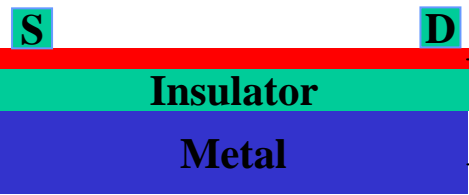


# **Granular Ni**

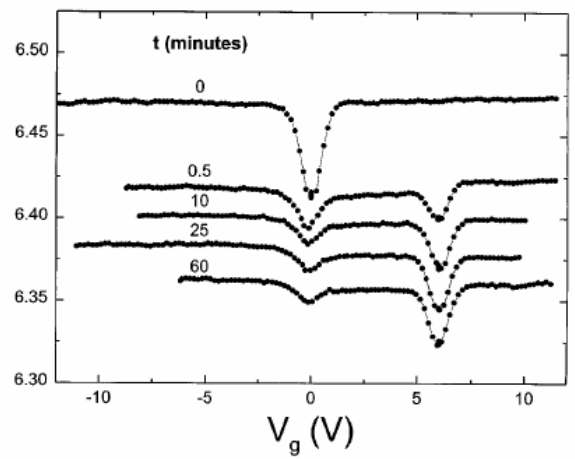
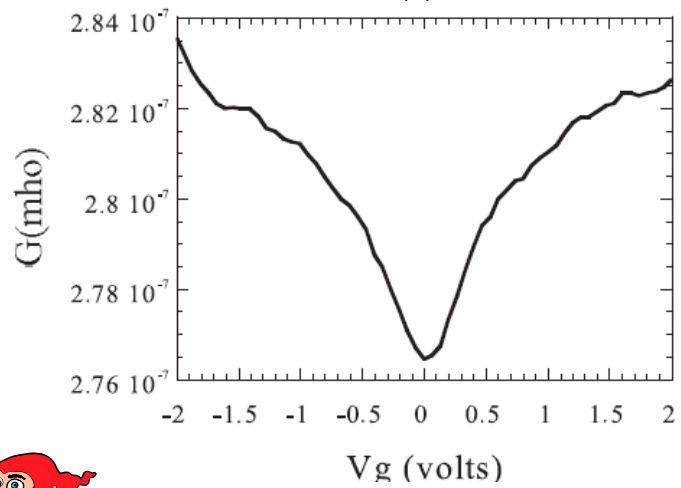
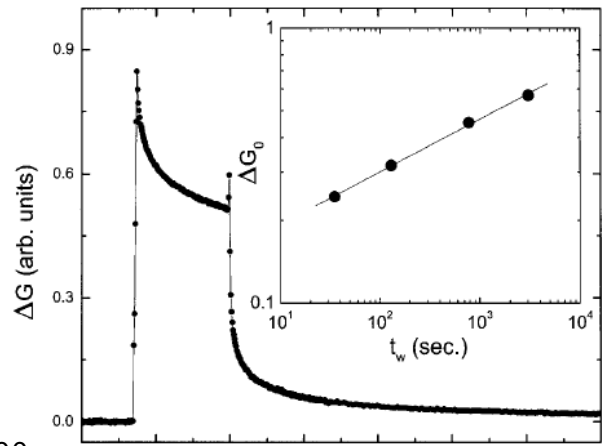
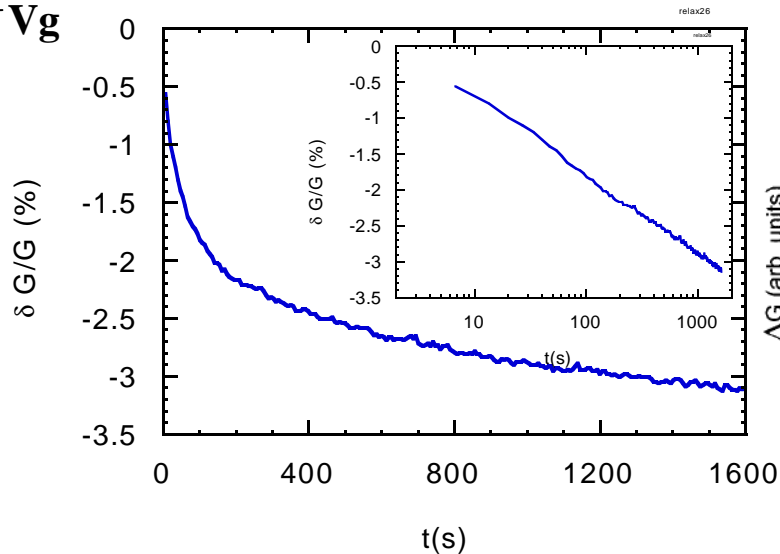
## **Ferromagnetic electron glasses**

***Ariel Eisenbach and Aviad Frydman***  
***Bar Ilan University***

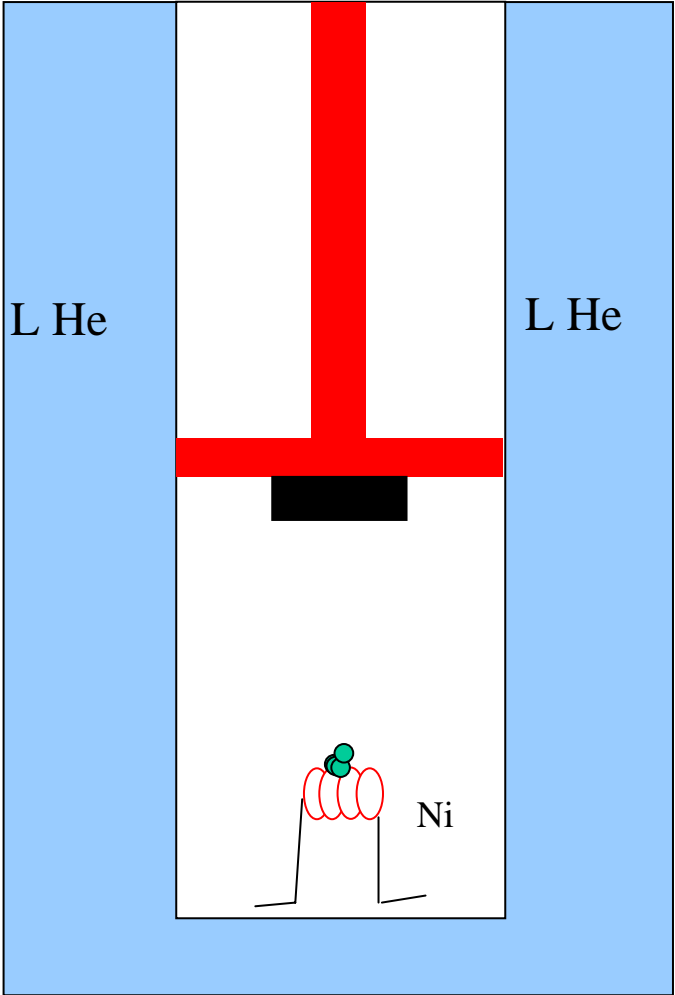
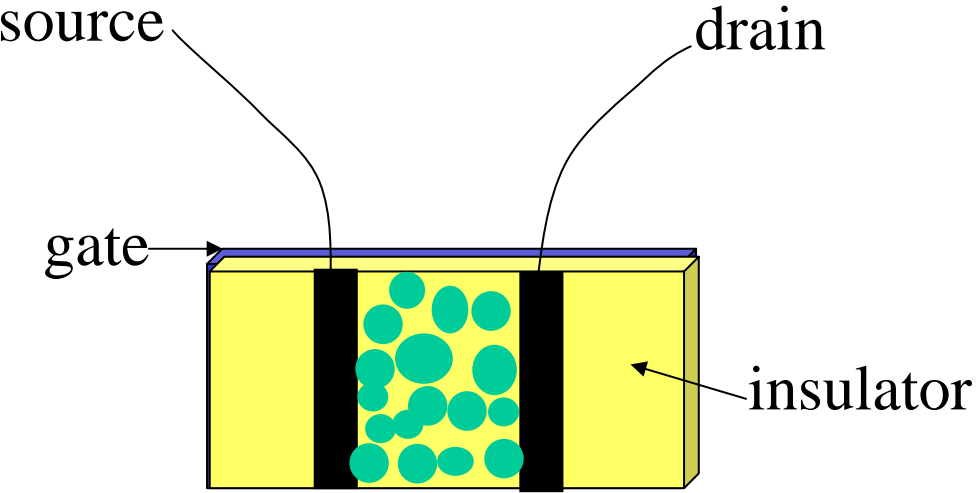


# Electron Glasses

- InO
- $\text{In}_2\text{O}_{3-x}$
- Be
- Granular Al
- Granular Au
- Pb
- Bi
- Si
- Granular Ni



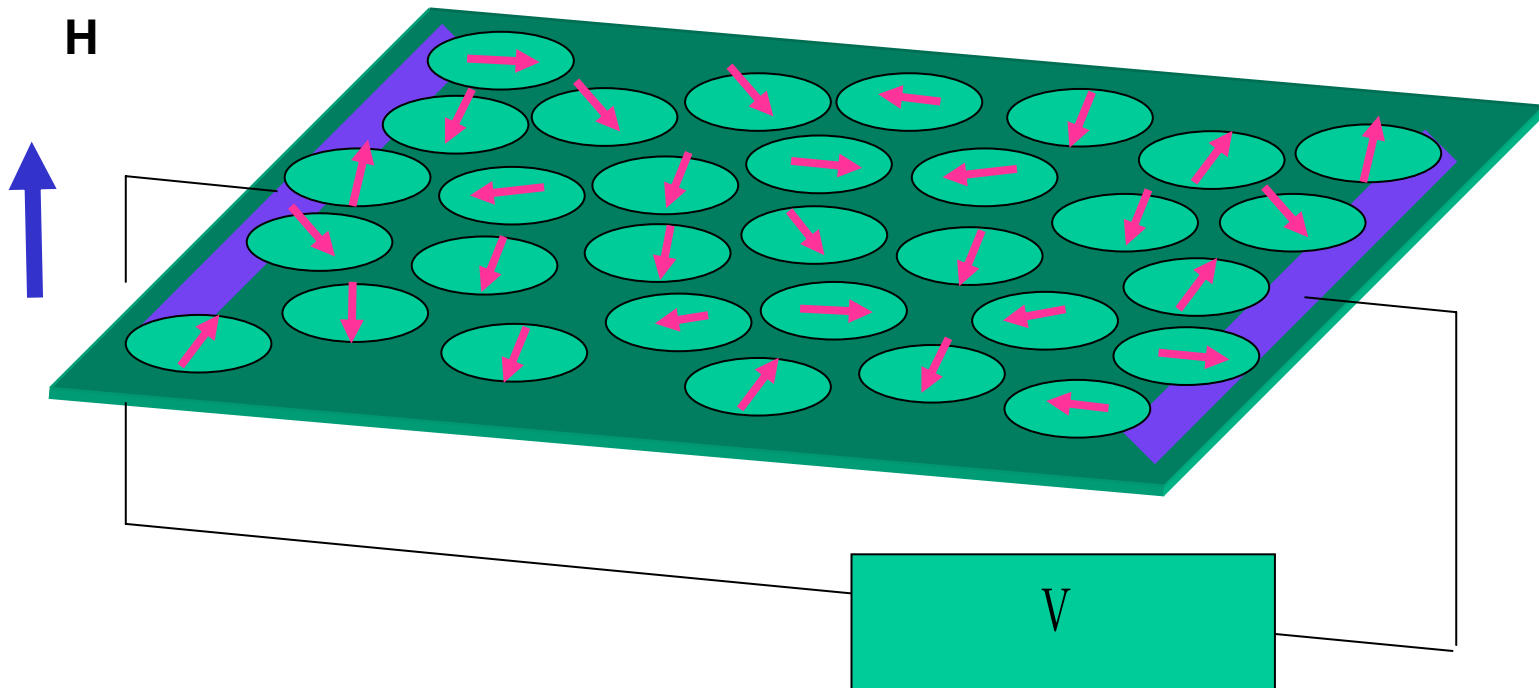
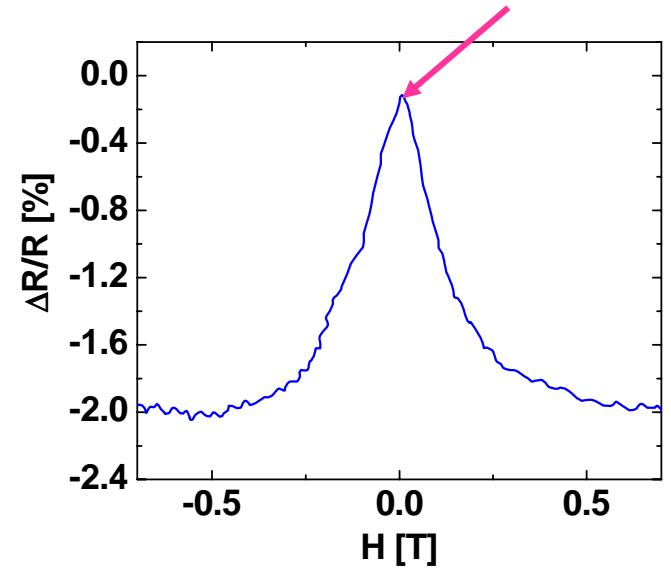
# Quench Condensation



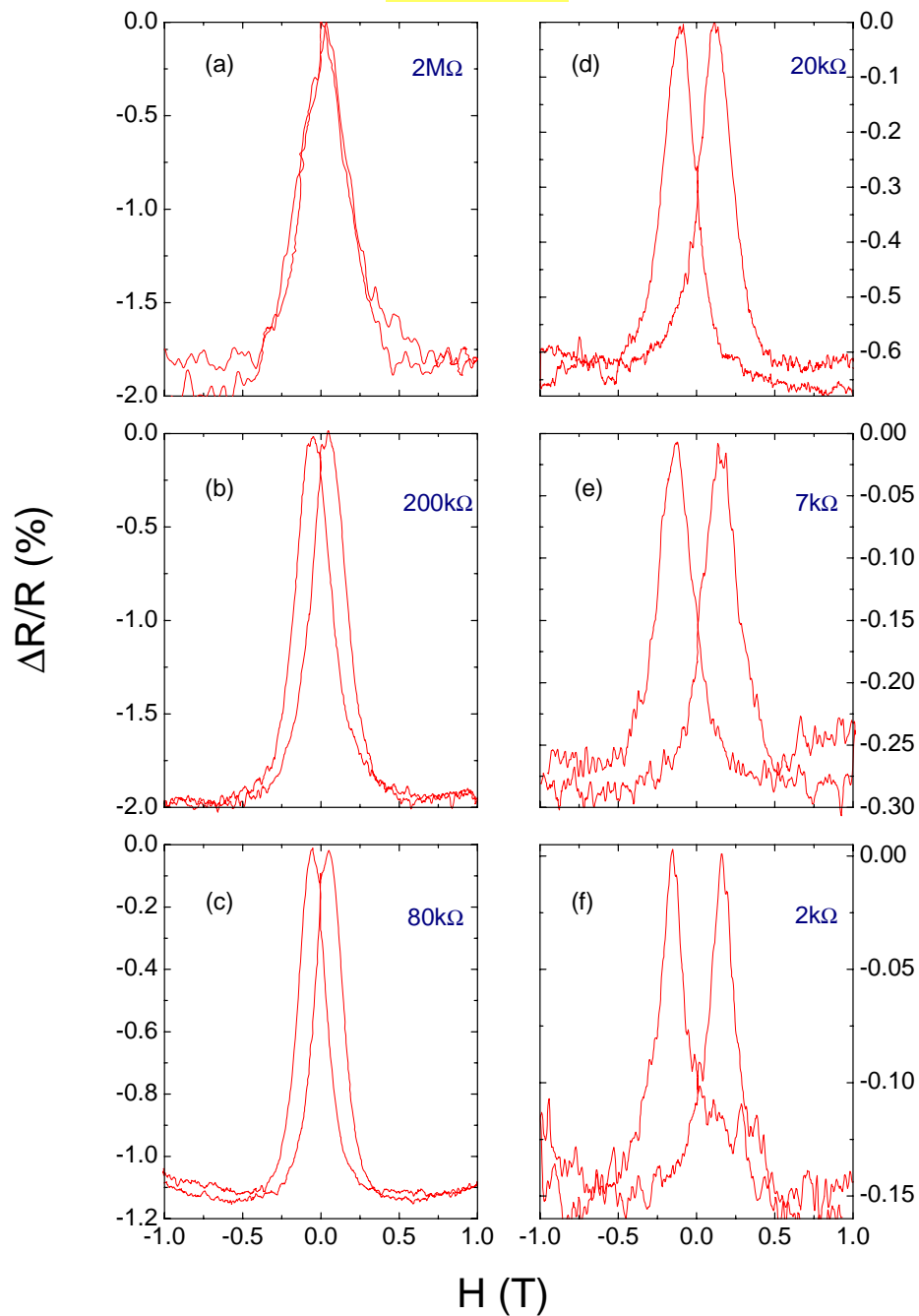
# Magnetoresistance of granular ferromagnets

$$\frac{\Delta R_{ij}}{R_{ij}} = \frac{1 + P^2 \cos \theta_{ij}}{1 + P^2} - 1$$

Slonczewski, PRB, 1989.

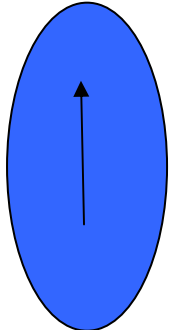


**T=4k**

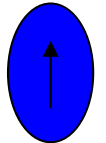


# superparamagnetism

$$k_B T < KV$$



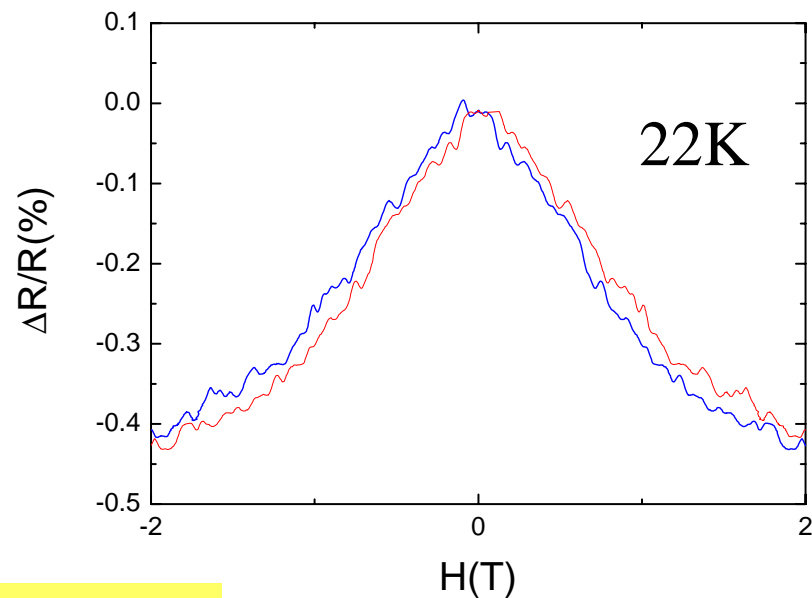
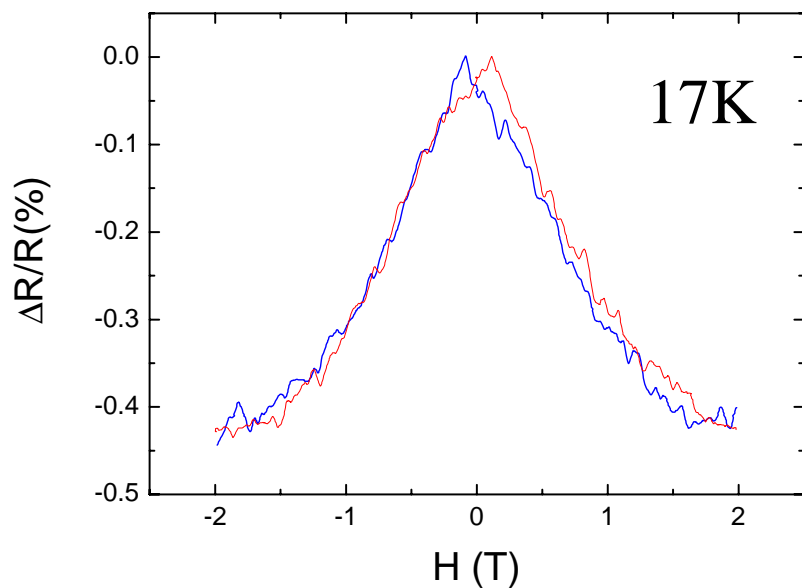
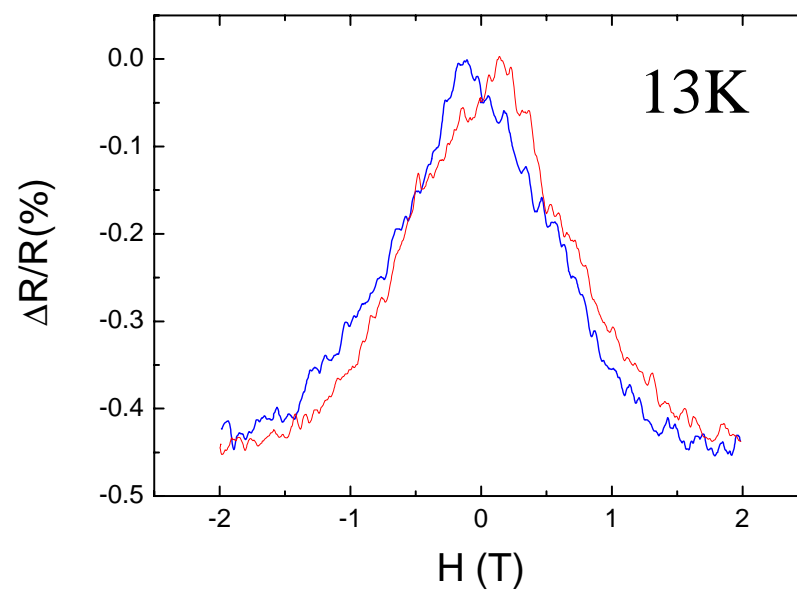
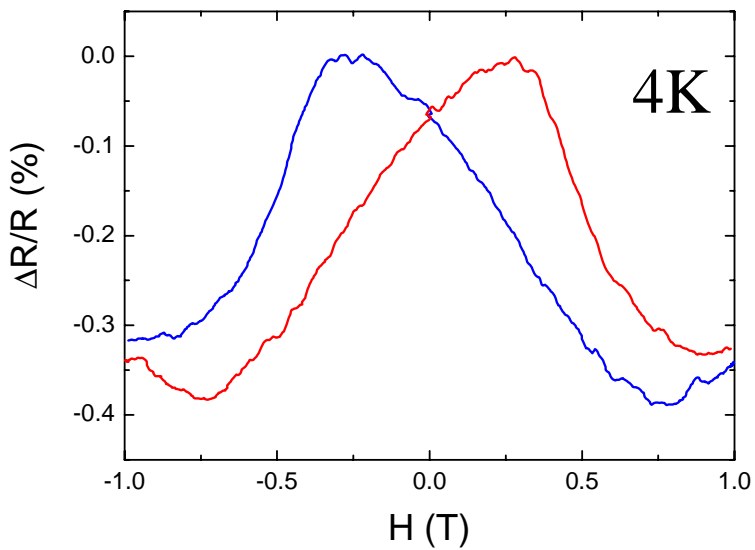
$$k_B T > KV$$



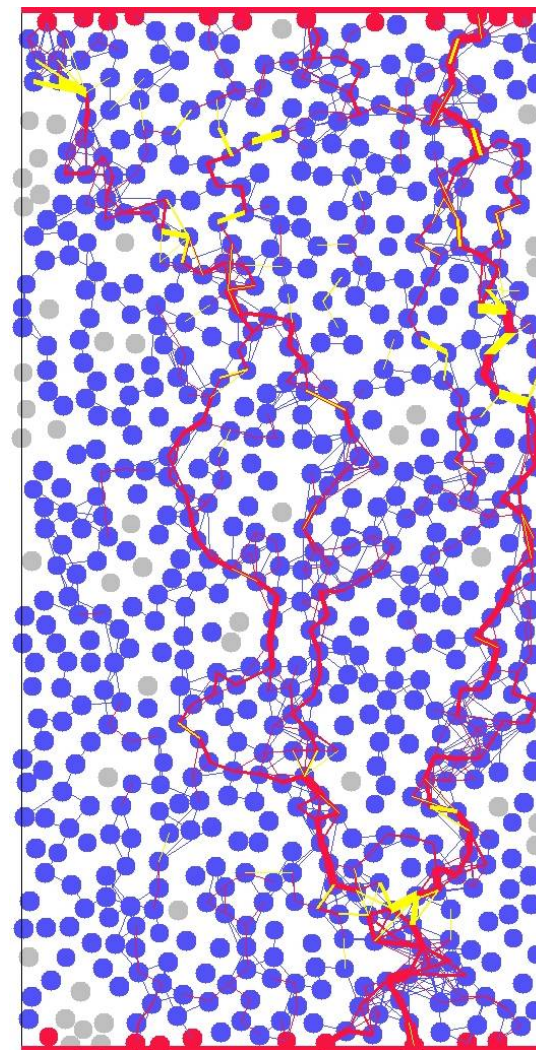
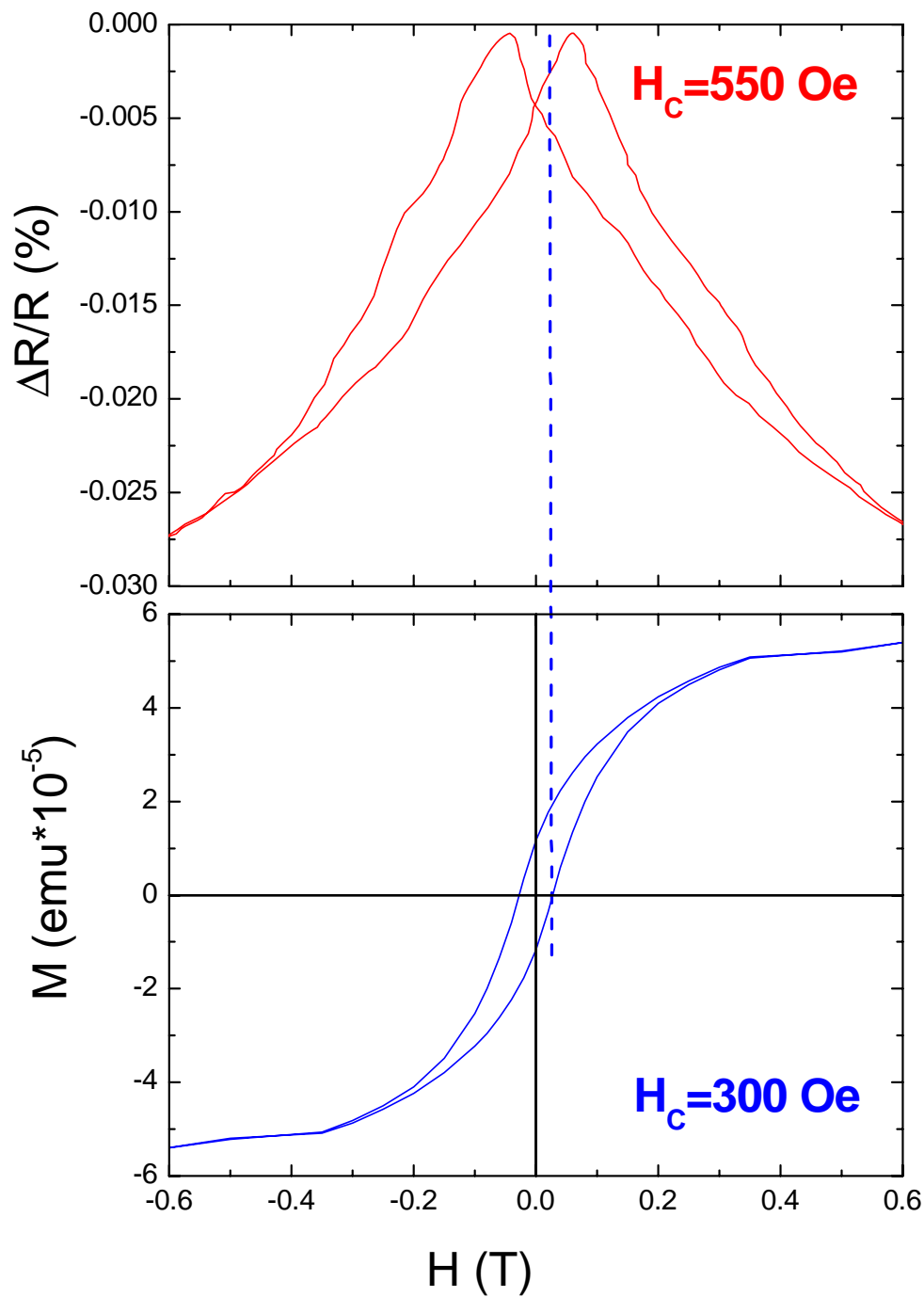
$$T_B = \frac{KV}{C \cdot k_B}$$

$$\tau \propto \exp\left(\frac{KV}{k_B T}\right)$$

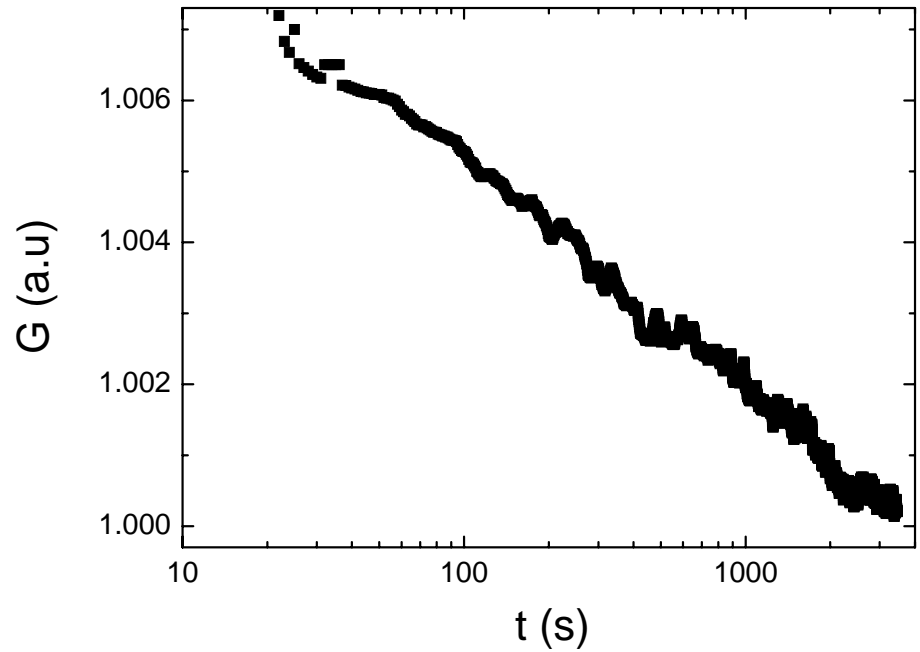
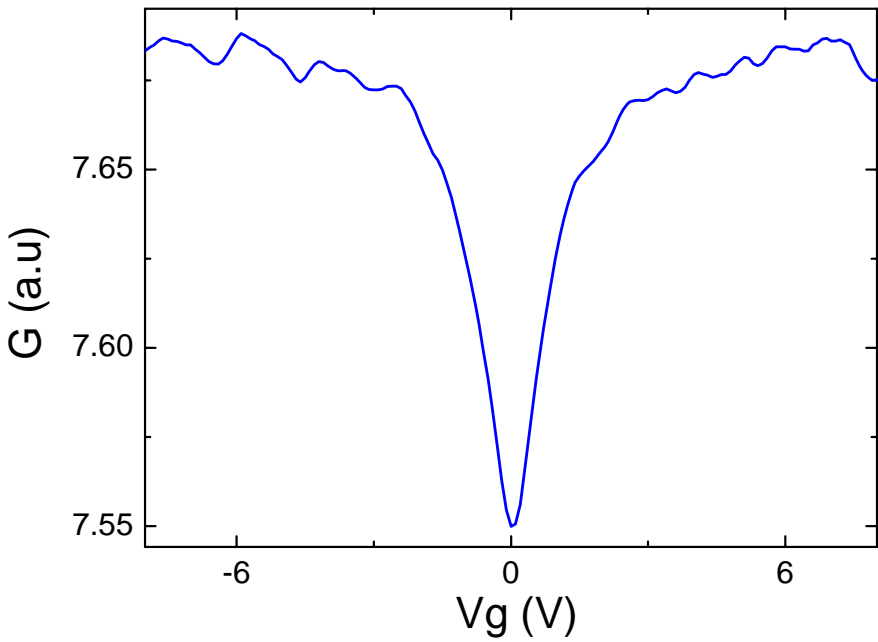
# Temperature dependence



**$T_B \approx 22K$**

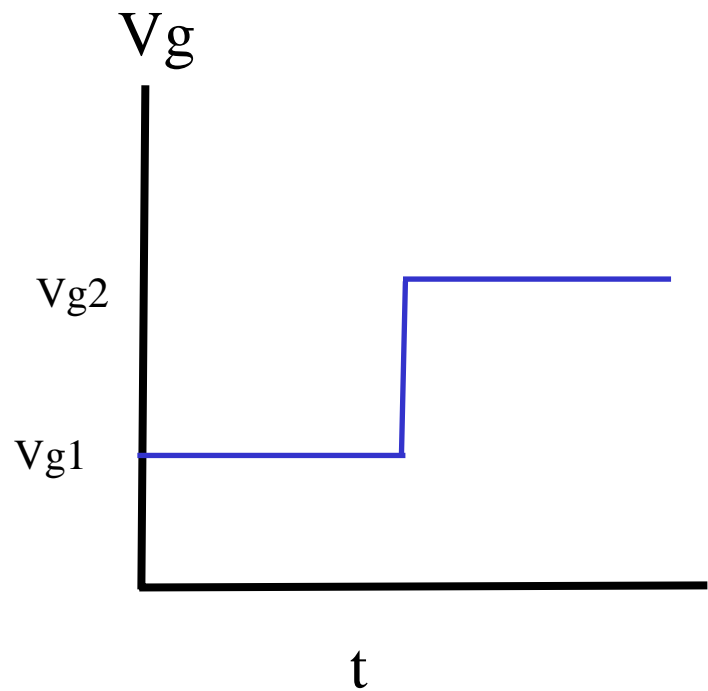


# Glassy behavior

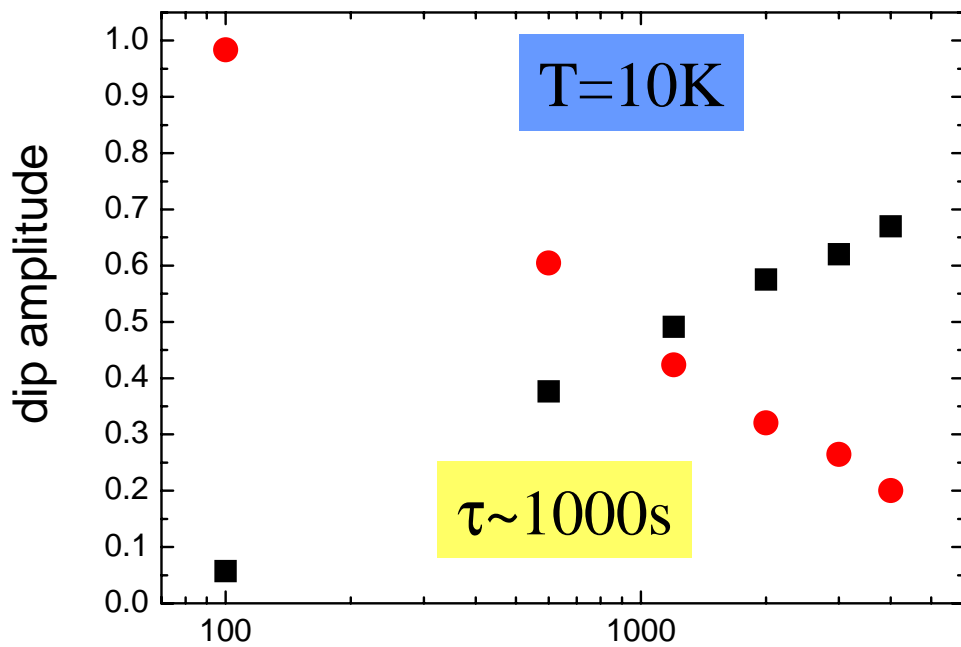
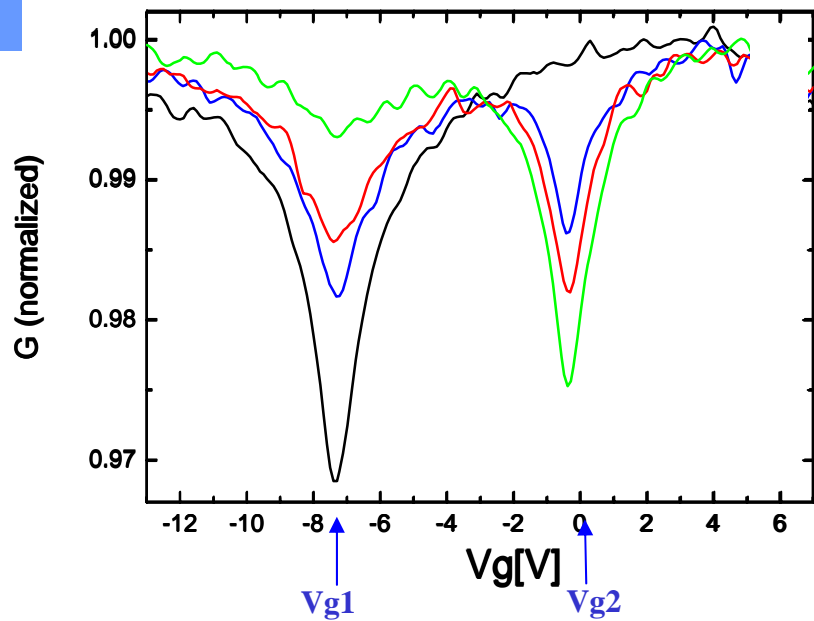


$\tau?$





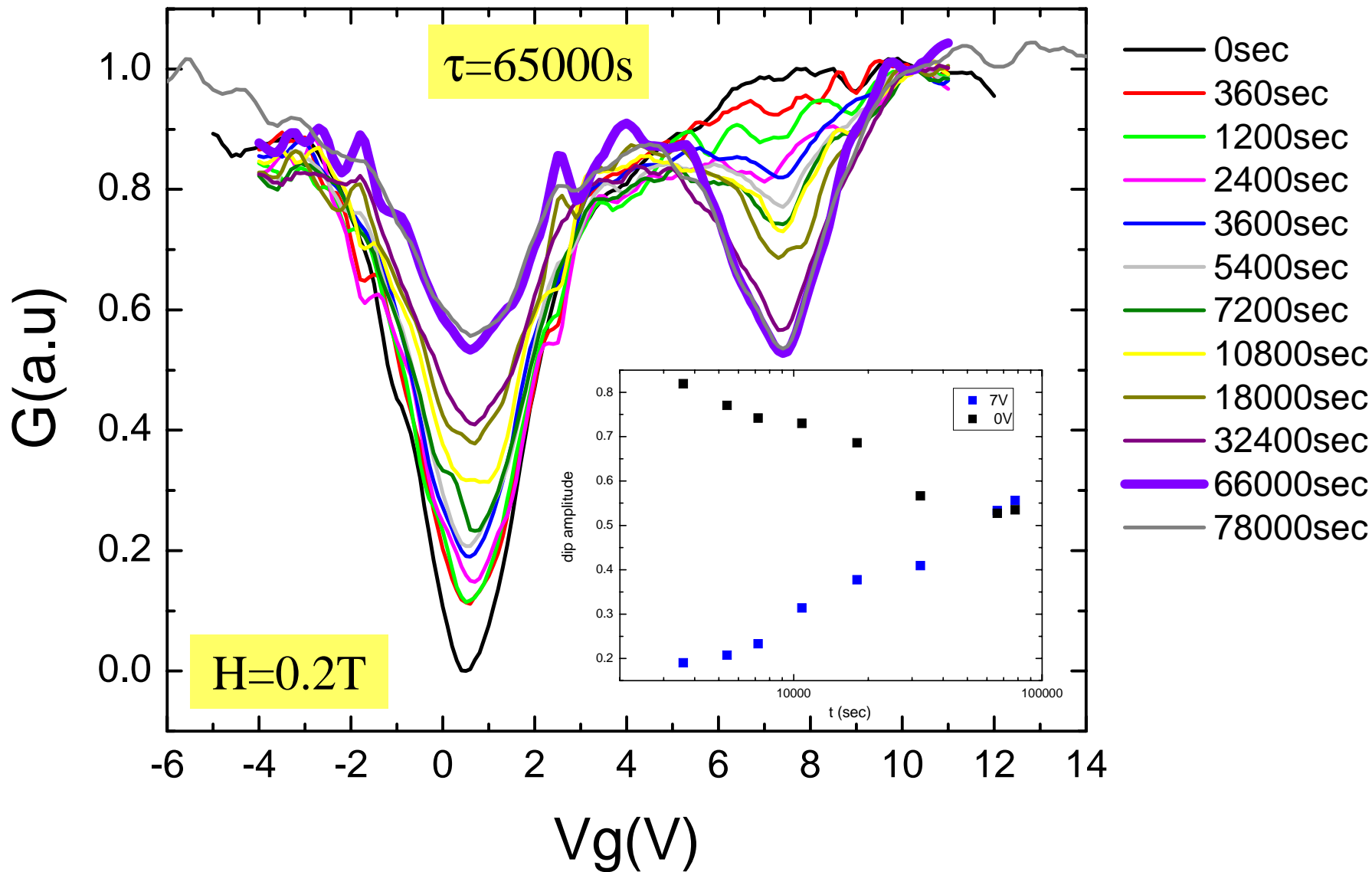
$\tau_{2\_dip}$



**T=4K**

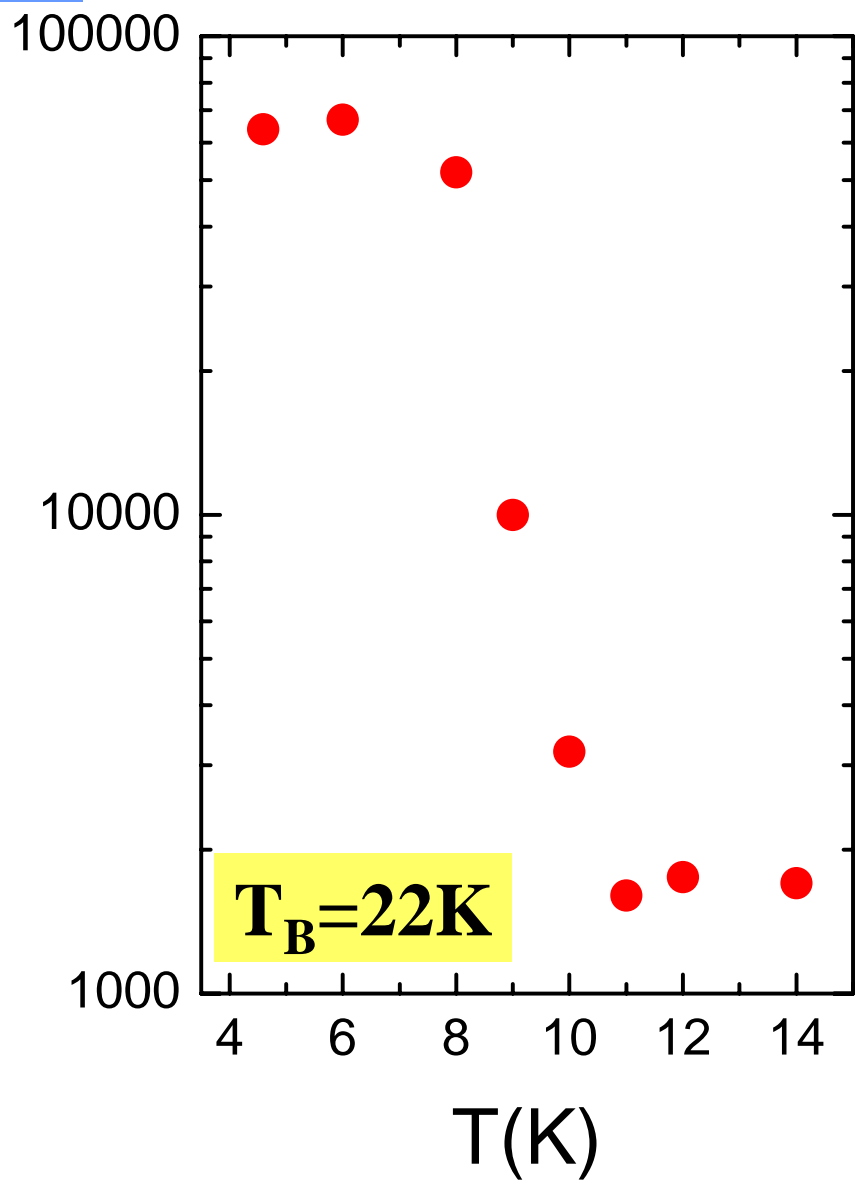
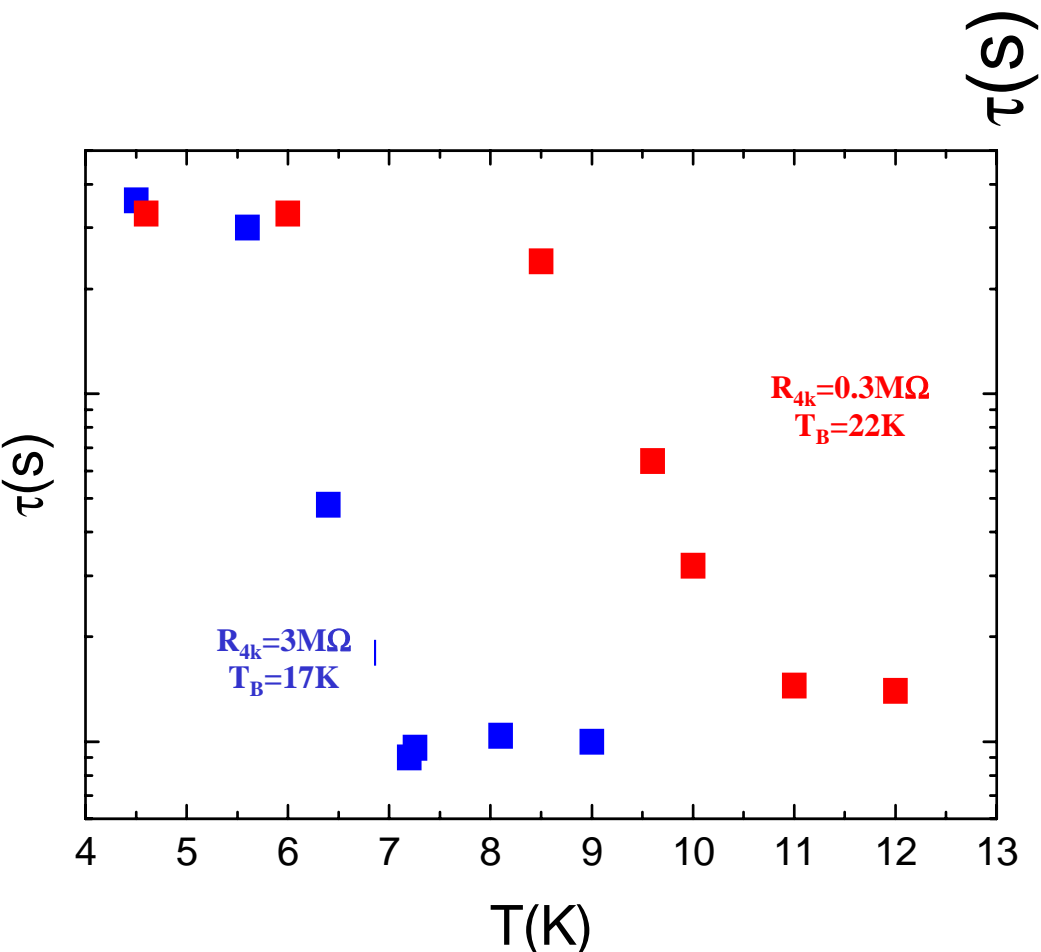
$\tau=65000\text{s}$

**H=0.2T**



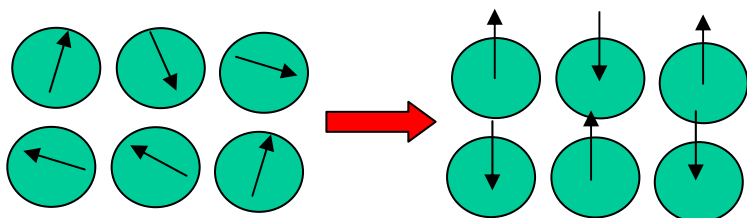
# Temperature dependence

SP-FM in relatively small grains

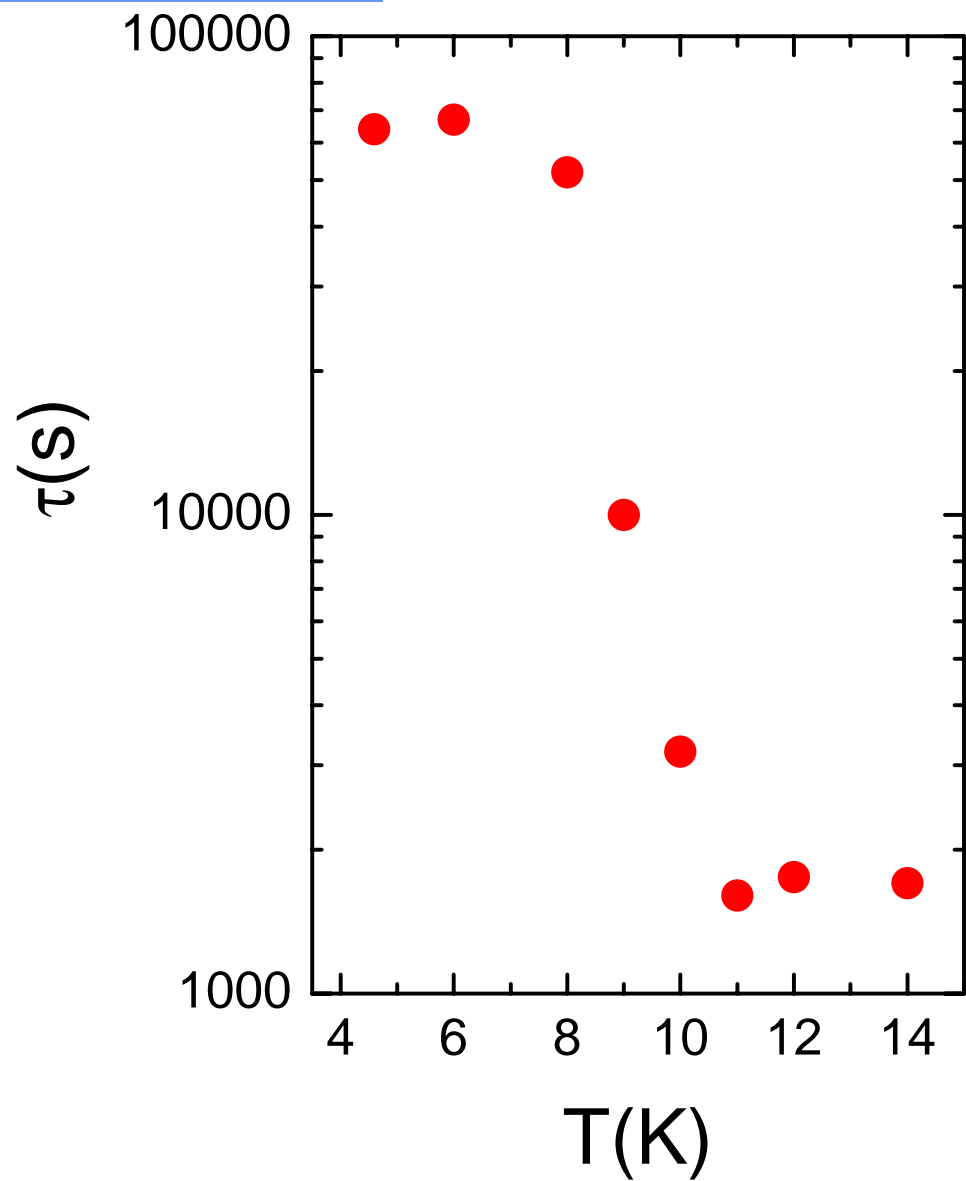


# Temperature dependence

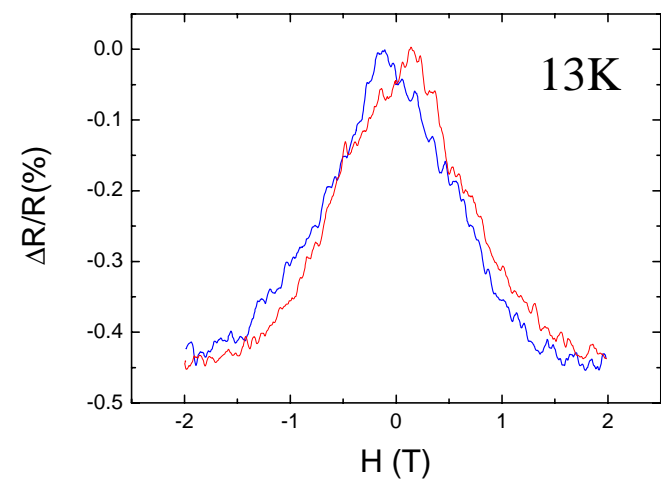
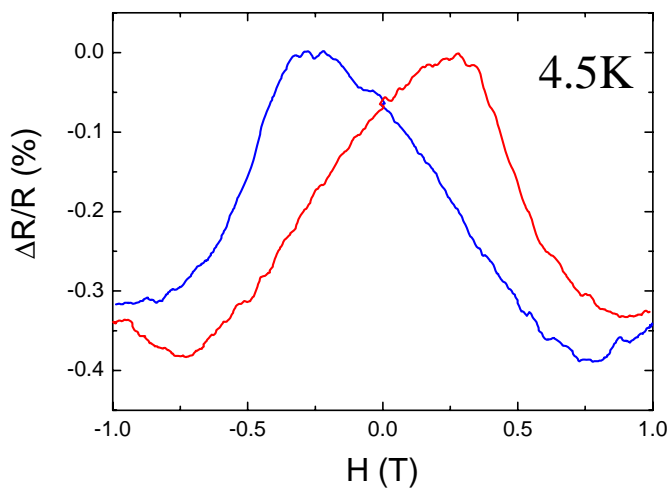
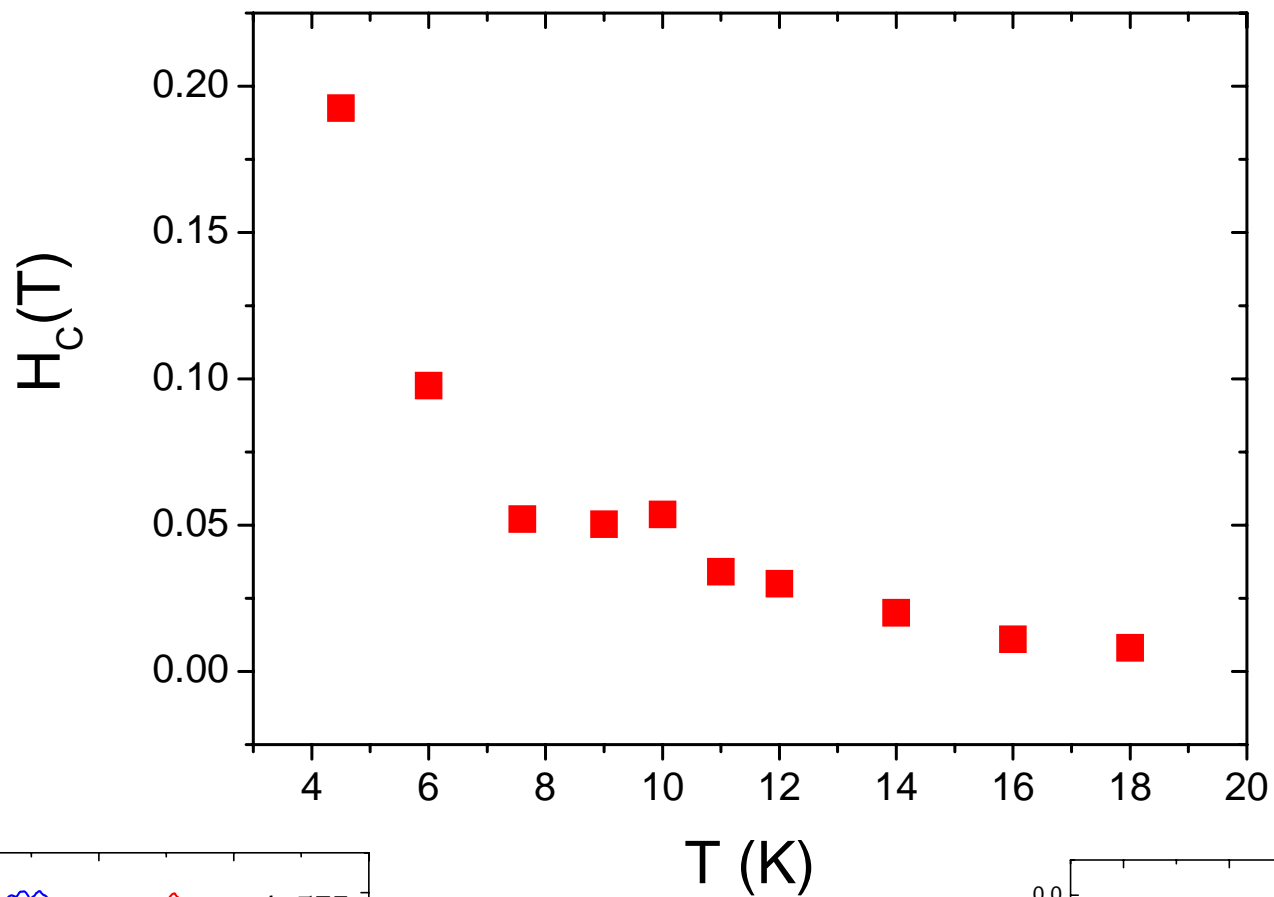
Inter-grain interactions



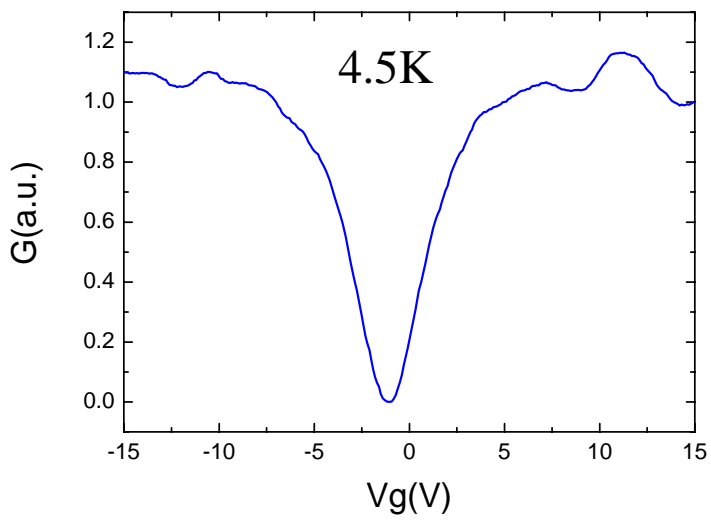
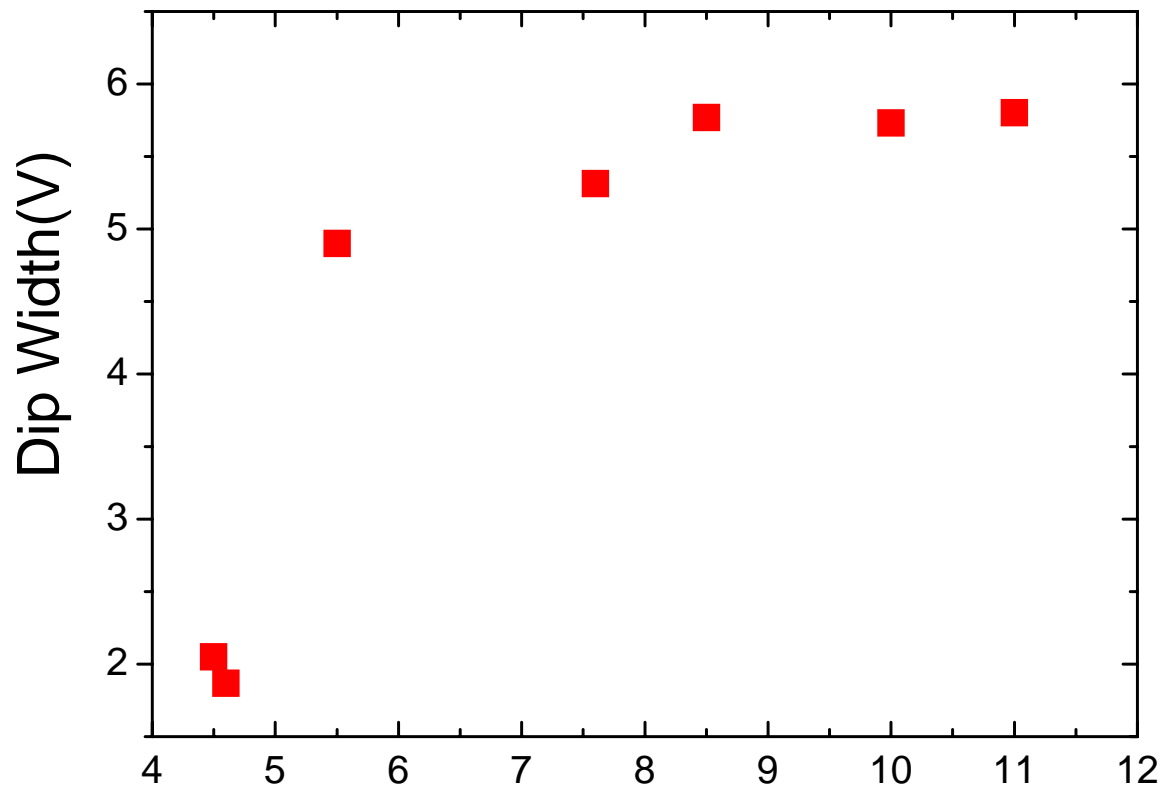
$$\frac{\mu_i \bullet \mu_j}{r_{ij}^3} \approx 10K$$



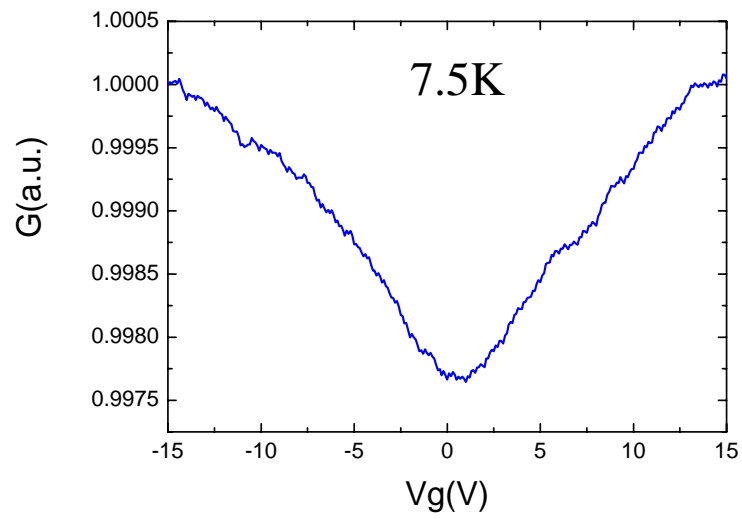
# Hysteresis vrs T



# Dip width vrs T

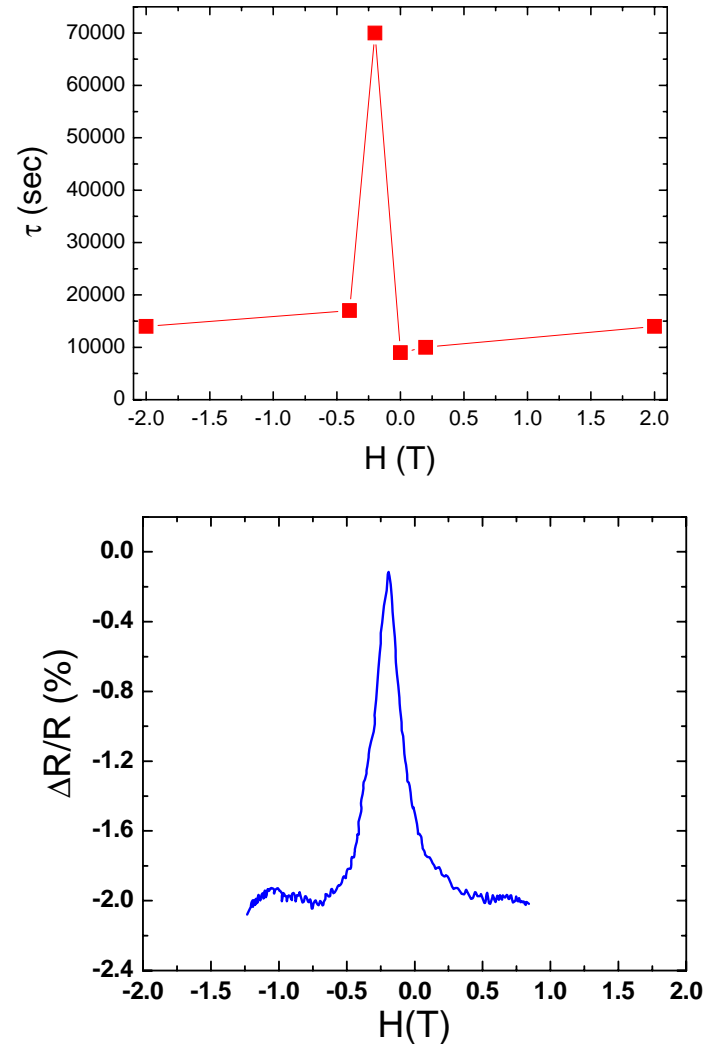


T (K)

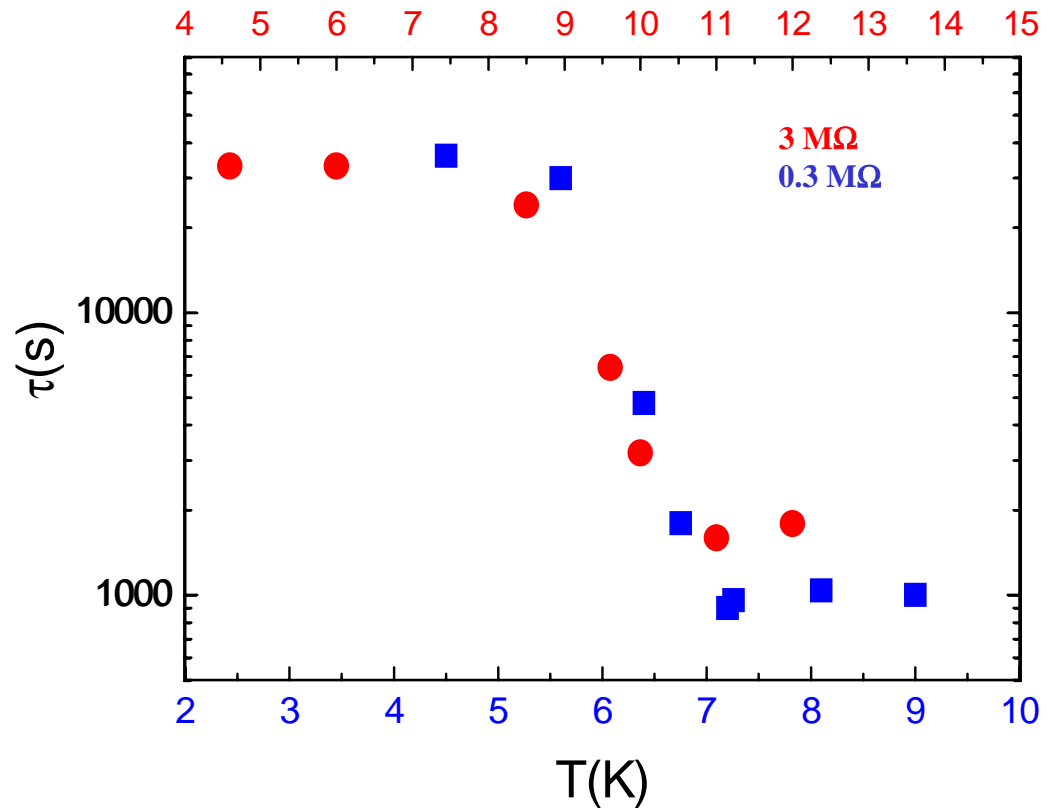


- Apply H=0
- Heat to 25k for 2 hours
- Cool down to 4.2k
- Establish memory dip (base line)
- Apply magnetic field
- 2 dip experiment

## $\tau$ vrs H



## Disorder



# Summary

- Granular Ni shows slow relaxation and memory effects
- Very sharp increase of relaxation time upon cooling below  $\sim 10\text{k}$   
(Characteristic temperature lower than  $T_B$ )
- $\tau(H)$  mimics the  $R(H)$  but amplitudes are orders of magnitude larger
- Magnet ordering seems to have a small effect on conductivity  
but huge effect on relaxation