NSLS-II First-Experiments Workshop

“Coherence, Dynamics and Polarization”
Hard Materials and Condensed Matter Physics

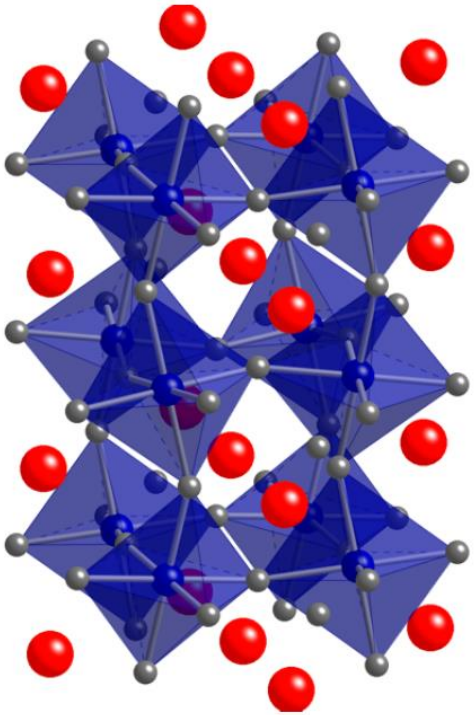
THE UNIVERSITY OF WARWICK

Tom Hase

Talk Outline

- Science that is currently possible
- New Opportunities with NSLS-II

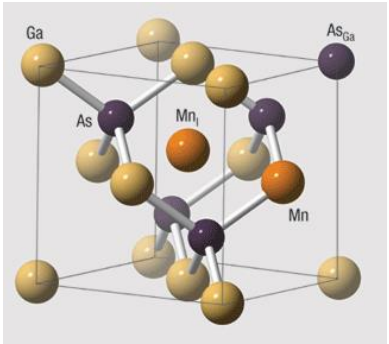
Topical Areas

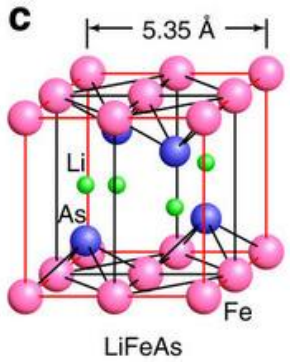


Electronic structure in complex oxides.

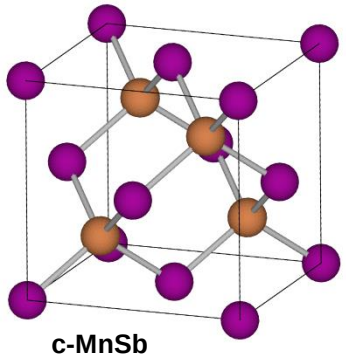
Metal-insulator transitions etc.

Ferromagnetic semiconductors and semi-metals for spintronic applications

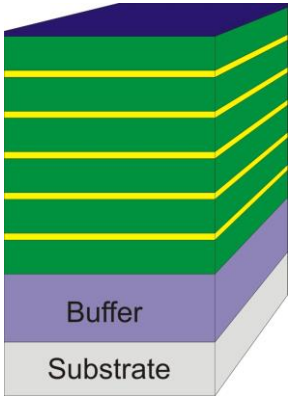


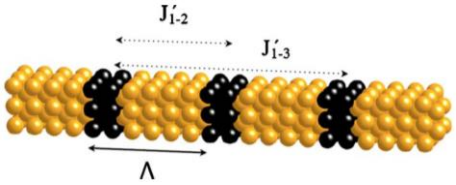


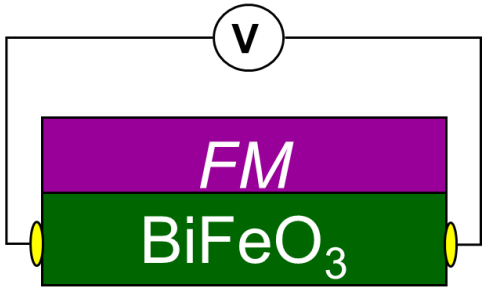
LiFeAs



c-MnSb



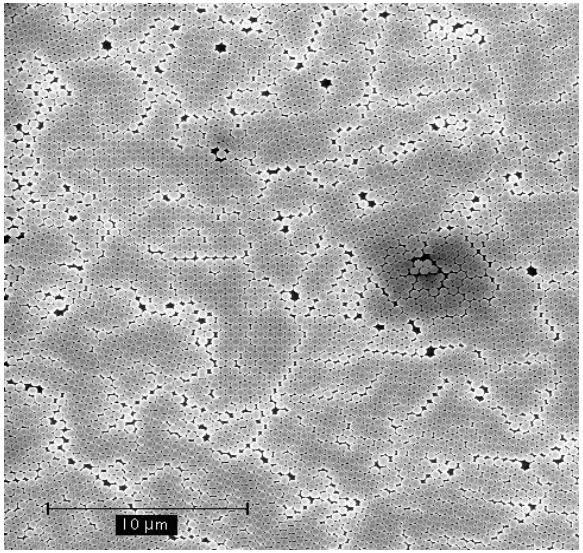


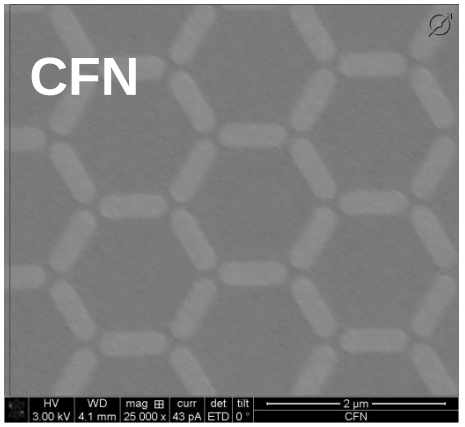


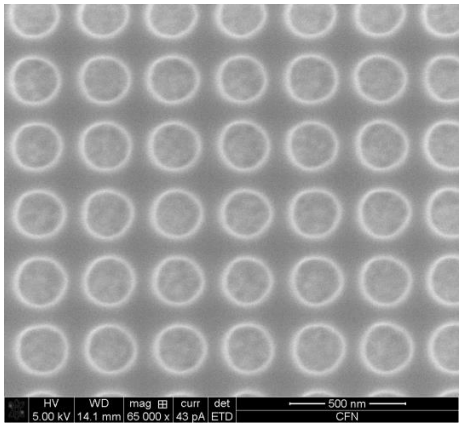
Heterostructures provide new ways of manipulating layer and interface interactions for tailored exploitation

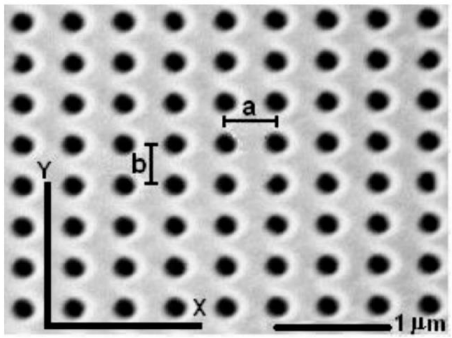
Deng *et al.* Nature Comm. 2 422 (2011; MacDonald *et al.* Nature Mat. 4 195 - 202 (2005)

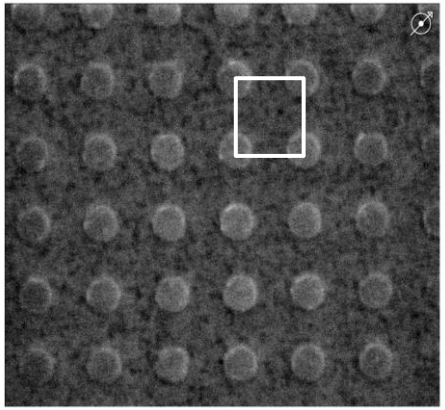
Nanostructures



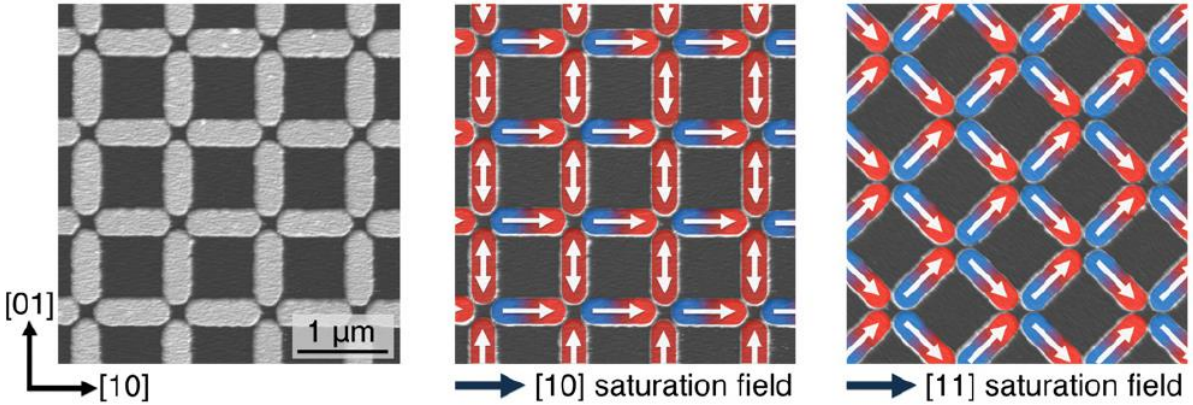








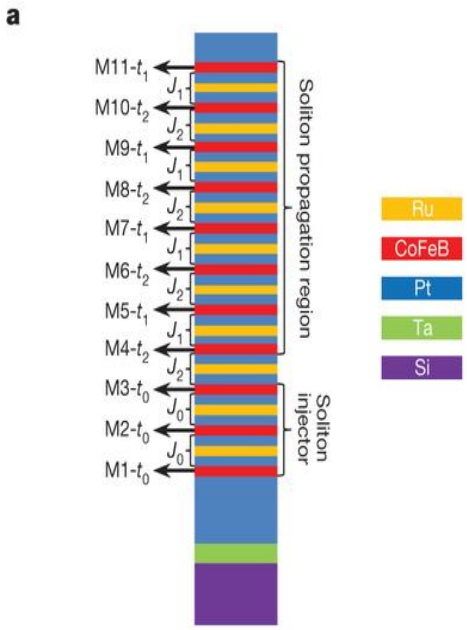
Self assembled or engineered structures

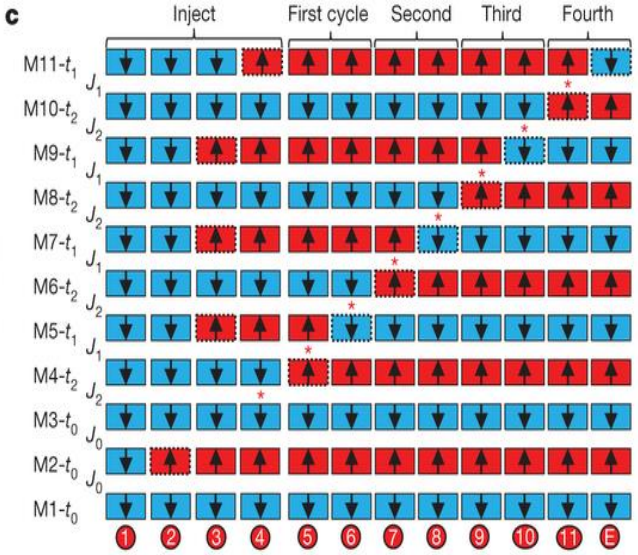


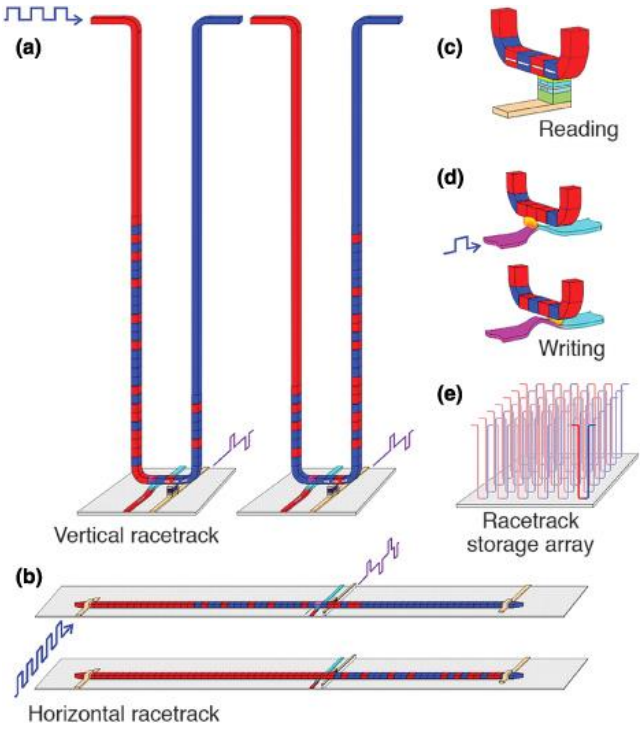
Tailored interactions between elements. New energy landscapes included through element shape and lattice geometry (frustration).

Eftekhari, *et al.* APL 92 253102 (2008); Kapaklis *et al.* New Journal of Physics 14 (2012);

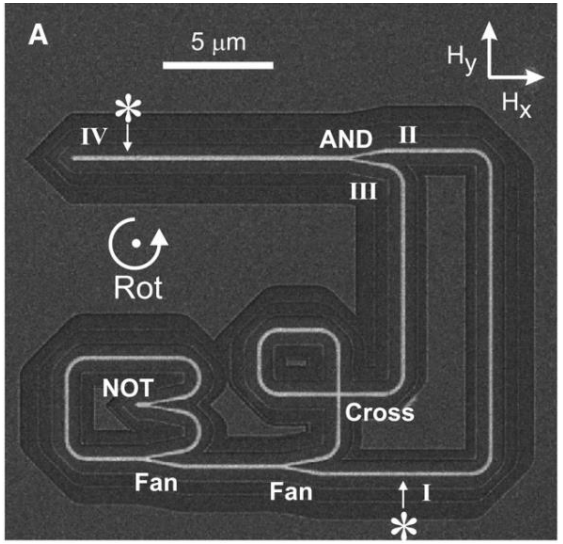
Manipulating Domains







New 3D magnetic logic and memory elements can be realised through the control of domains in nanostructures or through the layer moments in multilayers.

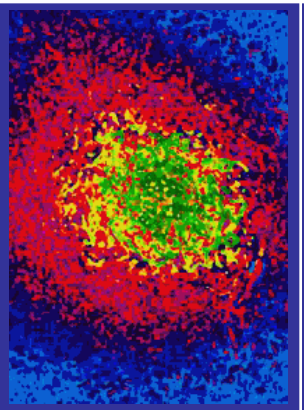


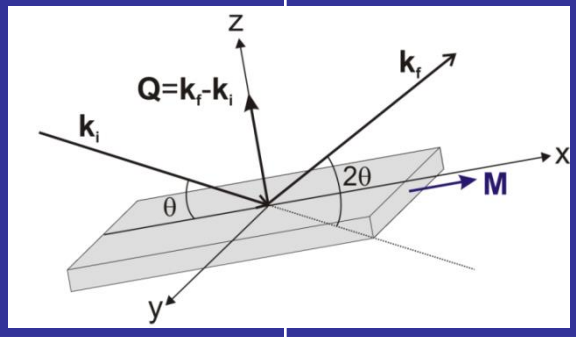
Lavrijsen *et al.* Nature 493, 647(2013); Parkin Science 320 190 (208); Allwood *et al.* Science 309 1688 (2005);

Characterisation

Coherent Diffraction	Spectroscopic	Scattering

• 'Real Space reconstruction'
• XPCS (magnetic & charge)
  • Real time dynamics (μs)
• High resolution of localised features
  • Size, shape, domains
	• Average information from beam footprint
	• Absorption measurement
	• Dichroism (circular or linear)
	• Sum rules
		• Q sensitive through manipulation of the internal electric fields
		• Diffraction
		• Reflectivity
		• Complex scattering factors that depend on polarisation & Q





Current Limitations: **Capacity and Capability,** Flux, resolution, polarisation control, stability,….

Polarisation

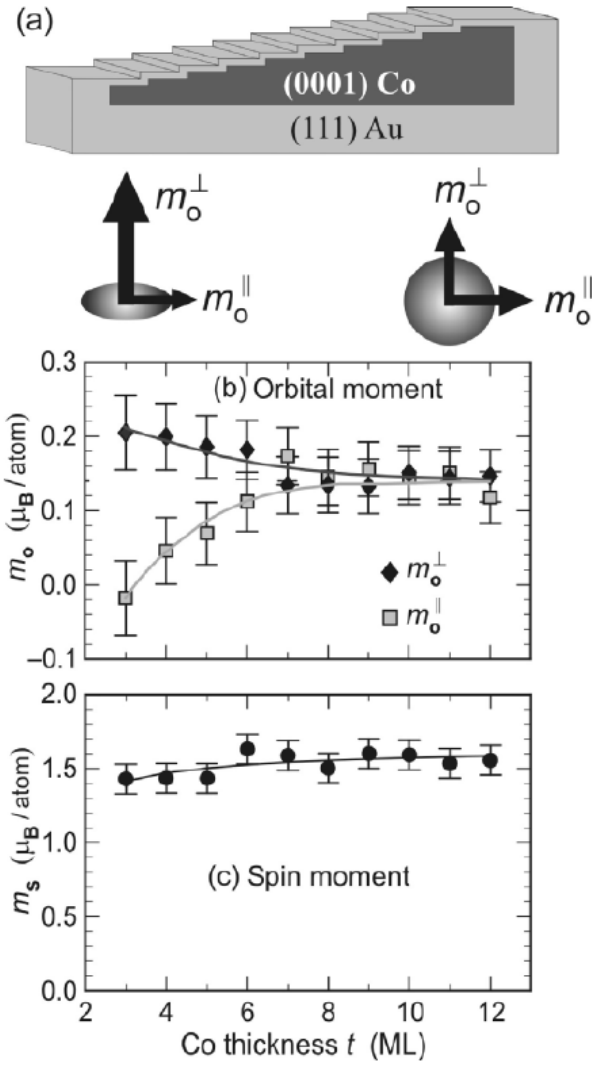
Polarisation dependent x-ray measurements underpin the characterisation, exploitation and design of new materials:

- **Element specific**
- **Site and bond specific**
  - Magnetic and electronic structure
- **Magnetism**
  - Ferromagnetic materials using circular polarisation
  - Antiferromagnetic materials using linear polarisation
- **More general ‘dichroic’ systems**
- **Coherent Studies**

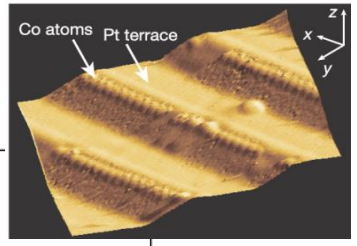
Spectroscopic Studies: XMCD, XMLD

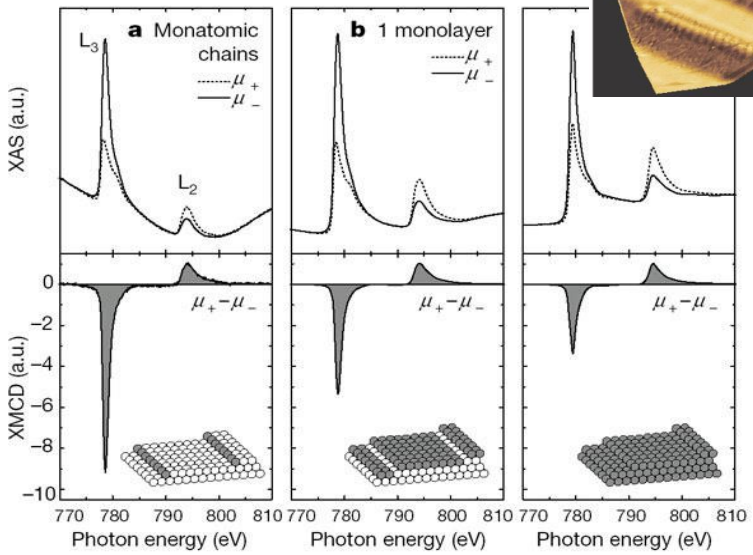
Scattering: Diffraction and reflectivity

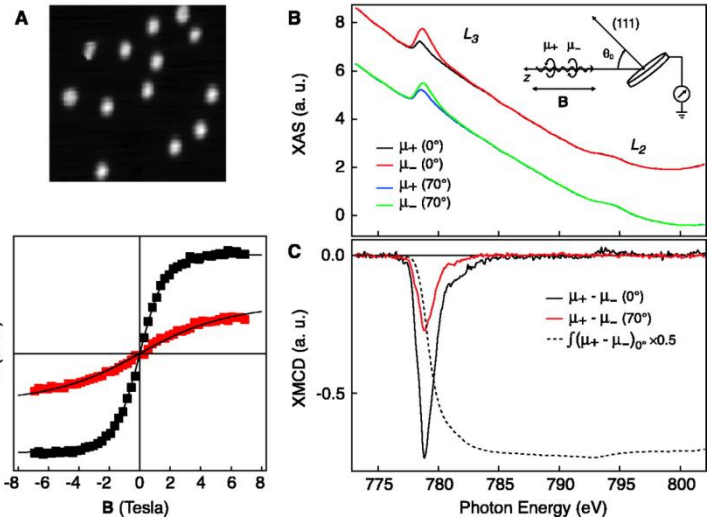
XMCD examples



Co on Pt (111)







P. Gambardella, *et al.* Science 300 (5622) 1130 (2003) and Nature 416, 301-304 (21 March 2002); J. Stöhr & H.C. Siegmann, Magnetism: from Fundamentals to Nanoscale Dynamics, Springer (2006).

Time resolution

XMCD, XMLD, XRMS,

Using pump-probe techniques magnetic information can be obtained with time resolution.

Coherent as well as spectroscopic and scattering studies.

- Limited by bunch length (100ps)
- Noise
- Reproducibility

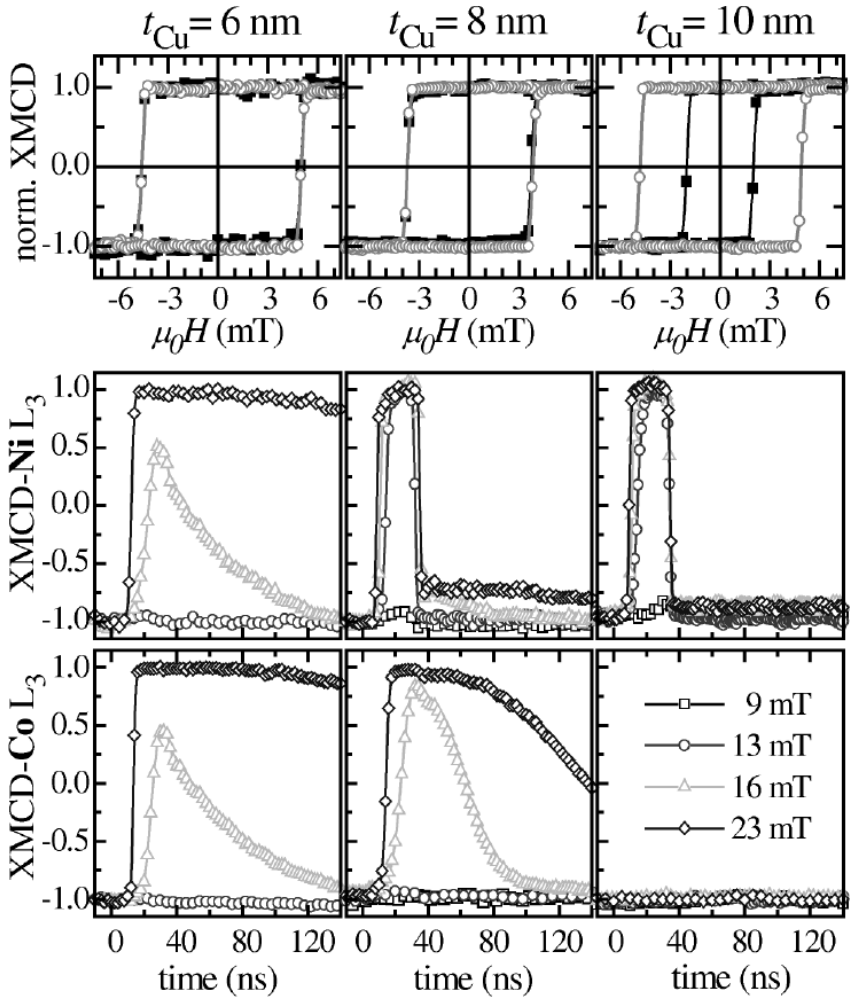
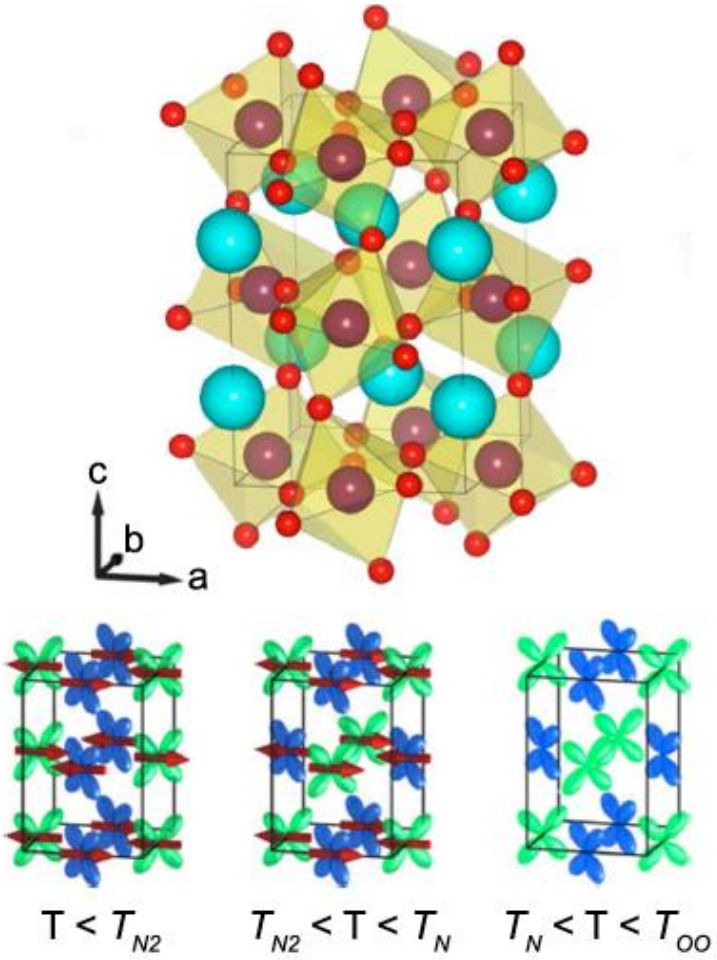


FIG. 2. Static and dynamic measurements in Co(5 nm/Cu/$Ni_{80}Fe_{20}$(5 nm) trilayers (t_{Cu} = 6, 8, and 10 nm). Top: site-selective hysteresis loops measured by XMCD for the Co (open dots) and $Ni_{80}Fe_{20}$ (squares) layers. Bottom: Dynamical response of the permalloy layer (top) and cobalt layer (bottom) to fields (H_{pulse} + H_{bias}) of amplitude 9 to 23 mT and width 30 ns (H_{bias} = −5 mT).

M. Bonfim *et al.* Phys. Rev. Lett. 86 (16) 3646-3649 (2001)

Electronic Structure & Multiferroics

Although the q-range is limited at soft energies, polarisation analysis essential for solving a range of problems in hard condensed matter physics. Many new applications can be found in exploiting complex metal oxides.

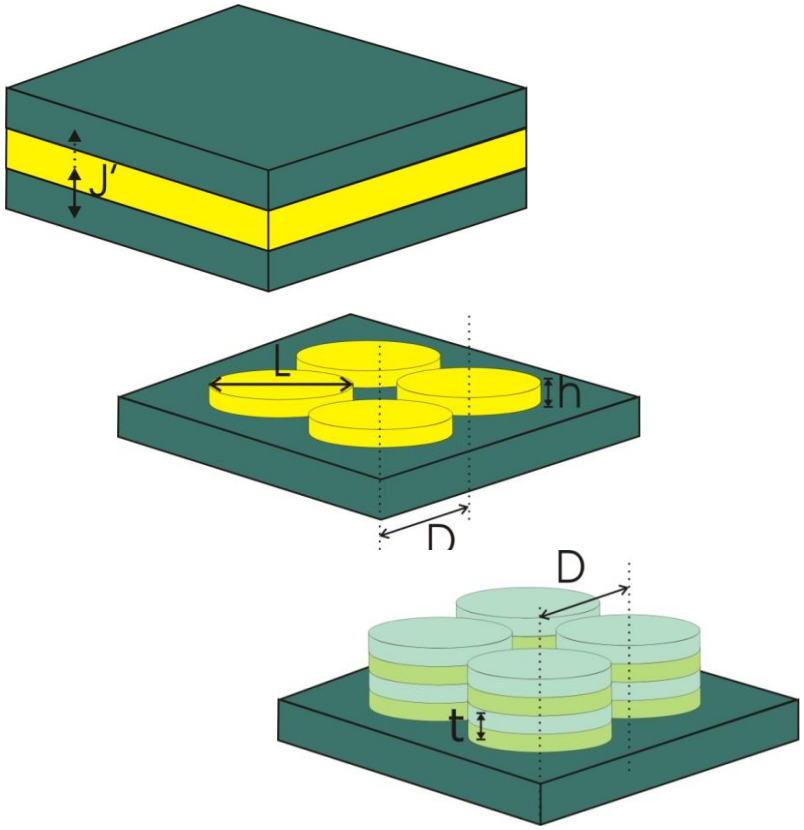


- Magnetic and electronic structure
- Metal insulator-transitions
- Orbital & Spin ordering
- Bulk & Interface Superconductivity
- Ferroic and Multiferroic behaviour.

Limitations: Flux, sample environments, beam size, noise, polarisation control & efficiency

Thin Films and Multilayers

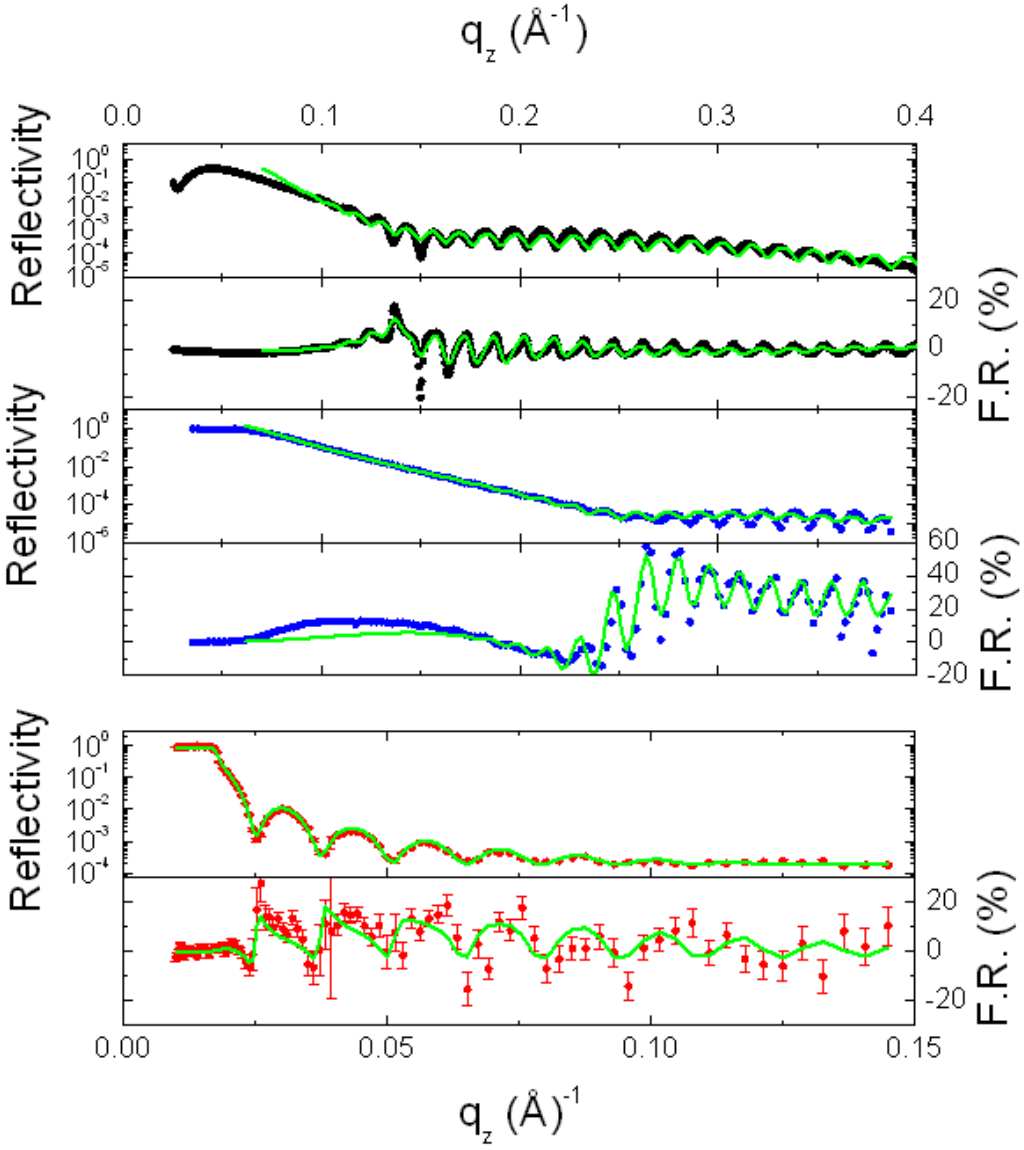
Thin film heterostructures and multilayers continue to be at the forefront of modern technology. By incorporating new materials and growth conditions novel applications continue to come to market.

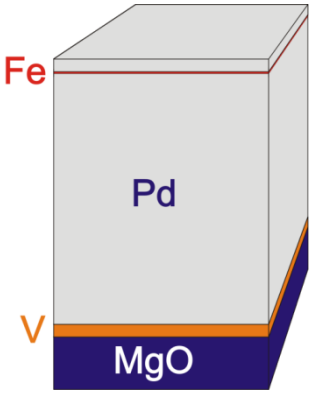


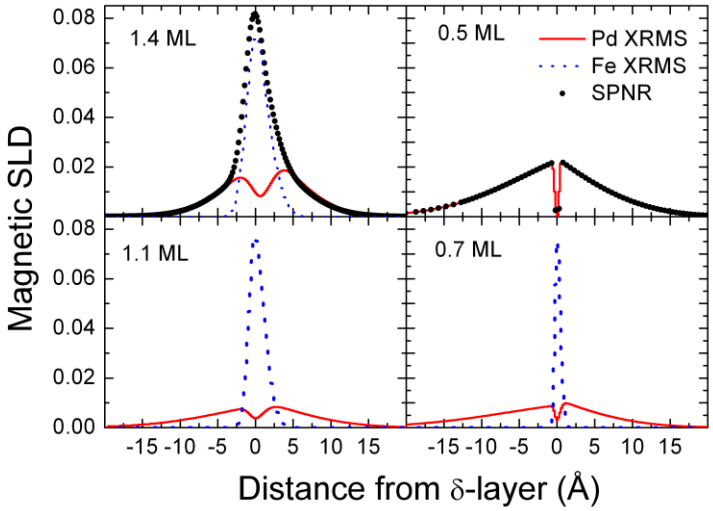
- Amorphous vs. crystalline
- Bulk and Interface anisotropy
- Inter and intra layer coupling
- Proximity effects and ordering phenomena
- Interactions within and between dots
- Control and manipulation of domain structure

Limitations: Flux, sample environments, beam size, noise, polarisation

Magnetic profiles in FePd



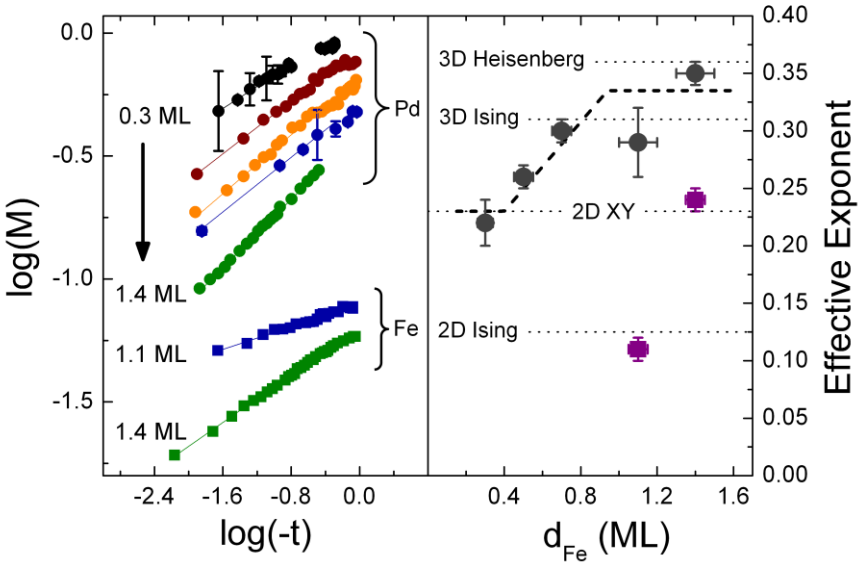


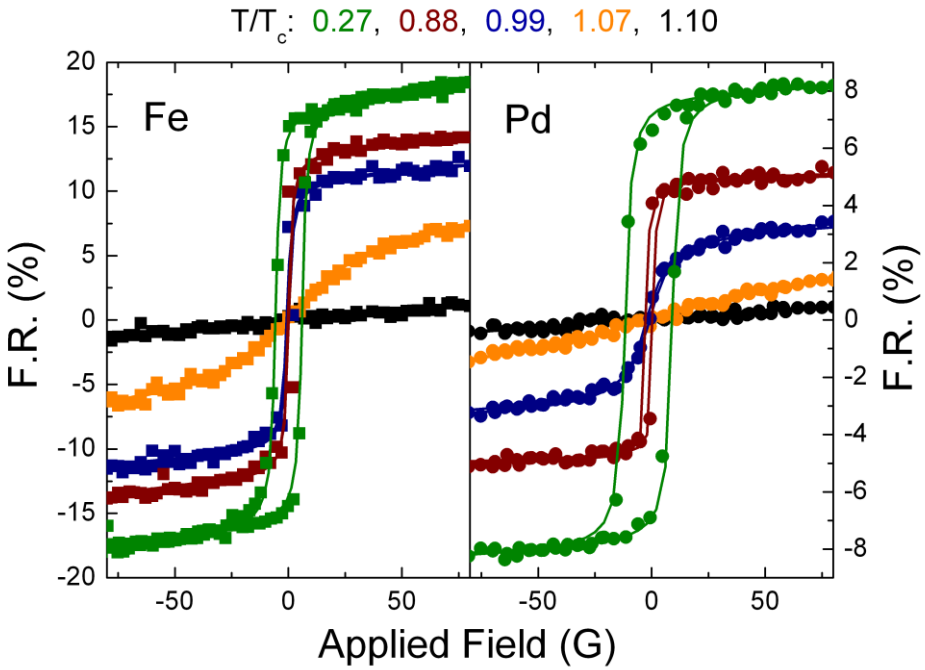


Slow polarisation switching allows the magnetic **equilibrium** profile to be modelled.

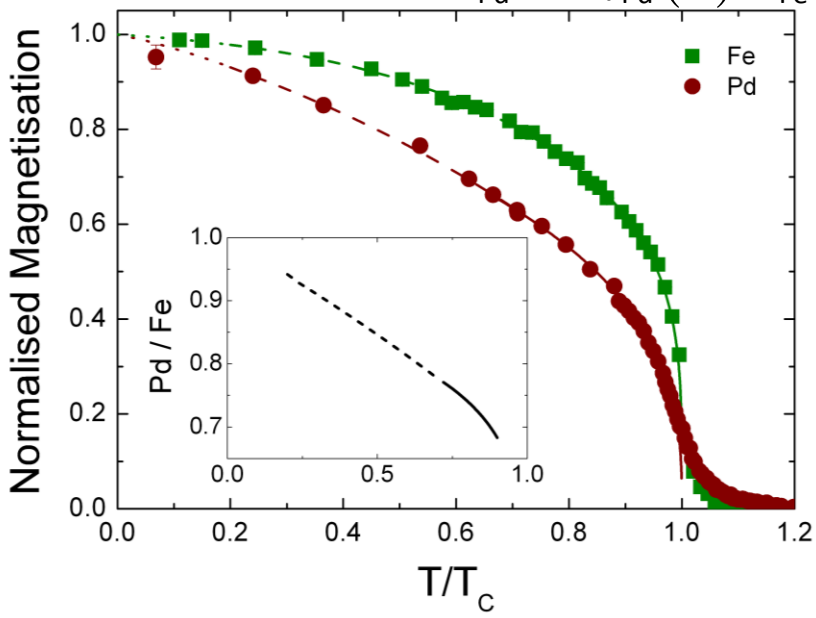
Magnetic Ordering

Recording the hysteresis loops as a function temperature at the appropriate energy allows the ordering phenomena of the two sub-lattices to be compared with standard models.





$$M_{Pd} \propto \chi_{Pd}(T) M_{Fe}$$

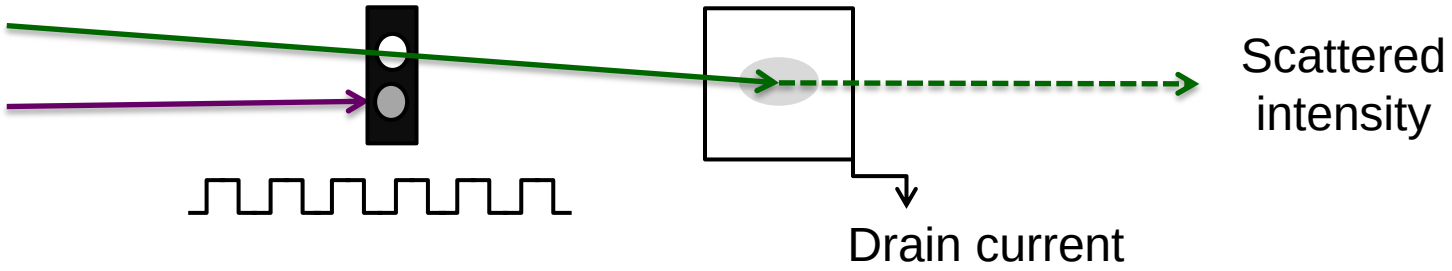


What we gain with NSLS-II

- Increased flux & coherence
  - New chambers from a brighter and more stable source
  - Faster dynamics
  - Enhanced capacity and capabilities
- Enhanced polarisation control
  - all polarisations are available above C edge
- Faster and controlled reversal of helicity
  - Lock-in techniques
  - Measurements of ever smaller signals
  - New experimental paradigms
- Opportunities to use both beams simultaneously on CSX-2
  - Dynamics towards the ps level
- Roll-up experiments in user defined end chambers
- Better overlap of communities

Fast Switching on CSX-2

Switch between the output from the 2 undulators and detect using a single detector

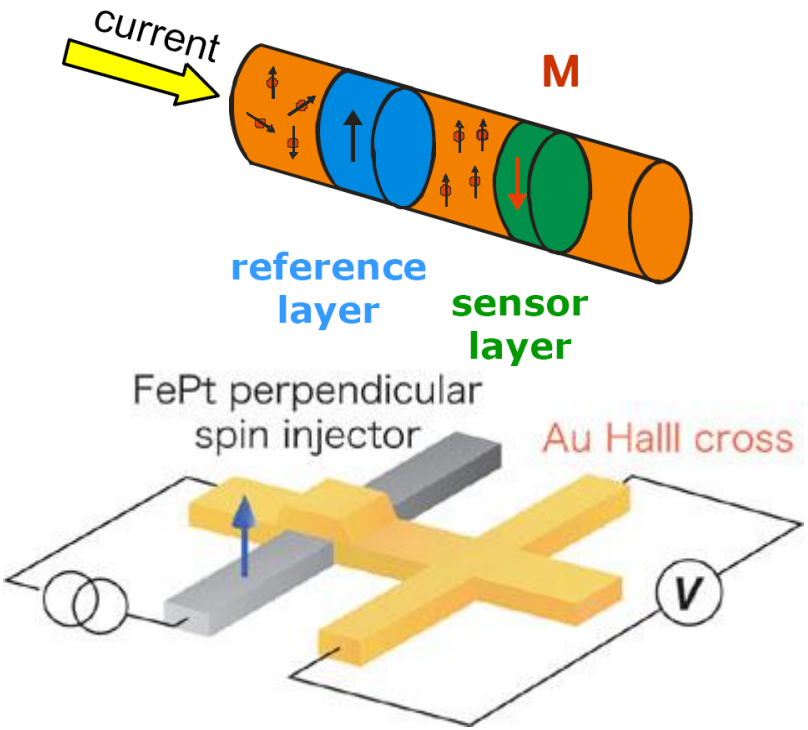


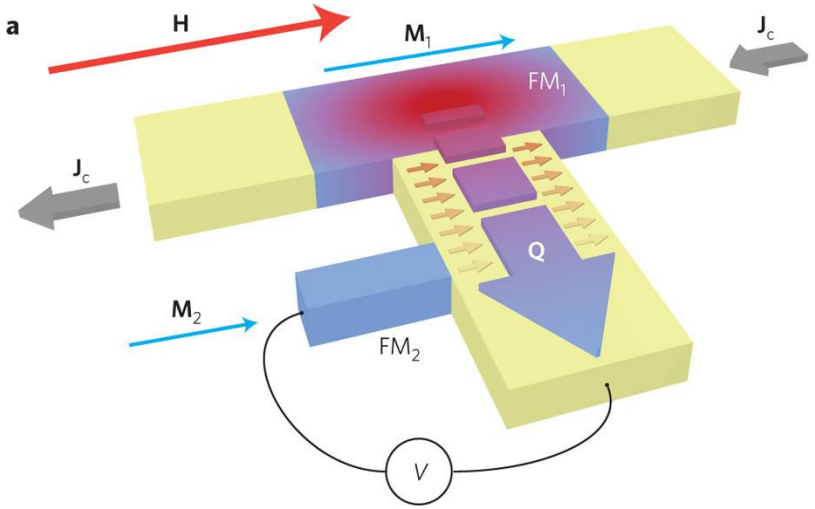
- Faster switching of polarisation
  - Lock-in detection for ever small signals (analogue or gated counters)
  - Field dependent studies
  - Increase in signal to noise for XPCS
  - XMCD, XMLD and XRMS
  - Interface with new sample environments
    - Magnetic, electric fields

Real spintronics

Perturbation away from equilibrium:

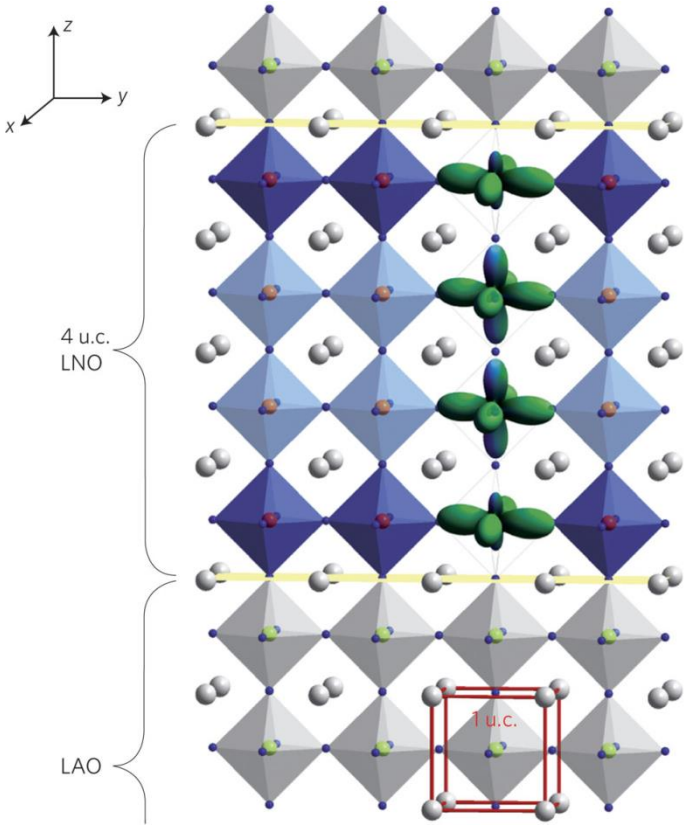
Direct measurement of spin accumulation and spin torque in nanostructures.

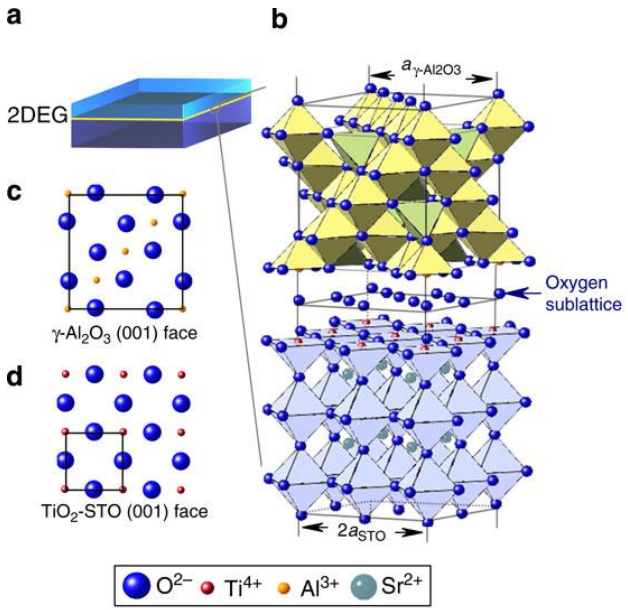


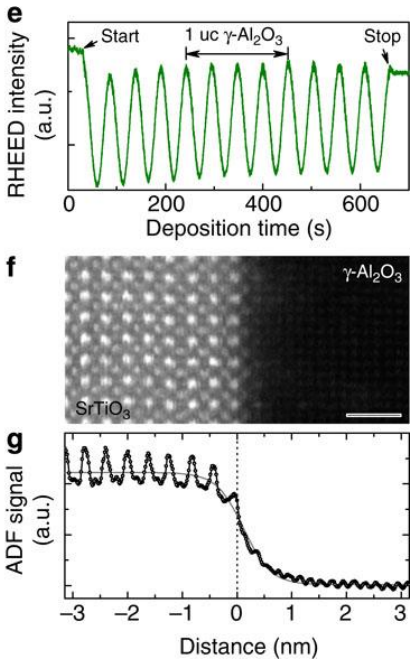


Bauer *et al.* Nature Materials 11, 391–399 (2012);
http://www.imr.tohoku.ac.jp/en/info/results/2008/giantspinHalleffect.html

Emergent phenomena





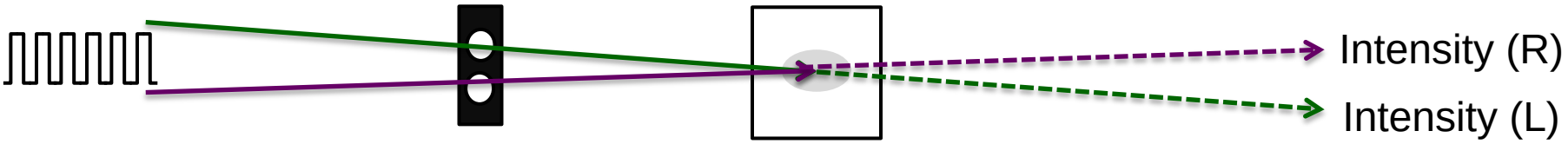


Interfaces are crucial in defining emergent phenomena.

H. Y. Hwang, *et al.* Nature Materials 11, 103–113 (2012); **Y. Z. Chen *et al.*** Nature Communications 4, (2013)

Simultaneous use of 2 Beams

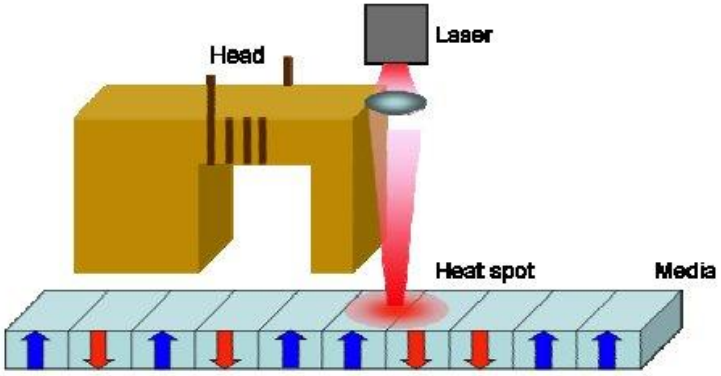
Use the output from both undulators and detect the scattered light using 2 spatially separated detectors

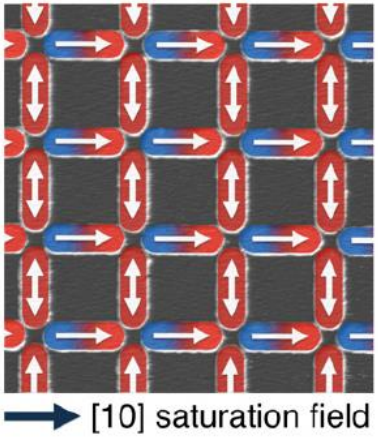


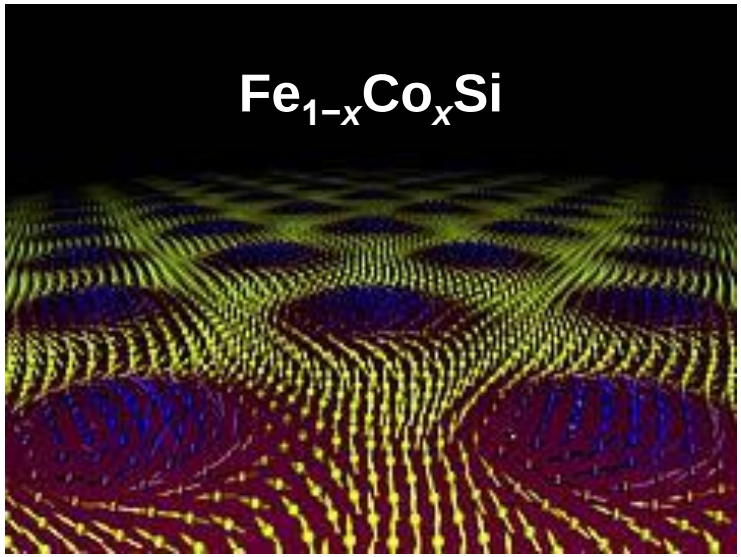
- Simultaneous Detection
  - Beam interference?
  - Same sample under identical conditions for both beams thereby increasing signal to noise
  - Scattering only but opens up the time domain
  - Faster field dependent studies
  - Interface with new sample environments
    - Magnetic, electric fields

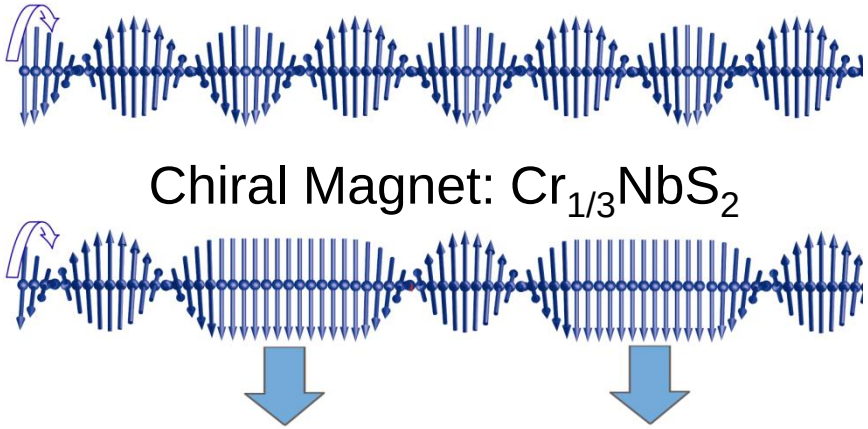
Simultaneous use of Beams

Look for magnetic excitations as a function of temperature and applied field close to ordering temperatures









Mühlbauer, *et al.* Science, 323(5916) 2009; Stebel et al. Rev. Sci. Instrum. 82, 123109 (2011); **Toshiba;**

Togawa *et al.* PRL **108** 107202 (2012)

Conclusions

NSLS-II opens up transformative opportunities in material science and condensed matter physics:

- New materials for exploitation
- Samples being perturbed away from equilibrium
- Stable control of polarisation
- Measurements from small samples
  - Enhanced signal to noise
- Exploring the time domain in real and reciprocal space
  - ms through to ps

Exciting times ahead!