# Experimental signatures of emergent quantum electrodynamics in $Pr_2Hf_2O_7$

R. Sibille[a*], N. Gauthier,[a] H. Yan,[b] M. Ciomaga Hatnean,[c] J. Ollivier,[d] B. Winn,[e] G. Balakrishnan,[c] M. Kenzelmann,[a] N. Shannon,[b] and T. Fennell[a]

a. Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
b. Okinawa Institute of Science and Technology, Onna-son, Okinawa 904-0495, Japan
c. Physics Department, University of Warwick, Coventry, CV4 7AL, UK
d. Institut Laue-Langevin, CS 20156, 38042 Grenoble Cedex 9, France
e. Neutron Scattering Division, Oak Ridge National Laboratory, Tennessee, USA

* romain.sibille@psi.ch

Magnetic systems with competing interactions often adopt exotic ground states, which can be relevant to study new physics in quantum matter. A recurrent ingredient to stabilize such phases is geometrical frustration, such as in pyrochlore oxides where rare-earth magnetic moments decorate a lattice of corner-sharing tetrahedra. An unusual spin liquid appears for example in the pyrochlore $Ho_2Ti_2O_7$, which features a classical spin ice short-range correlated state. A local constraint – the 2-in-2-out ice rule acting on each tetrahedron – leads to a manifold of degenerate ground states in which the spin correlations give rise to emergent magnetostatics [1]. Spin flips violating the ice rule generate magnetic monopole excitations, a mobile magnetic charge regarded as a quasiparticle carrying half of the dipole moment. A quantum analogue of the spin ice state is predicted to be a quantum spin liquid formed through the coherent superposition of spin ice configurations [2]. Remarkably, this dynamical ground state leads to emergent electrodynamics. In $Pr_2Hf_2O_7$, the single-ion ground state doublet [3] has a dipole moment of about $2.4\mu_B$ and, perpendicular to it, electric quadrupoles that allow quantum tunneling between the in and out states of the dipole [4]. A correlated ground state with macroscopic indications of spin ice correlations forms below 0.5 K [3]. The experimental structure factor has pinch points – a signature of a classical spin ice – that are partially suppressed, as expected in the presence of quantum dynamics [5]. Moreover, a continuum of magnetic excitations is observed in inelastic neutron scattering, which relates to the monopoles of spin ices that become quantum-coherent fractionalized excitations – akin to the spinons found for instance in quantum spin chains.

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