MAGNETISM IN Superconducting Sandwiches!

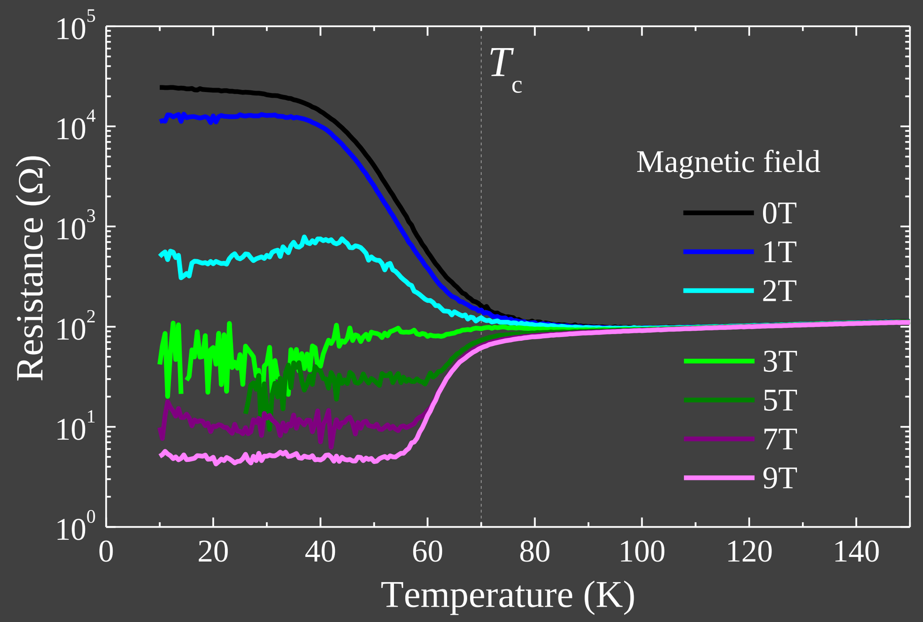
Andrew Chan[1,2,3], Grace Causer[3], Wai-Tung (Hal) Lee[3], Kirrily Rule[3], Tilo Söhnel[1,2], Christian Bernhard[4], Ben Mallett[1,2]
[1]School of Chemical Sciences, Faculty of Science, The University of Auckland, New Zealand
[2]MacDiarmid Institute for Advanced Materials and Nanotechnology
[3]Australia Nuclear Science and Technology Organization, Lucas Heights, NSW2234, Australia
[4]Department of Physics and Fribourg Center for Nanomaterials, University of Fribourg, Switzerland

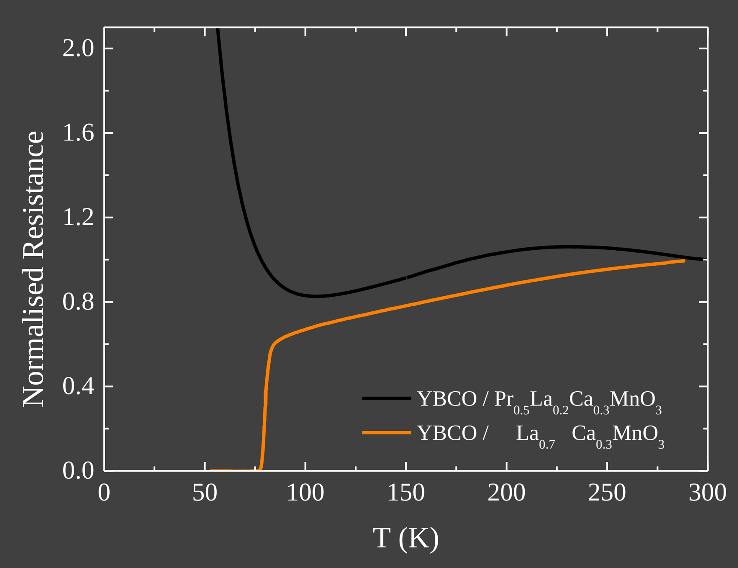
INTRODUCTION

Multi-layered materials host novel and sometimes useful properties. For example, a multilayer of *p*- and *n*-doped Si makes a diode, and underlies virtually all modern electronics. More recently, thin-film multilayers (sandwiches!) made from metal-oxides allow for a wide range of combined states, such as superconductivity and magnetism and present new physics from the interfaces [1].

Near-universally, superconducting properties worsen in strong magnetic fields. Our superconducting cuprate-manganite sandwiches, however, show the opposite behaviour – the superconducting properties improve in magnetic fields [2]!

<u>Figures</u>: Magnetic fields are detrimental for all cuprate superconductors – except our superconductor sandwiches! Here a magnetic field effects an insulating-to-superconducting transition [2].
The exact reason for this remains a mystery, however...





...this unique insulating-to-superconducting transition is due to particular properties of the manganite, $Pr_{0.5}La_{0.2}Ca_{0.3}MnO_3$ in this case. For example, it is not seen cuprate-manganite multilayers made from the chemically near-identical $La_{0.7}Ca_{0.3}MnO_3$ (e.g. [3]).

AIMS

We investigate the role magnetism plays in causing the insulator-superconductor transition by:

- Determining the magnetic properties of the manganite.
- Searching for an interaction between the superconductor and manganite.

SAMPLE DETAILS

Superconducting sandwiches were grown by pulsed laser deposition at the University of Fribourg, Switzerland.

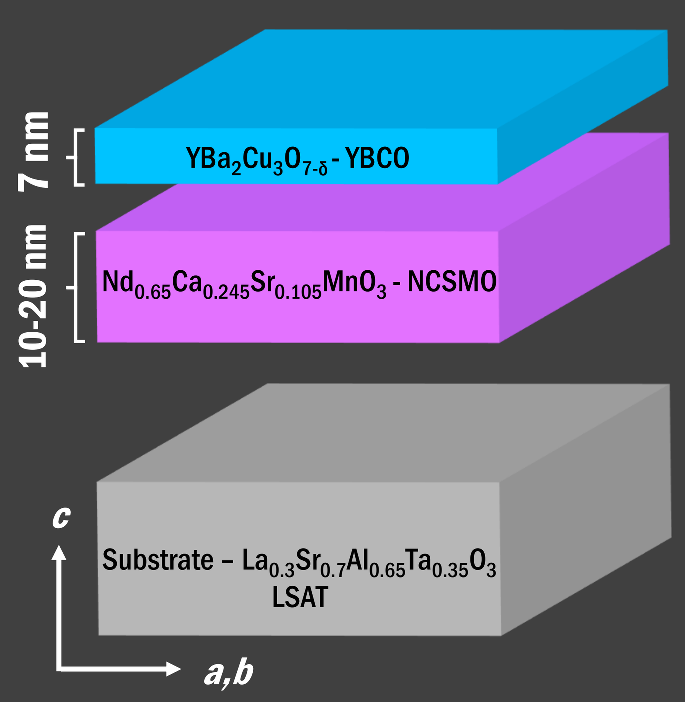
Materials:

<u>Cuprate superconductor</u>: $YBa_2Cu_3O_{7-\delta}$ – YBCO
Typically grown to 7 nm thick

<u>Manganite</u>: $Nd_{0.65}Ca_{0.245}Sa_{0.105}MnO_3$ – NCSMO
Grown 10, 20 or 100 nm thick
NB chosen so as to facilitate resonant x-ray studies.

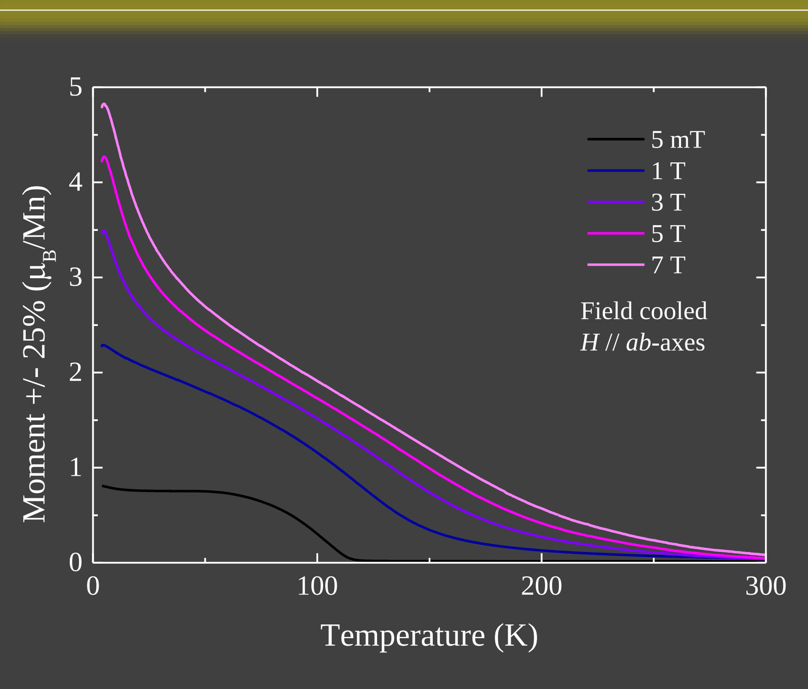
<u>Protective cap</u>: $LaAlO_3$ – LAO
Grown 2 nm thick

<u>Substrate</u>: $(La_{0.3}Sr_{0.7})(Al_{0.65}Ti_{0.35})O_3$ – LSAT



Schematic of a NCSMO-YBCO bilayer sandwich produced by pulsed laser deposition.

MAGNETIC BEHAVIOUR

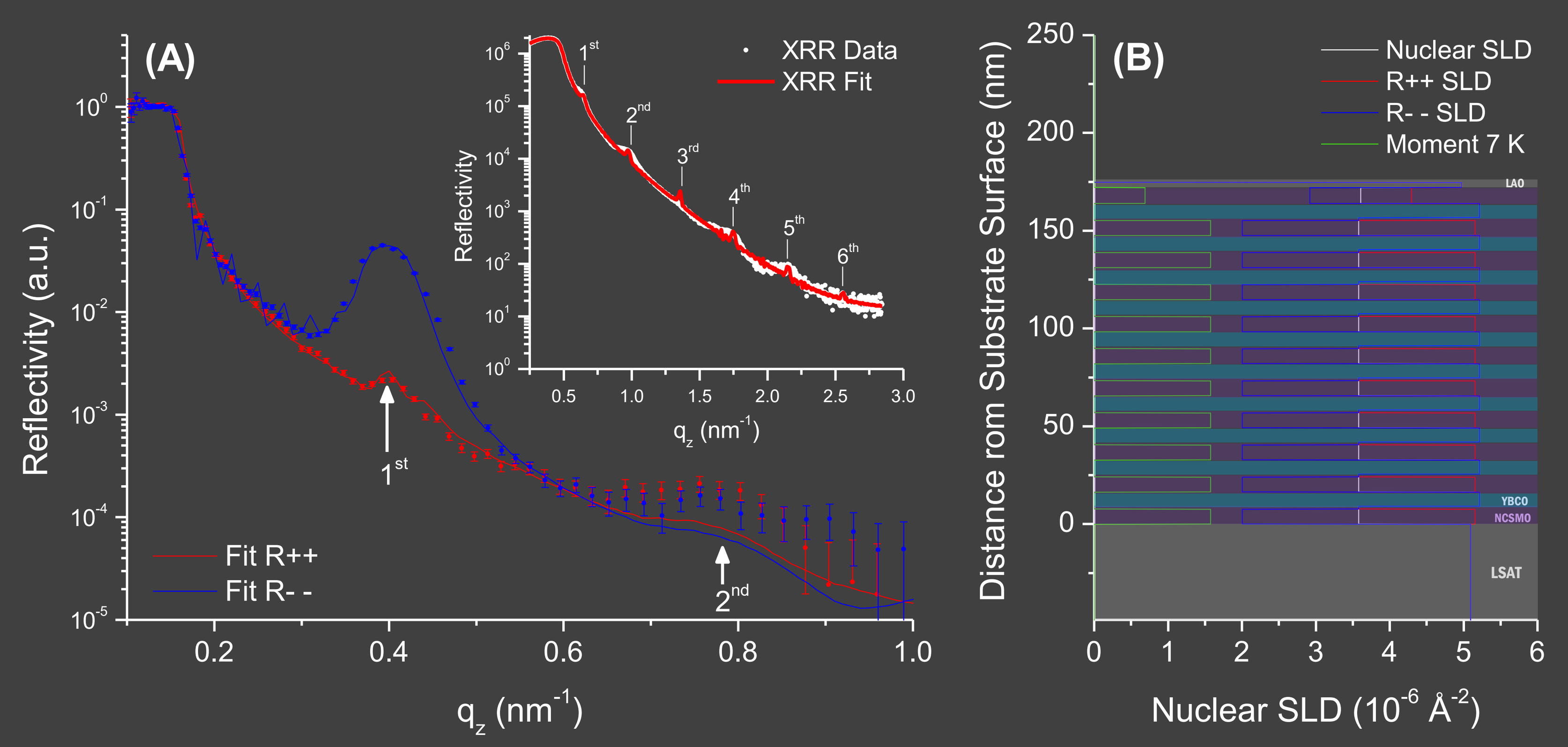


The NCSMO magnetically orders below 120 K in small fields. Antiferromagnetic ordering, probably with canted ferromagnetic component.

Ferromagnetism develops in larger magnetic fields. Near full Mn moment of ~3.7 μ_B. Ordering of Nd^{3+} around ~15K.

POLARIZED NEUTRON REFLECTION

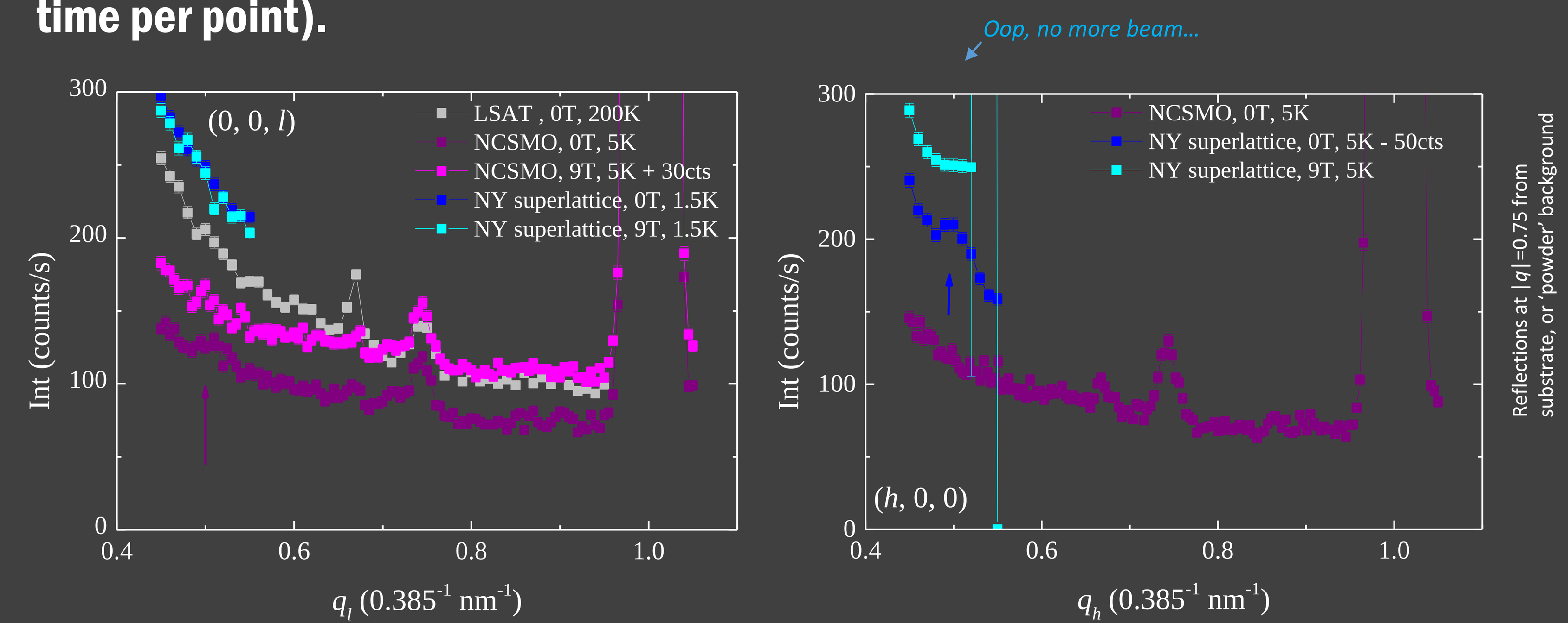
Studies on trilayer and superlattice samples at 300,120,65 and 7 K, and 5 mT, 1 T fields. Corroborate x-ray reflectivity results. Clear magnetism below 120 K, but good fits to R++ and R-- require complex magnetization profiles.



<u>Figure</u>: Superlattice cooled to 7 K in 1 T. Modelling shows a near full in-plane magnetic moment on the NCSMO layer (3.5 μ_B/Mn). There is a near full cancellation of nuclear SLD by the magnetic SLD – leads to the suppression of 1st order peak in R++. Surface layer and interface effects require further free parameters.

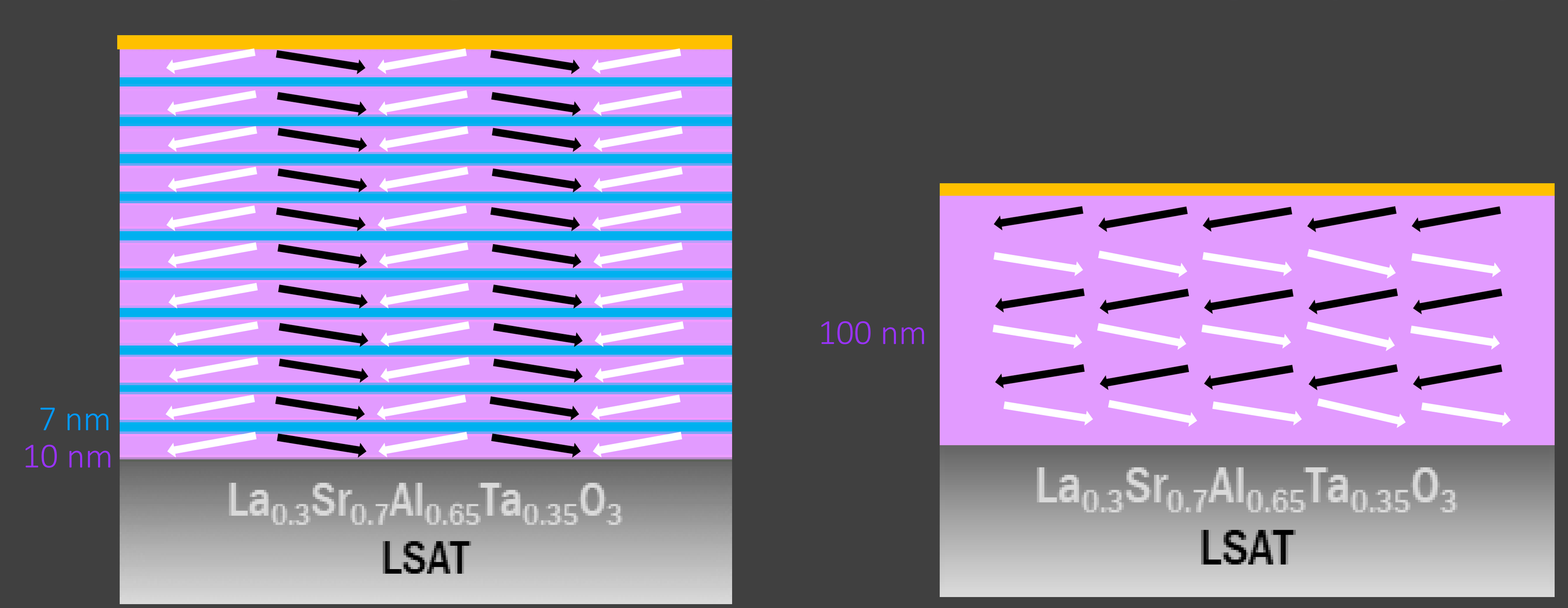
ELASTIC NEUTRON DIFFRACTION

Success! Magnetic reflections are observed from the thin-film (at 60s count time per point).



Focusing on the ½ order peaks:

- Observed at low temperature only.
- Suppressed by 9 T field cooling.
- (½ 0 0) ordering for the multilayer, (0 0 ½) for the single layer manganite.



Disclaimers:
Spin orientation not certain
Ordering in orthogonal direction not known
Subsequent magnetization measurements planned
. . .

CONCLUSIONS + FUTURE WORK

PNR indicates inequivalent magnetic moment within and between manganite layers.

Antiferromagnetic ordering re-orientates from out-of-plane for the single layer manganite (0 0 ½), to in-plane in the multilayer (½ 0 0). Intermediate temperatures will show effect of superconductivity on ordering. More detailed magnetization measurements planned (requires breaking the sample!).

Magnetic state of the manganite appears to be modified by the superconductor in our sandwiches- yet another way to alter manganite magnetic states. The connection to the magnetic field driven insulating-to-superconducting transition remains allusive.

[1] Hwang *et al*. Emergent phenomena at oxide interfaces. *Nature Materials* (2012), 11, 103.
[2] Mallet *et al*. Granular superconductivity and magnetic-field-driven recovery of macroscopic coherence in a cuprate/manganite multilayer. *Physical Review B* (2016), 94, 180503(R).
[3] Malik *et al*. Pulsed laser deposition growth of heteroepitaxial $YBa_2Cu_3O_7/La_{0.67}Ca_{0.33}MnO_3$ superlattices on $NdGaO_3$ and $Sr_{0.7}La_{0.3}Al_{0.65}Ta_{0.35}O_3$ substrates. *Physical Review B* (2012), 85, 054514.

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