J-PARC **MLF Experimental Report**	提出日 Date of Report September 24, 2016
課題番号 Project No. 2014B0256 実験課題名 Title of experiment: Verification of unusual quantum effect in magnetic excitations in the spin-1/2 triangular lattice antiferromagnet using $Ba_3CoSb_2O_9$ and related system 実験責任者名 Name of principal investigator Hidekazu Tanaka 所属 Affiliation Tokyo Institute of technology	装置責任者 Name of responsible person Kenji Nakajima 装置名 Name of Instrument/(BL No.) AMATERAS (BL14) 実施日 Date of Experiment June 18 to 22, 2016 June 29 to 30, 2016

試料、実験方法、利用の結果得られた主なデータ、考察、結論等を、記述して下さい。(適宜、図表添付のこと)
Please report your samples, experimental method and results, discussion and conclusions. Please add figures and tables for better explanation.

1. 試料 Name of sample(s) and chemical formula, or compositions including physical form.

$Ba_3CoSb_2O_9$

2. 実験方法及び結果 (実験がうまくいかなかった場合、その理由を記述してください。)

Experimental method and results. If you failed to conduct experiment as planned, please describe reasons.

The ground state in zero and finite magnetic field of the spin-1/2 triangular lattice Heisenberg antiferromagnet (TLHAF) is theoretically well understood. However, the excitations of S=1/2 TLHAF are less understood. Theoretical consensus is limited. It was shown that the dispersion relation of the low-energy single magnon excitations near the Bragg point (K point) is described by the linear spin wave theory (LSWT). However, in large area of the Brillouin zone apart from the K and Γ points, the excitation energy is significantly renormalized downward, so that the dispersion curve becomes flat [1,2]. Series expansion approaches demonstrated that the dispersion curve shows rotonlike minimum at M point [1], which cannot be derived from the spin wave theory.

Experimental study of the magnetic excitations in S=1/2 TLHAF with uniform triangular lattice is limited. $Ba_3CoSb_2O_9$ is known to be the best realization of the S=1/2 TLHAF [3,4]. Recently, magnetic excitations in $Ba_3CoSb_2O_9$ were investigated by Ma *et al*. [5]. However, the excitation spectrum seems to be somewhat indistinct. In this experiment, we measured magnetic excitations in $Ba_3CoSb_2O_9$ in details, using a cold-neutron diskchopper spectrometer AMATERAS (BL14) installed at J-PARC. The sample of 2.0 g was mounted in ^{3}He cryostat with c^* and (H, H) directions in the horizontal plane. The temperature of sample was lowered down to 1.0 K, which is sufficiently lower than T_N=3.8 K. The wave vector $\boldsymbol{k}_i$ of incident neutron was first set to be parallel to the c^* axis. We observed well-defined excitation spectra, which shows a two-dimensional (2D) magnetic character. Next, rotating sample around the (-K, K) direction, we measured excitation spectra to observe the dispersion along the c^* direction (L) and to obtain excitation spectra in wider momentum-energy space. Figure 1(a)-(d) show the excitation spectra along the $\boldsymbol{Q}$=(H, H) and $\boldsymbol{Q}$=(0.5-K, 0.5+K), where the intensities along the c^* direction are integrated. As shown in Figs. 1(b) and (d), excitation spectra have a three-stage structure. The lowest stage is composed of two dispersions branches of single magnon excitations. The middle and highest stages are dispersive continua. The highest stage is accompanied by columnar continua

2. 実験方法及び結果（つづき） Experimental method and results (continued)

extending above 8 meV, which is five times larger than the exchange interaction J=1.67 meV. This three-stage structure of excitation spectra was first observed in the present experiment. Solid lines in Figs. 1(a) and (c) are dispersion curves calculated by LSWT with J=1.67 meV and Δ=0.047, which are determined by the saturation field and the zero-field gap observed by ESR, respectively [4], where Δ is the anisotropy parameter defined by $\Delta=(J^{\perp}-J^{\parallel})/J^{\perp}$. We see that the low-energy single magnon excitations near K and Γ points are well described by the LSWT. However, for the high-energy single magnon excitations at the wave vectors $\boldsymbol{Q}$ being away from these points, the excitation energy is largely renormalized downward. Rotonlike minima in dispersion curves are clearly observed at M point. These observations are consistent with the theory [1,2].

Because the low-energy excitations can be described by the LSWT, we evaluated from the dispersion relations along $\boldsymbol{Q}$=(1/3, 1/3, L) the interlayer exchange interaction J' to be J'=0.080 meV. Solid lines in Fig. 1(e) are the fit with J=1.67 meV, Δ=0.047 and J'=0.080 meV. For high-energy single magnon excitations above 1 meV, the dispersion is almost independent of L, as shown in Fig. 1(f). This indicates good 2D nature in $Ba_3CoSb_2O_9$.

To summarize, we observed the whole picture of magnetic excitations in $Ba_3CoSb_2O_9$, which approximates the S=1/2 TLHAF. The most striking feature of the excitation spectra is two dispersive continua above 1meV. The high-energy continuum was calculated, using the spin wave theory and mean field Schwinger boson approaches. However, the results are different according to theory. Also there is a significant difference between our experimental observation and theoretical results.

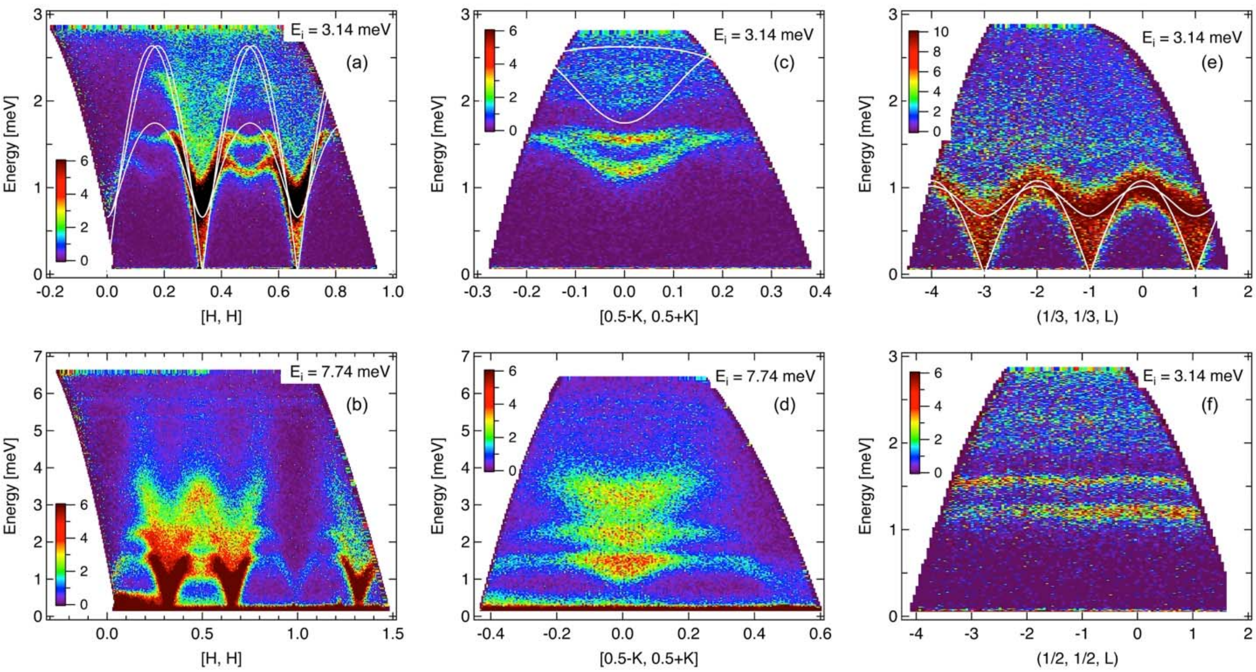

Fig. 1: Energy-momentum map of the scattering intensity measured by using AMATERAS with incident neutron energies of E_i=3.14 and 7.74 meV, (a) and (b) for $\boldsymbol{Q}$=(H, H), (c) and (d) for $\boldsymbol{Q}$=(0.5-K, 0.5+K), and (e) and (f) for $\boldsymbol{Q}$=(1/3, 1/3, L). Solid lines are the dispersion relations calculated by LSWT.

References

[1] W. Zheng, J. O. Fjærestad, R. R. P. Singh, R. H. McKenzie and R. Coldea: Phys. Rev. B **74** (2006) 224420.
[2] O. A. Starykh, A. V. Chubukov and A. G. Abanov: Phys. Rev. B **74** (2006) 180403.
[3] Y. Shirata, H. Tanaka, A. Matsuo and K. Kindo: Phys. Rev. Lett. **108** (2012) 057205.
[4] T. Susuki, N. Kurita, H. Tanaka *et al.*: Phys. Rev. Lett. **110** (2013) 267201.
[5] J. Ma, Y. Kamiya, M. Matsuda *et al.*: Phys. Rev. Lett. **116** (2016) 087201.
[6] M. Mourigal, W. T. Fuhrman, A. L. Chernyshev and M. E. Zhitomirsky: Phys. Rev. B **88** (2013) 094407.
[7] E. A. Ghioldi, A. Mezio, L. O. Manuel, R. R. P. Singh *et al.*: Phys. Rev. B **91** (2015) 134423.