Strain-control of local magnetism in manganite films on barium titanate substrates

X. Moya[1], L. E. Hueso[2,3], F. Maccherozzi[4], A. I. Tovstolytkin[5], D. I. Podyalovskii[5], C. Ducati[1], L. C. Phillips[1], M. Ghidini[1,6], O. Hovorka[2], A. Berger[2], M. E. Vickers[1], E. Defaÿ[1,7], S. S. Dhesi[4] and N. D. Mathur[1]

[1]Department of Materials Science, University of Cambridge, UK
[2]CIC nanoGUNE Consolider, San Sebastian, Spain
[3]IKERBASQUE, Basque Foundation for Science, Spain
[4]Diamond Light Source, Didcot, UK
[5]Institute of Magnetism, Kyiv, Ukraine
[6]Department of Physics, University of Parma, Italy
[7]CEA, LETI, Grenoble, France

Financial support: Herchel Smith Fund

Strain-control of local magnetism in manganite films on barium titanate substrates

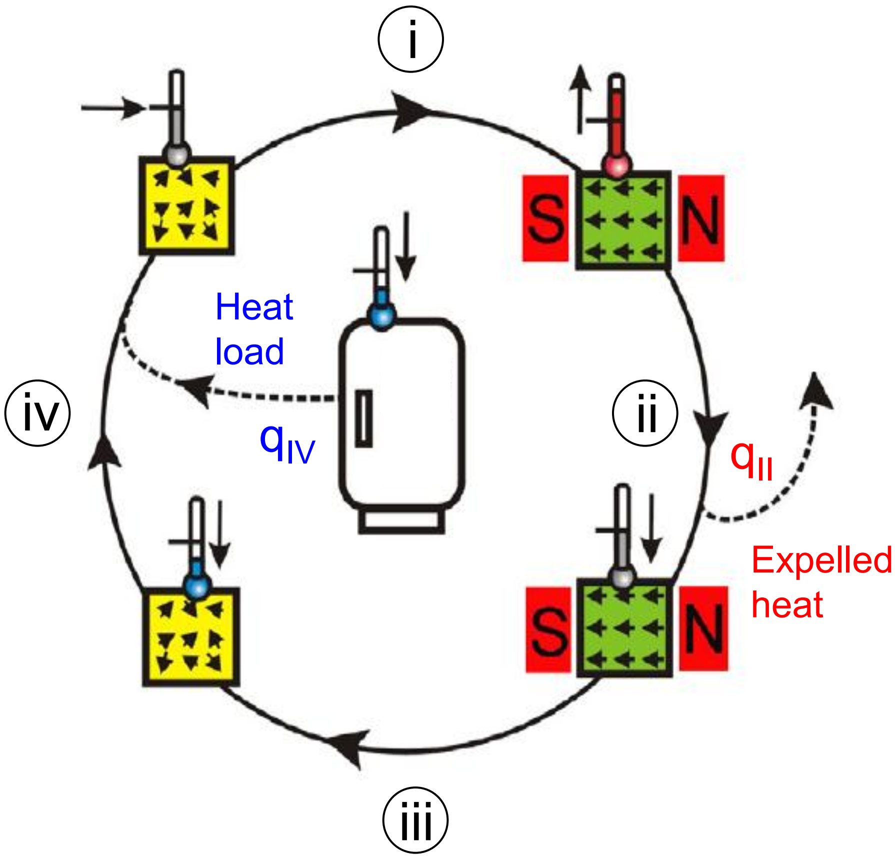
Extrinsic magnetoelectric effect in LSMO/BTO

Extrinsic magnetocaloric effect LCMO/BTO

(Nature Materials, DOI:10.1038/NMAT3463)

Magnetocaloric effect

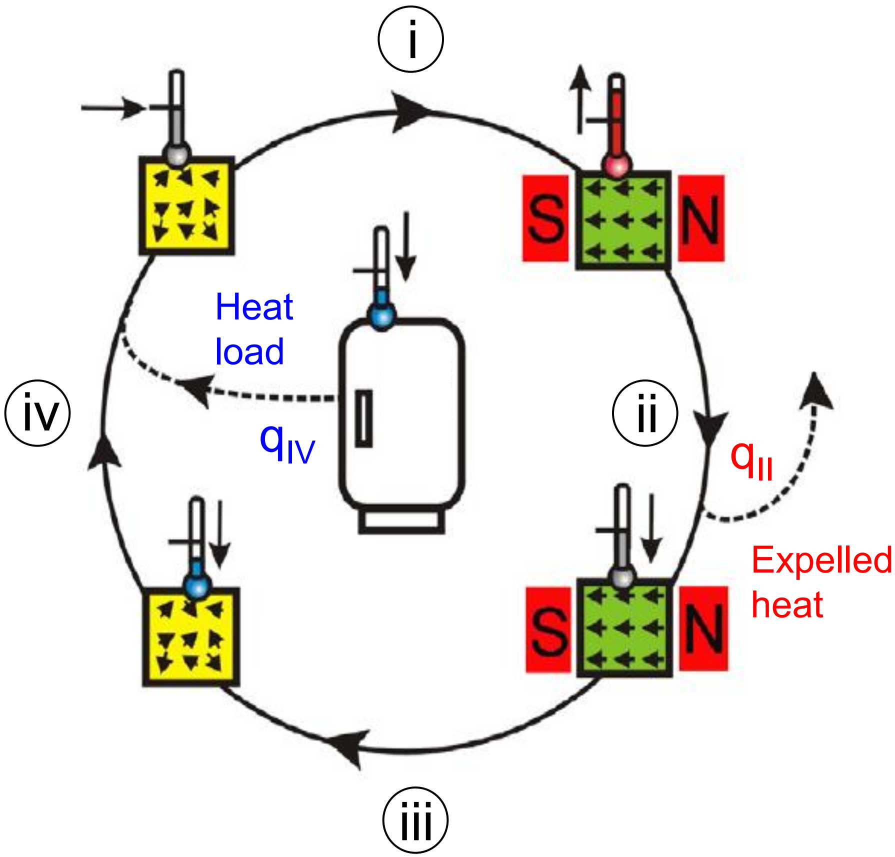
Coupling between magnetic and thermal properties



O. Tegus *et al.* Nature **415**, 150 (2002)

Magnetocaloric effect

Coupling between magnetic and thermal properties



O. Tegus *et al.* Nature **415**, 150 (2002)

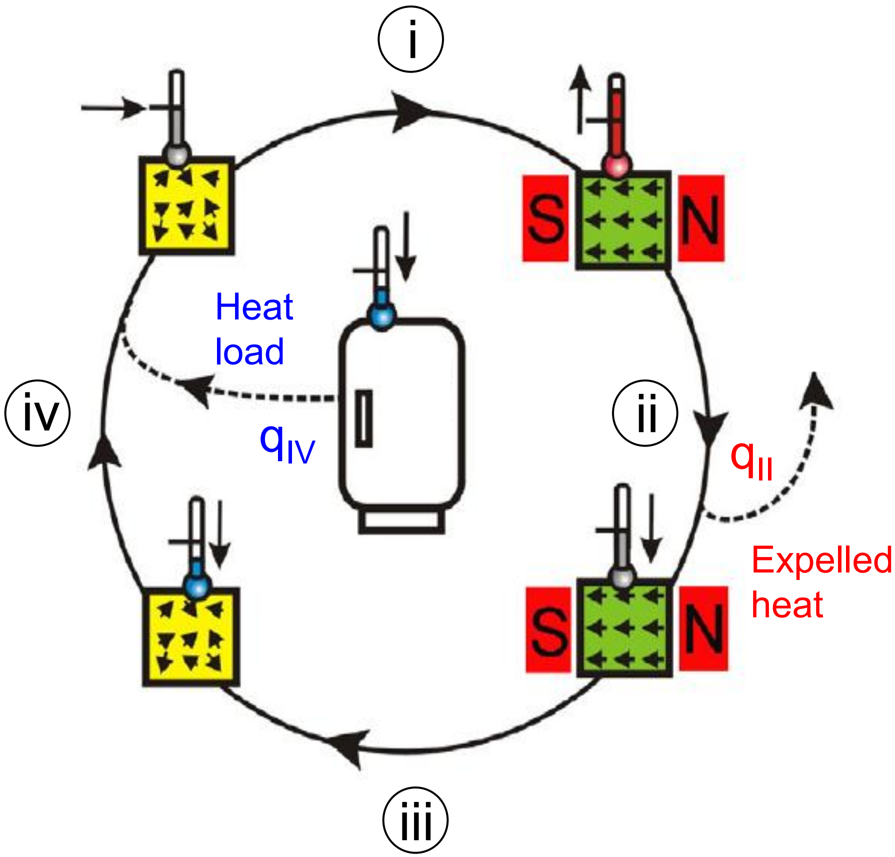
MCE magnitudes:

$$\Delta S = \mu_0 \int_0^H \left(\frac{\partial S}{\partial H'}\right)_T dH'$$

$$\Delta T = -\frac{T}{C}\Delta S$$

Magnetocaloric effect

Coupling between magnetic and thermal properties



O. Tegus *et al.* Nature **415**, 150 (2002)

MCE magnitudes:

$$\Delta S = \mu_0 \int_0^H \left(\frac{\partial M}{\partial T}\right)_{H'} dH'$$

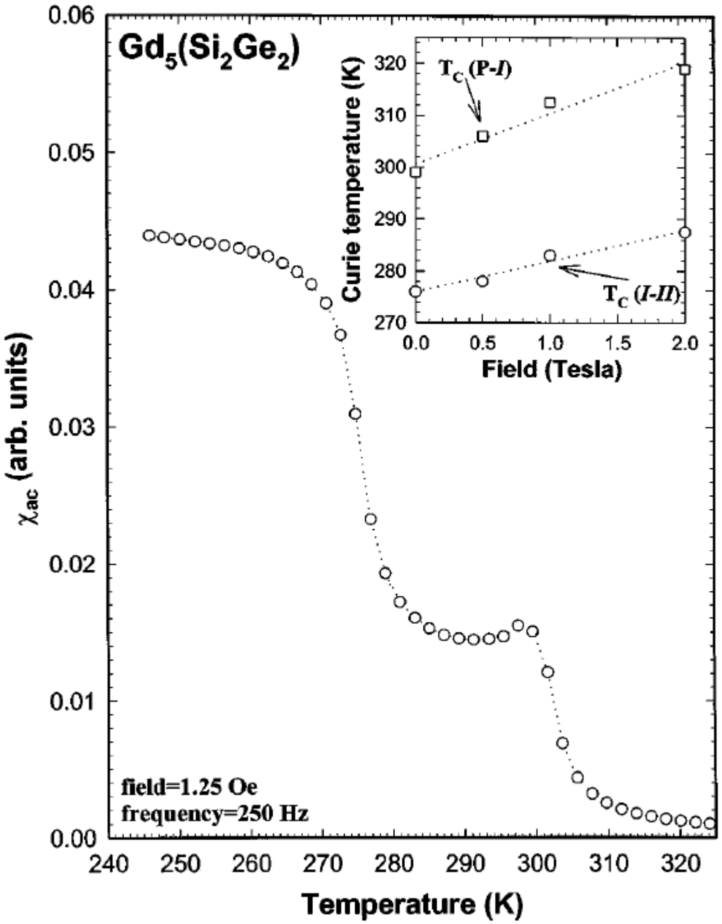
$$\Delta T = -\frac{T}{C}\Delta S$$

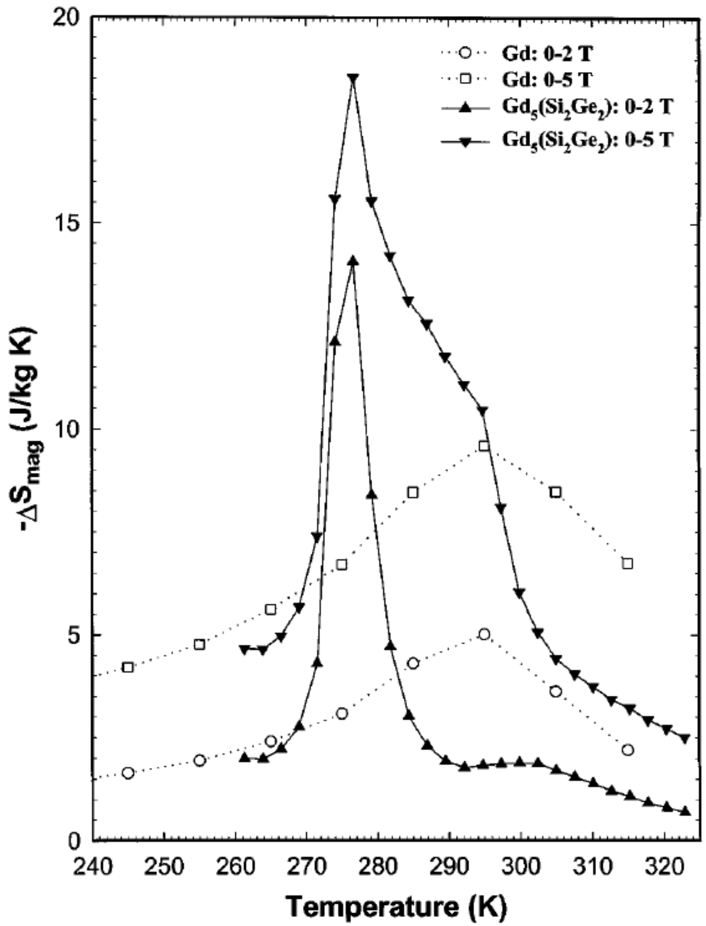
Large at phase transitions

1st order

Giant magnetocaloric effect

First-order magnetostructural transition: large $(\partial M/\partial T)_H$





V. K. Pecharsky *et al.,* Phys. Rev. Lett. **78**, 4494 (1997)

Giant magnetocaloric materials

Material	T_t (K)	$\Delta S/\mu_0 \Delta H$ (J K^{-1} kg^{-1} T^{-1})	Reference
$Gd_5Si_2Ge_2$	276	-3.8	Pecharsky *et al.* PRL **78**, 4494 (1997)
$Gd_5Si_1Ge_3$	136	-13.6	Pecharsky *et al.* APL **70**, 3299 (1997)
MnAs	318	-6.4	Wada *et al.* APL **79**, 3302 (2001)
$LaFe_{11.57}Si_{1.43}H_{1.3}$	291	-5.6	Fujita *et al.* PRB **67**, 104416 (2003)
$CoMnSi_{0.95}Ge_{0.05}$	215	1.8	Sandeman *et al.* PRB **74**, 224436 (2006)
$Ni_{53}Mn_{23}Ga_{24}$	295	-3.6	Hu *et al.* PRB **64**, 132412 (2001)
$Ni_{50}Mn_{37}Sn_{13}$	299	3.8	Krenke *et al.* Nat. Mat. **4**, 450 (2005)
$Ni_{50}Mn_{34}In_{16}$	219	2.4	Moya *et al.* PRB **75**, 184412 (2007)
LCMO	259	-0.87	Zhang *et al.* APL **69**, 3596 (1996)

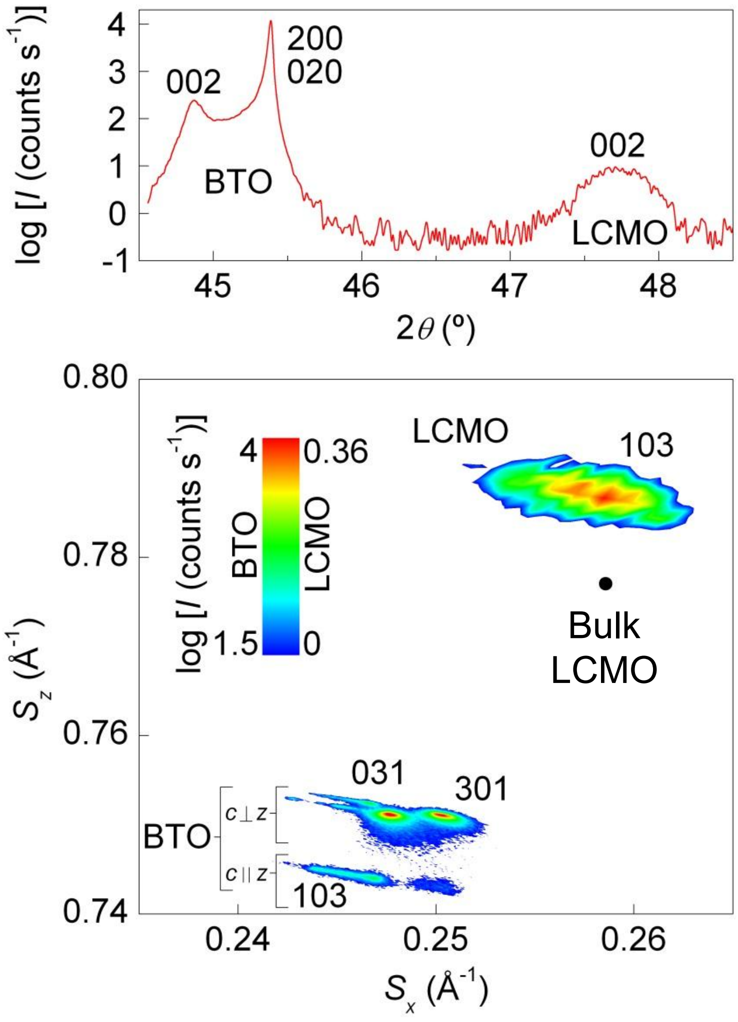
Few materials, suffer hysteresis

LCMO/BTO

Samples grown by PLD

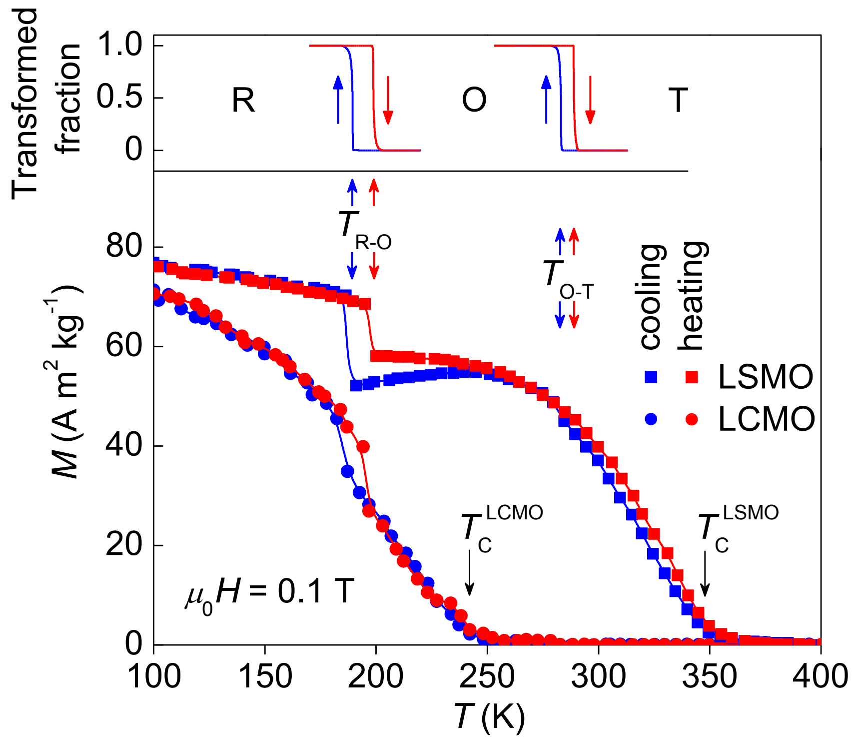
34 nm $La_{0.7}Ca_{0.3}MnO_3$
0.5 mm $BaTiO_3$ (001)

XRD

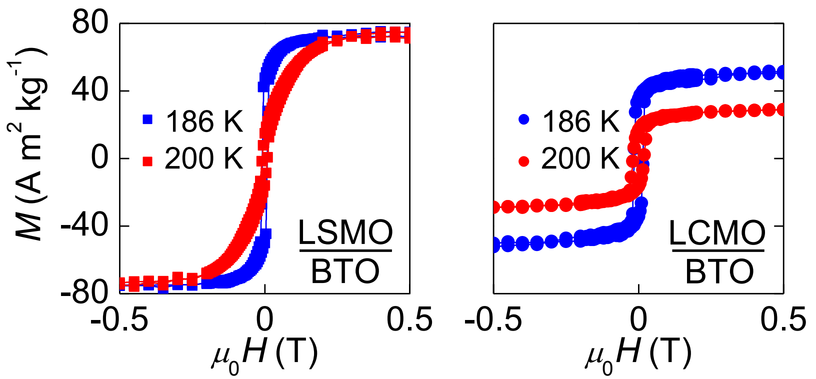


Macroscopic magnetic properties

***M*(*T*)**



***M*(*H*)**

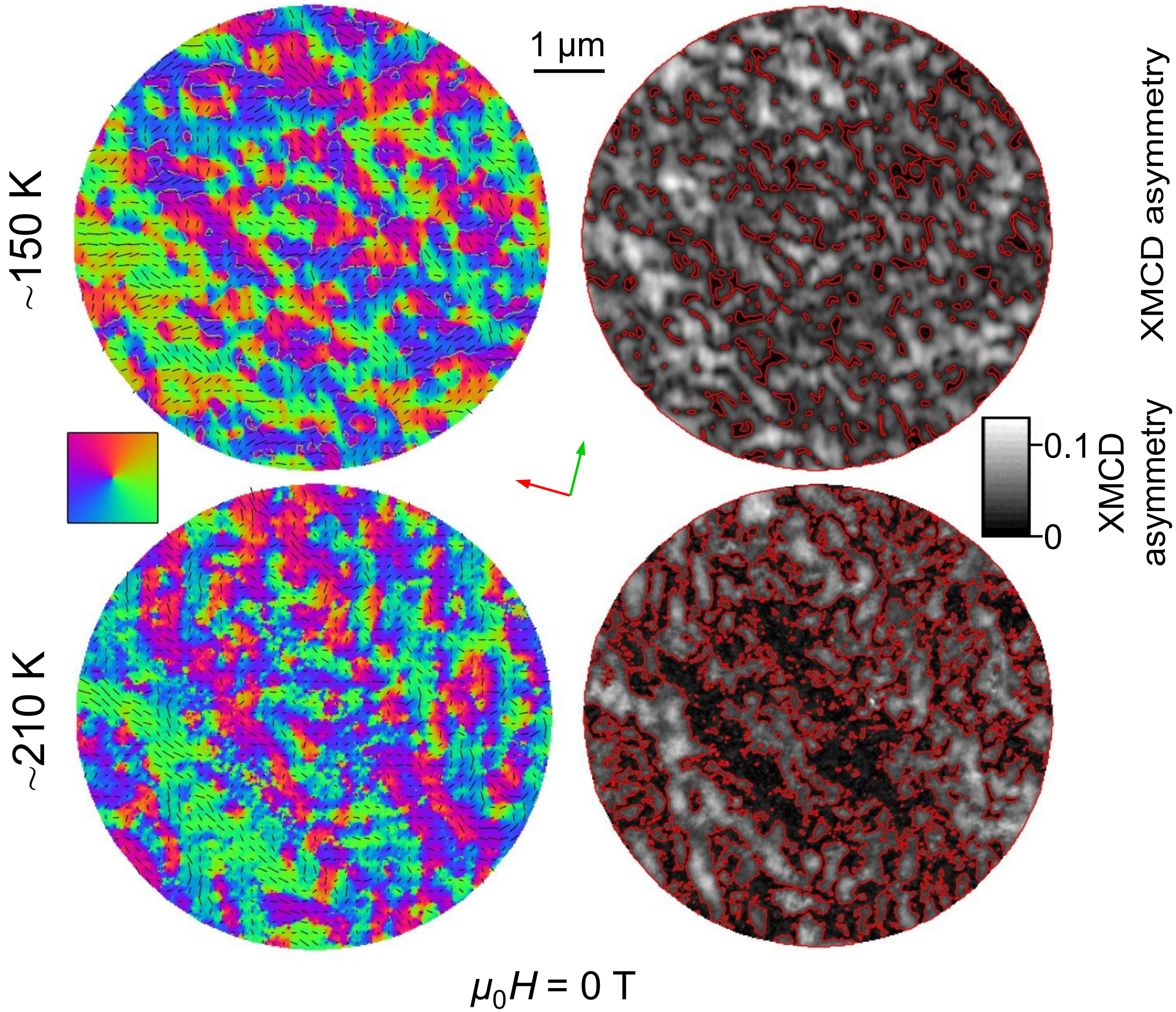


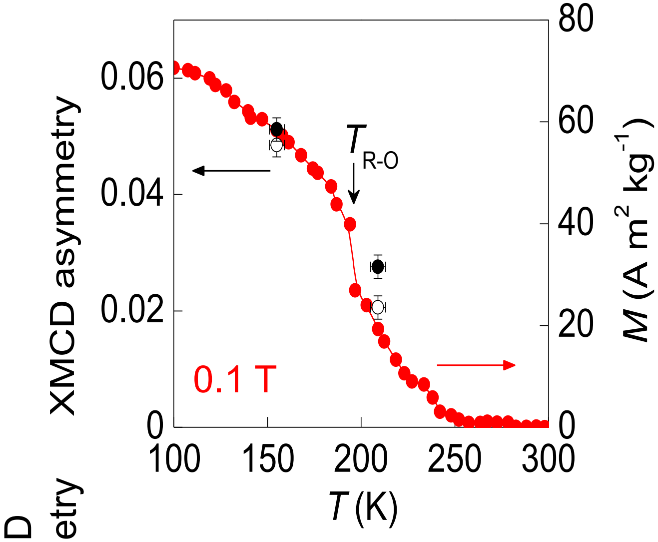
LSMO
Anisotropy change

LCMO
Entropy change

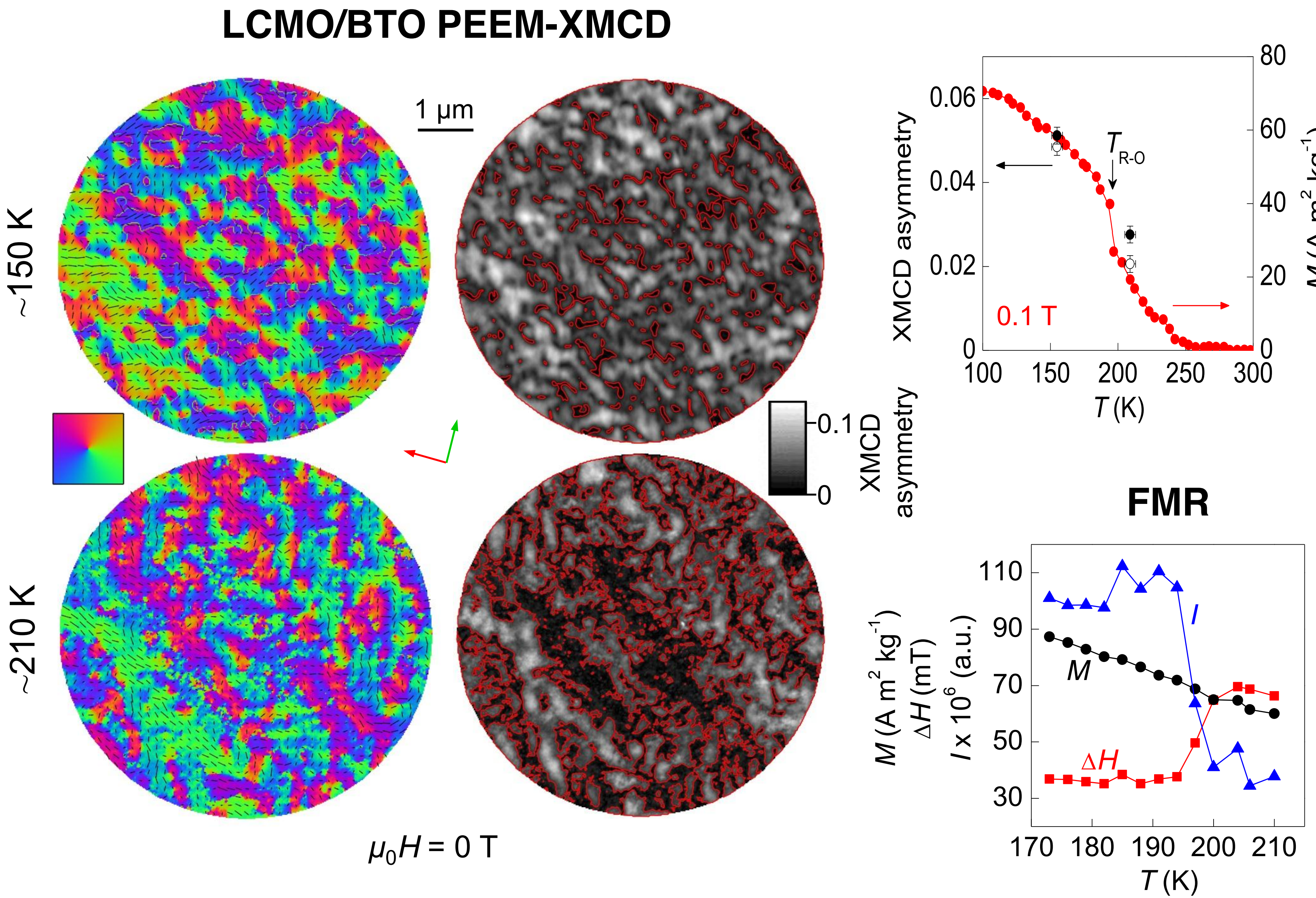
Temperature-Driven Phase Interconversion

LCMO/BTO PEEM-XMCD





Temperature-Driven Phase Interconversion

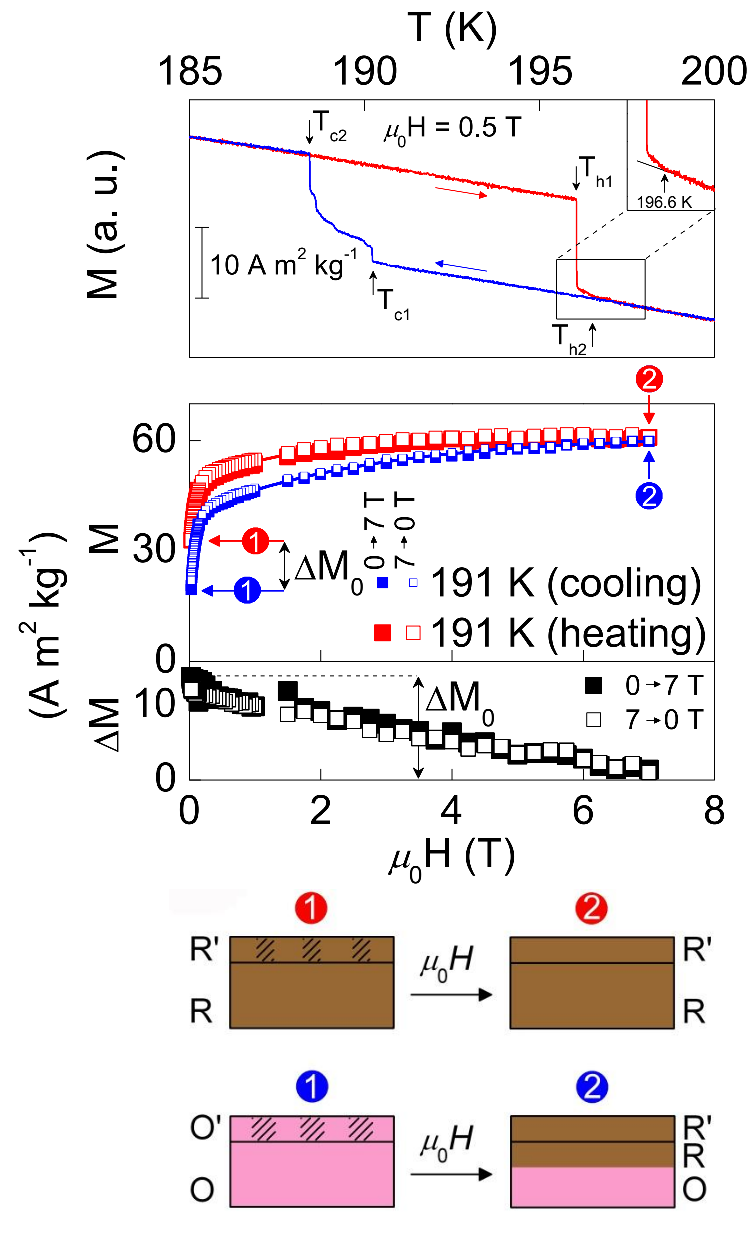


Magnetic-Field-Driven Phase Interconversion

Detail of transition in *M*(*T*)

Drive transition directly
Reversible

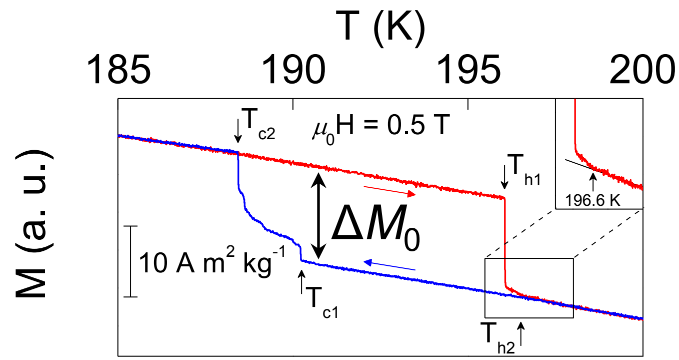
Schematics



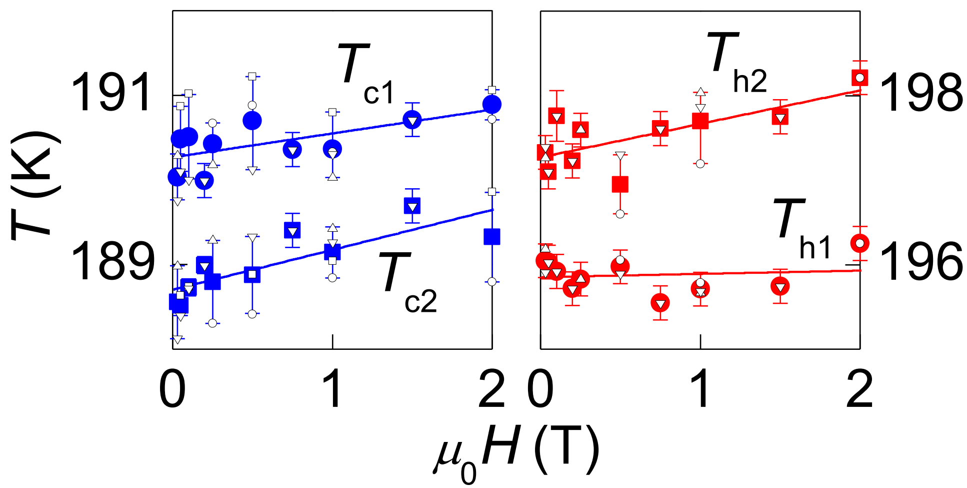
Feedback

Quantifying the MC effect (1)

Detail of transition in *M*(*T*)



Clausius-Clapeyron: $$\frac{dT_0}{\mu_0 dH} = -\frac{\Delta M_0}{\Delta S}$$



$\Delta M_0 \sim 13.5$ A m^2 kg^{-1}

$$\frac{dT_0}{\mu_0 dH} \sim 0.4 \text{ K T}^{-1}$$

↓

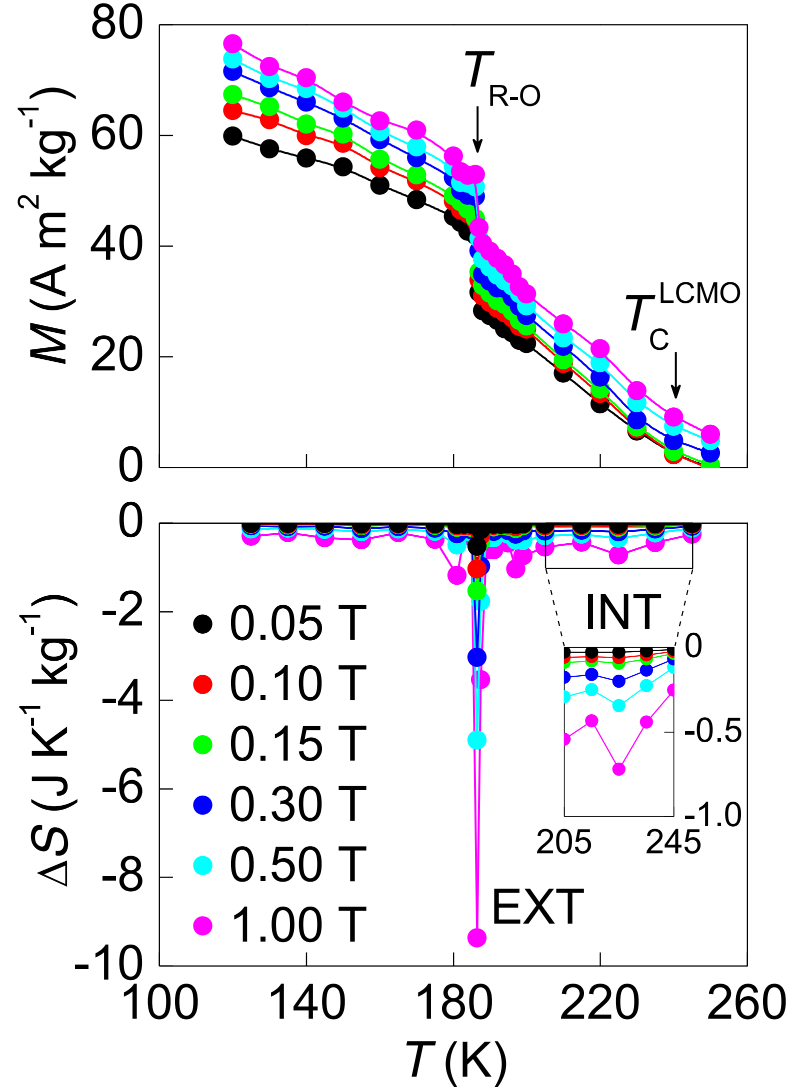
$\Delta S/\mu_0 \Delta H \sim -9$ J K^{-1} kg^{-1} T^{-1}

Quantifying the MC effect (2)

$$\Delta S = \mu_0 \int_0^H \left(\frac{\partial M}{\partial T}\right)_{H'} dH'$$

INT ~ - 0.7 J K^{-1} kg^{-1} T^{-1}

EXT ~ - 9 J K^{-1} kg^{-1} T^{-1}



Giant magnetocaloric materials

Material	T_t (K)	$\Delta S/\mu_0\Delta H$ (J K^{-1} kg^{-1} T^{-1})	Reference
$Gd_5Si_2Ge_2$	276	-3.8	Pecharsky *et al.* PRL **78**, 4494 (1997)
$Gd_5Si_1Ge_3$	136	-13.6	Pecharsky *et al.* APL **70**, 3299 (1997)
MnAs	318	-6.4	Wada *et al.* APL **79**, 3302 (2001)
$LaFe_{11.57}Si_{1.43}H_{1.3}$	291	-5.6	Fujita *et al.* PRB **67**, 104416 (2003)
$CoMnSi_{0.95}Ge_{0.05}$	215	1.8	Sandeman *et al.* PRB **74**, 224436 (2006)
$Ni_{53}Mn_{23}Ga_{24}$	295	-3.6	Hu *et al.* PRB **64**, 132412 (2001)
$Ni_{50}Mn_{37}Sn_{13}$	299	3.8	Krenke *et al.* Nat. Mat. **4**, 450 (2005)
$Ni_{50}Mn_{34}In_{16}$	219	2.4	Moya *et al.* PRB **75**, 184412 (2007)
LCMO	259	-0.87	Zhang *et al.* APL **69**, 3596 (1996)

Giant magnetocaloric materials

Material	T_t (K)	$\Delta S/\mu_0\Delta H$ (J K^{-1} kg^{-1} T^{-1})	Reference
$Gd_5Si_2Ge_2$	276	-3.8	Pecharsky *et al.* PRL **78**, 4494 (1997)
$Gd_5Si_1Ge_3$	136	-13.6	Pecharsky *et al.* APL **70**, 3299 (1997)
MnAs	318	-6.4	Wada *et al.* APL **79**, 3302 (2001)
$LaFe_{11.57}Si_{1.43}H_{1.3}$	291	-5.6	Fujita *et al.* PRB **67**, 104416 (2003)
$CoMnSi_{0.95}Ge_{0.05}$	215	1.8	Sandeman *et al.* PRB **74**, 224436 (2006)
$Ni_{53}Mn_{23}Ga_{24}$	295	-3.6	Hu *et al.* PRB **64**, 132412 (2001)
$Ni_{50}Mn_{37}Sn_{13}$	299	3.8	Krenke *et al.* Nat. Mat. **4**, 450 (2005)
$Ni_{50}Mn_{34}In_{16}$	219	2.4	Moya *et al.* PRB **75**, 184412 (2007)
LCMO/BTO	186	-9	**Extrinsic**

Strain-control of local magnetism in manganite films on barium titanate substrates

BTO strain creates extrinsic magnetic transitions

LSMO/BTO: *T* and *E* control of magnetic anisotropy
sharp and persistent ME effects

LCMO/BTO: *T* and *H* control of phase interconversion
giant and reversible MC effects