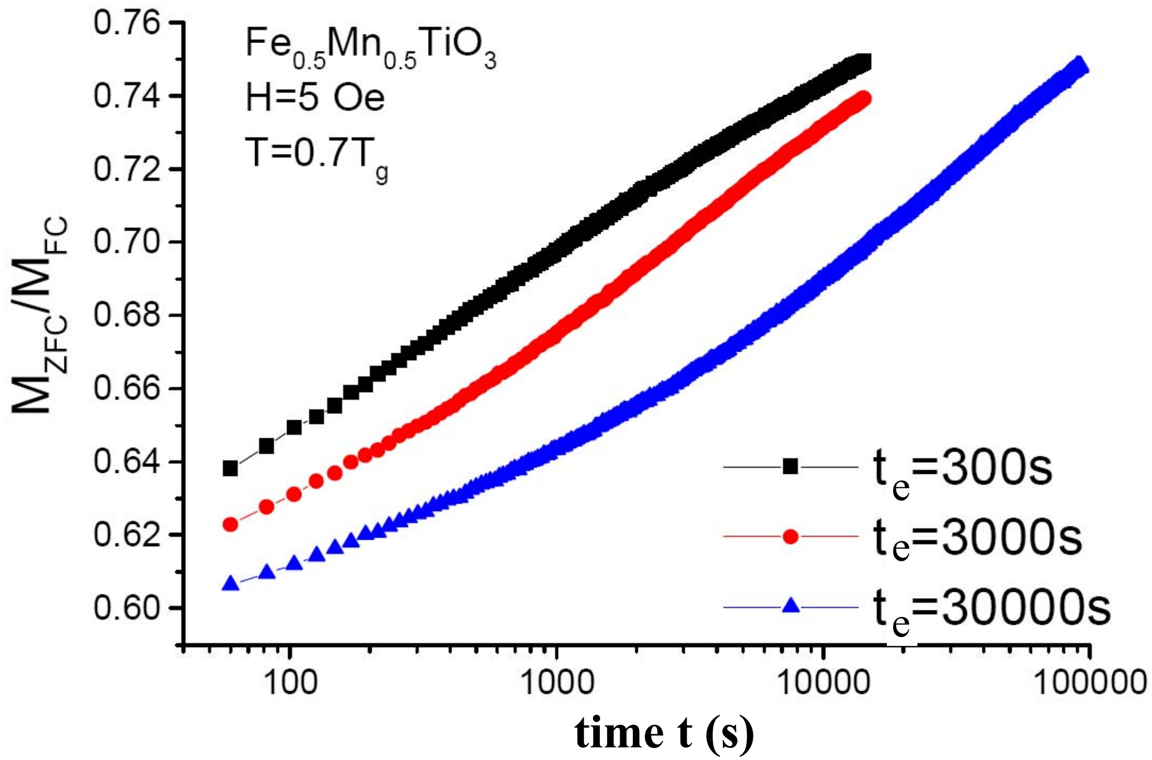
i.e. «effective» relaxation time distribution depends on the system's age:

→ AGEING !

Example of spin glasses

Zero field cooling relaxatic

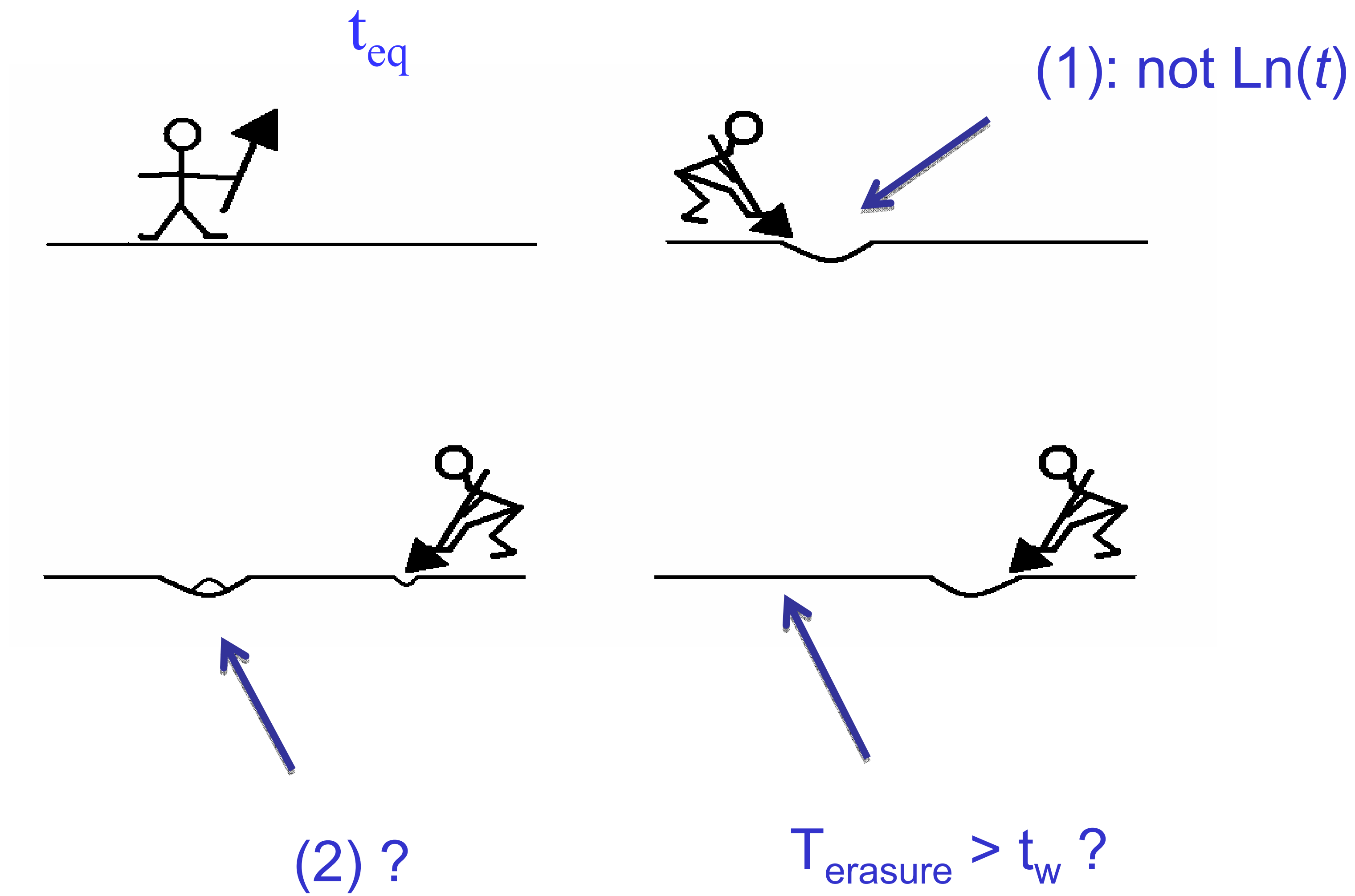




E. Vincent, 2006

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

Ageing in the two dip protocol ?

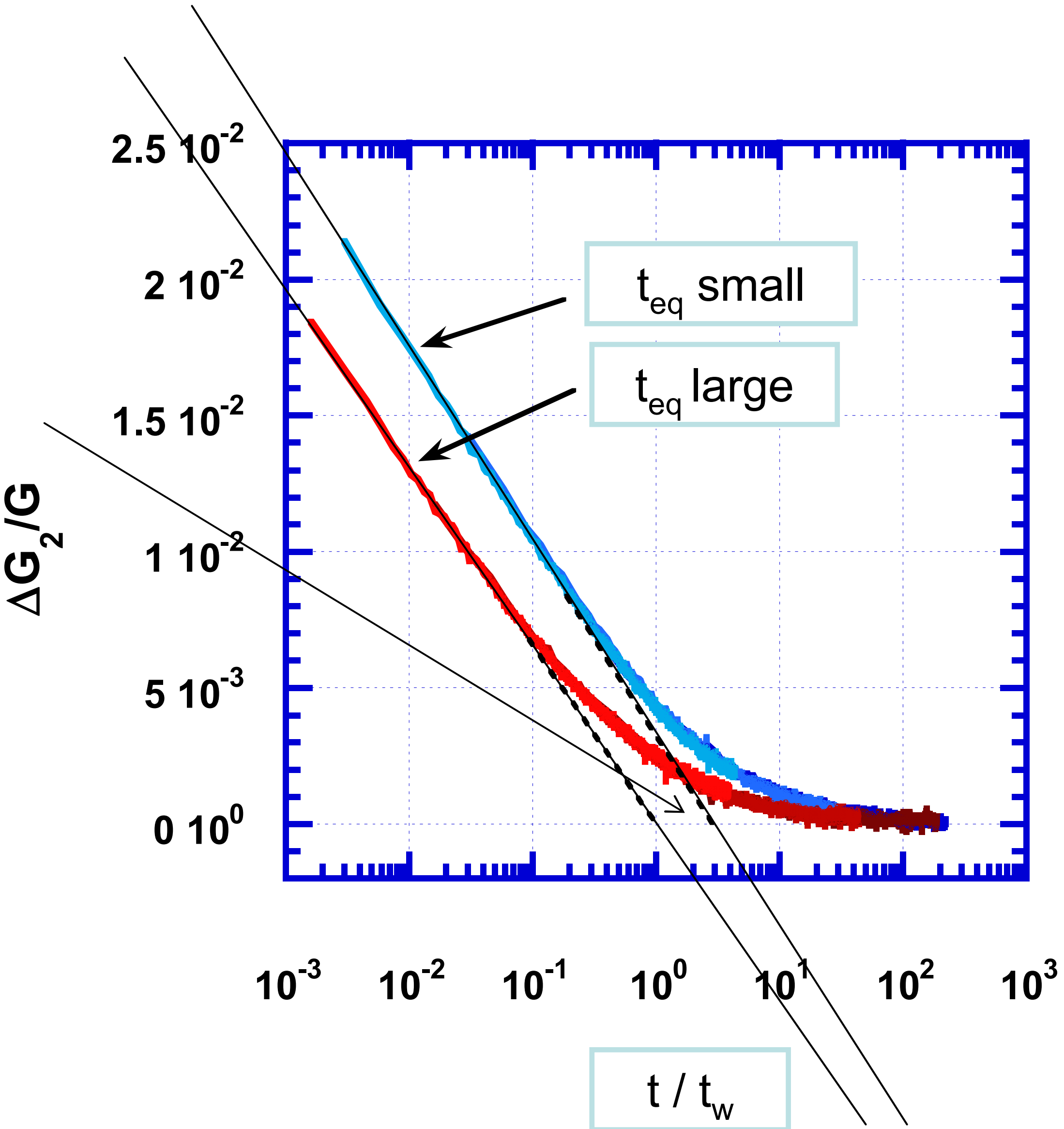


Ageing in the two dip protocol

Indeed when t_{eq} is small:

$t_{erasure} > t_w$

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



Conclusions about ageing

- In very « old » (already aged) samples ageing was hardly visible

- In « young » samples ageing is prominent (and consists in deviations from the « regular » two dip protocol behaviour)

- « old » samples can be rejuvenated e.g. by a moderate higher T excursion or by a large enough V_g change (large perturbations tend to erase any history of the sample) → ageing is restarted

- models involving simple degrees of freedom acting in parallel (independently) are ruled out, we have a glassy behaviour in a strict sense

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- how it started
- some aspects of the « glassiness » in granular Al
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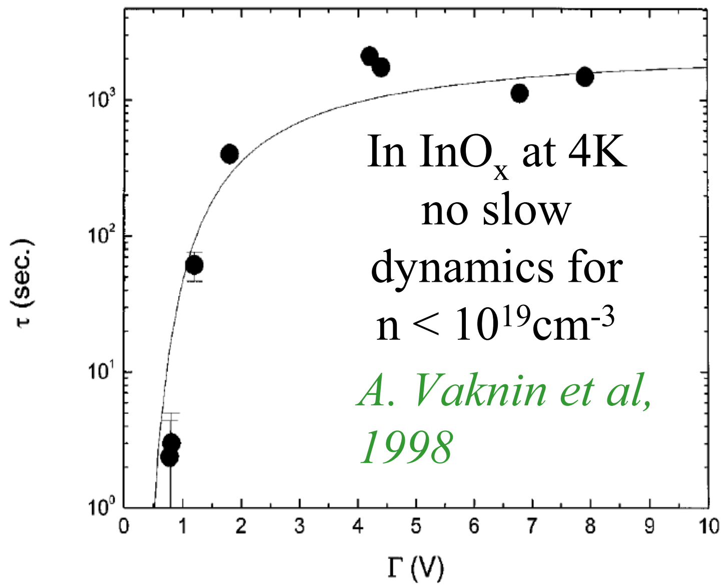
Is this glass purely electronic ?

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

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

- 1) a good indication in Indium oxide: effect of carrier concentration

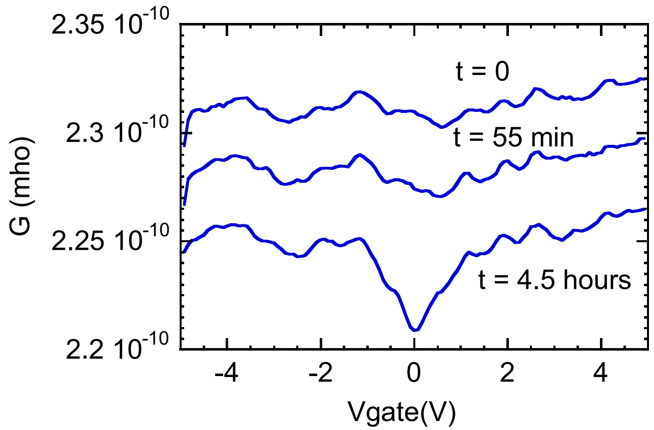
The closer the carriers are from each other, the more correlated they are (consistent with coulomb glass)



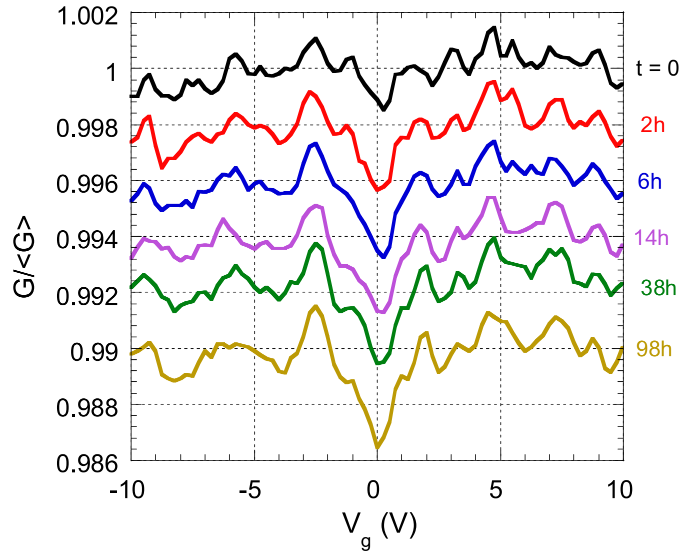
Is this glass purely electronic ?

- 2) slow relaxation in mesoscopic samples :

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 ?

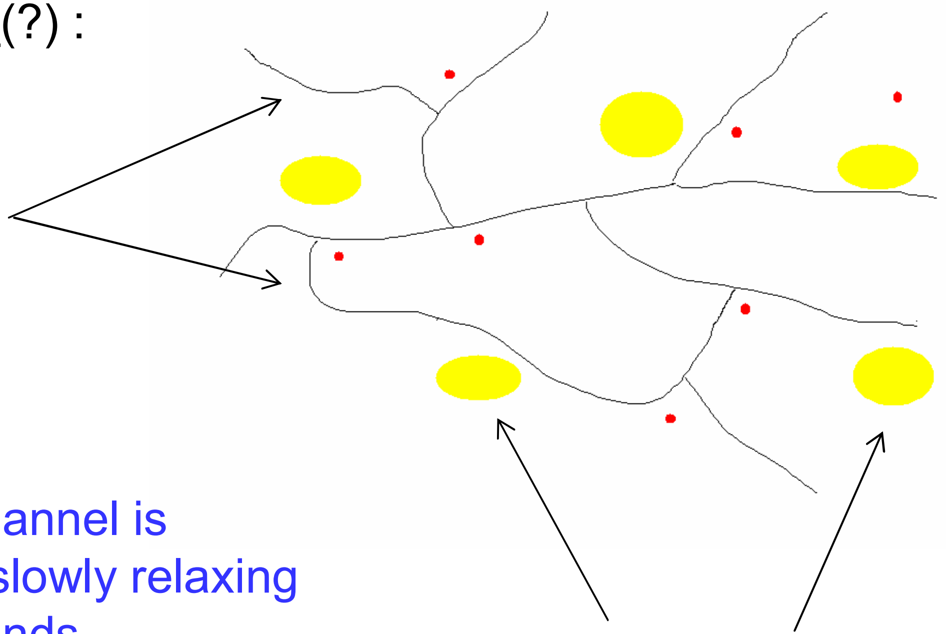
Apparent paradoxes:

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

- very slow electrons even for weakly insulating samples

Consistent picture (?) :

Conduction path
(percolation):
« fast » electrons



Islands of coulomb glass
« slow » electrons

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

Is this glass purely electronic ?

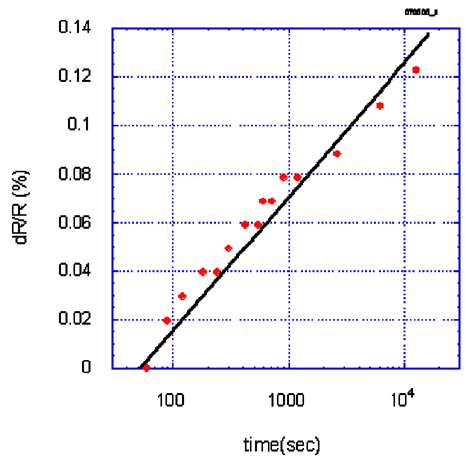
- 3) <u>systematics in other materials</u>:

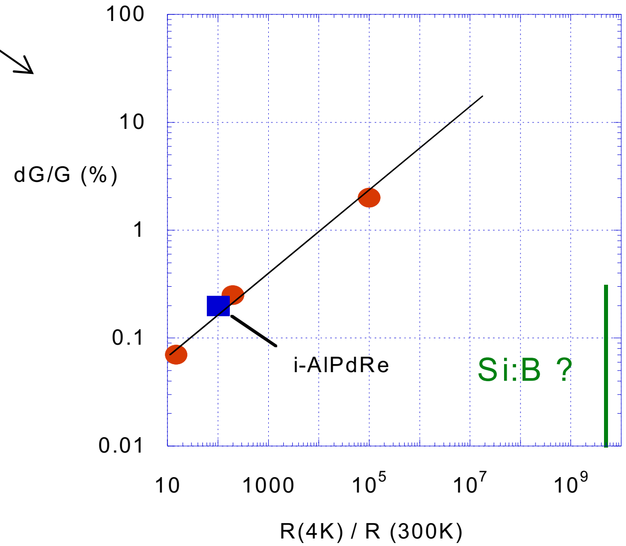
Up to now:

- studied in: indium oxide, granular aluminium

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

- maybe present in icosahedral insulating quasicrystal i-AlPdRe





All these may be a priori good candidates for the coulomb glass: disordered insulators with high electron concentrations

… and the materials we've heard about in this conference (MoGe etc…) could also be good candidates !