# Research Group for Condensed Matter Theory

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We study new functional materials emerging from the electrons internal degrees of freedom (spin, charge and orbital) and the electrons correlation. New principle and new function of devices are also our important targets. In this fiscal year, we proposed a new method to generate a spinmotive force by a time-dependent electric-field [1]. This makes it possible to control the spinmotive force by an electric field free from magnetic properties such as ferromagnetic resonance frequency. Furthermore, we found a new principle to generate a spin current in a non-magnetic metal by surface acoustic waves [2]. By this method, conventional metals such as Al and Cu can be useful material for spintronics. The latter one is summarized in Research Highlights. Below, progress on dynamical property of a frustrated quantum spin system is reported [3].

**Magnetic excitations in a frustrated two-legged spin-ladder**

Spinons are elementary excitations characteristic of strongly correlated electron systems in low dimensions, and observable by angle-resolved photoemission spectroscopy and neutron scattering. There are a manifestation of electron fractionalization called spin-charge separation, which instead of forming a single quasiparticle, the electronic excitation splits into spin (spinon) and charge (holon) degrees of freedom. In the frustrated spin systems with exotic ground states such as spin-liquid and valence-bond-solid states, the spinon is associated with a topological excitation similar to the magnetic domain wall. In contrast to the collective excitation in a magnetic long-ranged ordered state, i.e., magnon, the spinon carries a fractional quantum number, spin 1/2, accompanied by a spin string. Because of this topological nature, two spinons make in some instance a bound state called a triplon.

We theoretically studied the magnetic excitations in a frustrated two-leg spin-ladder system, in which antiferromagnetic exchange interactions act on the nearest-neighbor ($J_1$) and next-nearest-neighbor ($J_2$) bonds in the leg direction, and on the nearest-neighbor ($J_p$) bonds in the rung direction. A dynamical spin correlation function at zero temperature is calculated using the dynamical density-matrix renormalization-group method for possible magnetic phases, i.e., columnar-dimer (CD) and rung-singlet (RS) phases. The CD phase is characterized by multi-spinon excitations with spin gap, whereas the RS phase is dominated by the triplet excitation in the rung direction. One major difference found between these two phases appears in the spectral weight of magnetic excitations, in particular, the bonding ($q_y=0$) and anti-bonding ($q_y=\pi$) modes in the rung direction (See Fig. 1). Therefore, we can distinguish one phase from the other by the difference of the spectral weight. Furthermore, we examine the effect of frustration on both modes in the rung-singlet phase with a perturbation theory from the strong coupling limit. The anti-bonding mode is shown to be stable against frustration, and a wavenumber with minimum excitation energy is shifted from being commensurate to being incommensurate. In contrast, the bonding mode is merged into the continuum of multiple triplet excitations by increasing frustration. By comparing our results with inelastic neutron scattering experiments for $BiCu_2PO_6$, the magnitude of the magnetic exchange interactions and the ground state will be determined by analyzing some experimental data obtained in J-PARC.

**References**

[1] Y. Yamane *et al.*, Phys. Rev. B **88**, 014430 (2013).
[2] M. Matsuo *et al.*, Phys. Rev. B **87**, 180402(R) (2013).
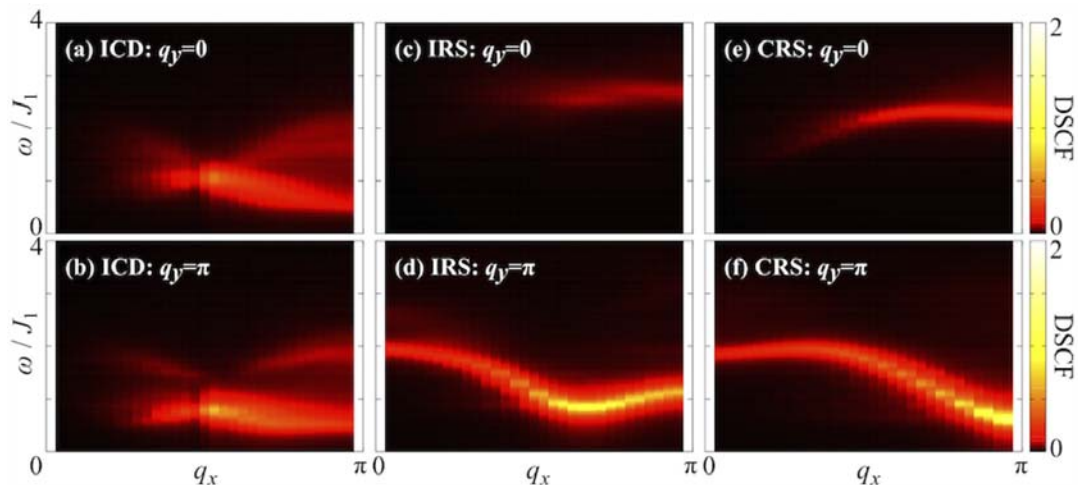[3] T. Sugimoto *et al.*, Phys. Rev. B **87**, 155143 (2013).

Fig. 1 The spectral weight of magnetic excitation in a 32-rung frustrated ladder for the three phases: (a), (b) the incommensurate columnar dimer (ICD) phase ($J_p/J_1=0.2$, $J_2/J_1=0.6$), (c), (d) the incommensurate rung singlet (IRS) phase ($J_p/J_1=1.0$, $J_2/J_1=0.6$), and (e), (f) the commensurate rung singlet (CRC) phase (($J_p/J_1=1.0$, $J_2/J_1=0.1$). (a), (c), and (e) [(b), (d), and (f)] represent the excitations with $q_y=0$ [$q_y=\pi$], which corresponds to the bonding (anti-bonding) mode. We set the DMRG truncation number to be 150 and the broadening factor as for 0.1.