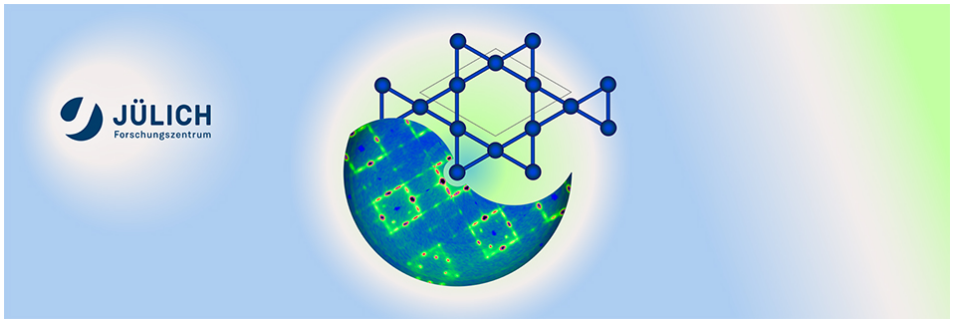
JCNS Workshop 2025, Trends and Perspectives in Neutron Scattering. Quantum Materials: Theory and Experiments

Dienstag, 7. Oktober 2025 - Donnerstag, 9. Oktober 2025

Evangelische Akademie Tutzing



Buch der Abstracts

Contents

Emergent phenomena in functional and nano-magnets / 108

Magnetic Morphologies and Exchange Interactions in Ferrite Nanoparticles

Autor Sabrina Disch[1]

[1] *University of Duisburg-Essen*

Korrespondenzautor: sabrina.disch@uni-due.de

Magnetic nanoparticles and nanostructures reveal interesting magnetic properties and relaxation phenomena which make them relevant for sensor technology, imaging techniques, or magnetic heating, applicable to magnetic hyperthermia and thermocatalysis applications. Whereas the implementation of nanomagnetic properties into technological applications is progressing rapidly, fundamental questions remain challenging, such as the intricate interplay of nanoscale magnetization and magnetization relaxation with structural characteristics.
Our approach to such questions lies in the cross-scale investigation of structure and magnetization in nanostructured materials using X-ray and polarized neutron scattering. Aiming at the nanoscale spatial resolution, magnetic small-angle neutron scattering (SANS) has emerged as a versatile technique to probe chemical morphology and magnetization [1,2].
In this talk, I will present our most recent results on the compositional and magnetic intraparticle morphology in ferrite nanoparticles [3,4]. Being intrinsic to nanomaterials, disorder effects crucially determine the magnetization properties of magnetic nanoparticles [5]. The classical picture considers single-phase magnetic nanoparticles as a collinearly magnetized core with a structurally and magnetically disordered surface region. Using magnetic SANS, we have established a significant field-induced growth of the integral moment by a magnetic ordering transition at the structurally disordered surface [3]. On this basis, we have elucidated the intra-particle distribution of the spin disorder energy, a characteristic that indirectly provides unprecedented insight into the structural defect profile in magnetic nanoparticles.

[1] S. Mühlbauer et al., Rev. Mod. Phys., 91, 015004 (2019).
[2] D. Honecker et al., Nanoscale Adv. 4, 1026 (2022).
[3] D. Zákutná, S. Disch et al., Phys. Rev. X, 10, 031019 (2020).
[4] D. Zákutná, N. Rouzbeh, S. Disch et al., Chem. Mater., 35, 2302 (2023).
[5] A. Lak, S. Disch, P. Bender, Adv. Science, 8, 2002682 (2021).

Emergent phenomena in functional and nano-magnets / 76

Observing emergent magnetic correlations in artificial spin systems with neutron and x-ray scattering

Autoren Flavien Museur[1]; Laura Heyderman[1]

[1] *Laboratory for Mesoscopic Systems - ETH - PSI*

Korrespondenzautoren: flavien.museur@psi.ch, laura.heyderman@psi.ch

Artificial spin ices—engineered arrays of nanoscale magnetic elements arranged on various lattices—serve as highly controllable platforms for studying emergent phenomena in frustrated magnetism [1]. These systems, inspired by natural spin ices and spin liquids, host rich phase diagrams and exotic excitations, such as emergent magnetic monopoles [2,3] and Coulomb phases [4]. Currently established imaging techniques, such as lab-based magnetic force microscopy and synchrotron x-ray photoemission electron microscopy (PEEM) have provided direct real-space access to static configurations, or at best slow dynamics on the seconds to minutes timescale; but they lack the capability to probe ensemble-averaged and dynamic correlation functions. Neutron scattering, with its sensitivity to magnetic correlations over a broad range of length and time scales, is ideally suited to fill this gap

—but has been historically underutilized due to the inherently low volume of these lithographically defined systems.
In recent work [5], it has been demonstrated that grazing-incidence small-angle neutron scattering (GISANS) can be successfully applied to artificial spin ices. GISANS was used to probe spin correlations in distorted triangular-lattice artificial Ising systems, on the MARIA reflectometer at JCNS. This revealed diffuse magnetic scattering signatures consistent with spin-liquid-like correlations, extracted from the weak spin-flip scattering signal. This work established GISANS as a viable probe of in-plane spin correlations in thin frustrated systems. Complementary results were obtained in Ref. [6], where soft x-ray resonant magnetic scattering (SXRMS) was employed to study critical behavior in thermally active artificial square ice. The SXRMS patterns revealed the evolution of magnetic Bragg peaks as the system was cooled through the phase transition temperature. Critical exponents consistent with the two-dimensional Ising universality class could be extracted, underscoring the power of reciprocal-space probes for characterizing phase transitions.
Despite these advances, several experimental challenges remain. The magnetic neutron scattering signal from artificial spin systems is extremely weak, requiring large sample areas (~cm^2), large sample volumes obtained by stacking several samples together, long integration times, and careful polarization analysis to isolate spin-flip channels from the structural background. The upcoming European Spallation Source (ESS) is expected to significantly expand the experimental possibilities for neutron studies of artificial spin systems. In particular, the polarized reflectometer can perform GISANS measurements and is being designed with the study of arrays of nanomagnets in mind. These advances will open new avenues to explore frustration, glassiness, and topological phenomena in artificial spin lattices using neutron scattering.

[1] Skjærvø, S. H. et al., Nature Reviews Physics 2, 13 (2020)
[2] Ladak, S. et al., Nature Physics 6, 359–363 (2010)
[3] Mengotti, E. et al., Nature Physics 7, 68–74 (2011)
[4] Canals, B. et al., Nature Communications 7, 11446 (2016)
[5] Pip, P. et al., Nanoscale Horizons 6, 474 (2021)
[6] Sendetskyi, O. et al., Physical Review B 99, 214430 (2019)

Emergent phenomena in functional and nano-magnets / 87

Inverse proximity effect in a ferromagnet-superconductor thin film heterostructure investigated by GISANS with polarization analysis

Autor Emmanuel Kentzinger[1]

Co-Autoren: Annika Stellhorn [2]; Bob Vermeulen [3]; Cedric Gommes [4]; Kathryn Krycka [5]; Thomas Brückel [6]

[1] *Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science*

[2] *ESS*

[3] *University of Liège*

[4] *University of Liege*

[5] *NIST Center for Neutron Research*

[6] *FZJ, DE*

Korrespondenzautoren: annika.stellhorn@ess.eu, cedric.gommes@uliege.be, e.kentzinger@fz-juelich.de, klkrycket@gmail.com, bob.vermeulen@imec.be

Three direct proximity effects in ferromagnet-superconducting thin film heterostructures of Nb and FePd with a lateral domain pattern have been found by temperature dependent electrical resistivity measurements, showing the influence of the magnetic domain structure on the superconducting state: reversed domain superconductivity, domain wall superconductivity and generation of spin-triplet Cooper pairs [1].
In this system, the inverse proximity effect, i.e. the effect of the entrance in the superconducting state on the magnetic structure has been studied by temperature dependent grazing incidence small angle

neutron scattering (GISANS) on the KWS-3 diffractometer at the Heinz Maier-Leibnitz Zentrum [2] and by GISANS with polarization analysis on vSANS at the NIST Center for Neutron Research [3,4]. Guided by micromagnetic simulations [5], we present in this contribution simulations of the GISANS data within the distorted wave Born approximation [6,7]. We find that the domain walls width in FePd with strong perpendicular magnetic anisotropy increases when Nb enters the superconducting state [8].

[1] A. Stellhorn et al., New Journal of Physics, 22, 093001 (2020).
[2] Heinz Maier-Leibnitz Zentrum, Journal of Large-Scale Research Facilities 1, A31 (2015)
[3] J. Barker et al., Journal of Applied Crystallography, 55, 271 (2022)
[4] W.C. Chen et al., Journal of Physics: Conference Series, 2481, 012006 (2023)
[5] B. Vermeulen, Master Thesis, University of Liège and Forschungszentrum Jülich (2021) http://hdl.handle.net/2268.2/11448
[6] B.P. Toperverg, The Physics of Metals and Metallography, 116, 1337 (2015)
[7] E. Kentzinger et al., Physical Review B, 77, 104435 (2008)
[8] A. Stellhorn, PhD Thesis, RWTH Aachen University (2021)

E-mail of the corresponding author: e.kentzinger@fz-juelich.de

Emergent phenomena in functional and nano-magnets / 95

Insights into internal magnetic structure of iron oxide nanoparticles: a combined small-angle neutron scattering and magnetometry study

Autoren Artem Feoktystov[1]; Oleg Petracic[2]

Co-Autoren: Sascha Ehlert [3]; Baohu Wu [4]; Emmanuel Kentzinger [5]; Ulrich Ruecker [6]; Bastian Veltel [7]; Markos Skoulatos [7]; Elliot Paul Gilbert [8]; Nina-Juliane Steinke [9]

[1] *JCNS at MLZ*

[2] *FZ Jülich*

[3] *Forschungszentrum Jülich GmbH, JCNS-1*

[4] *Forschungszentrum Jülich GmbH, JCNS at MLZ*

[5] *Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science*

[6] *JCNS-HBS, Forschungszentrum Jülich*

[7] *Technical University of Munich*

[8] *Australian Nuclear Science and Technology Organisation ANSTO*

[9] *Institut Laue-Langevin*

Korrespondenzautoren: ba.wu@fz-juelich.de, u.ruecker@fz-juelich.de, a.feoktystov@fz-juelich.de, epg@ansto.gov.au, e.kentzinger@fz-juelich.de, o.petracic@fz-juelich.de, markos.skoulatos@frm2.tum.de, s.ehlert@fz-juelich.de, bastian.veltel@frm2.tum.de, steinkenj@ill.fr

This work continues our previous studies on iron oxide nanoparticles [1] to systematically investigate the magnetic structure of the nanoparticles in a broad range of particle sizes. The parameters of the core-shell structure were determined using small-angle neutron and X-ray scattering. A non-magnetic layer at the nanoparticle surface was determined using small-angle scattering with polarized neutrons at saturating fields. Room temperature hysteresis data was obtained using vibrating sample magnetometry and the M(H) curves were inverted to obtain the magnetic moment distribution within the nanoparticle systems.
The detailed magnetic structure of the nanoparticles is obtained by analyzing the results on the non-magnetic layer, the size distribution and magnetic moment distribution.

[1] T. Köhler et al., Nanoscale, 13, 6965 (2021).

Emergent phenomena in functional and nano-magnets / **99**

Magnetic and Transport Signatures of Strain in SrRuO3 Thin Films: Insights from STO and Si-Based Substrates

Autor Ankita Singh[None]

Co-Autoren: Connie Bednarski-Meinke [1]; Emmanuel Kentzinger [2]; Vitor Alexandre de Oliveira Lima [1]

[1] *JCNS-2*

[2] *Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science*

Korrespondenzautoren: e.kentzinger@fz-juelich.de, c.bednarski-meinke@fz-juelich.de, an.singh@fz-juelich.de, v.de.oliveira.lima@fz-juelich.de

SrRuO3 (SRO), a widely studied ferromagnetic metallic perovskite oxide, exhibits perpendicular magnetic anisotropy (PMA) when subjected to appropriate strain conditions. Its excellent lattice matching with SrTiO3 (STO) enables nearly perfect epitaxial growth, making it an ideal platform for investigating strain-induced effects in functional oxide systems [1]. Although strain-tuned ferromagnetism has been examined in several perovskite heterostructures, the influence of strain on the magnetic anisotropy and transport behavior of SRO remains an ongoing research focus. The anomalous Hall effect (AHE) in SRO displays non-traditional characteristics that are highly sensitive to strain, film thickness, and elemental doping, warranting further studies on how epitaxial strain modulates its electronic and magnetic responses. To delve deeper into these phenomena, ~20 nm SRO thin films were fabricated using high oxygen pressure sputtering (HOPS) on TiO_2-terminated STO (001) single crystals and on STO-buffered (4 nm) Si (001) substrates, under identical deposition conditions. X-ray diffraction (XRD) confirmed epitaxial growth, and X-ray reflectivity (XRR) provided precise information of film thickness and interfacial roughness. Magnetization studies indicated a Curie temperature (Tc) of 155 K for both film types but revealed contrasting magnetic anisotropies. The SRO/STO film demonstrated a stronger out-of-plane magnetic component, whereas the SRO/STO/Si film favored in-plane magnetization. This directional dependence was further reflected in magnetoresistance (MR%) measurements, which peaked when the magnetic field aligns with each sample's easy axis. Notably, AHE results for the SRO/STO/Si film showed an anomalous peak, potentially arising from Ru-site vacancies [2], implying the coexistence of multiple magnetic contributions within the film. These results highlight the pivotal influence of epitaxial strain in controlling both the magnetic orientation and electronic transport properties in SRO-based heterostructures. To further unravel the role of the STO buffer layer in modulating interfacial magnetism, we plan to conduct detailed polarized neutron reflectometry (PNR) measurements on SRO films grown on STO-buffered Si and single-crystal STO substrates. These experiments, scheduled for October 2025 at the Spallation Neutron Source (SNS), ORNL, USA, will offer deeper insights into strain-driven magnetic phenomena at the atomic scale in complex oxide systems.

Frustrated spin systems / **68**

Unconventional orderings in pyrochlore ruthenates

Autoren Abdellali Hadj-Azzem[None]; Elise Pachoud[None]; Elsa Lhotel[1]; Flavien Museur[None]; Félix Morineau[None]; Julien Robert[None]; Nathan Bujault[None]; Peter Holdsworth[None]; Sylvain Petit[None]; Virginie Simonet[None]

[1] *Institut Néel CNRS*

Korrespondenzautor: elsa.lhotel@neel.cnrs.fr

Pyrochlore oxides of formula R2M2O7, made of two interpenetrated pyrochlore lattices, are a rich playground in frustrated magnetism to stabilize unconventional magnetic phases, among which classical and quantum spin ice states or dipolar-octupolar phases [1-3]. When the M site is occupied by a magnetic atom such as iridium, it was shown that new magnetic states called fragmented states can emerge [4-6]. These states are characterized by the coexistence of a spin liquid phase and an

ordered phase, carried by a single degree of freedom, which manifests by the presence of both magnetic Bragg peaks and diffuse scattering in neutron scattering patterns.
In this talk, I will focus on the case where the M site is occupied by another magnetic atom, ruthenium. The ruthenium sublattice orders in the 100 K range in an easy plane antiferromagnetic structure, very different from the so-called "all in - all out" state stabilized by the iridium ion. I will show how this ordering affects the magnetic rare earth properties in the cases where R=Ho, Dy, Nd. It includes the discovery of a ferromagnetic fragmented state [7], and of unconventional dipolar-octupolar couplings.

[1] J. Gardner et al., Rev. Mod. Phys. 82, 53 (2010).
[2] M. Gingras et al., Rep. Prog. Phys. 77, 056501 (2014).
[3] E. Smith et al., Ann. Rev. Condens. Matter Phys. 16, 387 (2025). [4] M. Brooks-Bartlett et al. Phys. Rev X 4, 011007 (2014).
[5] E. Lefrançois et al., Nature Commun. 8, 209 (2017).
[6] V. Cathelin et al., Phys. Rev. Research 2 , 032073(R) (2020).
[7] F. Museur et al., arXiv:2411.10078.

Frustrated spin systems / 73

Ruthenium-Chlorine hybridization in alpha-RuCl3

Autoren Ezekiel Horsley[1]; Jiaming Wang[1]; Subin Kim[1]; Jennifer Sears[2]; Sonia Francoual[3]; C. S. Nelson[2]; Young-June Kim[1]

[1] *University of Toronto*

[2] *Brookhaven National Laboratory*

[3] *DESY*

Korrespondenzautor: youngjune.kim@utoronto.ca

In the last decade, alpha-RuCl3 has been extensively studied as a possible realization of the Kitaev quantum spin liquid state. However, the Kitaev model alone is insufficient to describe the magnetism in the material, and additional off-diagonal terms and Heisenberg interactions are known to be present. In addition, it is necessary to account for longer-range interactions arising from the itinerant aspect of electrons in this system. It has been known for some time that third-neighbour interactions are required to stabilize the zigzag magnetic order in this system. A recent modelling of the neutron magnetic form factor also found a substantial hybridization of Ru and Cl ions. In order to directly probe the role of chlorine in the magnetic ground state of alpha-RuCl3, we have carried out resonant elastic X-ray scattering (REXS) measurements at the Cl K-edge. We observed resonant enhancement of the magnetic Bragg peaks, indicating the presence of a magnetic moment on the Cl site. The temperature dependence of the resonant Bragg peaks matches that of the Ru edge, suggesting a similar magnetic origin. Our measurements provide evidence for the importance of Cl covalency to magnetism in alpha-RuCl3.

Frustrated spin systems / 64

Frustrated antiferromagnetism in a Kagome metal

Autor Wei Bao[1]

[1] *City University of Hong Kong*

Korrespondenzautor: weibao@cityu.edu.hk

While the 120 degree antiferromagnetic order is the way of Nature to relieve the frustration of antiferromagnetic interaction on triangular and Kagome lattices and it has been observed in numerous

insulating compounds of such lattices, Kagome metals have shown superconductivity and SDW phenomena. When antiferromagnetism in these Kagome metals is induced by doping, collinear antiferromagntic orders appears which break the three fold symmetry of antiferromagnetic interaction laying at the root of the frustration. Here we report new examples of frustrated antiferromagnetism in Sb doped FeGe with the hallmark 120 degree antiferromagnetic order and its evolution with Sb doping in a combined bulk and neutron study [1]. The robust of the 120 degree order is unexpected and surprising. To our knowledge, there is only one previous example of frustrated non-collinear antiferromagnet in the Kagome metal [2].

References
[1] J. Huang, et al., Phys. Rev. B, 2023, 108, 184431.
[2] Y. Chen, et al., Phys. Rev. B, 2020, 102, 054403.

Frustrated spin systems / **65**

Spin-liquid dynamics over multiple resolutions and dynamic ranges measured via time-of-flight neutron spectroscopy

Autor Ross Stewart[1]

Co-Autoren: Jem Pitcairn [2]; Joya Cooley [3]; Lucy Clark [2]

[1] *UKRI-STFC ISIS Neutron and Muon Source*

[2] *University of Birmingham*

[3] *California State University, Fullerton*

Korrespondenzautoren: j.pitcairn@bham.ac.uk, l.m.clark@bham.ac.uk, jcooley@fullerton.edu, ross.stewart@stfc.ac.uk

The measurement of the magnetic dynamical properties of strongly correlated frustrated spin-liquids presents a significant challenge for neutron scattering instrumentation. Spin-liquids can commonly present spin-fluctuations over a massive dynamical range, strongly correlated in Q-space. In addition, quantum spin-liquid candidate materials have low moments (spin-1/2 or 1) and therefore require high flux instrumentation to perform successful measurements.

Recently, Ramirez and co-workers [1,2] have pointed out the importance of the spin-glass transition in many quantum-spin-liquid materials, which counterintuitively, seems to be strongest in the limit of disorder-free samples. This underlines the importance of measuring spin-liquid materials with a wide energy range to cover the, often, high energy quantum spin-dynamics at low temperatures, and also to measure with high energy resolution to look for possible spin-freezing.

The quantum spin-liquid candidate material, ZnV2O4, contains just such a freezing transition in a sample which we have confirmed to be free of substitutional or occupational disorder and also free of lattice strain. We have used time-of-flight spectroscopy at both ISIS (MERLIN and LET) and the ILL (Panther) to examine the magnetic dynamical properties of ZnV2O4 with resolutions down to 30 μeV and dynamic ranges up to 50 meV at |Q| ~ 1.5 Å-1. ZnV2O4 exhibits complex, and highly correlated spin-dynamics over all energy scales measured, with a residual spin-dynamical spectral width of ~7 meV at the lowest temperatures - therefore due to quantum (non-thermally activated) fluctuations. The spin-glass freezing temperature is associated with only a fraction of the full magnetic spectral weight and is easily distinguished from temperature independent high-energy fluctuations. Our work highlights the importance of using a suite of instruments with various characteristics in order to get the full picture of the magnetic dynamics.

1. Syzranov and Ramirez, Nat. Comms. (2022) 13:2993
2. Syzranov, Phys. Rev. B 106 L140202 (2022)

Frustrated spin systems / 74

Nodal line spin liquid and fluctuation stabilized order on the face centered cubic antiferromagnet K2IrCl6

Autor Kemp Plumb[1]

[1] *Brown University*

Korrespondenzautor: kemp_plumb@brown.edu

Competing interactions in frustrated magnets can result in highly degenerate ground states from which correlated liquid-like states of matter often emerge. In the extreme quantum limit, these degenerate classical states may evolve into quantum spin liquids. The potential for discovering such exotic phases of matter is one reason that frustrated magnets occupy a major area of quantum materials research. However, even when a quantum spin liquid is not realized –as is usually the case – new collective physics often emerges from frustration. In this talk, I will present neutron scattering data on the face centered cubic (FCC) antiferromagnet K_2IrCl_6 that provide evidence for a new type of classical spin liquid state: a "nodal line spin liquid" where spins collectively fluctuate within a subextensive manifold spanning one-dimensional lines in reciprocal space. The nodal line spin liquid is susceptible to ordering induced by quantum or thermal fluctuations or by long-range exchanges. While each of these selection mechanisms is very weak, they cooperate to stabilize magnetic order at low temperatures. However, proximity to the nodal line spin liquid enhances the effects of quantum fluctuations, so that a semi-classical description of the magnetism in the ordered state of K_2IrCl_6 fails qualitatively to capture this excitation spectrum. The results demonstrate a new state of fluctuating matter and show how quantum fluctuations can act counter-intuitively in frustrated systems: instead of destabilizing ordering, at the brink of the nodal spin liquid quantum fluctuations serve to stabilize order despite the extremely weak order-by-disorder selection.

Frustrated spin systems / 81

Transition metal carbodiimides –A new playground for solid-state physics?

Autor Alexander Corkett[1]

Co-Autoren: Andrzej Grzechnik [1]; Karen Friese

[1] *Jülich Centre for Neutron Science (JCNS), Forschungszentrum Jülich GmbH*

Korrespondenzautoren: k.friese@fz-juelich.de, a.grzechnik@fz-juelich.de, a.corkett@fz-juelich.de

Transition metal oxides, particularly those with partially filled 3d shells, have been the playground for solid-state physics for many decades. These correlated oxides exhibit a competition between coulombic repulsion, which tends to localize electrons, and hybridization, which promotes delocalization, that leads to numerous many-body effects such as metal-insulator transitions, colossal magnetoresistance and superconductivity, to name but a few. Traditionally the modification of such phases, to imbue different physical properties, has relied on the doping of one cation for another to adjust both the electron count and degree of correlation. However, an alternative strategy may also be employed via anion substitution. Enter the divalent carbodiimide anion, [−]N=C=N[−], which is well considered a pseudo-oxide, but with enhanced covalent character [1]. Indeed, numerous quasi-binary transition metal carbodiimides, M_x(NCN)_y, have now been prepared, including CuNCN which exhibits spin-liquid behavior and a resonating-valence bond ground-state [2]. Here, however, we will take a closer look at MnHf(NCN)₃ and FeHf(NCN)₃, which are the first examples of transition metal carbodiimides with a perovskite-like AB(NCN)₃ composition [3]. These quasi-ternary phases adopt a chiral crystal structure, with P6₃22 symmetry, and magnetometry measurements on MnHf(NCN)₃ evidence strong AFM coupling of Mn²⁺ centers, but no evidence for long-range order. This suggests a degree of magnetic frustration in MnHf(NCN)₃ and highlights that the

types of quantum behavior observed in correlated oxides may also be accessible to their carbodiimide analogs.

Frustrated spin systems / 89

Coupled charge, orbital, and spin degrees of freedom in geometrically frustrated YFe2O4

Autoren Manuel Angst[1]; Thomas Mueller[2]

[1] *JCNS-2, Forschungszentrum Jülich GmbH*

[2] *JCNS at MLZ, Garching, Germany*

Korrespondenzautor: m.angst@fz-juelich.de

Rhombohedral rare earth ferrites RFe$_2$O$_4$ have a strong tendency for coupled charge (Fe$^{2+/3+}$) and spin order, despite the strong geometrical frustration of the interactions [1]. For R=Lu or Yb corresponding superstructure reflections or diffuse scattering appear at $(\frac{1}{3}\,\frac{1}{3}\,\ell)$. However, the size of Y^{3+} is considerably larger, with calculations [2] suggesting smaller in-plane propagation such as $(\frac{1}{4}\,\frac{1}{4})$. Here, we focus on single-crystal x-ray diffraction performed on highly stoichiometric single crystals [3] of YFe$_2$O$_4$. Magnetization vs T indicates two subsequent highly hysteretic magnetic transitions, separating a low-temperature (LT), an intermediate (IT), and a high-temperature (paramagnetic, HT) phase. XRD shows that these transitions are structural as well. In the HT phase, diffuse scattering at $(\frac{1}{3}\,\frac{1}{3}\,\ell)$ is similar to other rare earth ferrites. However, cooling into the magnetic phases, sharp superstructure reflections at different positions appear, with propagation $(\frac{2}{7}\,\frac{2}{7}\,\frac{3}{7})$ in IT and $(\frac{1}{4}\,\frac{1}{4}\,\frac{3}{4})$ in LT. We refined the superstructure in both phases and applied bond-valence-sum (BVS) analysis to probe the charge order [4].
In the LT phase, the structure is refined in P-1, with the inversion center between the two Fe layers. The BVS indicates a full charge order, with two of the Fe sites having valence close to 2+ and the other two close to 3+. Although of $(\frac{1}{4}\,\frac{1}{4})$-type, the arrangement of the valences differs from the prediction in [2]. Structural distortions also suggest (ferro) orbital order of the Fe^{2+} sites.
The IT phase is also refined in $P\bar{1}$. A clear splitting of one Y indicates the presence of disorder, which is likely connected to a fragile nature of this phase, which was not theoretically predicted. Of the 7 Fe sites, BVS shows 3 to have valences very close to 2+, indicating a strong localization of 3 electrons on these sites. However, the BVS of one of the sites is about 2.5, and for the remaining sites also further away from the ideal 3 (BVS~2.8). Thus the localization of electrons in the IT phase is incomplete, and it must be a dynamic situation with electron hopping occurring.

[1] M. Angst, Physica Status Solidi RRL, 7, 383 (2013).
[2] M. Naka, A. Nagano, and S. Ishihara, Phys. Rev. B, 77, 224441 (2008).
[3] Th. Mueller, J. de Groot, J. Strempfer, and M. Angst, J. Crystal Growth, 428, 40 (2015).
[4] Th. Mueller and M. Angst, submitted to PRB.

Frustrated spin systems / 90

Magnetism of a frustrated triangular lattice antiferromagnet

Autoren Flaviano José dos Santos[1]; Michal Stekiel[2]; Nikolaos Biniskos[3]

Co-Autoren: A. Labh [4]; A.M. Läuchli [5]; Bruce Normand [5]; Daniel Svitak [4]; Eric Ressousche [6]; Karin Schmalzl [7]; M. Valiska [4]; Nicola Marzari [8]; Petr Cermak [4]

[1] *PSI, CH*

[2] *JCNS Forzschungszentrum Jülich GmbH*

[3] *Charles University, CZ*

[4] *Charles University*

[5] *PSI Center for Scientific Computing*

[6] *Institut Laue-Langevin*

[7] *JCNS Outstation at ILL, Grenoble*

[8] *EPFL, CH*

Korrespondenzautoren: schmalzl@ill.fr, michal.stekiel@frm2.tum.de, petr.cermak@matfyz.cuni.cz

The study of geometrically frustrated systems with antiferromagnetically (AFM) ordered spins has recently gained considerable attention for their exotic quantum magnetic properties. In order to explore effects related to quantum magnetism we investigate the triangular AFM $Na_2BaMn(PO_4)_2$, a compound with S=5/2.

By performing single crystal neutron diffraction and theoretical modeling, for magnetic fields applied in the basal plane and along the c-axis of the trigonal symmetry. At zero field the system undergoes two successive magnetic transitions at about 1.25 K (AFM2) and 1.1 K (AFM1), respectively. The out-of-plane incommensurate component k of the propagation vector (1/3, 1/3, k) exhibits a significant change in the two phases and potentially indicates non-negligible interlayer couplings. Depending on the field direction, Na2BaMn(PO4)2 undergoes several magnetic field induced transitions, which are accompanied by changes in the propagation vector, before reaching the spin polarized state. Combining neutron diffraction, low-temperature specific heat and magnetization we construct the temperature-magnetic field phase diagrams for the two field directions.
The performed ab initio calculations and Monte Carlo simulations are crucial for the interpretation of the ground state, phase diagrams, and 3D structure. They show that the frustration mechanism involves out-of-plane couplings, and perfectly describe the constructed phase diagram.

This combined experimental and theoretical study reveals that $Na_2BaMn(PO_4)_2$ is a 2D-system with a weak 3D coupling acting only as a “witness” for what is happening in two dimensions. The separation between the two zero-field transitions (AFM1 and AFM2) depends on XXZ nature of the anisotropy and on the 3D coupling. Finally, we compare our results with the Co (with S=1/2) and Ni (with S=1) counterparts and we discuss their similarities and differences.

Frustrated spin systems / **96**

Magnetic neutron scattering of i-Tb-Cd quasicrystals

Autoren Andreas KREYSSIG[1]; Pinaki DAS[2]; Gregory S. TUCKER[2]; Andrey PODLESNYAK[3]; Feng YE[3]; Masaaki MATSUDA[3]; Tai KONG[2]; Sergey L. BUD'KO[2]; Paul C. CANFIELD[2]; Rebecca FLINT[2]; Peter P. ORTH[4]; Tsunetomo YAMADA[5]; Alan I. GOLDMAN[2]

[1] *Ruhr University Bochum, Experimental Physics IV, Bochum, Germany; Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, USA*

[2] *Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, USA*

[3] *Oak Ridge National Laboratory, Neutron Scattering Division, USA*

[4] *Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, USA; Saarland University, Department of Physics, Saarbrücken, Germany*

[5] *Tokyo University of Science, Department of Applied Physics, Tokyo, Japan*

i-Tb-Cd orders as icoshedral quasicrystal with the magnetic Tb^{3+} ions arranged in Tsai-type clusters. We studied the magnetic correlations and excitations by elastic and inelastic neutron scattering on single-grain isotopically enriched samples. The measurements of the crystalline-electric field excitations demonstrated that the Tb^{3+} moments are directed along the local fivefold axes of the Tsai-type clusters.[2] We calculated the magnetic diffuse scattering for the low-energy configurations using an Ising-type model for the moment arrangements on a single Tb^{3+} icosahedron. By comparison with our diffuse neutron scattering signals, we identified the most likely moment configuration in a single cluster.[3] We further studied the role of intercluster interactions for magnetic frustration and the magnetic scattering.

Work at the Ames Laboratory was supported by the US Department of Energy (DOE), Basic Energy Sciences, Division of Materials, Sciences and Engineering, under Contract No. DEAC02-07CH11358. A portion of this research used resources at the High Flux Isotope Reactor and the Spallation Neutron Source, US DOE Office of Science User Facilities operated by the Oak Ridge National Laboratory.

[1] A. I. Goldman, T. Kong, A. Kreyssig, A. Jesche, M. Ramazanoglu, K. W. Dennis, S. L. Bud'ko, and P, C. Canfield, Nat. Mater. **12**, 714 (2013).
[2] P. Das, P.-F. Lory, R. Flint, T. Kong, T. Hiroto, S. L. Bud'ko, P. C. Canfield, M. de Boissieu, A. Kreyssig, and A. I. Goldman, Phys. Rev. B **95**, 054408 (2017).
[3] P. Das, A. Kreyssig, G. S. Tucker, A. Podlesnyak, F. Ye, M. Matsuda, T. Kong, S. L. Bud'ko, P. C. Canfield, R. Flint, P. P. Orth, T. Yamada, R. J. McQueeney, and A. I. Goldman, Phys. Rev. **B** 108, 134421 (2023).

Frustrated spin systems / **101**

Intrinsic disorder in the candidate quantum spin ice Pr2Zr2O7

Autor Thomas Hicken[1]

Co-Autoren: Atilla Szabó [2]; Claudio Castelnovo [3]; David Voneshen [4]; Dharmalingam Prabhakaran [5]; Gabriele Sala [6]; Gavin Stenning [4]; Jon Goff [7]; Kalimuthu Moovendaran [5]; Lucile Mangin-Thro [8]; Matthew Stone [6]; Matthias Gutmann [4]; Paul Henry [4]; Phoebe Meadows [7]; Siân Dutton [3]; Tomas Northam de la Fuente [7]

[1] *Paul Scherrer Institute*

[2] *Max-Planck-Institut fu¨r Physik komplexer Systeme*

[3] *University of Cambridge*

[4] *ISIS Neutron and Muon Source*

[5] *University of Oxford*

[6] *Oak Ridge National Laboratory*

[7] *Royal Holloway University of London*

[8] *Institut Laue-Langevin, Grenoble, France*

Korrespondenzautor: thomas.hicken@psi.ch

Quantum spin liquids with long-range entanglement are of great interest for applications in quantum technology. The quantum spin ice Pr₂Zr₂O₇ is a promising example, where it is believed that structural disorder plays a key role in enhancing quantum mechanical effects by introducing strains that split the ground state doublet akin to the effect of a local disordered transverse field. However, the precise defect structure responsible for this behaviour is unknown. Here I will demonstrate how we have determined the intrinsic defect structure of Pr₂Zr₂O₇ using neutron and x-ray scattering techniques supported by density functional theory. Our results explain the single-ion magnetism by considering the non-magnetic singlets that arise as a result of the defect structure. These singlets account for additional features in the neutron-measured crystal electric field excitations. This makes a significant contribution towards the observed broadening of pinch points in the magnetic diffuse scattering, which was previously attributed purely to quantum effects.

Frustrated spin systems / **91**

probing structure and magnetism in a2comno6 (a = lu, ho) geometrically frustrated double perovskites

Autoren Athira Raghu[1]; S.D. Kaushik[1]

Co-Autoren: Jayakrishnan V.B. [2]; R. Harikrishnan [3]

[1] *UGC DAE ConsortiumFor Scientific Research Mumbai Centre India*

[2] *Bhabha Atomic Research Centre*

[3] *Indian Institute of Technology Madras*

Korrespondenzautoren: athiraraghu92@gmail.com, harikrishnan2990@gmail.com, jayakris@barc.gov.in, sdattakaushik@gmail.com

Compounds in Double perovskites (with general formula A2B'B"O6) are receiving significant attention in recent research work due to their potential applications in variety of fields [1]. These are derived from simple perovskite structure ABO3 (where A: large electropositive cation and B: small transition metal ion), and possesses diverse chemical and physical properties, ranging from insulating to metallic electronic structures and several magnetic orderings and frustrated states. This versatility originates due to the structural and compositional flexibility of the perovskite framework [2,3]. With the advent of spin frustrated multiferroics, wherein ferroelectricity is driven by exotic magnetic ordering rather than non-centro-symmetric crystal structure, understanding rare earth based double perovskites (RE2B'B"O6) becomes crucial where partial or complete cation substitution at different degrees at R and B', B"sites provide more flexibility to tailor physical properties such as it affects exchange pathways, influencing magnetic order, and can induce mixed valence states, modifying electron density and magnetic coupling[4]. Doping also introduces lattice distortions, affecting magnetic anisotropy, and allows precise control over magnetic transitions temperature. Furthermore, controlled substitution can create competing interactions, leading to exotic magnetic states such as spin liquids and multiferroics. Thus, exploring and innovating magnetic materials like A-site doped double perovskites is crucial for advancing material science, as they provide exceptional solutions for efficient, sustainable, and high-performance technologies.
Here we present synthesis and characterisation of A2CoMnO6 (A= Lu, Ho) double perovskite by employing ceramic route. Phase formation was confirmed by powder x-ray diffraction (XRD) and phase purity was ascertained by employing room temperature neutron diffraction using PD-III powder diffractometer at Dhruva, BARC India. The phase stability was confirmed by low temperature x-ray diffraction (LT-XRD ranging from 12 K –300 K) by employing 18kw Rigaku TTRAX III attached with CCR. The figure 1 shows Rietveld [5] fitted x-ray diffractogram, which confirms the compound crystallizes in monoclinic structure with P21/n space group goodness of fitting and cell parameters are exhibited in relevant figures. The structural analysis shows the the system is geometrically frustrated as the evidences of anti site disorder is observed which has strong correlations to the physical properties, especially the magnetic properties.The results of temperature dependent magnetization along with isothermal magnetization shows that with the isovalent doping of partially 4f filled Ho3+ into the fully filled 4f Lu3+ there is an enhancement in curie temperature from 30 K to liquid nitrogen temperature (~80 K). While comparing the structure part Holmium with ionic radius (~1.015Å), is expected to induce larger lattice distortion compared to Lutetium (0.816 Å) influencing the super exchange interactions between Co and Mn sites, affecting octahedral tilting and magnetic coupling. We are in a process of analysing the temperature dependent neutron diffraction data (2 K-300 K) to understand the magnetic structure as Ho3+ is magnetic ion (10.6 μB) and Lu3+ is nonmagnetic also the analysis microscopically explore role of antisite disorder in magnetic structure and correlate ferroelectric and structural parameters. Advanced characterizations viz. heat capacity, AC susceptibility and dielectric study are underway to understand magnetic interactions, and electric properties

[1] S. N. Achary, V. Katari, F. N. Sayed and A. K. Tyagi, J. Chem. Sci. 96,131, 2019.
[2] Y. Mao, J. Parsonsa, J.S. Mcloy, Nanoscale, ,5, 04720, 2013.
[3] HS Nair, R. Pradheesh, Yinguo Xiao, et al., J. Appl.Phys., 116, 123907. 2014
[4] A. Harbi, Y. Le Godec et al., Phys. Rev. B., 104, 054404. 2021
[5] J. Rodriguez-Carvajal, Phys. B., 5 192,1993

athiraraghu92@gmail.com , sdkaushik@csr.res.in

Low dimensional quantum magnetism / **72**

Quantum criticality and dimensional reduction in the sawtooth chain material atacamite

Autor Leonie Heinze[1]

[1] *Forschungszentrum Jülich GmbH*

Korrespondenzautor: l.heinze@fz-juelich.de

Quantum magnets with geometrical frustration stand out due to their highly degenerate ground states and their susceptibility to be tuned by applying pressure or magnetic field [1]. Such tuning can lead to quantum phase transitions from ordered to disordered states, or vice versa, with the emergent quantum critical points (QCPs) determining the deformed entropy landscapes in the respective phase diagrams. While, in general, there is fundamental interest in using the properties arising from such distorted entropy landscapes for applications (e.g. the magnetocaloric effect for low-temperature cooling [2,3]), I address here the role of residual exchange interactions in real materials. I demonstrate that a QCP can develop on a lower energy scale measured against the leading exchange couplings in the system.

In this talk, I present the case of the mineral atacamite $Cu_2Cl(OH)_3$, a sawtooth-chain compound where the non-uniform antiferromagnetic chain units [$\mathcal{J}$ ~ 336 K (basal-basal), $\mathcal{J}'$ ~ 102 K (basal-apical)] are embedded into a weak 3D network of interchain couplings [4]. I will show that the magnetic phase diagram of atacamite contains a field-induced quantum critical point at 21.9(1) T (**H** || *c* axis) which emerges on a much lower energy scale compared to the leading terms in the spin Hamiltonian derived by means of density-functional theory [4,5]. The QCP separates field regions with and without long-range magnetic order. In the latter, underpinned by numerical results, the sawtooth chains decompose, but far away from full field polarization [5].

[1] M. Vojta, Rep. Prog. Phys. **81**, 064501 (2018).
[2] M. Lang et al., Phys. Status Solidi B **250**, 457 (2013).
[3] Y. Tokiwa et al., Commun. Mater. **2**, 42 (2021).
[4] L. Heinze et al., Phys. Rev. Lett. **126**, 207201 (2021).
[5] L. Heinze, T. Kotte et al., Phys. Rev. Lett. **134**, 216701 (2025).

Low dimensional quantum magnetism / 93

Magnetic structure determination and putative anisotropic exchange coupling in the hybrid organic-inorganic perovskite (CH5NH2NH2NH3)2Mn

Autoren Chul-Ho Lee[1]; Garam Park[2]; Hodaka Kikuchi[3]; In-Hwan Oh[4]; Iurii Kibalin[5]; Jitae Park[6]; Karin Schmalzl[7]; Kazuhiro Nawa[8]; Ki-Yeon Kim[4]; Laura Canadillas-Delgado[9]; Lukas Beddrich[10]; Oscar Fabelo Rosa[9]; Sungdae Ji[4]; Yunxiao Liu[11]

[1] *National Institute of Advanced Industrial Science and Technology (AIST)*

[2] *Department of Physics Education, Kongju National University*

[3] *Institute for Solid State Physics, The University of Tokyo*

[4] *HANARO, Korea Atomic Energy Research Institute*

[5] *Institut Laue-Langevin*

[6] *MLZ, TUM*

[7] *JCNS Outstation at ILL, Grenoble*

[8] *Institute of Multidisciplinary Research for Advanced Materials, Tohoku University*

[9] *ILL*

[10] *JCNS-4, PANDA*

[11] *FRM II, TUM*

Korrespondenzautoren: schmalzl@ill.fr, l.beddrich@fz-juelich.de, jitae.park@frm2.tum.de

The interest in low-dimensional magnetism (LDM) is manifold, but can be summarized in two categories. First, it provides a rich test bed for fundamental research in many-body quantum phenomena to study the influences of restricted exchange pathways, frustration and enhanced quantum fluctuations. Second, LDM has been shown to have links with various phenomena such as high-temperature superconductivity, fractional excitations, spin liquids and multiferroicity, which are at the forefront of global solid-state research.
Metal-organic compounds (MOC) serve as an essentially infinite toolbox for building model systems for LDM research. Owing to their modular structure, the strength, type and direction of magnetic exchange can be tuned by the ligand molecules, which connect the magnetic ions. The perovskite Mn-PEA [fully $(C_6H_5CH_2CH_2NH_3)_2MnCl_4$] is considered to be one of the ideal layered 2D antiferromagnets, minimizing out-of-plane interactions by separating magnetically active Mn^{2+} ions by long organic chains.
We have successfully performed neutron diffraction (D10+, ILL) and inelastic neutron scattering experiments at the cold multiplexing spectrometer HODACA (JRR-3) and TAS (JRR-3, HANARO) on non-deuterated Mn-PEA single crystals to determine the magnetic structure and its spin wave excitations. The magnetic moments are antiferromagnetically aligned along the c-axis, with a slight canting into the ab-plane. The spin wave dispersion is completely l-independent which is characteristic of negligible exchange interactions across the separation layer of organic ligands. Using spinW, we apply linear spin wave theory including exchange coupling up to the next-nearest neighbors and DMI between nearest neighbors to account for the observation of a second dispersion branch along h.

Low dimensional quantum magnetism / **92**

Structural Chirality and Magnetic Properties in the Honeycomb Lattice Compound HoNi3Ga9

Autoren Feihao Pan[1]; Yixi Su[1]

[1] *Jülich Centre for Neutron Science (JCNS) at MLZ, Forschungszentrum Jülich GmbH*

Korrespondenzautoren: f.pan@fz-juelich.de, y.su@fz-juelich.de

Chiral magnetic materials are of great interest due to their potential to host noncollinear and noncoplanar spin textures, driven by the Dzyaloshinskii-Moriya (DM) interaction arising from the lack of inversion and mirror symmetry. These interactions, alongside crystal field effects and symmetric exchange, can stabilize exotic magnetic phases such as helical order and magnetic skyrmions, making them promising candidates for spintronic applications.

We report the successful growth of high-quality single crystals of the structurally chiral compound $HoNi_3Ga_9$, which crystallizes in a honeycomb lattice and exhibits **easy-plane magnetic anisotropy**. Magnetization measurements reveal an antiferromagnetic transition at 4.7 K and three distinct metamagnetic transitions at critical fields of 0.12 T, 1.35 T, and 2.70 T.

Neutron diffraction confirms a magnetic propagation vector of **(0, 0, 0.5)** in zero field and the presence of 180° magnetic domains. The interplay between Zeeman energy and DM interaction under applied magnetic fields is expected to give rise to topological spin textures, such as a **chiral soliton lattice (CSL)**. Further field-dependent neutron studies are planned to explore these phenomena.

Low dimensional quantum magnetism / **94**

Structural and Magnetic Characterization of RCrO3 (R = Ho, Gd) Complex Perovskites

Autor Komal Kanwar[1]

Co-Autoren: Manuel Angst [2]; Neeraj Panwar [3]; Vivek Kumar Malik [4]

[1] *Forschungszentrum Juelich*

[2] *JCNS-2, Forschungszentrum Jülich GmbH*

[3] *Associate Professor*

[4] *Professor*

Korrespondenzautoren: npanwar.phy@ccsuniversity.ac.in, m.angst@fz-juelich.de, k.kanwar@fz-juelich.de

Rare-earth orthochromites ($RCrO_3$) have attracted widespread attention in recent years due to their rich physical properties and potential applications in spintronics, thermomagnetic switches, photocatalysts, and low-temperature magnetic refrigeration [1-3]. $RCrO_3$ exhibits canted antiferromagnetic behavior with the canting caused by the Dzyaloshinskii–Moriya interactions and the interaction between Cr^{3+} and rare-earth magnetic sublattices, the latter of which also leads to negative magnetization under certain thermal and magnetic conditions [1]. These interactions and magnetic frustration lead to deviations from classical Curie–Weiss behavior at low temperatures. Among all the rare-earth orthochromites, we chose HoCrO3 (HCO) for our study, because in this compound, the Ho3+ ion owns a large magnetic moment ~ 10.6 μB. From the Curie-Weiss fit of magnetic susceptibility data, we observed a large negative value of the Weiss temperature, which showed the antiferromagnetic nature and magnetic frustration in the compound. We also found very large values of the magnetocaloric parameters [3]. This study opens an avenue for further investigation of other rare-earth metals to explore magnetic frustrations. GdCrO3 is another promising candidate for a variety of physical applications, especially its magnetic and giant magnetocaloric properties [4].
Therefore, in our current study, we aim to grow high-quality single crystals of GdCrO3 for detailed neutron scattering experiments to elucidate frustrated magnetic states and correlated spin dynamics. The prepared polycrystalline precursors were characterized using powder X-ray diffraction followed by Rietveld refinement to determine their structural and microstructural properties. Furthermore, magnetic studies revealed a negative magnetization at low temperatures, along with spin reorientation behavior. By fitting the dc magnetization data with the modified Curie–Weiss law, including the Dzyaloshinskii–Moriya antisymmetric exchange interaction (D) and the symmetric exchange constant (J), these parameters were obtained. This comprehensive characterization shows the precursors to be highly suitable for crystal growth, which is currently being pursued with laser floating-zone furnace. Available first results on crystals would be shown as well.

[1] A. A. Qahtan, et. al., Physica Scripta, 99, 072001 (2024).
[2] M. Rani, et. al., Ceramics International, 48, 19925-19936 (2022).
[3] K. Kanwar, et. al., Ceramics International, 47, 7386-7397 (2021).
[4] S. Mahana, et. al., Journal of Physics D: Applied Physics, 51, 305002 (2018).

Models of quantum magnetic systems / **107**

Altermagnetism and neutron scattering

Autor Paul Mc Clarty[1]

[1] *Laboratoire Leon Brillouin, Universitè Paris-Saclay, CEA-Saclay*

Korrespondenzautor: paul.mc-clarty@cnrs.fr

Altermagnetism refers to a class of collinear compensated magnets at weak spin-orbit coupling that have spin-split electronic bands and chirality-split magnon bands both with a distinctive anisotropic pattern in
momentum space. In this talk, I shall briefly summarize the state-of-the-art in the field and then describe how neutron scattering can be used to characterize the key signatures of altermagnetism in these materials.

In particular, I shall discuss altermagnetic domains, local order parameters and the power of polarized neutrons in probing chirality in the magnon bands.

Models of quantum magnetic systems / 69

Kalman filter enhanced active learning sampling for inelastic neutron scattering

Autor Nihad Abuawwad[None]

Co-Autoren: Hongbin Zhang ; Samir Lounis ; Yixuan Zhang

Korrespondenzautor: n.abuawwad@fz-juelich.de

Spin waves, or magnons, are fundamental excitations in magnetic materials that provide insights into their dynamic properties and interactions. Magnons are the building blocks of magnonics, which offer promising perspectives for data storage, quantum computing, and communication technologies. These excitations are typically measured through inelastic neutron techniques, which involve heavy and time-consuming measurements, data processing, and analysis based on various theoretical models. Here, we introduce a machine-learning algorithm that integrates adaptive noise reduction and active-learning sampling, which enables the restoration from minimal inelastic neutron-scattering point data of spin-wave information and the accurate extraction of magnetic parameters, including hidden interactions. Our findings, benchmarked against the magnon spectra of CrSBr, significantly enhance the efficiency and accuracy in addressing complex and noisy experimental measurements. This advancement offers a powerful machine-learning tool for research in magnonics and spintronics, which can also be extended to other characterization techniques at large facilities.

Models of quantum magnetic systems / 70

Chiral magnons and anisotropic damping in metallic g-wave altermagnets

Autor Wejdan Beida[1]

Co-Autoren: Christoph Friedrich [1]; Ersoy Sasioglu [2]; Gustav Bihlmayer [1]; Stefan Bluegel [1]; Yuiry Mokrousov [1]

[1] *Forschungzentrum Jülich*

[2] *Martin Luther University Halle-Wittenberg*

Korrespondenzautoren: g.bihlmayer@fz-juelich.de, c.friedrich@fz-juelich.de, y.mokrousov@fz-juelich.de, w.beida@fz-juelich.de, ersoy.sasioglu@physik.uni-halle.de, s.bluegel@fz-juelich.de

Altermagnets represent a novel class of magnetic materials that bridge the gap between conventional ferro- and antiferromagnets. A unique feature of altermagnets is the lifting of degeneracy of their spin-wave modes (magnons) along the same crystallographic directions in which electronic bands also exhibit spin splitting. This non-degeneracy leads to chirality and directional anisotropy in spin-wave dispersions. We study the interplay between electronic band spin splitting and chiral magnon excitations in a series of metallic g-wave altermagnets (\(MZ\), where \(M\)= V, Cr; \(Z\)= As, Sb, Bi) using the density functional theory and many-body perturbation theory [1]. We find that magnon damping due to Stoner excitations is highly wavevector-dependent, reaching substantial values in specific Brillouin zone regions. Among the compounds studied, CrSb exhibits the strongest chiral magnon band splitting. Recent RIXS experiments [2] on CrSb confirmed the presence of polarization-dependent magnon modes but lacked the energy resolution necessary to resolve the theoretically predicted 52 meV magnon splitting. In contrast, inelastic neutron scattering (INS) provides both the momentum and energy resolution required to test these predictions. Furthermore, our calculations reveal that VSb hosts low-energy chiral-split magnons (with energies up to 80 meV and a splitting of approximately 40 meV), placing them well within the detection range of modern INS techniques.

With an appropriate choice of lattice parameters, the ground state of VSb can be stabilized in a collinear antiferromagnetic configuration. These findings position our MZ compounds as promising candidates for future INS studies focused on chiral magnon transport, directional damping, and the broader application for spintronic and magnonic devices.
[1] E. Sasioglu et al., Phys. Rev. B 81,054434 (2010).
[2] N. Biniskos et al., arXiv:2503.02533 (2025).

Poster session / **97**

Nanoscale curvature enhances magnetization in CoPd alloy films on nanospheres

Autoren Asmaa Qdemat[1]; Connie Bednarski-Meinke[2]

Co-Autoren: Annika Stellhorn [3]; Emmanuel Kentzinger [4]; Johan Buitenhuis [5]; Mai Hussein Hamed [6]; Nina-Juliane Steinke [7]; Oleg Petracic [8]; Sabine Puetter ; Thomas Brückel [9]; Thomas Saerbeck [10]; Yifan Xu [11]

[1] *Spallation Neutron Source, ORNL*

[2] *JCNS-2*

[3] *ESS*

[4] *Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science*

[5] *Forschungszentrum Jülich GmbH, Institute of Biological Information Processing (IBI-4)*

[6] *Faculty of Science, Helwan University, Cairo, Egypt*

[7] *Institut Laue-Langevin*

[8] *FZ Jülich*

[9] *FZJ, DE*

[10] *Institut Laue Langevin*

[11] *Forschungszentrum Jülich GmbH*

Korrespondenzautoren: annika.stellhorn@ess.eu, saerbeck@ill.fr, s.puetter@fz-juelich.de, j.buitenhuis@fz-juelich.de, yi.xu@fz-juelich.de, e.kentzinger@fz-juelich.de, o.petracic@fz-juelich.de, c.bednarski-meinke@fz-juelich.de, steinkenj@ill.fr, mai.hussein@science.helwan.edu.eg, qdematai@ornl.gov

We have investigated the influence of curvature on the magnetic properties of a Co-Pd alloy by depositing Co-Pd alloy films, with different thicknesses, on monolayers of silicon dioxide (SiO_2) nanospheres, and on flat silicon substrates. The curved films exhibit enhanced magnetic scattering length density (mSLD), particularly for the thinner films, compared to the flat substrates. This is attributed to curvature induced strain and orbital hybridization, which boosts the local magnetic moment. However, as film thickness increases, the structural order of the nanosphere monolayers is disrupted, leading to rougher morphology and eventual coalescence into continuous films. SQUID magnetometry reveals that curvature alters magnetic anisotropy by weakening or tilting perpendicular magnetic anisotropy (PMA) and increasing coercivity. Polarized neutron reflectometry (PNR) confirms stronger in-plane magnetization in curved films, and shows that thinner films exhibit a higher magnetic scattering length density (mSLD) than thicker ones, due to enhanced interface effects in the ultrathin regime. Despite high structural ordering, grazing-incidence small-angle neutron scattering (GISANS) detects no lateral magnetic coherence or domain-related scattering. This study highlights the significant role of curvature in tuning the magnetic properties of CoPd alloy films and underscores the combined power of PNR and GISANS in probing magnetism in such systems.

Poster session / **98**

MBE thin-film growth of quantum materials

Autoren Connie Bednarski-Meinke[1]; Sabine Puetter[None]

[1] *JCNS-2*

Korrespondenzautoren: c.bednarski-meinke@fz-juelich.de, s.puetter@fz-juelich.de

Studying the physics of thin films is the first step towards understanding how 'quantum'devices will be controlled as the plethora of phenomena promised by quantum materials can only be fully exploited once they can be fabricated as thin films. Meanwhile, there is a growing focus on scaling up the growth of interesting quantum materials to 200–300 mm wafer size using molecular beam epitaxy (MBE), with the aim of integrating these materials into the semiconductor industry [1]. However, much remains to be discovered about growing quantum materials as thin films rather than in bulk and the effect this has on the quantum or topological properties of the materials and their subsequent control. In this review study, we identify systems in which quantum effects are particularly relevant when grown in thin film form, highlighting the challenges and initial successes and addressing issues such as feasibility and effort-to-impact ratios. These include: topological insulators, Weyl semimetals, and subsequent topological phase transitions; altermagnets (particularly those that exhibit altermagnetism only in thin film form); high-temperature superconductors and the emerging phenomena of oxides and nitrides; magnetic spin textures (particularly skyrmions and hopfions); quantum spin liquids and spin ices; and hexagonal perovskites and other 2D materials [2, 3, 4, 5]. Our goal is to generate interest in growing new thin-film quantum materials at the JCNS facilities and to initiate discussions about implementing these material systems. MBE is clearly at the heart of a materials revolution and will become an increasingly necessary growth process for furthering the fundamental science of quantum materials, as well as their utility in developing the next generation of devices.

[1] 'Introducing the latest production MBE systems for III-V and nitride materials!' DCA, (2025) [Online]. Available: https://dca.fi/introducing-the-latest-production-mbe-systems-for-iii-v-and-nitride-materials/
[2] C. Ha and Y. J. Chung, APL Materials, 12, 120901, (2024).
[3] N. Samarth, Nature Materials, 16, 1068, (2017).
[4] R. Cava, N. de Leon, and W. Xie, Chemical Reviews, 121, 2777, (2021).
[5] R. K. Goyal, S. Maharaj, P. Kumar, and M. Chandrasekhar, Journal of Materials Science: Materials in Engineering, 20, 4, (2025).

Poster session / **106**

Dynamics of Bloch points in regularized micromagnetic S3-model

Autor Vladyslav M. Kuchkin[1]

Co-Autoren: Andreas Haller [1]; Andreas Michels [1]; Nikolai S. Kiselev [2]; Thomas L. Schmidt [1]

[1] *Department of Physics and Materials Science, University of Luxembourg*

[2] *Peter Grünberg Institute, Forschungszentrum Jülich and JARA*

Korrespondenzautor: vladyslav.kuchkin@uni.lu

Magnetic singularities known as Bloch points (BPs) present a fundamental challenge for micromagnetic theory, which is based on the assumption of a fixed magnetization vector length. Due to the divergence of the effective field at a BP, classical micromagnetics fails to adequately describe BP dynamics. To address this issue, we propose a regularized micromagnetic model in which the magnetization vector can vary in length but not exceed a threshold value. More specifically, the magnetization is treated as an order parameter constrained to a S3-sphere. This constraint respects fundamental properties of local spin expectation values in quantum systems. We derive the corresponding regularized Landau–Lifshitz–Gilbert equation and the analogue of the Thiele equation describing the steady motion of spin textures under various external stimuli. We demonstrate the applicability of our theory by modeling the dynamics of several magnetic textures containing BPs, including domain walls in nanowires, chiral bobbers, and magnetic dipolar strings

[2]. The presented results extend micromagnetic theory by incorporating a regularized description of BP dynamics.

[1] Vladyslav M. Kuchkin, Andreas Haller, Štefan Liščák, Michael P. Adams, Venus Rai, Evelyn P. Sinaga, Andreas Michels, and Thomas L. Schmidt, Phys. Rev. Research 7, 013195 (2025).
[2] Vladyslav M. Kuchkin, Nikolai S. Kiselev, Andreas Haller, Štefan Liščák, Andreas Michels, and Thomas L. Schmidt, Phys. Rev. B 111, 174410 (2025).

Poster session / 103

Single-crystal growth and low-temperature physical properties of novel frustrated quantum magnets

Autor Yinghao Zhu[1]

Co-Autoren: Jörg Perßon [2]; Yixi Su [3]

[1] *Jülich Centre for Neutron Science JCNS at MLZ, Forschungszentrum Jülich*

[2] *FZJ, DE*

[3] *Jülich Centre for Neutron Science (JCNS) at MLZ, Forschungszentrum Jülich GmbH*

Korrespondenzautoren: yi.zhu@fz-juelich.de, y.su@fz-juelich.de

Frustrated magnets have competing interactions that prevent spins from aligning in a simple order, leading to highly degenerate ground states. To pursue the rich physics and exotic phenomena involved, a variety of geometrically frustrated materials have been uncovered, providing intriguing platforms for the manipulation of complex degrees of freedom [1].
Pyrochlore-structure frustrated magnets with the general formula R2B2O7 (where R represents magnetic 4f rare-earth ions and B is a non-magnetic cation) consist of a three-dimensional network of corner-sharing tetrahedra. This 3D geometry gives rise to a richer landscape of magnetic interactions and spin configurations compared to their 2D counterparts, such as triangular or kagome lattices. The nature of the magnetic anisotropy depends on the specific rare-earth ion: for instance, in Nd2Zr2O7, the Nd3+ ions exhibit local ⟨111⟩ Ising anisotropy, leading to an all-in–all-out antiferromagnetic ground state [2]. In contrast, Yb2Ti2O7 hosts XY-like spins with moments confined to planes perpendicular to the local ⟨111⟩ axes [3].
In this work, we introduce partial substitution of Nd3+ into Yb2Ti2O7, aiming to perturb the pure XY anisotropy of Yb^{3+} with Ising-like contributions from Nd3+. This allows us to explore the interplay between different types of magnetic anisotropy within the geometrically frustrated pyrochlore framework. High-quality single crystals of YbNdTi2O7 were successfully grown using the optical floating-zone method. Subsequently, axis-dependent magnetic susceptibility measurements were performed to probe the anisotropy of the system. Building on the high-quality single crystal obtained, future neutron scattering studies on YbNdTi2O7 are expected to provide valuable insights into the anisotropic spin correlations and potential emergent quantum phenomena arising from the interplay of Ising and XY interactions.

[1] L. Balents, Nature, 464, 199-208 (2010).
[2] E. Lhotel, S. Petit, S. Guitteny, et al., Physical Review Letters, 115, 197202 (2015).
[3] J. Gaudet, K. A. Ross, E. Kermarrec, et al., Physical Review B, 93, 064406 (2016).

Poster session / 105

Magnetic excitations in multiferroic Lu and Er rare earth orthoferrites for magnonic applications

Autoren Dnyaneshwar Bhosale[1]; Piotr Fabrykiewicz[2]

Co-Autoren: Martin Meven [3]; Astrid Schneidewind [4]; Stanislav Nikitin [5]; Devashibhai Adroja [6]; Anton Stampfl [7]; Michal Stekiel [8]

[1] *Jülich Centre for Neutron Science JCNS at MLZ, Forschungszentrum Jülich*

[2] *RWTH Aachen and JCNS at MLZ*

[3] *JCNS-4*

[4] *JCNS at MLZ, FZ Jülich*

[5] *PSI*

[6] *ISIS*

[7] *ANSTO*

[8] *JCNS Forzschungszentrum Jülich GmbH*

Korrespondenzautoren: d.bhosale@fz-juelich.de, piotr.fabrykiewicz@frm2.tum.de, martin.meven@frm2.tum.de, michal.stekiel@frm2.tum.de, a.schneidewind@fz-juelich.de

Rare-earth orthoferrites ($RFeO_3$, where R is a rare earth element) have been used as model systems in studies and theoretical considerations of magnetic structures since the 1960s [1]. Their complex multiferroic properties have made them potential candidates for modern applications, e.g. in the field of spintronics, and they have therefore regained considerable interest in the last years [2, 3, 4]. We investigated magnetic excitations in $ErFeO_3$ and $LuFeO_3$ using inelastic neutron scattering [5], the latter having only Fe as magnetic ions. The observed magnon dispersions and spectral intensities can be accurately reproduced within the framework of linear spin wave theory. This enables us to extract the key exchange parameters that govern the Fe–Fe interactions. In $ErFeO_3$, we modelled the Er^{3+} crystal field levels by refining a point-charge model guided by experimentally determined transition energies and their relative intensities.

[1] R. J. White, J. Appl. Phys., 40, 1061 (1969).
[2] J.-H. Lee et al., Phys. Rev. Lett., 107, 117201 (2011).
[3] Y. Tokunaga et al., Nat. Phys., 8, 838 (2012).
[4] J. Xu et al., Phys. Rev. Lett. 129, 117202 (2022).
[5] In preparation

Poster session / 80

Low-Temperature Lattice Dynamics of $KTaO_3$

Autor Yuliia Tymoshenko[None]

Co-Autoren: Paul Steffens [1]; Stephan Rosenkranz [2]; Marek Koza [3]; Rolf Heid [4]; Frank Weber [5]

[1] *Institut Laue-Langevin, Grenoble, France*

[2] *Material Science Division, Argonne National Laboratory, Lemont, Illinois, USA*

[3] *InstitutLaue-Langevin, Grenoble, France*

[4] *Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany*

[5] *Karlsruhe Institute of Technology*

Korrespondenzautoren: frank.weber@kit.edu, yuliia.tymoshenko@frm2.tum.de

$KTaO_3$ is a prototypical quantum paraelectric material that lies near a quantum critical point, where a second-order ferroelectric transition is suppressed by quantum fluctuations. Such systems provide unique opportunities to investigate emergent phenomena, including ferroelectricity and superconductivity, which can be induced by slight compositional changes. The study of low-temperature lattice dynamics in these materials is crucial for understanding their quantum critical behavior, especially through their structural susceptibilities and order parameters.
In this work, we present a comprehensive investigation of the lattice dynamics in $KTaO_3$ using cold

neutron triple-axis and thermal neutron time-of-flight spectroscopy, complemented by x-ray diffraction and density functional perturbation theory (DFPT) calculations. Our results aim to clarify the nature of quantum paraelectricity in $KTaO_3$ and address open questions regarding its low-temperature properties and proximity to ferroelectric order.

Poster session / **79**

Magnetic and Transport Properties of Mn3X (X = Ge, Sn) Weyl Semimetal

Autoren A. Stunault[1]; Jörg Perßon[2]; Karin Schmalzl[3]; Martin Meven[4]; Rajesh Dutta[5]; Shibabrata Nandi[6]; Subhadip Jana[None]; VENUS RAI[7]; Wolfgang Schmidt[8]

[1] *ILL, Grenoble*

[2] *FZJ, DE*

[3] *JCNS Outstation at ILL, Grenoble*

[4] *RWTH Aachen University*

[5] *Drexel University, USA*

[6] *Forscchungszentrum Juelich GmbH*

[7] *University of Luxembourg*

[8] *IIL, Grenoble*

Korrespondenzautoren: schmalzl@ill.fr, martin.meven@frm2.tum.de, s.nandi@fz-juelich.de, venus.rai@uni.lu

Topological quantum materials have attracted enormous attention since their discovery due to the observed anomalous transport properties, which originate from the non-zero Berry curvature. Mn3X compounds show interesting physical properties like Anomalous Hall Effect (AHE), Planar Hall effect (PHE), chiral magnetic effect, and non-local transport properties due to non-vanishing Berry flux emerging from the Weyl points [1]. It is widely believed that the magnetic structure and Weyl properties are intimately connected.
Nevertheless, the interpretation of negative longitudinal magnetoresistance (LMR), AHE, and PHE in Mn_3X compounds—particularly their connection to the chiral magnetic effect—remains a subject of ongoing debate. This presentation provides a concise overview of current insights into these phenomena, with a focus on experimental observations in Mn_3Sn and Mn_3Ge using neutron diffraction and complementary physical property measurement systems.

References:
[1] S. Nakatsuji, N. Kiyohara and T. Higo, Nature (London) 527, 212 (2015) .
[2] Y. Song, Y. Hao, and S. Wang, Phys. Rev. B 101, 144422 (2020)
[3] A. K. Nayak, J. E. Fischer, Y. Sun, B. Yan, J. Karel, A. C. Komarek, C. Shekhar, N. Kumar, W. Schnelle, J. Kübler, C. Felser, and S. S. P. Parkin, Sci. Adv. 2, e1501870 (2016)
[4] N. Kumar, S. N. Guin, C. Felser, and C. Shekhar, Phys. Rev. B 98, 041103(R) (2018)

Quantum materials / **100**

Hyperfine-Enhancement as a Route to Persistent Spin Dynamics in Singlet-State

Autor Stephen Blundell[1]

[1] *University of Oxford*

Korrespondenzautor: stephen.blundell@physics.ox.ac.uk

Many magnetically frustrated systems exhibit what is known as persistent spin dynamics (PSD) in μSR experiments, the origin of which has remained mysterious since their discovery in the 1990s. As the temperature is lowered, the muon-spin relaxation rate rises (as would be expected for the slowing-down of spin fluctuations) but this rate then saturates at low temperature, the low-temperature fluctuations being interpreted as PSD. To explain this phenomenon, we describe how muons can couple to singlet states and illustrate this with experimental data taken on $Tm_2Ti_2O_7$. The key idea is that the hyperfine interaction, usually neglected in treatments of electronic magnetism, provides a route in which excited states can be mixed into the ground state, and this new state can couple to the "quantum muon" [1]. This mechanism lies behind the effect found in some quantum spin ice compounds [2], but here it is not based on the distortion effects surrounding the muon. We will show how this idea can be extended to understand the way muons couple to a variety of systems exhibiting highly frustrated magnetism, as well as to dynamical problems more generally [3,4]. We will show how this idea can be extended to understand the way muons couple to a variety of systems exhibiting highly frustrated magnetism [5], as well as to dynamical problems more generally [3].

[1] S. J. Blundell, J. Phys.: Conf. Ser. **2462**, 012001 (2023).
[2] F. R. Foronda, F. Lang, J. S. Möller, T. Lancaster, A. T. Boothroyd, F. L. Pratt, S. R. Giblin, D. Prabhakaran and S. J. Blundell, Phys. Rev. Lett. **114**, 017602 (2015).
[3] J. M. Wilkinson and S. J. Blundell, Phys. Rev. Lett. **125**, 087201 (2020).
[4] S. J. Blundell and T. Lancaster, Appl. Phys. Rev. **10**, 021316 (2023).
[5] Hank C.H. Wu, Francis L. Pratt, Benjamin M. Huddart, Dipranjan Chatterjee, Paul A. Goddard, John Singleton, D. Prabhakaran, and Stephen J. Blundell, Phys. Rev. Lett. **135**, 046704 (2025).

Quantum materials / **85**

Phonon spectroscopy in Quantum Materials –x-rays and neutrons

Autor Frank Weber[1]

[1] *Karlsruhe Institute of Technology*

Korrespondenzautor: frank.weber@kit.edu

Interacting degrees of freedom in solids underlie new emergent ground states and competing phases with potential for new functionalities. Vibrations of the atomic lattice, i.e. phonons, can couple to electrons, magnetic, or orbital degrees of freedom. In particular, electron-phonon coupling (EPC) received a lot of attention as a microscopically understood origin of superconductivity. Furthermore, EPC has recently been in the focus of investigations of materials with competing phases such as cuprates and layered transition-metal dichalcogenides. On the other hand, research on chiral phonons, i.e., vibrational modes carrying a finite magnetic angular momentum, reports interesting phono-magnetic effects and establishes a direct coupling between lattice vibrations and spin excitations.
Here, I will review some of our recent lattice dynamical investigations of quantum materials, highlight effects of strong coupling to the electronic and magnetic degrees of freedom as well as discuss experimental details. In particular, I will highlight the complementary nature of neutron and x-ray scattering investigations in different experimental setups including high pressure.

Quantum materials / **88**

High resolution crystal analyzers spectrometers for long pulse neutron sources

Autor Jorg Voigt[1]

[1] *Forschungszentrum Jülich GmbH*

Korrespondenzautor: j.voigt@fz-juelich.de

We discuss different concepts to realized crystal analyzer spectrometers at long pulse neutron sources. For the novel High Current Accelerator driven neutron sources, crystal arrays designed for large acceptance enable resolutions down to 10 μeV with reasonable detector count rates.
For the ESS we present a concept that might enable neV resolution by using GaAs monochromators and analyzers and the full pulse of the ESS. The design enables the use of elastic and inelastic fixed window scans. As a special feature it extends the dynamic range by combined analysis of the fundamental Bragg reflection and the second order.

Topological magnetism and magnons / **82**

Low-Energy Phason Excitations in the Skyrmion Lattice of MnSi Probed by Neutron Spin Echo

Autor Hazuki Furukawa[1]

[1] *Ochanomizu University*

Korrespondenzautor: furukawa.hazuki@ocha.ac.jp

Magnetic skyrmions are vortex-like spin structures that are topologically stable. They have become an important topic in condensed matter physics because of their special properties and possible use in spintronics. In the chiral magnet MnSi, skyrmions form a regular lattice with a period of 18 nm. This lattice can be observed in real space by Lorentz transmission electron microscopy, and in reciprocal space by small-angle neutron scattering (SANS). However, it is still difficult to study the detailed dynamics of the skyrmion lattice, especially at low energies belowμeV and small wavevectors.
In this study, we used the neutron spin-echo (NSE) technique with SANS geometry to look at the low-energy excitations of the skyrmion lattice in MnSi. This method allows us to measure very small energy differences, below 5μeV, in the quasielastic region. We observed asymmetric phason-like excitations, which seem to come from the string-like nature of the skyrmion cores. Our results provide new understanding of how skyrmions move together, and they add to earlier studies using MIEZE and other methods.

Topological magnetism and magnons / **63**

Topological magnons driven by the Dzyaloshinskii-Moriya interaction in the centrosymmetric ferromagnet Mn5Ge3

Autoren Flaviano José dos Santos[1]; Frédéric Bourdarot[2]; Jörg Perßon[3]; Karin Schmalzl[4]; Manuel dos Santos Dias[5]; Nicola Marzari[6]; Nikolaos Biniskos[7]; Samir Lounis[8]; Stefan Blügel[3]; Thomas Brückel[3]

[1] *PSI, CH*

[2] *UGA, FR*

[3] *FZJ, DE*

[4] *JCNS Outstation at ILL, Grenoble*

[5] *STFC Daresbury Laboratory*

[6] *EPFL, CH*

[7] *Charles University, CZ*

[8] *MLU, DE*

Korrespondenzautoren: manuel.dos-santos-dias@stfc.ac.uk, schmalzl@ill.fr

The phase of the quantum-mechanical wave function can encode a topological structure with wide-ranging physical consequences, such as anomalous transport effects and the existence of edge states robust against perturbations. While this has been exhaustively demonstrated for electrons, properties associated with the elementary quasiparticles in magnetic materials are still underexplored. In our joint project, we have shown theoretically and via inelastic neutron scattering experiments that the bulk ferromagnet Mn5Ge3 hosts gapped topological Dirac magnons [1]. Although inversion symmetry prohibits a net Dzyaloshinskii-Moriya interaction in the unit cell, it is locally allowed and is responsible for the gap opening in the magnon spectrum. This gap is predicted and experimentally verified to close by rotating the magnetization away from the c-axis with an applied magnetic field. Hence, Mn5Ge3 realizes a gapped Dirac magnon material in three dimensions. Its tunability by chemical doping or by thin film nanostructuring defines an exciting new platform to explore and design topological magnons. More generally, our experimental route to verify and control the topological character of the magnons is applicable to bulk centrosymmetric hexagonal materials, which calls for systematic investigation.

[1] M. dos Santos Dias et al., Nat. Commun. 14, 7321 (2023).

Topological magnetism and magnons / **104**

Unconventional non-collinear magnetism in topological kagome metals

Autor Yixi Su[1]

Co-Autoren: Yishui Zhou [1]; Xiao Wang [1]

[1] *Jülich Centre for Neutron Science (JCNS) at MLZ, Forschungszentrum Jülich GmbH*

Korrespondenzautor: y.su@fz-juelich.de

Altermagnets, a new type of unconventional collinear antiferromagnet with spin-splitting arising from non-relativistic symmetry breaking effects, have recently attracted tremendous interests in magnetism and spintronics. Unconventional magnetism actually goes beyond altermagnets, and can also be found in some non-collinear antiferromagnets that possess spin-orbit coupling (SOC). In this talk, we will mainly present our recent neutron scattering and other complementary studies of various topological kagome metals including RV_6Sn_6 (R = rare earth) [1], RMn_6Sn_6 [2], and Mn_3Sn [3], with the focus on the complex temperature and magnetic-field evolution of non-collinear incommensurate magnetic orders. These non-collinear magnetic spiral phases are also found to be strongly linked to the observed topological Hall effects (THE) or anomalous Hall effects (AHE), thus hinting a fascinating interplay between unconventional magnetism and topologically non-trivial states in these kagome metals via intrinsic engineering of Berry curvature in both k-space and real space. Both competing magnetic exchange interactions and antisymmetric Dzyaloshinskii-Moriya interactions (DMI) could lead to the emergence of these non-collinear magnetic spiral phases. We will also discuss this important aspect based on our observations.

[1] Yishui Zhou, et al., Phys. Rev. Research **6**, 043291 (2024).
[2] Yishui Zhou, et al., (in preparation).
[3] Xiao Wang, et al., arXiv:2306.04312 (2023).

E-mail of the corresponding author: y.su@fz-juelich.de

Topological magnetism and magnons / **77**

Magnetic interactions in Nd2PdSi3 and the formation of skyrmion phases in centrosymmetric metals

Autor Viviane Peçanha-Antonio[1]

Co-Autoren: Andrew Boothroyd [2]; Bachir Ouladdiaf [3]; Christian Balz [1]; Daniel Mayoh [4]; Devashibhai Adroja [1]; Geetha Balakrishnan [4]; Iurii Kibalin [3]; Jakob Lass [5]; Juba Bouaziz [6]; Julie Staunton [4]; Marie Helene Lemee [3]; Michael Smidman [7]; Zhaoyang Shan [7]

[1] *ISIS Neutron and Muon Source*

[2] *University of Oxford, Clarendon Laboratory*

[3] *Institut Laue-Langevin*

[4] *University of Warwick*

[5] *PSI Center for Neutron and Muon Sciences*

[6] *The University of Tokyo*

[7] *Zhejiang University*

Korrespondenzautor: viviane.pecanhaantonio@physics.ox.ac.uk

We present an X-ray and neutron scattering study of the structure and magnetic excitations of Nd2PdSi3 [1], a sister compound of Gd2PdSi3 which was recently found to host a skyrmion phase despite its centrosymmetric crystal structure. Dispersive magnetic excitations corresponding to the complete crystal field scheme of the Nd atoms were measured throughout the reciprocal space Brillouin zone. The full measured spectrum was modelled by mean-field random-phase approximation (MF-RPA) to determine quantitatively the magnetic interactions between two distinct Nd sites. Our analysis finds that the exchange couplings in this system extend over large distances and are significantly affected by a crystallographic superstructure formed by ordering of the Pd and Si atoms. These results suggest that the skyrmion phase in Gd2PdSi3 is stabilised by long-range RKKY interactions rather than short-range triangular-lattice frustration. First principles theory results corroborate with a long-ranged RKKY interaction scenario, which has its basis in the complex, three-dimensional Fermi surface of this material.

[1] Peçanha-Antonio et al., arXiv:2504.10075v1

Topological magnetism and magnons / 84

Kondo coupling-driven topological phase transition in the Weyl semimetal candidate CeAlGe

Autoren Soohyeon Shin[1]; Soonbeom Seo[2]; Igor Plokhikh[None]; Jonathan S. White[3]; Harim Jang[4]; Vladimir Y. Pomjakushin[3]; Yixi Su[5]; Tuson Park[6]; Ekaterina Pomjakushina[3]

[1] *Forschungszentrum Juelich GmbH*

[2] *Changwon National University*

[3] *Paul Scherrer Institut*

[4] *Sungkyunkwan University*

[5] *Jülich Centre for Neutron Science (JCNS) at MLZ, Forschungszentrum Jülich GmbH*

[6] *Sungkyunkwan Univeristy*

Korrespondenzautoren: igor.plokhikh@tu-dortmund.de, so.shin@fz-juelich.de, ekaterina.pomjakushina@psi.ch, jonathan.white@psi.ch, y.su@fz-juelich.de, vladimir.pomjakushin@psi.ch

CeAlGe crystallizes in a tetragonal structure I41md, where the spatial-inversion symmetry is broken, and is expected to exhibit Weyl fermions near a Fermi surface that becomes more stable by broken time-reversal symmetry [1]. It has been known that the magnetic ground state and relevant topological properties of CeAlGe depend on the chemical stoichiometry. For example, CeAlGe grown by

the flux method yields 5 ~ 15% additional Al in the Ge site and exhibits a commensurate antiferromagnetic order below T = 5.1 K [2], whereas the crystal grown by floating-zone methods with 30 bar of Ar gas (p=30 bar) is resulted in stoichiometric composition and exhibits an incommensurate order below T = 4.4 K in which topological Hall effects are induced by external magnetic fields [3]. In this presentation, we will present the experimental results of newly synthesized CeAlGe using the optical floating-zone furnace with a lower Ar pressure of p=5 bar. Our neutron diffraction and electrical Hall transport experiments revealed that the topological magnetism is still stabilized with shorter periodicity. Furthermore, we performed electrical transport experiments under pressure up to 2 GPa. Given all experimental results obtained using flux-grown and two floating-zone-grown CeAlGe crystals, we will discuss the mechanism of topological magnetism with respect to the Kondo coupling strength.

[1]G. Chang et al., Physical Review B, 2018, 97, 01104.
[2]T. Suzuki et al., Science, 2019, 365, 377-381.
[3]P. Puphal et al., Physical Review Letters, 2020, 124, 017202.

Topological magnetism and magnons / 67

Quantum skyrmions and antiskyrmions in monoaxial chiral magnets

Autoren Štefan Liščák[1]; Andreas Haller[1]

Co-Autoren: Andreas Michels [1]; Thomas Schmidt [1]; Vladyslav Kuchkin [1]

[1] *University of Luxembourg*

Korrespondenzautoren: stefan.liscak@uni.lu, andreas.haller@uni.lu, vladyslav.kuchkin@uni.lu, andreas.michels@uni.lu, thomas.schmidt@uni.lu

Skyrmions are topological solitons with particle-like properties holding potential for applications in magnetic and quantum technologies. Recently, the quantum properties of skyrmions have garnered significant attention. Unlike their classical counterparts, quantum skyrmions exhibit novel physical phenomena arising from their entanglement properties of the underlying spin system –spin-1/2 particles. We investigate quantum skyrmions in so-called monoaxial chiral magnets, which are a class of materials with Dzyaloshinskii-Moriya interaction (DMI) present in just one crystallographic direction, while the Heisenberg exchange interaction remains isotropic. Classical monoaxial chiral magnets represent a unique magnetic system that allows for the stabilization of both skyrmions and antiskyrmions of equal energy. Unlike a similar situation in frustrated magnets, the energy landscape here is much simpler, consisting of only four states: the saturated ferromagnetic state, spin-spiral, skyrmion and antiskyrmion. This simplicity makes such systems interesting for potential applications that rely on manipulating these states.
We study the quantum analogue of the established classical theory by investigating the low-excitation spectra of a spin-1/2 quantum Heisenberg model with monoaxial DMI. We find that such a model supports the existence of skyrmion and antiskyrmion states of equal energy using density matrix renormalization group (DMRG) methods. This degeneracy allows for the existence of a mesoscopic superposition state exhibiting properties of both skyrmion and antiskyrmion. Interested in the experimental observation of this superposition, we calculate two-point spin correlations, which can be measured in neutron scattering experiments. Finally, we introduce a perturbation in the form of a magnetic gradient field to induce a non-trivial time evolution. We study this time evolution both using a numerical variational approach and the collective coordinates method.

Unconventional superconductivity / 86

Characterizing the effect of different superconducting bands in anisotropic superconductors

Autor Elizabeth Blackburn[1]

[1] *Lund University*

Korrespondenzautor: elizabeth.blackburn@fysik.lu.se

In many cases it is difficult to distinguish between anisotropic and multi-band superconductivity. Using the transition metal dichalcogenide superconductors as a starting point, we experimentally confirm the Thiemann-Kogan model for uniaxial anisotropic superconductors through measurements of the vortex lattice in transition metal dichalcogenide superconductors. We then use this information to identify different contributions to the superconductivity via their different effective coherence lengths. From these results, it is possible to place constraints on the level of interband coupling.

Unconventional superconductivity / **75**

Hidden Magnetic Texture in the Pseudogap Phase of the High-Tc Superconducting YBa2Cu3O6+x

Autor Dalila Bounoua[1]

Co-Autoren: Frédéric Bourdarot [2]; Jun Xian [3]; Lin Shan Guo [3]; Lucile Mangin-Thro [2]; Martin Boehm [2]; Paul Steffens [2]; Philippe Bourges [1]; Toshinao Loew [4]; Victor Balédent [5]; William Liège [1]; Xin Yao [3]; Yvan Sidis [1]

[1] *Laboratoire Léon Brillouin, CEA-CNRS, Université Paris-Saclay, Gif sur Yvette, France*

[2] *Institut Laue-Langevin, Grenoble, France*

[3] *Department of Physics and Astronomy, Shanghai Jiao Tong University , Shanghai , China*

[4] *Max Planck Institute for Solid State, Stuttgart, Germany*

[5] *Laboratoire de Physique des Solides, Orsay, France*

Korrespondenzautor: dalila.bounoua@cea.fr

The origin of the enigmatic pseudogap phase of high-Tc superconducting cuprates remains an unsolved mystery. Over the last decades, polarized neutron diffraction (PND) revealed that the pseudogap state hosts an intra-unit cell (or q=0) magnetism preserving the lattice translational (LT) symmetry and breaking the time-reversal and parity symmetries [1]. This q=0 magnetism is interpreted in terms of loop current (LC) patterns accompanied by anapoles [1].
Our PND measurements in YBa2Cu3O6+x with different hole doping levels [2-4] uncover a novel hidden magnetism that may be crucial to elucidate the pseudogap puzzle. This short-range magnetism is carried by the CuO2 layers and settles in at T*, the pseudogap onset temperature. Distinct from the q=0 magnetism, the related magnetic signal appears at the planar wavevectors q=(0.5,0) and (0,0.5), yielding a (2x2) quadrupling of the magnetic unit cell within the [a,b] plane (q=½ magnetism). The associated magnetic moment is predominantly pointing perpendicular to the CuO2 planes, consistent with the LC picture. Finally, the q=½ magnetism vanishes in the overdoped regime, following the doping dependence of the pseudogap [3].
The q=0 and q=½ magnetisms could be embedded within a single spread-out magnetic texture of LCs. Such a magnetic texture could be consistent with the theoretical proposal of LC supercells, breaking the LT and able to reconstruct the Fermi surface [5]. The existence of such broad entities reveals an unexpected aspect of the pseudogap physics, bringing new pieces to the puzzle of this enigmatic state of matter.

[1] P. Bourges et al., C.R.Phys, 22, 1 (2021) 7-31.
[2] D. Bounoua et al., Comm.Phys, 5 (2022) 268 ;
[3] D. Bounoua et al, Phys.Rev.B, 108 (2023) 214408.
[4] W. Liège, D. Bounoua et al., (in preparation)
[5] C.M. Varma, Phys.Rev.B, 99 (2019) 2245.

Unconventional superconductivity / **83**

Resolving spin density wave order in layered nickelates La3Ni2O7 and La2PrNi2O7 via neutron diffraction

Autor Igor Plokhikh[None]

Korrespondenzautor: igor.plokhikh@tu-dortmund.de

Layered nickelates, particularly La3Ni2O7 and its derivatives, have emerged as a compelling platform for exploring unconventional superconductivity [1, 2]. These materials exhibit high-temperature superconductivity under pressure, placing them among the few transition-metal oxides with such properties alongside cuprates and iron-based superconductors. The intricate interplay of spin density waves (SDWs) [3], charge density waves (CDWs), and electronic correlations in these systems highlights their potential as key candidates for elucidating the mechanisms of unconventional superconductivity.
In this study, I present direct evidence of long-range SDW order in bilayer nickelates La3Ni2O7 and La2PrNi2O7 using high-intensity neutron powder diffraction (NPD) [4]. Magnetic Bragg reflections were observed below 150 K at propagation vectors q1 = (0, ½, 0) for both compounds and an additional vector q2 = (½, ½, 0) exclusively in undoped La3Ni2O7. Representation and magnetic symmetry-guided analysis revealed spin-structures with alternating low- (0.05–0.075 μB) and high-moment (~0.66 μB) stripes within single Ni layers, forming bilayers through antiferromagnetic stacking along the c-axis. The proposed models are substantiated by the muon spectroscopy data. The coexistence of two distinct magnetic stacking polymorphs corresponding to q1 and q2 in La3Ni2O7 further underscores the quasi-2D nature of its magnetic order.
These findings provide critical insights into the magnetic ground state of layered nickelates and establish a foundation for understanding their role as precursor states to superconductivity. Future studies will be important to unravelling the connection between SDW suppression and superconducting onset, potentially confirming SDWs as competing or complementary instabilities in these systems. This work advances our understanding of nickelate physics while channelling the way for targeted exploration of superconductivity mechanisms in transition-metal oxides.
[1] M. Wang, H.-H. Wen, T. Wu et al. Chinese Physics Letters, 41, 077402 (2024).
[2] N. Wang, G. Wang, X. Shen et al. Nature, 634, 579–584 (2024).
[3] R. Khasanov, T. J. Hicken, D. J. Gawryluk et al. Nature Physics, 21, 430–436 (2025).
[4] I. Plokhikh, T. J. Hicken, L. Keller et al. arXiv:2503.05287 [cond-mat.supr-con] (2025).

Unconventional superconductivity / **102**

Superconductivity in pressurized trilayer nickelate single crystals

Autor Yinghao Zhu[1]

Co-Autoren: Enkang Zhang [2]; Lixing Chen [2]; Jun Zhao [2]

[1] *Jülich Centre for Neutron Science JCNS-4 at MLZ, Forschungszentrum Jülich*

[2] *Department of Physics, Fudan University*

Korrespondenzautor: yi.zhu@fz-juelich.de

The search for new high-temperature (high-Tc) superconductors beyond the copper-based paradigm offers exciting opportunities to deepen our understanding of superconductivity mechanisms and explore new applications [1]. Nickel, situated immediately to the left of copper on the Periodic Table, offers a playground for materials and chemistry designs aimed at replicating high-Tc unconventional superconductivity. Ruddlesden-Popper (RP) phase bilayer nickelate La3Ni2O7 was shown to exhibit superconductivity under high pressures, with transition temperatures (Tc) approaching 80 K [2]. This unexpected finding prompted discussions about the underlying mechanisms of superconductivity, including analogies to cuprates and the potential for multiorbital physics that goes beyond simple cupratelike models.

In this talk, I will present our successful synthesis of high-quality trilayer nickelate La4Ni3O10-δ single crystals with minimal oxygen deficiency, achieved through the high-pressure optical floating zone technique. Our results show that applying pressure effectively suppresses spin and charge order in La4Ni3O10-δ, leading to the emergence of superconductivity with a maximum Tc of around 30 K at 69.0 GPa [3]. Susceptibility measurements reveal a strong diamagnetic response below Tc, confirming bulk superconductivity. In the normal state, we observe 'strange metal' behavior, marked by linear temperature-dependent resistance up to 300 K. This system's layer-dependent superconductivity suggests a distinct interlayer coupling mechanism, distinct from cuprates. Recently, we have observed pressurized bulk superconductivity in Pr4Ni3O10 single crystals [4].
These findings offer insights into the superconducting mechanisms and introduce a new material platform to study the interplay between various electronic phenomena, including spin/charge order, flat band structure, interlayer coupling, strange metal behavior and superconductivity.

[1] J. G. Bednorz & K. A. Müller, Z. Phys. B Condens. Matter, 64, 189-193 (1986).
[2] H. Sun, M. Huo, X. Hu, Nature, 621, 493-498 (2023).
[3] Y. Zhu, D. Peng, E. Zhang, et al., Nature, 631, 531-536 (2024).
[4] E. Zhang, D. Peng, Y. Zhu, et al., Physical Review X, 15, 021008 (2025).