（ ※本報告書は英語で記述してください。ただし、産業利用課題として採択されている方は日本語で記述していただいても結構です。 ）

MLF Experimental Report	提出日 Date of Report June 21, 2013
課題番号 Project No. 2012A0090 実験課題名 Title of experiment Magnetic excitations in the spin-1/2 kagome lattice antiferromagnet $Cs_2Cu_3SnF_{12}$ 実験責任者名 Name of principal investigator Kittiwit Matan 所属 Affiliation Mahidol University	装置責任者 Name of responsible person Kittiwit Matan 装置名 Name of Instrument/(BL No.) BL-14 実施日 Date of Experiment October 31 to November 8, 2012

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.
Three co-aligned single crystals of $Cs_2Cu_3SnF_{12}$ of the total mass approximately 4 g.

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.

Magnetic excitations in the distorted kagome lattice antiferromagnet $Cs_2Cu_3SnF_{12}$ were measured using inelastic neutron scattering. The system is known to order at low temperatures (T_N = 20 K). The sample is aligned in (HHL) zone and cooled down to 7 K using a closed cycle He-4 cryostat. Two chopper configurations were used for two sets of accessible incident energies (E_i). In the first set-up, E_i of 27.64 meV, 11.67 meV, 6.403 meV, and 4.035 meV are accessible while in the second set-up, E_i of 51.04 meV, 16.98 meV, 8.388 meV and 4.988 meV are accessible. We found that E_i of 16.98 meV gives the optimal result in terms of the covering dynamic range and incident neutron flux.

Multiple datasets were acquired by rotating the sample about the vertical axis, which is parallel to [−1, 1, 0], in steps of 2° covering roughly 100° of sample orientation. The background was measured at 30 K, which is right above T_N, and 150 K for phonon background subtraction. These datasets were then combined to produce a background-subtracted, four-dimensional scattering-intensity function $I(Q, \omega)$, where Q is momentum transfer and ω is energy transfer. However, in this report we will only show the data taken at 7 K. The data were sliced and cut along high symmetry directions using "Utsusemi" to produce contour maps. The scattering intensity is mapped along two diagonal directions namely [1,1] and [−1,1]. The latter is perpendicular to the scattering plane. The intensity is integrated along the [0,0,L] direction, taking advantage of non-dispersive and rod-like scattering along the L axis, which is a result of the two dimensionality of the system.

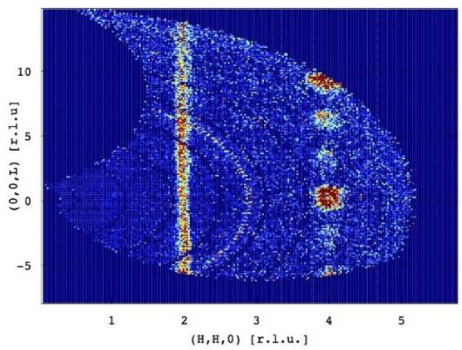


Figure 1. A intensity map shows the rod-like scattering along (0,0,L).

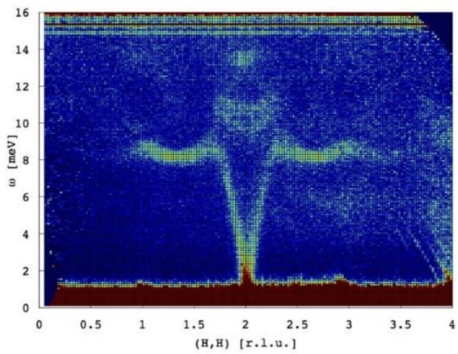
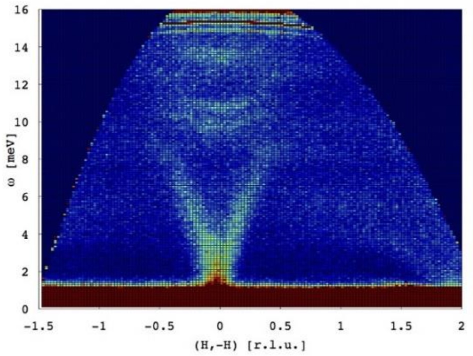


Figure 2. Spin-wave dispersion along (H,H)

The spin-wave dispersion along (H,H) shows a distinct feature (Figure. 2). We observe the flat mode, which is a characteristic of the frustrated kagome lattice, indicative of highly degenerate connected states. In the high energy region, scattering intensity in the majority of the Brillouin zone vanishes, which can be a result of magnetic structure factor or more interestingly caused by magnon instability. We note that the magnetic excitations observed in this system is dramatically different from those observed in a closely related compound $Rb_2Cu_3SnF_{12}$, in which the magnetic excitations are of a singlet-to-triplet type and scattering intensity is centered around the zone center.

The spin wave dispersion along (−H,H) shows the dispersive mode similar to that along (H,H) but the intensity of the flat mode becomes very weak along this direction as shown in Figure 3.

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



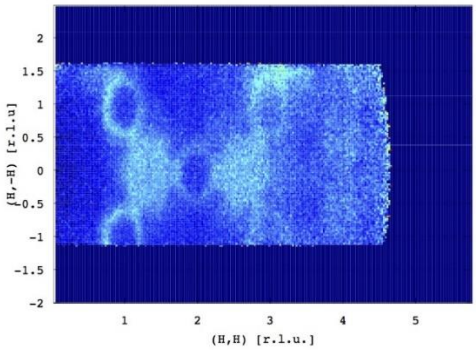


Figure 3. Spin-wave dispersion along (-H,H)　　Figure 4. A intensity map in the (H,K) plane with an energy range [7.5-9] meV

We note that the range of momentum transfer along (-H,H) is limited due to the smaller covering area of detector perpendicular to the scattering plane.　The asymmetry of scattering intensity of the flat mode along (H,H) and (-H,H) can be best observed in the intensity map plotted in the (H,K) plane at an energy transfer range of 7.5 meV to 9 meV as shown in Figure 4.　Our preliminary calculations of spin-wave intensity on this system show that this scattering intensity pattern can be reproduced assuming the q = 0 spin structure, where spins on each triangle points either toward or away from the center of the triangle, and non-uniform exchange interactions.

To summarize, we measured the spin-wave excitations in the distorted kagome lattice antiferromaget $Cs_2Cu_3SnF_{12}$ and observe the flat mode over extended region of the Brillouin zone.　In addition, we observe the absence of scattering intensity in the high energy region, which could be due to the structure factor or magnon instability.　We are currently working on the analysis of these results.　The preliminary analysis shows good agreement with the spin-wave calculations for low energy.　However, the spin-wave result fails to explain the weak and broad scattering at high energy.　Quantum renormalization and two magnon process could play a role to suppress or broaden the magnetic excitations at high energy. Further work is required to understand these phenomena in the highly frustrated magnet.

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The following sheet is for internal use only.　Description in Japanese is acceptable.

○論文等による成果発表の予定 (Your publication plan)

a）発表形式(*1) Publication style(*1)	b）発表先(誌名、講演先)(*2) Publication/Meeting information(*2) (Name of journal/book or meeting)	c)投稿/発表時期(*3) Date of paper submission or presentation(*3)
Peer-review article	Physical Review Letters or Physical Review B	2013-2014

【記入要領】(Instructions)

(*1)　原著論文、総説、プロシーディングス、単行本、特許、招待講演（国際会議）、その他口頭発表等、具体的な発表方法を示して下さい。
Please describe planned publication and/or presentation style; *ex.* refereed journal, review article, conference proceedings, book, patent, invited talk, oral presentation *etc.*

(*2)　成果を発表する誌名、講演先を示して下さい。
Please describe the name of journal or book you are planning to submit, or name of meeting you will make a presentation.

(*3)　およその発表予定時期を示して下さい。（３月以内、６月以内、１年以内、２年以内、２年以上先、等）
Please describe the estimated date of paper submission or presentation; *ex.* within 3 months, within 6 months, within 1 year, within 2 years, beyond 2 years, *etc.*

○成果になる予定が立たない場合の理由と今後の計画を記述してください。

In case you can not publish your results, please describe reasons and future plan.

（例：「論文になる十分な結果が得られなかった」、「複数回の実験が必要で次回の課題終了後に発表予定」、等）