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Magnetization of underdoped YBCO above the irreversibility line

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Theory [1] and early results from Nernst and torque experiments [2] suggest that in underdoped cuprates a large vortex liquid phase persists even at zero temperature. The issue of the existence of such a phase at high magnetic field is especially pressing as quantum oscillations have been observed just above the vortex melting field in underdoped YBCO [3] and there is still intense debate about whether Cooper pairs persist in the region of the H-T plane where quantum oscillations are seen. Two recent experiments on underdoped YBCO ($p=0.11$) have given conflicting answers to this question: Grissonanche et al. showed through thermal conductivity measurements that there is a sharp feature at 22T which corresponds to the extrapolation of the irreversibility field at $T = 0K$ and they interpret this signature as the upper critical field [4]; Fan Yu et al. found through high field torque magnetometry that the diamagnetism persists above 22T and conclude that the vortex-liquid phase exists well above 22T [5]. We performed our own torque measurements on underdoped YBCO ($p=0.12$) at fields up to 33T and temperature down to 4.5K. Our results are qualitatively similar to Fan Yu et al. [5], however there are important quantitative differences both below T_c and in the normal state. Detailed analysis suggests that the most likely scenario involves weak superconductivity above 22T that is heavily suppressed by competition with the charge density wave instability seen by X-ray scattering [7].

[1] Senthil, T. & Lee, P. A. Phys. Rev. B, **79**, 245116 (2009).

[2] Li Lu, et al. Phys. Rev. B, **81**, 054510 (2010).

[3] Doiron-Leyraud et al. Nature, **447**, 565 (2007).

[4] Grissonanche, G. et al. Nature Communications, **5**, 3280 (2014).

[5] Yu Fan et al. arXiv:1402.7371

[6] Kokanovic, I. et al. Euro. Phys. Lett., **98**, 57011 (2012).

[7] Chang, J. et al. Nature Physics, **8**, 871 (2012).