Nonequilibrium Dynamics of Spin Glasses: New Experimental Results

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Isothermal Aging – Domain size

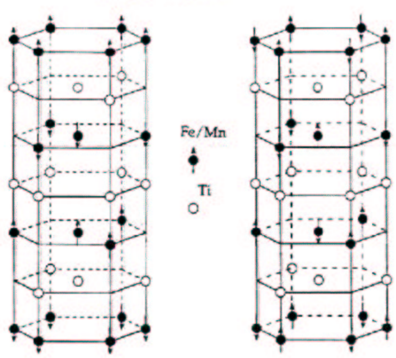
" – Memory

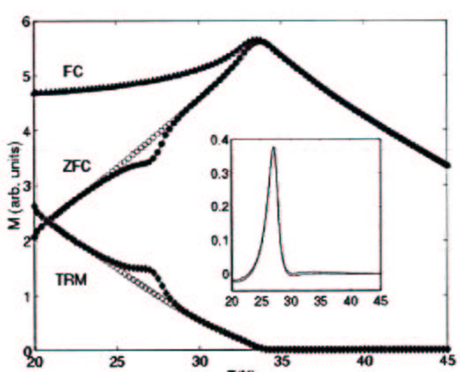
Accumulative ↔ chaos

3d SPIN GLASS MATERIALS

- $Fe_{0.5}Mn_{0.5}TiO_3$
- Insulating
- Short range interaction
- Tg = 21 K
- Ising
- Single crystal

- Ag(11 at% Mn)
- Metallic
- RKKY interaction
- Tg = 32 K
- Heisenberg
- Poly crystalline





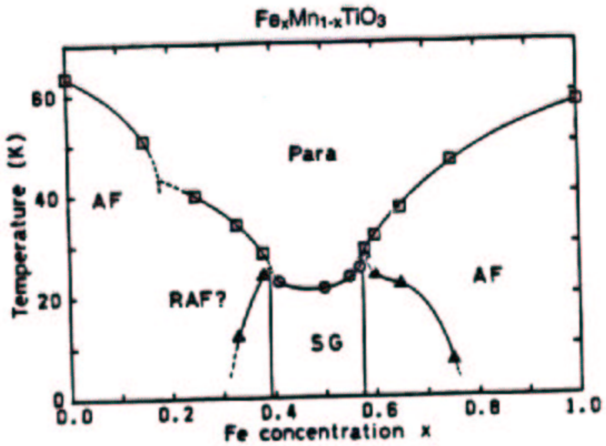


Fig. 3. Temperature versus Fe ion concentration phase diagram of the $Fe_xMn_{1-x}TiO_3$ system determined by the susceptibility measurements. The vertical lines near $x \sim 0.4$ and 0.6 are discussed in the text.

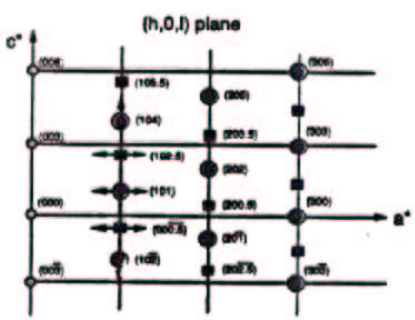


Fig. 4. Two scattering planes studied in the experiments.

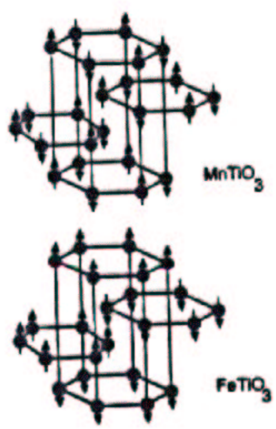


Fig. 2. Schematic magnetic structure of $MnTiO_3$ and $FeTiO_3$.

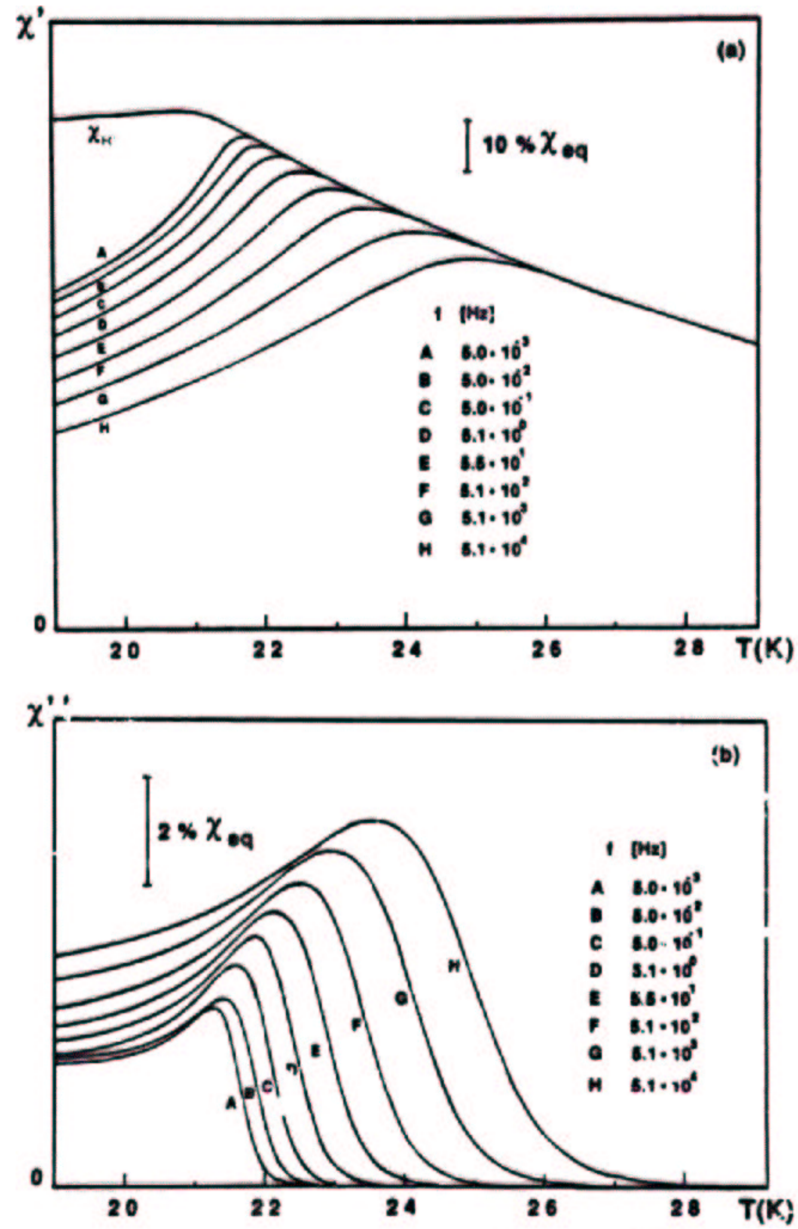
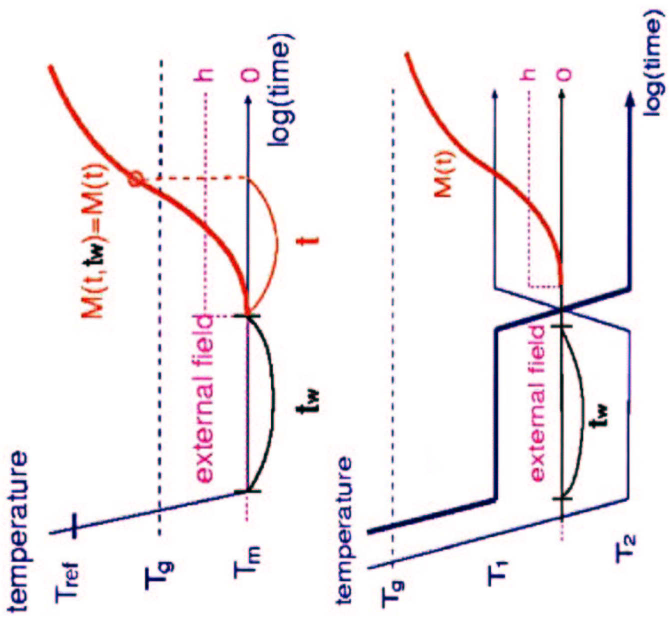
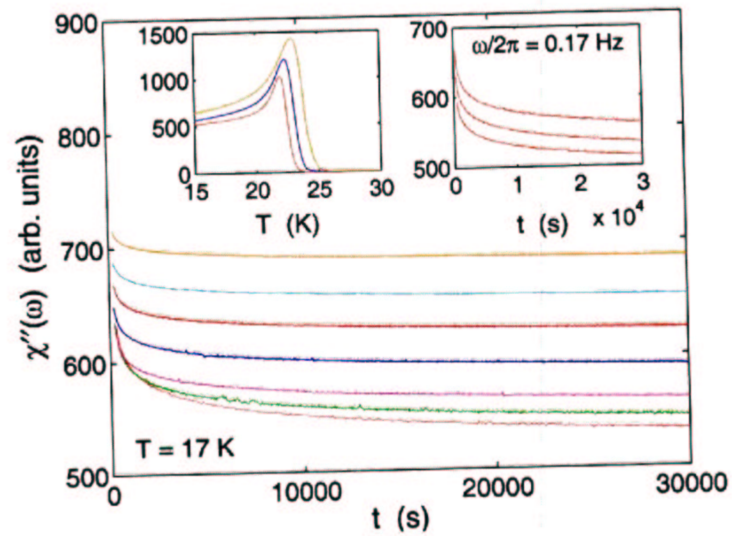


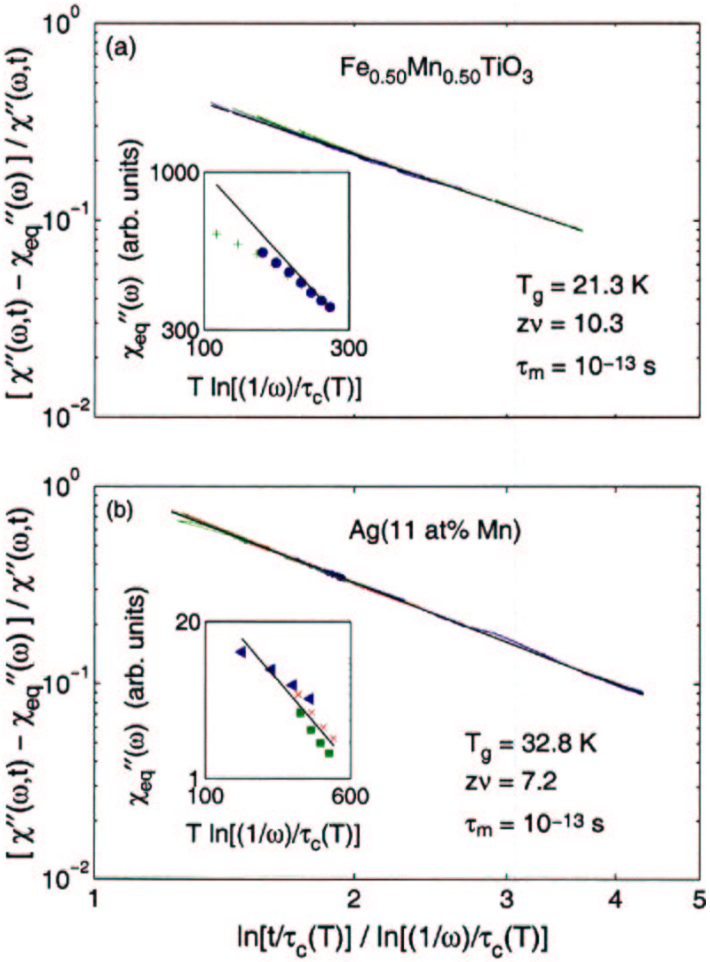
Fig. 2 Dynamic susceptibility of $Fe_{0.5}Mn_{0.5}TiO_3$

OBSERVABLES

- Dc Magnetization Relaxation
- Ac Susceptibility Relaxation
- $M(t,t_w)$ $S(t,t_w)$ $\chi(\omega,t_a)$







SG - DOMAINS

DROPLET:

$$R(T),\ L(T) \sim \left[\frac{k_B T \ln(t/\tau_c(T))}{\Delta(T)}\right]^{1/\psi} \quad \begin{cases} B \sim \Delta(T)\left(\frac{L}{L_0}\right)^{\psi} \\ \tau_c(T) = \tau_0 |\varepsilon|^{-z\nu} \end{cases}$$

$$\frac{\chi''(\omega,t) - \chi''_{eq}(\omega)}{\chi''(\omega,t)} \propto \left[\frac{L_T(1/\omega)}{L_T(t)}\right]^{d-\theta} = \left[\frac{\ln(t/\tau_c(T))}{\ln(1/\omega/\tau_c(T))}\right]^{\frac{d-\theta}{\psi}}$$

Algebraic:

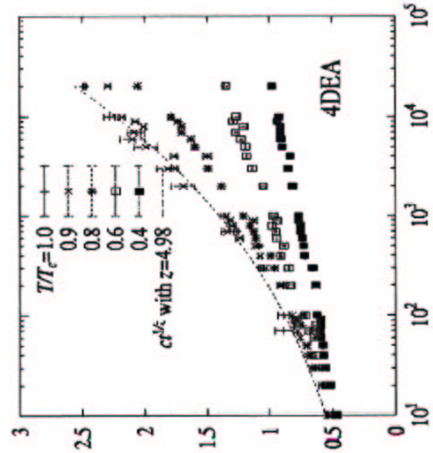
$$L_T(t) \sim (t/\tau_0)^{1/z(T)} \qquad z(T) \simeq z\,\frac{T_g}{T}$$

$$\begin{cases} \dfrac{\chi''(\omega,t) - \chi''_{eq}(\omega)}{\chi''(\omega,t)} \propto (\omega t)^{-k(T)} & k(T) = \dfrac{d-\theta}{z(T)} \\ \chi''_{eq}(\omega) \propto \omega^{\alpha(T)} & \alpha(T) = \theta/z(T) \end{cases}$$

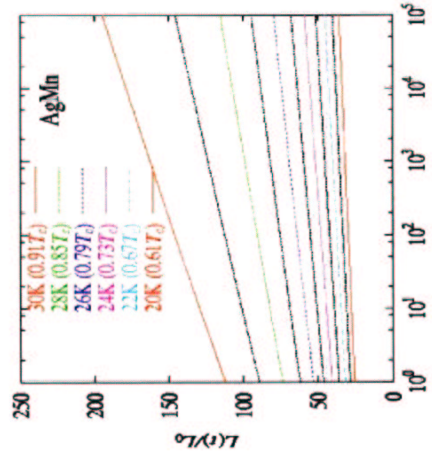
	Ising	AgMn
ψ	1.9	1.2
θ	0.2	1.0

Length Scales

Simulations of a 4D EA Spin glass



Exp. Ag(Mn)



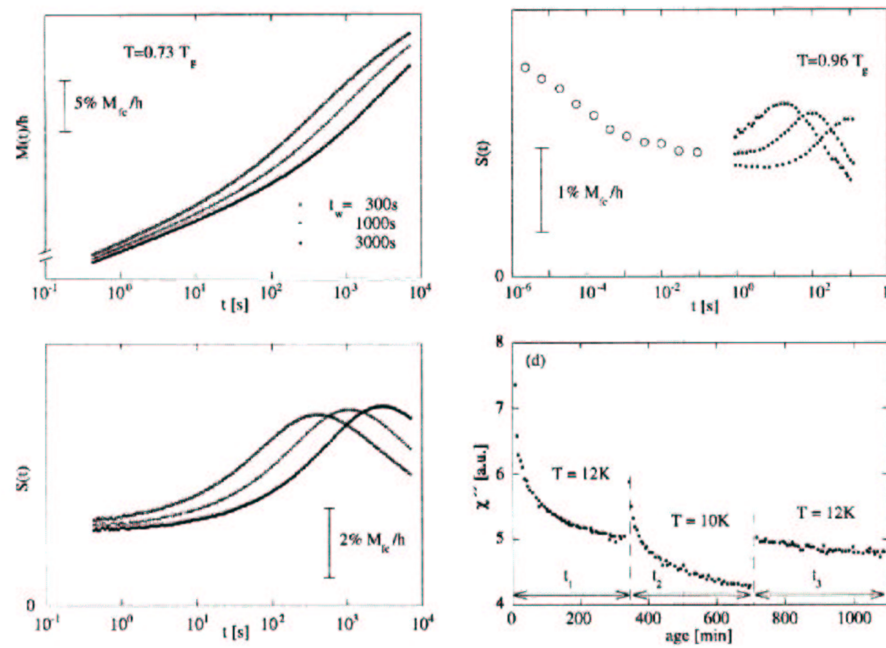
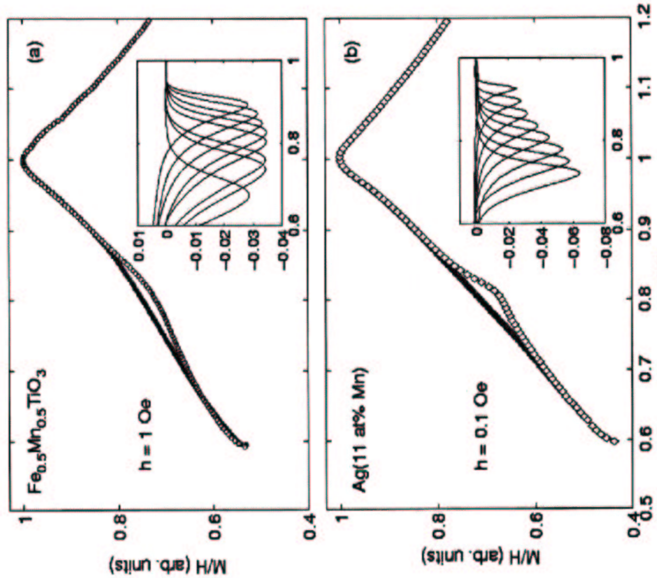


Fig. s4 Different effects of ageing. Amorphous metallic spin glass, $(Fe_{0.15}Ni_{0.85})_{75}P_{16}B_6Al_3$ and insulating spin glass (d), $CdCr_{1.7}In_{0.3}S_4$.

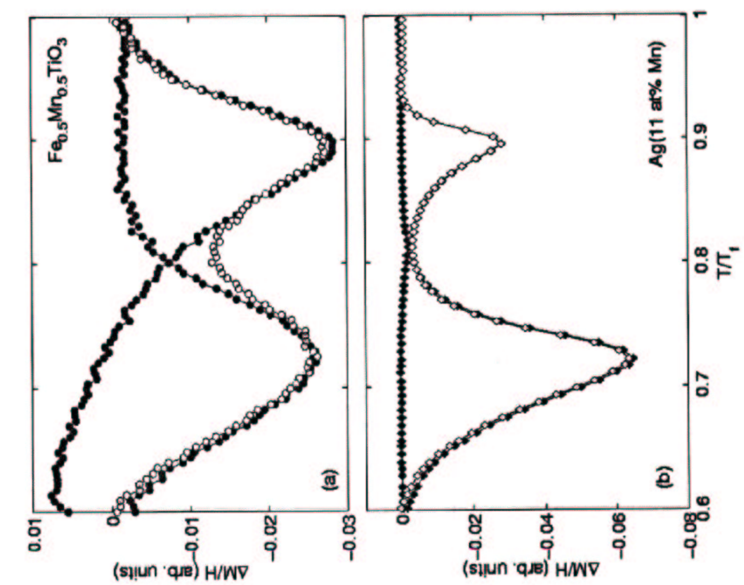
Rejuvenation and Memory



FeMnTiO3

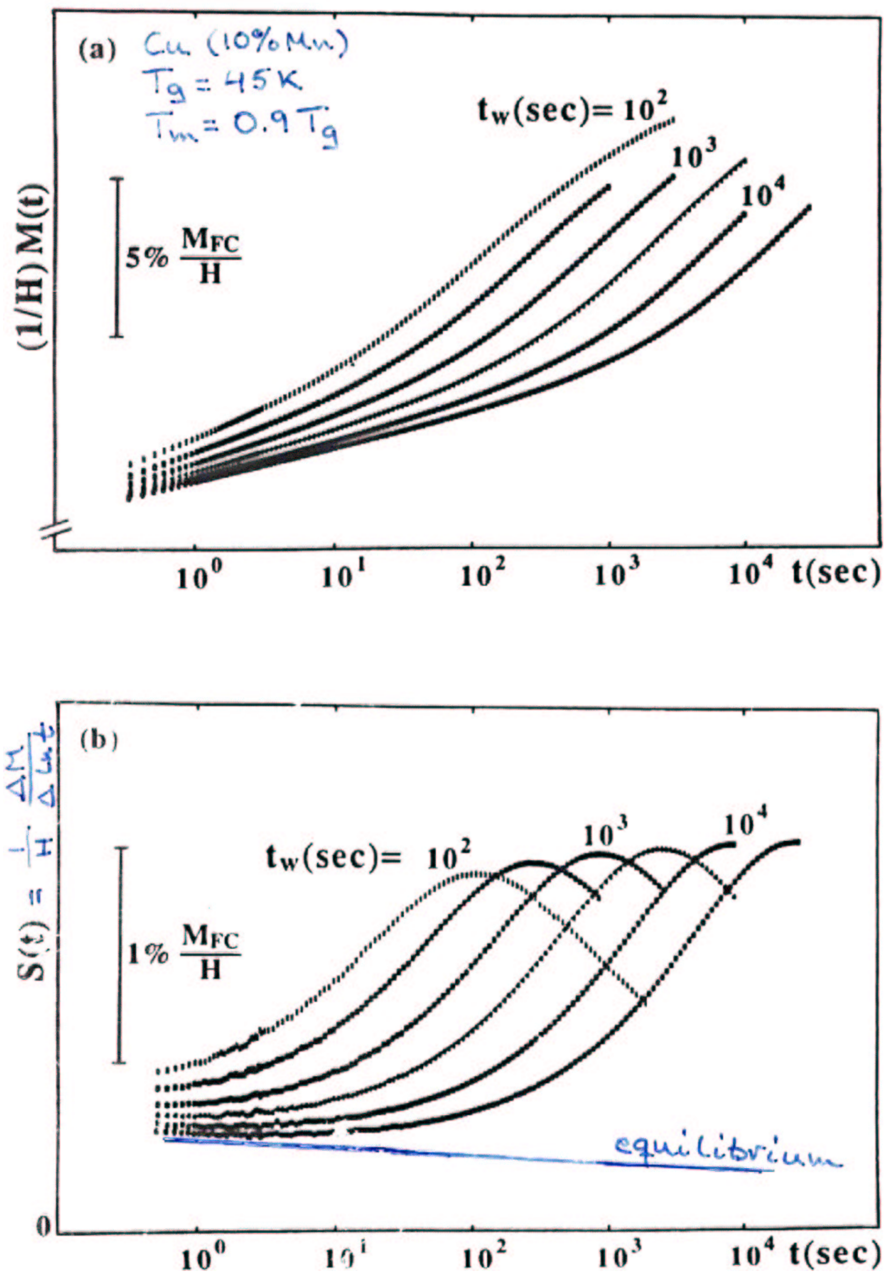
Ag(Mn)

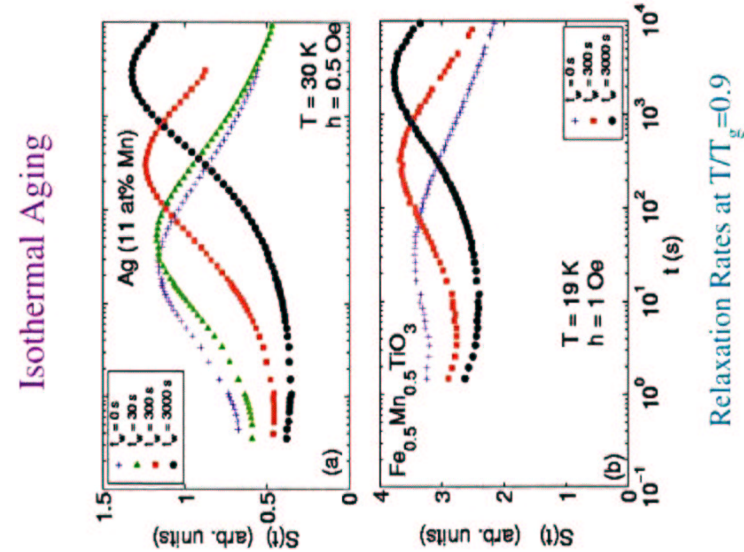
Double memory



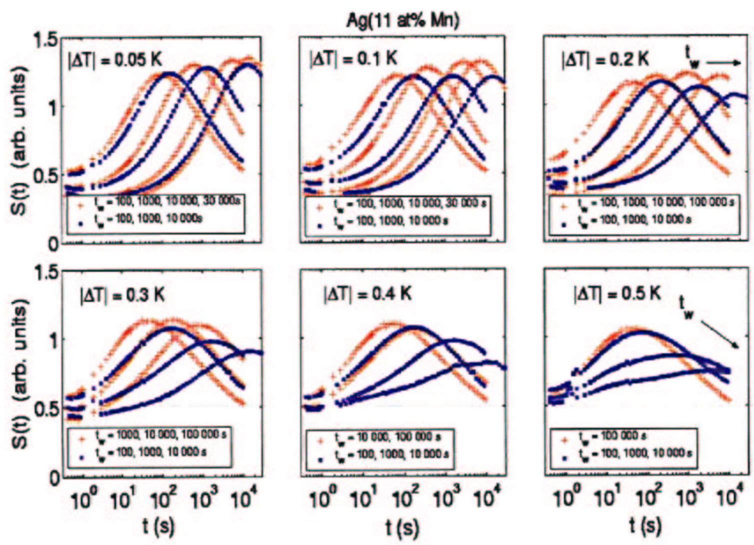
FeMnTiO

Ag(Mn)


(a)
Cu (10% Mn)
Tg = 45 K
Tm = 0.9 Tg
tw(sec)= 10²
10³
10⁴
(1/H) M(t)
5% MFC/H
10⁰
10¹
10²
10³
10⁴
t(sec)
(b)
S(t) = 1/H ΔM/Δ ln t
tw(sec)= 10²
10³
10⁴
1% MFC/H
equilibrium
0
t(sec)

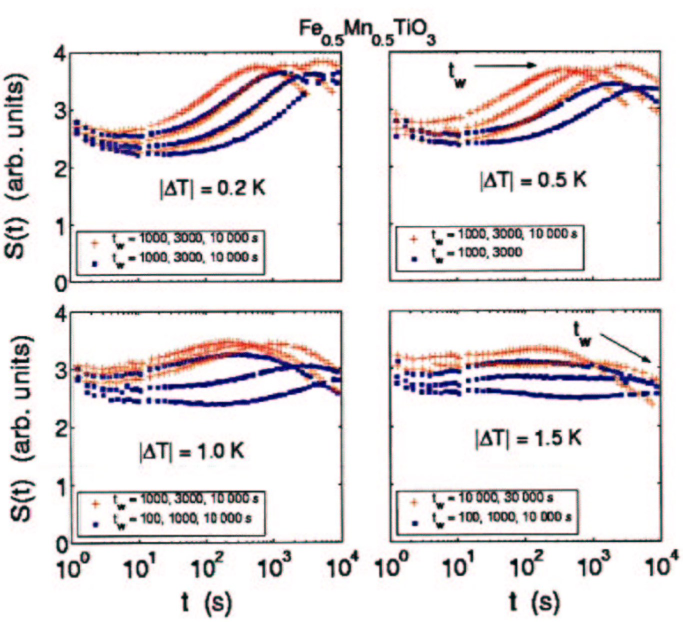

Isothermal Aging
Relaxation Rates at T/Tg=0.9
Ag (11 at% Mn)
T = 30 K
h = 0.5 Oe
Fe0.5Mn0.5TiO3
T = 19 K
h = 1 Oe
S(t) (arb. units)
t (s)

Temperature shifts (Ag(Mn))

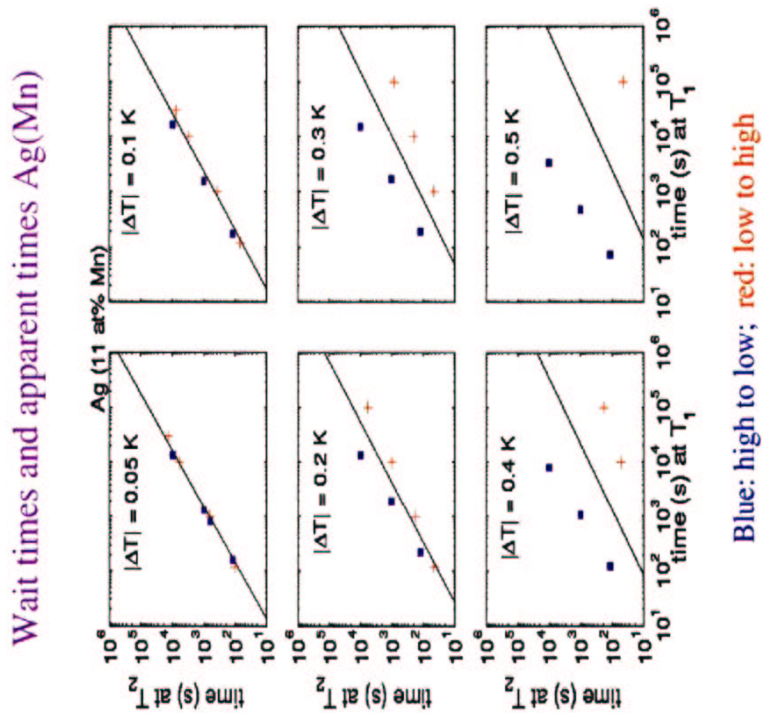


Age at Lower/higher temperature and measure at T_M.

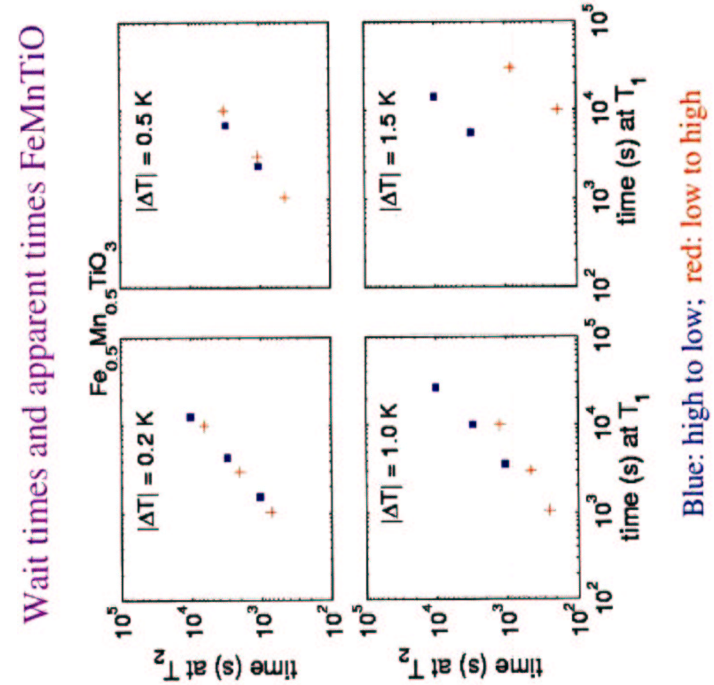
Temperature shifts FeMnTiO



Age at Lower/higher temperature and measure at T_M.

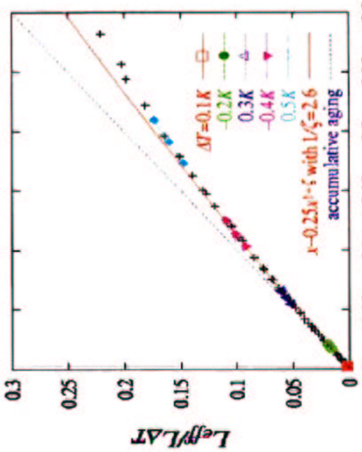


Wait times and apparent times Ag(Mn)
Ag (11 at% Mn)
|ΔT| = 0.05 K
|ΔT| = 0.1 K
|ΔT| = 0.2 K
|ΔT| = 0.3 K
|ΔT| = 0.4 K
|ΔT| = 0.5 K
time (s) at T2
time (s) at T1
Blue: high to low; red: low to high

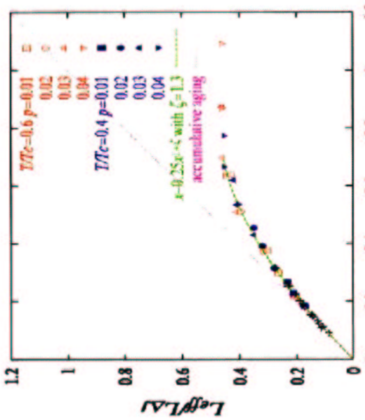


Wait times and apparent times FeMnTiO
Fe0.5Mn0.5TiO3
|ΔT| = 0.2 K
|ΔT| = 0.5 K
|ΔT| = 1.0 K
|ΔT| = 1.5 K
time (s) at T2
time (s) at T1
Blue: high to low; red: low to high

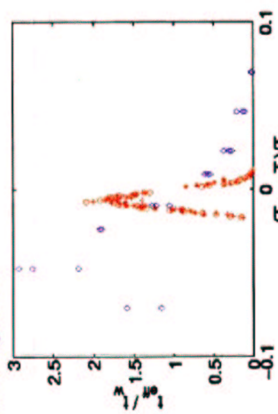
Domain Growth



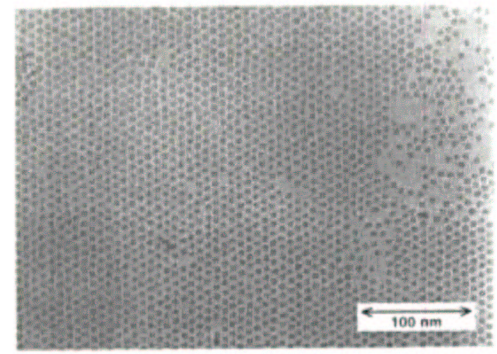
Scaling of the effective length after temperature shifts (Ag(Mn))



Simulation, 4d EA spin glass data



A Magnetic Nano Particle System (Fe(C))



TEM image

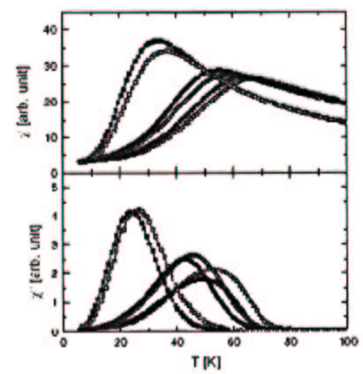


Figure 1. AC susceptibilities for the [illegible] vol% (□), 5 vol% (▽) and 17 vol% (△) samples at frequencies of f = 1.5 Hz (filled symbols) and f = 1000 Hz (open symbols)

Simplified dynamics in particles systems

Arrhenius-Néel in a non-interacting particle system:

$$\tau = \tau_0 \exp\left(\frac{E_b}{T}\right)$$

Critical slowing down in a strongly dipolar interacting system:

$$\tau_c = \tau\left(\frac{T - T_g}{T_g}\right)^{-z\nu}$$

In the correlated system dynamics occurs on all time scales τ to τ_c.

There are similarities between the physics of dilute metallic alloys (spin glasses) and strongly interacting nano-particle systems suggesting a parallel description of the transition from a disordered paramagnetic - superparamagnetic behaviour at high temperatures to a correlated spin (super spin) glass state at low temperatures.

Where an equivalence is made between the atomic spin (one single value) and the particle moment (a (narrow) distribution of sizes); and the atomic relaxation time (temperature independent) and the relaxation time of the particle moments (temperature dependent and distributed)

Dynamic scaling example

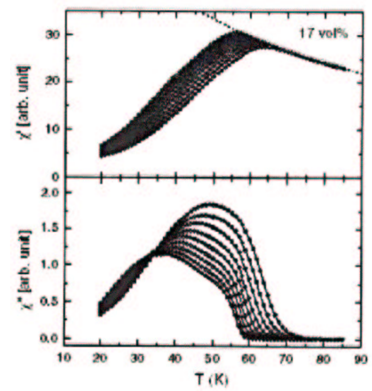


Figure 4. AC susceptibilities for the 17 vol% sample using the frequencies (left to right) $f = 0.017$, 0.051, 0.17, 0.51, 1.7, 5.1, 17, 51, 170 Hz. The dashed curve indicates the equilibrium susceptibility.

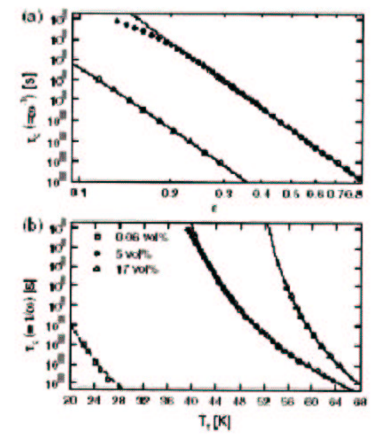


Figure 6. (a) Relaxation time $\tau_f = \omega^{-1}$ versus reduced temperature for the 5 and 17 vol% samples. Open and filled points are obtained from AC susceptibility and ZFC relaxation measurements, respectively. The curves are fits to equation (5) as described in the text. (b) Relaxation time versus temperature for the 0.06, 5 and 17 vol% samples. The freezing temperatures for the 5 and 17 vol% samples were obtained from χ' as described in the text. For the 0.06 vol% sample, the data correspond to the peak temperatures of χ'', and the Arrhenius–Néel expression with parameter values as given in the text is shown as a dotted curve.