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Spin Correlations in Hole-Doped Ladder Cuprates

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We report results of NMR experiments in the hole-doped spin ladder compounds $Sr_{14-x}Ca_xCu_{24}O_{41}$ as well as in the undoped parent material $La_6Ca_8Cu_{24}O_{41}$. Extensive measurements of the frequency shift and the spin-lattice relaxation rate ($1/T_1$) at the Cu and the two distinct oxygen sites in the Cu_2O_3 ladder layers allowed us to distinguish spin fluctuations with different wave vectors. We found that $1/T_1$ at the Cu sites are highly enhanced compared with the two oxygen sites for most of the temperature and doping range studied, indicating that the major spectral weight of low frequency spin fluctuations is located near $q \sim (\pi, \pi)$. This means that the activation energy of $1/T_1$ at the Cu sites is determined by damping of excitations near (π, π) and should not be identified as the spin gap at T=0. Thus the apparent discrepancy between NMR and neutron experiments is resolved. The two oxygen sites show similar temperature dependence of $1/T_1$ in the lightly doped material (x=0) but quite different behavior in the heavily doped material (x=12). This indicates that singlet correlations along the rung becomes weaker with increasing temperature above about 60 K in place of growing antiferromagnetic correlations along the leg in heavily doped materials. Such behavior is most likely caused by dissociation of bound hole pairs.

KEYWORDS: spin ladder, spin gap, hole doping, NMR