Experimental Physics of
Nanostructured Materials

Why are flux avalanches deflected by a metallic layer?

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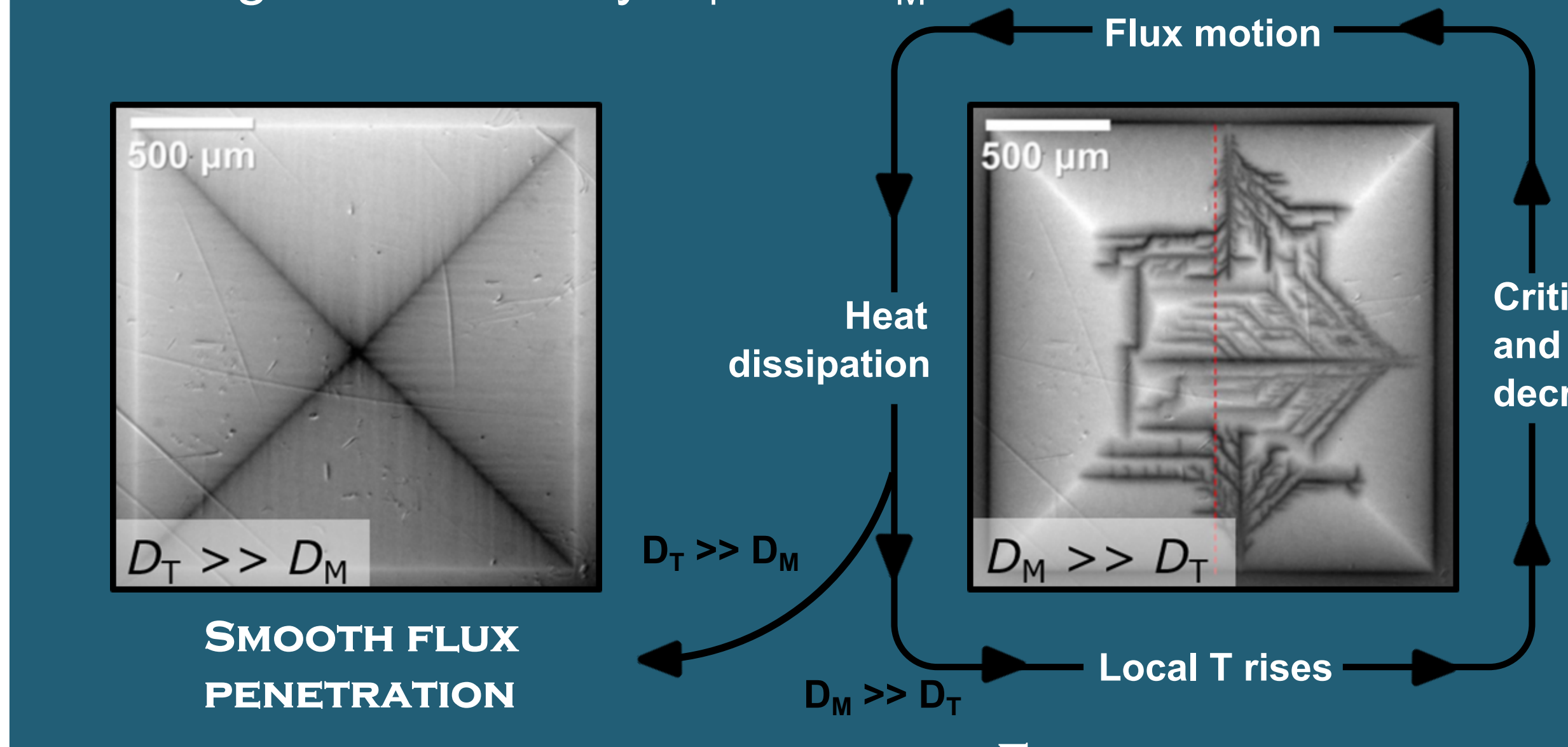
Sudden avalanches of magnetic flux bursting into a superconducting sample undergo deflections of their trajectories when encountering a conductive layer deposited on top of the superconductor. Remarkably, in some cases the flux is totally excluded from the area covered by the conductive layer. We present a simple classical model that accounts for this behaviour and considers a magnetic monopole approaching a semi-infinite conductive plane. This model suggests that electromagnetic braking is an important mechanism responsible for avalanche deflection.

What are flux avalanches? Why to avoid them?

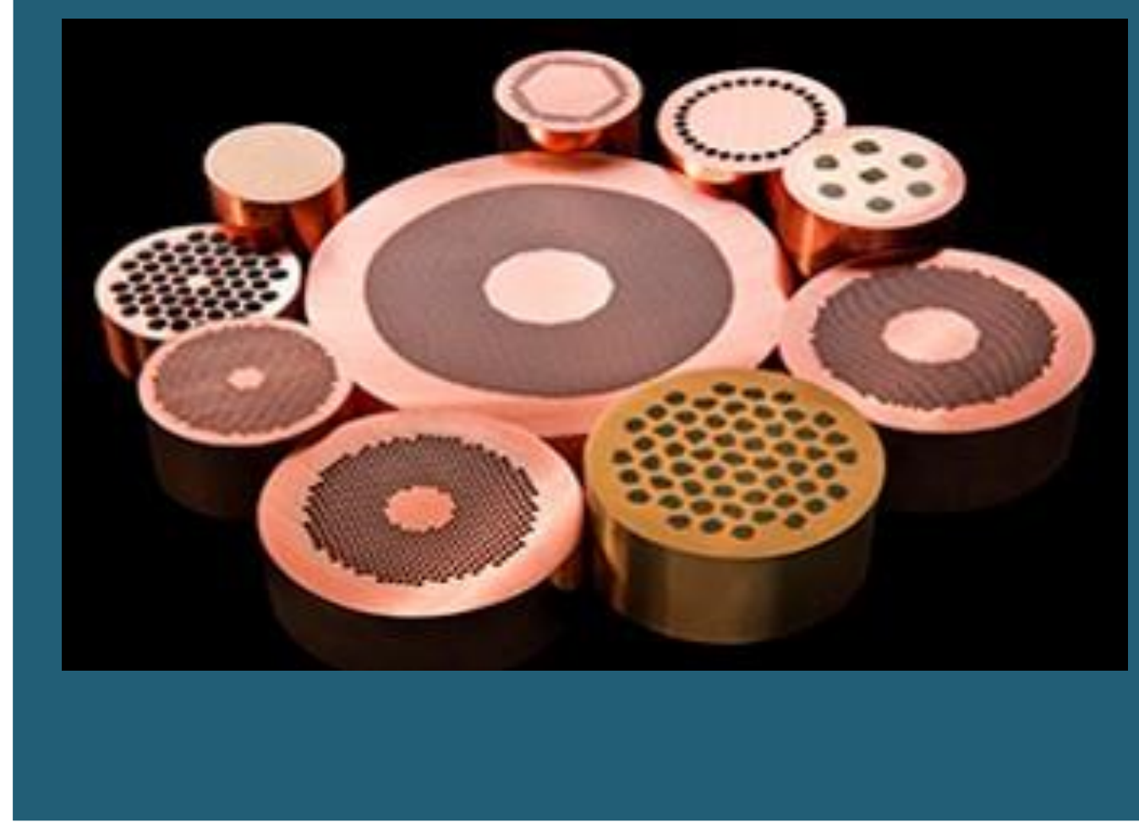
The penetration of magnetic flux in a superconducting film depends on the thermal and magnetic diffusivity D_T and D_M :



FLUX AVALANCHES

In avalanches, flux can move at velocities as high as 100 km/s and the temperature can go well over the critical temperature T_C [1].

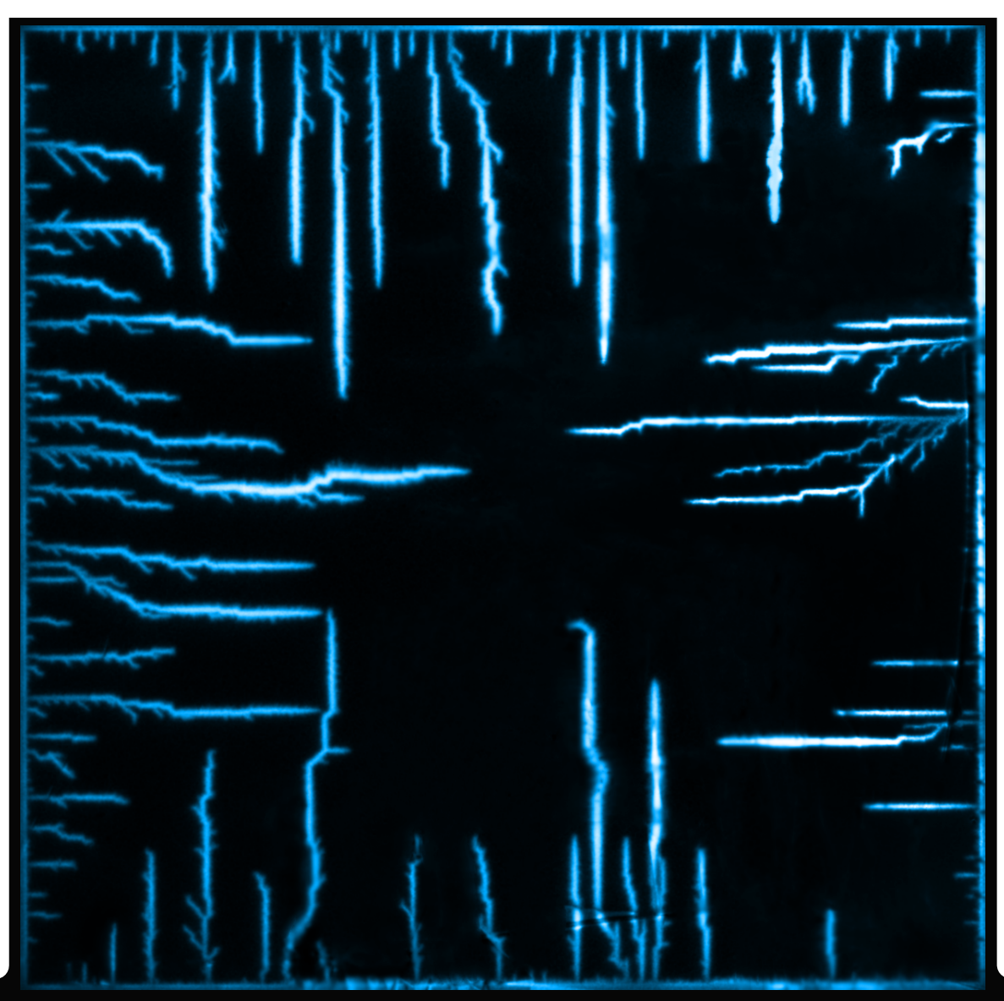
Flux avalanches destroy superconductivity and are therefore harmful to applications. Fortunately, flux avalanches can be prevented by coating the superconductor with a metallic layer.



This has been widely exploited in devices, with the following benefits [2]:

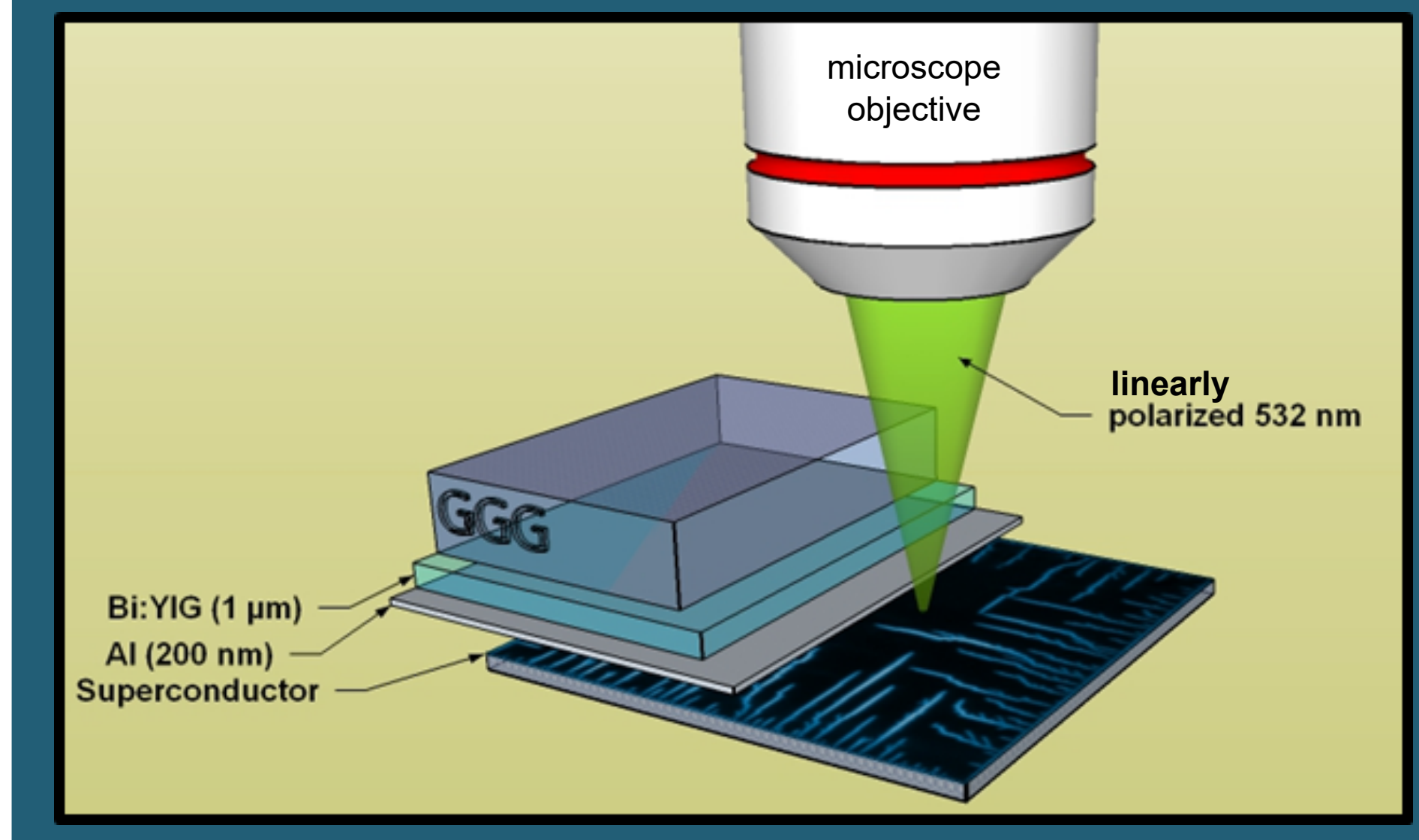
- reduce the size and speed of flux jumps (**electromagnetic braking**)
- increase the thermal conductivity (**heat removal**)
- provide protection against quenching

Flux avalanches in a 200 nm-thick Nb film (2 mm x 2 mm) at 2.5 K in a 10 Oe perpendicular field [7]. The sample was cooled before the field was applied.



Observe avalanches: Magneto-optical imaging

Magneto-optical imaging (MOI) is a technique that allows *in situ* visualisation of the magnetic field distribution [3]. It works as follows:



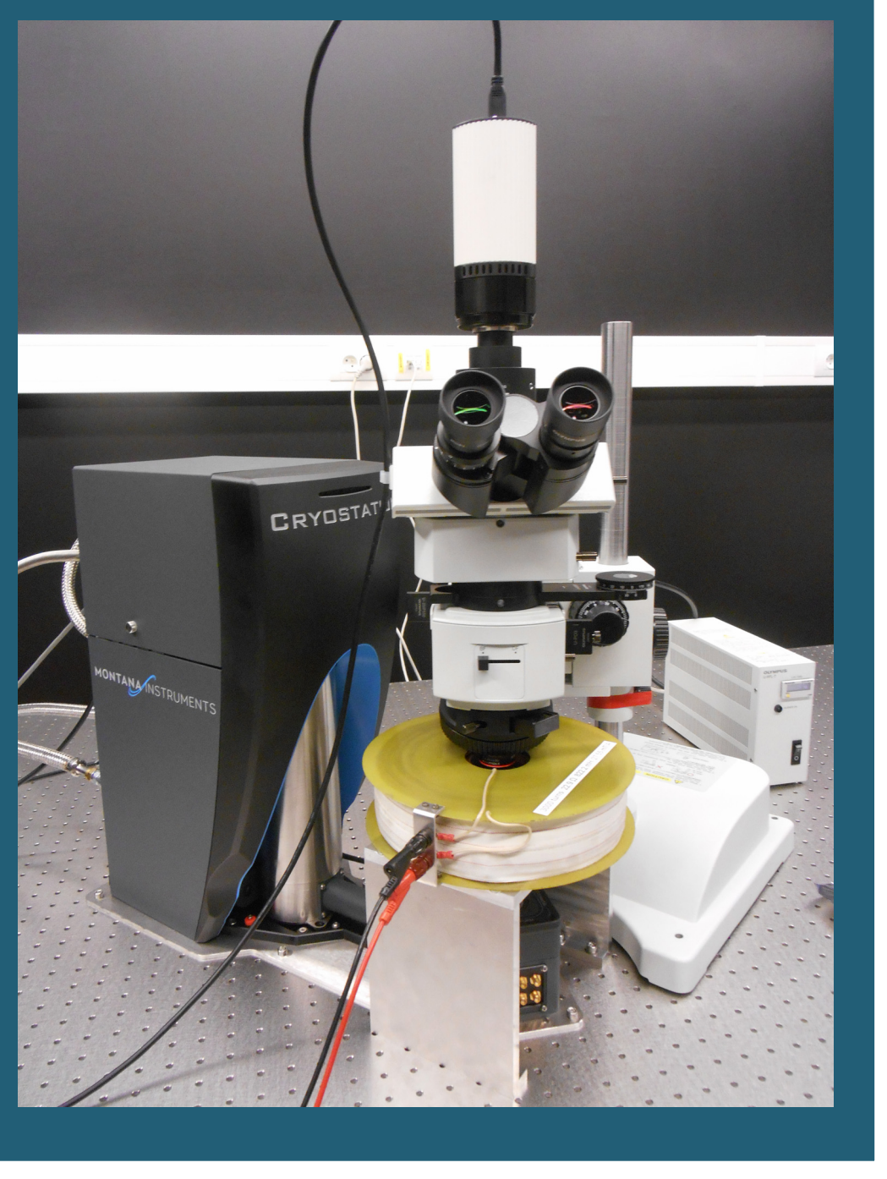
1. **The polarization of light is rotated proportionally to the local magnetic field** in the Bi:YiG (**Faraday effect**).
2. Light is reflected by the Al mirror and send back to the objective.
3. The beam crosses an analyzer oriented at 90° with respect to the polarizer.

In first approximation, each pixel intensity *I* is thus proportional to the local magnetic field H:

$$I \propto 2VdH$$

V is the Verdet constant, depending on the indicator, and *d* is the thickness of the Bi:YIG layer.

MOI gives real time images of the magnetic field at the surface of the sample.

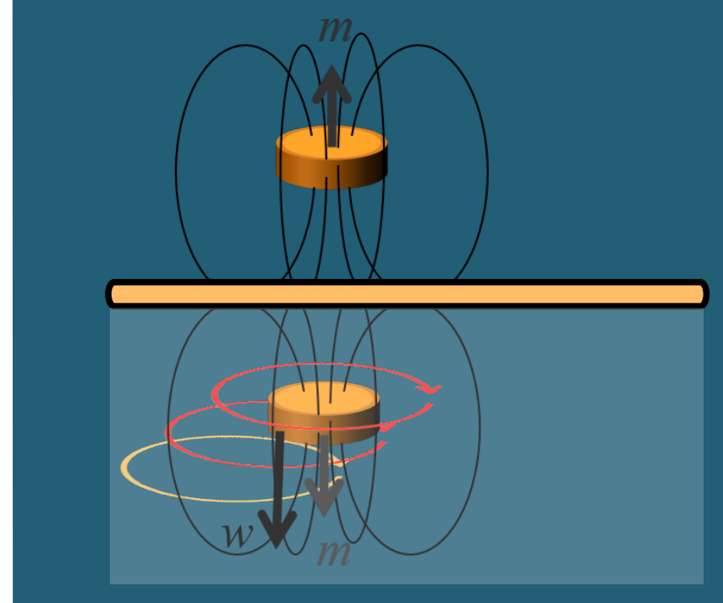


Example of a setup using a He closed-cycle cryostat and a home-made coil to apply a magnetic field.

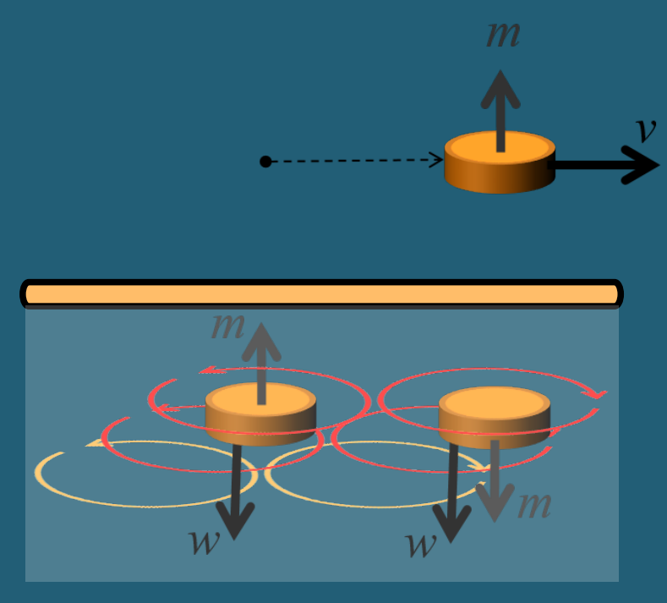
Electromagnetic braking

Electromagnetic braking comes from **eddy currents** induced in the metal.
It can be explained in terms of **Maxwell's images method**: currents are described by receding image magnets [4,5].

Assumptions:
- Avalanche front = single vortex (**magnetic monopole**)
- Constant distance z_0 from an infinite conducting plate
- Overdamped medium (**constant driving force**)



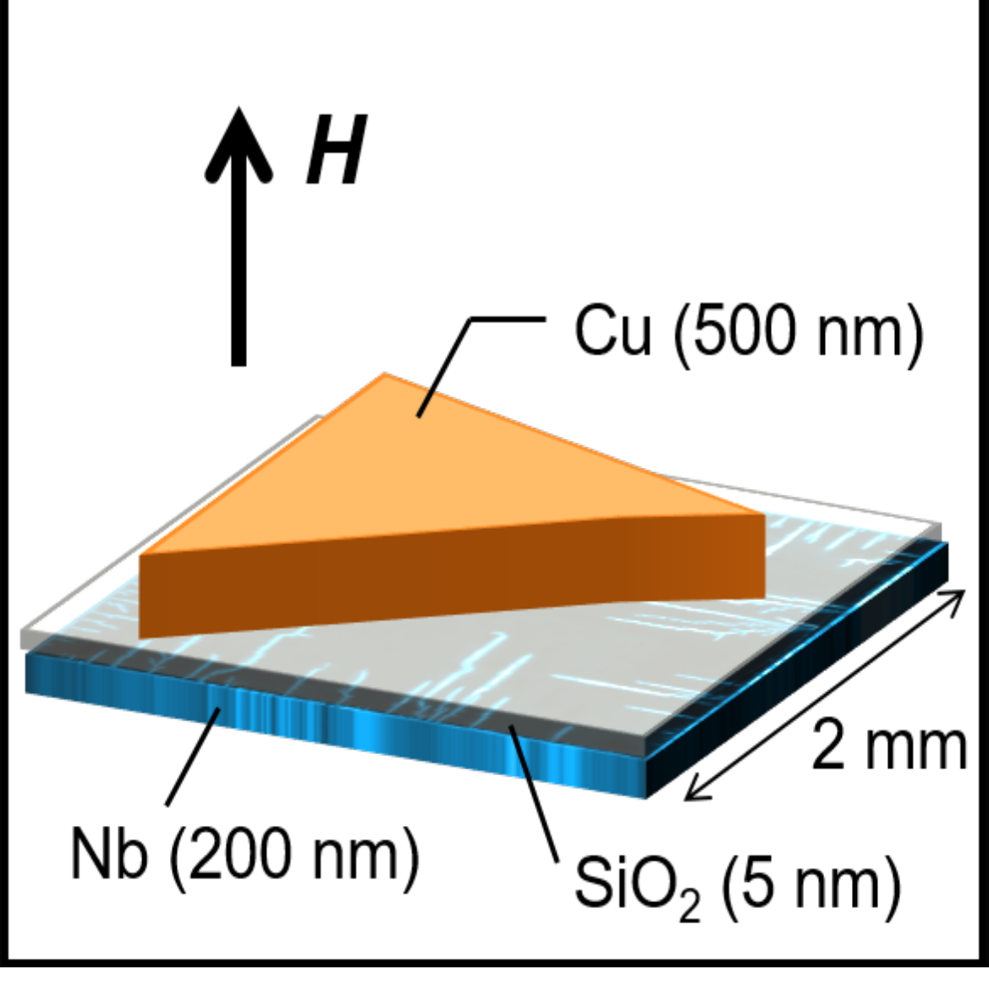
A magnet appears and induces a receding image magnet (eddy currents decay)



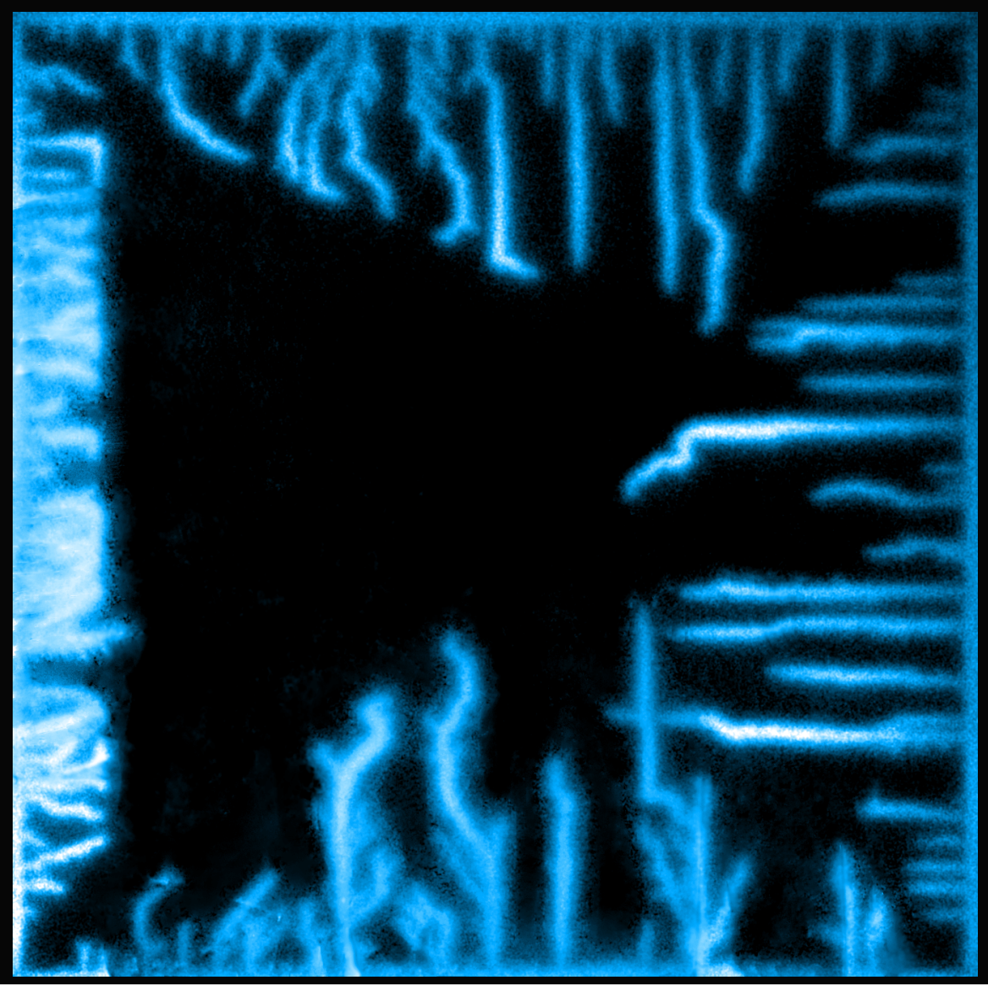
A moving magnet leaves a trail of receding images and interacts with them.

A lift force F_L and a drag force F_D appear from the interaction between the magnet and the eddy currents:

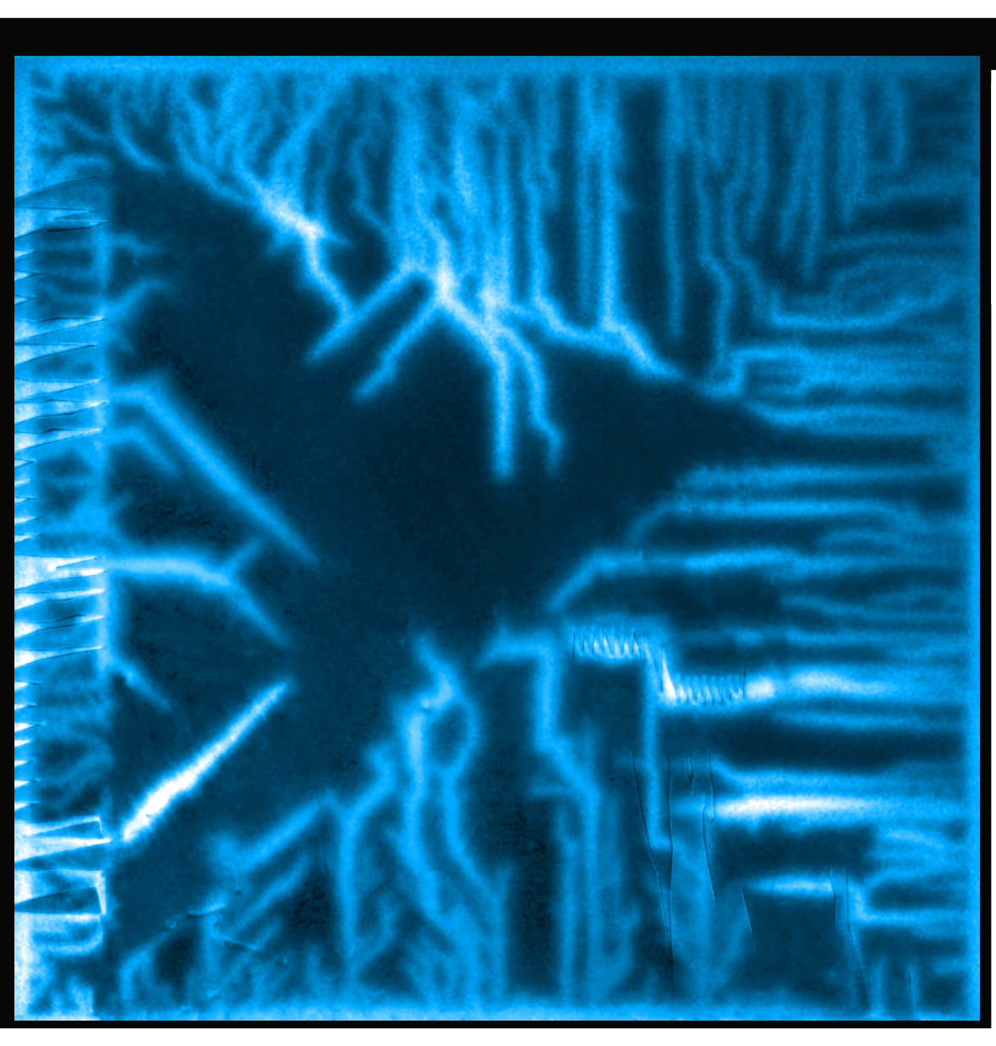
$$F_L = C\left(1 - \frac{w}{\sqrt{v^2 + w^2}}\right) \qquad F_D = \frac{w}{v} F_L$$



The studied sample has a critical temperature T_c of 8.3 K [7]. It is patterned with a periodic square array of antidots to ease the triggering of avalanches.

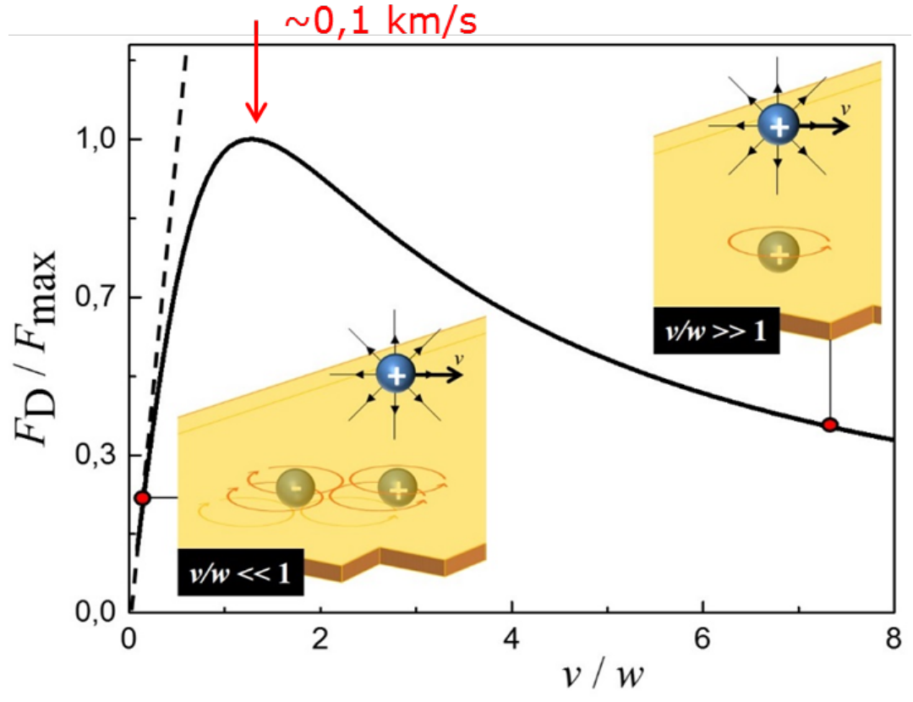


Same sample as above under the same conditions, but with an additional 500 nm-thick Cu layer [7]. The avalanches are completely excluded from the capped area.

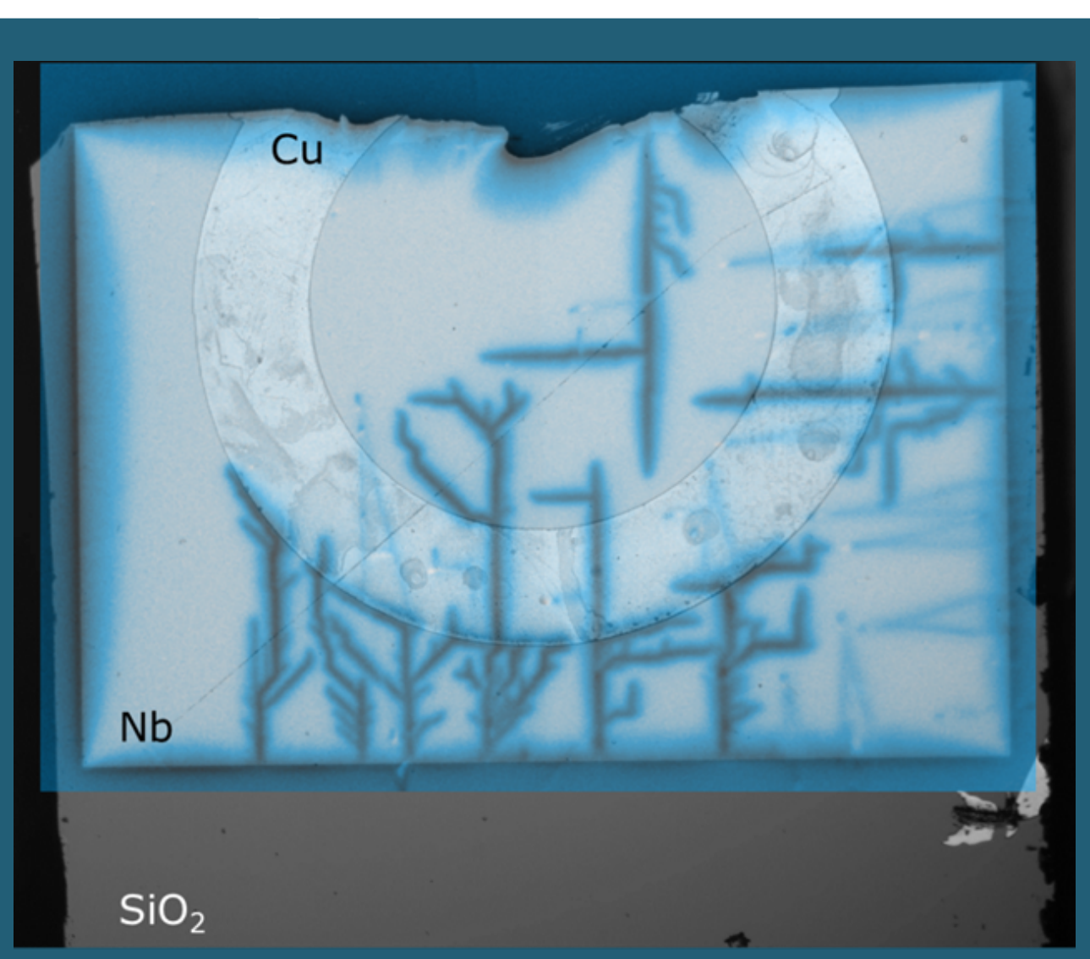


When the field is increased to 20 Oe, avalanches eventually start to penetrate the covered region [7]. Some avalanches change their trajectories at the inferface.

These forces are also valid for a magnetic monopole (*C* is different).



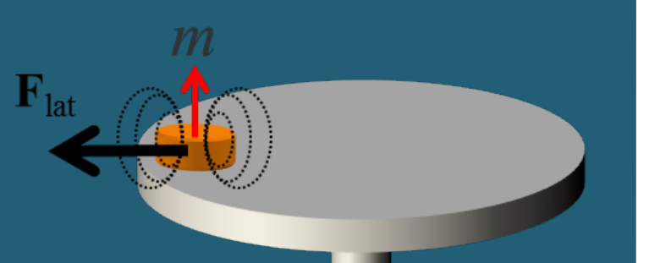
The drag force is non linear and non monotonous at high velocities.



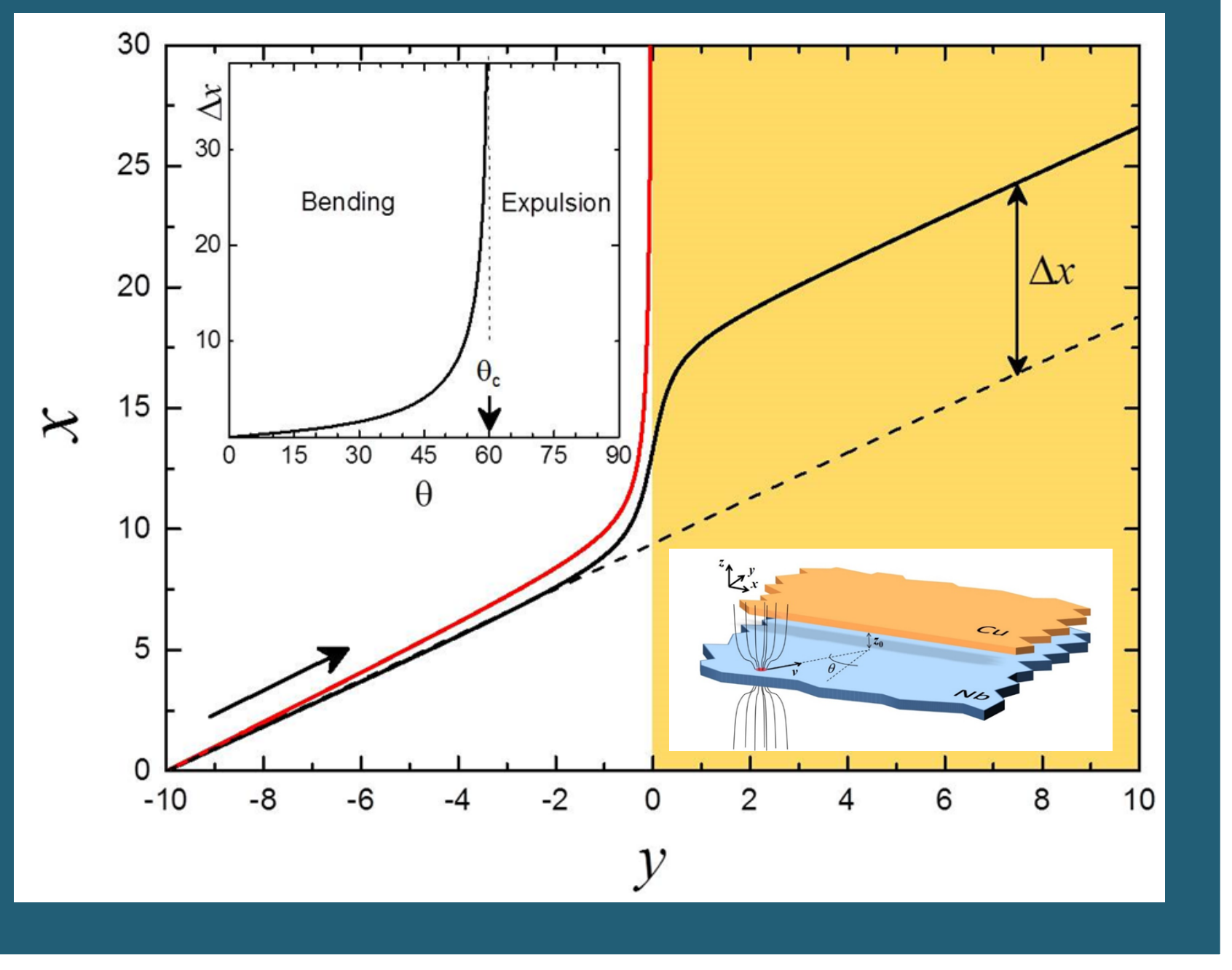
Deflection of avalanches in the same Nb sample, where the Cu triangle has been replaced by a ring. A 10 Oe field was applied before cooling the sample, and was then set to zero.

Avalanches deflection

The avalanche deflection observed in the experiments arises from the repulsive force appearing at the metal border [6]. This force comes from the assymetry in the eddy current distribution.



The trajectories for different incident angles θ reproduce the two regimes we observed in the experiments: exclusion and deflection [7].



Acknowledgments

FNRS FREEDOM TO RESEARCH
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