Higgs transition in quantum spin ice

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In a class of frustrated magnets known as spin ice, magnetic monopoles emerge as classical defects and interact via the magnetic Coulomb law, forming a classical magnetic Coulomb liquid with Pauling’s residual entropy. Once quantum-mechanical spin-flipping interactions are active as in quantum spin ice [1], however, these magnetic charges are carried by fractionalized bosonic quasi-particles, spinons, providing a unique opportunity for a quantum magnetic Coulomb liquid, i.e., U(1) spin liquid, that hosts gapped electric and magnetic monopole and gapless photon excitations. With this gauge theory description, we find that the quantum magnetic Coulomb liquid is stable in a model for Pr$_2$Zr$_2$O$_7$ [2]. On the other hand, the spinons can also undergo Bose-Einstein condensation through a first-order transition via the Higgs mechanism, which establishes conventional long-range ordered states. In particular, we report minimal evidence, obtained with polarized neutron-scattering experiments, of a first-order Higgs transition from a magnetic Coulomb liquid to a ferromagnet in single-crystal Yb$_2$Ti$_2$O$_7$ at $T_C$~0.21 K [3]. The results are explained on the basis of a quantum spin-ice model, whose high-temperature phase is effectively described as a magnetic Coulomb liquid, whereas the ground state shows a nearly collinear ferromagnetism with gapped spin excitations.