μSR Study on Triangular Lattice Spin Liquid Candidate $NaYbSe_2$

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Motivations

- Triangular lattice spin liquid candidate $YbMgGaO_4$ was found to exist exchange disorder between Mg^{2+} and Ga^{3+} [1].
- The structure of $NaYbSe_2$ is free of exchange disorder [2].
- No phase transition down to 50 mK from results of specific heat and magnetic susceptibility[2].

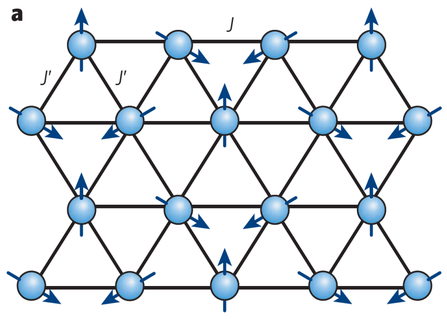

Fig. 1. Geometrical frustration on triangular lattice. [3]

Experiments

- μSR is a sensitive method to detect local static or dynamic magnetic field.
- Many plate single crystals are aligned along their *c*-axis.
- Zero field μSR (ZF-μSR) down to 88 mK is performed to check if there is magnetic order.
- Longitudinal field μSR (LF-μSR) under different magnetic fields along *c*-axis at 0.1 K is performed to tell the spin is dynamic or static.

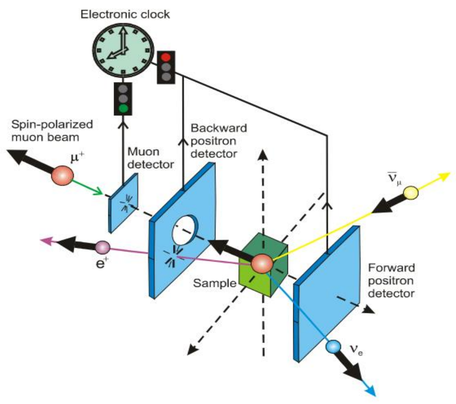

Fig. 2. ZF/LF-μSR [4].

Results

1. ZF-μSR

- Fitting function: $a(t) = A_1 e^{-(\lambda t)^\beta} + A_2\left[\frac{2}{3}(1-\sigma^2 t^2)e^{-\frac{1}{2}\sigma^2 t^2} + \frac{1}{3}\right]$
- 1st term: stretched exponential, dynamic (spin-liquid-like).
- 2nd term: Kubo-Toyabe (KT), static (nuclear moment or spin-glass-like) [5].
- Constant background subtracted (silver sample holder).
- Neither oscillation of asymmetry (long-range-order) nor initial asymmetry loss (short-range-order) observed.
- With decreasing temperature, the 1st term changes from Gaussian (β = 2) to Lorentzian form (β = 1).
- Temperature independent regime of λ below 0.2 K: persistent spin dynamics.
- Increase of A_2 and significant increase of σ: spin-glass-like freezing below 6 K.

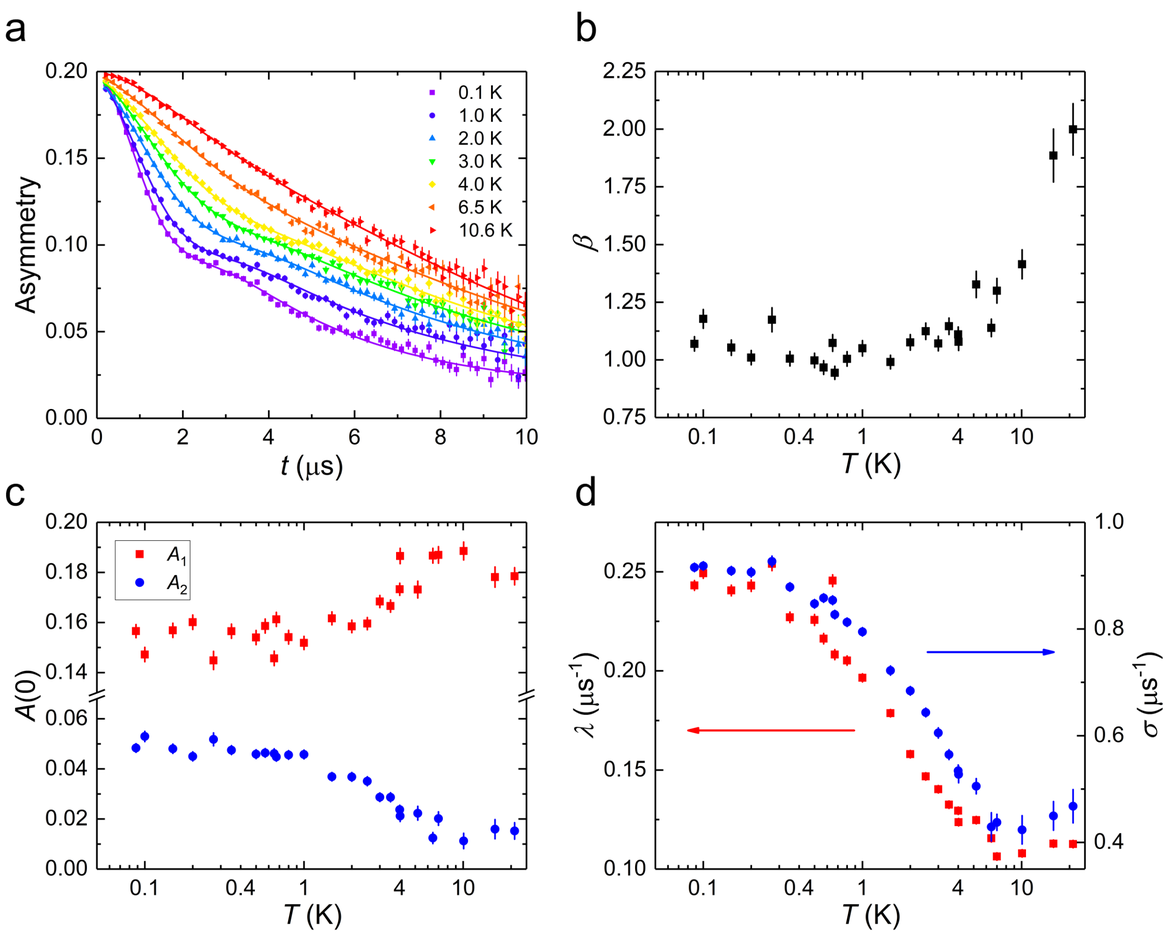

Fig. 3. **Results of ZF-μSR**. **a.** Selected asymmetry spectra at different temperatures. The constant background has been subtracted for clearance. **b.** Temperature dependence of stretched exponent β. **c.** Temperature dependence of the initial asymmetry of stretched exponential term A_1 and KT term A_2. **d.** Temperature dependence of relaxation rates of the stretched exponential term λ and KT term σ.

2. LF-μSR

- Fitting function: $a(t) = A_1 e^{-(\lambda t)^\beta} + A_2\left[\frac{2}{3}(1-\sigma^2 t^2)e^{-\frac{1}{2}\sigma^2 t^2} + \frac{1}{3}\right] + B$
- $\beta \sim 1$.
- Total asymmetry varies for small geometrical change under strong field.
- Static field is suppressed by 50 Oe.
- Dynamic field is suppressed by more than 1 kOe.

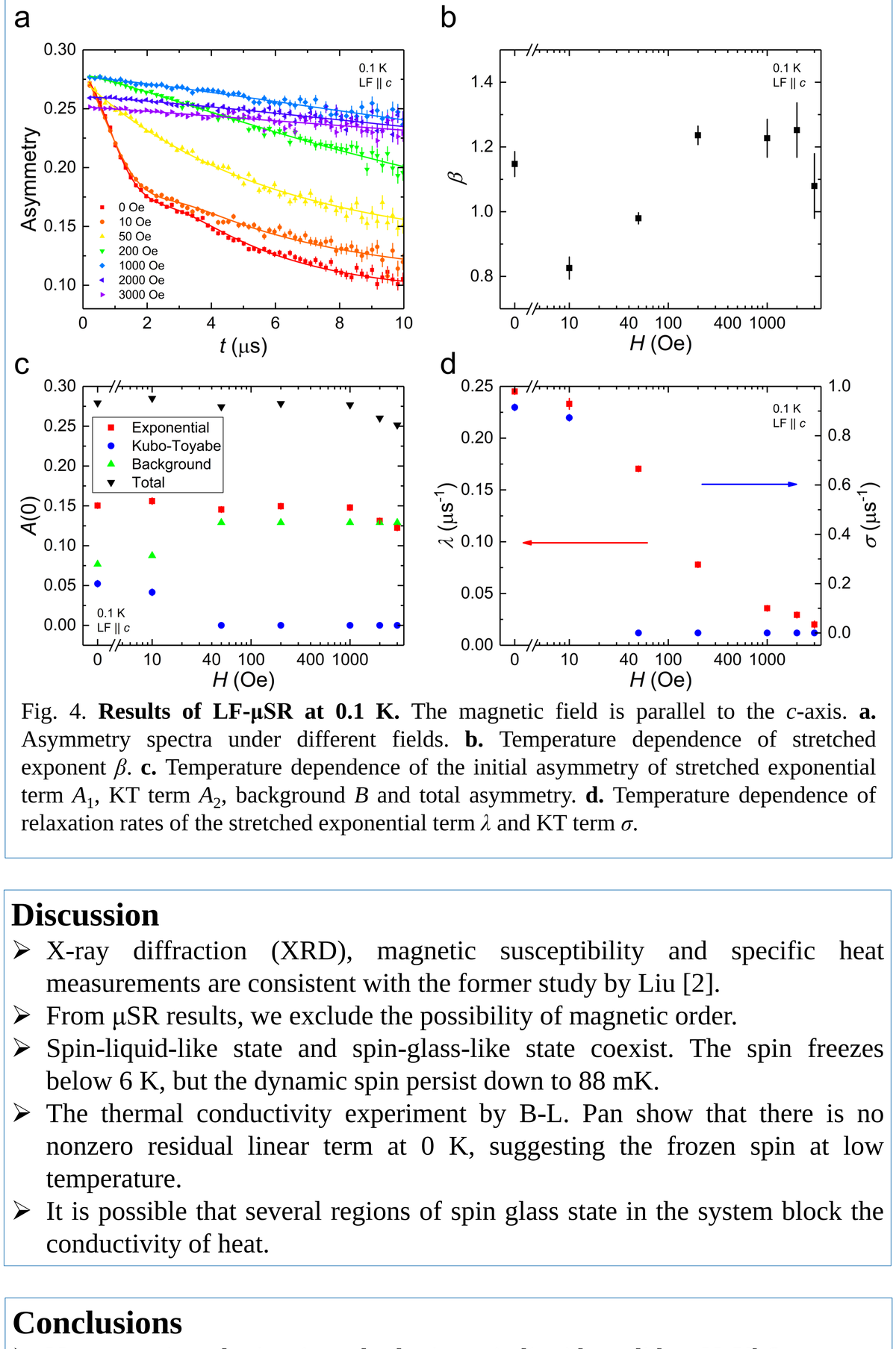

Fig. 4. **Results of LF-μSR at 0.1 K.** The magnetic field is parallel to the *c*-axis. **a.** Asymmetry spectra under different fields. **b.** Temperature dependence of stretched exponent β. **c.** Temperature dependence of the initial asymmetry of stretched exponential term A_1, KT term A_2, background B and total asymmetry. **d.** Temperature dependence of relaxation rates of the stretched exponential term λ and KT term σ.

Discussion

- X-ray diffraction (XRD), magnetic susceptibility and specific heat measurements are consistent with the former study by Liu [2].
- From μSR results, we exclude the possibility of magnetic order.
- Spin-liquid-like state and spin-glass-like state coexist. The spin freezes below 6 K, but the dynamic spin persist down to 88 mK.
- The thermal conductivity experiment by B-L. Pan show that there is no nonzero residual linear term at 0 K, suggesting the frozen spin at low temperature.
- It is possible that several regions of spin glass state in the system block the conductivity of heat.

Conclusions

- No magnetic order in triangular lattice spin liquid candidate $NaYbSe_2$.
- Spin-liquid-like state and spin-glass-like state coexist.
- Spin dynamics persists down to 88 mK, but can be suppressed by a not very large field [6].
- Spin freezes below 6 K.
- It could be a spin liquid system containing significant spin glass "impurities".

Acknowledgements

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