Large Positive Magnetoresistance of the Lightly Doped La$_2$CuO$_4$ Mott Insulator

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Introduction
In doped Mott insulators, the presence of several competing ground states combined with a Coulomb repulsion between electrons leads to various nanoscale inhomogeneities and the expected emergence of glassy dynamics. In cuprates, for example, spin glass behavior is well established at temperatures $T < T_{SG}(x)$ ($x$ – doping). Moreover, in $\text{La}_{1.97}\text{Sr}_{0.03}\text{CuO}_4$ at $T \ll T_{SG}$, charge heterogeneities are also dynamic, consistent with an underlying cluster glass ground state that results from Coulomb interactions [1]. In the same $T$ regime, the out-of-plane magnetoresistance (MR) in the magnetic field $B || c$ axis was found to be positive [1], in contrast to most reports on $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ (LSCO) and other cuprates, and exhibited signatures of glassiness, such as hysteresis and memory [1]. Here we present a detailed study of both in-plane and out-of-plane MR over a wide range of $T$ and $B$ in single crystals of both LSCO and $\text{La}_{2-x}\text{Cu}_{1.4}\text{Li}_{0.6}\text{O}_4$ (Li-LCO) with $x=0.03$. For this value of $x$, only short-range antiferromagnetic (AF) order is present in LSCO, while in Li-LCO the long-range AF order of the parent compound is still present in the experimental $T$-range.

Experimental
MR was measured in a dilution refrigerator ($0.050 < T (K) < 0.7$) up to 9 T and in SCM2 with a He$^3$ system ($0.300 < T (K) < 70$ K) up to 18 T. $B$ was applied both parallel ($B || ab$) and perpendicular to the CuO$_2$ planes ($B || c$).

Results and Discussion
Both materials exhibit the emergence of a strong, positive MR at $T \ll T_{SG}$ in both in-plane and out-of-plane transport for both $B$ orientations [see, e.g., Fig. 1(a)]. This positive MR, associated with charge glassiness, grows as $T \to 0$ and exhibits hysteresis and memory [2]. Moreover, the positive MR $R(T,B)$ is described by a universal scaling function (Fig. 1(b), [2]), similar to a broad class of nonmagnetic disordered insulators with strong Coulomb interactions. At higher $T$, the MR is negative, consistent with other studies.

Conclusions
It is surprising and striking that, in spite of the presence of the AF order (long-range in Li-LCO and short-range in LSCO), the lightly doped La$_2$CuO$_4$ shows behavior that is characteristic of systems that are far from any magnetic ordering. This is consistent with the picture AF domains, frozen at low $T$, and holes confined to the domain walls. The charge glass observed in lightly doped La$_2$CuO$_4$ thus seems analogous to that in other disordered, interacting systems, except that here only holes in the domain walls contribute to transport and glassiness.

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References