OUT OF EQUILIBRIUM FLUCTUATIONS IN AGING SYSTEMS: GELS, POLYMERS

Sergio Ciliberto.

• Summary of the experimental results on the noise in aging materials

a) spin-glass, polymers and gels
b) local versus global measurements
c) The intermittency
d) The observable dependence

• The dielectric measurements in PVAc (intermittency ?)

•The local-global measurements in a gel. The quenching rate

•The quench at the critical point

Fluctuation Dissipation Ratio (FDR) during aging

In equilibrium

$$\chi(t,t_w) = \frac{1}{k_B T}(C_\theta(t,t) - C_\theta(t,tw))$$

$$\chi(t,t_w) = \frac{<\Delta>}{\Gamma_{ext}} = \int_{t_w}^{t} R(t,t')dt' \qquad C_\theta(t,t_w) =< \delta\theta(t)\delta\theta(t_w) >$$

Out equilibrium (Cugliandolo and Kurchan 1992) **FDR**

$$\chi(t,t_w) = \frac{X(t,t_w)}{k_B T}(C_\theta(t,t) - C_\theta(t,tw)) \qquad X(t,tw) = \frac{T}{T_{eff}(t,t_w)}$$

Experimentally this idea has been tested in

- **Spin glasses** — Magnetic susceptibility
- **Colloids** — Dielectric response
- **Polymers** — Rheology

and the associated noise

Fluctuation Dissipation Ratio (FDR) during aging

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Experimentally this idea has been tested in

- **Spin glasses**
- **Colloids**
- **Polymers**

Controversial results

Need for experiments where the results can be directly compared with theoretical models

Experimental procedure

Temperature controlled system (spin-glasses, polymères and gels)

I) The sample is prepared at a temperature Ti > Tg

II) The sample is quenched very fast at a final temperature Tf <Tg

III) The noise and the response are measured as a function of the time tw spent by the sample at Tf

IV) The steps I)-III) are repeated many time to increase the statistics

Experimental problems
Tiny quantities : pN, fA, pm, µG
Several drawbacks may appear
in out of equilibrium

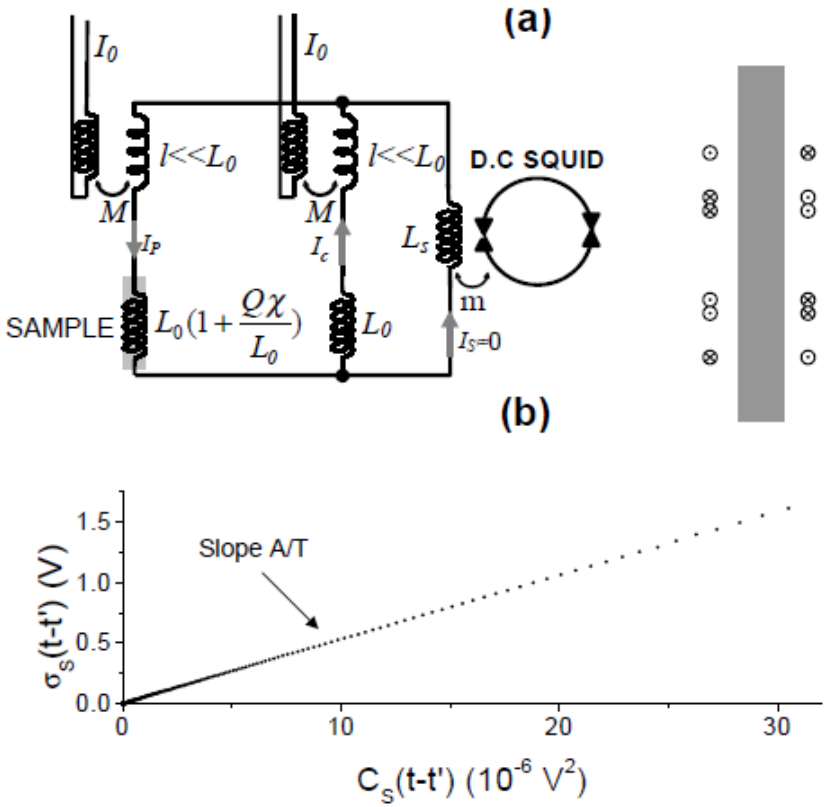
Non thermal systems (colloids)

a) Time evolution after preparation

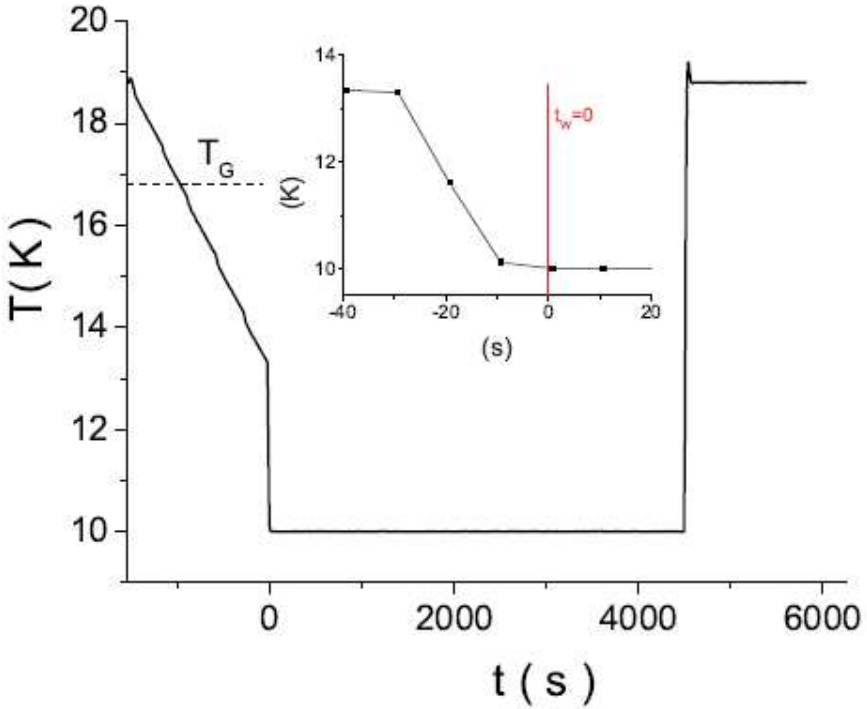
b) Time evolution after shearing or stirring the sample

Spin-Glass experiment (Herisson, Ocio 2002)

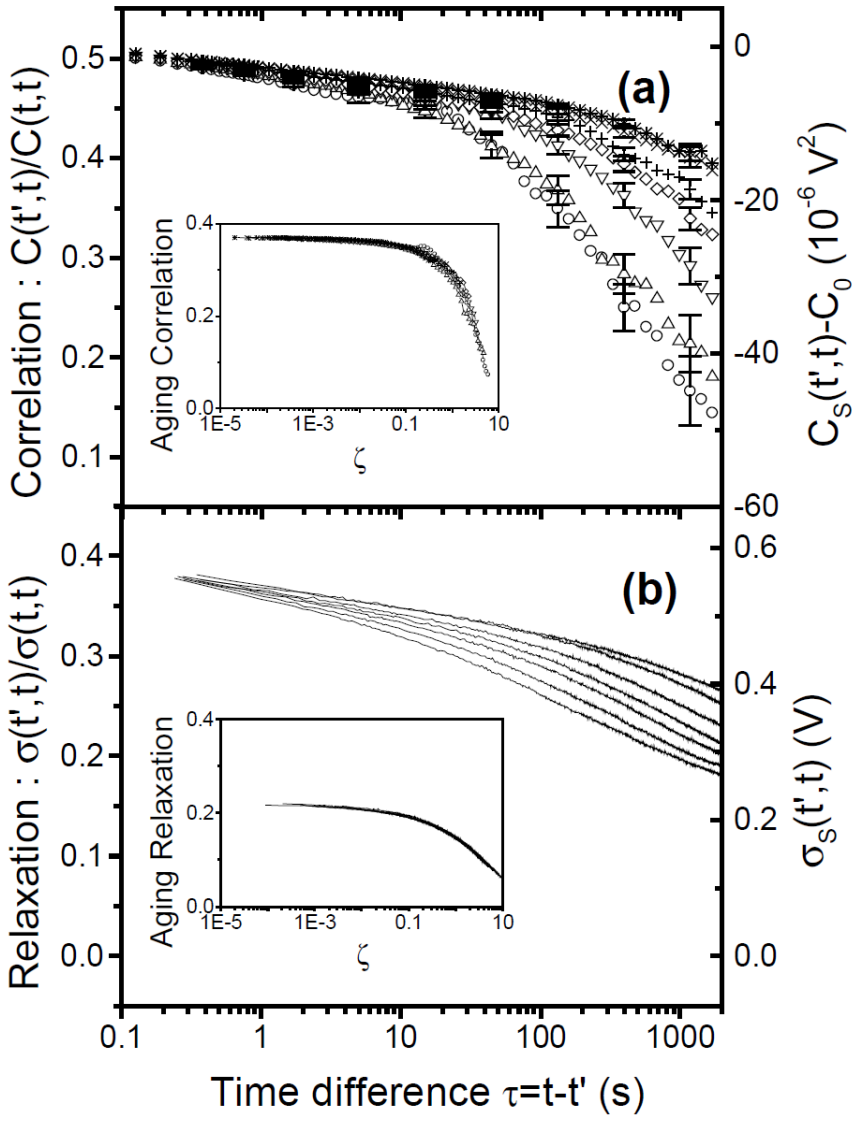
The experimental system

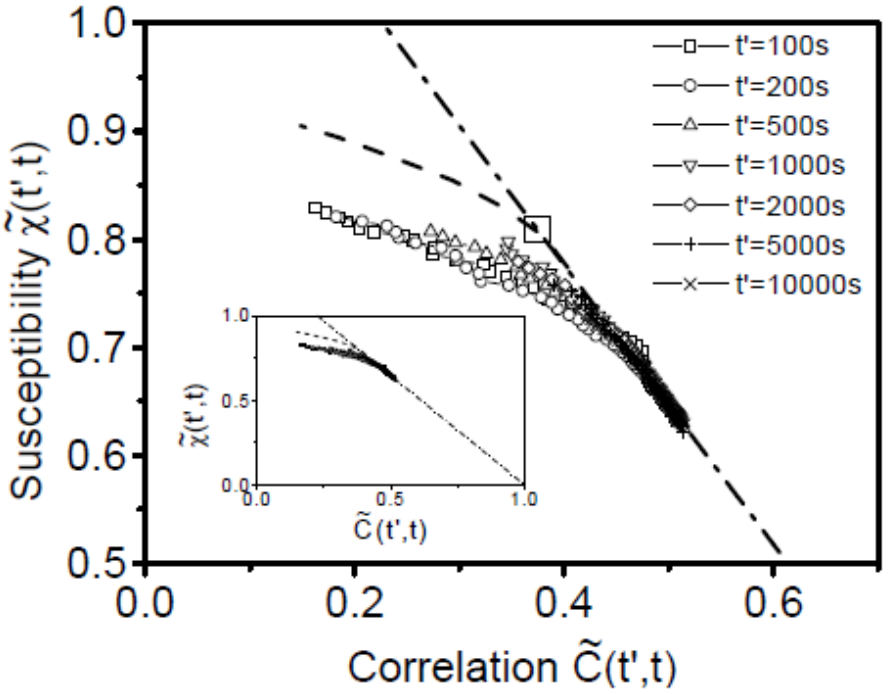


The fast quench



Spin-Glass experiment (Herisson, Ocio 2002)





Questions :

a) The local aspect is missed

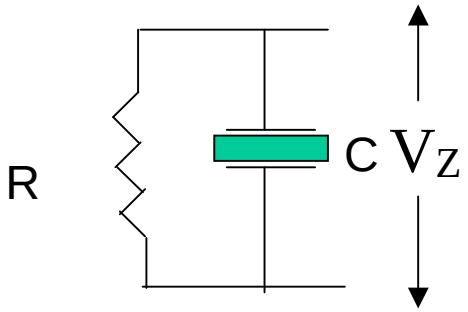
b) What is the statistics of the signals

c) What does Teff at very long time ?

Polymers

Dielectric measurements

The FDT for a dielectric



$$Z(t_w,\omega) = \frac{R}{(1 + i\omega\ R\ C)}$$

$$S_Z(t_w, f) = 4\ K_B\ T_{eff}(\omega, t_w)\ Real[Z(t_w,\omega)]$$

Several experimental difficulties :

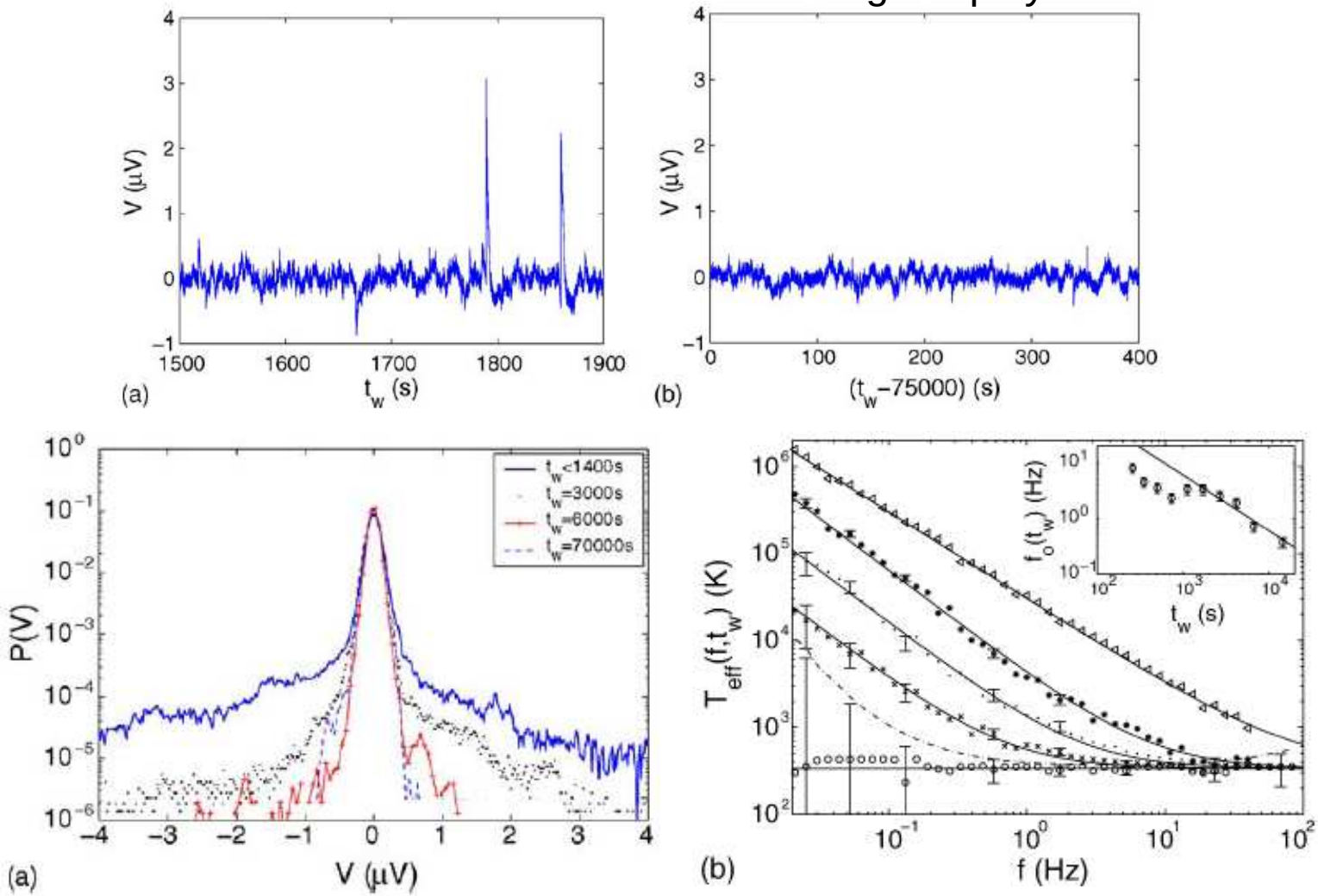
a) Extremely high Z at low frequencies (> 10GΩ)
b) Signal very weak (< 10fA)
c) Signal to noise ratio always close to 1 at low frequencies.

3 experiments have been performed and show strong intermittency

Epoxy glass former, Lucchesi et al PVAc, N. Israeloff et al
Polycarbonate L. Buisson et al.

Dielectric noise polycarbonate

Intermittent bursts in the noise voltage of polycarbonate



L. Buisson, S. Ciliberto, Physica D ***204*** *(2005)*

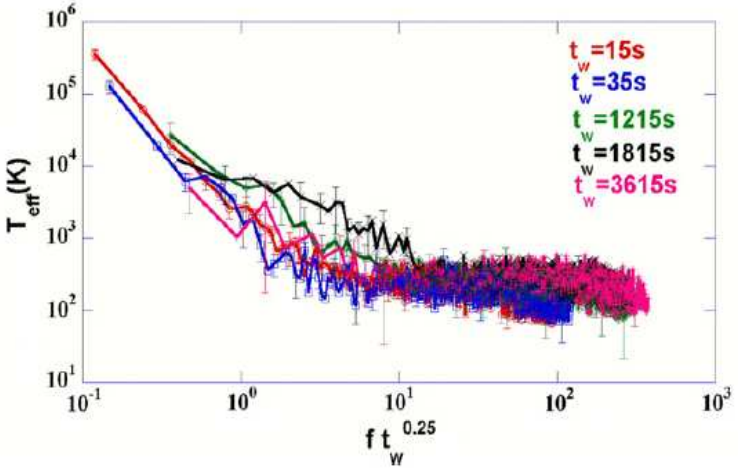
Dielectric measurements on PVAc

Comparisons of two experiments

N.E. Israeloff et al.
J. Non-Crystalline Solids 352 (2006) 4915–4919

C=92pF,
Quench
from 55°C to 25°C
Quenching time =15 sec

PVAc
Tg=34°C



Strong intermittency

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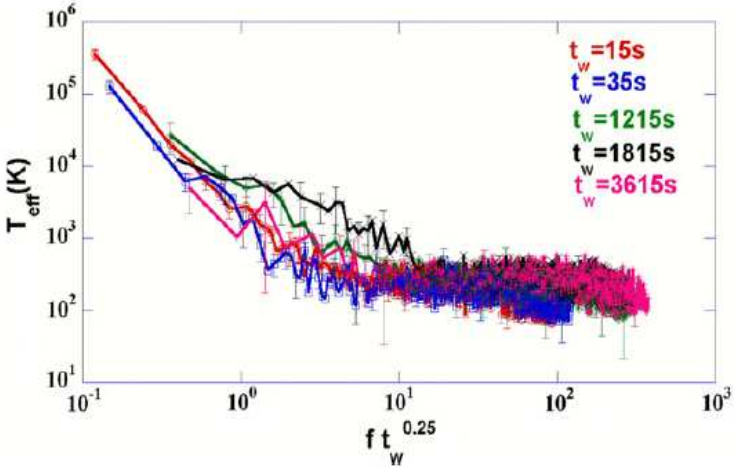
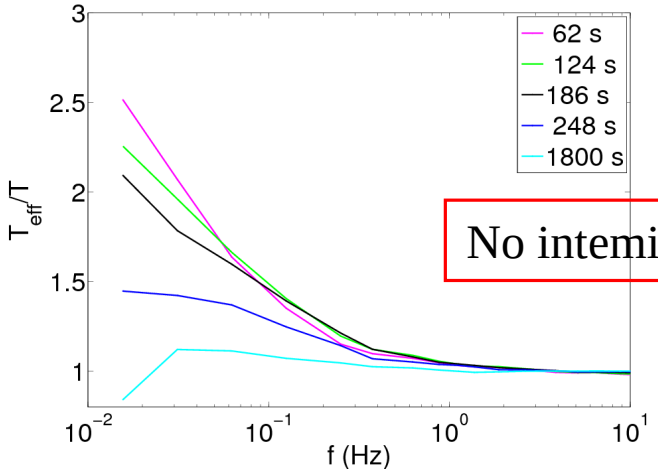


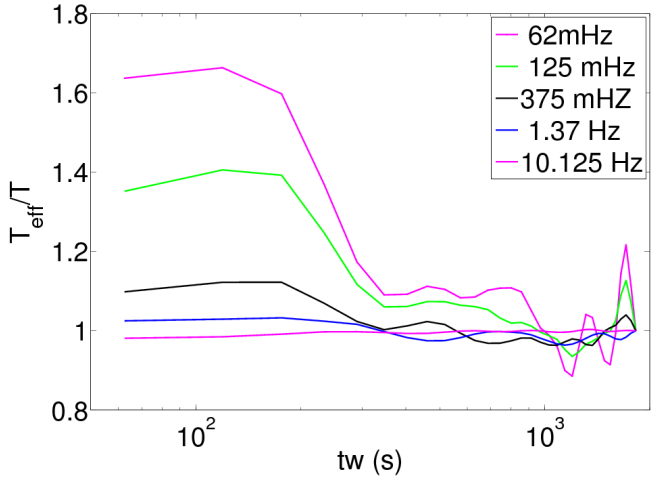
Strong intermittency

A. Naert et al., unpublished

C=5000pF
Quenching time =60sec



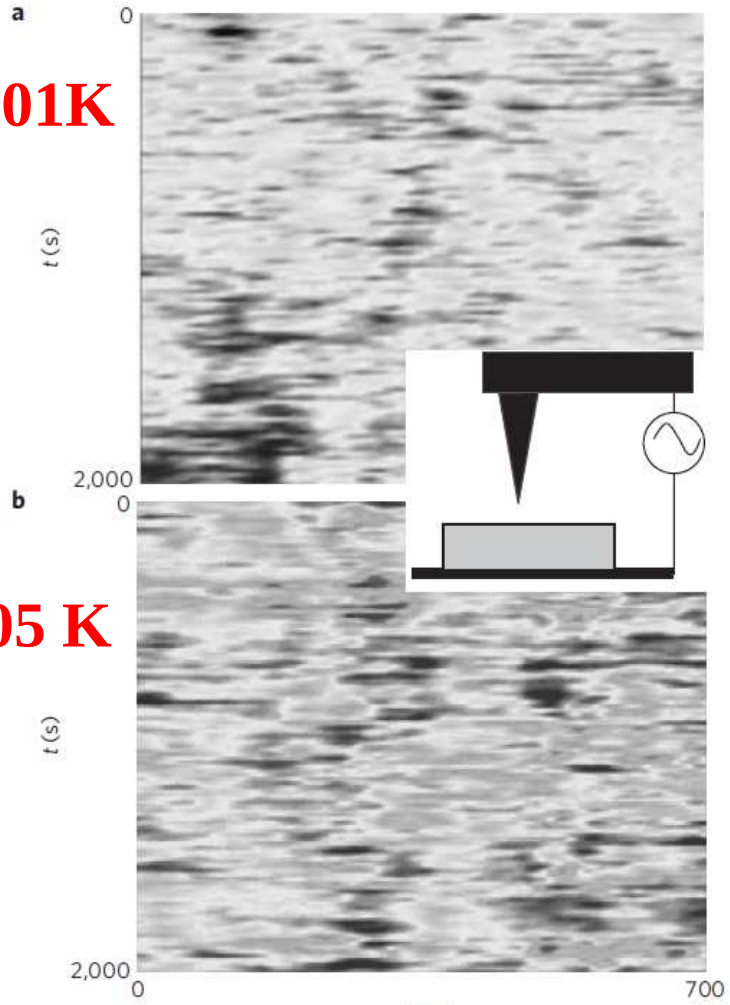
No intemittency



Local Dielectric in PVAc

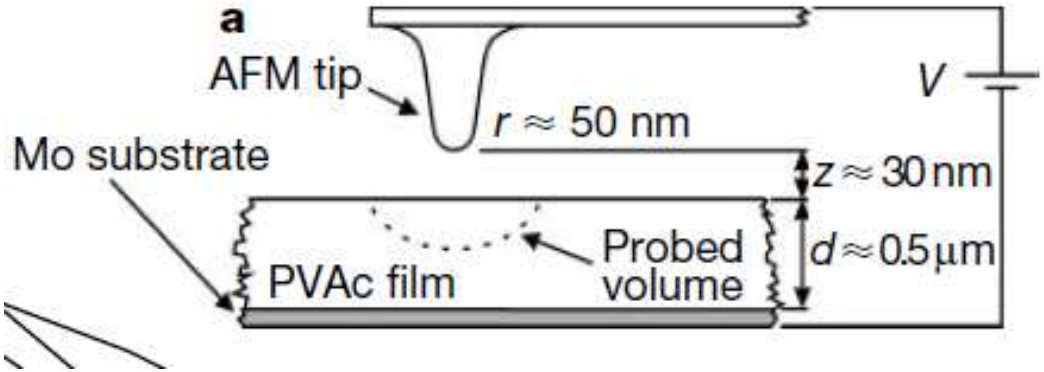
Hassan Oukris and N. E. Israeloff
NATURE PHYSICS, 6 , FEBRUARY, 2010

301K



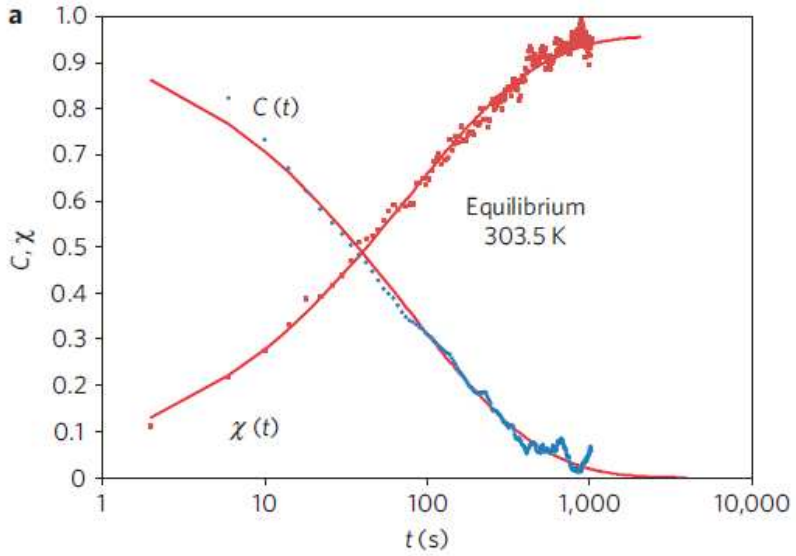
305 K

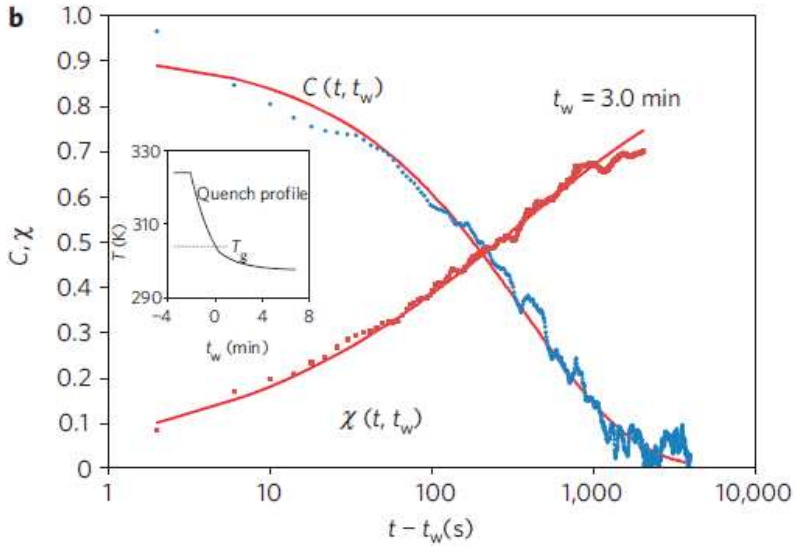
Tg=304 K

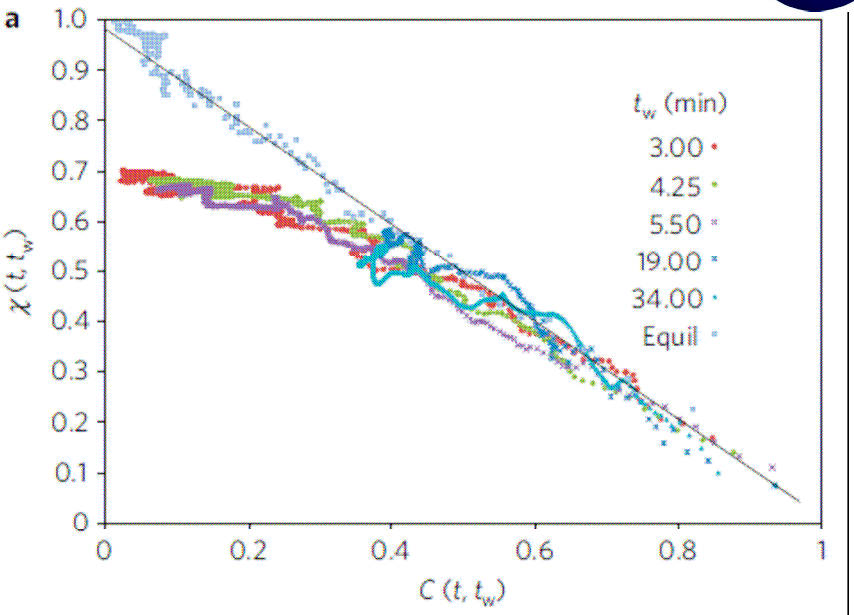


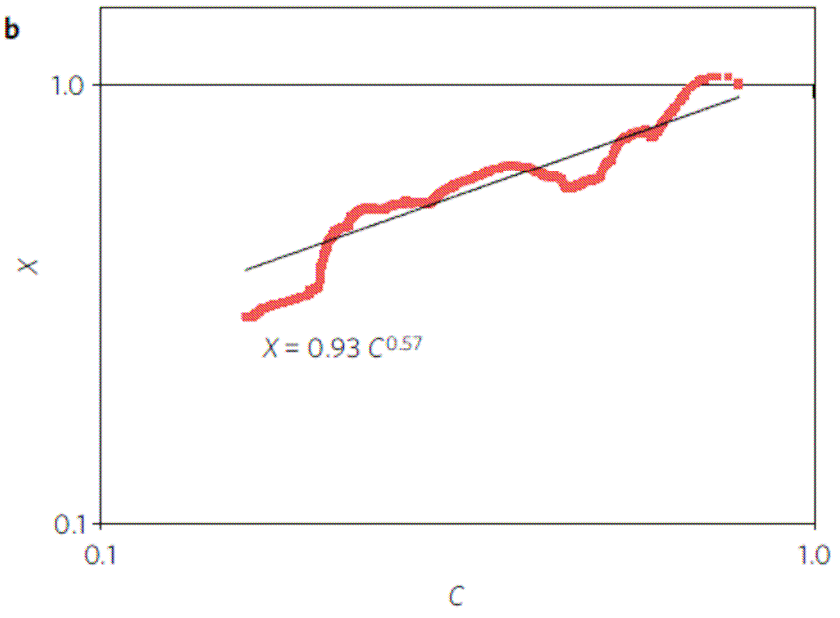
$$\delta f = \frac{1}{2}\frac{f_0}{k}\frac{\partial F}{\partial z} = -\frac{1}{4}\frac{f_0}{k}\frac{\partial^2 C_{\text{tip}}}{\partial z^2}(V - V_{\text{P}})^2$$

Local Dielectric in PVAc







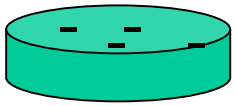


FDR in gels

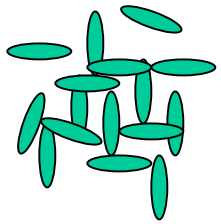
Previous Results in Laponite

Colloidal Suspension :

discs: d=25 nm, h=1 nm



Fluid -> gel/colloidal glass



Fluid-Colloidal glass transition in a few hours

Prepared under N_2 atmosphere

Φ_m = 1.2 à 3 wt% in water

pH = 10

Ionic Force : I de 10^{-4} à 5 10^{-3} M

FDR in gels

Previous Results in Laponite

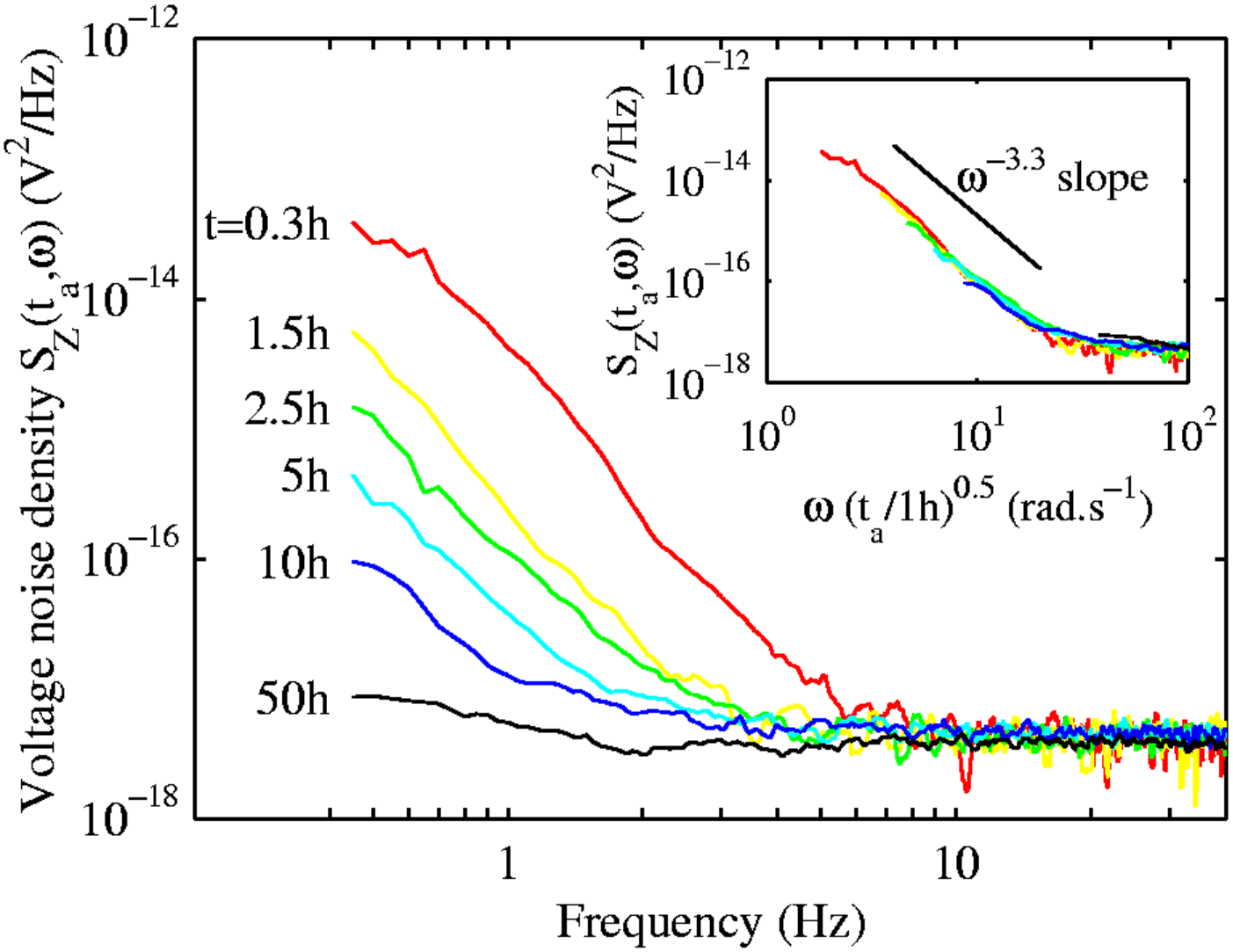
L. Bellon, S.C. Physica D 168, 325 (2002)

Dielectric measurements

$T_{eff} >> T_{bath}$

Strong intermittency

Dielectric measurements in Laponite



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Rheology

L. Bellon, S.C. Physica D 168, 325 (2002)
Thermal rheometer, global measurements

$T_{eff} = T_{bath}$

S. Jabbary Farouji et al. PRL 98,108302 (2007)
Brownian particle, Active and passive micro-rheology.

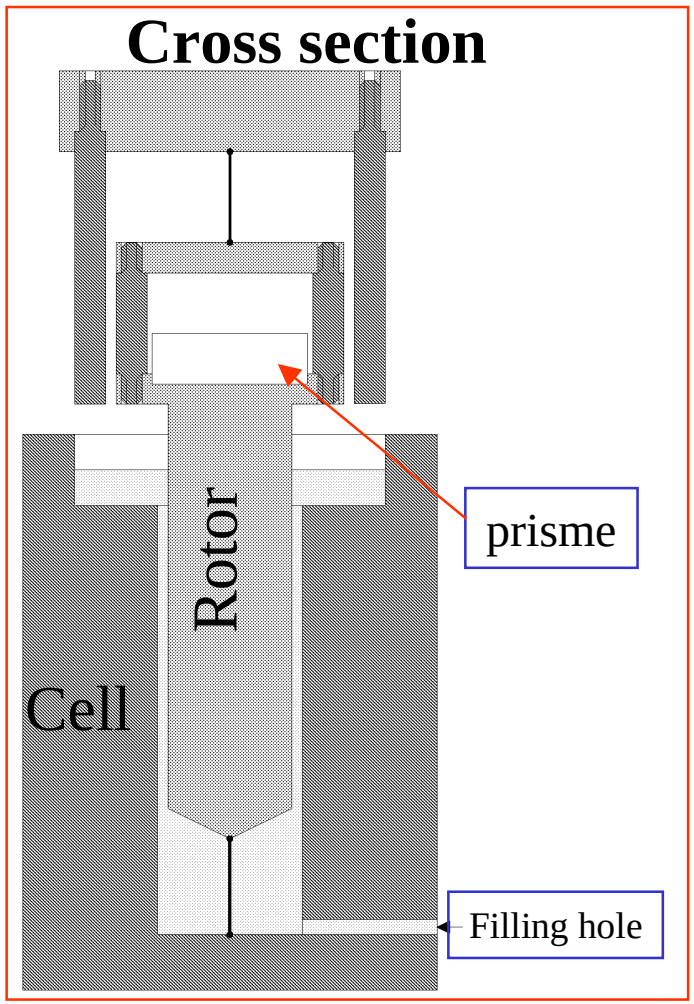
B.Abou, F. Gallet, PRL 93,160603, 1-4 (2004)
Brownian particle, response and flcutuations

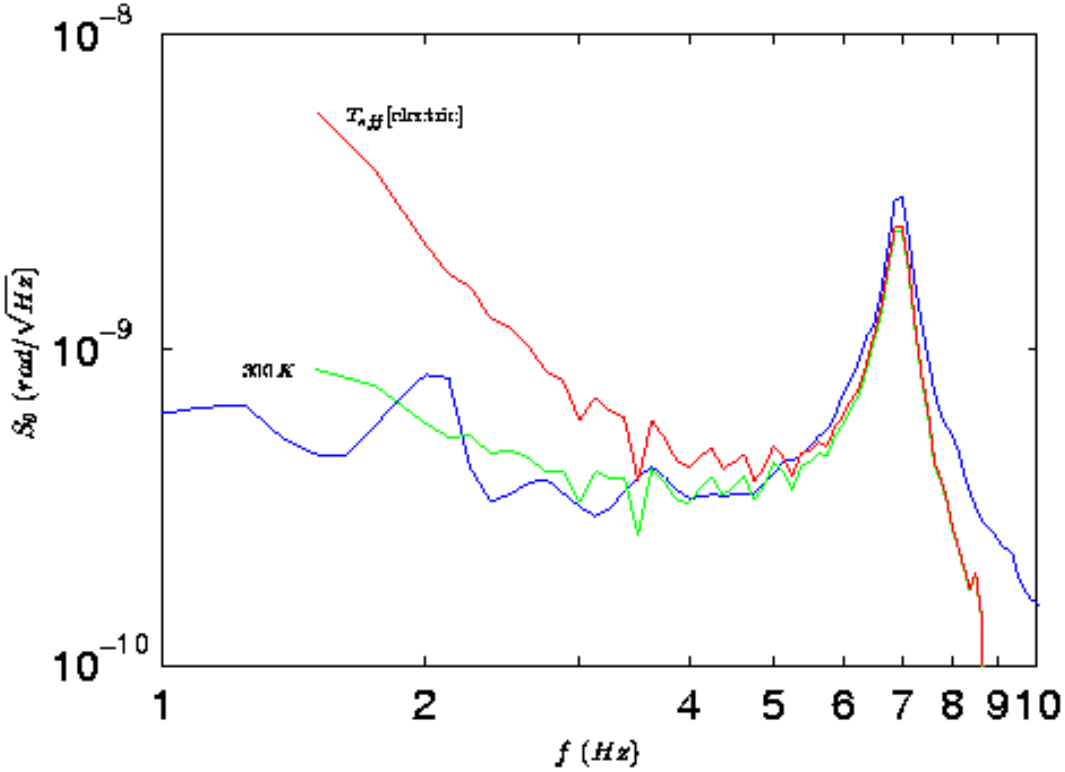
$T_{eff} > T_{bath}$

N. Greinert et al PRL 97, 265702 (2006)
Brownian particle, energy equipartiction

Thermal rheometer, global measurements

L. Bellon, S.C. Physica D 168, 325 (2002)





Rheometer

Brownian particle, Active and passive micro-rheology.

S. Jabbary Farouji et al. PRL 98,108302 (2007)

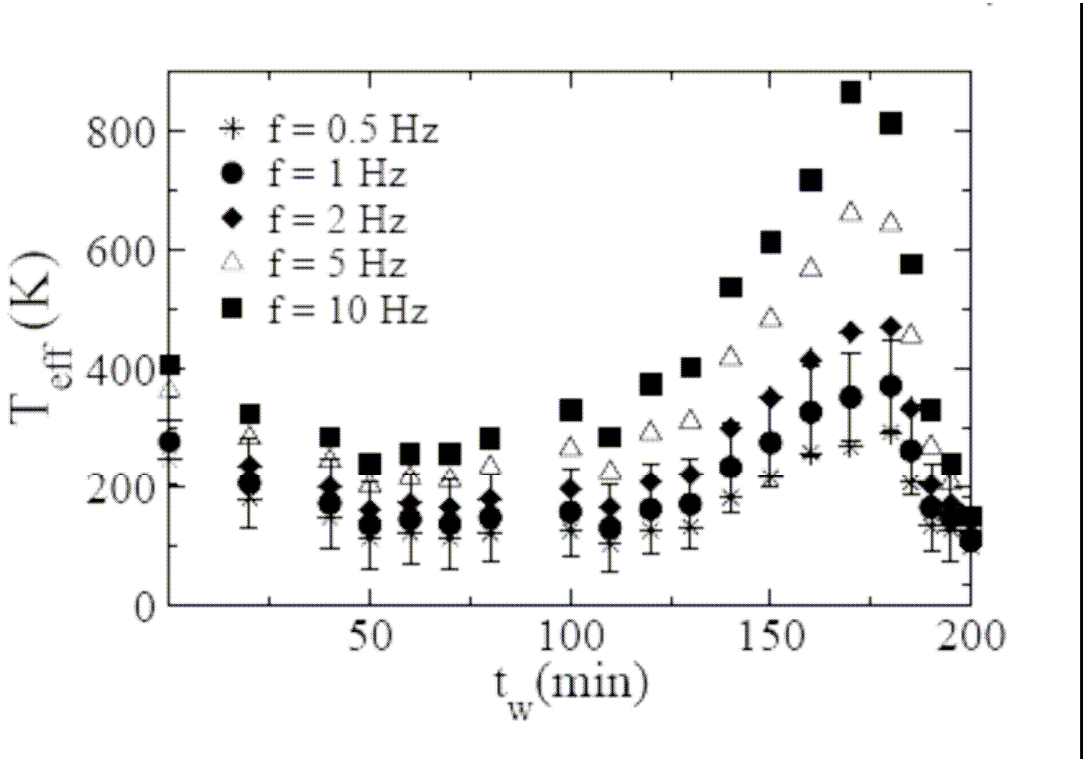
TABLE I. The effective temperature obtained for different frequencies averaged over 2 h time intervals. Within the uncertainty in the experiments, $T_{\text{eff}}/T_{\text{bath}} = 1$.

	$T_{\text{eff}}/T_{\text{bath}}$				
t_a	7.5 rad/s	68 rad/s	728 rad/s	6.5 rad/s	75 rad/s
0–2 h	0.75 ± 0.3	1 ± 0.1	0.95 ± 0.1	0.85 ± 0.1	1.0 ± 0.1
2–4 h	1.2 ± 0.3	1 ± 0.1	1 ± 0.1	0.9 ± 0.1	1.0 ± 0.1
4–6 h	1.4 ± 0.3	1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1
6–8 h		0.85 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.0 ± 0.1

2.8% Wt, Laponite XLG, filtered

Brownian particle, response and fluctuations

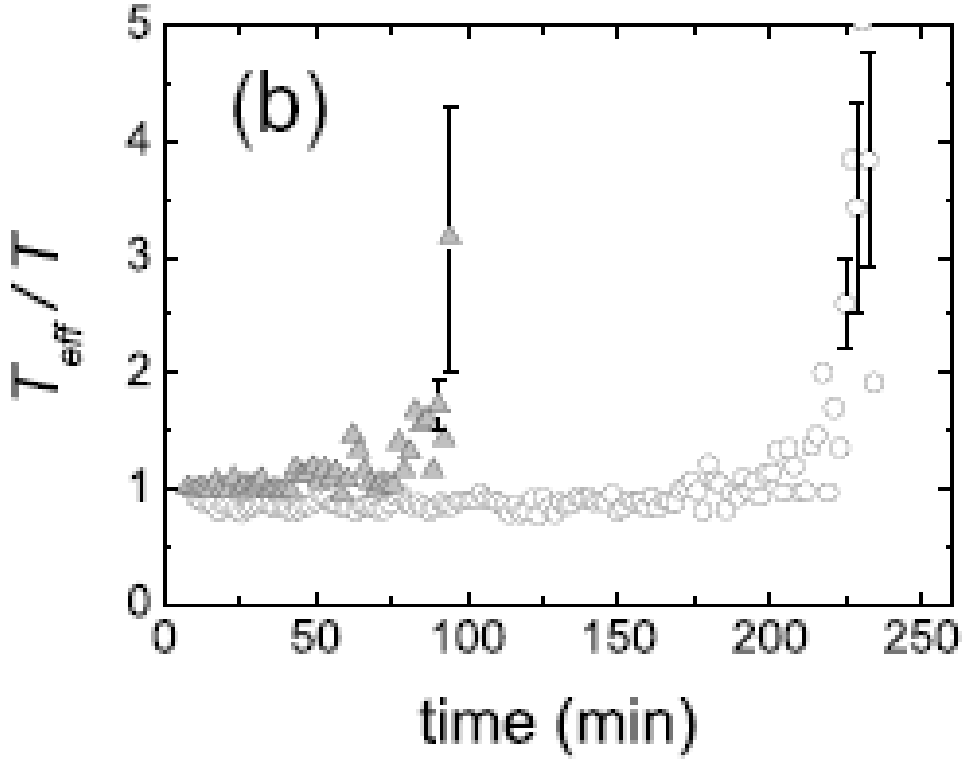
B.Abou, F. Gallet, PRL 93,160603, 1-4 (2004)



Laponite RD, 2.3 wt%, filtered, 2 μm silica bead

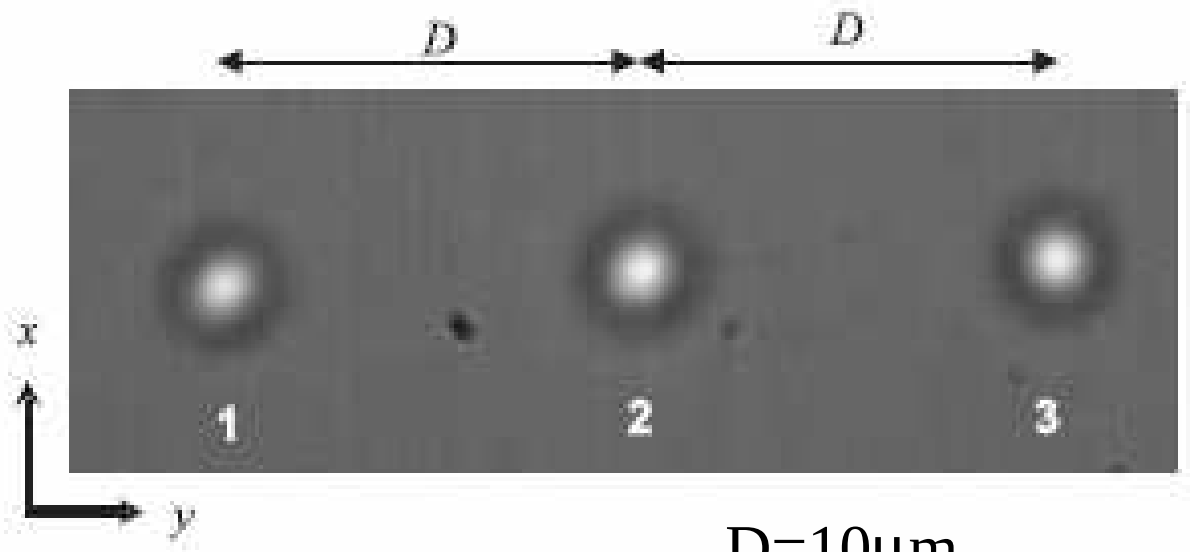
Brownian particle, energy equipartition

N. Greinert et al PRL 97, 265702 (2006)



Laponite RD, 2.4% and 2.8%, filtered 1 um silica beads

Simultaneous measurements of three beads in Laponite



D=10μm

Stiffness:

$k_2 = k_3$

and

$k_1 = k_2/2$

$k_2 = 7.15\ pN/\mu m$

We apply four different techniques to measure Teff.

1) Active microrheology
2) Passive microrheology
   - Equipartition
   - Kramers-Kroning
   - Heat fluctuations

Do they give the same results ?

P. Jop, R. Gomez-Solano, A. Petrosyan, S.C., J Stat. Mech. (2009) P04012.

Microrheology

Motion of a Brownian particle trapped by a laser Beam

Viscoelastic Langevin dynamics

$$\int_{-\infty}^{t} \Gamma(t-t', t_w)\dot{x}(t')dt' + k\ (x - x_o) = \xi(t),$$

The applied oscillating force $$f_o(t) = \ k\ x_o(t, \omega)$$

The linear response $$\hat{\chi}(\omega, t_w) = \frac{\hat{x}(\omega, t_w)}{\hat{f}_0(\omega)}$$

$$|\widehat{x}(\omega, t_w)|^2 = \frac{4k_B T_{eff}(\omega, t_w)\ \gamma(\omega, t_w)}{\omega^2\gamma^2(\omega, t_w) + (k + K_{gel}(\omega, t_w))^2}$$

Passive Rheology - Measure of the T_{eff}

Hp:
The global potential (colloid+laser) is harmonic

Equipartition holds out of equilibrium

$$C_i = K_{Lap} + K_i \text{ and } < \Delta x_i^2 >= \frac{K_B\ T_{eff}}{C_i}$$

K_i is the trap stiffness

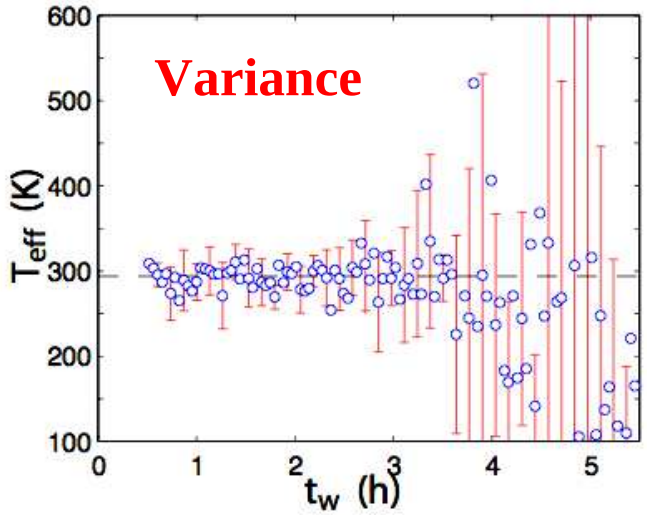
Measure of the fluctuations for 2 intensities

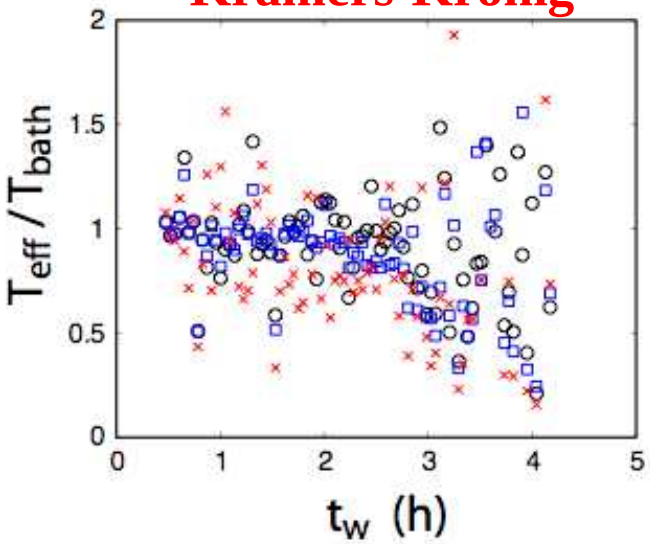
$$K_B\ T_{eff} = (K_2 - K_1)\frac{<\Delta x_1^2><\Delta x_2^2>}{(<\Delta x_1^2> - <\Delta x_2^2>)}$$

$$K_{Lap} = \frac{(K_1<\Delta x_1^2> - K_2<\Delta x_2^2>)}{(<\Delta x_1^2> - <\Delta x_2^2>)}$$

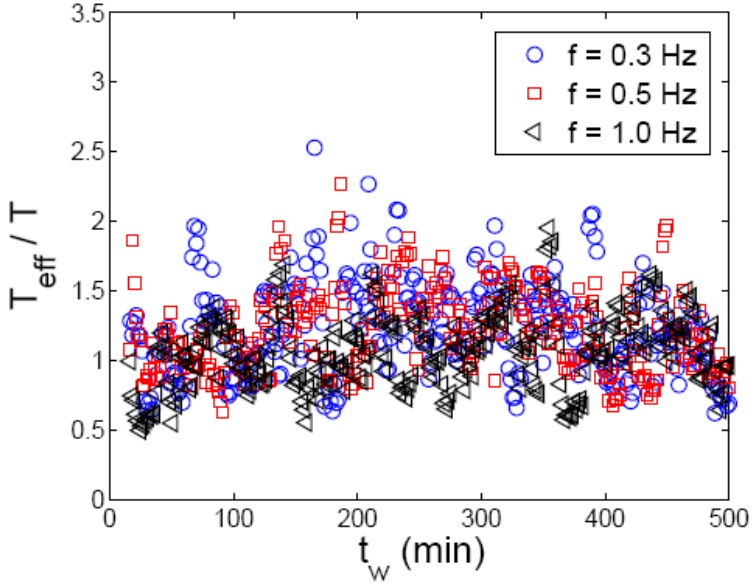
Simultaneous measurements of three beads in Laponite

Passive microrheology





Active microrheology



The three methods give the same results

$T_{eff} = T_{bath}$

Heat fluctuations confirm the result

Conclusions on previous results on FDR in various systems

Experiments gives controversial results

Questions

- **Spin glasses:** Teff> T, good agreement with theory

  a) The local aspect is missed
  b) Statistics of the signals
  c) Teff at very long time

- **Colloids :** Laponite
  Teff=T in rheology
  Teff >>T in dielectric

  a) Other gels
  b) Quenching rate
  c) Confinement

- **Polymers :**

  a) Local measurements : Teff > T
  b) Global measurements
  Intermittency, Teff >> T
  Teff > T only for very fast quench

Needs of a more close comparison of theory with experiments

New experiments

Improved experimental design in dielectric measurements
A. Naert, M. Tanase, L. Bellon, D. Bagchi

Aging at the critical point
A. Caussarieu, S. Joubaud, A. Petrosyan

a) More close comparison theory-experiment
b) Quenching rate

Confined liquid-gel transition
R. Gomez Solano, A. Petrosyan

a) Other gels
b) Quenching rate
c) Confinement

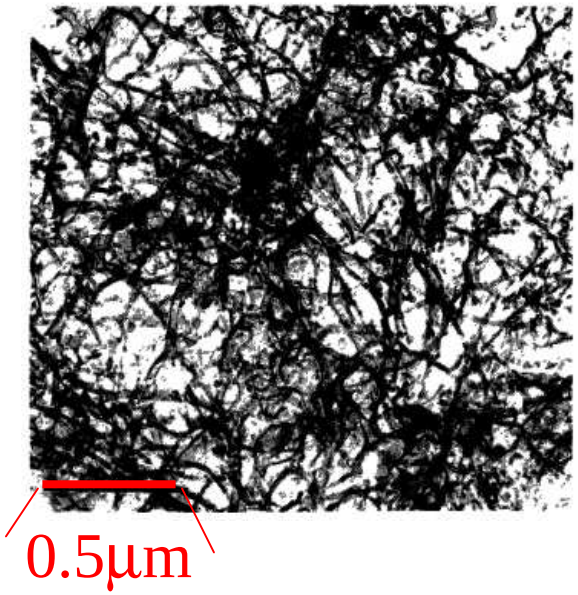
Questions about an aging gel

How is this scenario modified if

- the gel is confined in a volume comparable with the bead size ?
- a very fast quench of 1ms is peformed ?
- the energy instead of the displacement is used as the relevant variable ?

R. Gomez Solano, A. Petrosyan, S.C. arXiv:1102.4750

Gelatine liquid-solid transition



Gelatine :

liquid for Tm>32°C

solid for Tg< 28°C

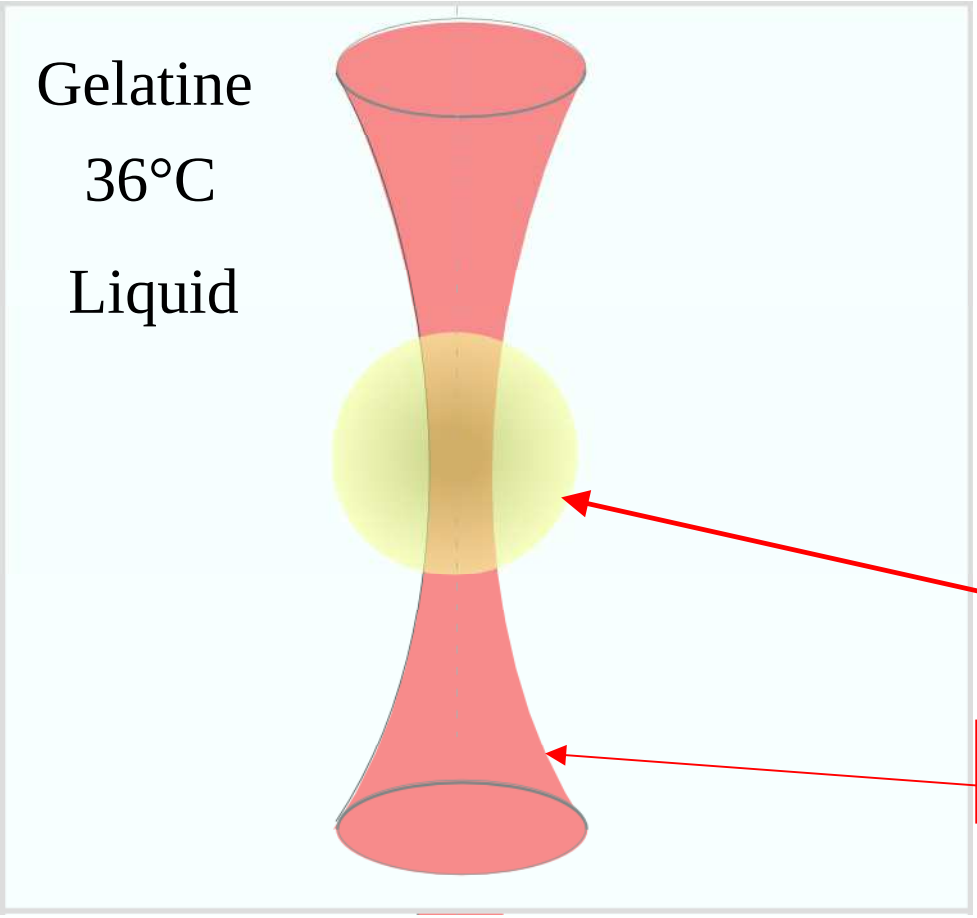
In our experiment we use

10%wt concentration in water

For T<Tg gelatine presents : aging and memory effects

at 10%wt concentration after a cooling at 26°C it takes ~2h to solidify

Gelatine liquid-solid transition



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10%wt concentration
in water

Trapped glass particle R=1µm

Trapping laser

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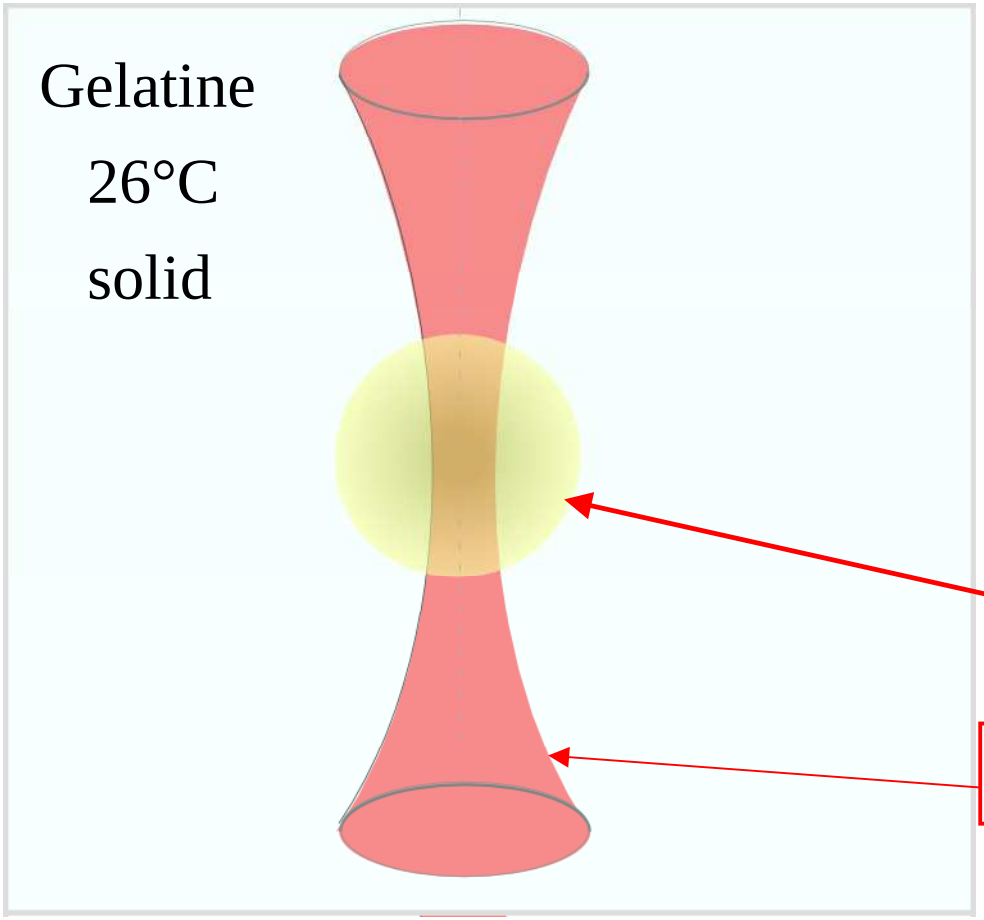

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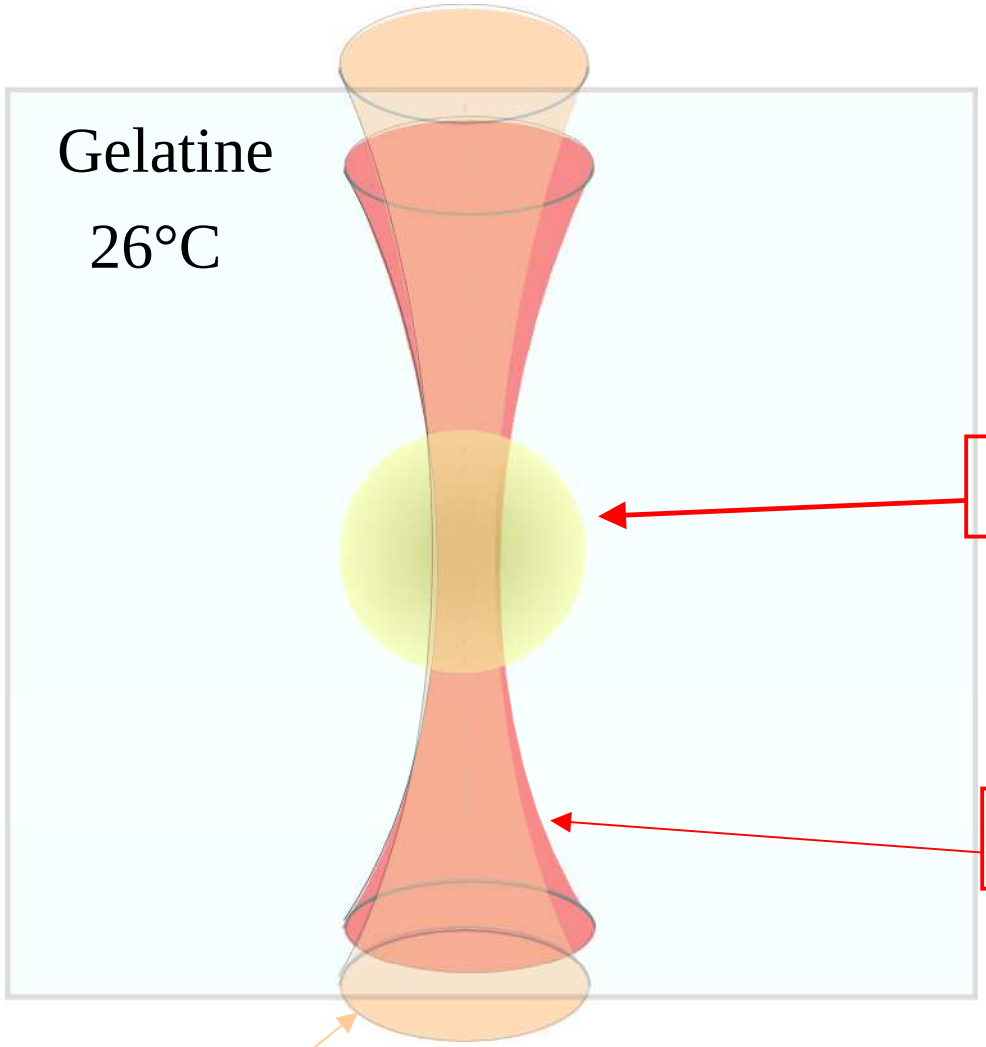
Gelatine liquid-solid transition (heating)

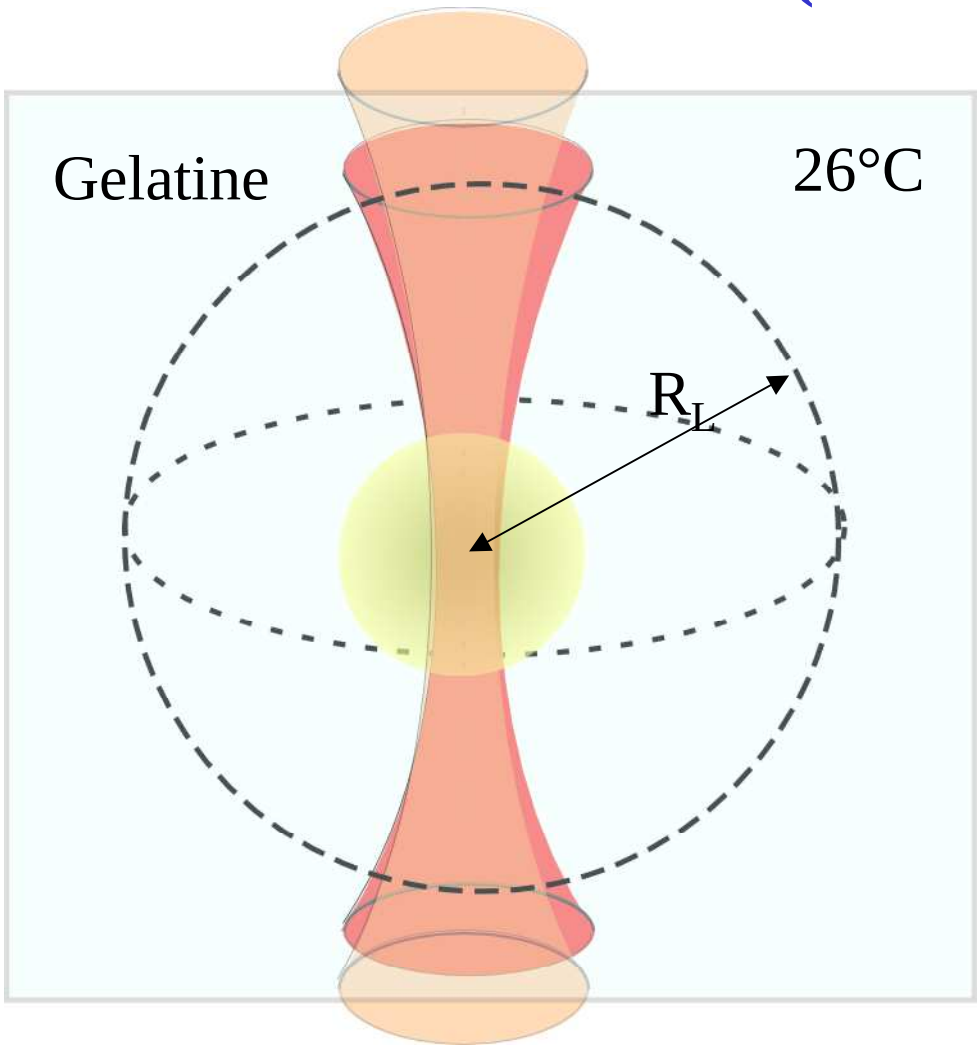


Trapped glass particle R=1µm

Trapping laser

Infrared Laser switched on for a few minutes

Gelatine liquid-solid transition (heating)



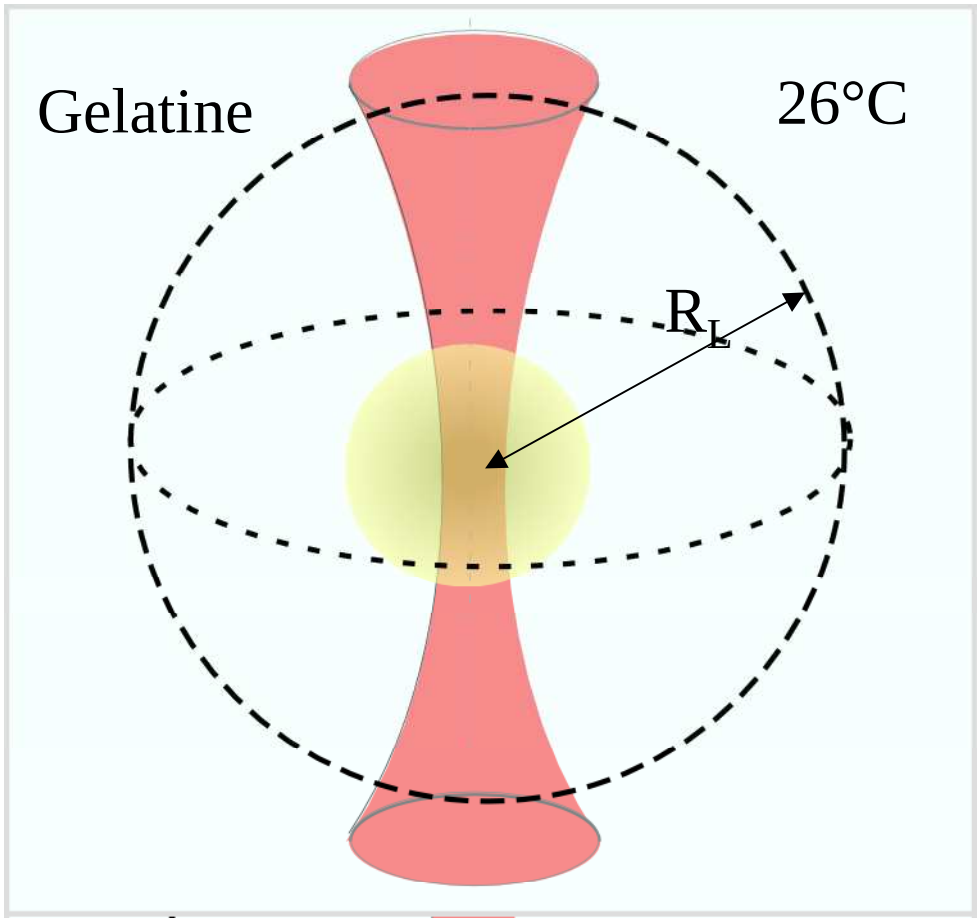
The temperature around the focus grows till 36°C

A drop of liquid of radius R_L=10 μm is formed

After a few minutes the infrared laser is switched off

The drop cools in about 1mS

Gelatine liquid-solid transition (quench)



At t=3ms after the switch off

Drop of an unstable liquid
at 26°C
inside a stable solid

What happens ?

Does the transition start
from the frontier ?

How long does it take
to solidify ?

Microrheology

Motion of a Brownian particle trapped by a laser Beam

Viscoelastic Langevin dynamics

$$\int_{-\infty}^{t} \Gamma(t-t', t_w)\dot{x}(t')dt' + k\ (x - x_o) = \xi(t),$$

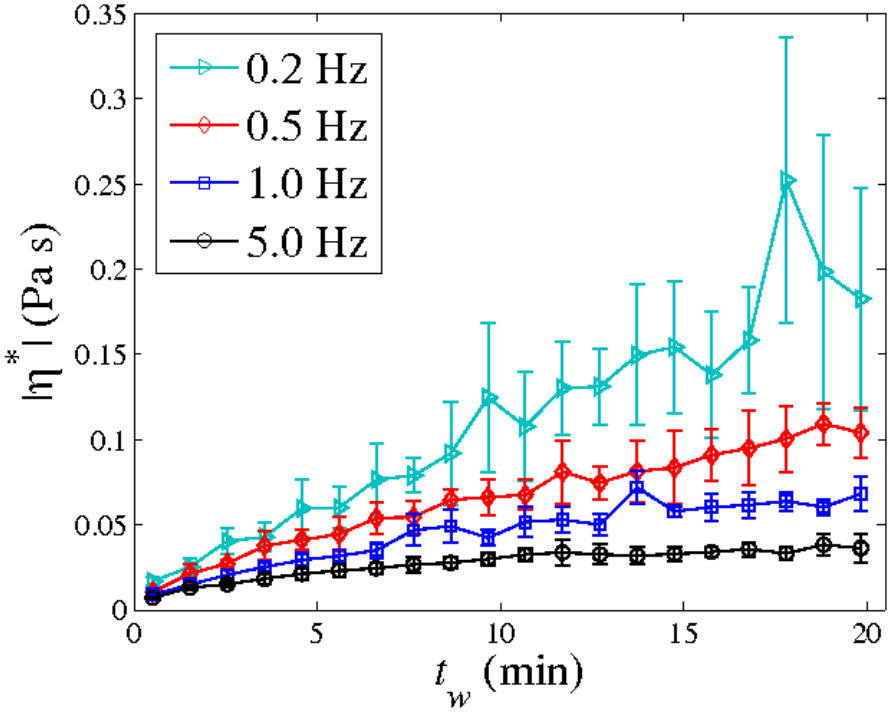
The applied oscillating force $$f_o(t) = \ k\ x_o(t, \omega)$$

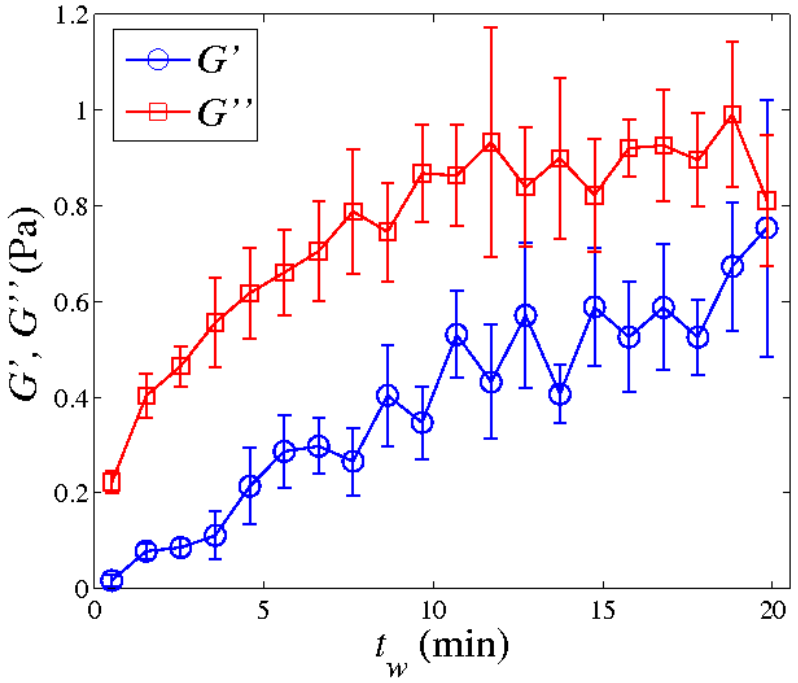
The linear response $$\hat{\chi}(\omega, t_w) = \frac{\hat{x}(\omega, t_w)}{\hat{f}_0(\omega)}$$

$$|\widehat{x}(\omega, t_w)|^2 = \frac{4k_B T_{eff}(\omega, t_w)\ \gamma(\omega, t_w)}{\omega^2\gamma^2(\omega, t_w) + (k + K_{gel}(\omega, t_w))^2}$$

Gelatine liquid-solid transition

Time evolution of the viscosity and elastic modulus

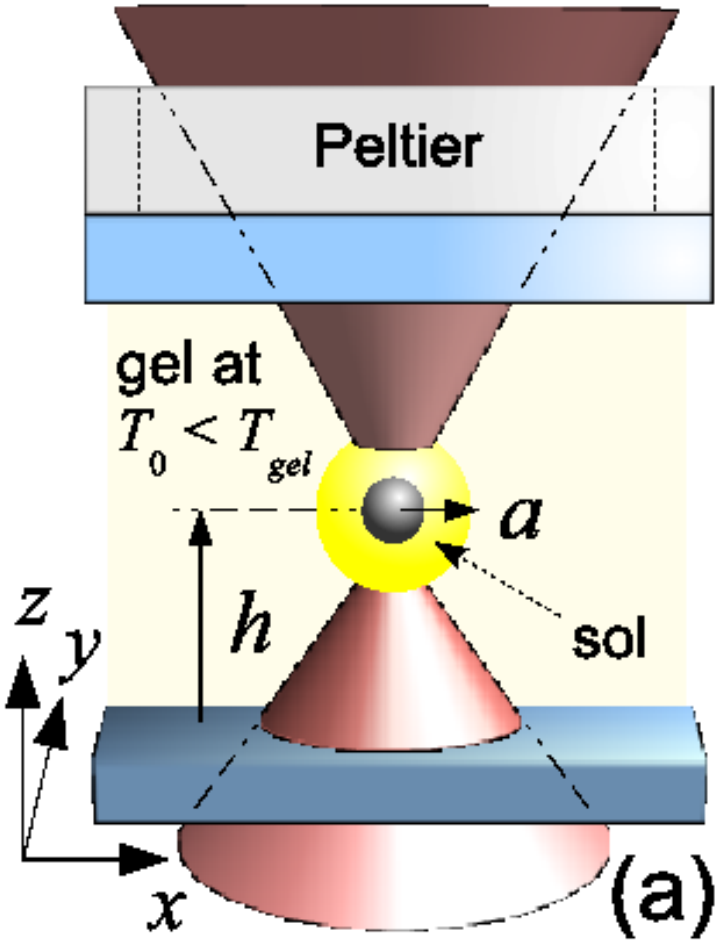


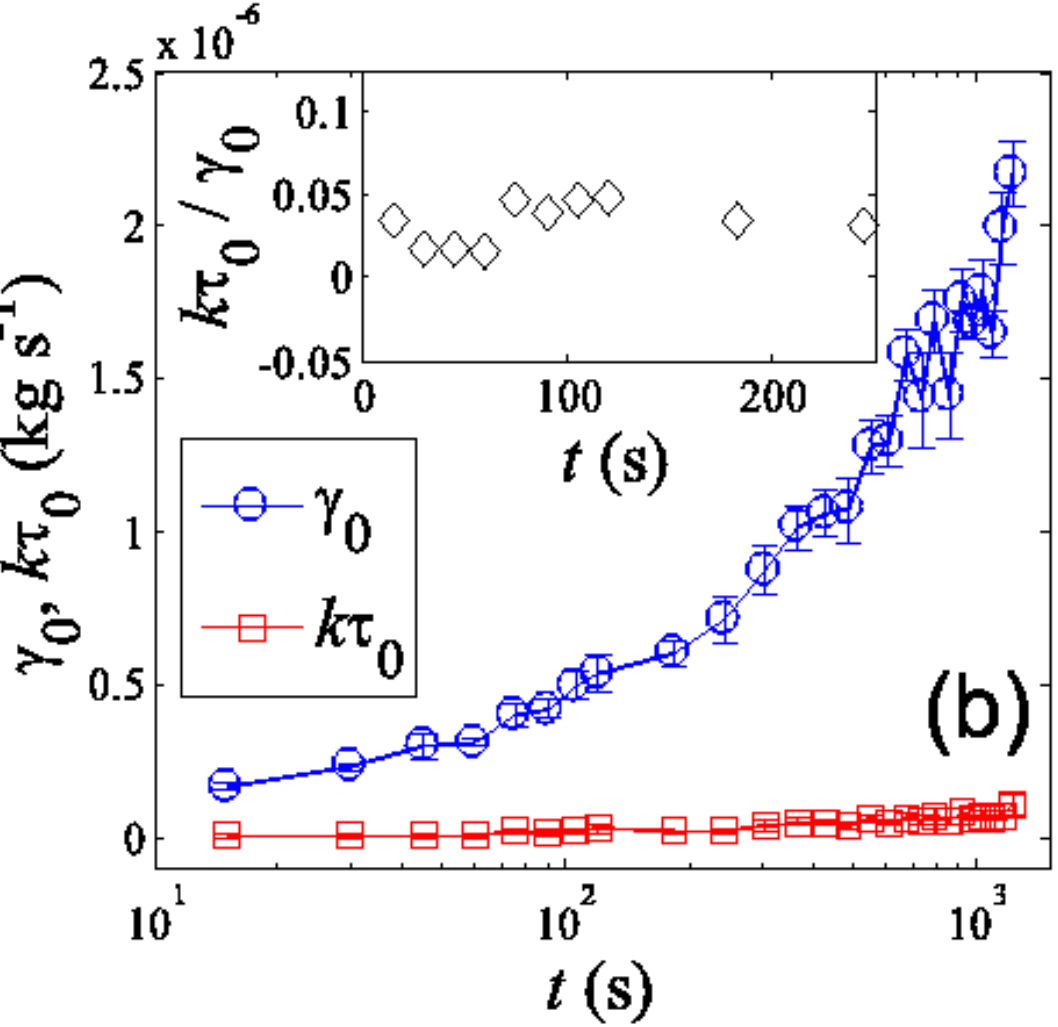


The gel forms in about 30 min

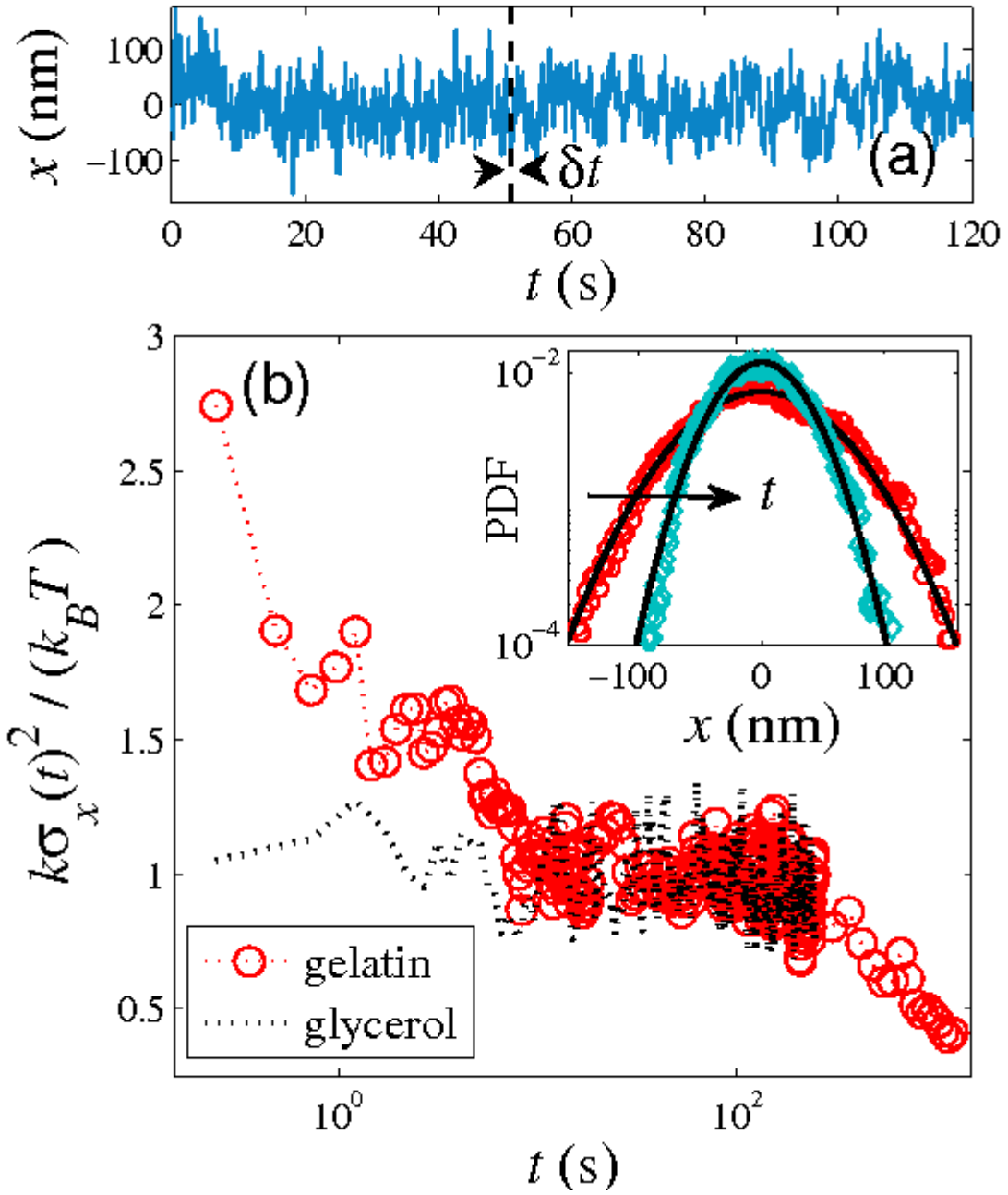
This time evolution is independent
of the distance from the boundary of the drop

Gel/trap elasticity

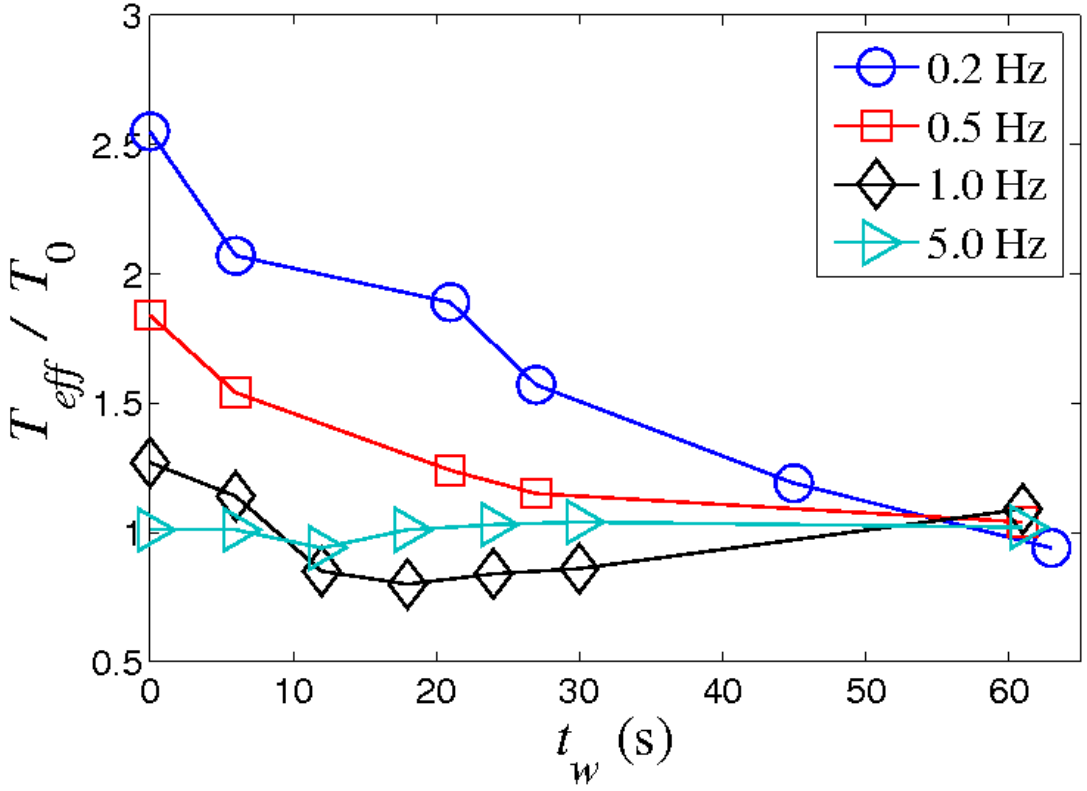




Gelatine liquid-solid transition



Effective Temperature after the quench



Experiment in gelatine
at 10%wt
sol-gel transition at 28°C

Heat fluctuations

Energy balance in Langevin equation

Sekimoto K, Progress of Theoretical Phys. supplement (130), 17 (1998).

$$\int_{-\infty}^{t} \Gamma(t-t', t_w)\dot{x}(t')dt' + kx = F + \xi(t),$$

Multiplying by $\dot{x}(t)$ and integrating for a time τ starting at t_w:

$$\Delta U_\tau(t_w) - W_\tau = Q_\tau(t_w),$$

$$\Delta U_\tau(t_w) = \frac{1}{2}k(x(t_w+\tau)^2 - x(t_w)^2) + \int_{t_w}^{t_w+\tau} \dot{x}(t)(K_t * x)(t, t_w)dt,$$

$$Q_\tau(t_w) = \int_{t_w}^{t_w+\tau} \xi(t')\dot{x}(t')dt' - \int_{t_w}^{t_w+\tau} \dot{x}(t')(\gamma_t * \dot{x})(t, t_w)dt',$$

$$W_\tau = \int_{t_w}^{t_w+\tau} F\dot{x}dt$$

Q and W are fluctuating quantities which satisfy Fluctuation Theorem

Heat Fluctuations

For F=0 then:

$$\Delta U_\tau(t_w) = Q_\tau(t_w)$$

$$\Delta U_\tau(t_w) = \frac{1}{2}k(x(t_w+\tau)^2 - x(t_w)^2) + \int_{t_w}^{t_w+\tau} \dot{x}(t)(K_t * x)(t, t_w)dt,$$

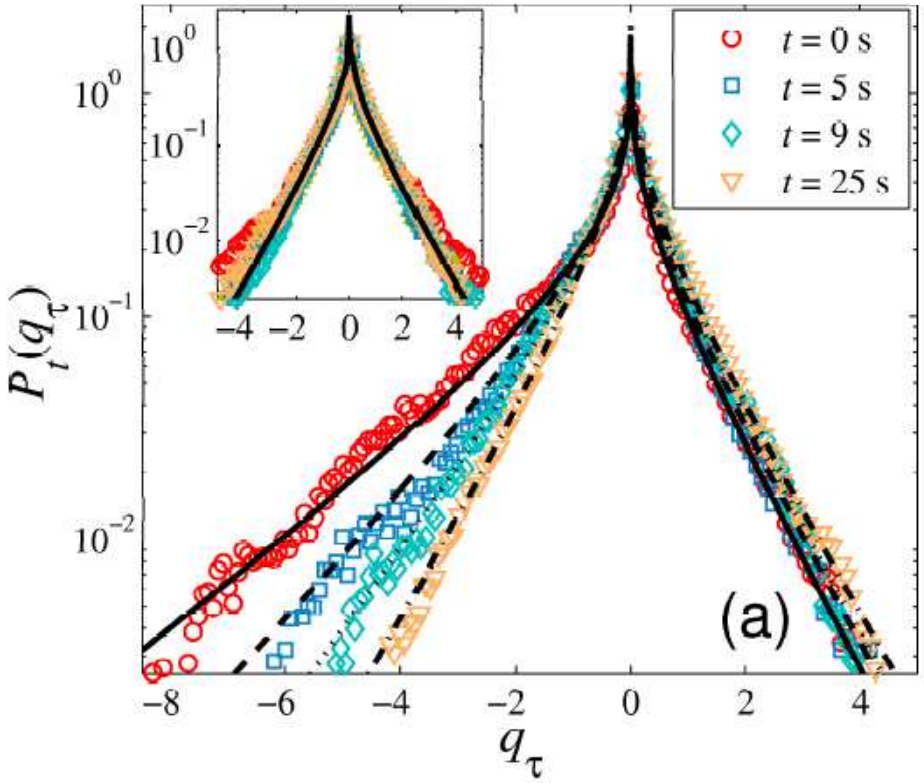
for $t_w < 200$s

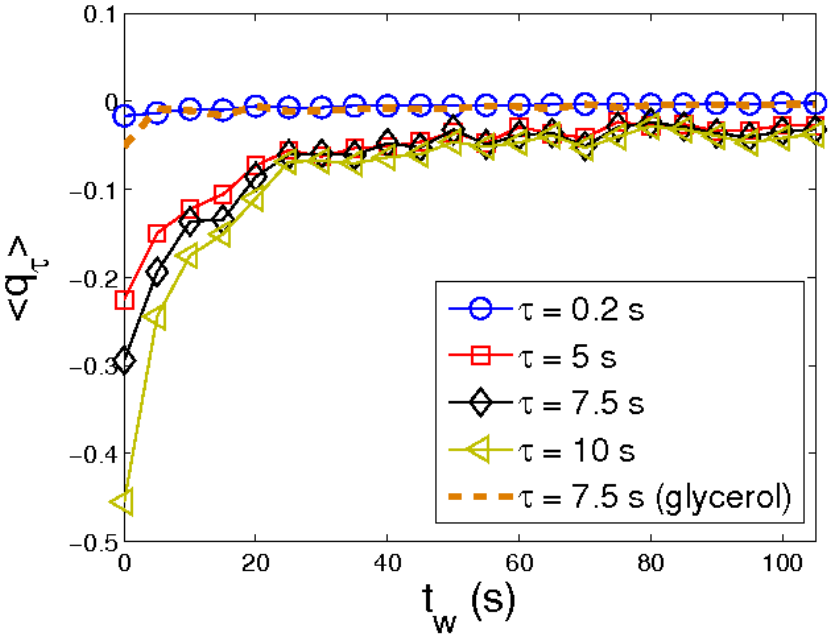
For $t_w < 200$s, Q_τ can be computed from ΔU_τ.

A. Crisanti and F. Ritort, Europhys. Lett. **66**, 253 (2004).

Energy PDF

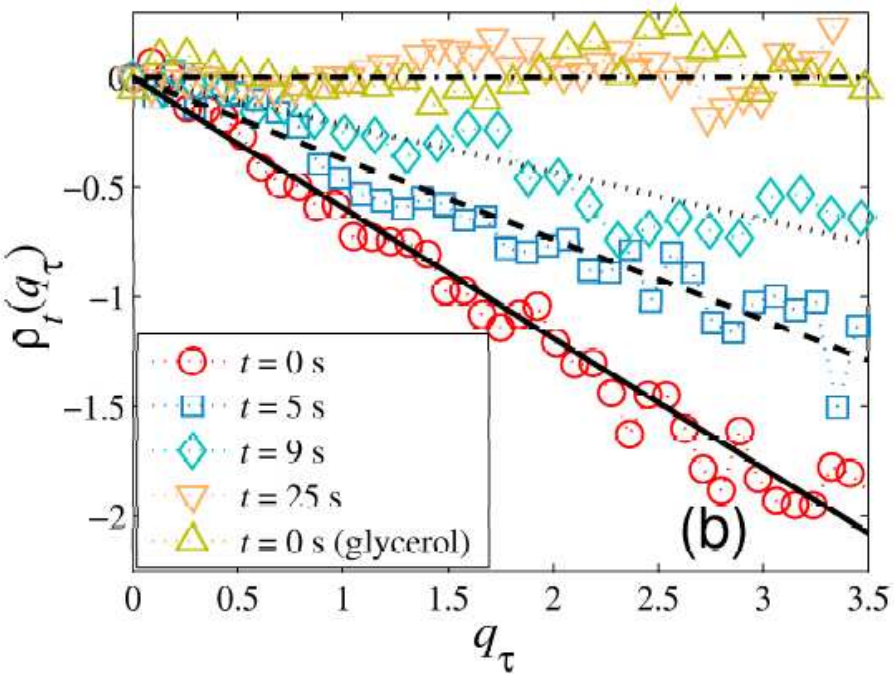
$$q_\tau = \frac{Q_\tau}{k_B\, T}$$





Mean heat

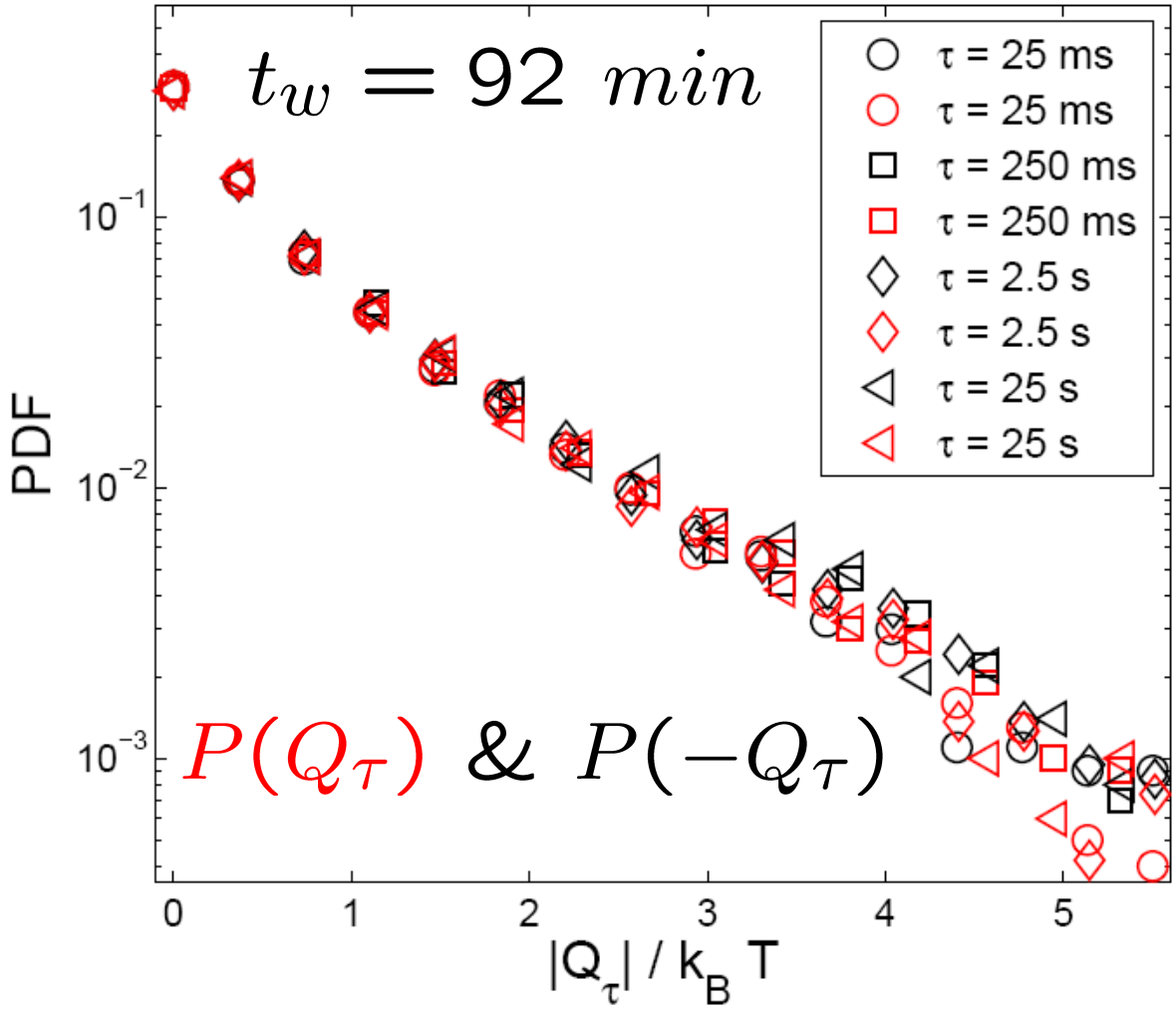
Gelatine liquid-solid transition



$$\rho(q_\tau) = \log \frac{P(q_\tau)}{P(-q_\tau)}$$

$$\rho(q_\tau) = -\left(\frac{1}{T_{eff}(t+\tau)} - \frac{1}{T_{eff}(t)}\right) T \; q_\tau$$

Heat Fluctuations for Laponite



$P(Q_\tau) = P(-Q_\tau)$ for $t_w \leq 350\ min$ and $T_{eff} = T$.

Conclusions on local heating of gelatine

The liquid-solid transition is studied inside a drop of liquide

a) Relaxation dynamics independent of the distance from the boundary of the drop

b) The dynamics transfers heat towards the bath

c) The FDT is violated

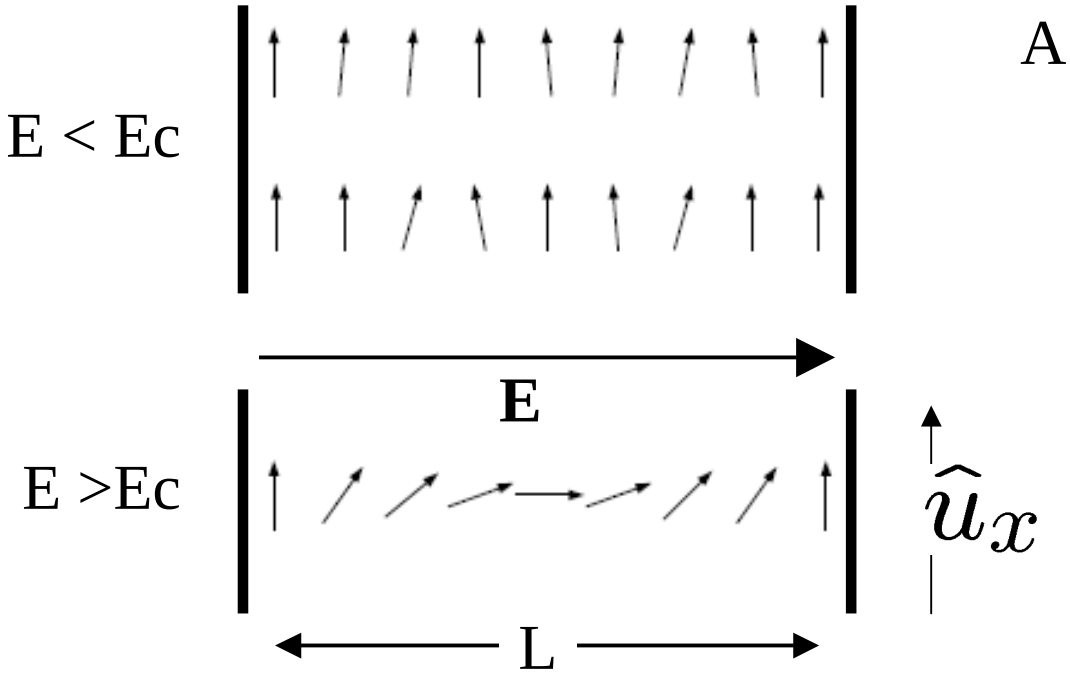
d) The fluctuations of heat are asymmetric

Aging at the critical point

Fréedericksz transition

A. Caussarieu, S. Joubaud, B. Géraud, A. Petrosyan

Liquid Crystals and Fréedericksz transition (I)



A liquid crystal consists of elongated molecules

$\hat{n}$ is the director

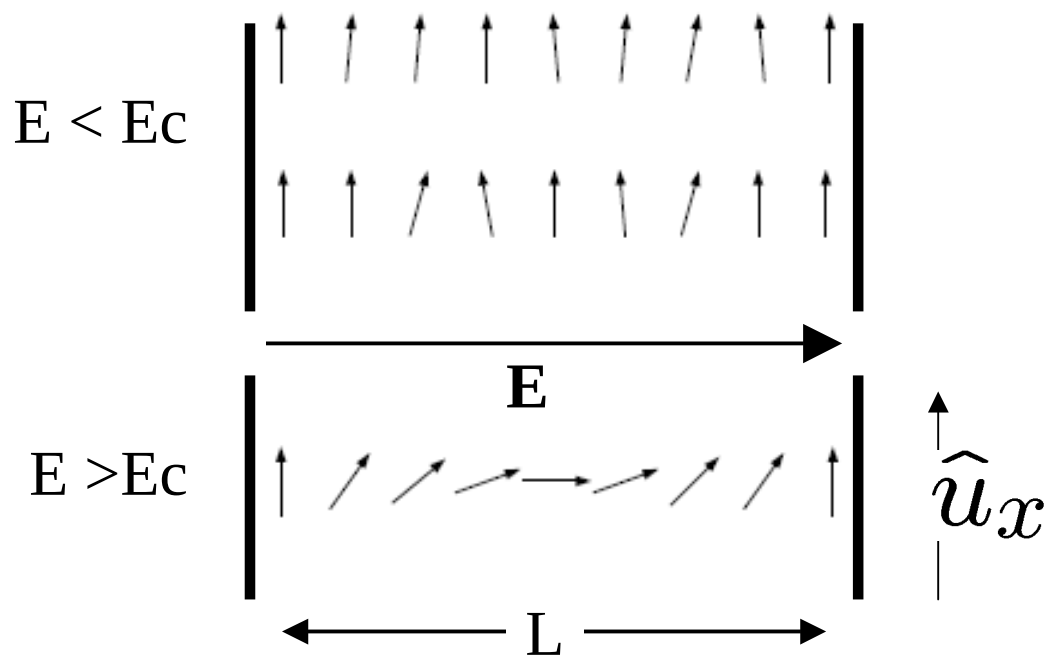
Surface treatement.
Parallel anchored
(planar allignement)

Competition between :

- **Elastic energy** $\hat{n} // \hat{u}_x$
- **Electrostatic energy** $\hat{n} // \vec{E}$

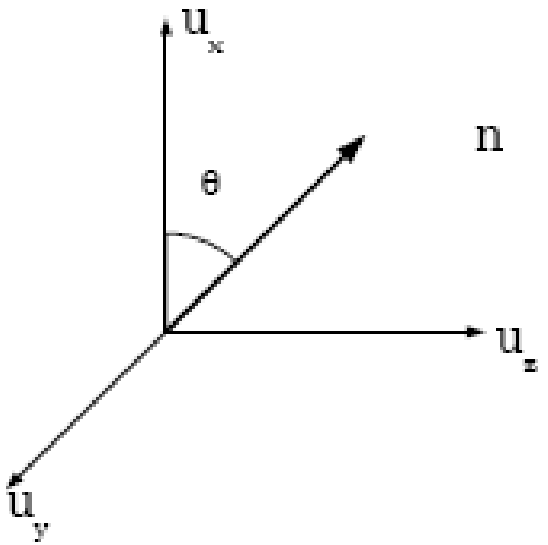
Control parameter :
voltage difference U

Liquid Crystals and Fréedericksz transition (II)



$\hat{n}$ is the director

Control parameter :
voltage difference U



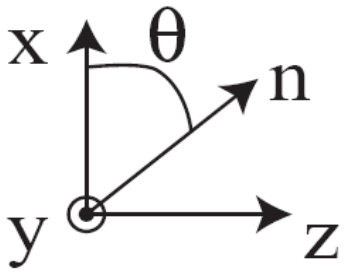
Solution of the form: $\theta(z) = \theta_o(x,y)\sin(\frac{\pi z}{L})$

Fréedericksz transition

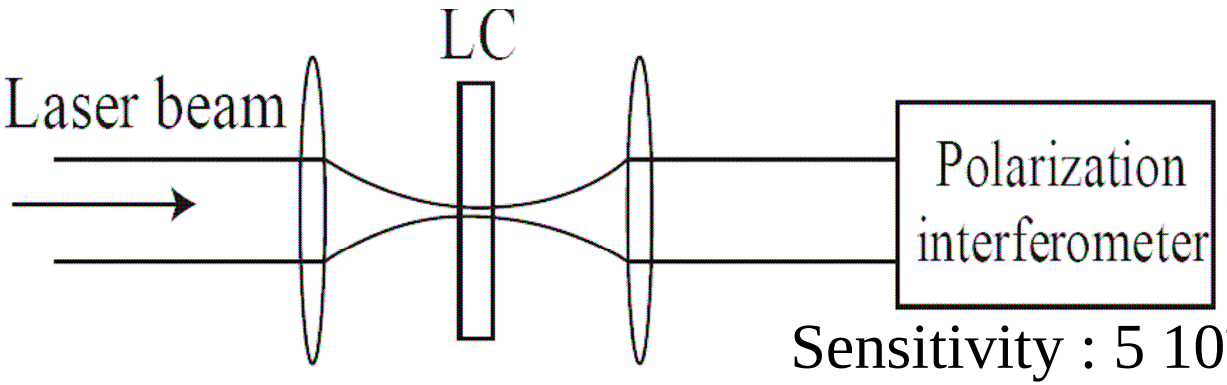
- The Fréederick transition is a second order phase transition
- The order parameter is $\theta_0(x, y)$
- The control parameter is $\epsilon = U^2/U_c^2 - 1$
- The relaxation time is $\tau_{relax} = \tau_o/\epsilon$
- The correlation length $\xi_r = \frac{L}{\pi\sqrt{\epsilon}}$

Experimental set-up

$E_0(\hat{\mathbf{x}} + \hat{\mathbf{y}})$



$E_0(\exp(i\Phi_x)\hat{\mathbf{x}} + \exp(i\Phi_y)\hat{\mathbf{y}})$



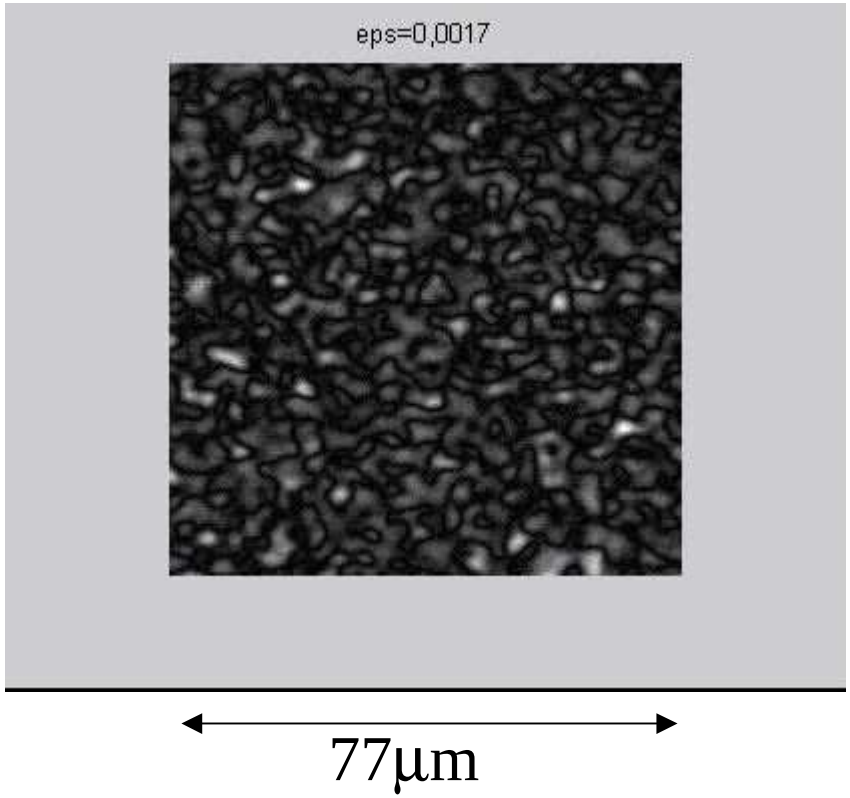
Sensitivity : 5 10^{-14} m/$Hz^{1/2}$

L=7µm

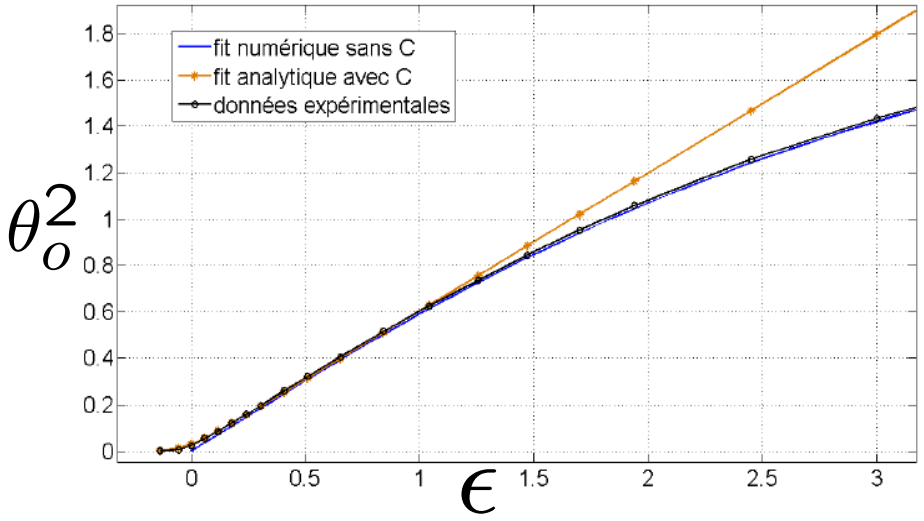
$$\zeta = \iint_A \theta_0^2 \, \frac{dxdy}{A}$$

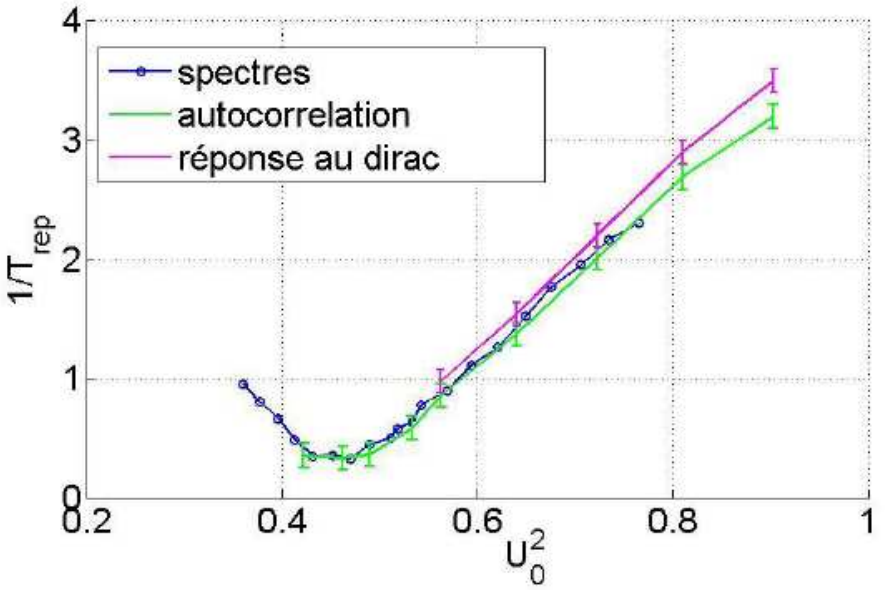
A is the measuring area

Space-time dynamics



Liquid Crystals and Fréedericksz transition

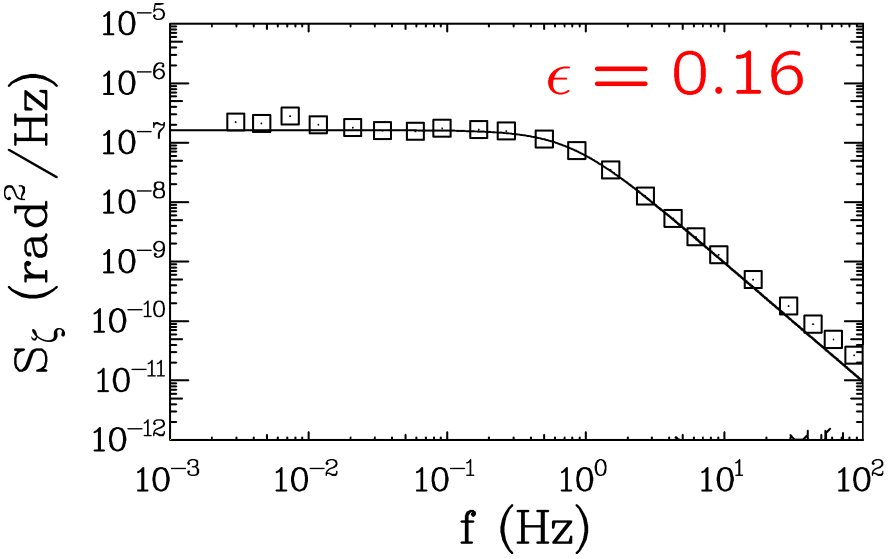




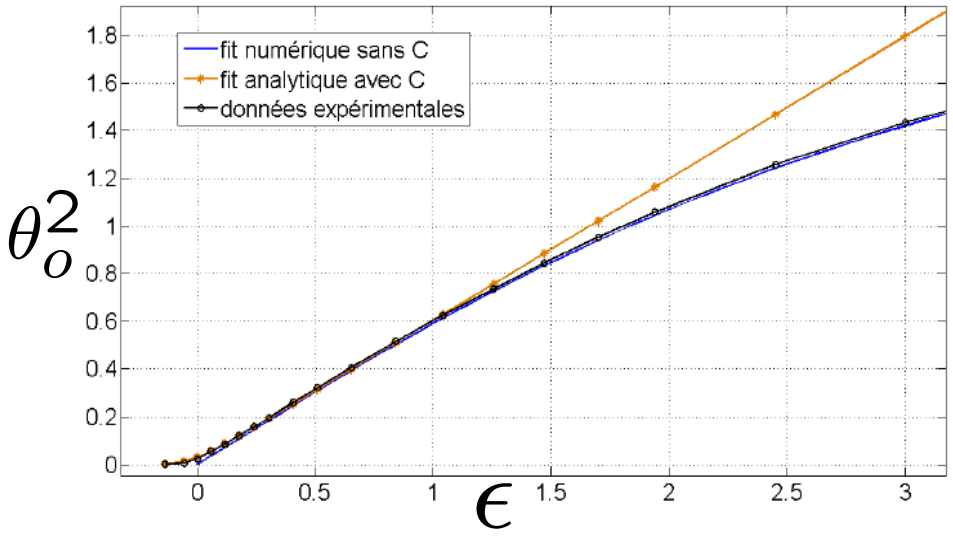
$$\tau_0 \dot{\theta}_o = \epsilon\ \theta_0 - \alpha\ \theta_0^3$$

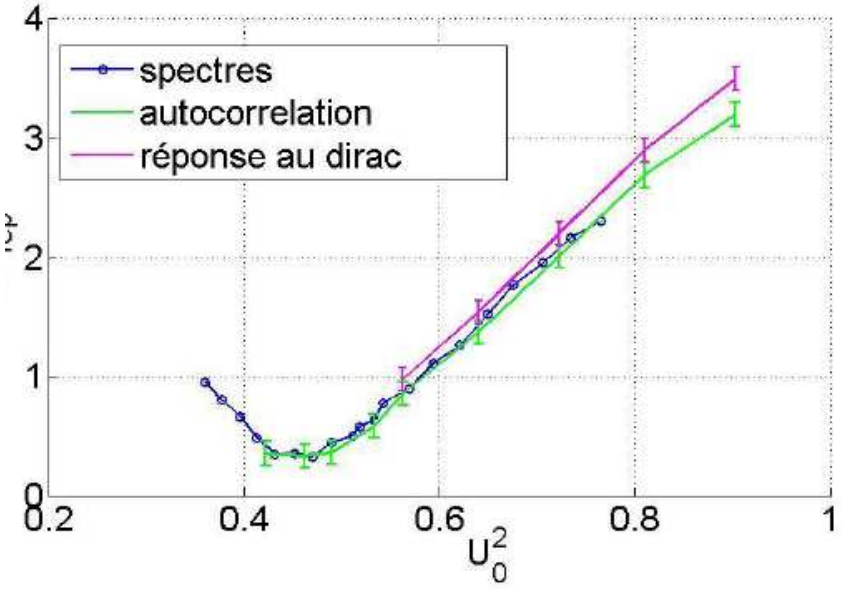
$$\tau_0 \delta\dot{\theta}_o = -2\epsilon\ \delta\theta_0 + \eta(t)$$

$$\epsilon = \frac{Uo^2}{U_c^2} - 1$$



Liquid Crystals and Fréedericksz transition

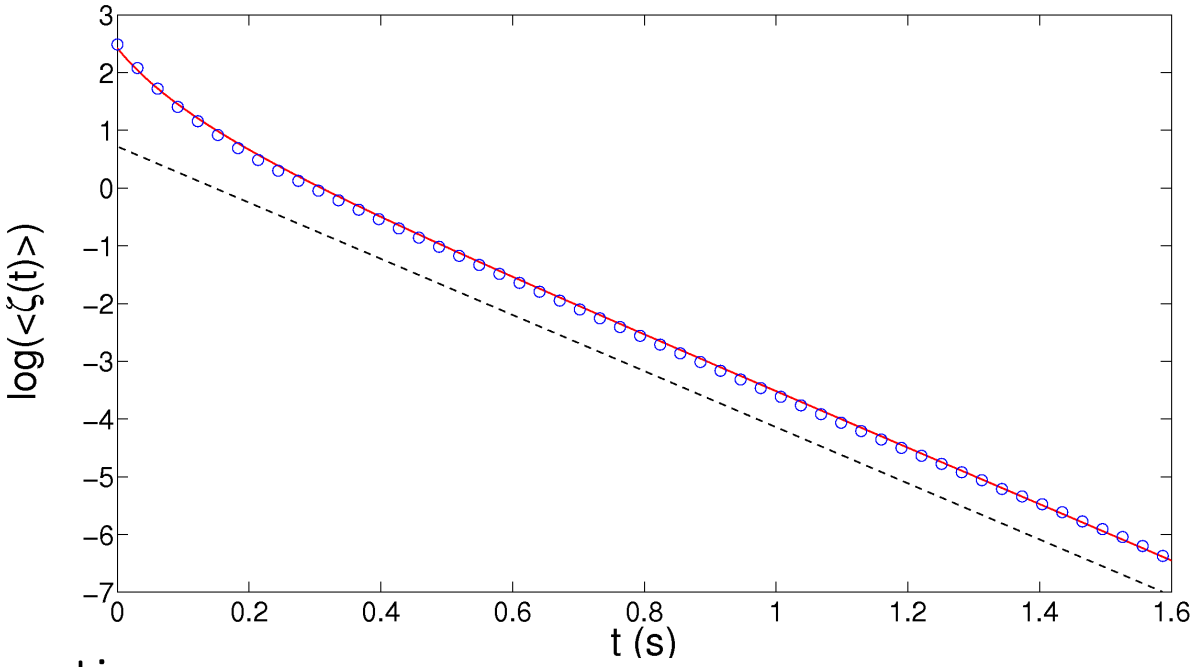




$$\tau_0 \dot{\theta}_o = \epsilon\ \theta_0 - \alpha\ \theta_0^3 + C$$

Time evolution after a quench in LC

from $\epsilon_1 = 0.3$ to $\epsilon_0 = 0.01$



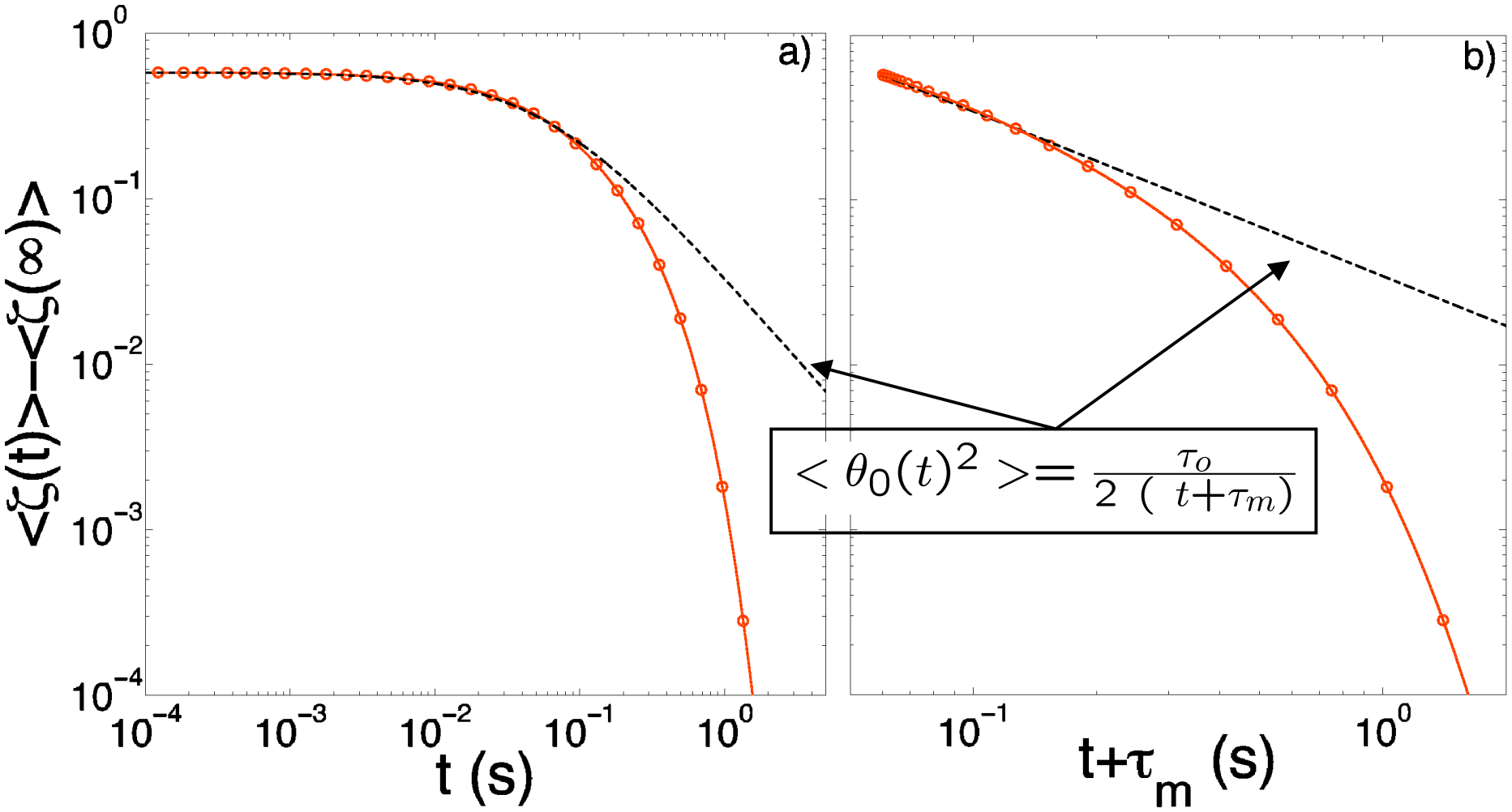
Fit function

$$\langle\ \zeta(t)\rangle = \frac{\langle\zeta(\infty)\rangle}{1+\left(\frac{\langle\zeta(\infty)\rangle}{\langle\zeta(0)\rangle}-1\right)\exp\left(-\frac{2\epsilon_0 t}{\tau_0}\right)},$$

with $<\zeta(\infty)>=\frac{2\epsilon_0}{(2k+\epsilon_0+1)}$ and $<\zeta(0)>=\frac{2\epsilon_1}{(2k+\epsilon_1+1)}$

Time evolution of ζ after a quench

Quench from $\epsilon_1 \simeq 0.3$ to $\epsilon_0 \simeq 0.01$ $\tau = \frac{\tau_0}{2\epsilon} \simeq 0.22s$



Correlations

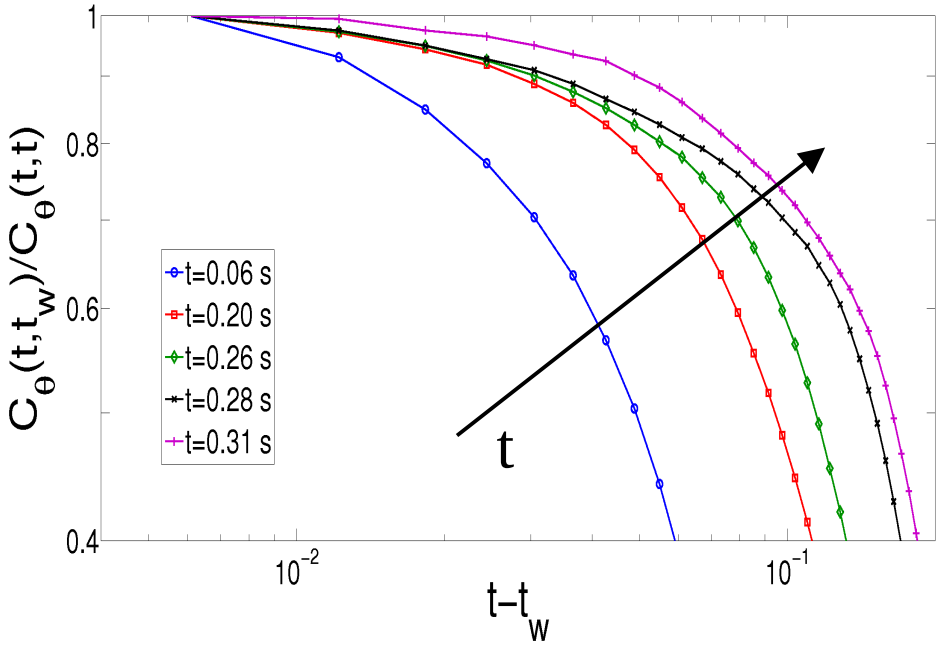
$$\zeta(t) = \theta_0(t)^2 = \psi_0^2(t) + 2\psi_0\delta\theta = < \zeta(t) > + \delta\zeta(t)$$

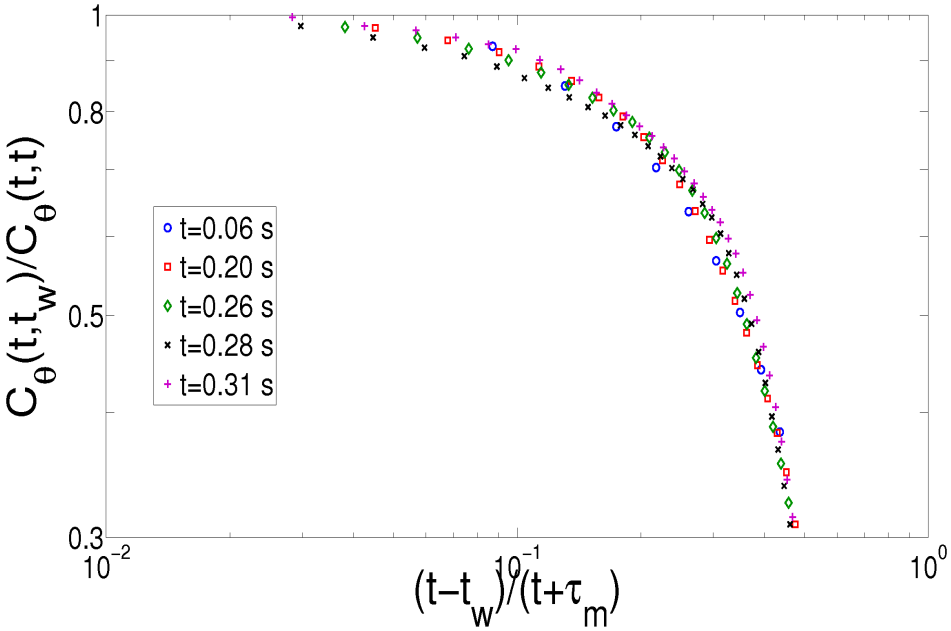
$$\psi_0^2(t) = < \zeta(t) >$$

$$C_\zeta(t, t_w) = < \delta\zeta(t)\delta\zeta(t_w) > = 4\psi_0(t)\psi_0(t_w)\ C_\theta(t, t_w)$$

Master curve by rescaling

$$(t - t_w) \rightarrow (t - t_w)/(t + \tau_m)$$





FDT in the LC experiment: the measure of the response function

$$\chi(t,t_w) = \frac{<\Delta\theta>}{\Gamma_{ext}} = \int_{t_w}^{t} R(t,t')dt' \qquad C_\theta(t,t_w) = <\delta\theta(t)\delta\theta(t_w)>$$

FDR $$\chi(t,t_w) = \frac{1}{k_B T_{eff}(t,t_w)}(C_\theta(t,t) - C_\theta(t,tw))$$

In equilibrium $T=T_{eff}$

Which is the appropriate external torque Γ_{ext} for the LC ?

$\Delta\theta$ is the response of θ to $\delta\epsilon$

$$\tau_0 \Delta\dot{\theta} = [\epsilon - 3\ \alpha\ \theta_0(t)^2]\ \Delta\theta(t) + \delta\epsilon\ \theta_0(t)$$

Γ_{ext}

FDT in the LC experiment:

$$\delta\theta = \frac{\delta\zeta(t)}{2\psi_0(t)} \qquad \Gamma_{ext} = 4B\psi_0(t)\ \delta\epsilon$$

Experimental test of these results (JSTAT P01033, 2009) :

1) Out of equilibrium, using the Transient Fluctuation Theorem
2) FDT in equilibrium

In equilibrium $\psi_0(t) = \psi_0(t_w) = \psi_0$

$$\chi(\tau) = \frac{\langle \Delta(\tau) \rangle}{\Gamma_{ext}} = \frac{\chi_{\zeta,\delta\epsilon}}{4B\ \psi_0^2}$$

$$C_\zeta(t, t_w) = 4\psi_0^2\ C_\theta(t, t_w)$$

and FDT

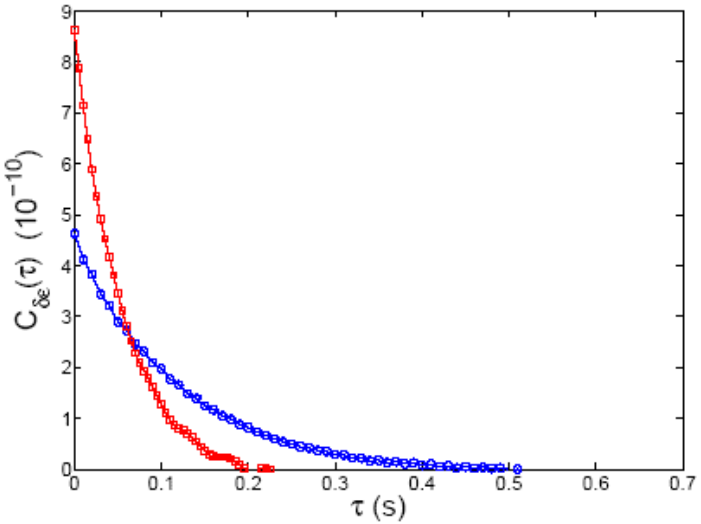
$$\frac{\chi_{\zeta,\delta\epsilon}}{B} = \frac{1}{k_B T}(C_\zeta(t,t) - C_\zeta(t,t_w))$$

with $B = \mathcal{A}\pi^2 K_1/4L$

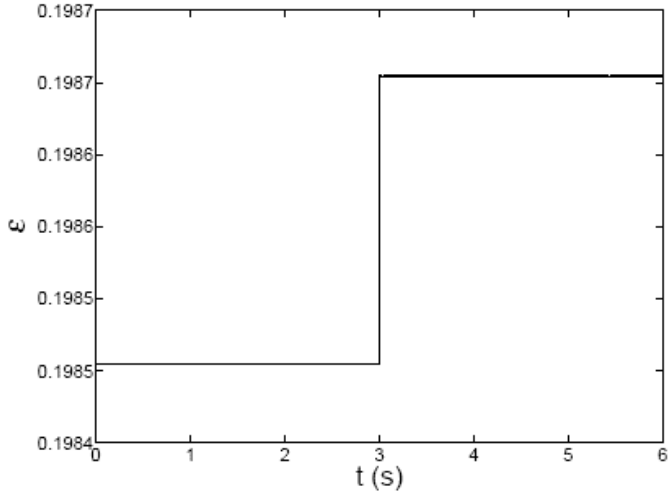
FDT in the LC experiment in equilibrium

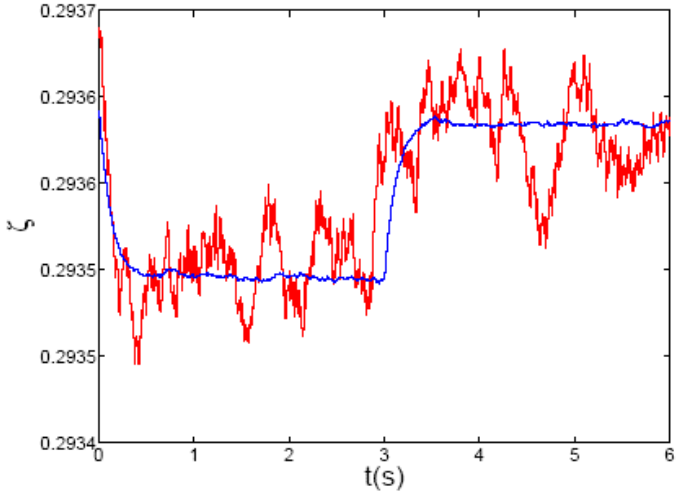
$\varepsilon_0 = 1{,}039$

$\varepsilon_0 = 0{,}1985$



• response function

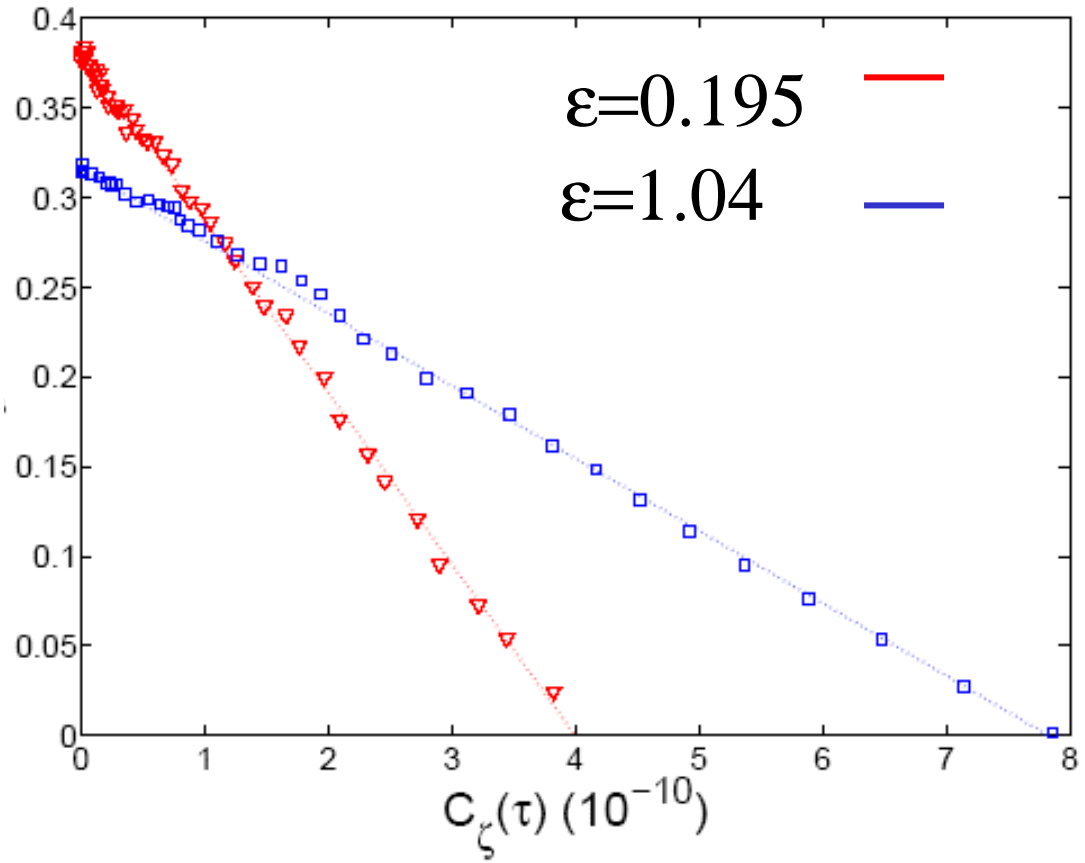




FDT in the LC experiment in equilibrium

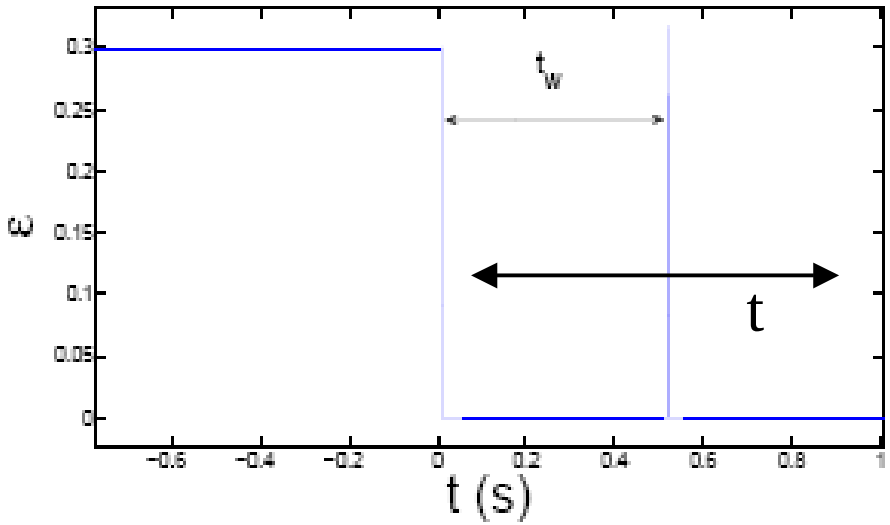
$$\frac{\chi_{\zeta,\delta\epsilon}}{B} = \frac{1}{k_B T}(C_\zeta(t,t) - C_\zeta(t,t_w)) \quad \text{with } B = \mathcal{A}\pi^2 K_1/4L$$

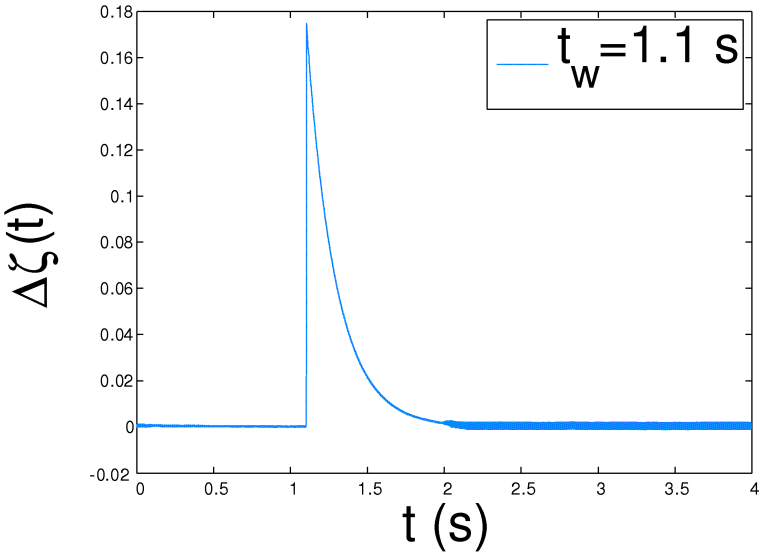
$\chi_{\zeta,\delta\epsilon}(t,t_w)$



at $\epsilon = 0.195$, $\frac{B}{k_B T} = 8.4\ 10^8$, $\mathcal{A} = 2.4mm^2$ and $D_0 \simeq 1.8mm$

Response function during aging





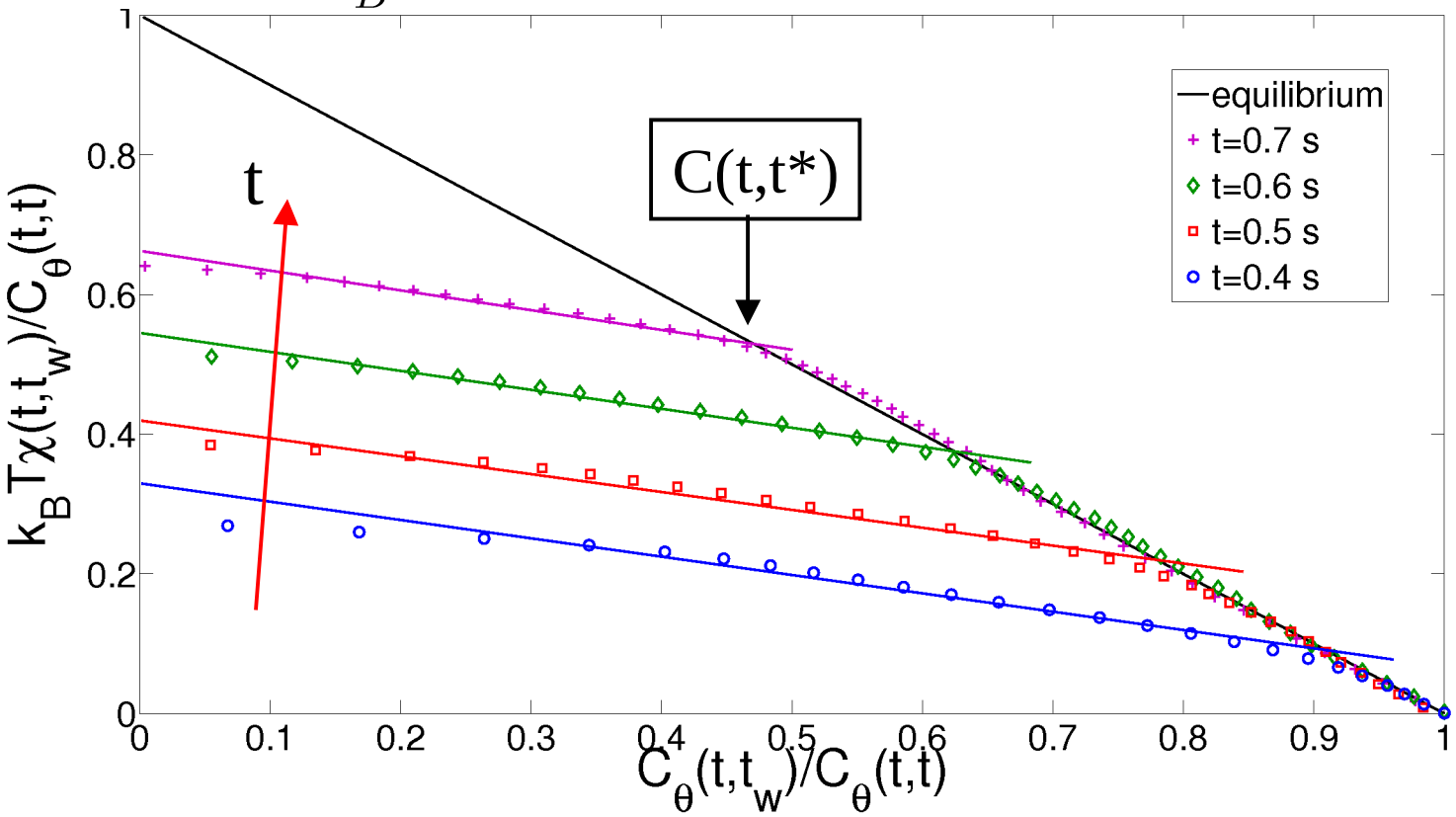
$$\Delta = \theta_0(t) - \psi_0(t) \quad \text{and} \quad \Delta = \frac{\zeta(t) - \psi_0(t)^2}{2\psi_0(t)} = \frac{\zeta(t) - <\zeta(t)>}{2\Psi_0(t)} = \frac{\Delta\zeta}{2\psi_0(t)}$$

$$R(t, t_w) = \frac{< \Delta(t) >}{\Gamma_{ext}(t_w)} = \frac{R_{\zeta,\delta\epsilon}(t, t_w)}{4B\ \psi_0(t_w)\ \psi_0(t)}$$

$$\chi(t, t_w) = \frac{< \Delta(t) >}{\Gamma_{ext}} = \int_{t_w}^{t} R(t, t')dt'$$

FDT out of equilibrium: fixed t as a function of tw

$$\chi(t,t_w) = \frac{X(t,t_w)}{k_B T}(C_\theta(t,t) - C_\theta(t,tw)) \qquad \text{with} \quad T_{eff} = \frac{T}{X(t,t_w)}$$



for $C(t,t_w) > C(t,t^*)$, $X = 1$ and $T_{eff} = T$

for $C(t,t_w) < C(t,t^*)$, $X \simeq 0.33$ and $T_{eff} \simeq 3T$

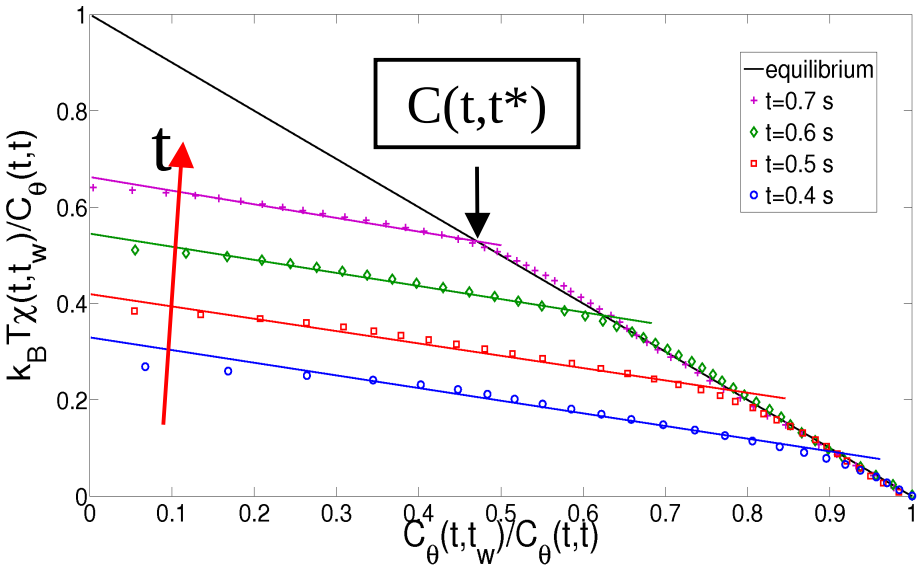
L. Cugliandolo, J. Kurchan, and L. Peliti, Phys. Rev. E 55, 3898 (1997).

D. Hérisson and M. Ocio, Phys. Rev. Lett. 88, 257202,(2002)

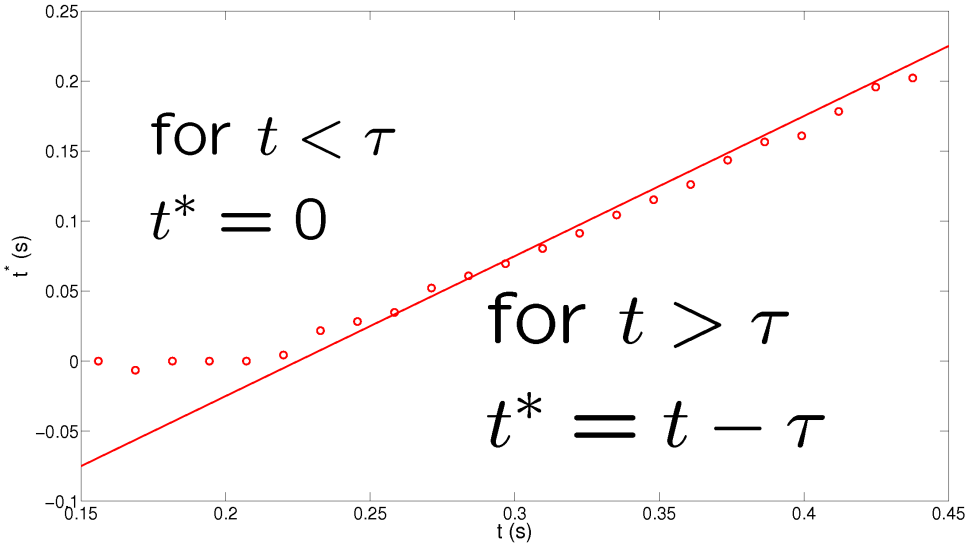
FDT out of equilibrium: fixed t as a function of tw

for $C(t,t_w) > C(t,t^*)$, $X = 1$ and $T_{eff} = T$

for $C(t,t_w) < C(t,t^*)$, $X \simeq 0.33$ and $T_{eff} \simeq 3T$



evolution of t* as a function of t



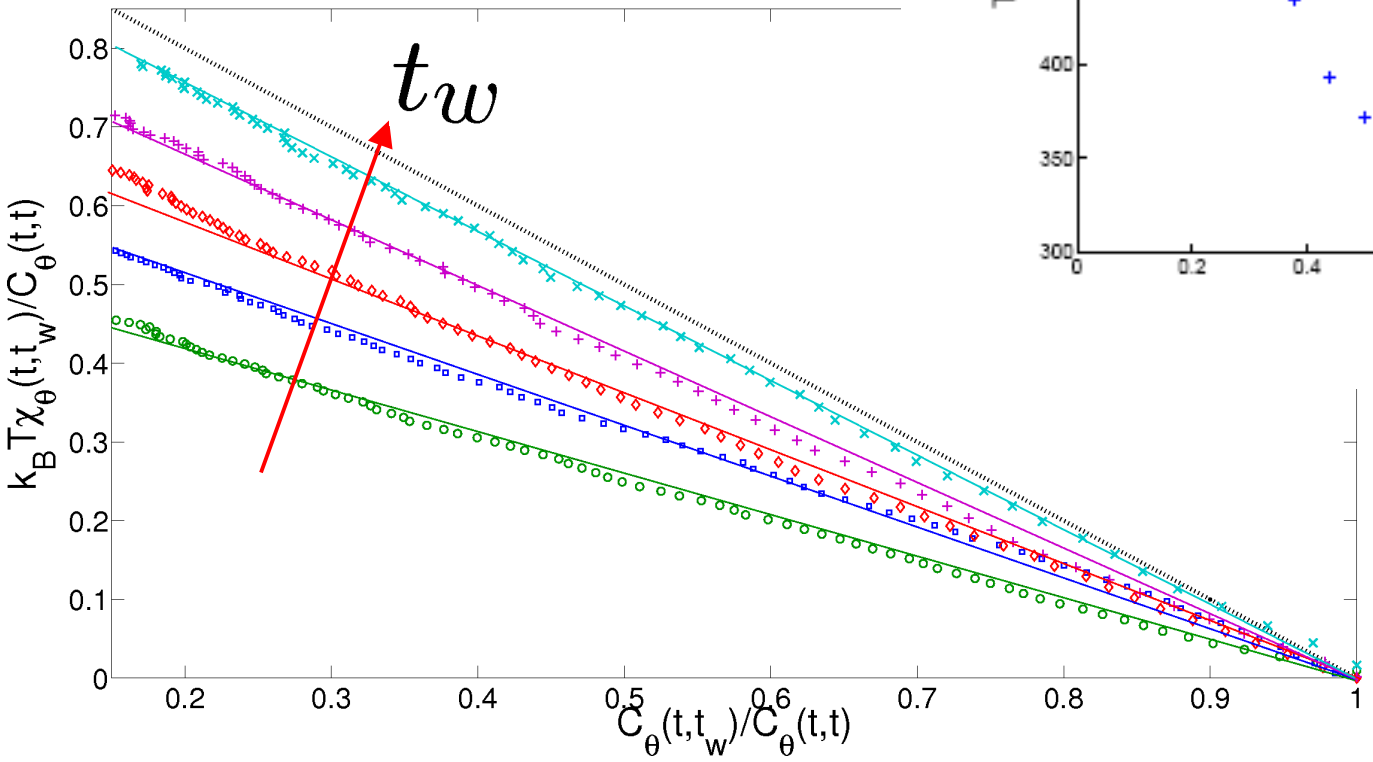
$\frac{t^*}{t} = 1 - \frac{\tau}{t}$ for $t > \tau$ defines the lenght of the equilibrium interval with respect to the total time.

At $\epsilon_0 = 0, \Rightarrow \ \tau = \infty$: the equilibrium interval does not exist.

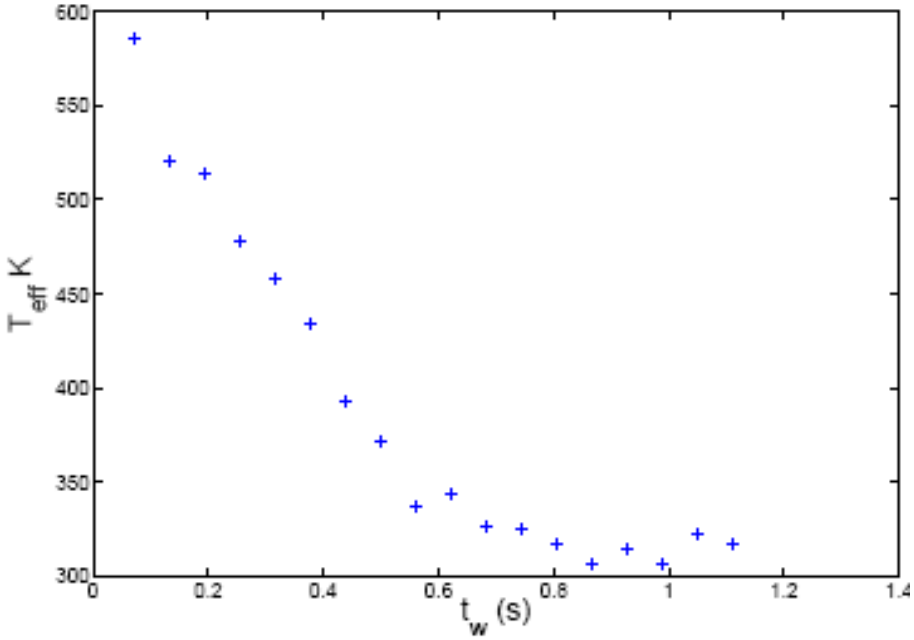
FDT out of equilibrium: fixed tw as a function of t

$$\chi(t,t_w) = \frac{X(t,t_w)}{k_B T}(C_\theta(t,t) - C_\theta(t,tw))$$

with $T_{eff} = \frac{T}{X(t,t_w)}$



evolution of Teff versus tw



Conclusions on the quench at critical point

Using a liquid crystal driven by an electric field at the Fréedericksz transition we observe that :

- After a quench close to the critical point the system presents power law decay. A rescaling similar to the one used in aging materials, produces a master curve of correlations

- FDT is violated during the decay. The observed violation depends on the procedure used to define t and tw.

- For the ‘’good procedure’’ an asympothique temperature can be defined, which is not the one computed from mean field.

Perspectives

- Dependence on the observable
- Intermittency
- Confinement
- Space time dependence
- High order moments
- FDT violation versus aging of response