Over the past year, we have continued making progress in understanding the fundamental physics of kagomé lattice systems. This work has been pushing forward on two fronts: further investigations of S=1/2 systems and detailed measurements of the magnetic phase transitions in an S=5/2 system. Here, we will focus on results pertaining to the S=1/2 materials. Our previous thermodynamic and neutron scattering measurements on the S=1/2 kagomé lattice antiferromagnet ZnCu$_3$(OH)$_6$Cl$_2$ revealed the possibility that the ground state represents a new state of matter.\textsuperscript{1,2} This work addressed an important challenge in condensed matter physics: the search for quantum spin liquid states in two dimensional systems. These states are unusual in that neither translational nor spin rotational symmetries are broken. It is believed that the S=1/2 Heisenberg antiferromagnet on a kagomé lattice (composed of corner sharing triangles) is an ideal system to look for spin liquid physics due to the high degree of frustration. The measured susceptibility of ZnCu$_3$(OH)$_6$Cl$_2$ indicates a Curie-Weiss temperature of $q_{CW} \approx -300$ K; however, no magnetic order is observed down to 50 mK. Inelastic neutron scattering reveals a spectrum of low energy spin excitations with no observable gap down to 0.1 meV. These results suggest that an unusual spin-liquid state with essentially gapless excitations is realized in this kagomé lattice system.

Due to the difficulty in making single crystals of ZnCu$_3$(OH)$_6$Cl$_2$, all current measurements have been performed on powder samples. In order to better interpret the current wealth of experimental data, one of the most pressing questions to address next is the role of impurities and/or spin anisotropy in affecting the low energy physics. For example the upturn in the magnetic susceptibility at low temperature may due to a few percent of spin impurities or a Dzyaloshinskii-Moriya (DM) interaction (which arises due to the buckled Cu-O-Cu bond). Recent NMR work by our collaborators\textsuperscript{3} indicates that some degree of structural inhomogeneity exists in the material as evidenced by broad NMR lineshapes. A peak in the NMR relaxation rate as a function of temperature points to a lattice freezing occurring below around 50 K, presumably associated with OH bonds. In order to get further information on the relevant terms in the spin Hamiltonian, we have performed a systematic study of the ground state and excitations in the related Cu$_2$(OH)$_3$Cl material. This material consists of Cu kagomé lattice layers separated by Cu triangular lattice layers. Hence, it is not an ideal two-dimensional system, and in fact it magnetic orders below $T=6$ K. By measuring the canted moment in the ordered phase as well as the spin-wave excitations, we have estimated the magnitude of the DM interaction to be roughly on the order of ten percent of the magnetic exchange.

The most direct way to determine the magnitude of spin anisotropy in ZnCu$_3$(OH)$_6$Cl$_2$ would be to measure the magnetic response of single crystal samples. Therefore, we have made a targeted effort to grow large single crystals. In a recent breakthrough, we have developed hydrothermal methods that yield appreciably sized crystalline samples (an example is shown in Figure 1). Crystals as large as 2 mm have been grown; however, the largest crystals currently suffer from multiple twin domains. Refinement of the growth technique and preliminary thermodynamic measurements are ongoing. On a simultaneous path, we have pursued synthesis of other structurally perfect S=1/2 kagomé materials. One recent success has been the organic-inorganic hybrid compound Cu(1,3-bdc) as shown in Figure 2. Again Cu ions form the two-dimensional kagomé network. The measured susceptibility indicates $q_{CW} \approx -33$ K, and a cusp in the specific heat indicates a phase transition occurring at $T_N=2$ K. The large ratio of $q_{CW}/T_N$ indicates a high degree of frustration. Further work is in progress to determine the nature of the ordered phase below $T=2$ K.
