INSTITUT NEEL Grenoble

PhD thesis project

Searching for Quantum Spin Ice through disorder

Context :
Geometrical frustration in magnetism has become a central challenge in contemporary condensed matter physics. It is the source of many exotic ground states whose understanding remains a problem for both theoreticians and experimentalists. "Spin ice" is an example of such a state where the magnetism is governed by local rules giving rise to a ground state degeneracy, and whose excitations can be described as magnetically charged quasiparticles, called magnetic monopoles [1].
When quantum fluctuations are present in spin ice, a new magnetic state is stabilized, called "Quantum spin ice" (QSI), in which new excitations emerge, especially at low energy where the existence of an emergent photon quasiparticle has been predicted [2].
However, constraints are very strong to stabilize this exotic QSI state and experimental realizations of this state remain scarce, and debated. A novel route has been proposed to reach this state: the introduction of disorder. In the case of non-Kramers ions (ions with integer spins), non-magnetic disorder can indeed generate transverse fields, which in turn can induce quantum fluctuations and then may stabilize a QSI state [3].

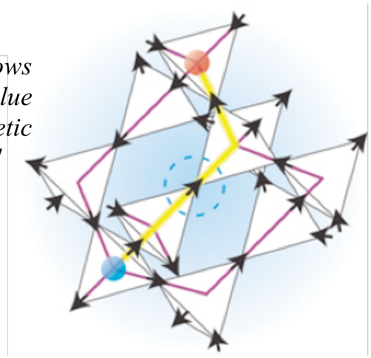

Figure : Illustration of a spin ice state. Black arrows represent the spins on the magnetic sites. Red and blue spheres represent excitations, known as magnetic monopooles which move on the lattice. From ref [4]

[1] Harris et al. Phys. Rev. Lett. 79, 2554 (1997),
Castelnovo et al, Nature 451, 42 (2008).
[2] Gingras et al., Rep. Prog. Phys. 77, 056501 (2014).
[3] Savary et al., Phys. Rev. Lett. 118, 087203 (2017).
[4] Moessner, Nature Phys. 5, NV (2009).

Objectives and means available :
In this thesis, we will study systems based on the classical spin ice $Ho_2Ti_2O_7$ in which we have introduced disorder on the non-magnetic Ti site via a Hf subsitution. This will allow us to explore the possibility of controlling quantum fluctuations using chemical disorder in these $Ho_2(Hf_{1-y}Ti_y)_2O_7$ solid solutions.
In spin ice, the dynamics are very slow at low temperature, but extend on a large time scale. The introduction of quantum fluctuations through disorder is expected to fasten these dynamics. The objective of this thesis is thus to probe systematically the dynamics down to very low temperature (70 mK) in these systems by ac susceptibility and neutron spin echo meaurements, in order to access the relaxation time in the 10^{-9} to 10^{3} s range. This will provide us a quantitative picture of the effect of disorder in the introduction of quantum flucutations.
The experiments will be performed on very low temperature magnetometers developed at the Institut Néel and neutron scattering large scale facilities. The PhD thesis will encompass developments on these magnetometers to improve the sensitivity and the frequency range of our measurements.

Possible collaboration and networking :
Thsi study is performed in collaboration with Romain Sibille (PSI) who provides the samples.

Required profile : Master 2 in Physics

Foreseen start: October 2023

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