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Anomalous Excitation Spectra of Frustrated Quantum Antiferromagnets

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Recommended and Commentary by Matthew Fisher, UCSB

In the ongoing search for exotic quantum phases in strongly correlated electron models with time reversal invariance, frustrated quantum magnets with low spin provide perhaps the simplest theoretical and experimental setting. In the absence of itinerant electrons, it is possible to obtain quantum spin model Hamiltonians which should be reasonably faithful to the microscopics of experimental systems, and indeed in a few cases with small enough exchange interactions the Hamiltonians can be essentially measured experimentally via neutron scattering in the presence of strong spin polarizing fields. Perhaps the best experimental candidates to date which appear to be showing signatures of exotic "spin liquid" behavior and/or strongly suppressed magnetic ordering, are $s = 1/2$ anisotropic triangular lattice antiferromagnets, notably Cs_2CuCl_4 and one organic material in the κ-(BEDT) family.

The holy grail in such frustrated quantum magnets is to find, explore and characterize genuine "spin liquid" phases of Mott insulators with $s = 1/2$ per unit cell which do not exhibit magnetic long-ranged order or any other type of symmetry breaking. On the theoretical front, this search is greatly impeded by the intrinsic intractability of even the simplest models of frustrated quantum magnets, - plagued with "sign" problems which preclude reaching low temperatures in quantum Monte Carlo, much as for the Hubbard model. Moreover, despite the comparatively "small" Hilbert spaces compared to the itinerant electon models, exact diagonalization studies on the quantum spin models are severely restricted by finite size difficulties.

A small glimmer of light in this theoretical impasse is provided by the most old fashioned of approaches - perturbation theory - or high order series expansions. The condmat article by W. Zheng et. al. represents the latest efforts by a group of (the comparatively few) experts in this method to garner some information about the $s = 1/2$ triangular lattice antiferromagnetic. Specifically, the reported calculations involve high order series expansions to obtain the excitation spectra in a class of anisotropic models interpolating between the square and triangular lattice models, which exhibit both collinear and coplaner order in the ground state phase diagram. Of interest are deviations from spin wave analysis due to the frustration. Their main conclusion is that as the frustration is increased deviations from spin wave theory become increasingly pronounced, and moreover the excitation spectra show the development of local minima at particular wavevectors in the magnetic Brillouin zone. The authors refer to these minima as "rotons", in analogy with the spectra of superfluid He^4.

The interpretation and ultimate importance of these "roton" minima is subject to debate. The authors ascribe the minima to spinon-pair bound states of an underlying spin-liquid state which has developed coincident magnetic order. Although not stated by the authors, this state would constitute a truly exotic antiferromagnet, inaccessible via adiabatic evolution from the magnetic states obtained within spin wave theory. A simpler scenario might be that the softening of the spectra are signatures of a nearby quantum transition out of the magnetic state, perhaps into a spin liquid. In either case, the particular momenta of the roton minima give one rather specific information that constrains any theory of spin liquid phases in triangular lattice models. A possible theoretical scenario is a quantum phase transition from the Neel state to a gapless "algebraic" spin liquid due to a softening at just these roton minima. In any event, series expansions of this sort which can give one extremely non-trivial dynamical information are exceedingly valuable. Hopefully, more work along these lines is forthcoming, including, perhaps, generalizations to Kagome lattice $s = 1/2$ AFMs.