Evidence of the Bean-Livingston barrier in type-II superconductors

William Magrini, Ivan S. Veshchunov,, Sergei V. Mironov, Jean-Baptiste Trebbia, Philippe Tamarat, Alexandre I. Buzdin, Brahim Lounis

► To cite this version:

William Magrini, Ivan S. Veshchunov,, Sergei V. Mironov, Jean-Baptiste Trebbia, Philippe Tamarat, et al.. Evidence of the Bean-Livingston barrier in type-II superconductors. Vortex 2015, May 2015, El Escorial, Spain. hal-01208123

HAL Id: hal-01208123
https://hal-iogs.archives-ouvertes.fr/hal-01208123

Submitted on 5 Oct 2015

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Evidence of the Bean-Livingston barrier in type-II superconductors

William Magrini[1,2,3], Ivan Veshchunov[1,2], Sergey Mironov[3], Jean-Baptiste Trebbia[1,2], Philippe Tamarat[1,2], Alexander Buzdin[3], Brahim Lounis[1,2]

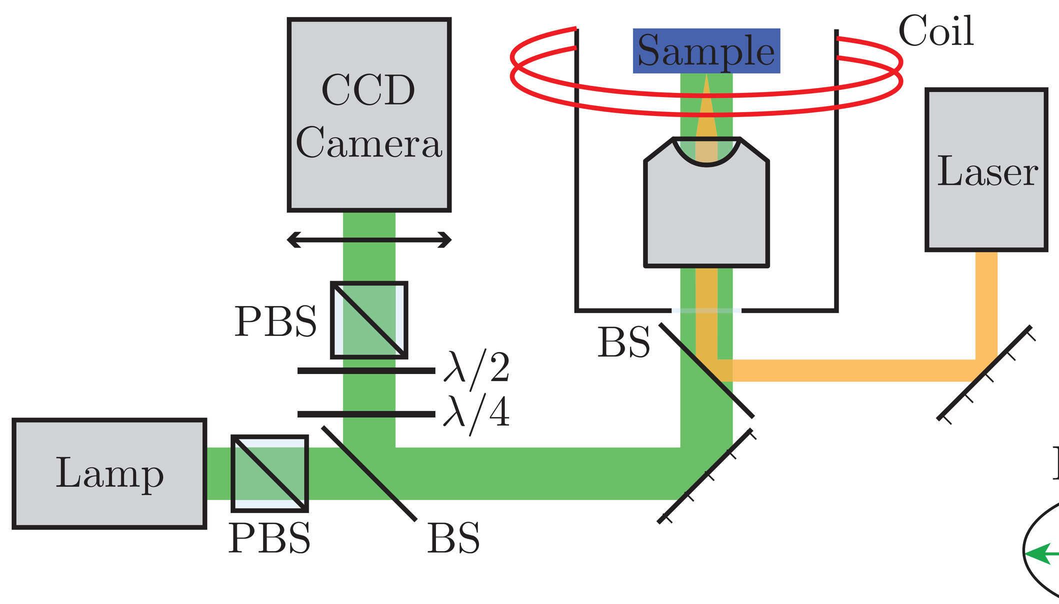
[1] *University of Bordeaux, LP2N, F-33405 Talence, France*
[2] *Institut d'Optique & CNRS, LP2N, F-33405 Talence, France*
[3] *University of Bordeaux, LOMA, F-33405 Talence, France*

Abstract

A magneto-optical imaging (MOI) system capable to resolve single vortices is combined with a focused laser beam to reorganize vortex matter in dense vortex clusters. The local heating of the superconductor with the laser produces a temperature profile which induces an attraction of the vortices towards the center of the laser spot. We analyze the collective vortex dynamics under high-power laser irradiation. The formation of vortex clusters is described with a model very similar to the one describing the first vortex entry into a type-II superconductor.

Experimental Setup

Magneto-optical imaging system capable to resolve single vortex on a Niobium film 450 nm thick and focused laser beam with λ=575 nm :



- Closed cycle cryogen free cryostat, T_{min}~4 K
- Single lens N.A. = 0.5
- Two Glan polarizers (ε~10^{-6})

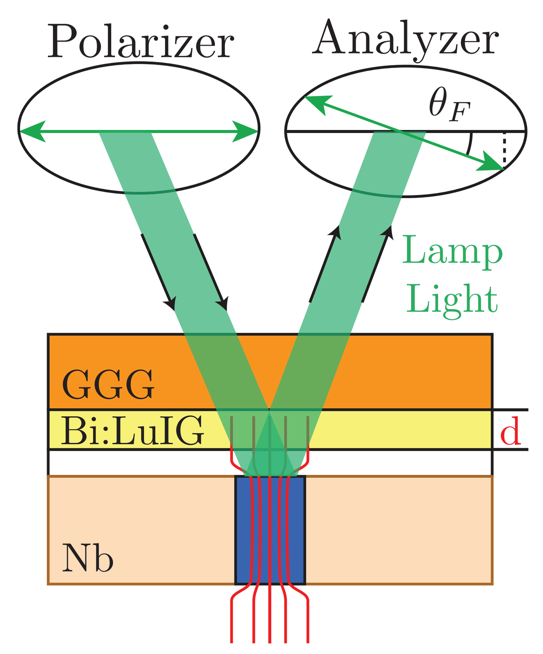
Rotation of the polarization by Faraday effect through a material with Verdet constant V :

$$\theta_F = 2VB_z d$$

MO contrast after analyzer with angle π/2±Φ :

$$C = \left| \frac{-4Vd(\Phi - \theta_F)}{(\Phi - \theta_F)^2 + \varepsilon} \right|$$

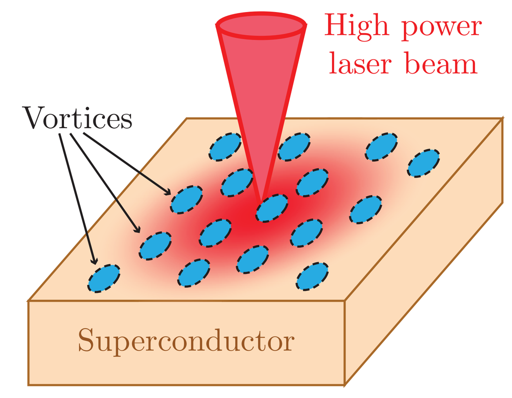
At low temperature, we have extinction ratio ε=1.4 10^{-3}. MO contrast : C=0.52 with SNR=10.

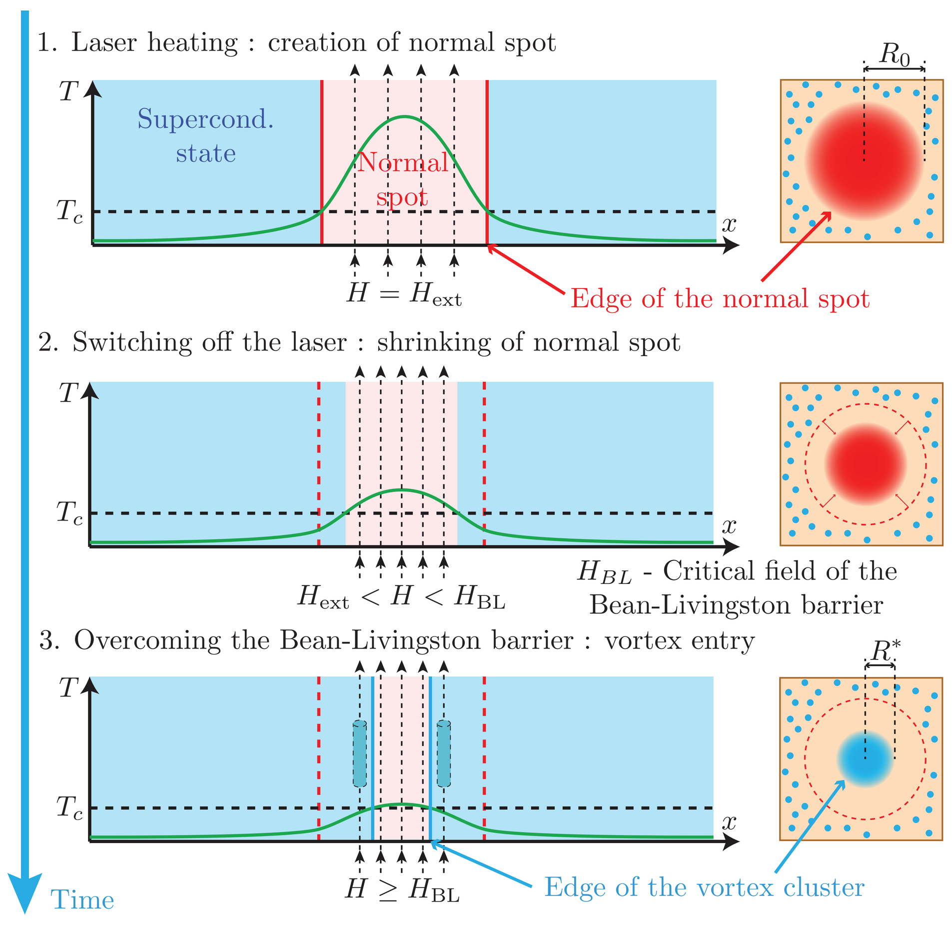


Faraday rotation : 0.05 deg/mT µm for 2,5 µm thick Bi-LuIG layer

Creation of dense vortex clusters

By focusing a laser beam with high power on the surface of the superconductor, we locally destroy superconductivity.
We can thus observe the vortex entry in superconductors during cooling down.





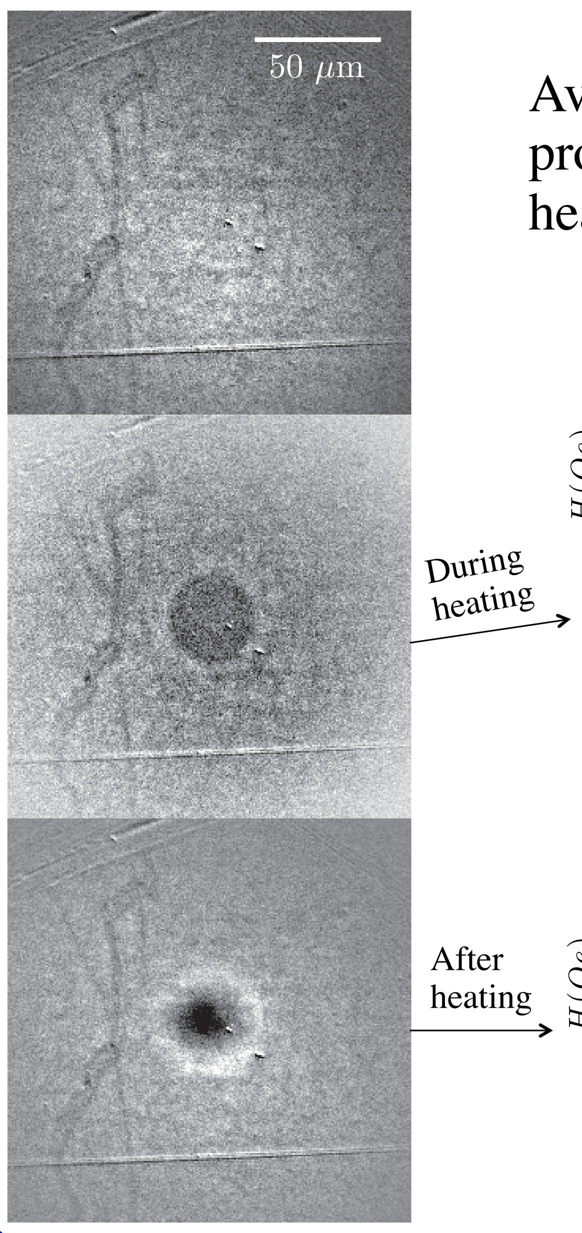
1. Initial distribution of vortices created by the magnetic field $H=H_{ext}$ at $T=T_0$.
2. Laser is focused on the sample. Region with radius R_0 becomes normal.
3. After switching the laser off, temperature decreases. Vortices stay in the N region because of the BL barrier. Average magnetic field increases.
4. Vortices start to penetrate when the radius of the N region becomes less than :

$$R^* = R_0 \sqrt{H_{ext} / H_{BL}}$$

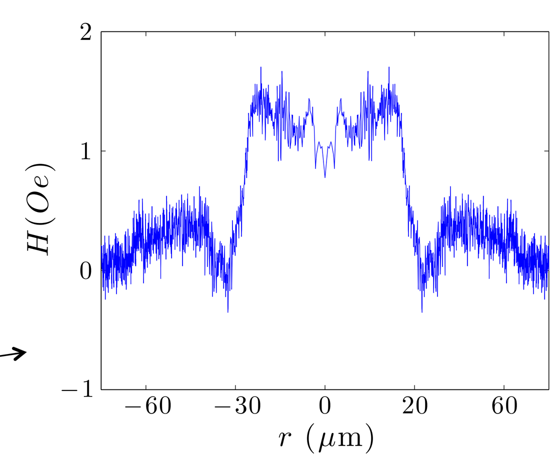
$$H_{BL} = \frac{H_c}{\sqrt{2}} = \frac{\Phi_0}{4\pi\mu_0 \lambda(T)\xi(T)}$$

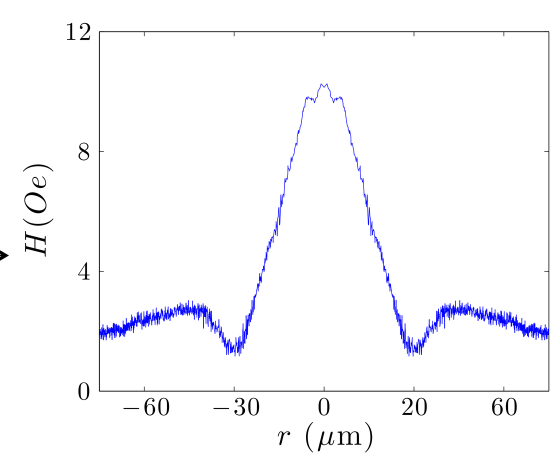
Study of the Bean-Livingston barrier

Sample is cooled down at T=4.7 K under external magnetic field and heated by the focused laser beam with power P=1.5 mW.



Averaged magnetic field profiles during and after heating :



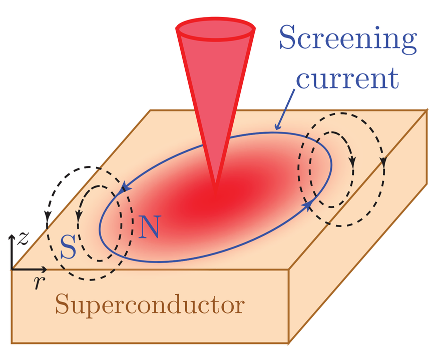


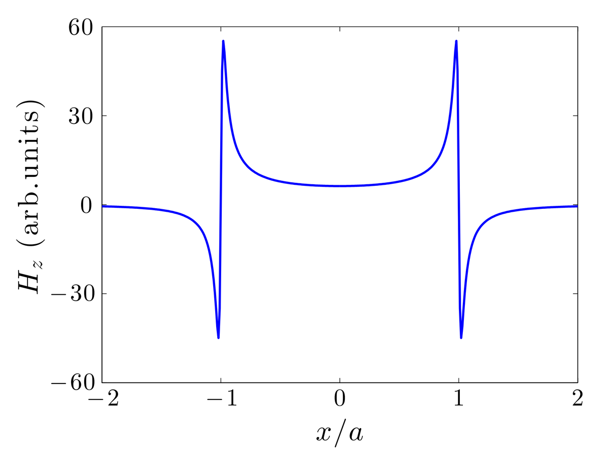
Simulation with Biot-Savart's law for a current loop gives a good approximation of the magnetic field profile during heating :

$$H(r,z) = \frac{2}{\sqrt{(1+r)^2 + z^2}} \left[K(k) + \frac{(1 - r^2 + z^2)E(k)}{(1-r)^2 + z^2} \right]$$

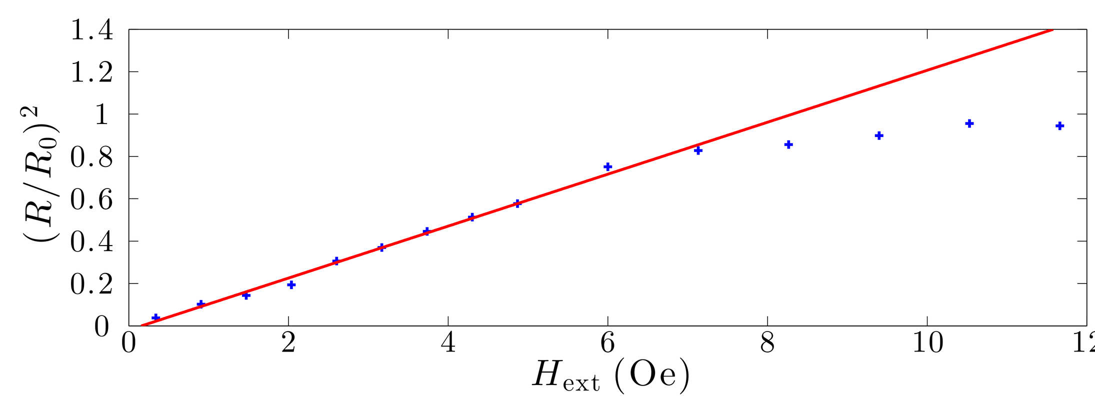
K and E are complete elliptic integrals of the first and second kinds.

$$k = \frac{4r}{(1+r)^2 + z^2} \quad \text{and } z=0.02 \cdot R_0$$





Estimation of H_{BL} is given by the ratio between the radius of normal spot during heating R_0 and the radius of the cluster after penetration of vortices in the sample R.



Ratio of the two radius plotted as a function of the applied magnetic field.

Fit : H_{BL}=8.6 Oe

Saturation of R/R_0 with respect to H_{ext} : H_{BL}~8 Oe

Conclusion & perspectives

We use the temperature gradient induced by a laser beam focused on a superconductor cooled down under external magnetic field to structure the vortex matter into dense clusters. In a high pinning Niobium sample, we evidence the Bean-Livingston barrier preventing the vortex entry into the superconductor. We also observe the screening currents circulating around the heated area. The measured magnetic field profiles obtained during laser heating can be qualitatively reproduced by using a Dirac radial current distribution in the calculation of the magnetic field. A quantitative study will require a more realistic superconducting current radial distribution. The model used to calculate the Bean-Livingston critical field will also be extended to low pinning samples by considering the repulsion of vortices during the creation of the cluster.

References

[1] Bean, C. P. et al. *Physical Review Letters* 12, no. 1 (1964)
[2] Tokunaga, M. et al. *Physica C: Superconductivity*, 437–438 (2006).
[3] Gurevich, A. et al. *Physical Review B* 87, no. 5 (2013)

Agence Nationale de la Recherche ANR
erc
REGION AQUITAINE