Magnetocaloric Material: YbGG

Acknowledgements

- ANR Matadire - For funding
- E. Lhotel (Institut Néel, Grenoble)
- C Paulsen (Institut Néel, Grenoble)
- Neutron Scattering
  - J. Ollivier (ILL, Grenoble)
  - P. Steffens (ILL, Grenoble)
  - L. Mangin-Thro (ILL, Grenoble)
- ADR Application
  - J.-M. Duval (DSBT CEA, Grenoble)
  - D. A. Paixao Brasiliano (DSBT CEA, Grenoble)
  - Jean-Louis Durand (DSBT CEA, Grenoble)
- Materials
  - C. Marin (Pheliqs IRIG CEA, Grenoble)
  - E. Bichaud (Pheliqs IRIG CEA, Grenoble)
  - N.-R. Camara. (Pheliqs IRIG CEA, Grenoble)
- Neutron Scattering
  - S. Raymond (Pheliqs IRIG CEA, Grenoble)
  - E. Ressouche (Pheliqs IRIG CEA, Grenoble)
- Specific Heat / Thermal Conductivity
  - G. Knebel (Pheliqs IRIG CEA, Grenoble)
  - J.-P. Brison (Pheliqs IRIG CEA, Grenoble)
- Theoretical support
  - M. E. Zhitomirsky (Pheliqs IRIG CEA, Grenoble)

Introduction

- Introduction to material YbGG
- Measurement of magnetocaloric effect and magnetic behaviour
- Yttrium doped samples
- Prospects for practical applications

YbGG structure

- $Yb_3Ga_5O_{12}$
- Garnet – cubic structure
- Yb ions sit on network of corner sharing triangles - “hyperkagome”
- Well separated J=7/2 ground state leads to effective S=1/2
- $\Theta_{CW} = 97$ mK → FM interactions
- $\mu = 1.75\ \mu_B$

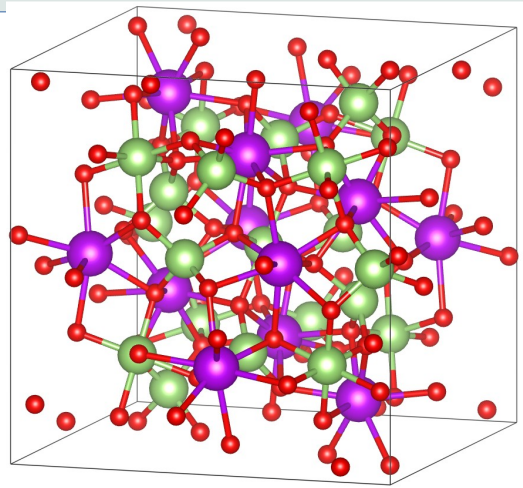
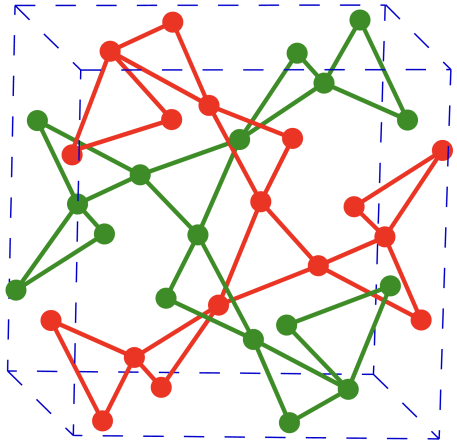
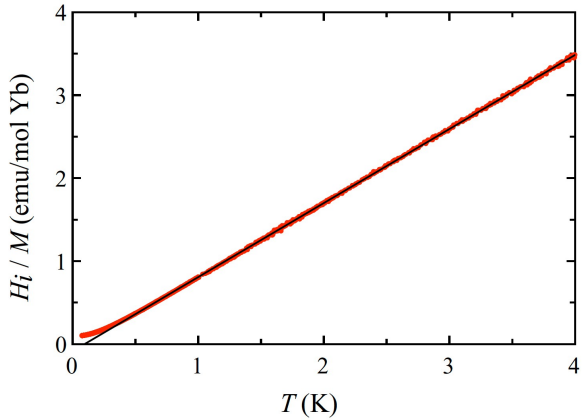


Image produced using VESTA



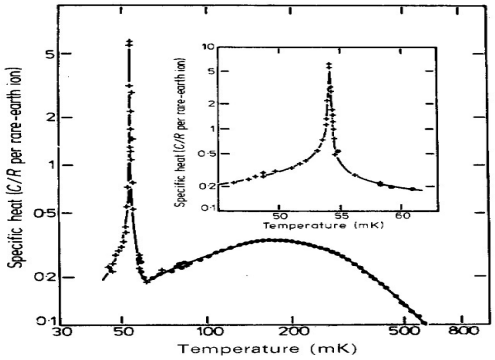


Lhotel, E. et al *Physical Review B* 104, 024427 (2021)

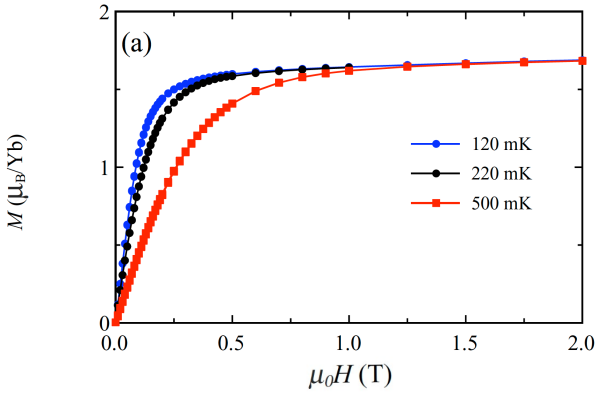
YbGG for ADR

Two key attributes make it a promising candidate for ADR:

- No ordering to low temperature (at least 54 mK)
- Magnetisation changes rapidly and saturates at low field



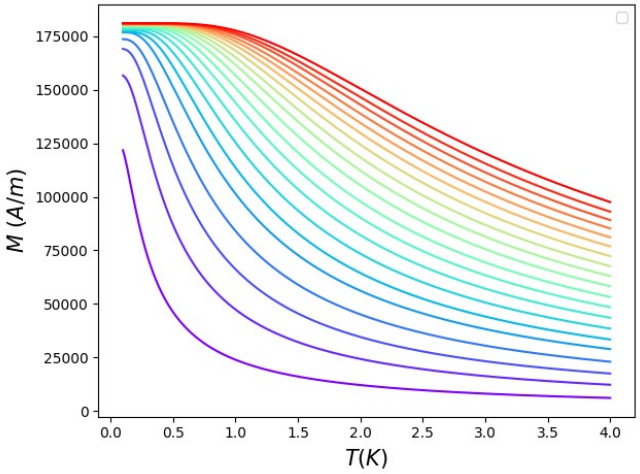
Filippi, J., et al. *Journal of Physics C: Solid State Physics* 13.7 (1980): 1277



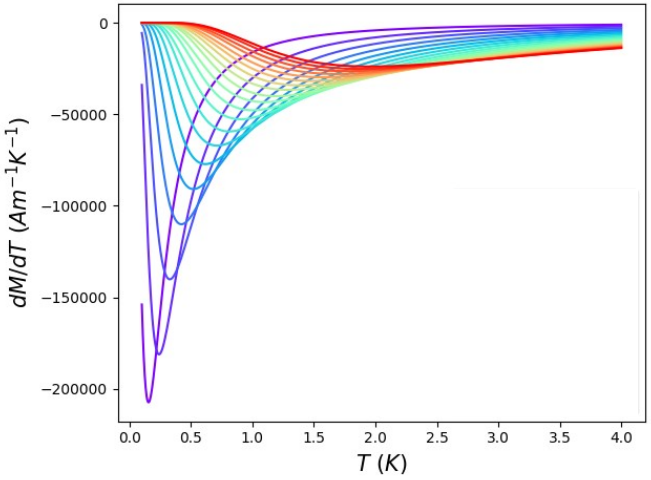
Lhotel, E. et al *Physical Review B* 104, 024427 (2021)

Magnetocaloric effect

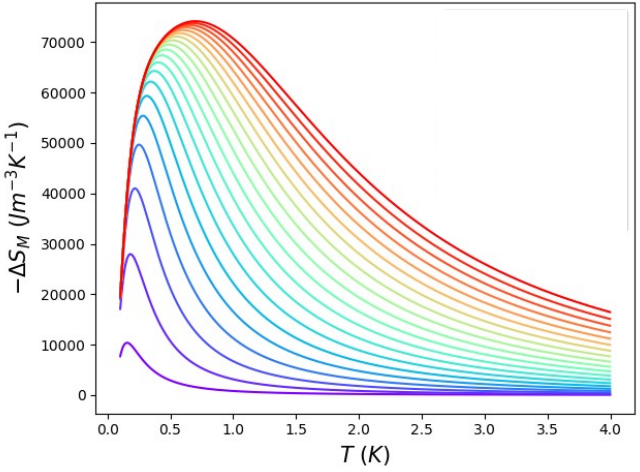
$$\Delta S = \int_0^B \frac{dM}{dT} d B^{'}.$$



Measure M vs T



Find derivative dM/dT



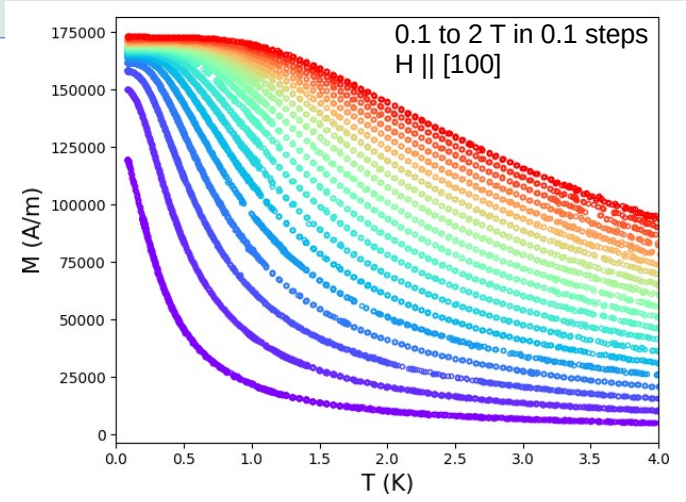
Integrate along B

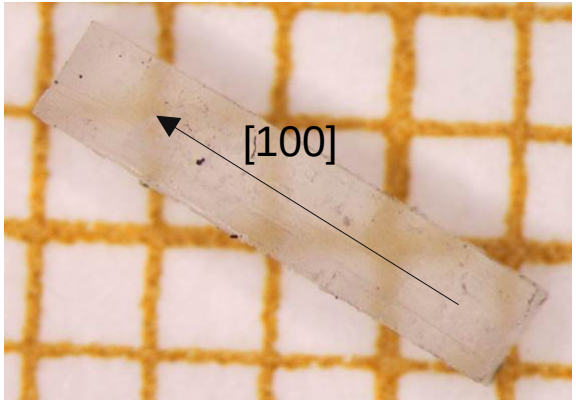
YbGG Measurements

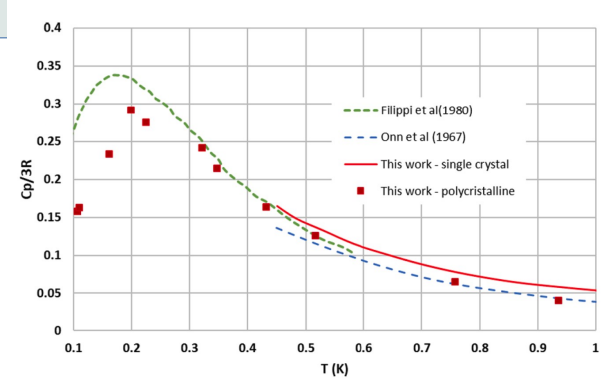
- Measured in dilution refrigerator @ institut Néel – Grenoble, using SQUID magnetometer

  (developed by C. Paulsen)

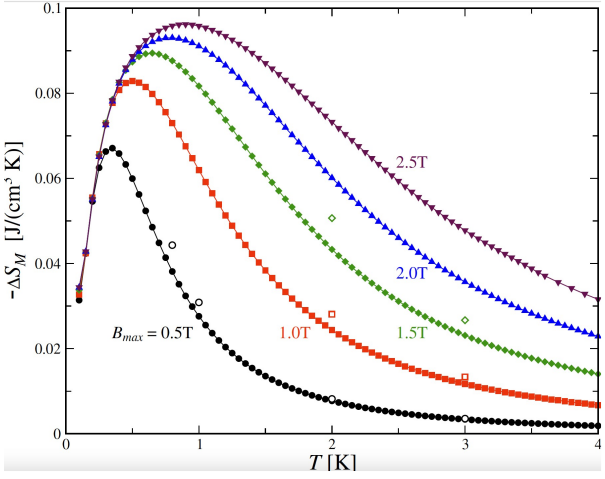
- Single crystal sample and powder samples similar





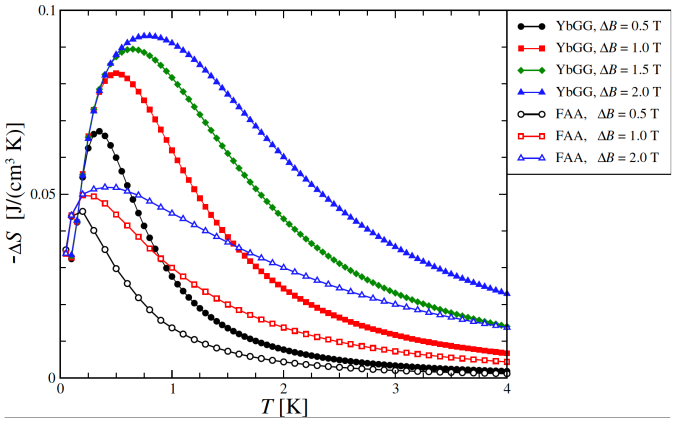


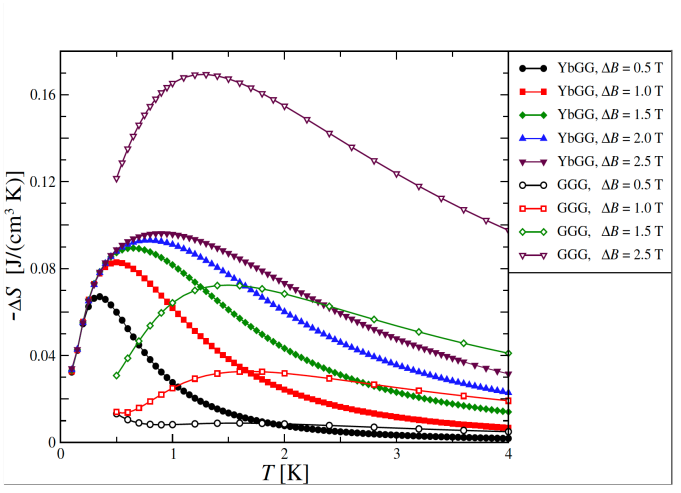
Brasiliano, Diego Augusto Paixao, et al. *Cryogenics* 105 (2020): 103002.



Comparison With Other Compounds

- Paramagnetic salt ferric ammonium alum (FAA)
  - YbGG greater change above 250 mK
- Gadolinium Gallium garnet (GGG)
  - YbGG greater change below 1.5 K for fields <2 T
- YbGG suitable material between these temperatures

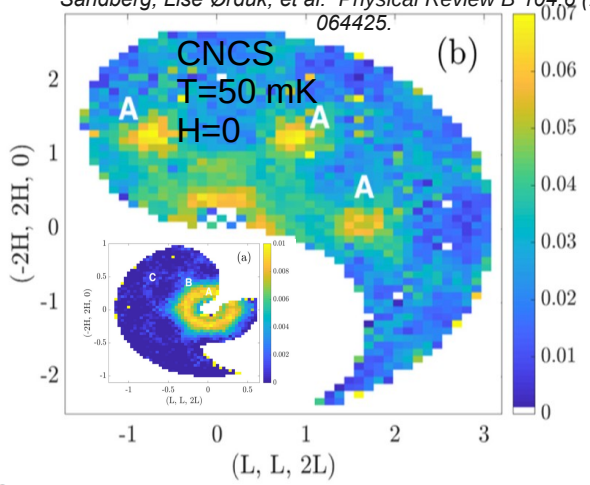


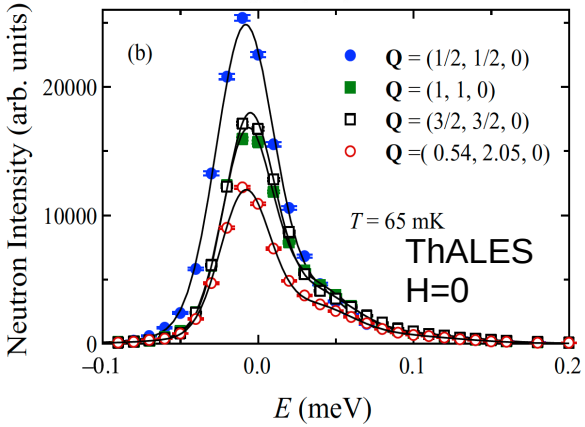


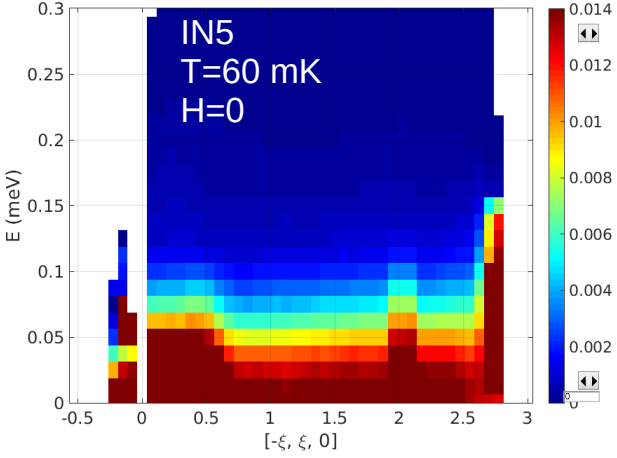
Neutron Scattering

- Neutron scattering technique is microscopic probe of magnetic properties
- Objective is to understand origin of magnetocaloric properties
- Presence of low lying excitations in multiple Q directions that are not well understood
- Still area of active research

Sandberg, Lise Ørduk, et al. Physical Review B 104.6 (2021): 064425.



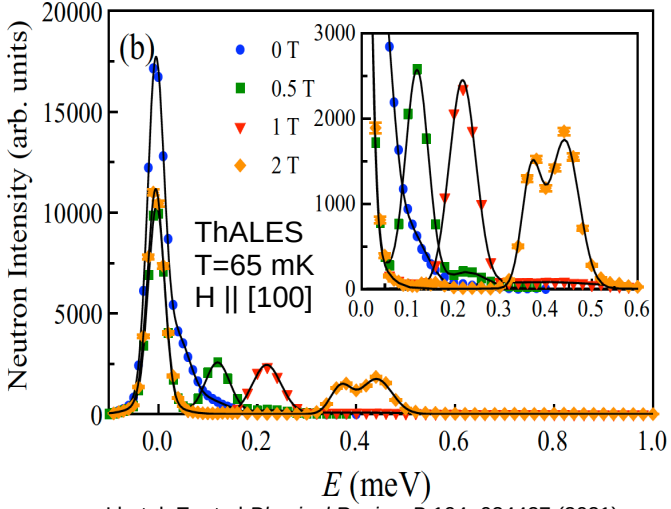




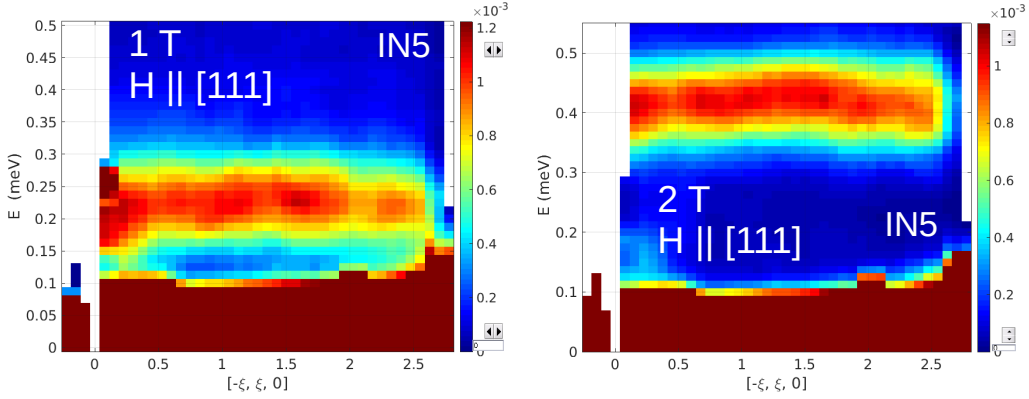
Lhotel, E. et al *Physical Review B* 104, 024427 (2021)

Field Induced Behaviour

- Excitations move to higher energy upon application of field

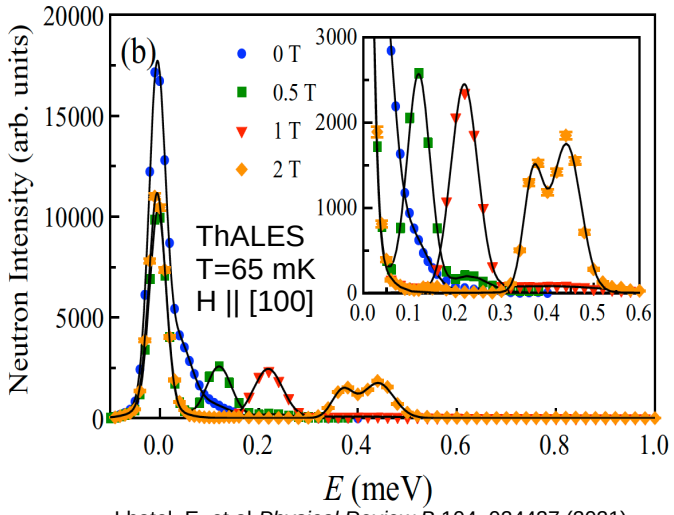


Lhotel, E. et al *Physical Review B* 104, 024427 (2021)

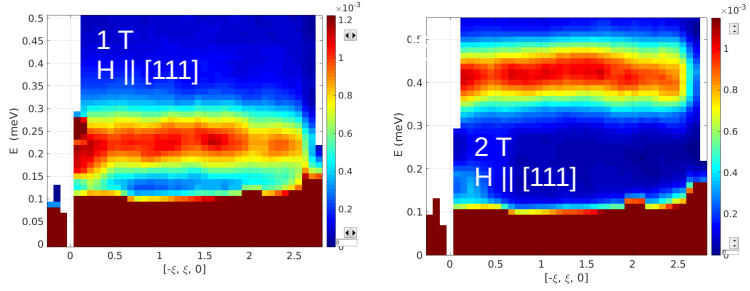


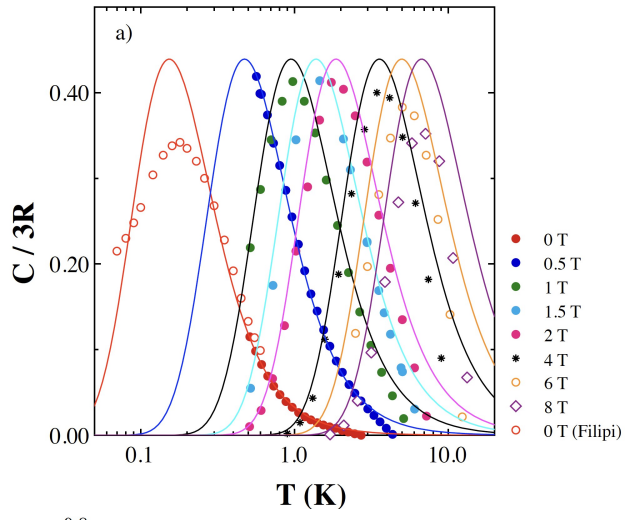
Field Induced Behaviour

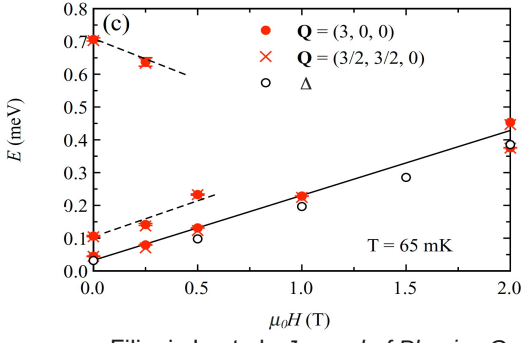
- Excitations move to higher energy upon application of field
- Fitting to Schottky anomaly and comparing with neutron data indicates energy scale from Zeeman splitting
- E = 2μH indicates μ=1.7 μ_B
- Agreement with theoretical models for long range dipolar interactions



Lhotel, E. et al *Physical Review B* 104, 024427 (2021)







Filippi, J., et al. *Journal of Physics C: Solid State Physics* 13.7 (1980): 1277.

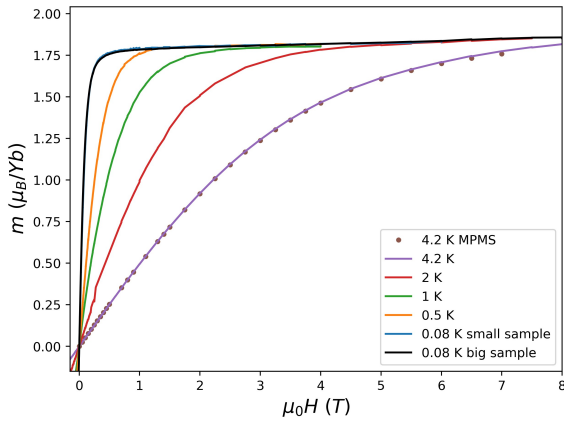
$Yb_{(3-x)}Y_xGa_5O_{12}$

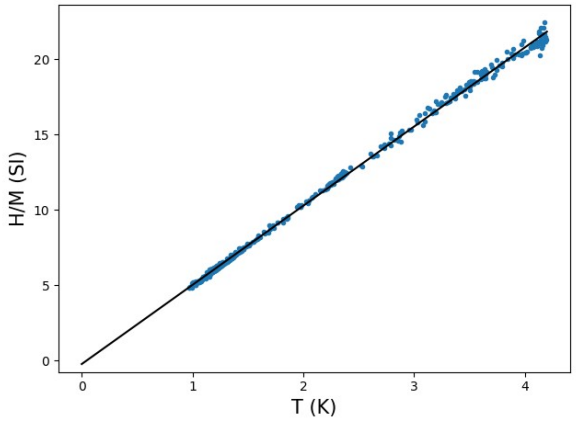
$Yb_{(3-x)}Y_xGa_5O_{12}$

- Measured 2 doped samples to investigate impact on magnetocaloric effect
  - 20% Y
  - 40% Y

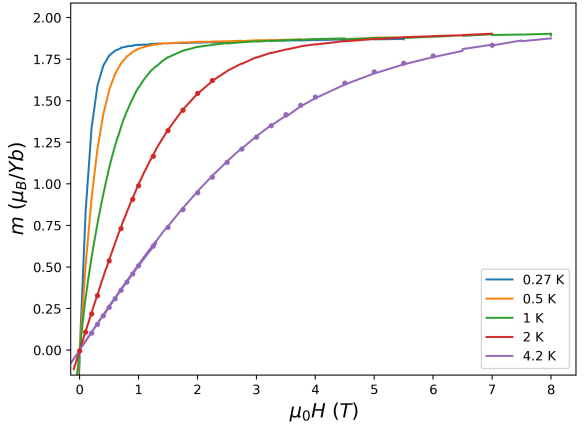
	$\mu_{per\ Yb}$ @ 2T, 8T	Θ_{CW}
Y:0%	$1.7\mu_B$, $1.76\mu_B$	97 mK
Y:20%	$1.85\mu_B$, $1.9\mu_B$	92 mK
Y:40%	$1.8\mu_B$, $1.85\mu_B$	42 mK

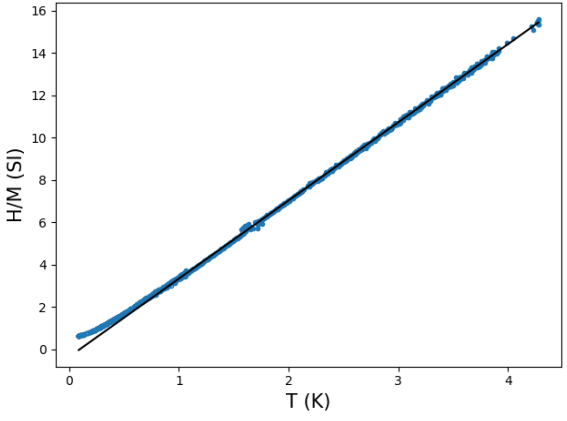
40%





20%

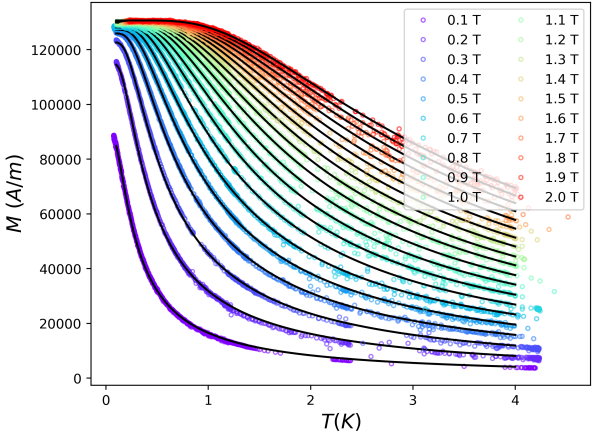




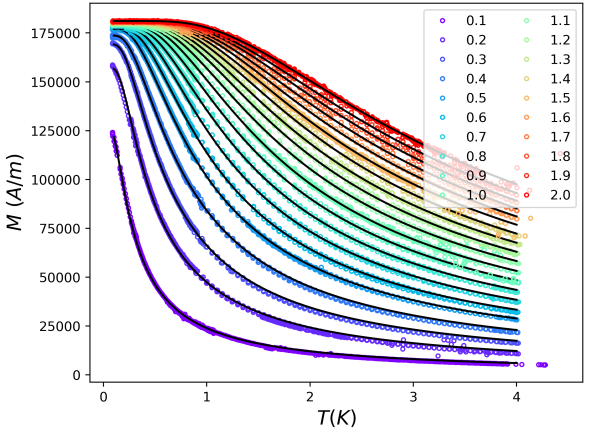
$Yb_{(3-x)}Y_xGa_5O_{12}$

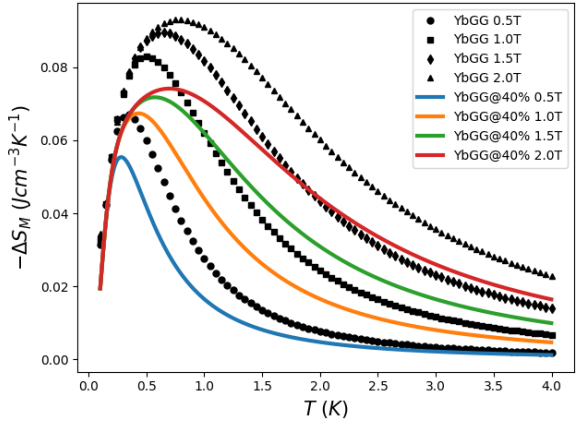
- 40% sample has magnetocaloric power ≈0.6x YbGG
- 20% sample shows greater effect than undoped sample
- Larger moments and increased magnetocaloric effect a mystery
- Existence of strong MCE effect evidence of long range dipolar correlations

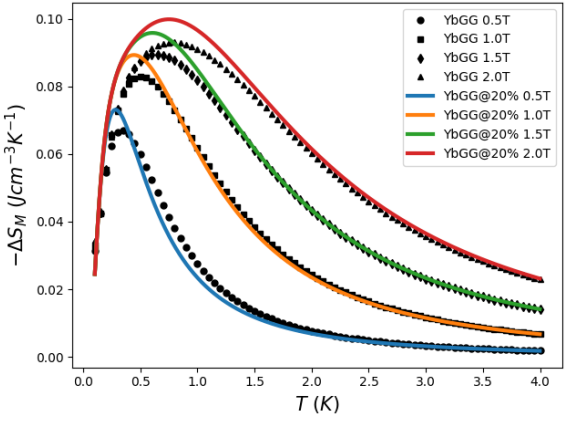
40%



20%







YbGG for ADR Applications

- Single crystals are limited in size and fragile

  → Inconvenient for practical applications

  → Particularly for space

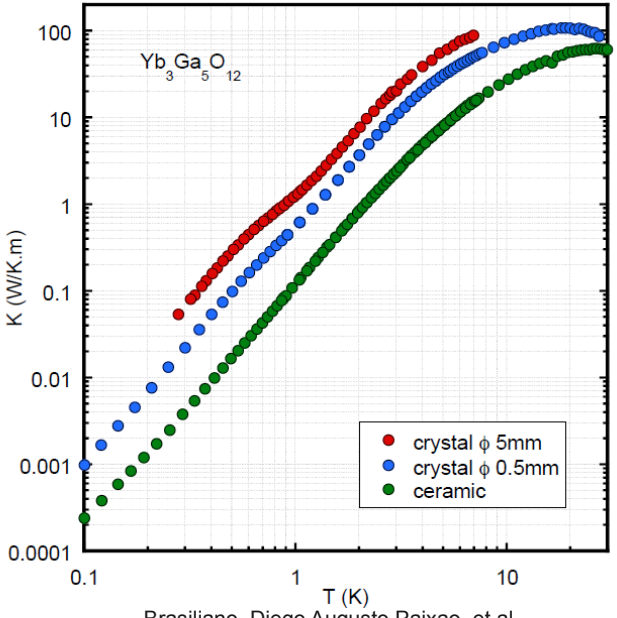
- Can instead use ceramics

  + Easy to work with/machine

  + Can be made into any shape

  + Up to 95% density of single crystals

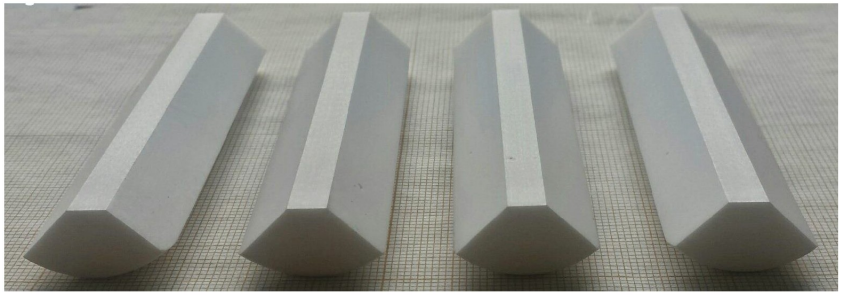
  - BUT much reduced thermal conductivity



Brasiliano, Diego Augusto Paixao, et al.
Cryogenics 105 (2020): 103002.

YbGG for ADR Applications

- To mitigate this a design with high thermal coupling is required
- Ceramic samples are brazed to copper mount
- Ongoing work (C. Marin, N.-R. Camara) to achieve good thermal coupling



Summary

- YbGG identified as a suitable material for ADR between 250 mK and 1.5 K
  - Lower fields than GGG
  - Greater power than FAA
- Magnetic response in field from Zeeman splitting of doublet
- Doped materials study finds:
  - Further evidence for dipolar interactions
  - Possible increased magnetocaloric power
- Techniques under development for effective application of YbGG to ADR