# Magnetic Field Dependence of Charge Order in Underdoped YBCO

T. Wu (LNCMI Grenoble, France), M-H. Julien (LNCMI Grenoble, France), P.L. Kuhns (NHMFL), A.P. Reyes (NHMFL)

## Introduction

Recent observations of quantum oscillations at high fields in the cuprates have contributed to the resurgence of interest in the underlying nature of the resistive state in High Tc superconductors. This work is a follow up of our recent discovery of magnetic field induced charge order in the underdoped high temperature superconductor $YBa_2Cu_3O_y$ [1]. This result has caused considerable interest because it explains (at least qualitatively) quantum oscillation results [2-3], and because it provides the first direct evidence of charge order in a clean cuprate, and therefore suggests that the competition between charge order and superconductivity may be a generic feature of cuprate superconductors.

## Experimental

We have measured the splitting of oxygen $^{17}O$ and copper $^{63}Cu$ NMR lines due to the charge order in a high quality single crystal of $YBa_2Cu_3O_{6.56}$, for different magnetic field values from 28 to 45 T in the hybrid magnet at $T$=3 K.

## Results and Discussion

By expanding the field range with respect to prior experiments at LNCMI Grenoble, the experiments at NHMFL have allowed us to observe the saturation of the quadrupole splitting (which we take to be related to the amplitude of the charge modulation) at $H_{sat}$≈30-40 T, as shown in **Figure 1**. This field scale is remarkably similar to the upper critical field $H_{c2}$ in this doping range [2-5]. Although the precise value of $H_{c2}$ is a matter of debate [2-6], a dip of $H_{c2}$ near $p$=0.12 and values in the range 24-60 T appear to be robust conclusions. Thus, these results indicate that the amplitude of the charge and superconducting order parameters are anti-correlated, i.e. *the amplitude of the superconducting order parameter limits the growth of charge order*. This correlation is a direct manifestation of a competition between superconductivity and charge order.

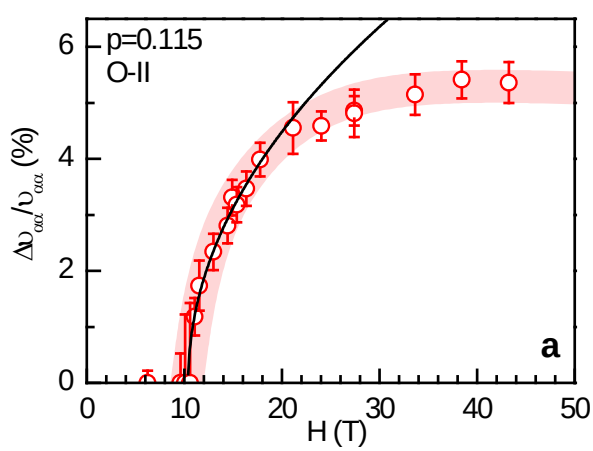


**Figure 1**. Quadrupole part of the $^{17}O(2)$ NMR line splitting in $YBa_2Cu_3O_{6.56}$.

## Conclusions

Now, in order to better understand the microscopic origin of charge order and its possible relevance to superconductivity, a full doping dependence is necessary and this will require the highest fields since superconductivity is stronger away from $p$=0.12.

## Acknowledgements

This work was funded by Pôle SMIng - Université J. Fourier - Grenoble and by the ANR project Superfield.

## References

[1] Wu, T. *et al*. *Nature* **477**, 191 (2011).
[2] LeBoeuf, D. *et al*. *Nature* **450**, 533 (2007).
[3] Sebastian, S. E. et al. Nature **454**, 200 (2008).
[4] Ando, Y. & Segawa, K. Phys. Rev. Lett. **88**, 167005 (2002).
[5] Ramshaw, B. *et al*. Phys. Rev. B **86**, 174501 (2012).
[6] Riggs, S. C. *et al*. Nature Phys. **7**, 332 (2011).