Usage Report for Fiscal Year 2024

**Project Title:**

**Spin supersolid in the spin-1/2 triangle lattice Heisenberg antiferromagnets**

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1. Background and purpose of the project, relationship of the project with other projects

The supersolid has coexisting superfluidity and spatial symmetry breaking order which is originally proposed as an exotic quantum state in Helium. Given the fact that the boson models can be mapped to the spin models, the spin supersolid may also exist in frustrated spin lattice models with the triangular lattice Heisenberg antiferromagnets as the most promising platform. Motivated by the recent experimental observation of supersolid phases in the $Na_2BaCo(PO_4)_2$ triangular lattice compounds, we study the magnetic field-induced spin supersolid phases in the spin-1/2 nearest neighbor Heisenberg model. We study the off-diagonal order parameters and superfluid density and map out the phase diagram with magnetic fields. In addition, we calculate the spin spectral functions in the presence of impurities, where clear differences are expected between the supersolid phases and magnetic ordered phases.

Recently there have been many studies of the spin supersolid state in the spin-1/2 triangular lattice Heisenberg model because of its experimental realization in $Na_2BaCo(PO_4)_2$. However, to date there is no direct experimental evidence of the superfluidity in the material. One of the properties for the superfluid is that the particle scattering is independent from local impurities, which may be tested in experiments. Thus, our study can provide direct characterization of the nature of the spin supersolid state.

2. Specific usage status of the system and calculation method

We use numerical Density Matrix Renormalization Group (DMRG) methods to calculate finite size lattices on a cylinder. The numerical algorithm is implemented through the open-source package ITensor (https://itensor.org). The time evolution is conducted using the Time-Dependent Variational Principle (TDVP) methods.

3. Result

The ground state and static properties of the model Hamiltonian has been obtained. We also have got preliminary results of the spectral functions on small size lattices.

4. Conclusion

We calculate the phases transitions with magnetic field. The superfluid density and supersolid order parameters indicate that the phase below and above the 1/3 magnetization plateau are supersolid phases.

The dynamical structure factor, also known as the spectral function, remains the same with impurities added to the system in the supersolid phases, as opposed to the up-up-down phase.

5. Schedule and prospect for the future

We will continue to calculate the spectral function with and without impurities on larger size systems. In addition, we will calculate the effect of different impurity density and the position of the impurity.

## Fiscal Year 2024 List of Publications Resulting from the Use of the supercomputer

### [Oral presentation]

Yixuan Huang, Seiji Yunoki, S. Maekawa, Magnetic Field-induced Spin Supersolid Phases on the Triangular Lattice Heisenberg Antiferromagnets, Joint March Meeting and April Meeting: Global Physics Summit 2025, Mar 16-21, 2025, Anaheim, CA, United States

### [Poster presentation]

Yixuan Huang, Seiji Yunoki, S. Maekawa, Magnetic Field-induced Spin Supersolid Phases on the Triangular Lattice Heisenberg Antiferromagnets, APW-RIKEN-Tsinghua-Kavli workshop, Nov. 1-3, 2024, Wako Campus, RIKEN