# SPIN FLUCTUATIONS IN QUANTUM ANTIFERROMAGNETS

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## Abstract

In this thesis we discuss dynamical properties of magnetic structures emerging in parent compounds of high-$T_c$ cuprate and iron-pnictide superconductors, and the effects of chemical substitution. We also study dynamics of the amplitude (Higgs) modes in dimerized quantum antiferromagnets.

In chapter 2 the problem of stability of the antiferromagnetic (AF) phase in lanthanum-based cuprates against hole doping is addressed. In particular, we investigate the role of exchange anisotropies and magnon masses in stabilization of the AF state of $La_{2-x}Sr_xCuO_4$ for $x < 0.02$. The main result of this chapter is identification of the constraints that the approximate rotational symmetry of the spin system imposes on the low-energy spin-wave dynamics in the presence of coupling between magnetic and electronic subsystems. On the basis of this analysis we show that direct renormalization of the magnon gaps by mobile holes is ineffective, which prevents destabilization of the AF phase, even in the spin-isotropic system. The latter means that, contrary to currently adopted view, spin anisotropies are of secondary relevance to the addressed problem. Finally, we attribute observed magnon mass reduction to softening of the magnetic subsystem by electronic excitations and related enhanced quantum spin fluctuations. Within this scheme we determine both doping and temperature dependence of the anisotropy gaps and demonstrate good agreement with experiment.

In chapter 3 we evaluate longitudinal spin excitations (LSEs) as a probe of microscopic origin of magnetic ordering in iron-pnictide parent compounds $BaFe_2As_2$ and NaFeAs, where LSEs account for sizable fraction of the low-energy magnetic spectral weight. Currently adopted interpretation of the LSEs as particle-hole (P-H) excitations unambiguously points toward itinerant-electron magnetism. The latter scenario is, however, difficult to reconcile with optical measurements and part of angle-resolved photoemission studies which suggest that P-H excitations should appear at energies notably larger than LSEs seen in experiment. We propose a qualitatively distinct mechanism, based on multi-magnon excitations, which contributes to LSEs in the proper energy range and is consistent with optical spectroscopy. Multi-magnon fluctuations, contrary to the P-H continuum, emerge both in local-moment and itinerant-electron systems, hence sole observation of sizable LSEs does not imply contribution of itinerant electrons to magnetism. As the main result of this chapter we show that both qualitative features of measured LSEs and reported range of intensities can be reproduced within the local-moment scenario of magnetic ordering if the system is in the vicinity of a quantum phase transition. The latter possibility is supported by existing studies of iron-pnictides based on frustrated $J_1$-$J_2$ models.

In chapter 4 we address the problem of stability of the amplitude (Higgs) modes in $D = 3+1$ antiferromagnets. Recently, these excitations have been observed in dimerized quantum antiferromagnets near $D = 4$ quantum critical points. As the main result of this chapter we derive upper bounds on the mass and width to mass ratio of the amplitude mode (AM) being a basic measure of its stability. We relate these constraints to the triviality property of $D = 4$ scalar models (which implies relations between macroscopic quantities and the high-energy cutoff scale). We then perform a detailed analysis of the AM stability for a well experimentally characterized antiferromagnet $TlCuCl_3$ near pressure induced quantum phase transition and demonstrate that the bounds are respected. In a range of pressures the constraints are shown to be highly restrictive, which explains small width of the AM in this material.

The undertaken research is presented in broader context in chapter 1 and the results are summarized in chapter 5.