Title: Experimental signatures of phase competition in quantum XY pyrochlores

Date: Jun 07, 2017 02:50 PM

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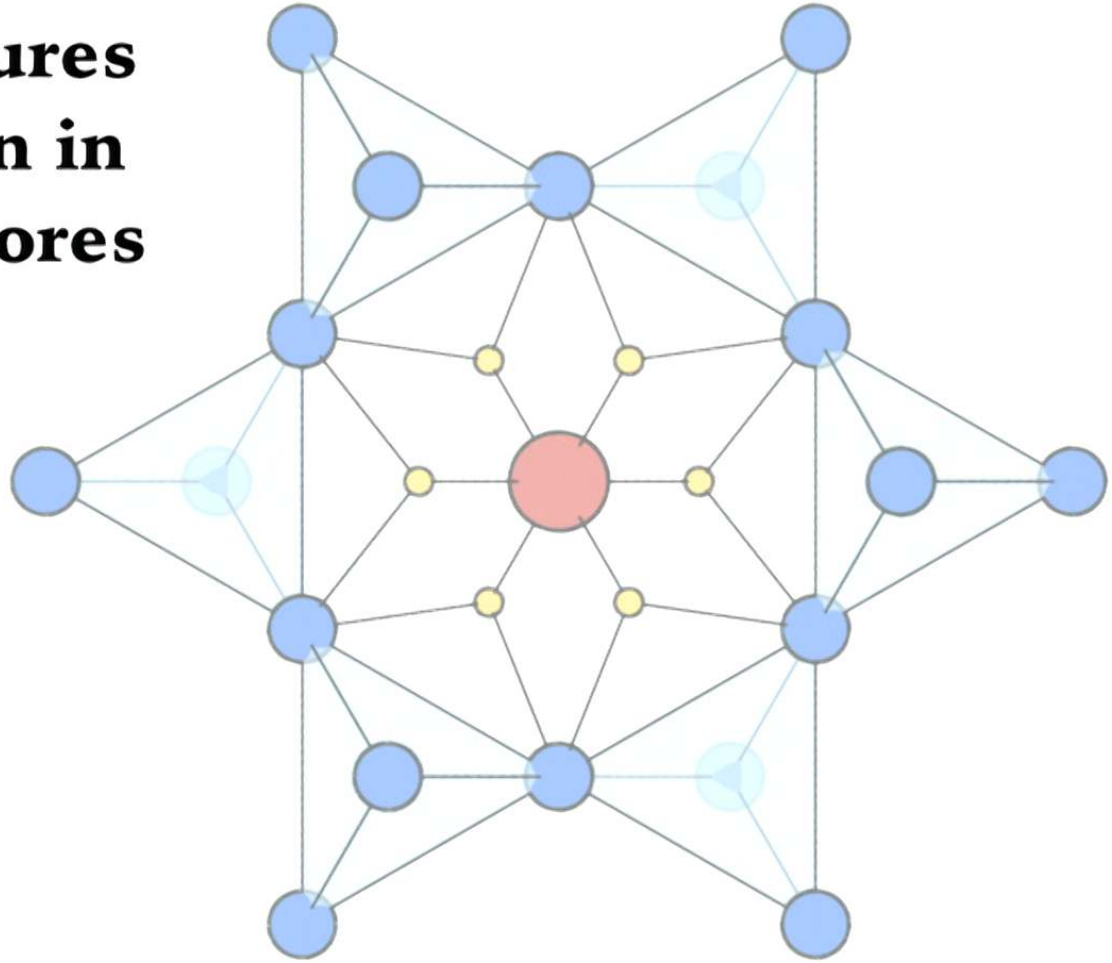
Abstract: The erbium and ytterbium rare earth pyrochlores exhibit local XY spin anisotropy. Experimental and theoretical investigations of XY pyrochlores have revealed a strong propensity for quantum magnetic phenomena, such as order-by-disorder and the quantum spin ice state. We have conducted a systematic investigation of the family of XY pyrochlores, Yb2B2O7 and Er2B2O7, spanning many non-magnetic B site cations (B = Ge, Ti, Pt, and Sn). We have characterized the magnetism of these XY pyrochlores using heat capacity, muon spin relaxation, neutron diffraction, and inelastic neutron scattering. A diversity of magnetic ground states and behaviours are represented among this family, ordered states ranging from ferromagnetic to antiferromagnetic, and in the case of one material, an absence of magnetic order to at least 100 mK. Moreover, we find that the magnetic ground state properties of these materials are strongly influenced by proximity to competing magnetic phases, consistent with theoretical predictions. We empirically demonstrate the signatures for phase competition in the frustrated XY pyrochlores: multiple heat capacity anomalies, suppressed TN or Tc, sample and pressure dependent ground states, and unconventional spin dynamics.

Experimental Signatures of Phase Competition in Quantum XY Pyrochlores



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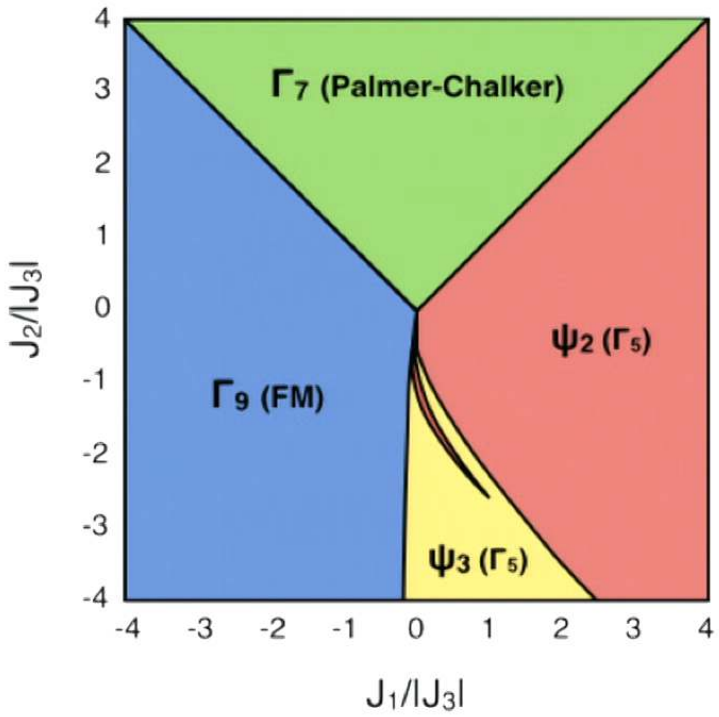
Nick Butch
Guangyong Xu

ORNL (USA)
Adam Aczel
Matt Stone

Theoretical work on phase competition in the XY pyrochlores



PRL 115, 267208 (2015) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2015

Are Multiphase Competition and Order by Disorder the Keys to Understanding $Yb_2Ti_2O_7$?

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(Received 20 May 2015; revised manuscript received 12 September 2015; published 29 December 2015)

PHYSICAL REVIEW B 95, 094422 (2017)

Theory of multiple-phase competition in pyrochlore magnets with anisotropic exchange with application to $Yb_2Ti_2O_7$, $Er_2Ti_2O_7$, and $Er_2Sn_2O_7$

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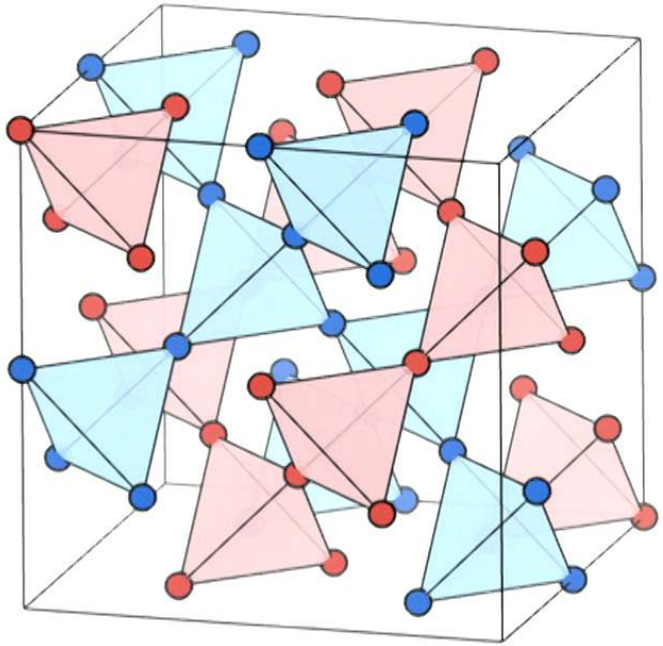
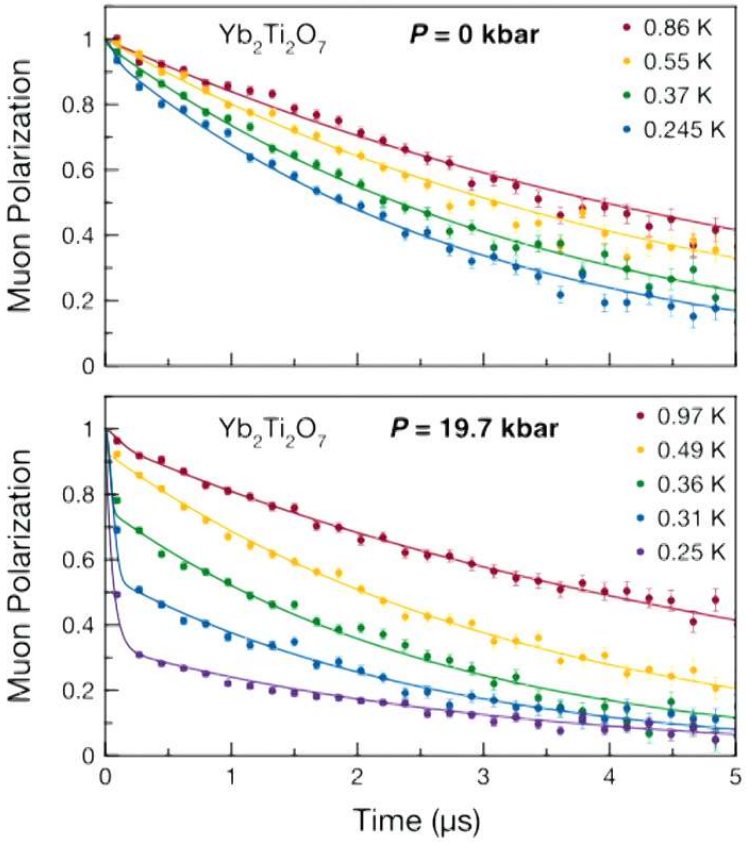
(Received 20 December 2013; revised manuscript received 21 February 2017; published 17 March 2017)

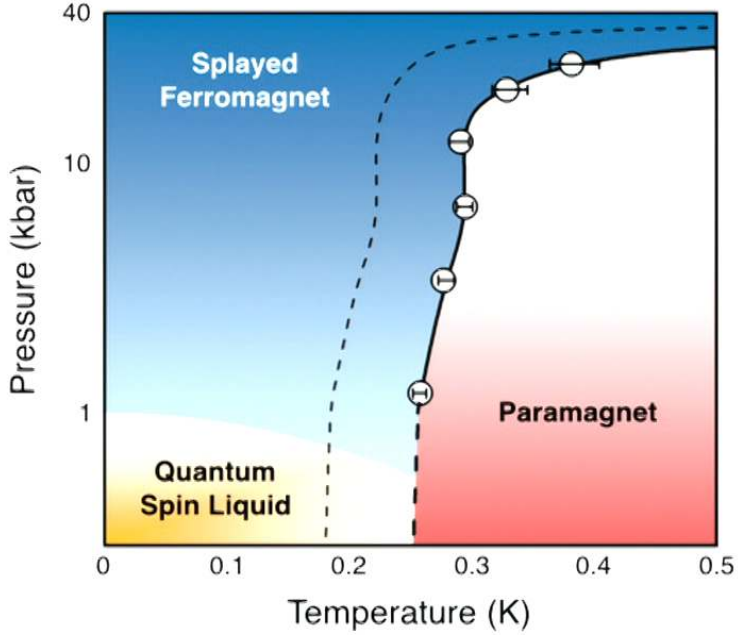
Many of the experimentally observed properties of the XY pyrochlores can be accounted for by a model of phase competition



- Several different magnetic ground states obtained within a narrow range of exchange parameters (via chemical pressure) *(this talk)*
- Suppressed ordering transition, T_N or T_C *(this talk)*
- Sensitivity to disorder *(e.g. talk of Tyrel McQueen)* and sensitivity to applied pressure *(e.g. Kermarrec et al., Nature Comm. 2017)*

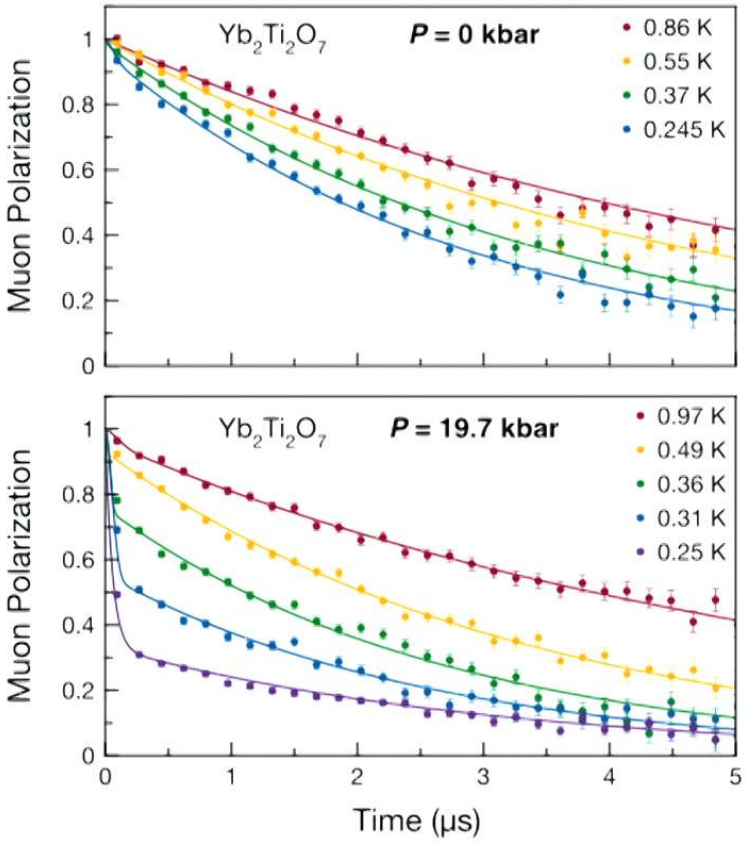
Sensitivity to externally applied pressure in $Yb_2Ti_2O_7$

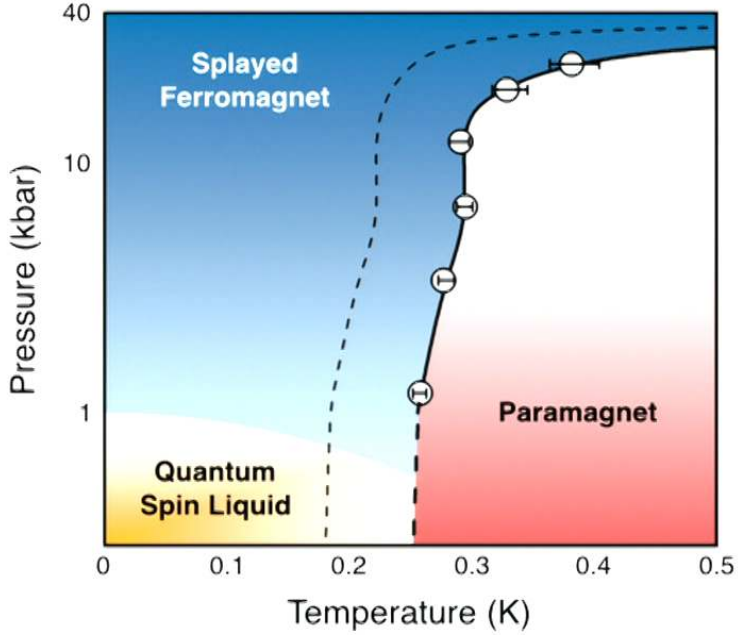




Kermarrec, Gaudet, Gaulin et al., Nature Comm. 8 14810 (2017).

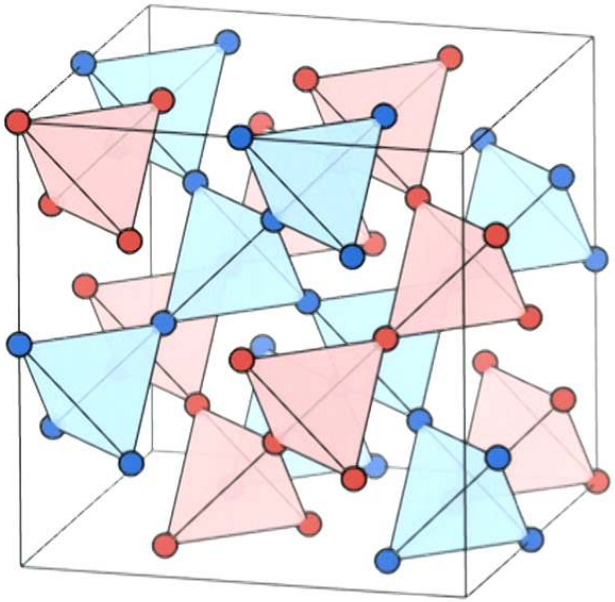
Sensitivity to externally applied pressure in $Yb_2Ti_2O_7$





Kermarrec, Gaudet, Gaulin et al., Nature Comm. 8 14810 (2017).

This talk will examine the effect of *chemical* pressure on the ground states of the XY pyrochlores.



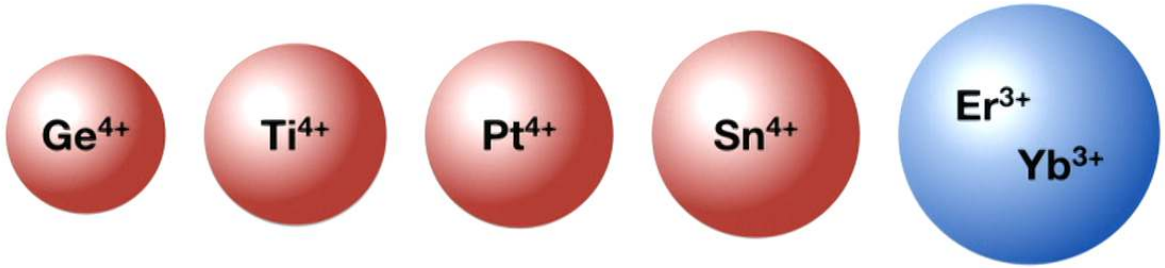
$(Yb^{3+})_2(B^{4+})_2O_7$ & $(Er^{3+})_2(B^{4+})_2O_7$

Yb^{3+}: [Xe] $4f^{13}$, $J = {}^7/_2$

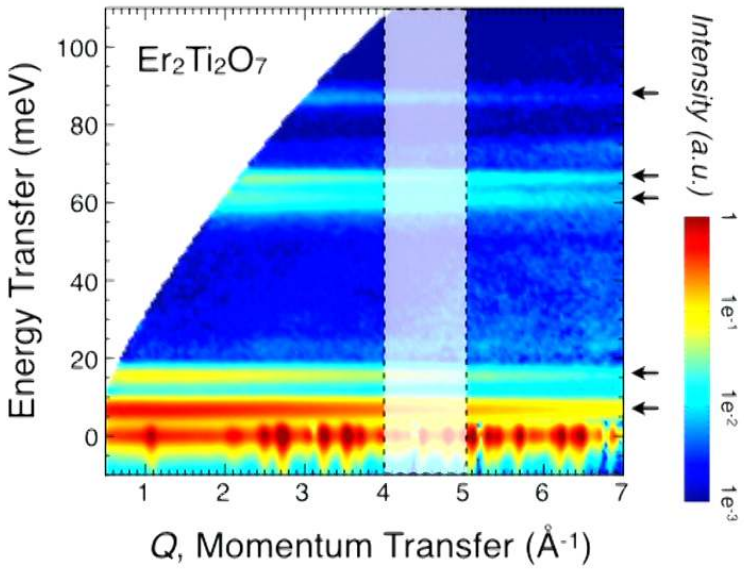
Er^{3+}: [Xe] $4f^{11}$, $J = {}^{15}/_2$

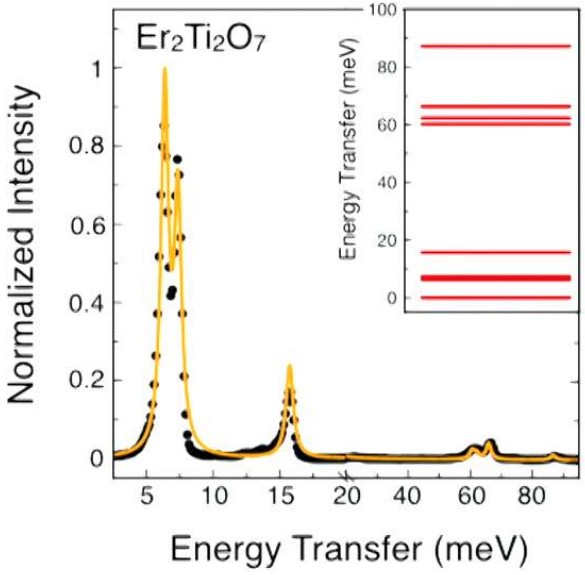
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al		P	S	Cl	Ar
K	Ca		Ti				Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr			Nb						Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba			Ta	W	Re			Pt	Au	Hg				Po	At	Rn

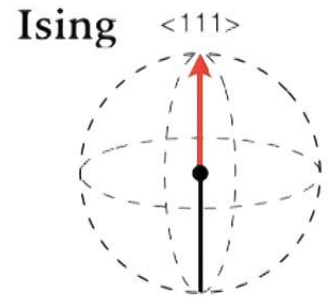
									Er		Yb		
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

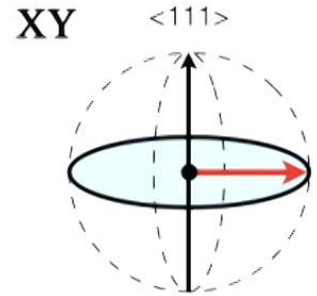


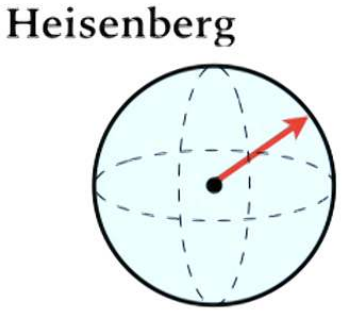
Each of the $Er_2B_2O_7$ and $Yb_2B_2O_7$ (B = Ge, Ti, Pt, Sn) pyrochlores has local XY spin anisotropy







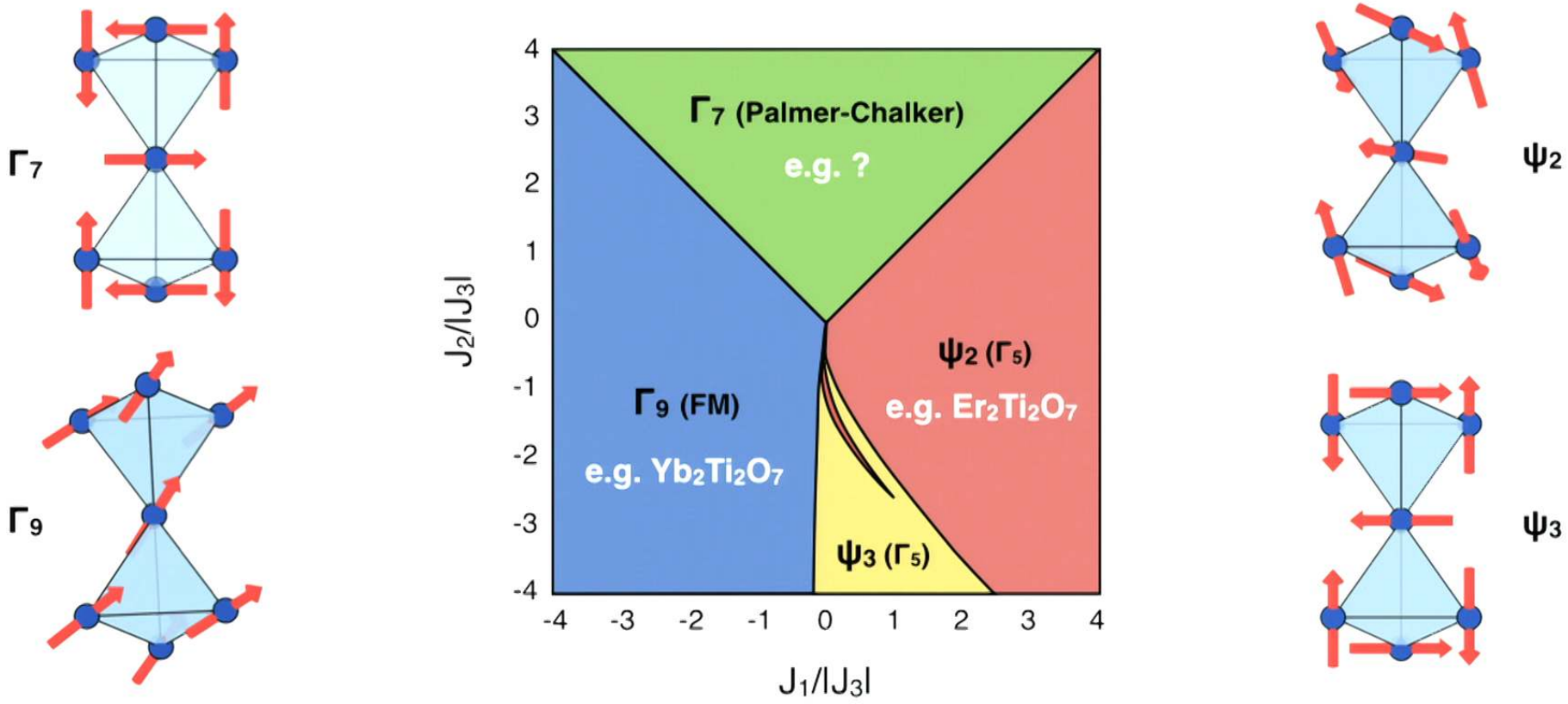




$$g_\perp = 6.3 \qquad g_z = 3.9$$

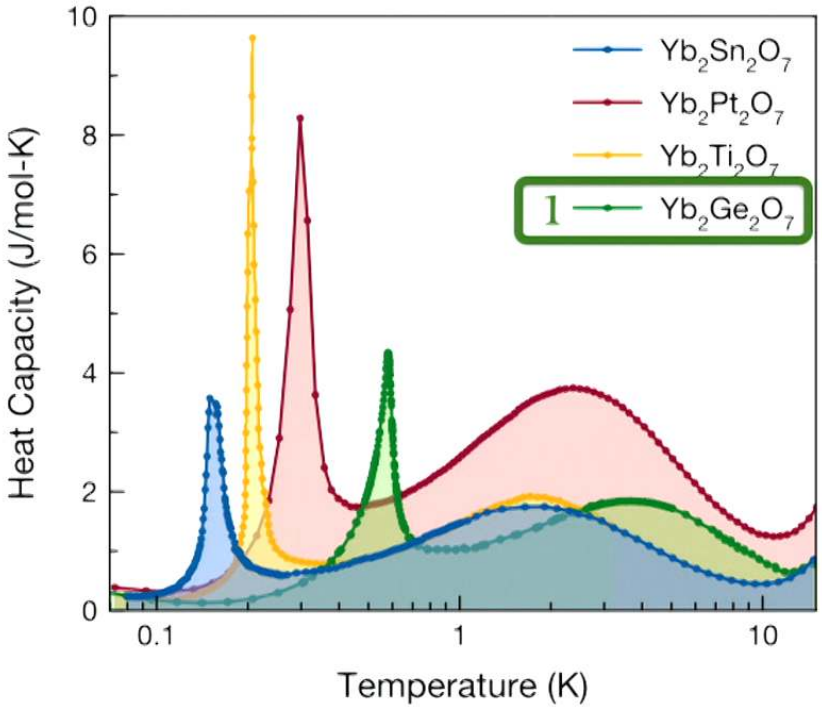
*$Yb_2Ti_2O_7$: Gaudet et al., PRB **92**, 134420 (2015).*
*$Yb_2Ge_2O_7$: Hallas et al., PRB **93**, 104405 (2016)*
$Er_2B_2O_7$: Gaudet et al., in preparation

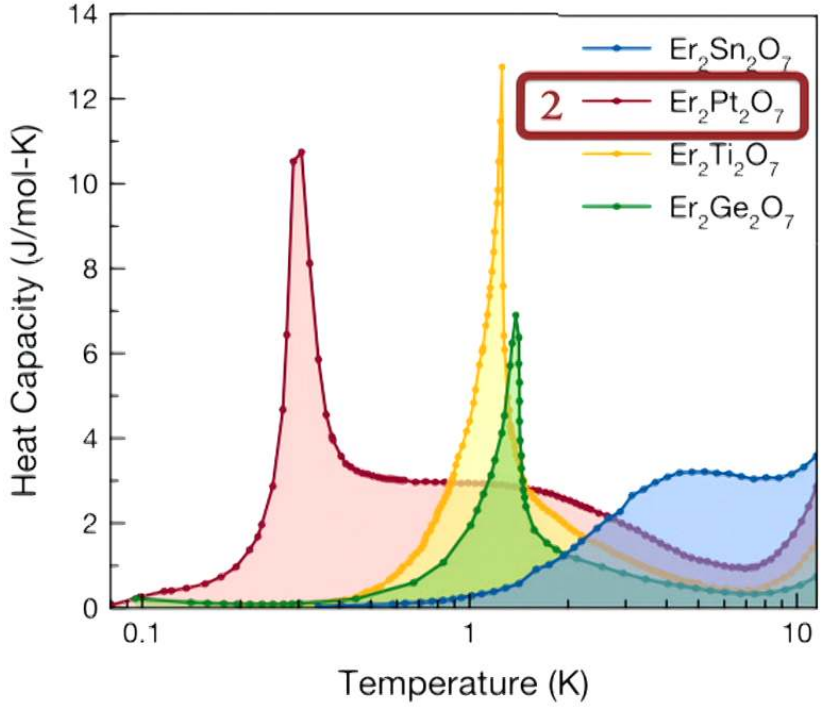
Four classical states in the anisotropic exchange phase diagram for XY pyrochlores.



Yan, Benton, Jaubert and Shannon, PRB 95 094422 (2017).

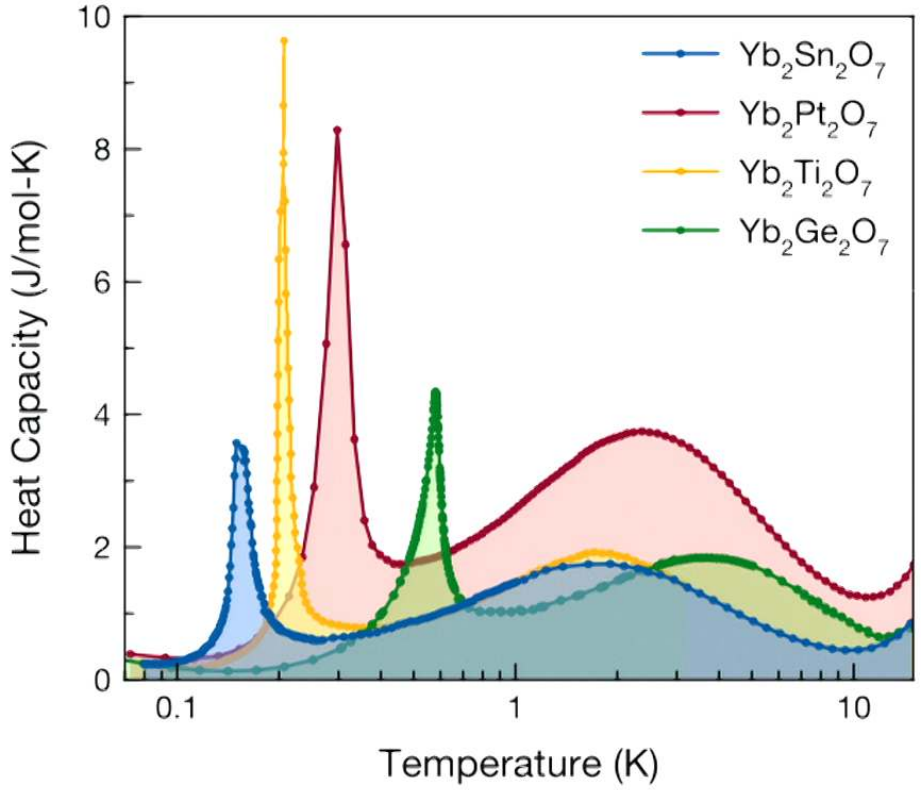
We have investigated the low temperature magnetism of two new members of the XY pyrochlore family.





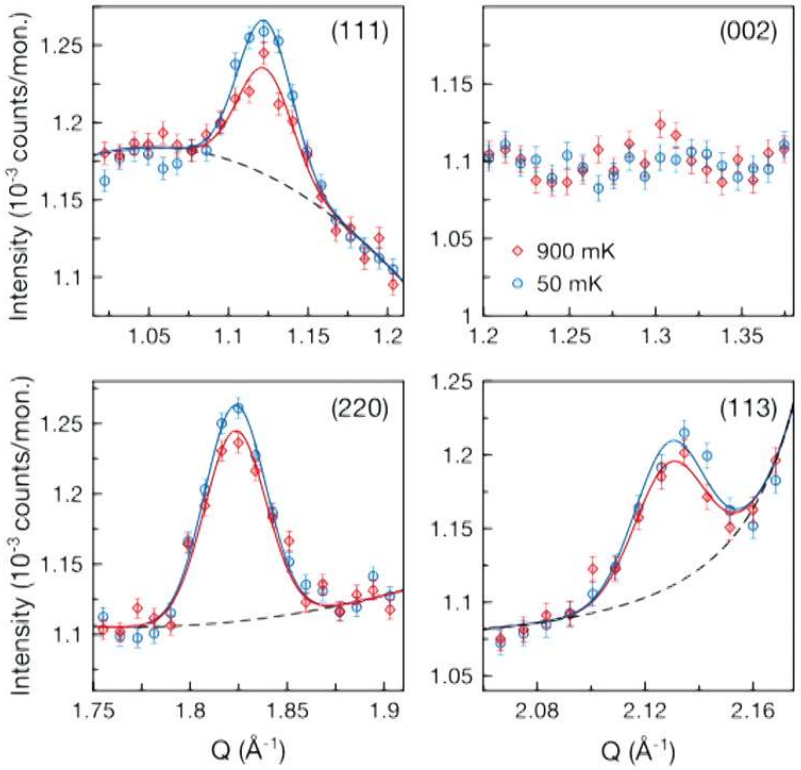
Hallas, Gaudet, Gaulin, to appear in Annual Reviews of Condensed Matter Physics

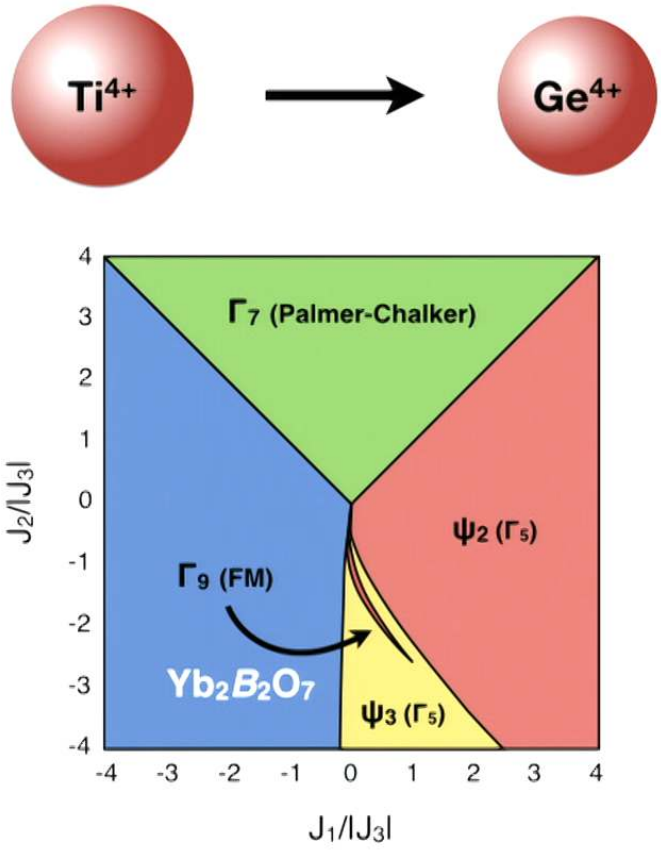
The Yb pyrochlores share a common form for their specific heat.



Hallas, Gaudet, Gaulin, to appear in Annual Reviews of Condensed Matter Physics

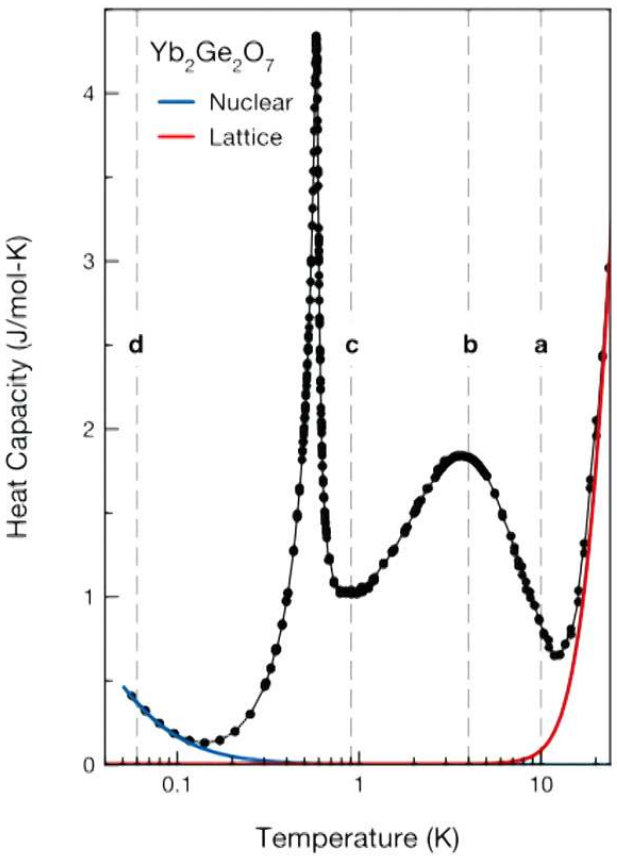
Positive chemical pressure takes $Yb_2B_2O_7$ from Γ_9 ferromagnet to Γ_5 antiferromagnet (ψ_2 or ψ_3).

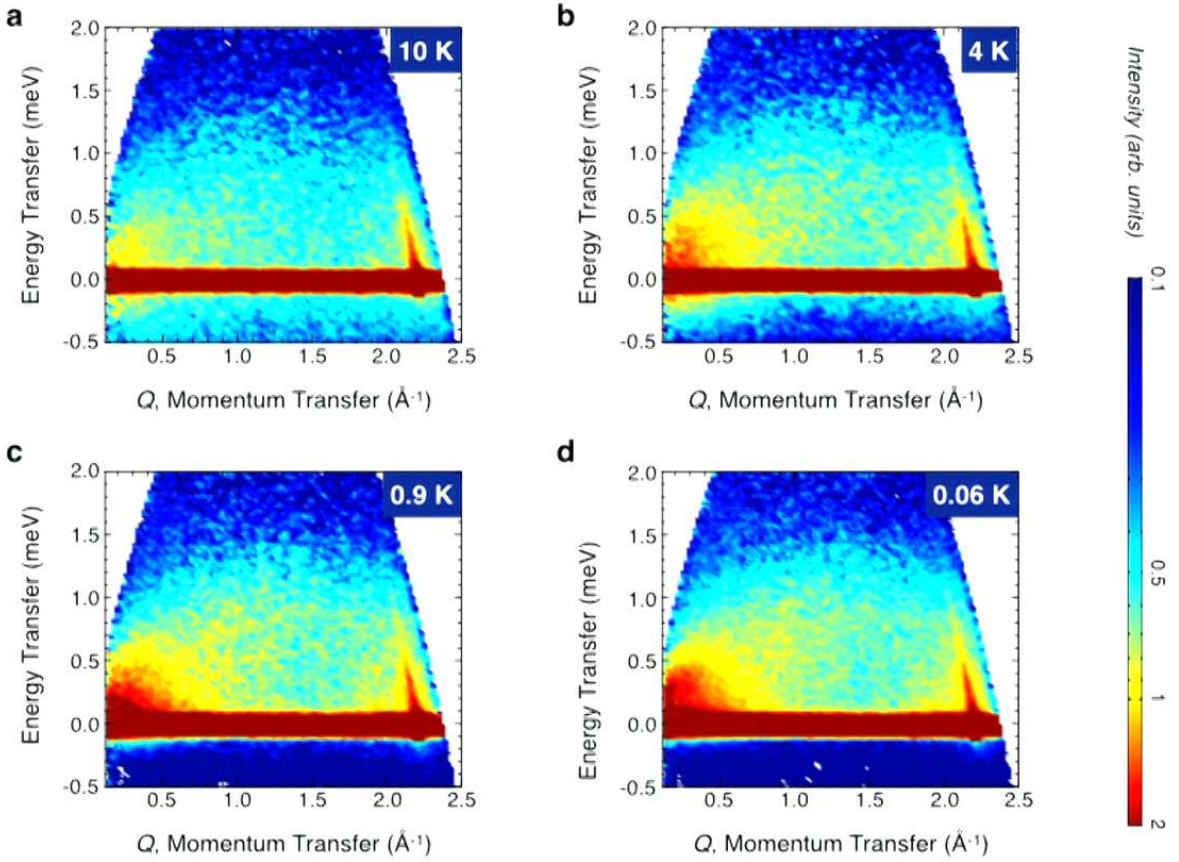




Hallas et al., PRB **93**, *104405 (2016)*

The spin excitations of $Yb_2Ge_2O_7$ do not evolve below T_N = 0.6 K.



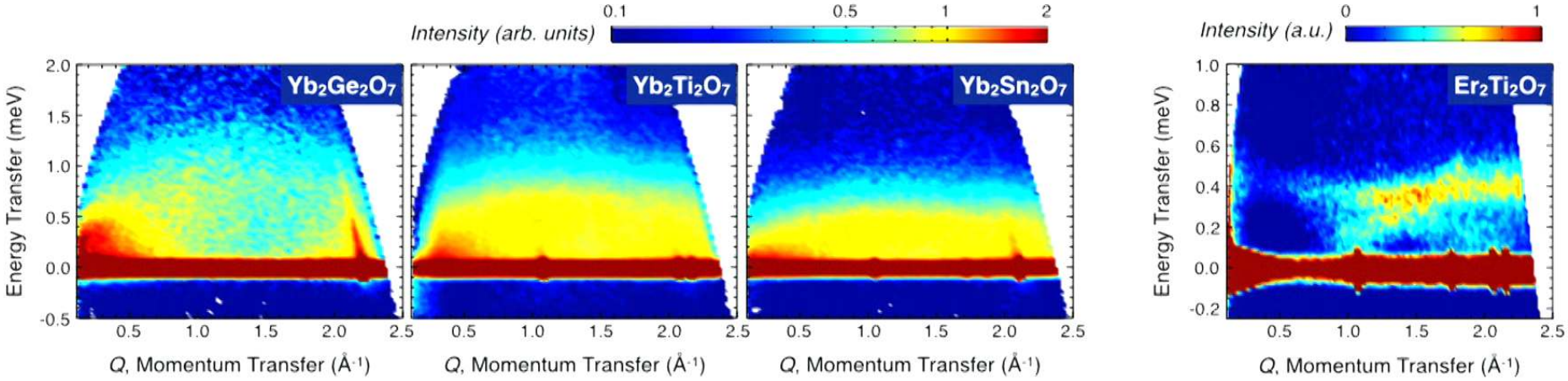


Hallas et al., PRB **93**, *100403(R) (2016).*

The low temperature spin excitations of the ytterbium pyrochlores share a ubiquitous form.

Gapless Continuum of Excitations

Spin Waves



AFM Γ_5

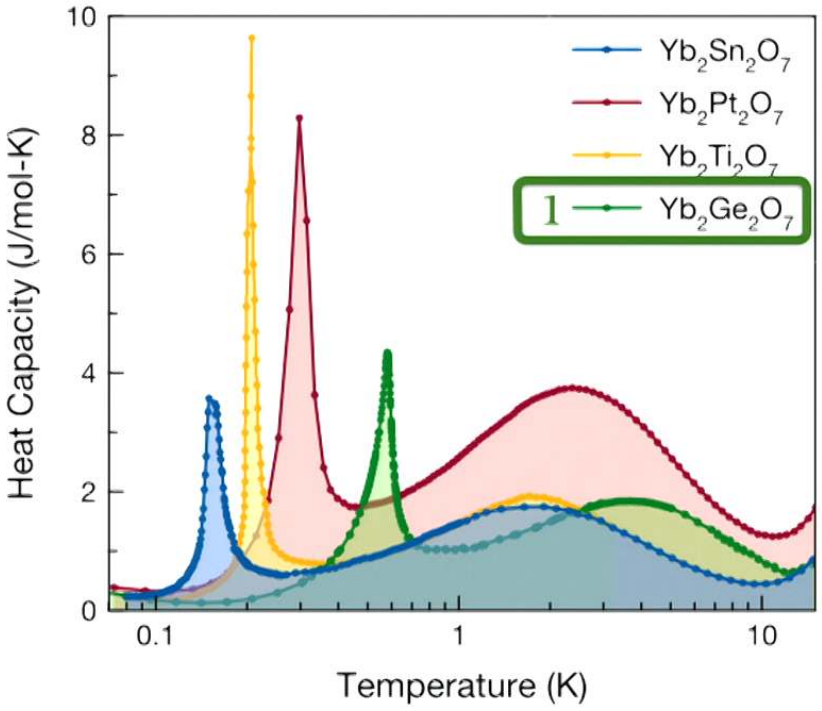
FM Γ_9

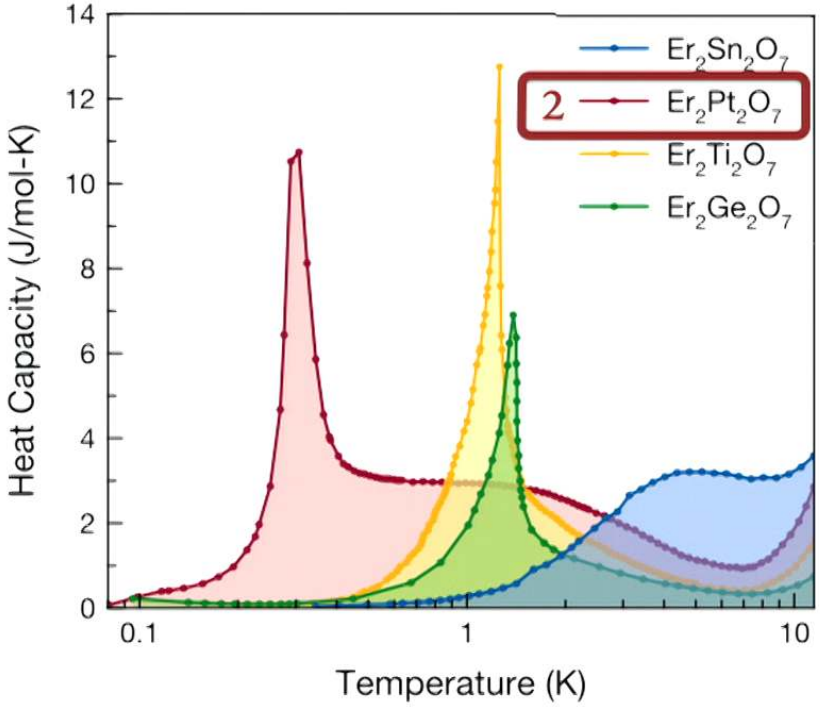
FM Γ_9

AFM Γ_5

Hallas et al., PRB **93**, *100403(R) (2016).*

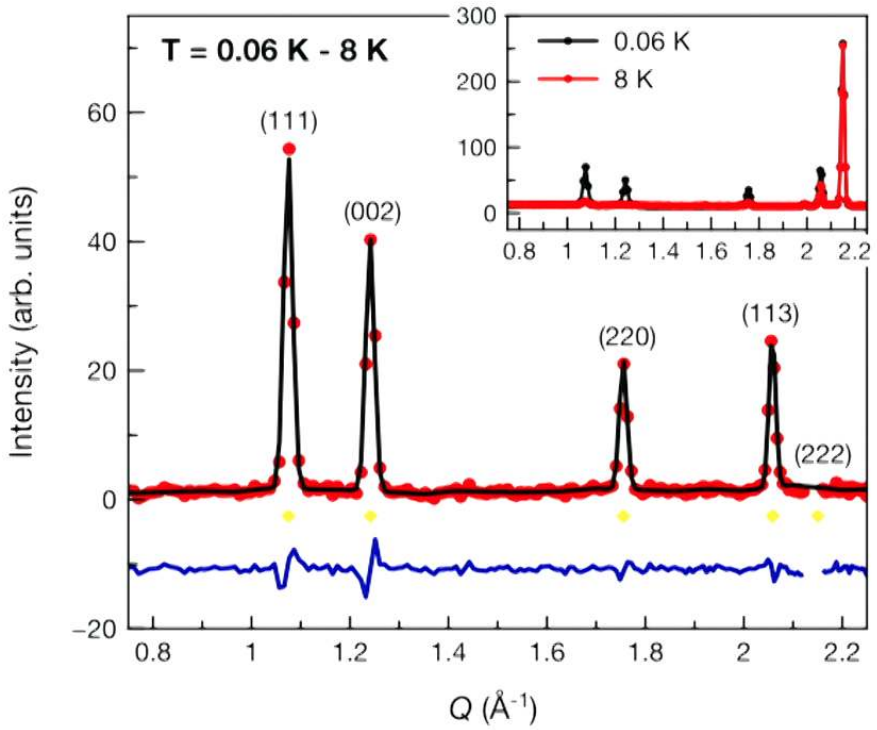
We have investigated the low temperature magnetism of two new members of the XY pyrochlore family.

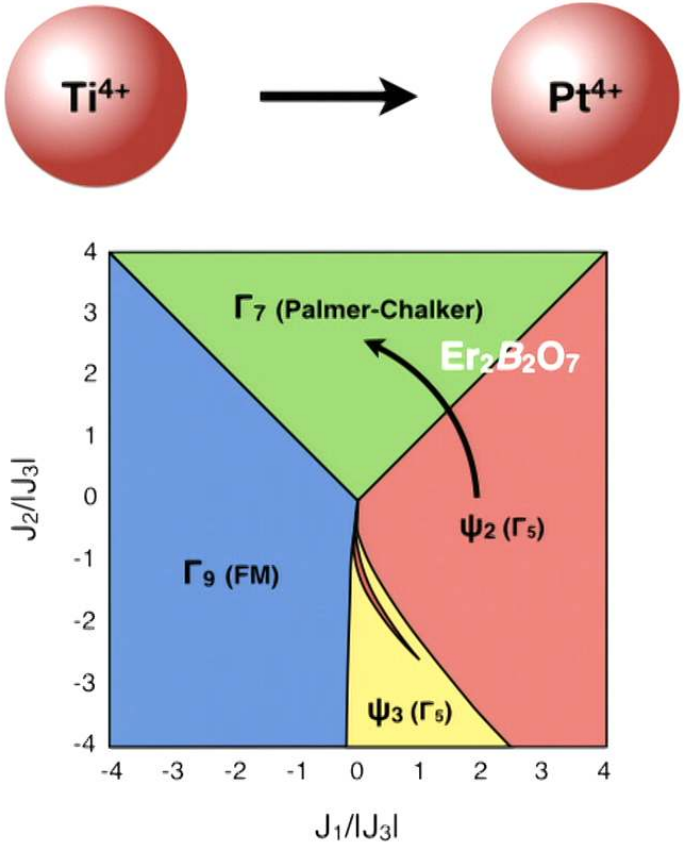




Hallas, Gaudet, Gaulin, to appear in Annual Reviews of Condensed Matter Physics

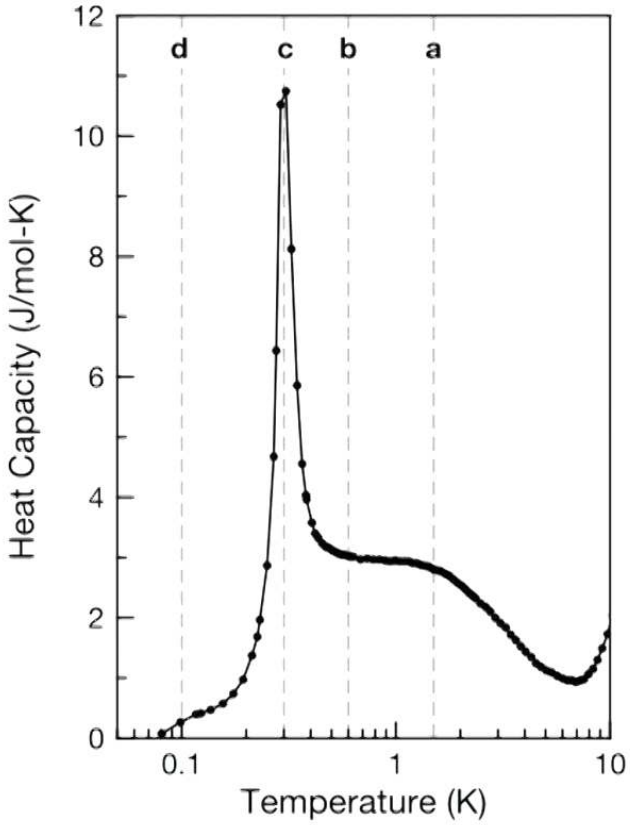
Negligible chemical pressure takes $Er_2B_2O_7$ from ψ_2 antiferromagnet to Γ_7 Palmer Chalker antiferromagnet.

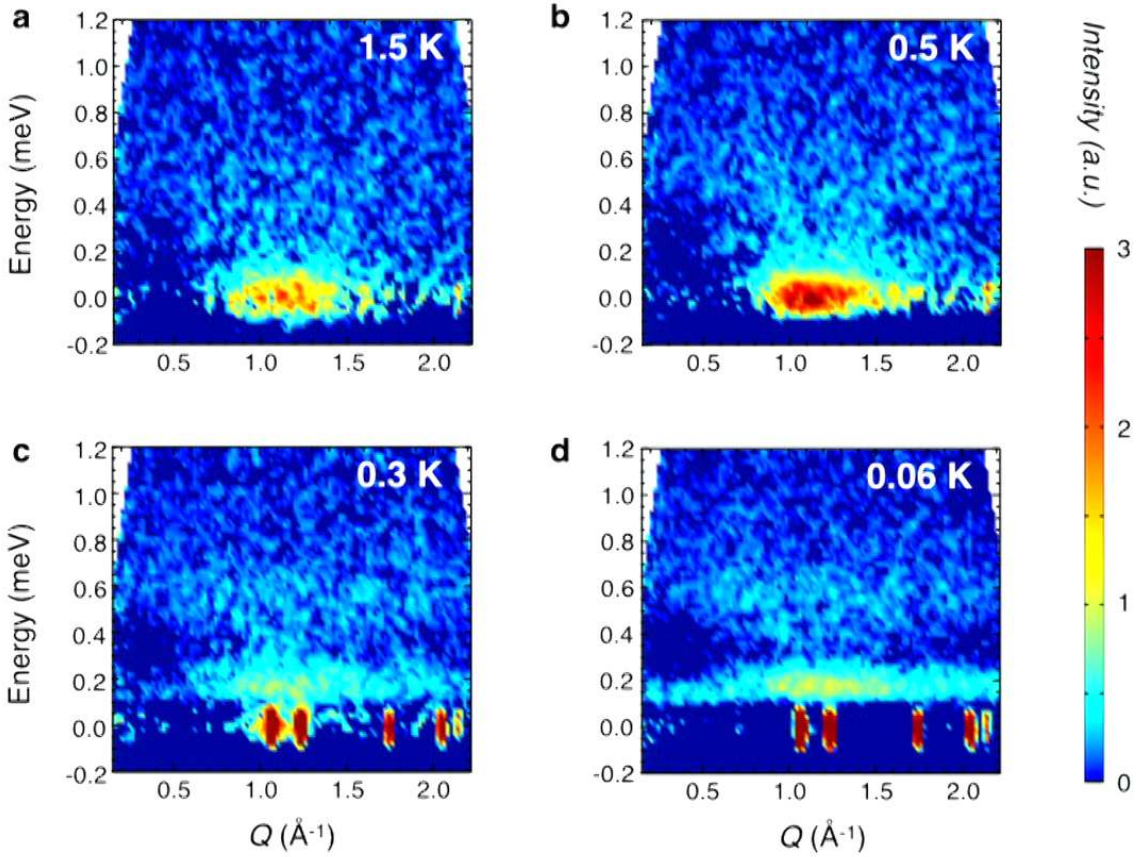




Hallas et al., arXiv 1705.06680 (2017)

Short range correlations develop in $Er_2Pt_2O_7$ at T* = 1.5 K.





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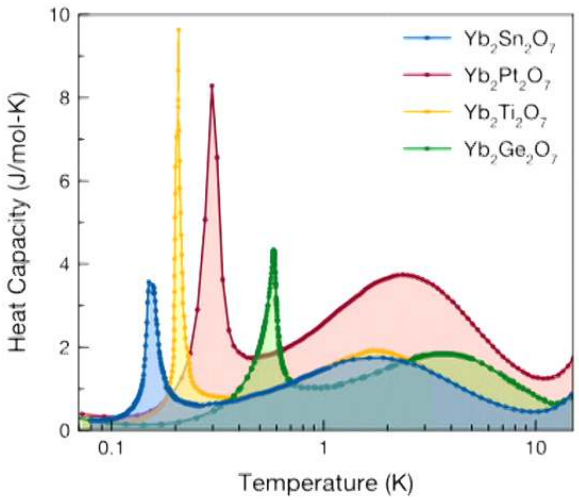
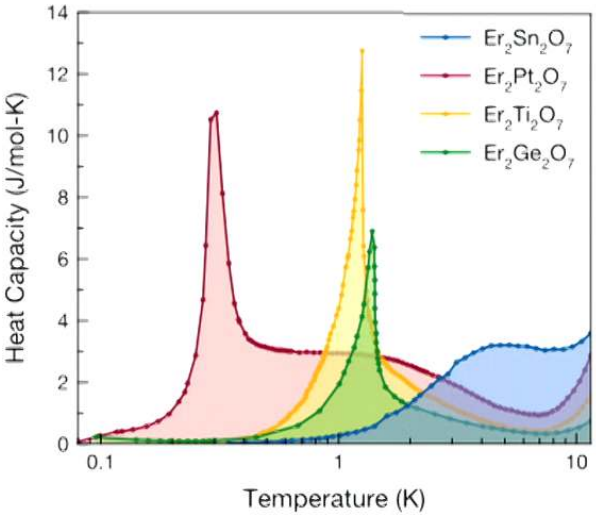
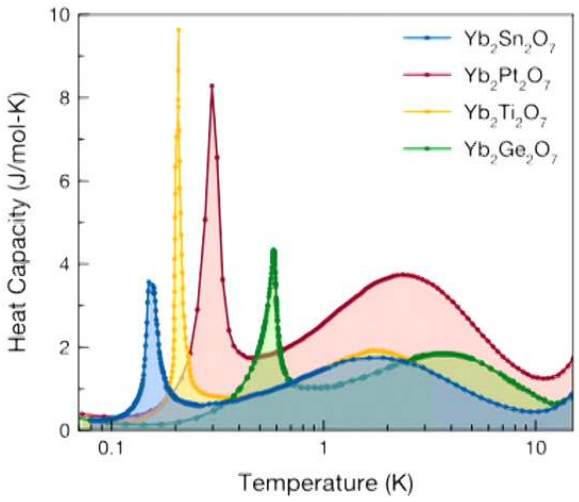
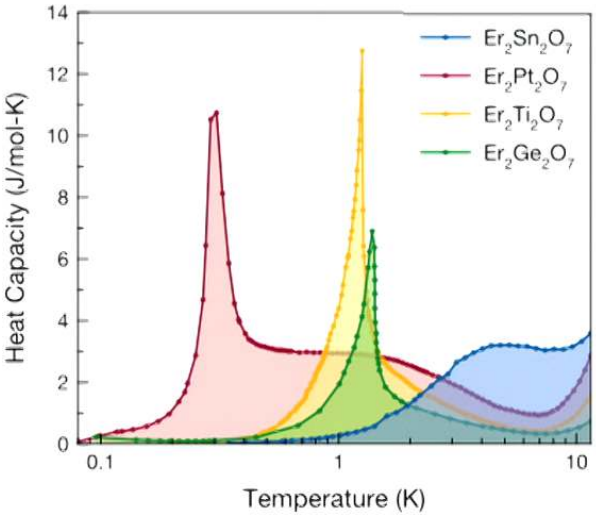




$Er_2Ti_2O_7$ & $Er_2Ge_2O_7$

$Yb_2B_2O_7$, $Er_2Pt_2O_7$, & $Er_2Sn_2O_7$





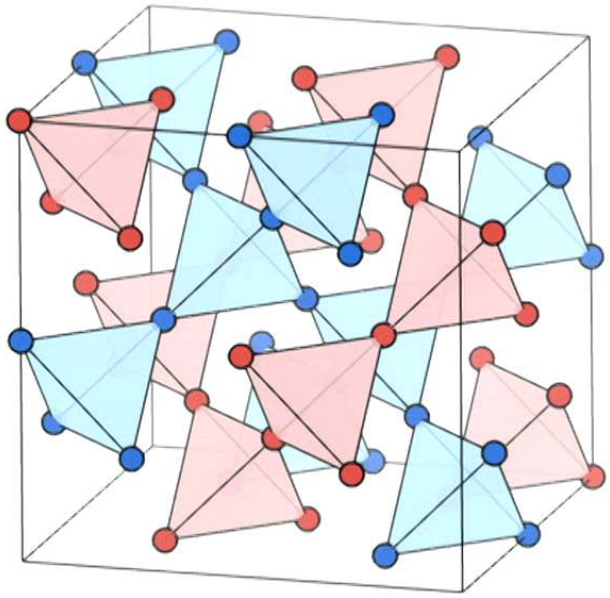
$Er_2Ti_2O_7$ & $Er_2Ge_2O_7$

- Order above 1 K
- Single sharp heat capacity anomaly
- No known sensitivity to disorder

$Yb_2B_2O_7$, $Er_2Pt_2O_7$, & $Er_2Sn_2O_7$

- Order well below 1 K
- Two stage entropy release
- Strong sensitivity to disorder ($Yb_2Ti_2O_7$)

Many of the experimentally observed properties of the XY pyrochlores can be accounted for by a model of phase competition



- Several different magnetic ground states obtained within a narrow range of exchange parameters (via chemical pressure) *(this talk)*
- Suppressed ordering transition, T_N or T_C *(this talk)*
- Sensitivity to disorder *(e.g. talk of Tyrel McQueen)* and sensitivity to applied pressure *(e.g. Kermarrec et al., Nature Comm. 2017)*
- Multiple heat capacity anomalies and unconventional spin dynamics *(this talk and talk of Radu Coldea)*