# Experimental report

01/07/2022

**Proposal:** 4-05-793 **Council:** 4/2020

**Title:** Origins of the Quantum Spin Ice state and Threshold Effect in Pr2Hf2O7

**Research area:** Physics

**This proposal is a resubmission of 4-05-772**


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**Local contacts:** Jacques OLLIVIER


**Samples:** Pr2Hf2O7

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| IN5 | 5 | 5 | 25/02/2021 | 02/03/2021 |


## Abstract:

The Quantum Spin Ice (QSI) state, where the two-in-two-out configurations formed by the Ising variables are allowed to tunnel among themselves, is realised in Pr2Hf2O7 based on our last measurements on IN5 (Nature Physics, 14, 711-715 (2018)). The quantum field theory (quantum electrodynamics) that was used to compare with our data, predicts another distinctive feature for this ground state: the suppression of the pinch points, as compared to the sharp anisotropic features observed in classical spin ices, should be progressive as a function of temperature (Phys. Rev. B, 86, 075154 (2012)). We propose to measure this temperature dependence, which will put further limits on the parameters of the theory used to reproduce the experimental data. Moreover, in a second time, we propose to use a longer wavelength in order to better measure the lower edge of the continuum of spin excitations, where a 'threshold effect' was recently predicted by theory (arXiv:1906.01628).

**Experiment: 4-05-793 : Origins of the Quantum Spin Ice state and Threshold Effect in Pr2Hf2O7**

After being carefully mounted on a dilution fridge oriented with the [1-10] crystallographic direction vertical (thus giving access to the HHL scattering plane), the sample (single crystal of $Pr_2Hf_2O_7$) was cooled down to base temperature (~50mK). A first quick (almost) full rotation of the crystal was performed in order to determine the accessible reciprocal space using 5.5 Å incident wavelength, as well as absorption effects (Fig. 1).
Based on the obtained map, two small rotation ranges were chosen to investigate the temperature dependence of the spin ice signal in two different regions of reciprocal space. A first range covering the HHH direction was chosen (2° steps on 50°) and measured using a 10Å incident wavelength at base temperature (Fig. 2) and at 20K (used for background subtraction). A second one covering the 00L arm of the spin ice pattern was defined (1° steps on 28°) and investigated using 5.5Å incident wavelength at base temperature (Fig. 3), 0.3 K, 0.8 K and 20 K (once again for background subtraction).

Mantid routines were used to generate the final NXSPE data files and used to reconstitute the S(Q,E) space using Horace. D3d objects were created by integrating over +/- 0.06 reciprocal lattice units perpendicular to the scattering plane. Absorption corrections were applied to the d3d object before high temperature subtractions.

Data are now investigated by integrating along various directions in reciprocal space and over different energies (see example in Fig. 4).

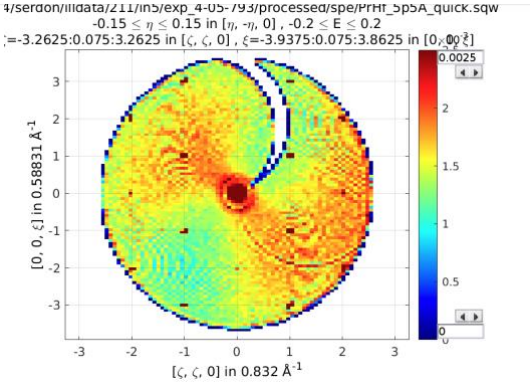


**Figure 1:** Close to full rotation of the sample using incident wavelength of 5.5 Å.

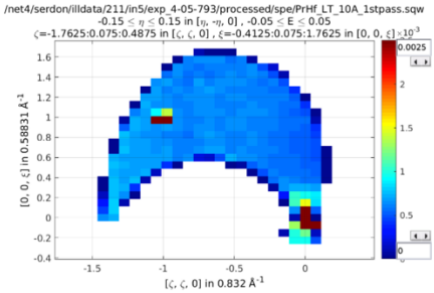


**Figure 2:** Coverage of the HHH direction using an incident wavelength of 10 Å at base temperature.

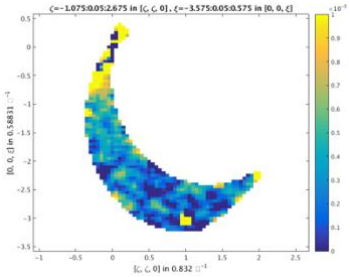

**Figure 3:** Coverage of the 00L direction using an incident wavelength of 5.5 Å at base temperature, corrected for absorption.

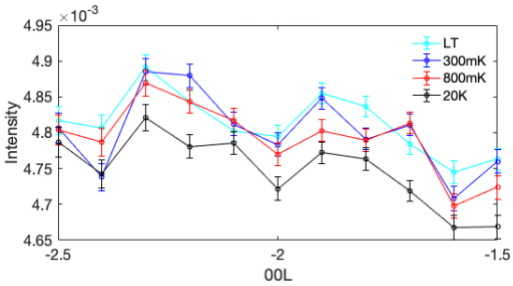


**Figure 4:** Investigation of the spin ice signal's temperature dependence, along the 00L direction. The current plot was integrated over +/- 0.06 meV and over +/-0.25 along the HH0 direction.