AGjDPG 2: Topological Defects in Magnetic Materials: from Devices to Cosmos (PhD-Student Symposium jointly with MA)

Organizers: Sinéad Griffin, Krzysztof Dymkowski, Yaël Birenbaum (ETH Zurich)

No longer a mathematical curiosity, the number of condensed-matter systems exhibiting topological defects is ever increasing. In particular, recently-discovered topological magnetic materials provide an ideal test-bed for understanding the properties and behaviour of these defects. Among these are skyrmions; a magnetic configuration that, like a Mobius strip, contains a twist that cannot be removed. To date skyrmions have been observed in both magnetic and multiferroic systems. In the field of multiferroics, recently discovered vortices in the hexagonal-manganite family have been shown to be topologically protected, and obey the same scaling laws as expected by the formation of topological defects in the early universe. The direct imaging of such defects is enabled by their property of multiferroism - they ferroelectric order is used to visualise the polar domains and defects which then sets the resulting magnetic order. The proposal and discovery of "magnetic monopoles" in spin-ice provides an interesting analog to the magnetic monopoles first proposed by Dirac. These bundles of magnetism, acting like isolated magnetic charges, were subsequently observed in pyrochlore lattices. Not only is the observation and study of these mathematical objects illuminating, it may also have practical application in the field of quantum computation due to their 'topological' robustness. The organizers thank MaNEP for the generous financial support of the symposium.

Time: Tuesday 9:30–13:45 Location: H16

Invited Talk AGjDPG 2.1 Tue 9:30 H16
Skyrmions in magnets — •Maxim Mostovoy — Zernike Institute for Advanced Materials, University of Groningen, The Netherlands

Skyrmions form an important class of topological defects in uniformly ordered states. They emerge in a variety of different physical contexts and have rather unusual properties directly related to their non-trivial topology. First introduced by T. H. R. Skyrme in his unified theory of baryons and mesons, Skyrmions have made their way into condensed matter physics, e.g. as excitations in Quantum Hall ferromagnets and Bose-Einstein condensates. They have been recently observed in a number of helicoidal magnets with non-centrosymmetric crystal lattices, where they play the role of quantized fluxes of effective magnetic field acting on spin-polarized electrons. I will discuss phenomenological description of Skyrmions, microscopic mechanisms for their stabilization in magnetic materials and effects of the coupled dynamics of spins and charges at these topological objects.

Invited Talk AGjDPG 2.2 Tue 10:00 H16
Experimental studies of skyrmions in chiral magnets — •Christian Pfleiderer — Physik Department E21, Technische Universität München, D-85748 Garching, Germany

Present day limitations of information technology involving magnetic materials may be traced to the notion that all magnetic materials known until recently represent topologically trivial forms of long-range magnetic order. Recently the first example of a new form of magnetic order has been discovered, which is composed of topologically stable spin solitons driven by chiral spin interactions – so called skyrmions. The skyrmions known to date display several exceptional properties: a topological winding number of -1 implying great stability, very efficient coupling to the conduction electrons in metallic systems by virtue of Berry phases, very weak pinning by defects and magnetic anisotropies, all paving the way to spin torque effects at ultra-low current densities. I will review the current status of the research on skyrmions and related topological solitons in bulk compounds and thin films, focussing on similarities and analogies with conventional magnetic materials.

AGjDPG 2.3 Tue 10:30 H16
Rotating skyrmion lattices by spin torques and field or temperature gradients — •Karin Everschor-Sitte[1,2], Markus Garst[2], Benedikt Binz[2], Florian Jonietz[1], Sebastian Mühlbauer[3], Christian Pfleiderer[1], and Achim Rosch[2] — [1]Physik-Department E21, Technische Universität München — [2]Institut für Theoretische Physik, Universität zu Köln — [3]Forschungsneutronenquelle Heinz Maier Leibnitz (FRM II), Technische Universität München

Chiral magnets like MnSi form lattices of skyrmions, i.e., magnetic whirls, which react sensitively to small electric currents j above a critical current density j_c. The interplay of these currents with tiny gradients of either the magnetic field or the temperature can induce a rotation of the magnetic pattern for $j > j_c$. Either a rotation by a finite angle of up to 15° or – for larger gradients – a continuous rotation with a finite angular velocity is induced. We use Landau-Lifshitz-Gilbert equations extended by extra damping terms in combination with a phenomenological treatment of pinning forces to develop a theory of the relevant rotational torques [1]. Experimental neutron scattering data on the angular distribution of skyrmion lattices suggest that continuously rotating domains are easy to obtain in the presence of remarkably small currents and temperature gradients.

[1] K. Everschor *et al.*, PRB **86**, 054432 (2012)

AGjDPG 2.4 Tue 10:45 H16
Giant generic topological Hall resistivity of MnSi under pressure — •Robert Ritz[1], Marco Halder[1], Christian Franz[1], Andreas Bauer[1], Michael Wagner[1], Robert Bamler[2], Achim Rosch[2], and Christian Pfleiderer[1] — [1]Physik-Department E21, Technische Universität München — [2]Institut für Theoretische Physik, Universität zu Köln

We report detailed low temperature magneto-transport and magnetization measurements in MnSi under pressures up to ~ 12 kbar. Tracking the role of sample quality, pressure transmitter, and field and temperature history allows us to link the emergence of a giant topological Hall resistivity $\sim 50\,\mathrm{n\Omega cm}$ to the skyrmion lattice phase at ambient pressure. We show that the remarkably large size of the topological Hall resistivity in the zero temperature limit must be generic. We discuss various mechanisms which can lead to the much smaller signal at elevated temperatures observed at ambient pressure.

15 min. break

Topical Talk AGjDPG 2.5 Tue 11:15 H16
Topological Defects and Quantum Computing — •Simon Trebst — University of Cologne

Topological defects are not only entities of fundamental theoretical beauty, they have also become highly sought-after objects in tabletop condensed matter experiments around the world. Part of their attraction comes from their possibly far-reaching relevance as the elementary building blocks in a topological quantum computer. In this talk, I will introduce the main conceptual ideas underlying these computing proposals and discuss beyond the current experimental status of identifying non-Abelian topological defects a number of possible obstacles that will need to be overcome on the way to build the first topological quantum computer.

Topical Talk AGjDPG 2.6 Tue 11:45 H16
Cosmic strings in multiferroics — •Nicola Spaldin — ETH Zurich, Switzerland

A key open question in cosmology is whether the vacuum contains topological defects such as cosmic strings, believed to have formed as a result of symmetry-lowering phase transitions in the early universe. An inexpensive, laboratory-based route to shedding light on the answer is to test the predicted scaling laws for topological defect formation (the so-called Kibble-Zurek mechanism) in condensed matter systems. Here we show that the multiferroic hexagonal manganite oxides – with their coexisting magnetic, ferroelectric and antiphase orderings – have an appropriate symmetry-lowering phase transition for testing the Kibble-Zurek scenario. We present an analysis of the Kibble-Zurek theory of topological defect formation applied to the hexagonal magnanites, show that the recently observed domain vortex cores are formally topologically protected, and that recent literature data are quantitatively consistent with our predictions from first-principles electronic structure theory. Finally, we explore experimentally for the first time to our knowledge the cross-over out of the Kibble-Zurek regime and find a surprising "anti-Kibble-Zurek" behavior.

AGjDPG 2.7 Tue 12:15 H16

Ferroelectric Vortices in Hexagonal $YMnO_3$ — •Martin Lilienblum — Department of Materials, ETH Zurich

Hexagonal rare earth manganites $RMnO_3$ (R= Sc, Y, Dy-Lu) exhibit an intriguing domain structure with kaleidoscopic intersections of always six individual domains. These ferroelectric vortices can be seen as topological defects that forms while cooling across the ferroelectric phase transition. Topological defect formation is of general interest since, for example, topological defects may have played an important role during the evolution of the early universe. Here we present an experimental study on the stability of the ferroelectric vortices in flux grown $YMnO_3$ single crystals in annealing experiments up to the phase transition temperature of around 1300 K. In a second experiment we studied the dependence of the density of ferroelectric vortices on the cooling rate. In order to ensure the visualization of the true bulk domain structure we performed an elaborate sample processing by annealing, polishing and piezoresponse force microscopy. In a third experiment we studied the progression of the ferroelectric order parameter below the phase transition by optical second harmonic generation.

15 min. break

Topical Talk AGjDPG 2.8 Tue 12:45 H16

Topological physics: from quantum Hall Skyrmions to optical Chern lattices — •Roderich Moessner — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

Topological physics as we understand it today started 30 years ago with the experimental discovery of the quantum Hall effects. Here, we discuss the physics of Skyrmions, spin textures in quantum Hall states exhibiting both conventional and topological forms of order in a delicately intertwined way: they combine, in a physically transparent way, fundamental concepts such as topological stability and Berry phase physics. We provide a detailed analysis of Skyrmion lattices for multicomponent quantum Hall systems, such as (bi)layer graphene or multi-valley semiconductors in a magnetic field. We also point out how these results can be used to inspire a robust design strategy for optical topological band structures for use in cold atomic systems.

Topical Talk AGjDPG 2.9 Tue 13:15 H16

Magnetricity and Magnetic Monopoles in Spin ice — •Steve Bramwell — University College London

The analogy between spin configurations in spin ice materials like Ho2Ti2O7 and proton configurations in water ice, H2O, has been appreciated for many years (see Ref. [1] for a review). However it is only in the last few years that this equivalence has been extended into the realm of electrodynamics [2,3]. In this talk I shall describe our recent experimental work that identifies emergent magnetic charges ("monopoles"), transient magnetic currents ("magnetricity") and the universal properties expected of an ideal magnetic Coulomb gas (magnetic electrolyte - "magnetolyte"). These universal properties include the Onsager-Wien effect, "corresponding states" behaviour, Debye-Huckel screening and Bjerrum pairing [4-6]. I will describe experimental results for both traditional spin ice materials (Ho2Ti2O7, Dy2Ti2O7) and a recently discovered system (Dy2Ge2O7).

References:

[1] Bramwell and Gingras, Science, 294 1495 2001 [2] Castelnovo, Moessner & Sondhi, Nature 451 42 (2008) [3] Ryzhkin, JETP 101 481 (2005); [4] Bramwell et al. Nature 461 956 (2009) [5] Fennell et al., & Bramwell Science 326 415 (2009) [6] Giblin, Bramwell et al., Nature Physics 7 252 (2011) [7] Zhou, Bramwell et al., Nat Comm. 478, 1483 (2011)