# Laboratori Nazionali di Frascati
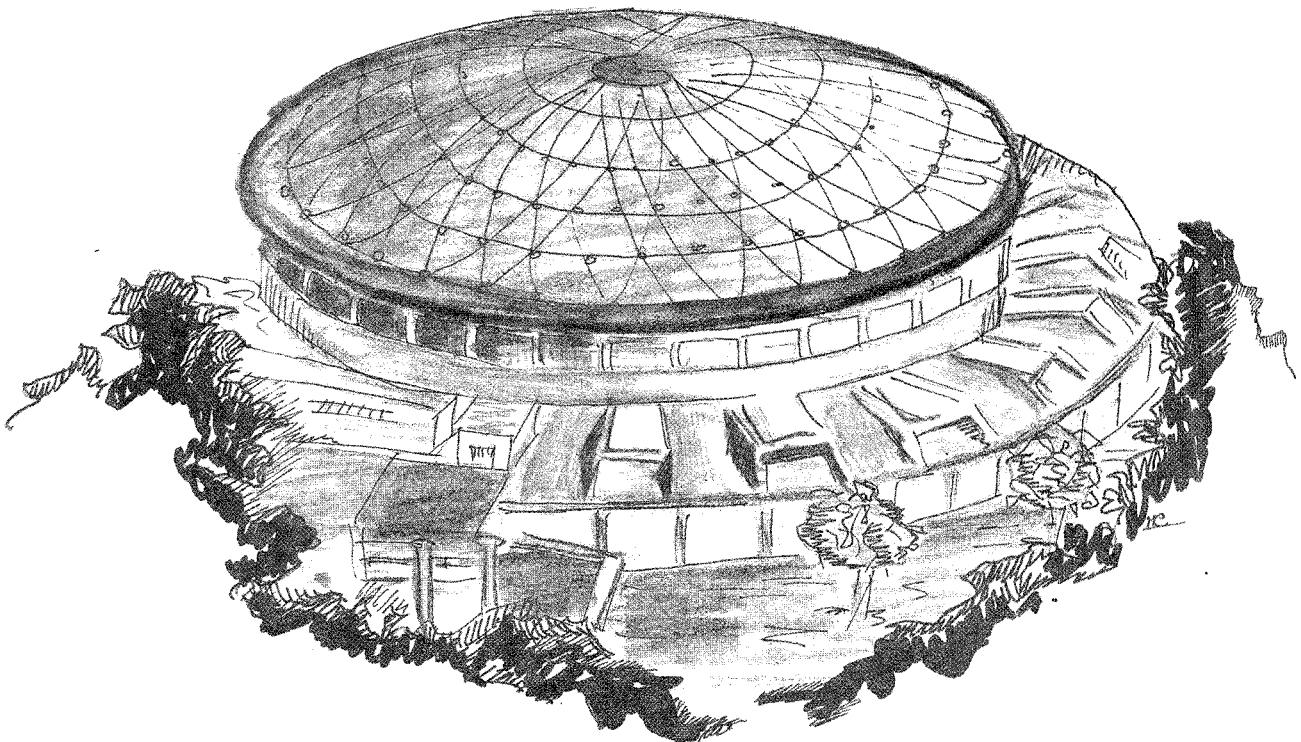
F. Celani, R. Messi, N. Sparvieri, S. Pace, A. Saggese, C. Giovannella, L. Fruchter, C. Chappert, I.A. Campbell:

## ON THE FIELD COOLED SUSCEPTIBILITY OF SUPERCONDUCTING YBaCuO SAMPLES

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## ABSTRACT

Using a SQUID magnetometer, we have studied the magnetization of different samples of high $T_c$ superconductors in field cooled (FC) conditions. Depending on the sample, very different trends in the variation of the saturation value of the FC magnetization with the field have been observed; in particular, for good samples, it increases progressively with decreasing H. We suggest that the observed diversity is to be associated to the different strength of coupling between grains, which depends on the preparation conditions. Data obtained by complementary techniques also support this explanation.

SQUID magnetometry is a unique tool to investigate the low field properties of the disordered junction system existing in both sintered pellets and "single crystals" of YBCO. In a normal experimental procedure, the sample is first cooled in zero field (< 0.2-0.5 mOe) and then is slowly warmed up, in the applied measuring field, to a temperature well above that for complete transition to the normal state, while the zero field cooling (ZFC) magnetization is recorded. As last step of the experiment, the sample is slowly cooled down in the measuring field and the saturation level of the field cooling (FC) magnetization is measured. The ZFC results, obtained in what we call a "clean" experimental situation, have been recently used[1] to describe the critical behaviour, under a magnetic field, of the 3D disorder junction system (JJ) and will not be discussed here any longer. The FC data, being recorded in a "dirty" experimental situation, have been subjected to several interpretations. First, they have been though to give a measure of the Meissner Effect; and this has been clearly shown not to be the case[2]; subsequently, they have been considered as a support to the glassy state model, and some months later to a much more classical flux pinning model[3] by which it should be possible to explain the observed $H^{2/3}$ dependence of the FC magnetization on the field.

The experimental situation, however, is not so simple and, depending on the sample preparation, very different trends are observed, see Fig. 1. In fact, in a same field range (in our case 3 mOe - 20 Oe), samples with poorly connected grains, like the "old" LSCO ones, shows a slow increase of the saturation value of the FC magnetization up to a critical field for which an abrupt transition occurs; standard YBCO samples (60% - 70% dense), on the other hand, show only a flat plateau, while very dense samples (90% - 95% dense) produced by a modified pyrolitique method are characterized by an increase of the saturation value of the magnetization with the decrease of the field (but not as $H^{2/3}$). These behaviours apparently very different can find a common explanation in the existence of the Josephson Junction system and can be considered to mirror the evolution with the field of its connectivity. In poorly connected samples, during the FC procedure, some junctions reconstruct and trap fluxons in those intergranular zones for which the Josephson coupling,

$$J_{ij} = \Delta(T) / R_{ij} \, \text{tgh} \, [\Delta(T) / 2R_{ij}T] \qquad (1)$$

is weaker because of the bigger distance between grains, i.e. because of the larger normal state resistence $R_{ij}$. As long as the field overcomes the critical value at which does not exist any longer a connected network, $J_c$ is in average zero, the junction system breaks down and does not trap any longer (or only poorly) fluxons. As the quality of the sample becomes better (higher density), the flux is expulsed more and more from the intergranular volume and the FC magnetization level increases. Of course, if we were able, in the case of the dense sample, to use higher field we could observe the evolution of the JJ system up to its breaking. The above picture is strongly supported by Fig. 2 in which the low field hysteresis loops of all the three samples are shown[4]. In the case of the LSCO sample the loop closes at about 10 Oe, justifing the breaking of the JJ system shown

in Fig. 1. The loop of the 60% dense YBCO closes at about 45 , justifing also the plateau observed in Fig. 1. A similar plateau, actually would be observable also in the hysteresis loop once that it is corrected for the diamagnetic contribution of the grains. The increase in the level of the FC magnetization observed by SQUID in the case of the dense sample is not visible in its hysteresis loop; but it derives from the low sensitivity of the Foner and from the non perfect screening of the earth magnetic field; and indeed a remanence is always observed. However it is worthwhile to stress that in going from the LSCO sample to the very dense YBCO sample, the intensity of the magnetization, measured by FONER at constant field, increases continuously and the hysteresis loop extends more and more, in agreement with the M/H ratio shown in Fig. 1. Further support to this picture is also given by the measure of the resistivity transition shown in Fig. 3. The long tail visible near by the offset temperature is related to the existence of the junction with a wider spread of coupling strength. Moreover the more dense YBCO shows, as expected from (1), a lower $R_{ij}$.

The saturation value of the FC magnetization cannot be straightforwardly related to the superconducting glass problem because the system is in "dirty" state with fluxons trapped all over. However, it is interesting to remark that in the case of dense samples (and in our field range) we were not able to perform any precise determination of the value of a possible crossover exponent, and this, as suggested in ref. (6), comes from the fact that in this case we are in a field range in which the system change topology (i.e. the penetration length increases) and not in the case in which it is the "status" of the junction to change.
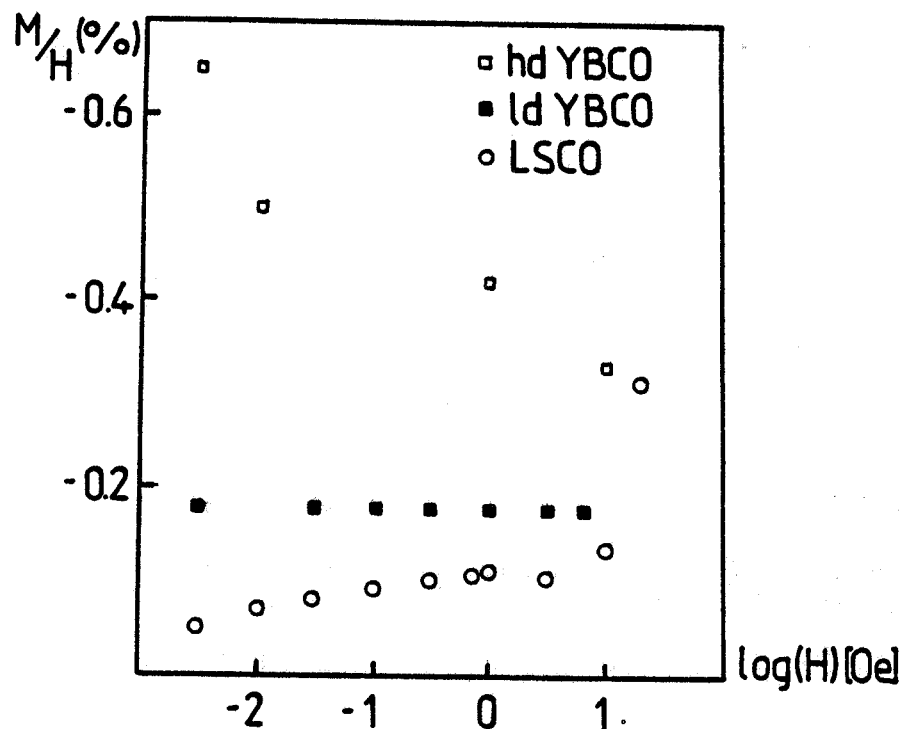


FIG. 1 - Saturation values of the ratio M/H with M magnetization and H cooling field plotted against H for samples of LaSrCuO, standard (ld) YBaCuO and dense (hd) YBaCuO.
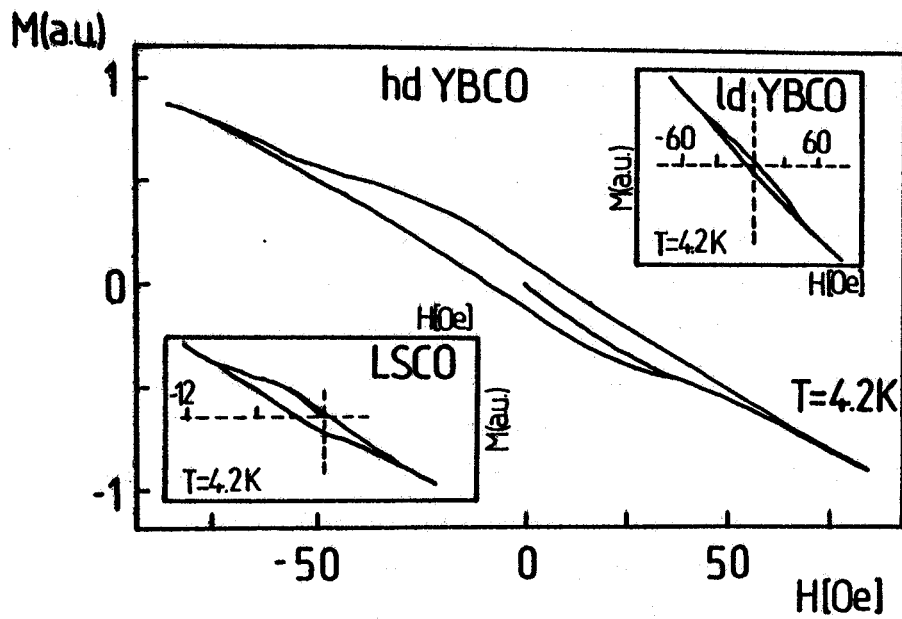
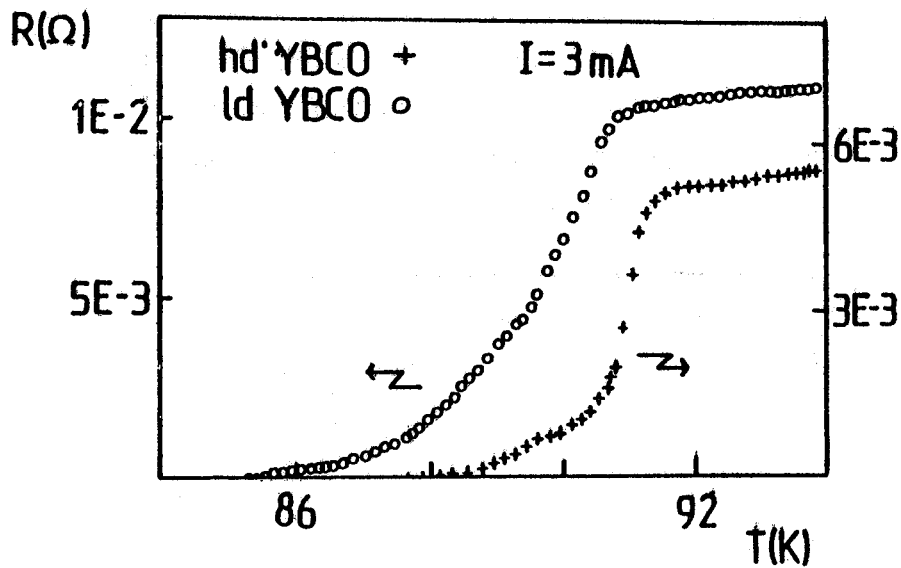FIG. 2 - Loop field hysteresis loops for samples as in Fig. 1.



FIG. 3 - Resistive transition for the ld YBaCuO (circle) and the hd YBaCuO (cross) samples.

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