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Fast relaxation experiments in molecular magnets

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Fast Relaxation Experiments in Molecular Magnets

(SAW & Magnetic Avalanches)

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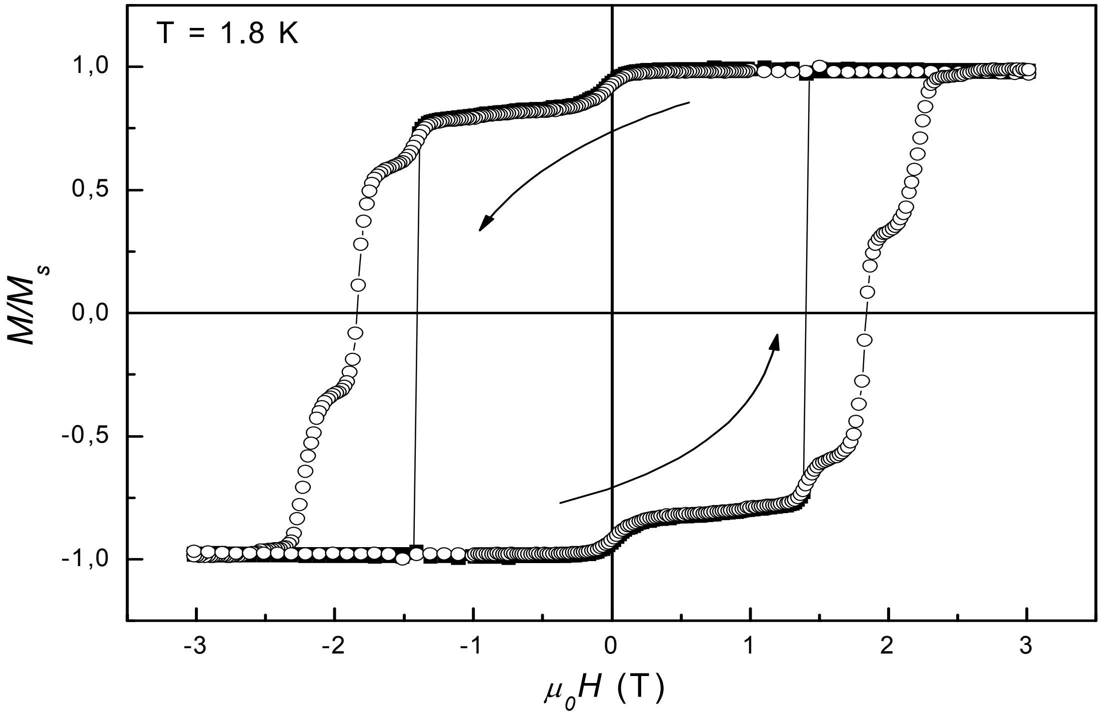
What are magnetic avalanches?

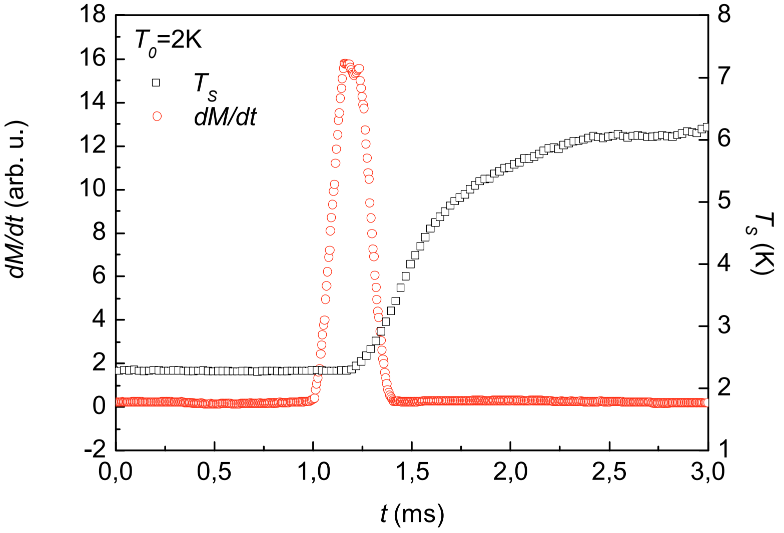
A magnetic avalanche is an abrupt reversal of the magnetic moment

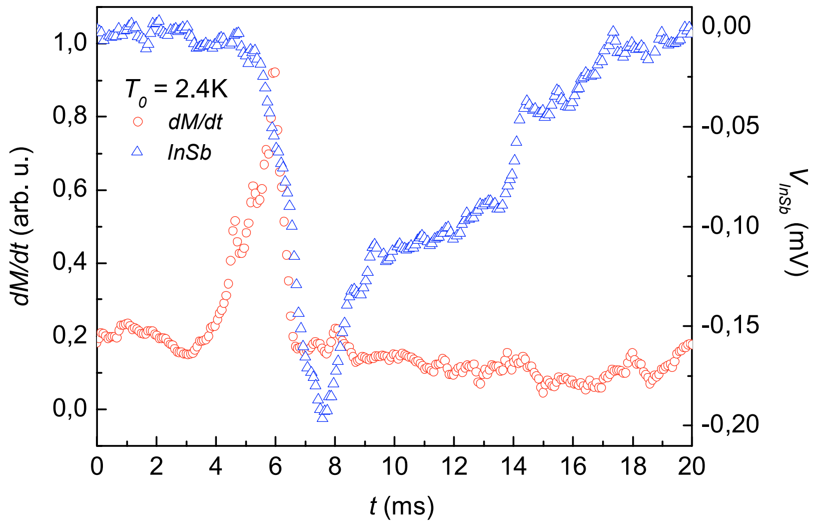


Why are we interested in magnetic avalanches?

They present some interesting features:

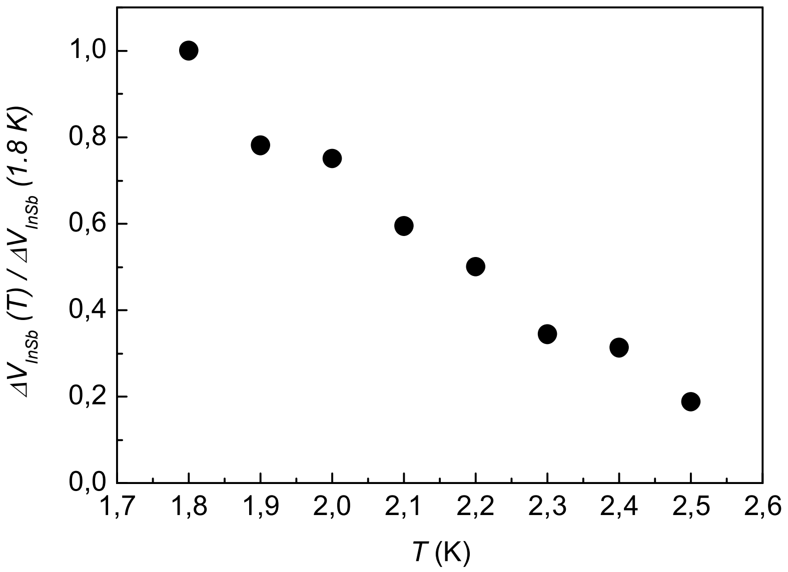
1. Magnetic moment is reversed in ~1 ms
2. Maximum temperature occurs after the reversal of the magnetization
3. Electromagnetic signal associated with avalanches has been detected

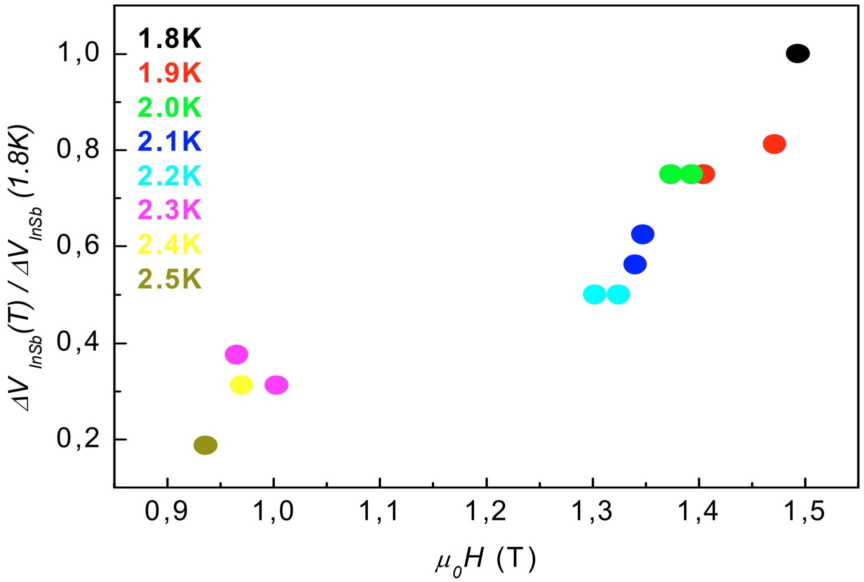




Electromagnetic signal associated with avalanches

This electromagnetic signal depends on both the temperature of the sample and the external magnetic field.





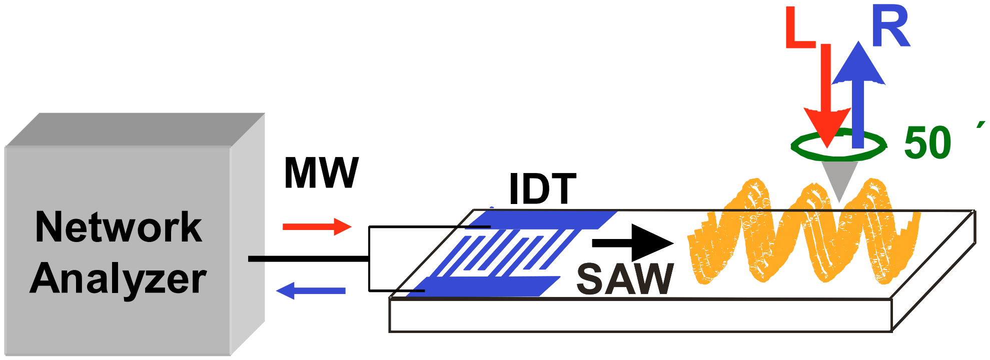
What are SAW?

Surface acoustic waves (SAW) are low frequency acoustic phonons with a linear energy versus wave vector dispersion, whose eigenmodes are described by elasticity theory

The elastic vibrations in the piezoelectric materials can be classified according their particle displacement pattern as longitudinal (LA) and transverse (TA) accoustic modes.

SAW generation and detection

The SAW are generated by microwaves using interdigital transducers (IDT) deposited on the surface of the piezoelectric to excite the acoustic mode.



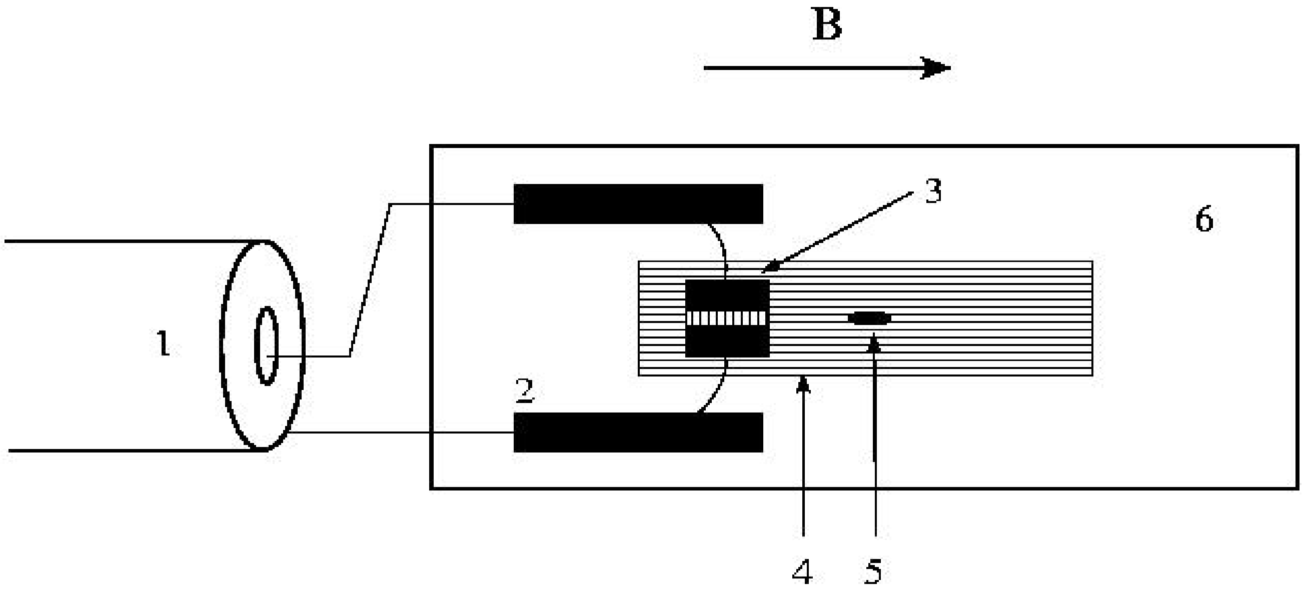
They can be detected by different methods:

- Interferometric measurements
- Reflectivity measurements.....

....we propose a new method: magnetic measurements

Magnetic detection of SAW: Experimental set up

The coaxial cable is connected to a HP microwave signal generator



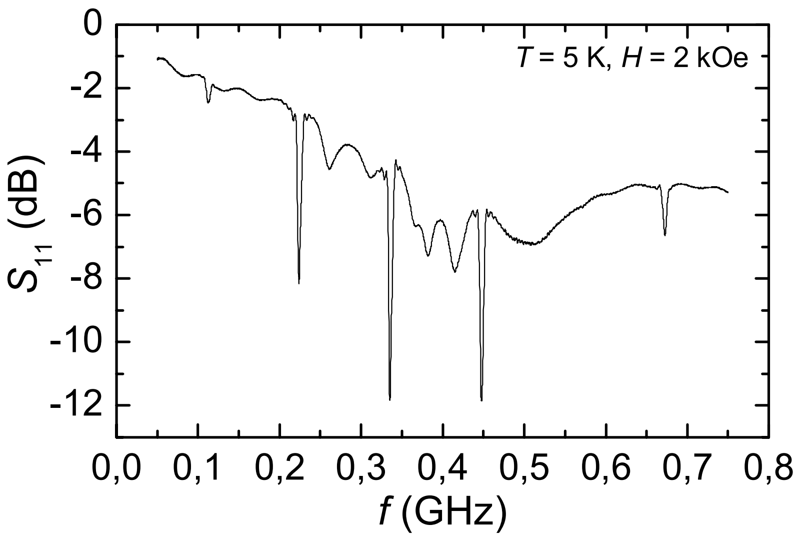
1. Coaxial cable
2. Conducting stripes
3. IDT
4. piezoelectric ($LiNbO_3$)
5. Mn12-Acetate
6. support

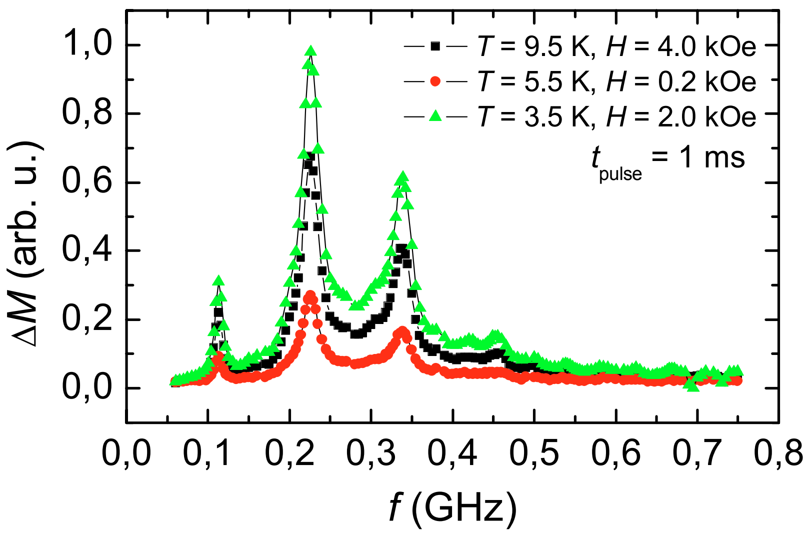
Magnetic detection of SAW: Results

Figure 1: reflectivity of the experimental assembly

Figure 2: variation of the magnetization versus
frequency of the Mn_{12}.

The peaks in the reflexion coefficient
match with the maximun
in the magnetic measurement!!!





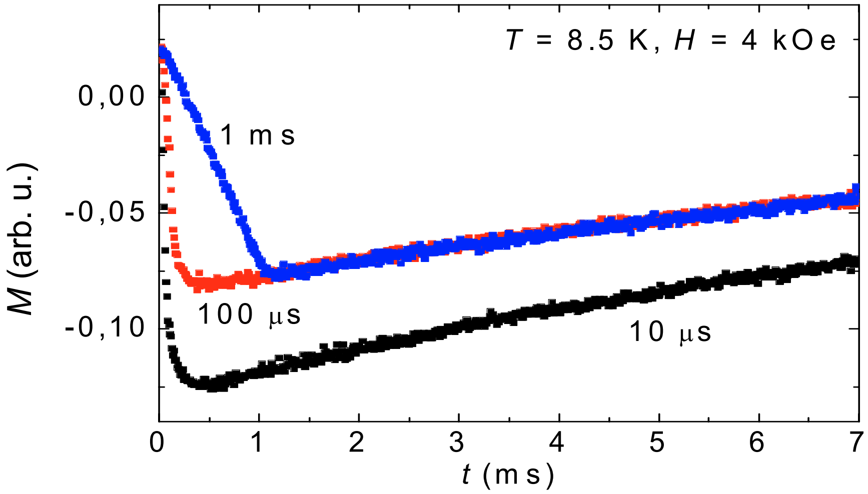
Time evolution of the magnetization

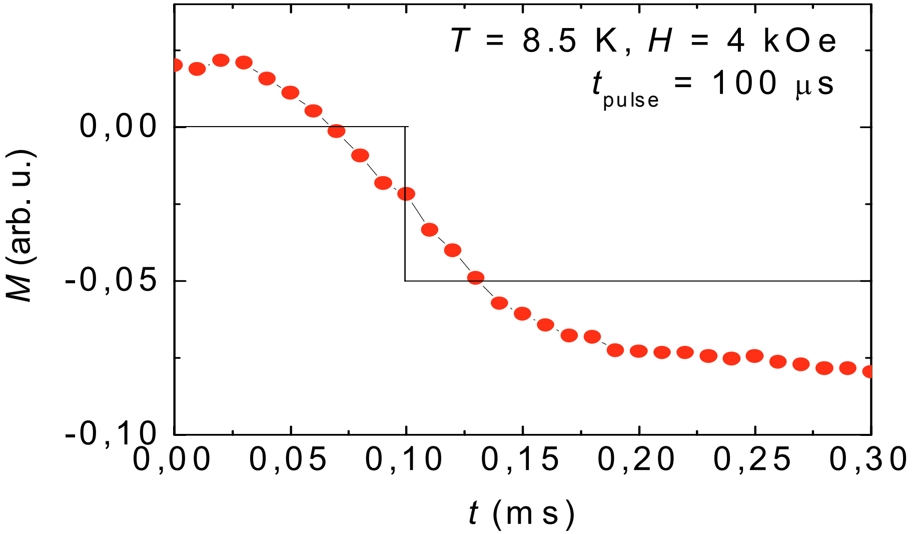
- The time needed by the Mn_{12} sample to recover its equilibrium state is neither depending on the width of the pulse (Fig 1) nor on the final temperature (forward figs)

- From this time we estimate the thermal diffusivity

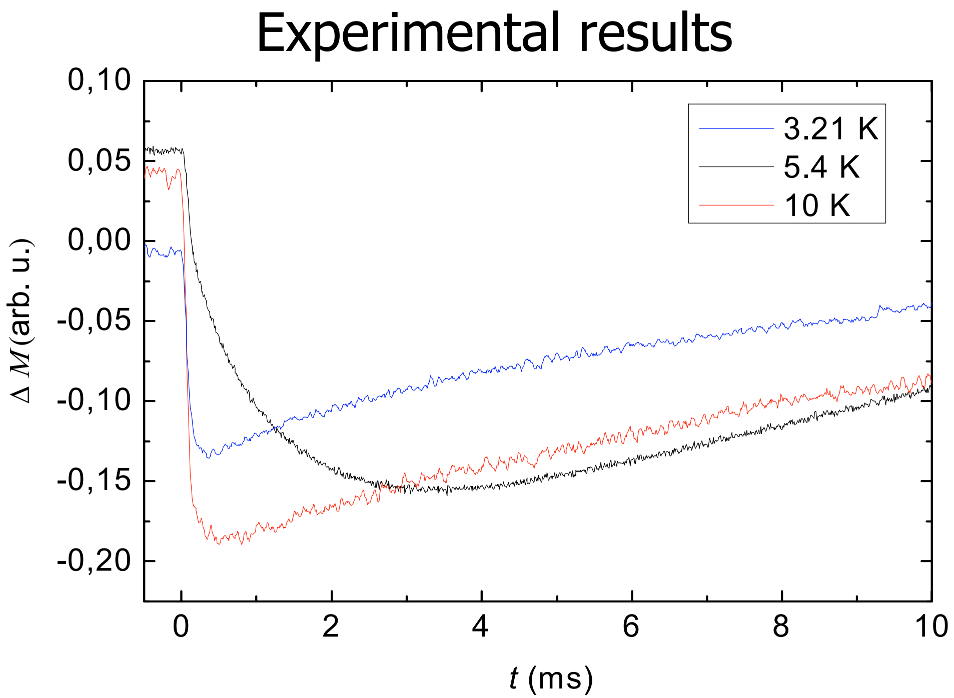
$$\kappa = \frac{l^2}{t} = \frac{1mm \times 1mm}{20ms} = 5 \cdot 10^{-5} m^2 / s$$

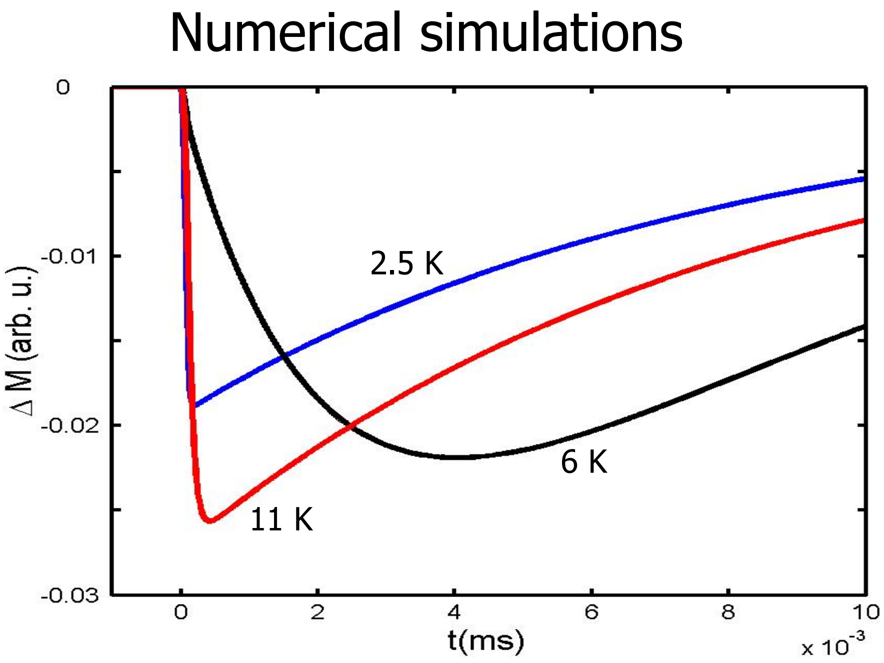
- The analisis of the shape of magnetization short pulses may be indicative of the lifetime of the SAWs.





Time evolution of the magnetization

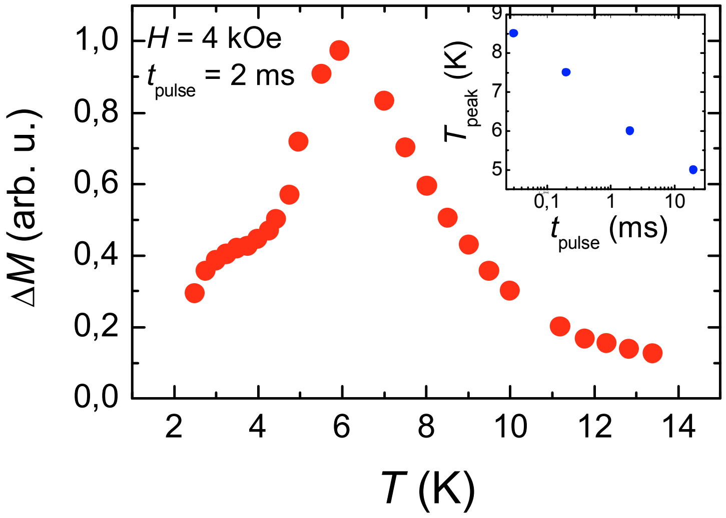




- At low temperatures the magnetization is blocked and the time variation of magnetization corresponds to only the Boltzmann population of the two wells.
- At hight temperatures the magnetization is unblocked and the variation of magnetization corresponds to superparamagnetic transitions between the two wells.
- At temperaures near the blocking, the time variation of magnetization is governed by the slow spin transitions between two wells.

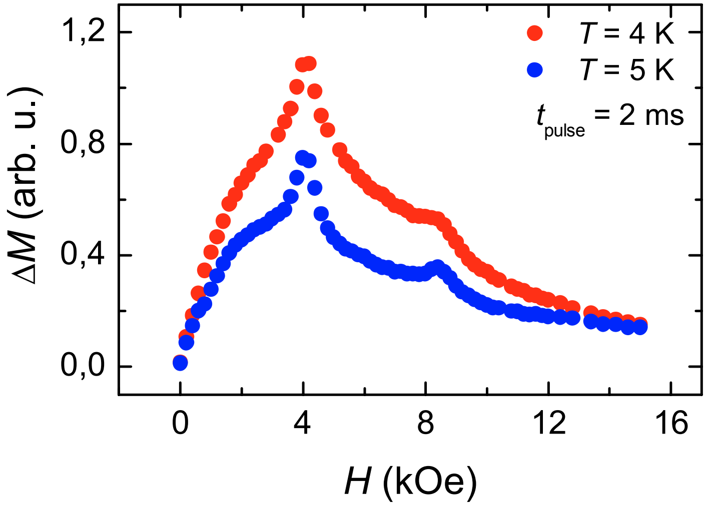
Magnetization versus T & magnetic field

- In Fig 1 we see the variation of magnetization as a function of temperature for pulses of 2 ms.
- The inset corresponds to the dependence on the pulse durations for the blocking temperature.



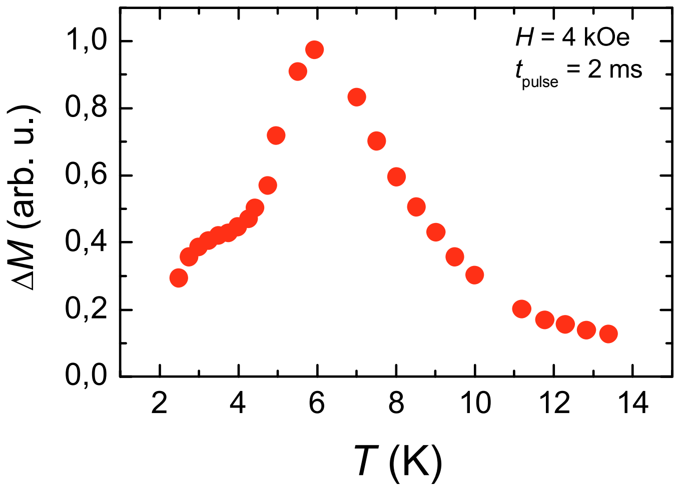
$$t(H,T) = \tau_0 \exp\left[\frac{U(H)}{k_B T}\right]$$

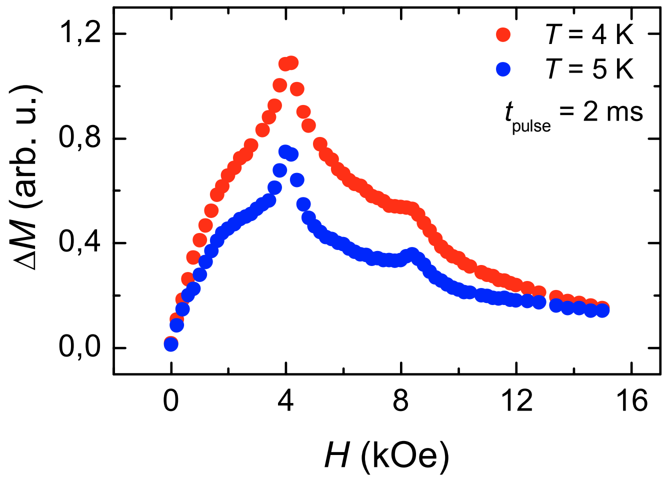
- Fig 2 shows the variation of magnetization as a function of the applied magnetic field.
- The first and second resonance can be clearly seen.



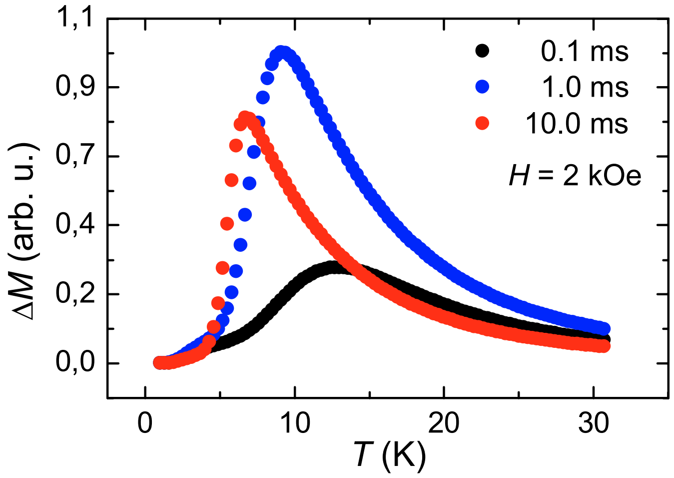
Magnetization versus T & magnetic field

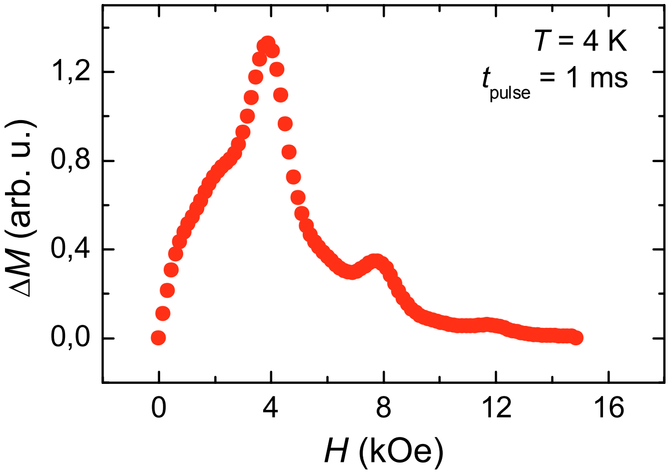
Experimental results





Numerical simulations



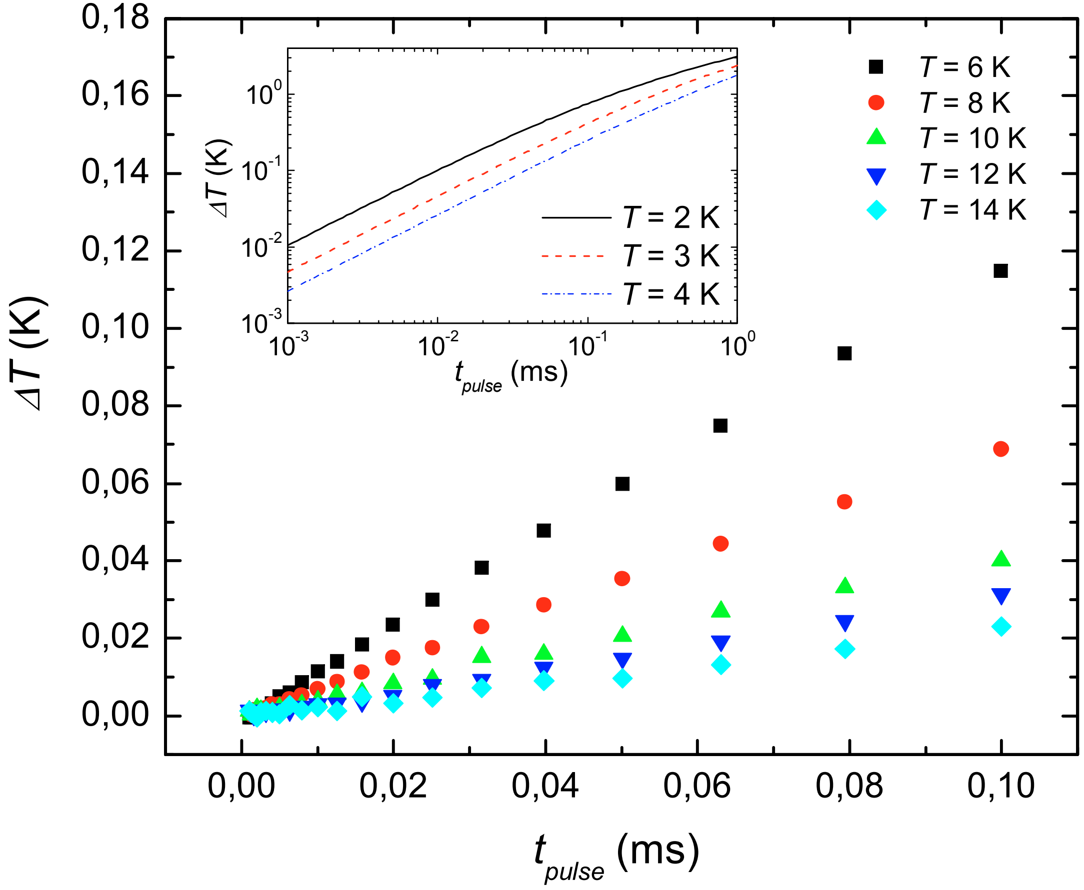


Energy released by the SAW

- We apply microwave pulses of constant frequency and power to the piezoelectric.
- Above T_B there is a direct relationship:

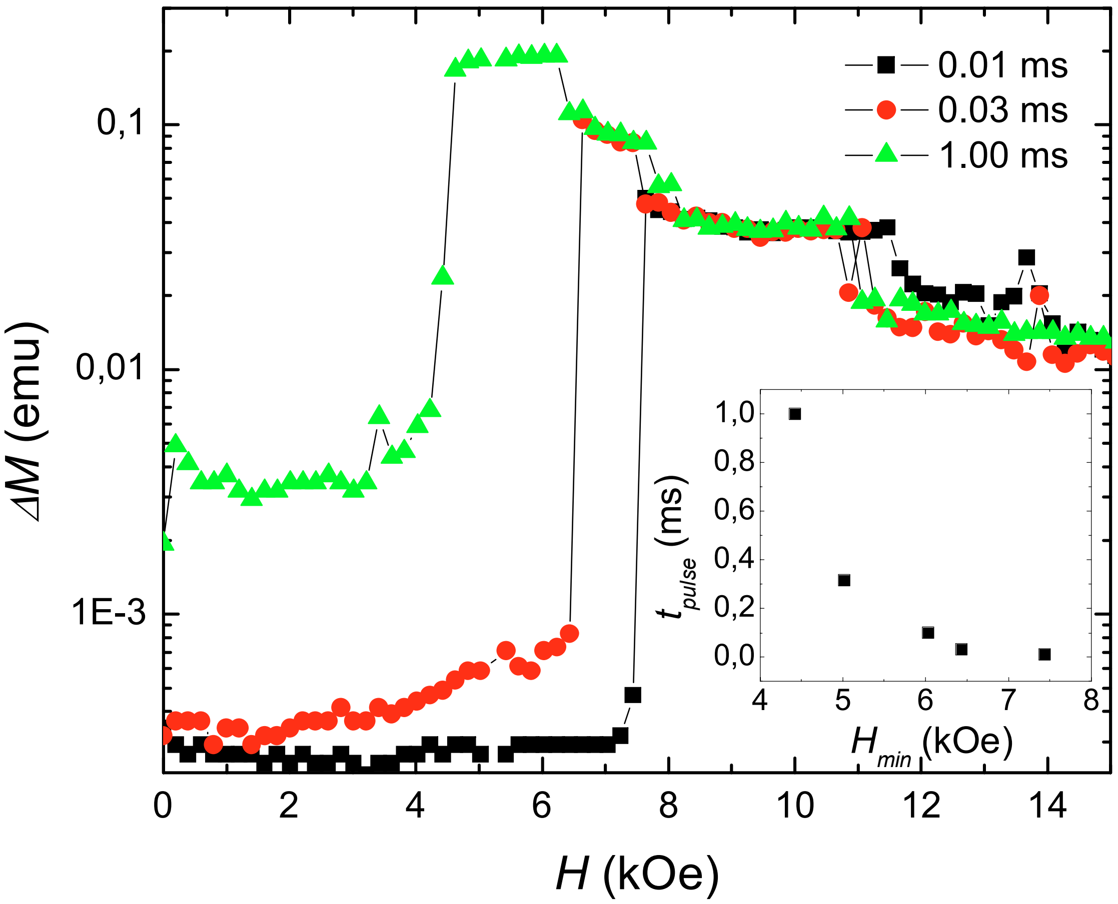
  $$\Delta T/T=\Delta M/M$$

- Measurements of ΔM allow us to know the value of ΔT only above T_B
- We estimate that in our experiments the energy aborbed by the samples is of the order of μJ



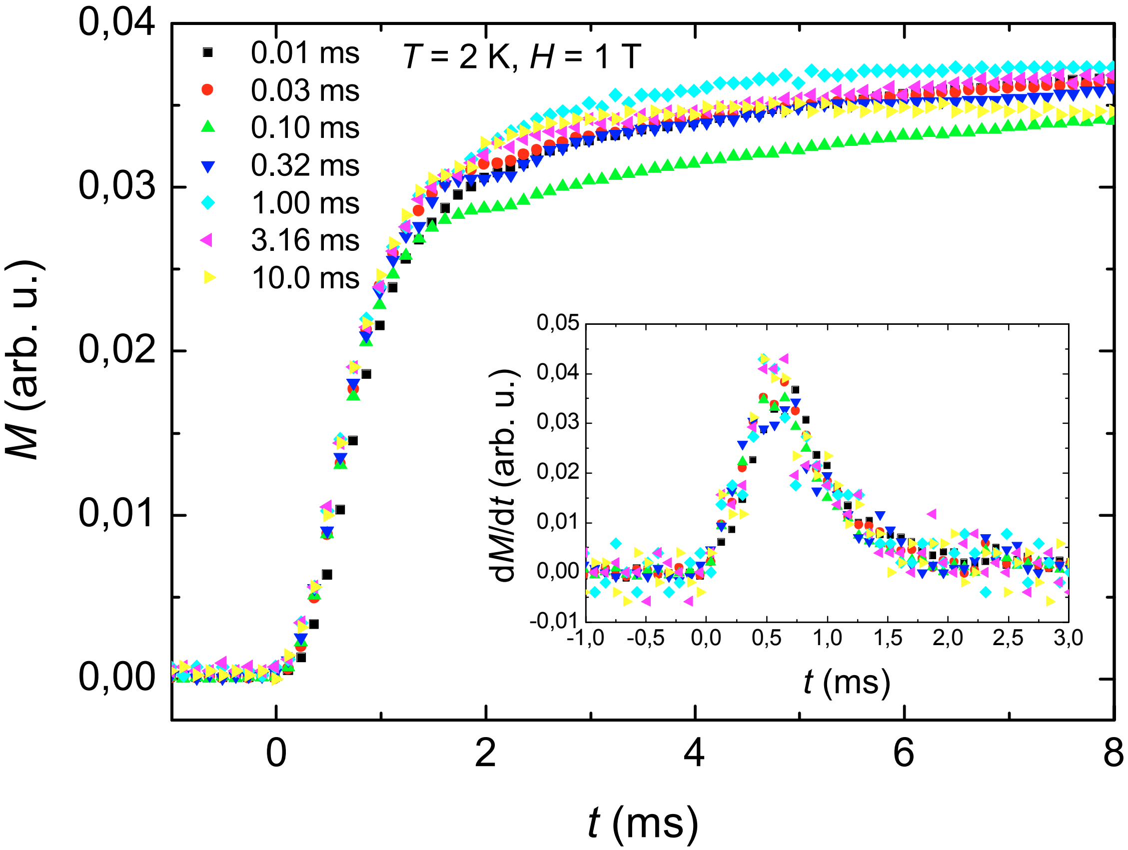
Energy threshold to produce avalanches

- 5 single crystals deposited on the surface of the piezoelectric.
- We apply pulses of constant nominal power (20 dBm) and different duration.
- For every value of the pulse there is a minimun field below which avalanches do not occur.



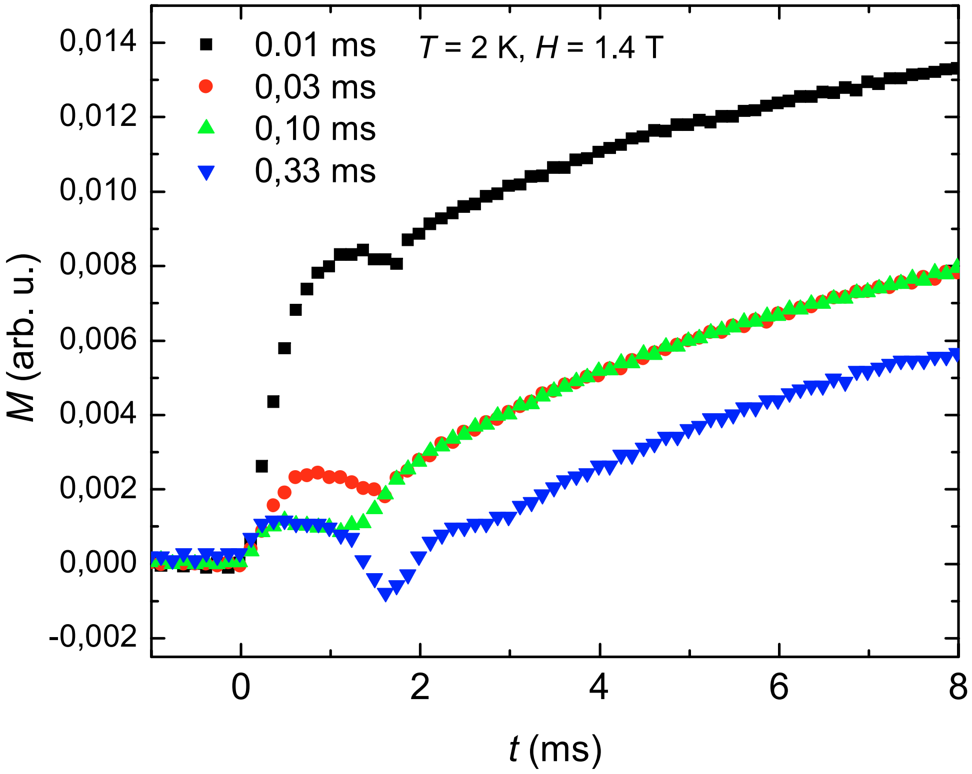
Time evolution of magnetic avalanches

- At $H > H_{th}$ the time evolution of the magnetization does not depend on the energy released by the SAW
- The duration of the magnetic avalanche is roughly 1.5 ms.



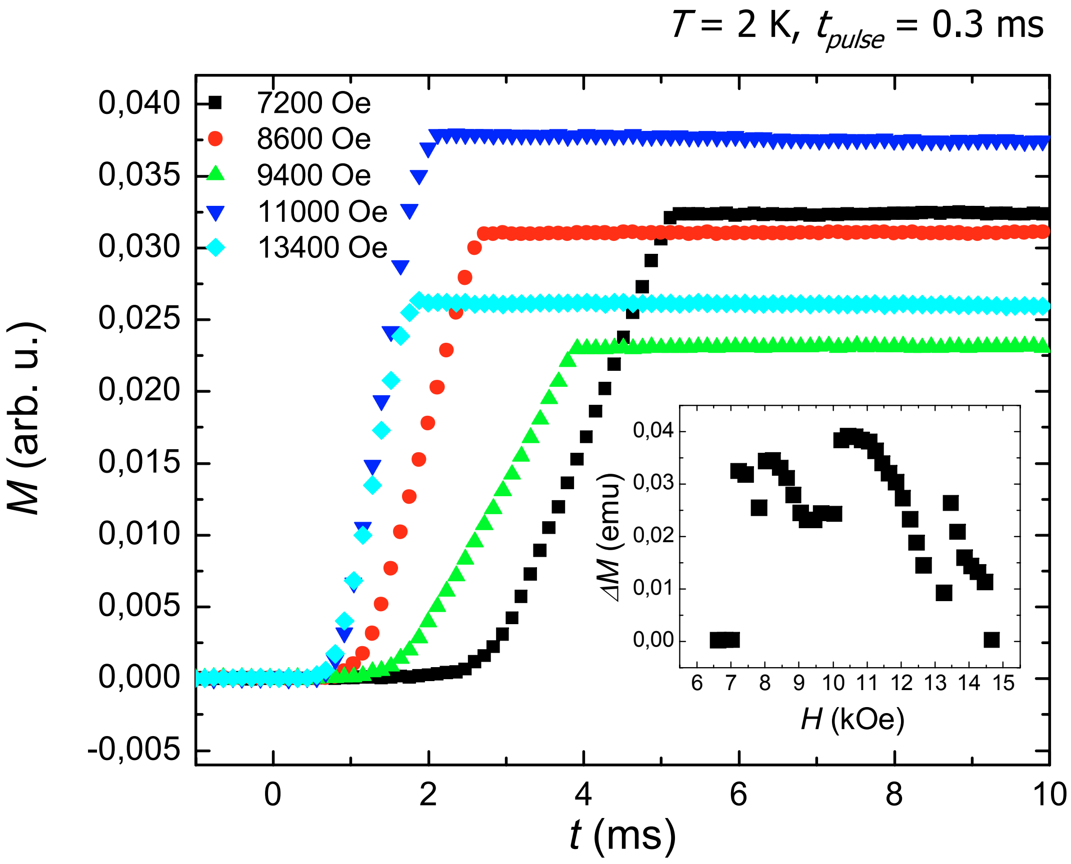
Time evolution of magnetic avalanches

- High magnetic fields: as H increases, the magnetization reversal in the sample made of 5 single crystals is slower and begins to exhibit a non-monotonous behaviour.



Magnetic avalanches in 1 single crystal

- Experiments done with 1 single crystal show a modulation in the magnitude of the avalanche versus the applied magnetic field (see inset).

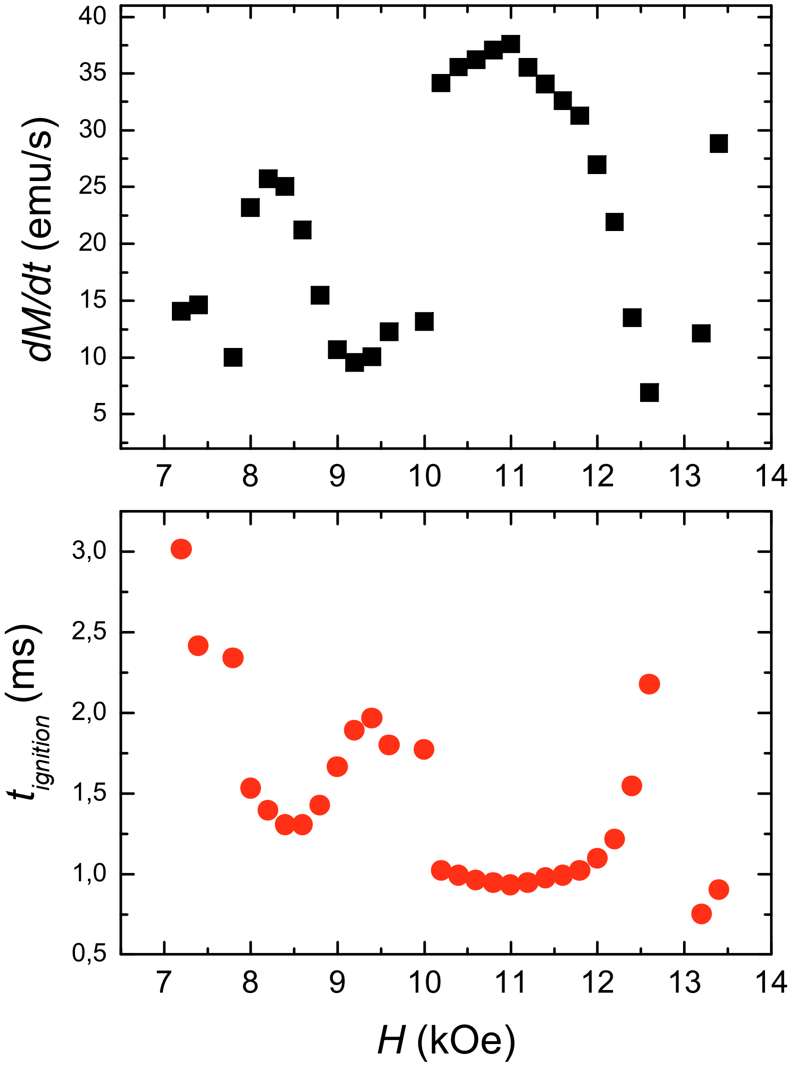


Magnetic avalanches in 1 single crystal

We observe also a modulation in:

1. The rate of change of the magnetization (upper panel)

2. The time that takes the sample to start the avalanche (lower pannel)



Conclusions

1. SAW can be efficiently detected by magnetic measurements. (frequency, lifetime and Q values)

2. By SAW we can induce magnetic avalanches.

3. Our experiments show that there is a threshold energy necessary to produce the avalanche.

4. Both the threshold energy and the ignition time depend non-monotonicaly on the applied magnetic field.