



# Magnetic monopole dimers in “correlated” spin ice

The gas of magnetic monopoles in spin ice is governed by the monopole chemical potential. A significant variation of this parameter might lead to new phenomena arising from monopole correlations, like monopole dimerization, critical phase separation, or charge ordering. All previously known spin ices have values of chemical potential that place them deeply within the weakly correlated regime, where none of these phenomena occur. Here we used a high-pressure synthesis route to create a new monopole host,  $\text{Dy}_2\text{Ge}_2\text{O}_7$ , with a radically altered chemical potential that stabilizes a large fraction of monopole dimers, resulting from correlations.

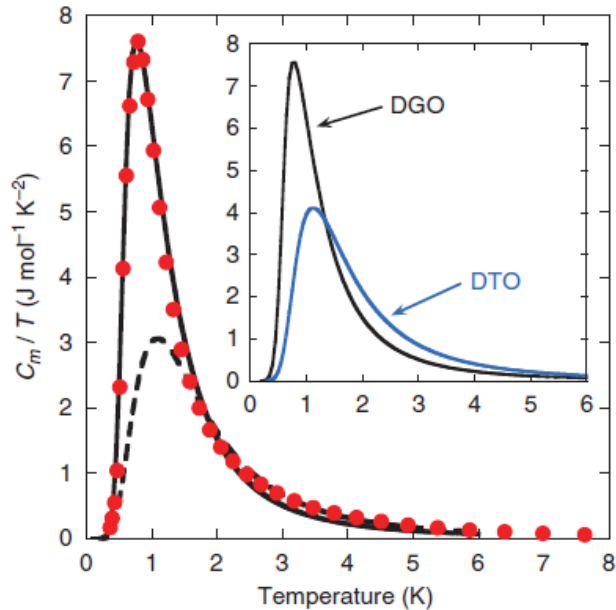


Fig. 1. Heat capacity of  $\text{Dy}_2\text{Ge}_2\text{O}_7$  at zero field compared with theoretical models. The modified Debye-Hückel theory (black line), gives an excellent description of the experimental data (points). Dashed black line shows  $C/T$  for an ideal lattice gas with onsite exclusion. This model describes the data well at low temperatures where Coulomb interactions are neglected, and at high temperatures where the interactions are strongly screened. Inset: the effect of varying chemical potential from  $-3.35$  K (appropriate to  $\text{Dy}_2\text{Ge}_2\text{O}_7$  (DGO)) to  $-4.35$  K (appropriate to  $\text{Dy}_2\text{Ti}_2\text{O}_7$  (DTO)).

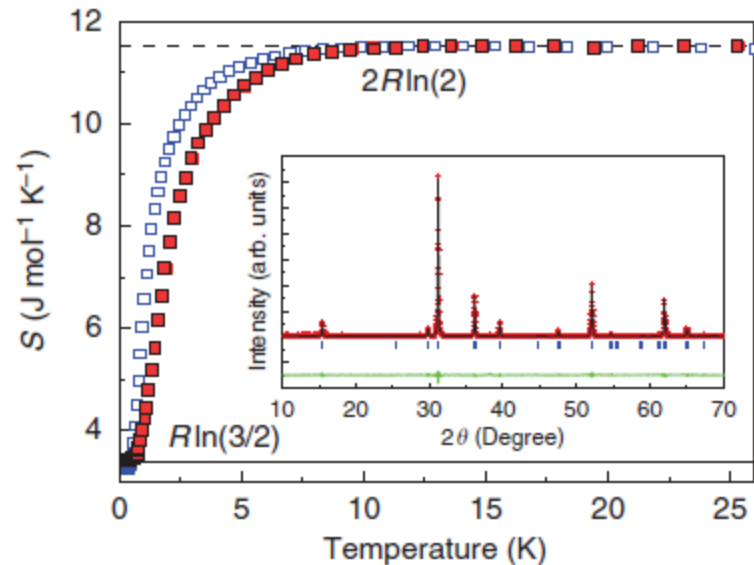


Fig. 2. Proof that  $\text{Dy}_2\text{Ge}_2\text{O}_7$  (open) and  $\text{Ho}_2\text{Ge}_2\text{O}_7$  (solid) have the characteristic Pauling *zero point* entropy of spin ice and water ice. The inset shows the Rietveld refined x-ray powder diffraction pattern of the cubic pyrochlore phase of  $\text{Dy}_2\text{Ge}_2\text{O}_7$ .

Zhou, H.D.; Bramwell, S.T.; Cheng, J.G.; Wiebe, C.R.; Li, G.; Balicas, L.; Bloxson, J.A.; Silverstein, H.J.; Zhou, J.S.; Goodenough, J.B. and Gardner, J.S., *High pressure route to generate magnetic monopole dimers in spin ice*, Nature Communications, **2**, 478 (2011)