Magnetic North

VI

Gimli, Manitoba June 11-14, 2019

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Magnetic North VI

Welcome to the sixth conference in the Magnetic North Series. The Magnetic North conference series was started in 2010 to serve as a forum linking Canadian magnetism researchers to each other and to international collaborators. The focus of the series has always evolved over many years. This year highlights hybrid states of matter incorporating a magnetic degree of freedom, frustrated magnetic systems, and atomic level effects or dynamics.

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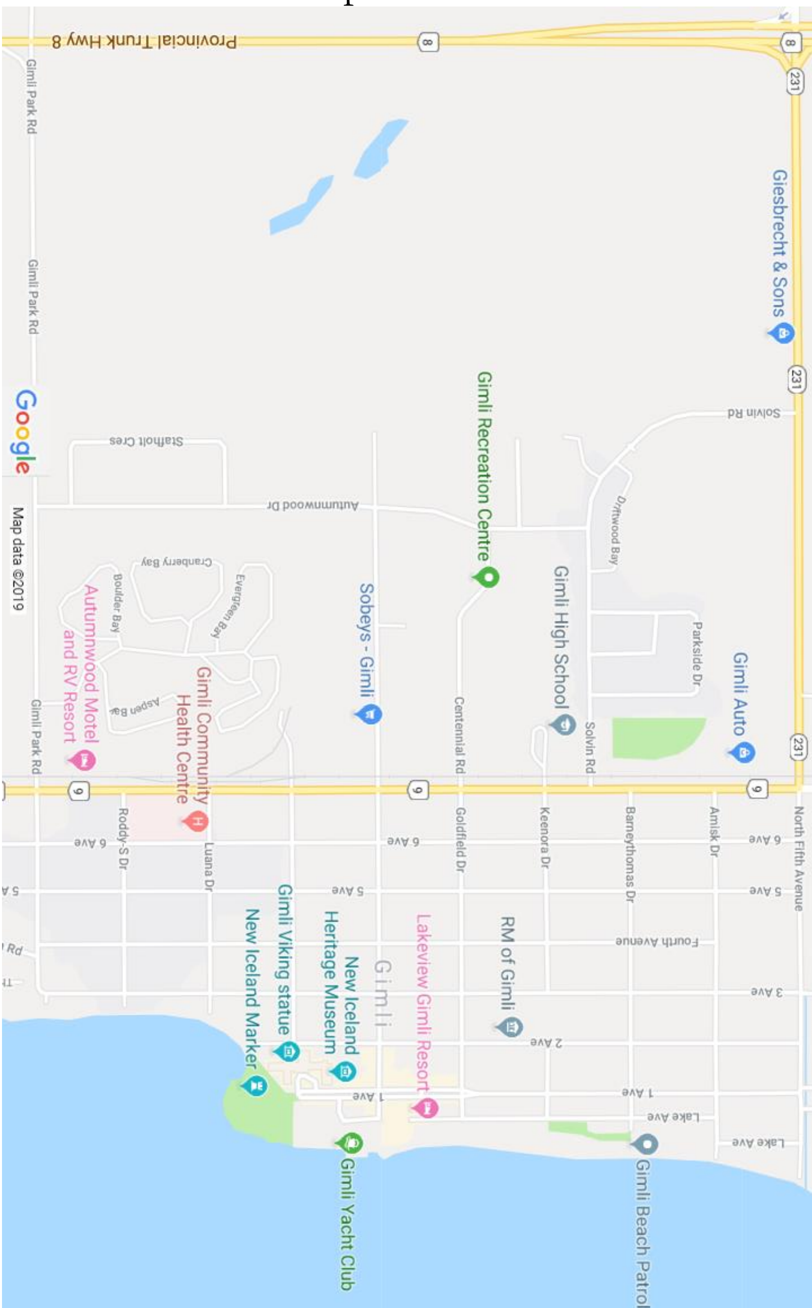
Maps of Gimli



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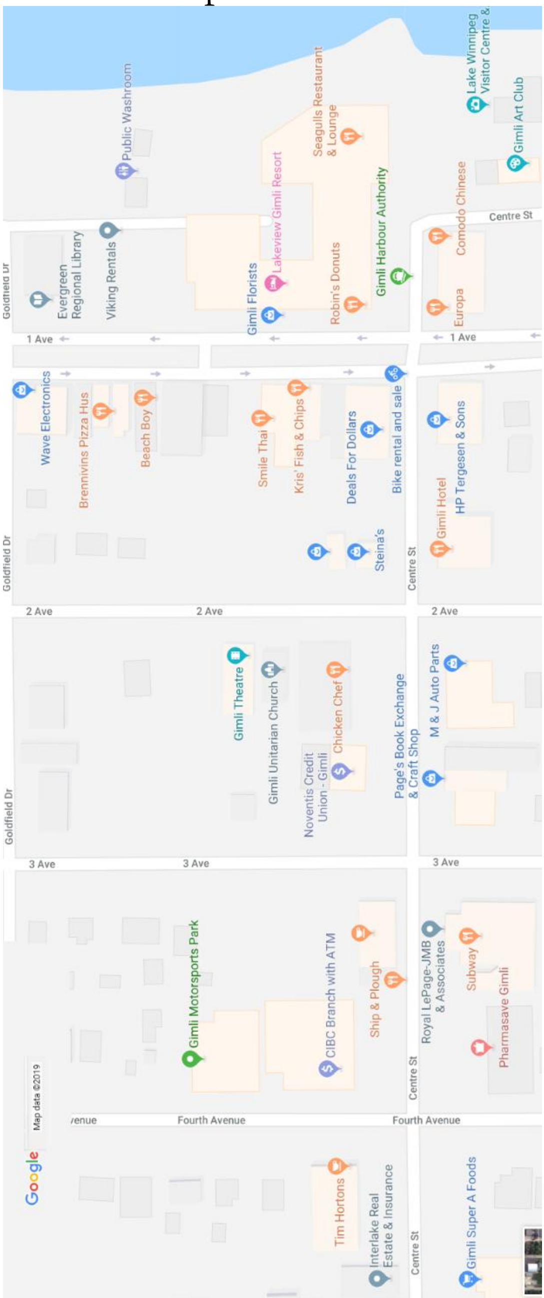


Magnetic North VI Preliminary Conference Program

	11-Jun-19 Tuesday	12-Jun-19 Wednesday	13-Jun-19 Thursday	14-Jun-19 Friday
7:00		Breakfast	Breakfast	Breakfast
8:00				
		Opening Remarks	Erol Girt (invited)	Karen Livesey (invited)
9:00		**Plenary** George Sawatzky	D. Venus	Kate Ross (invited)
			R. Camley	
			P. Omelchenko	M. Li
10:00		Coffee Break	Coffee Break	Coffee Break
		Sebastian Loth (invited)	Kimberly Hall (invited)	Ted Monchesky (invited)
11:00		Alexander Weismann (invited)	Igor Proskurin (invited)	A. Aczel
				M. Shepit
		Wolfgang Klassen	Tomas Jungwirth (invited)	C. Potts
		C. Mauws		3 Minute Talk Competition
12:00		Lunch	Lunch	Closing Remarks
				Departure
13:00		Mark Freeman (invited)	Bruce Gaulin (invited)	
		Dany Lachance-Quirion (Invited)	V. K. Paidi	
			Kyle Hall	
14:00		M. Harder	Gavin MacAuley	
		A. Morin	C. Wiebe	
		Coffee Break	Free Time	
15:00	Registration	Akif Ahmed		
		Y.-P. Wang		
		Graeme Luke (invited)		
16:00		Poster Session		
17:00				
18:00	Welcome BBQ		Banquet	
		Poster Venue Closes		
19:00				
20:00	Welcome BBQ Ends		Banquet Ends	

Session 1	Plenary
Session 2	Atomic Systems
Session 3	Hybrid Systems
Session 4	Hybridization and Frustration
Session 5	Thin Film
Session 6	Spintronic
Session 7	Frustrated Materials II
Session 8	Layer Structures
Session 9	Nano and Novel Systems

Tuesday

Registration – 15:00-18:00

Welcome BBQ – 18:30-21:00

Wednesday

Breakfast 07:00-08:30

Opening Remarks

08:45-09:00 – Opening Remarks (Jacob Burgess/Martin Plummer)

Session 1: Plenary – Chaired by Byron Southern

09:00-10:00 – George Sawatzky – Magnetism in high oxidation state transition metal compounds

Coffee Break

Session 2: Atomic Systems – Chaired by Jacob Burgess

10:30-11:00 – Sebastian Loth – Correlation and entanglement of magnetic atoms on surfaces

11:00-11:30 – Alexander Weismann – Inducing and Tuning Molecular and Atomic Magnetism by Shifting Orbital Energies

11:30-11:45 – Wolfgang Klassen – Precision magnetometry for the TUCANnEDM experiment

11:45-12:00 – C. Mauws– Destruction of Moment Fragmentation Through Symmetry Breaking

Lunch 12:00-13:00

Session 3: Hybrid Systems – Chaired by Can-Ming Hu

13:00-13:30 – Mark Freeman – Two-axis cavity optomechanical torque characterization of small magnetic structures

13:30-14:00 – Dany Lachance-Quirion – Quantum sensing of magnons in quantum magnonics

14:00-14:15 – Michael Harder – Level Attraction of Hybridized Magnon-Photon States

14:15-14:30 – Antoine Morin – Effect of dipolar interaction in strongly coupled photon-magnon systems of two yttrium iron garnet spheres

Coffee Break

Session 4: Hybridization and Frustration – Chaired by Chris Wiebe

15:00-15:15– Akif Ahmed - THz spectroscopy performed on $BiFeO_3$

15:15-15:30 – Yi-Pu Wang - Nonreciprocity in the cavity magnonics system

15:30-16:00 – Graeme Luke – Discovery and Characterization of New Frustrated Magnetic Systems

Poster Session 16:00-19:00

Thursday

Session 5: Thin Films – Chaired by Johan van Lierop

08:45-09:15 – Erol Girt – Non-collinear interlayer exchange coupling

09:15-09:30 – David Venus – Finite size Kosterlitz-Thouless transition in Fe/W(001)

09:30-09:45 – Robert. Camley – Creating Magnetic Rogue Waves

09:45-10:00 – Paul Omelchenko – Spin Pumping in Acoustic and Optical modes of FM/Pt/FM structure

Coffee Break

Session 6: Spintronics – Chaired by Byron Southern

10:30-11:00 – Kimberly Hall – Hybrid organic-inorganic perovskites: New class of spintronic material?

11:00-11:30 – Igor Proskurin – Spin currents in antiferromagnetic insulators: optical excitation 'zitterbewegung' and magnon conductivity

11:30-12:00 – Tomas Jungwirth – Antiferromagnetic spintronics: Symmetry, topology, and transport

Lunch 12:00-13:00

Session 7: Frustrated Materials II – Chaired by Russell Mammei

13:00-13:30 – Bruce Gaulin – Ground State Selection in Quantum Pyrochlore Magnets

13:30-13:45 – Vinod K. Paidi – A puzzle solved: Hybridization is the missing ingredient for the origin of ferromagnetism in nanoscale CeO_2

13:45-14:00 – Kyle Hall – Continuous Degeneracy in Dipolar Magnets

14:00-14:15 – Gavin MacAuley – Ordering and defects in Artificial Spin Ice topologies

14:15-14:30 – Chris Wiebe – High pressure synthesis and characterization of the new J_{eff}=1/2 pyrochlores $A_2RH_2O_7$ (A=Y,Lu)

Free Time 14:30-18:00

Banquet 18:00-21:00

Friday

Breakfast 07:00-08:30

Session 8: Layer Structures – Chaired by Robert Stamps

08:45-09:15 – Karen Livesey – Magnetic thin film heterostructures for signal processing in the GHz and THz regimes

09:15-09:45 – Kate Ross – A Novel Strongly Spin-Orbit Coupled Quantum Dimer Magnet: $Yb_2Si_2O_7$

09:45-10:00 – Ming Li – Effects of bi-quadratic and interlayer exchange coupling on the magnetization process of stacked triangular lattice antiferromagnets

Coffee Break

Session 9: Nano and Novel Systems – Chaired by Martin Plumer

10:30-11:00 – Ted Monchesky – In-plane skyrmions in epitaxial MnSi films

11:00-11:15 – A. Aczel – Revisiting Kitaev material candidacy in Ir4+ double perovskite iridates

11:15-11:30 – Michael Shepit - Unravelling the Strange Ferromagnetic Behaviour of Shape-Selective Antiferromagnetic Co_3O_4 Nanoparticles

11:30-11:45 – Clinton Potts – Cavity magnonics at the University of Alberta

Special Session: 3 Minute Poster Presentations

11:45-12:00 – Three Minute Talk Competition for Poster Prize Winners

Closing Remarks

12:00-12:15 – Closing Remarks and Prize Distribution (Jacob Burgess/Martin Plummer)

Magnetism and electronic structure of high oxidation state Chalcogenides

George A Sawatzky [1,2]

1) Stewart Blusson Quantum Matter Institute,

2) University of British Columbia

Starting from the basic picture of the electronic structure of transition metal and Rare earth chalcogenide insulators in which the on site coulomb interaction on the transition metal ion and the anion to cation charge transfer energy compete for the determination of the lowest energy electron removal and the lowest electron affinity states we develop a picture encompassing so called Mott Hubbard, or charge transfer insulators. In this talk I will extend this to and extend this to include mix valent systems for a charge transfer energy close to zero such as in SmB_6 and the negative charge transfer gap subsystem such as $RENiO_3$ or $BaBiO_3$. In each of these aside from the MH systems it is important to include the anion valence orbitals explicitly in the description of the electron removal and addition states or upon electron of hole chemical substitution. This explicit inclusion of the anion orbitals results in a complete break down of the original Hunds rule like picture for the lowest electronic states of the TM ion resulting in a strong modification of our thinking with regard to the magnetic properties of the material in which high and low spin states are reversed as are effective crystal or ligand field splitting's. I will use as examples the Curate superconductors in which the first ionization states in certain regions of momentum space could be high rather than low spin states, the Rare earth Nickelates in which the electron phonon coupling introduces and attractive Hubbard U effectively resulting in molecular like pairing interactions and spin zero states, SmB6 in which the effective inter-site hoping integrals are strong supressed due to the strong reduction of the so called coefficients of fractional parentage and Ba or Sr BiO_3 the parent high temperature oxide superconductor in which the electron phonon coupling together with the negative charge transfer gap character results in a strong attractive interaction between holes or electrons in a rather local molecular orbital like wave function.

Correlation and entanglement of magnetic atoms on surfaces

Sebastian Loth [1,2]
1) University of Stuttgart, Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany
2) Max Planck Institute for Solid State Research, Stuttgart, Germany

Magnetic atoms become open quantum systems when placed onto conducting surfaces. The interaction between the atoms and the conduction electrons of the surface is often undesirable because it introduces decoherence of the atom's spin. But by using atom manipulation with a scanning tunneling microscope it is possible to design few-atom spin systems that use this environmental interaction as a resource to tailor magnetic properties and even enhance coherence of specific spin states.

We employ a combination of high-resolution inelastic electron tunneling spectroscopy and fast electronic pump-probe spectroscopy to measure the magnetization dynamics of magnetic molecules on ultrathin superconducting Pb films and magnetic atoms on Cu_2N/Cu(100). We find that the formation of Yu-Shiba-Rusinov states can be used as sensitive indicator for orbital overlap between a spin and the surface [1]. In addition, the interplay between magneto-crystalline anisotropy of the atoms and strength of the surface-mediated spin-spin interaction can stabilize different spin ground states that either feature an entangled spin ground state or only classical spin-spin correlations [2]. These spin systems can be used for remote magnetic sensing over distances of several nanometers [3].

These experiments are first steps in the development of experimental tools that can control entanglement in solid-state quantum systems at the atomic level. This capability may make magnetic atoms on surfaces a viable platform for applications quantum information science.

[1] L. Malavolti, M. Briganti, M. Hänze, G. Serrano, I. Cimatti, G. McMurtrie, E. Otero, P. Ohresser, F. Totti, M. Mannini, R. Sessoli, S. Loth, *Nano Letters* **18**, 7955 (2018).
[2] D.-J. Choi, R. Robles, S. Yan, J.A.J. Burgess, S. Rolf-Pissarczyk, J.-P. Gauyacq, N. Lorente, M. Ternes, S. Loth, *Nano Letters* **17** 623 (2017).
[3] S. Yan, L. Malavolti, J.A.J Burgess, A. Droghetti, A. Rubio, S. Loth, *Science Advances* **3**, e1603137 (2017).

Inducing and Tuning Molecular and Atomic Magnetism by Shifting Orbital Energies

Alexander Weismann[1]

1) Institute of Experimental and Applied Physics, Christian-Albrechts-University of Kiel, Germany

Controlling orbital energies relative to the Fermi level of a metal substrate would enable tuning many physical effects including ground state properties, excitation spectra, magnetic anisotropy and transport properties.

Here we show how organic, closed shell molecules containing only C, N and H atoms can be tuned to become magnetic by arranging other molecules in their vicinity. Kondo resonances and Yu-Shiba-Rusinov bound states in the superconducting gap of the substrate can be induced and tuned by altering their relative position, tautomerization and by inducing conformational changes. DFT calculations are able to reveal the relevant coupling mechanisms.

I will further present how crystal field splitting of single Co atoms on a Cu(111) substrate can be modified by placing them at the side or the end of long monoatomic Cu chains containing hundreds of atoms.

Compared to the Kondo resonance of Co atoms on the pristine surface distinctly different amplitudes, widths and spectroscopic line shapes are observed. The observations are qualitatively reproduced by multi orbital many body calculations combining DFT with continuous time quantum Monte Carlo.

Precision magnetometry for the TUCAN nEDM experiment

Wolfgang Klassen [1], Russ Mammei[1,2], Jeff Martin [1,2]
1) University of Manitoba 2) University of Winnipeg

The TUCAN collaboration aims to provide a factor of 30 improvement on the current upper bound for the neutron electric dipole moment, resulting in a planned sensitivity of 10^{-27} e*cm. EDM experiments of this kind require measuring changes in the precession frequency of bottled ultracold neutrons[1] as we subject them to parallel and anti-parallel electric and magnetic fields. In order to reach the planned sensitivity, precise control of these magnetic fields and their gradients is required. To this end, I am developing an array of ultra-sensitive optical magnetometers and analysis software sensitive enough to measure the strength of the 1 μT holding field to a precision of 10 fT, and determine field gradients to third order in a harmonic expansion.
I will discuss the operating principles and design challenges associated with optical magnetometry.

[1] S. Ahmed *et al.*,"First ultracold neutrons produced at TRIUMF", *Phys. Rev. C,* vol. 99, no. 2, p. 25503, 2019.

Destruction of Moment Fragmentation Through Symmetry Breaking

Cole Mauws [1,2], Christopher Wiebe[1]
1) University of Winnipeg 2) University of Manitoba

Moment fragmentation is a phenomenon observed in various neodymium containing pyrochlores and has been suggested to occur in iridium containing pyrochlores. In moment fragmentation the Ising antiferromagnetic ground state only contains 1/3 of the total moment. A low energy (~70 μeV) excited dynamic ferromagnetic mode is populated well below the T_N, and contains 2/3 of the moment due to the larger degeneracy.
Here Nd_2ScNbO_7 is analyzed with respect to moment fragmentation. Due to the charge disordered nonmagnetic Sc^{+3}, Nb^{+5} ions the local symmetry constraints required for moment fragmentation are broken. We observe moment fragmentation in a small population of Nd ions that retain symmetry and show that it is destroyed in the remaining population. This indicates that moment fragmentation is intrinsically linked to the local symmetry and that moment fragmentation can exist as a single ion property.

Two-axis cavity optomechanical torque characterization of small magnetic structures

MR Freeman[1], G Haji-salem[2,3], JE Losby[1,3], G de Oliveira Luiz[2,3], MG Dunsmore[1], M Belov[3], V Sauer[1], T Firdous[1,3] and PE Barclay[2]

1) Physics, Univ. of Alberta 2) NRC-NANO, Edmonton
3) Physics & Astronomy, Univ. of Calgary

High quality optical nanocavities with mode volumes of order one cubic wavelength are readily compatible with nanoscale mechanical torque sensors, and can markedly increase their sensitivity [1,2]. In addition, the nanocavities offer significant extensions in functionality through their ability to transduce mechanical displacement along more than one Cartesian axis.

Two-axis torque studies of small magnetic structures via nanophotonic optomechanical devices will be described. Combining hysteresis measurements from orthogonal directions of torque allows the separation of magnetic moment and radio frequency susceptibility contributions to the torque signals. Data will be presented from a permalloy island, exhibiting complex susceptibility features due both to localized (in applied field) Barkhausen features arising from its polycrystallinity, and from global shape anisotropy. Finally, a transition from quasi-static studies to additional, direct mechanical probing of spin dynamics may begin within the range of the fundamental torsional modes considered here, in the HF radio band.

[1] M Wu, NLY Wu, T Firdous et al. *Nature Nanotech* **12**, 127 (2017).
[2] JE Losby, VTK Sauer and MR Freeman, *J Phys D* **51**, 483001 (2018).

Quantum sensing of magnons in quantum magnonics

D. Lachance-Quirion [1], S. P. Wolski[1], Y. Tabuchi [1],

S. Kono [1], K. Usami [1], Y. Nakamura [1,2]

1) Research Center for Advanced Science and Technology (RCAST), The University of Tokyo, Meguro-ku, Tokyo 153-8904, Japan

2) Center for Emergent Matter Science, RIKEN, Wako, Saitama 351-0198, Japan

The engineered strong and coherent interaction between a superconducting qubit and the uniform precession mode, or Kittel mode, of a spherical ferromagnetic crystal has enabled one to explore magnonics in the quantum regime [1-3]. Notably, quanta of collective spin excitations, or magnons, have been resolved in a millimeter-sized ferromagnetic crystal by reaching the so-called strong dispersive regime of quantum magnonics [2, 3]. In this presentation, we will present two distinct protocols of quantum-enhanced sensing of magnons using this regime. First, through an entangling operation between the Kittel mode and the superconducting qubit, we demonstrate the single shot detection of a single magnon with an efficiency reaching 70%, bringing to magnonics the equivalent of the single-photon detector. Secondly, we use a quantum sensing protocol that relies on magnon-induced dephasing of the qubit to achieve a magnon detection sensitivity of about 10^{-3} magnons/$\sqrt{\text{Hz}}$. These two complementary quantum sensing methods could find applications in quantum technologies based on magnonics.

[1] Y. Tabuchi, et al. *Science* **349**, 405 (2015).
[2] D. Lachance-Quirion, et al. *Science Advances* **3**, e1603150 (2017).
[3] D. Lachance-Quirion, et al. *arXiv:1902.03024*.

Level Attraction of Hybridized Magnon-Photon States

M. Harder [1], Y. Yang[2,3], B. M. Yao[3], C. H. Yu[4], J. W. Rao[2], Y. S. Gui[2], R. L. Stamps[2] and C.-M. Hu[2]

1) Kwantlen Polytechnic University, Surrey, Canada
2) University of Manitoba, Winnipeg, Canada
3) Chinese Academy of Sciences, Shanghai, China
4) Nantong University, Nantong, China

Traditional magnon-photon coupling due to electrodynamic phase correlation is characterized by level repulsion [1]. Such hybridized states function as an excellent transducer allowing, e.g., non-local spin current manipulation [2]. However our recent experiments have revealed a new form of coupling due to the cavity-Lenz effect, which is characterized by level attraction and is deeply connected to the physical ideas of exceptional points, PT symmetry and synchronization [3]. In this talk I will describe the origin of level attraction in ferrimagnetic systems and an experimental platform allowing continuous, in-situ, tuning between level attraction and level repulsion, which paves a new path for the utilization of light-matter coupling in cavity-spintronic applications.

[1] M. Harder and C.-M. Hu, Solid State Physics 69, 47 (2018).
[2] L. Bai, et al., Phys. Rev. Lett. 118, 217201 (2017).
[3] M. Harder, et al., Phys. Rev. Lett. 121, 137203 (2018).

Effect of dipolar interaction in strongly coupled photon-magnon systems of two yttrium iron garnet spheres

A. Morin, C. Lacroix, D. Ménard

Department of Engineering Physics, Polytechnique Montréal, Montréal, Qc

We studied the strong-coupling regime of two yttrium iron garnet (YIG) spheres in a microwave cavity [1] to investigate the effect of dipolar interactions on this regime for densely packed nanomagnets systems, such as arrays of magnetic nanowires. In this work, we show that the coupling strength between a microwave cavity and two YIG spheres substantially decrease when the spheres are close to each other and aligned with the external magnetic field. Calculations of the reciprocal interaction of the static dipolar field between each sphere allow us to replicate accurately these results, suggesting that the diminution originates from this interaction. This is also supported by simulations done with the software COMSOL and OOMMF. These results suggest that dipolar interactions must be considered when designing future devices based on photon-magnon coupling that involve a dense collection of ferromagnetic objects.

[1] Morin, A., Lacroix, C., & Ménard, D. *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM).* IEEE, 2016.

THz spectroscopy performed on $BiFeO_3$

Akif Ahmed [1], Aimé Braconnier [1], Josh Gibbs [1], Nils Refvik[1], Sangeev Selvaratnam [1], August Mendelsohn[1], Marcin Bialek [2], Jean-Phillipe Ansermet [2], C.-M. Hu [1], Jacob Burgess[1]
1) Department of Physics and Astronomy, University of Manitoba, Canada
2) École Polytechnique Fédérale de Lausanne, Switzerland

We use a THz time domain spectrometer to explore spectroscopic features in a polycrystalline slab of bismuth orthoferrite (BFO). The spectrometer is based on an intermediate power fibre laser and tilted pulse front optical rectification in lithium niobate. This permits the generation of relatively intense THz pulses at high repetition rates. This approach is ideal for spectroscopy on BFO, a canted antiferromagnet exhibiting multiferroic properties. Prominent peaks are found which match room temperature spin cycloid resonances reported for the BFO lattice. The peaks are tunable via application of an electric field and show significant promise for studying of coupling between THz photons and the antiferromagnetic lattice.

[1] M. Bialek, A. Magrez, A. Murk, and J.-Ph. Ansermet, *PRB, **97** 054410*, (2018).

Nonreciprocity in the cavity magnonics system

Yi-Pu Wang [1], Jinwei Rao[1], Ying Yang [1], Yongsheng Gui[1], C.-M. Hu [1]
1) Department of Physics and Astronomy, University of Manitoba, Winnipeg R3T 2N2, Canada

Reciprocity is important and common in natural systems. However, sometimes it's advantageous to break it with practical applications and functional designs, especially in the linear regime. Recently, the cavity magnonics and cavity spintronics systems have attracted a lot of attention for their fundamental interest and great potential in quantum information processing. We focus on our efforts to address the realization of nonreciprocity in the coupled cavity photon-magnon system and we experimentally observed the nonreciprocal microwave propagation induced by the interference between coherent coupling and dissipative coupling within a specially designed setup. This is an entirely new method to get nonreciprocity and it provides a new perspective to investigate non-reciprocal phenomena in the linear response regime. Together with the high tunability and extendibility of the cavity magnonics system, more interesting physics and a suite of practical applications are to be vividly portrayed.

Discovery and Characterization of New Frustrated Magnetic Systems

Graeme M. Luke [1,2]

1) Dept. of Physics & Astronomy, McMaster University, L8S 4M1

2) TRIUMF, Vancouver, BC, V6T 2A3

Magnetic frustration occurs when a material's lattice geometry prevents it from finding the classical ground state which minimizes pairwise magnetic interaction energies. In such situations, novel ground states with exotic properties can emerge: examples include classical and quantum spin ice and classical and quantum spin liquids. Many different states and excitations have been predicted theoretically, but the study of their physical properties requires real physical realizations of these models.

We have been searching for new geometrically frustrated magnetic materials to broaden the range of materials that can be studied to identify new ground states and novel excitations. I will describe our work to synthesis a stacked triangular system $ErMgGaO_4$ and the related garnet $Er_3Ga_5O_{12}$, which we have characterized with magnetic susceptibility, specific heat, muon spin relaxation and neutron scattering. We find that the spins in remain dynamic down to our lowest temperatures (50mK), making this system a candidate spin liquid.

I will also describe our ongoing work on new materials whose lattice is derived from the highly frustrated pyrochlore and kagome lattices where we have successfully synthesized single crystal and polycrystalline specimens of several new compounds.

Non-collinear interlayer exchange coupling

Z. Nunn[1], **E. Girt**[1]

1) Simon Fraser University, Burnaby, Canada

The rapid increase in magnetic memory storage density over the last three decades has been made possible by the discovery of interface-induced phenomena in ferromagnetic/non-magnetic multilayers. One of the interface effects that have been intensively studied, for controlling magnetization reversal processes and magnetic stray fields in magnetic multilayers, is the interlayer exchange coupling. This phenomenon has not been used to its full potential, since traditional coupling layers only allow for collinear orientation of magnetic moments of the ferromagnetic layers. Recently, we discovered new coupling layer materials, which can be inserted between two ferromagnetic layers to precisely control the relative orientation of the magnetic moments of ferromagnetc layers [1]. These new coupling layers have potential to be used in majority of spintronic devices, as the optimal design of magnetic nano-devices almost always requires non-collinear alignment between at least two neighboring ferromagnetic layers. In this talk the emphases will be on characteristics and origin of the non-collinear interlayer exchange coupling across these novel coupling layers that leads to almost an order of magnitude larger biquaratic coupling strength than ever before observed.

[1] Z. Nunn, E. Girt, arXiv:1901.07055 (2019).

Finite size Kosterlitz-Thouless transition in Fe/W(001)

D. Venus, J. Atchison, A. Bhullar, B. Norman

McMaster University

The Kosterlitz-Thouless (KT) transition involves the unbinding of topological excitations (vortex-antivortex pairs) in an infinite, isotropic, 2DXY system. In real 2D ferromagnetic films, it is not clear that such a transition occurs in the presence of crystalline anisotropy and finite size effects. We report MOKE magnetic susceptibility measurements χ(T) of the 4-fold in-plane system Fe/W(001), where a prominent peak is observed. Above the peak temperature, the paramagnetic susceptibility is in excellent agreement with the form expected for a vortex-antivortex gas: $\chi(T) = \chi_0 \exp[B/(\frac{T}{T_{KT}} - 1)^a]$, with $a = 0.50 \pm 0.03; B = 3.48 \pm 0.16$. In accord with finite size KT theory, T_{KT} is tens of K below the susceptibility peak, so that the "finite size" is consistent with μm magnetic domains. Fitting instead to a power law, consistent with a 2nd order transition, gives unphysical parameters $\gamma_{eff} = 3.7 \pm 0.7,$ and a Curie temperature T_C far below the peak temperature. Below the peak, the measured χ(T) has a complicated behaviour qualitatively consistent with the re-emergence of 4-fold anisotropy and magnetic domains.

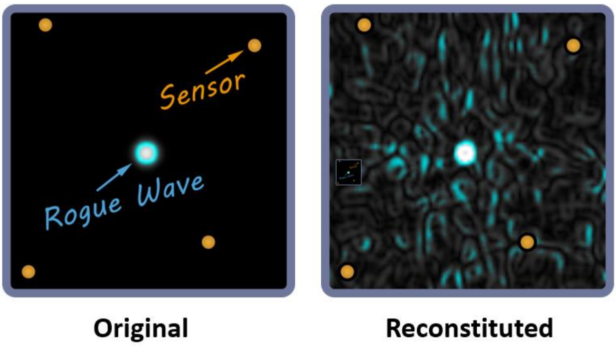
Creating Magnetic Rogue Waves

Matthew Copus [1], **Robert Camley**[1]

1) Center for Magnetism and Magnetic Nanostructures, University of Colorado at Colorado Springs

Rogue waves in oceans are a well-known phenomenon where a large wave that can overturn a ship spontaneously arises. We study whether it is possible to create a rogue wave in a magnetic system. We do this initially in micromagnetics by starting with a rogue wave configuration and letting it evolve in time. Instead of collecting data over the entire sample and using time reversal to produce the rogue wave[1], we collect time-dependent magnetic data at a small number of sites (typically around 4) in the sample. Simply using time reversal on just 4 sites can create the rogue wave from a system in equilibrium. The figure shows the initial rogue wave and the regenerated wave produced by the data from just 4 sites. We also show that rogue waves can be created by using oscillating fields to create a rogue wave at a designated site. Unlike the ocean, magnetic systems are anisotropic and tunable. We investigate how this influences the reconstruction of the rogue wave.

[1] A. Przadka, *Phys Rev Letters,* **109,** 064501 (2012)



Spin Pumping in Acoustic and Optical modes of FM/Pt/FM structure

P. Omelchenko [1], E. Girt [1], B. Heinrich [1]

1)Simon Fraser University

We present a study of spin pumping into Pt by magnetic damping measurements of the acoustic (in-phase precession) and optical (out-of-phase precession) modes of the Ni80Fe20/Pt/ Ni80Fe20 structure. The interlayer exchange coupling through Pt allows one for a unique and fundamental study of spin pumping which not only probes the magnitude of the spin current but also its phase. Main question being addressed is the validity of the standard spin pumping theory, derived for sharp interfaces, in proximity polarized Pt[1]. The remarkable agreement between experiment and standard spin pumping theory suggests that enhancement in damping due to Pt is very well described by spin pumping, without any additional contributions to damping.

[1] P. Omelchenko, B. Heinrich and E. Girt. Appl. Phys. Lett. **113**, 142401 (2018).

Hybrid organic-inorganic perovskites: New class of spintronic material?

K. C. Hall[1], D. B. Riley[1], S. B. Todd[1], C. Clegg[1], A. Binai-Motlagh[1], A. Ramachandran[1], S. A. March[1], I. G. Hill[1], C. C. Stoumpos[2], J. M. Hoffman[2], M. G. Kanatzidis[2], Zhi-Gang Yu[3]

1) Department of Physics and Atmospheric Science, Dalhousie University Halifax, NS B3H 4R2 Canada
2) Department of Chemistry, Northwestern University, Evanston, IL 60208 United States
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The hybrid-organic inorganic perovskites exhibit strong spin-orbit interactions owing to the incorporation of heavy elements such as lead and iodine. The most well-studied of these materials is $CH_3NH_3PbI_3$, but a wide range of alternative compositions are currently under intensive study, including 2D perovskites which form a self-assembled multiple quantum well structure with controllable well width and band gap. The strong spin-orbit coupling in these materials has led to the prediction [1] and recent observation [2] of a giant Rashba effect, leading to the potential for spintronic devices with low-threshold spin gating [3]. In addition, these materials have been shown to possess an large Faraday rotation [4], making them of interest for spin-optoelectronic devices such as optical isolators and spin-polarization switches [5]. Despite this promise, very little is known about the spin-related properties of these materials. Here we report measurements of the coherent carrier response in 3D $CH_3NH_3PbI_3$ [6] as well as spin-dependent measurements of carrier kinetics in butylammonium methylammonium lead iodide 2D perovskite [7]. Both experiments suggest that Rashba effects strongly influence the carrier kinetics in these systems.

[1] M. Kepenekian and J. Even, J. Phys. Chem. Lett. 8, 3362 (2017).
[2] D. Niesner et al. Phys. Rev. Lett. 117, 126401 (2016).
[3] K. C. Hall and M. E. Flatte, Appl. Phys. Lett. 88, 162503 (2006).
[4] D. Giovanni et al. Nano Lett. 15, 1553 (2015).
[5] K. C. Hall et al. Appl. Phys. Lett. 75, 4156 (1999).
[6] S. A. March et al. ACS Photonics 4, 1515 (2017); S. A. March et al. Sci. Rep. 6, 39139 (2016).
[7] S. B. Todd et al. arXiv:1807.10803 (2018).

Spin currents in antiferromagnetic insulators: optical excitation, "zitterbewegung", and magnon conductivity

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Antiferromagnetic insulators are promising candidates with which to address the problem of creating and transmitting spin currents, which is a key issue in terahertz optospintronics – a direction targeting optical control of spin states in magnetic materials.

In this talk, I am going to discuss several aspects of creating and manipulating magnon spin current in antiferromagnets. First, a new mechanism for generating spin currents by optical excitation of spin dynamics is proposed [1]. The mechanism involves polarized light and is motivated by the photogalvanic effect in metals, where circularly polarized light can produce a direct electron photocurrent, which direction depends on the polarization. I will show that an analogous nonlinear effect exists for antiferromagnetic insulators wherein the total spin of light and spin waves is conserved.

Secondly, I will consider the analogy between magnon motion in an antiferromagnet and a massless relativistic particle described by the Dirac equation [2]. This analogy allows to find a magnonic analog of the *zitterbewegung* (trembling motion) effect [3], which also contributes to the magnon spin current. We discuss the relation between the zitterbewegung terms and spin conductivity of magnons, as well as their relation to the geometric terms, which appear for materials with complex lattice structures and Dzyaloshinskii-Moriya interactions.

[1] I. Proskurin, et al. *Phys. Rev. B* **98**, 134422 (2018).
[2] I. Proskurin, et al, *Phys. Rev. Lett.* **119**, 177202 (2018)
[3] W. Wang, et al. *Phys. Rev. B* **96**, 024430 (2017).

Antiferromagnetic spintronics: Symmetry, topology and transport

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The suppression of dipolar fields in antiferromagnets is favorable for high density integration of memory elements and makes them robust against magnetic field perturbations. Other unique merits of antiferromagnetic spintronics include the multi-level switching, suitable for integrating memory with logic or neuromorphic functionalities, and the ultra-fast THz spin dynamics.

In the lecture we will first give a brief overview of the multiple directions in current research of antiferromagnetic spintronics [1,2]. We will then outline the rich symmetry landscape of antiferromagnets which allows for a range of transport phenomena suitable for manipulating and detecting antiferromagnetic spins. Our main focus will be on electrical readout of spin-reversal in antiferromagnets. This can be facilitated by a second-order magnetoresistance effect in antiferromagnets with broken time and space-inversion symmetries [3]. In the linear response, we introduce a mechanism of the spontaneous Hall effect in collinear antiferromagnets in which the required breaking of time-reversal and other symmetries is caused by the arrangement of non-magnetic atoms in the lattice [4].

[1] T. Jungwirth et al., *Nature Physics* **14**, 200 (2018).
[2] K. Olejnik et al., Science Adv. **4**, eaar3566 (2018)
[3] J. Godinho et al., *Nature Communications* **9**, 4686 (2018).
[4] L. Šmejkal et al., arXiv:1901.00445.

Ground State Selection in Quantum Pyrochlore Magnets

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The pyrochlore lattice, a network of corner-sharing tetrahedra, is one of the most pervasive crystalline architectures in nature that supports geometrical frustration. We and others have been interested in a family of rare earth pyrochlore magnets, that can display quantum S=1/2 magnetism on such a lattice. The quantum S=1/2 degrees of freedom arise due to crystal field effects, as I will describe. The ground states for some of these materials may be described by a model known as "spin ice", a model with the same frustration and degeneracy as solid ice, as well as by a quantum version of this model known as "quantum spin ice" that possesses an emergent quantum electrodynamics. I'll describe how this comes about and how we can understand these materials, with an emphasis on modern neutron scattering. I'll also discuss a generalized phase diagram for the ground states of these materials, with emphasis on the Yb2Ti2O7, Er2Ti2O7, and Er2Pt2O7 [1].

[1] A. M. Hallas, J. Gaudet, and B.D. Gaulin, Ann. Rev. Condensed Matter Physics, 9, 105 (2018).

A puzzle solved: Hybridization is the missing ingredient for the origin of ferromagnetism in nanoscale CeO_2

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Nanoscale CeO_2 is a prototypical system that presents d^0 magnetism. Using a combination of x-ray absorption spectroscopy, x-ray magnetic circular dichroism and modelling, I will show that the mechanism that allows defects, disorder and non-stoichiometry to enable magnetism is magnetically polarized Ce 4*f* and O 2*p* hybridized states captured by the vacancy orbitals.

I will also demonstrate that foreign ions (Fe and Co) enhance the magnetic moment at Ce 4*f* sites while the number of vacancy orbitals is unchanged. This points clearly to the mechanism of orbital hybridization being the missing ingredient to understanding the unexpected ferromagnetism in many nanoscale magnetic oxides and semiconductors.

Continuous Degeneracy in Dipolar Magnets

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Results [1] are presented on analytic and computational analyses of the spin states associated with a three-dimensional (3D) fcc lattice composed of ABC stacked kagome planes of magnetic ions with only long-range dipole-dipole interactions. The 3D lattice exhibits a continuous degeneracy characterized by two spherical angles involving six sublattice spin vectors. Thermal fluctuations reduce this degeneracy at very low temperature in an order-by-disorder process. A magnetic field applied along directions of high symmetry also results in lifting the continuous degeneracy. The results can be relevant to a class of magnetic compounds having the AuCu3 crystal structure.

[1] A. R. Way, K. P. W. Hall, I. Saika-Voivod, M.L. Plumer & B.W.Southern, PRB 98, 214417 (2018)

Ordering and defects in Artificial Spin Ice topologies

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Artificial Spin Ices (ASIs) are arrays of strongly correlated nano-scale magnetic islands. They prove an excellent playground to study the role of topology on critical phenomena. Here [1], we investigate a variation on the classic square geometry based on rotating each island through an angle. We fabricate arrays using electron beam induced deposition and image their magnetic configuration after thermal annealing using Lorentz TEM. From this, we observe a predicted transition [2] from antiferromagnetic to ferromagnetic ordering. This leads to a change in the dimensionality of defects (from 1*d* strings in the AFM phase, to 2*d* vortices in the FM phase). The density of these defects is consistent with the Kibble-Zurek mechanism (KZM). These results illustrate how magnetic order in ASI can be tuned by geometry (such that a truly frustrated ice-rule system is possible in two-dimensions), and allow for comparison of the KZM across these two phases.

[1] G. Macauley et al., in preparation, (2019).
[2] R. Macêdo, et al., *Phys. Rev. B*, **98**, 014437 (2018).

High pressure synthesis and characterization of the new $J_{eff}=1/2$ pyrochlores $A_2Rh_2O_7$ (A = Y, Lu)

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4) University of Tennessee-Knoxville 5) Zhejiang University
6) Columbia University 7) NIMS, Tsukuba, Japan
8) University of Edinburgh 9) CSEC, University of Edinburgh
10) TRIUMF 11) CIFAR 12) University of Winnipeg

New cubic pyrochlores of the form $A_2Rh_2O_7$ (A = Y, Lu), based on $4d^5$ Rh^{4+} species, have been synthesized by high pressure methods and characterized via thermodynamic, electrical transport, and muon spin relaxation measurements. Magnetic susceptibility measurements reveal large temperature-independent Pauli paramagnetic contributions, while heat capacity shows an enhanced Sommerfeld coefficients. Muon spin relaxation measurements confirm that both materials remain paramagnetic down to 2 K. Taken in combination, these three measurements suggest that $A_2Rh_2O_7$ are correlated paramagnetic metals. Furthermore, although the magnitude of the resistivity of $Lu_2Rh_2O_7$ is that of a semiconductor, the temperature dependence of does not obey any conventional form. Thus, we propose that these pyrochlores may belong to the same novel class of non-Fermi liquids as the nonmetallic metal FeCrAs. [1]

[1] A. M. Hallas, et al. *npj Quantum Materials* **4**, 9 (2019).

Magnetic thin film heterostructures for signal processing in the GHz and THz regimes

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Ferromagnets and ferrimagnets can be used to make high-frequency signal processing devices such as filters and isolators that operate in the 1-50 GHz range. Two problems exist:
(1) a large applied field is needed to tune these devices, and
(2) there is currently a strong desire to have devices operate at higher frequencies, in the 100 GHz – 1 THz range.

I will discuss our calculations that show ways to overcome these two problems using heterostructures comprised of thin and ultrathin ferromagnetic films, alternated with non-magnetic, conducting films. The resulting metamaterials have:
(1) a band-pass frequency that can be tuned by 30 GHz using just a small, static 500 Oe field [1], and
(2) the possibility to see strong coupling to electromagnetic waves in the 300-600 GHz range [2].

R.M. acknowledges support from the Leverhulme Trust. P.M.Y. is supported by a UCCS Mentored Doctoral Fellowship.

[1] R. Macêdo, K.L. Livesey and R.E. Camley, *Appl. Phys. Lett.* **113**, 121104 (2018).
[2] P.M. Yarbrough, K.L. Livesey, R.E. Camley and R. Macêdo, ***submitted*** (2019).

A Novel Strongly Spin-Orbit Coupled Quantum Dimer Magnet: $Yb_2Si_2O_7$

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The quantum dimer magnet (QDM) is the canonical example of "quantum magnetism". This state consists of entangled nearest-neighbor spin dimers and often exhibits a field-induced "triplon" Bose-Einstein condensate (BEC) phase. We report on a new QDM in the strongly spin-orbit coupled, distorted honeycomb-lattice material $Yb_2Si_2O_7$ [1]. Our single crystal neutron scattering, specific heat, and ultrasound velocity measurements reveal a gapped singlet zero field ground state with sharp, dispersive excitations. We find a field-induced magnetically ordered phase reminiscent of a BEC phase, with exceptionally low critical fields of H_{c1} ~0.4 T and H_{c2} ~1.4 T. Using inelastic neutron scattering we observe a Goldstone mode (gapless to within $\delta E = 0.037$ meV) that persists throughout the entire field-induced magnetically ordered phase, suggestive of the spontaneous breaking of U(1) symmetry expected for a triplon BEC. However, in contrast to other well-known cases of this phase, the high-field ($H >$ 1.2T) part of the phase diagram in $Yb_2Si_2O_7$ is interrupted by an unusual regime signaled by a change in the field dependence of the ultrasound velocity and magnetization, as well as the disappearance of a sharp anomaly in the specific heat. These measurements raise the question of how anisotropy in strongly spin-orbit coupled materials modifies the field induced phases of QDMs.

[1] Gavin Hester, H. S. Nair, T. Reeder, D. R. Yahne, T. N. DeLazzer, L. Berges, D. Ziat, J. A. Quilliam, J. R. Neilson, A. A. Aczel, G. Sala, and K. A. Ross. A Novel Strongly Spin-Orbit Coupled Quantum Dimer Magnet: $Yb_2Si_2O_7$. arXiv:1810.13096 [cond-mat.str-el] (2018)

Effects of bi-quadratic and interlayer exchange coupling on the magnetization process of stacked triangular lattice antiferromagnets

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The evolution of ground spin states with an applied magnetic field of the stacked planar triangular antiferromagnet with AF interlayer interaction J_c is explored using a 3D classical Heisenberg model. A bi-quadratic coupling is also used to mimic the effect of spin fluctuations [1] which are known to stabilize the magnetization plateau. A single ion anisotropy allows us to determine the magnetic states with **H** // *a*-axis and *c*-axis. For **H** // *a*-axis, an additional new state, in contrast to 2D model [1], is obtained with weak interlayer interaction, while the magnetization plateau vanishes at large J_c and other new states with z components of spins emerge. For **H** // *c*-axis, an extra state, compared with 2D model, is obtained with a weak interlayer interaction. When J_c is large enough, only the state corresponding to the Umbrella phase in 2D model exits.

[1] M. E. Zhitomirsky, *J. Phys.: Conf. Series* **592**, 012110 (2015).

In-plane skyrmions in epitaxial MnSi films

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Chiral interactions in magnetic materials are unique in their ability to stabilize static magnetic solitons, known as skyrmions. At surfaces and interfaces, the chiral interaction results in novel magnetic surface states [1]. These surface twists help to further stabilize skyrmions in thin films [2], together with the influence of epitaxy induced magnetocrystalline anisotropy. These interactions play a crucial role in determining the observed magnetic textures, and lead to dramatically different behaviour in films as compared to bulk crystals.

The magnetic structure of MnSi thin films has been highly controversial. Our group was the first to report in-plane skyrmions [4], and the suppression of skyrmions out of plane [5], in contrast to reports from other groups. To resolve the controversy, we measured the magnetic structure of the in-plane skyrmions in epitaxial MnSi/Si(111) thin films, probed in three dimensions by the combination of polarized neutron reflectometry (PNR) and small angle neutron scattering (SANS) [6]. We demonstrate that skyrmions exist in a region of the phase diagram above a temperature of 10 K. PNR shows the skyrmions are confined to the middle of the film due to the potential well formed by the surface twists.

[1] M. N. Wilson *et al.*, Phys. Rev. B 88, 214420 (2013).
[2] A. O. Leonov *et al.*, Phys. Rev. Lett., 117, 087202 (2016).
[3] M. N. Wilson *et al.,* Phys. Rev. B 89, 094411 (2014).
[4] M. N. Wilson *et al.,* Phys. Rev. B 89, 094411 (2014).
[5] T. L. Monchesky *et al.* Phys. Rev. Lett., (112), 059701 (2014).
[6] S. A. Meynell *et al.* Phys. Rev. B 96, 054402 (2017).

Revisiting Kitaev material candidacy in Ir^{4+} double perovskite iridates

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Quantum magnets with significant bond-directional Ising interactions, so-called Kitaev materials, have attracted tremendous attention recently in the search for exotic spin liquid states. Here I present a comprehensive set of measurements investigating the crystal structures, Ir^{4+} single ion properties, and magnetic ground states of the double perovskite iridates La_2BIrO_6 (B = Mg, Zn) and A_2CeIrO_6 (A = Ba, Sr). Despite the variance in the non-cubic crystal field experienced by the Ir^{4+} ions in these materials, X-ray absorption spectroscopy and resonant inelastic x-ray scattering are consistent with $J_{eff} = 1/2$ moments in all cases. Furthermore, neutron scattering and resonant magnetic x-ray scattering show that these systems host A-type antiferromagnetic order. These electronic and magnetic ground states are consistent with expectations for face-centered-cubic magnets with significant antiferromagnetic Kitaev exchange, which indicates that spacing magnetic ions far apart may be a promising design principle for uncovering additional Kitaev materials.

[1] A.A. Aczel *et al*, arXiv: 1901.08146

Unravelling the Strange Ferromagnetic Behaviour of Shape-Selective Antiferromagnetic Co_3O_4 Nanoparticles

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Co_3O_4 is nominally an antiferromagnetic oxide with strong antiferromagnetic order mediated by exchange interactions between Co^{2+} ions. These interactions are disrupted at the surface enabling Co_3O_4 nanoparticles to display very interesting magnetic properties, including both hard and soft induced surface ferromagnetism and an antiferromagnetic spin-flop transition that yields an inverted hysteresis loop.
Structural and magnetic characterizations performed on cubes, spheres and hexagonal plates show that the spin-flop transition changes with Co^{3+}-to-Co^{2+} surface termination ratio. This leads to hysteresis loops that are inverted over a range of temperatures between 10 K and T_N, but which show ‘normal’ hysteresis below 10 K. We find that the strength of the exchange interactions coupled with the shape and resulting exposed surface planes decide the overall magnetism. I will present some of our recent findings that address the physics underlying these features.

Cavity magnonics at the University of Alberta

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I will discuss recent work performed in the Davis lab at the University of Alberta focusing on magnons within YIG spheres. This work has been a recent addition to the group; nevertheless, it has demonstrated early success. To date, strong coupling between microwave photons and magnons has been observed at cryogenic and room-temperatures, as well as the investigation of optical whispering gallery modes within YIG spheres.
Current work has been on transitioning the focus into fields for which the Davis group has previous experience. This includes low-temperature experiments in the millikelvin regime [1], and optomechanics [2].

[1] T.J. Clark, V. Vadakkumbatt, F. Souris, H. Ramp and J.P Davis, *Rev. Sci. Inst.* **89**, 114704 (2018)
[2] H. Ramp, B.D. Hauer, K.C. Balram, T.J. Clark, K. Srinivasan, and J.P. Davis, *under review* (2018)

Poster Submissions

1. **Y.S. Gui** - Coherent control of magnon radiative damping with local photon states
2. **Michael Dunsmore** - An apparatus for mechanical torque measurement of spin-lattice relaxation
3. **J.W. Rao** - Level attraction and level repulsion of magnon coupled with a cavity anti-resonance
4. **K. Mori** - The Einstein - de Haas effect at radio frequencies
5. **Y. Yang** - Control of the magnon-photon level attraction in a planar cavity
6. **N**. **Refvik** – Time domain analysis of level-coupling in multi-etalon systems
7. **Peng-Chao Xu** - Long-range coherent coupling and dissipative coupling between magnetic moments
8. **Yutong Zhao** - Level attraction in metamaterials
9. **B. Alkadour** - Triangular array of iron-oxide nanoparticles: A simulation study of intra-and inter-particle magnetism
10. **K.L Livesey** - Beyond the blocking model to fit nanoparticle ZFC/FC magnetization curves
11. **Rachel Nickel** - Controlling the Verwey transition of Fe_3O_4 with strain
12. **Y. Wroczynskyj** - Anisotropic zeta-potentials: shape and magnetic field dependent nanoparticle mobilities

13. **Sara H. Monfared** - Magnetic Properties of Core-Shell $CoFe_2O_4$ @ $BiFeO_3$ Nanocomposites

14. **Joann Hilman** - Structure, composition and magnetism of transition-metal doped ε-Fe_2O_3

15. **J.A. Lussier** - Synthesis and Magnetic Properties of the New Spin Liquid Candidate, $Ca_3Cu_2GeV_2O_{12}$

16. **M. Abbasi Eskandari** - Effect of Ca, Sr and Ba for La substitution on the magnetocaloric effect in La_2MnFeO_6 double perovskites

17. **Megan Rutherford** - Anomalous magnetic behaviour of the mixed b-site pyrochlore Dy_2ScNbO_7

18. **I.A. Assi** - Magnetic Excitations in Three Families of Rare Earth Pyrochlores

19. **N. Brahiti** - Large magnetocaloric effect of $La_{2-x}Sr_x$ Mn_{2-y} Fe_y O_6 perovskites close to room temperature

20. **K.P.W. Hall** - Computational Simulations of Exotic Spin Systems

21. **A. Zelenskiy** - Magnetic Ordering in $RbFe(MoO_4)_2$

1. Coherent control of magnon radiative damping with local photon states

Y. S. Gui[1], B. M. Yao[1, 2], J. W. Rao[1], Y. T. Zhao[1],

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Magnon radiation arises when decaying to the ground state by emitting travelling photons to an open system. Recently, strong interaction between cavity photons and magnons has been reported, allowing for the manipulation of magnon radiation via tailoring photon states. Here, based on a one-dimensional circular waveguide cavity, a significant magnon radiative damping has been, with its radiation rate found to be proportional to the local density of states (LDOS) of photons. By modulating LDOS including its magnitude and/or polarization, we can flexibly tune the magnon radiative damping on demand. Our study provides a general way in manipulating photon emission from magnon radiation and opens promising paths for harnessing energy and angular momentum generation, transfer and storage modulated by magnon in the waveguide quantum electrodynamics.

2. An apparatus for mechanical torque measurement of spin-lattice relaxation

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1) Department of Physics, University of Alberta

AC mechanical measurements of magnetic torque implicitly contain information from a new perspective on spin-lattice relaxation: namely, as experienced by the lattice. Most dramatically, mechanical measurements will begin to fail when spin-lattice relaxation rates fall below the AC detection frequency.

A modern interferometric apparatus for variable-temperature mechanical torque detection of spin resonance is under construction, to continue the pioneering angular momentum pumping experiments of Alzetta and co-workers [1]. Observations of magnetic anisotropy and Einstein - de Haas signatures from YIG spheres, as obtained during initial characterizations of the apparatus, will be discussed.

[1] G. Alzetta, E. Arimondo, C. Ascoli and A. Gozzini, *Il Nuovo Cimento* **LII B**, 392 (1967).

3. Level attraction and level repulsion of magnon coupled with a cavity anti-resonance

J. W. Rao[1], C. H. Yu[2], Y. T. Zhao[1], Y. S. Gui[1] and C.-M. Hu[1],
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We report on coherent and dissipative coupling between a magnon mode and an anti-resonance in a microwave cavity. By placing a ferrimagnetic sphere within the cavity, we observe both level repulsion and attraction. A careful examination reveals distinct differences in line shape and phase evolution between them. For a quantitative understanding of the interactions between the magnon mode and cavity anti-resonance, we develop a model which precisely describes all experimental observations. Our work sets the footing for understanding the strong coupling between magnon modes and cavity anti-resonances. In addition, it also confirms the ubiquity of level attraction in coupled magnon-photon systems, which may help to deepen the current understanding of magnon-based light-matter interactions.

4. The Einstein - de Haas effect at radio frequencies

K Mori[1], JE Losby[1,2], MG Dunsmore[1], M Belov[2] and MR Freeman[1]

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The Einstein-de Haas (EdH) effect is the result of conservation of angular momentum in response to a change in magnetic moment. The effect is small (the electron charge-to-mass ratio is very large) and its detection generally requires mechanically-resonant methods.

The original measurements of Einstein – de Haas [1] and others were revisited early in the 21st century by Wallis et al. in a micromechanical context [2]. Continuing the scale-down in size, one approaches the regime where the EdH torque induced by an RF magnetic field can become comparable to the cross-product torques induced by the same magnitude drive applied at right-angles to the torque axis. The EdH torque additionally manifests a signature phase shift. These features commend EdH measurements as a general-purpose nanomechanical tool complementing conventional torque magnetometry.

[1] A. Einstein & W.J. de Haas, *Proc. - KNAW* **18**, 696 (1915).
[2] T.M. Wallis, J. Moreland and P. Kabos, *APL* **89**, 122502 (2006).

5. Control of the magnon-photon level attraction in a planar cavity

Y. Yang[1,2], J. W. Rao[1], Y. S. Gui[1], B. M. Yao[2], W. Lu[2], and C.-M. Hu[1]

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A resistive coupling circuit is used to model the recently discovered dissipative coupling in a hybridized cavity photon-magnon system. With this model as a basis we have designed a planar cavity in which a controllable transition between level attraction and level repulsion can be achieved. This behaviour can be quantitatively understood using an LCR circuit model with a complex coupling strength. Our work therefore develops and verifies a circuit method to model level repulsion and level attraction and confirms the universality of dissipative coupling in the cavity photon-magnon system. The realization of both coherent and dissipative couplings in a planar cavity may provide new avenues for the design and adaptation of dissipatively coupled systems for practical applications in information processing.

6. Time domain analysis for low signal amplitude in multi-etalon systems

Nils Refvik[1], Akif Ahmed [1], Aimé Braconnier [1], Josh Gibbs [1], Sangeev Selvaratnam [1], August Mendelsohn[1], Jacob Burgess[1],

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In time domain THz spectroscopy any dielectric slab used as an optical element often contributes multiple reflections of THz pulses and therefore acts as an etalon. These can arise from standard optics like non-linear crystals used for electro-optic sampling but also may carry meaningful information from samples themselves. Searching for extremely small signals, such as magnon modes in materials with weak coupling to electromagnetic fields, can be challenging among a forest of cavity modes. We expand on a standard method for the removal of etalon oscillations [1] to isolate signals related to our samples.

[1] M. Naftaly and R.E. Miles, *Optics Communications.* **280,** 291-295 (2007)

7. Long-range coherent coupling and dissipative coupling between magnetic moments

Peng-Chao Xu [1,2], J.W. Rao[1], Y.T. Zhao [1], Y.S. Gui [1] ,Xiaofeng Jin [2] , C.-M. Hu [1]

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Recently, a new type of dissipative coupling caused by the cavity Lenz effect was revealed in the cavity magnon polariton system, which gives new possibilities to long-range coupling between magnets. By placing two ferrimagnetic spheres within a cavity, we observe both level repulsion and level attraction between magnon-like modes. A comprehensive model has been developed based on a recent theory of magnon photon coupling, which quantitatively describes experimental observations. In the presence of both coherent and dissipative coupling, our work revisits the cavity mediated coupling with an exotic degree of freedom, which paves the way for controlling and utilizing light-matter interactions.

8. Level attraction in metamaterials

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As a general physical phenomenon, level attraction arising from dissipative coupling widely exists in diverse systems, for instance the recent discoveries in optomechanical system[1], coupled cavity magnon system[2] and cavity trion-polariton system[3]. In this work, we report level attraction can also exist in metamaterials. By coupling two sets of resonant structures, we observed the coalescence of hybridized modes in the frequency domain. Furthermore, electric control of level attraction has also been demonstrated by incorporating an actively tunable component into one resonant structure. Our work has spotted the dissipative coupling effect in metamaterials, which may have been ignored in this research field over time. The experimental observations reported in this work may offer a new insight to characterize and design metamaterials.

[1] N. R. Bernier, Phys. Rev. A 98, 023841 (2018).
[2] M. Harder, Phys. Rev. Lett. 121, 137203 (2018).
[3] S. Dhara, Nature Physics 14, 130–133 (2018).

9. Triangular array of iron-oxide nanoparticles: Simulations study of intra-and inter-particle magnetism

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A study of maghemite nanoparticles on a two dimensional triangular array was carried out using a sLLG approach. Results for simple dipoles show the expected phase transition to a ferromagnetic state at a finite temperature but with a ground state exhibiting a continuous degeneracy that was lifted by an order-from-disorder mechanism at infinitesimal temperatures. The nanoparticle array consisted of 7.5~nm diameter maghemite spheres with bulk-like superexchange interactions between Fe-ions in the core, and weaker exchange between surface Fe-ions and a radial anisotropy. We find that the vacancies on the octahedral sites in the nanoparticles combine with the surface anisotropy to produce an effective random temperature-dependent anisotropy for each particle[1]. This leads to a reduction in the net magnetization of the nanoparticle array at zero temperature compared to the simple dipole array.

[1] B. Alkadour, J. I. Mercer, J. P. Whitehead, J. van Lierop,and B. W. Southern, Phys. Rev. B 93, 140411 (2016).

10. Beyond the blocking model to fit nanoparticle ZFC/FC magnetization curves

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Field cooled (FC) and zero-field-cooled (ZFC) magnetization measurements, as a function of temperature, have long been used to characterize the anisotropy energy, mean size, and size distribution of magnetic nanoparticle samples. Typically, the peak in the ZFC curve is associated with the mode Blocking temperature. This is the temperature at which a particle transitions from being superparamagnetic to ferromagnetic, for a given measurement timescale. Recently, authors have suggested that the mode Blocking temperature actually is *lower* than the ZFC peak. [1]

We consider the probability of a magnetic nanoparticle to flip its magnetization near the blocking temperature, and use this to develop quasi-analytic expressions for the ZFC and FC magnetization, which go beyond the usual critical energy barrier approach to the superparamagnetic transition. The particles in the assembly are assumed to have random alignment of easy axes, and to not interact. In particular, we find that the mode blocking temperature is at a lower temperature than the peak in the ZFC curve, in agreement with experiment and previous rate-equation simulations [1], but in contrast to the assumption many researchers use to analyze experiments. [2]

We show that the quasi-analytic expressions agree with Monte Carlo simulation results but have the advantage of being very quick to use to fit data. We also give an example of successfully fitting experimental data and extracting the anisotropy energy density K to be a value incredibly close to that of bulk.

[1] I. Bruvera *et al.*, *J. Appl. Phys.* **118**, 184304 (2015).
[2] K. Livesey *et al.*, *Sci. Rep.* **8**, 11166 (2018)

11. Controlling the Verwey transition of Fe3O4 with strain

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For three systems of Fe_3O_4 nanorods, we determined that the Verwey temperature changes as a function of nanorod size using TEM, XRD, XMCD, Mössbauer spectroscopy and magnetometry measurements. We attribute the different transition temperatures to the intrinsic strain within each sample, suggesting that the transition may be tuned. The formation of trimerons in the system with the highest transition temperature is evidenced by the increased orbit to spin ratio at low T. These results are among the first evidence of trimerons in the nanoscale.

12. Anisotropic zeta-potentials: shape and magnetic field dependent nanoparticle mobilities

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Nano-surfaces undergo dynamic charge equilibriation when introduced into biological media, forming an interface layer that ultimately mediates the nano-biological interaction. This equilibriated charge distribution, or protein corona, is determined not only by media composition, but by the local charge distribution on the nanoparticle surface that can be further influenced by external stimuli such as magnetic fields. It is particularly challenging to assess protein corona formation since techniques commonly used to characterize nanoparticle surface properties have restrictions on media that preclude measurements in application conditions. The electroacoustic effect has no such media restrictions. I have developed a new electroacoustic technique that allows direct measurements of nanoparticle mobilities in external magnetic fields. Experiments performed on different shapes and sizes of nanoparticles showed orientation and magnetic field strength dependent mobilities, providing new insights into protein corona formation.

13. Magnetic Properties of Core-Shell $CoFe_2O_4$ @ $BiFeO_3$ Nanocomposites

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Amongst the magnetoelectric multiferroic materials, some of 0–3 type particulate composites are exhibiting a promising magnetoelectric effect at room temperature. However, the biggest defect in this structure is the current leakage problem [1]. An important property in magnetoelectric multiferroic nanocomposites is the exchange bias effect. This effect is an interfacial phenomenon and its strength depends on the quality and connectivity of the composite interface [2]. In order to solve the current leakage problem and also to enhance the exchange bias in $CoFe_2O_4$-$BiFeO_3$ nanocomposites, a novel core-shell multiferroic nanostructures of cobalt ferrite–bismuth ferrite was synthesized using a two-step wet chemical procedure, by combining co-precipitation and sol–gel techniques. In the prepared sample, the fraction of cobalt ferrite in the nanostructures is 43 wt %. The X-ray diffraction confirmed the presence of both spinel and perovskite phases. Transmission electron microscopy data show two-phase composite nanostructures consisting of a cobalt ferrite core surrounded by a bismuth ferrite shell-like coating with an average size of 35 nm. The results showed the synthesis method employed was effectively producing nanocomposites in a core-shell configuration that shows the expected ferrimagnetic behavior. The effect of the exchange bias on field-cooled and zero-field cooled hysteresis loops for core-shell nanocomposite shows a significant shift in the magnetization of about 2800 Oe and 750 Oe, respectively. We also fabricated a typical 0-3 type of this nanocomposite with the same fraction of cobalt ferrite using the one step sol gel synthesizing method. X-Ray diffraction substantiated the presence of both spinel and perovskite phases. Finally, a comparison between the magnetic properties of core-shell nanocomposites and the typical form of 0-3 nanocomposites showed a significant enhancement in magnetization, coercivity and an exchange bias effect in $CoFe_2O_4$@$BiFeO_3$ core-shell structure.

[1] B. Gojdka, et al. *Journal of Applied Physics* 112, 044303 (2012).
[2] J. Nogues, et al.. *Journal of Magnetism and Magnetic Materials* 192, 203-232 (1999).

14. Structure, composition and magnetism of transition-metal doped ε-Fe_2O_3

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ε-Fe_2O_3 is a metastable iron oxide polymorph whose structure has only recently been identified, and its properties are little known compared to the other iron oxides (α, and γ-Fe_2O_3, and Fe_3O_4). Of specific interest is the unusually large magnetocrystalline anisotropy which results in application-worthy properties as a hard-magnet replacement with no expensive rare-earth elements. In this work the effects of transition-metal dopants on the magnetism of ε-Fe_2O_3 were studied. ε-Fe_2O_3 doped with 2 and 4 percent atomic weight of Ag, Cu, Ni, and Co were prepared. Doping percentages were verified using EDX analysis and phase purity was determined from XRD pattern refinement. The average crystallite sizes were found to range from 8 to 10 nm (using TEM). The magnetic properties were studied using a SQUID magnetometer. We find that doping affects the magnetocrystalline anisotropy in a way contrary to the other iron-oxides. For example, while the coercivity (a measure of the anisotropy) of pure ε-Fe_2O_3 was 880 Oe at 300 K, the coercivity for 2 and 4 atomic weight percent Cu-doped ε-Fe_2O_3 was 400 Oe and 350 Oe, respectively, at 300 K. From spectroscopy results, we tracked the dopants' site preferences.

15. Synthesis and Magnetic Properties of the New Spin Liquid Candidate, $Ca_3Cu_2GeV_2O_{12}$

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There are a number of known materials which are considered spin liquid candidates. Most of these compounds are frustrated systems, to avoid ordering, paired with an S=1/2 magnetic ion. Due to its spin, the copper (II) ion is often chosen when searching for new spin liquid candidates.

We will present our recent work on the solid state compound, $Ca_3Cu_2GeV_2O_{12}$. This is a material which crystallizes in the garnet structure (s.g. #230, Ia-3d), where 3-dimensional frustration is known to occur. Heat capacity has shown a lack of magnetic ordering down to 0.35 K, confirmed with low temperature neutron diffraction. This system displays a Weiss temperature of -0.9 K indicating frustrated antiferromagnetic order and implies significant J1-J2 competition. Using both neutron and X-ray diffraction, along with heat capacity, and magnetometry, the work presented here will show that our compound, $Ca_3Cu_2GeV_2O_{12}$, shows promise as a new spin liquid candidate.

16. Effect of Ca, Sr and Ba for La substitution on the magnetocaloric effect in La_2MnFeO_6 double perovskites

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We report the effect of the Ca, Sr and Ba substitutions for La in La_2FeMnO_6. The orthorhombic $La_{2-x}A_xFeMnO_6$ samples show a ferromagnetic behavior with a broad transition. The broadening of the magnetic transition leads to significant magnetocaloric effect over a large temperature range on the order of 200K for Sr doping. Such dependence is highly desirable for cooling devices based on the magnetocaloric effect.

17. Anomalous magnetic behaviour of the mixed b-site pyrochlore Dy_2ScNbO_7

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The spin ice state, a magnetic ground state exhibiting Pauling entropy analogous to water ice, has been well characterized in the rare-earth pyrochlores $Dy_2Ti_2O_7$, and $Dy_2Sn_2O_7$. To explore the response of the spin ice state to non-magnetic perturbation in dysprosium based pyrochlores, we present here a new species Dy_2ScNbO_7, which we have synthesized as both powder and single crystal. Our physical characterization has shown unexpected behaviour arising from the disordered b-site, with increased spin dynamics and an anomalously low spin-freezing temperature. We performed heat capacity measurements with an applied magnetic field along the [111] direction, notable in pyrochlores for its alternating Kagomé-Triangular layers, and the [110] direction, a bond direction between magnetic species. The phase diagrams we have constructed from these measurements and other recent physical characterization results show a divergence from spin ice behaviour, which we present to this meeting for discussion.

18. Magnetic Excitations in Three Families of Rare Earth Pyrochlores

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Rare earth pyrochlores have the attention of many researchers due to their geometrical frustration and their applications [1]. The spins of the rare earths are essentially doublets, due to the crystal electric field, which come in three different varieties labelled $\Gamma_{5,6}$, Γ_3 and Γ_4; the general form of the nearest neighbor exchange interaction is slightly different in each case [2]. For each of these three models, we apply linear spin wave theory to calculate magnon dispersions for different rare earth compounds, including, $Er_2Ti_2O_7$, $Er_2Sn_2O_7$ and $Yb_2Ti_2O_7$. In our calculations, we have considered different magnetic ordered states, such as "all-in-all-out", Palmer-Chalker states, and others [3].

[1] Rau, J. G., & Gingras, M. Annual Rev. of Cond. Matt. Phys 10 (2018)
[2] Curnoe, S. H, J. Phys.: Condensed Matter 30, 235803 (2018)
[3] Yan, H et al, Phys. Rev. B 95, 094422 (2017)

19. Large magnetocaloric effect of $La_{2-x}Sr_x$ Mn_{2-y} Fe_y O_6 perovskites close to room temperature

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We present an investigation of structural, magnetic and magnetocaloric properties of La_{2-x} $Sr_xMn_{2-y}Fe_yO_6$ ($0.05 \leq x \leq 1.4$, $y = 0.02$ and 0.3), a derivative of double perovskites, synthesized by a solid state reaction method. Looking to optimize the cooling capacity of these materials, we observe that the ferromagnetic (FM) to paramagnetic (PM) transitions have been observed for all the prepared samples and are highly sensitive to Sr concentration. The Curie temperature Tc increases from 150 K to 380 K by changing the concentration of strontium from x=0.05 to x=1.4. In addition, the magnetocaloric properties near Tc and room temperature can be further controlled by the growth conditions. The maximum of magnetic entropy change ΔS_M and the operating temperature range are found to be largely sensitive to the sintering temperature.

20. Computational Simulations of Exotic Spin Systems

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Current research concerning the general free energy of the semi-classical spin system associated with MnSi using analytic and computational methods will be presented. This material belongs to the B20 group of crystals which have been shown, experimentally, to exhibit exotic spin systems such as helical spin structure[1] and skyrmions[2]. This work aims to find the effective exchange constants if the completely general, symmetry-allowed free energy for MnSi.

[1] P. Dalmas de Réotier, A. Maisuradze, A. Yaouanc, et al. PRB 93, 144419 (2016).
[2] S. Mühlbauer, B. Binz, F. Jonietz, et al. Science 323, 5916 (2009).

21. Magnetic Ordering in $RbFe(MoO_4)_2$

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Geometrically frustrated magnetic materials have been studied extensively due their rich phase diagrams and intricate connections of geometry and magnetic order. Triangular lattice antiferromagnet $RbFe(MoO_4)_2$ is an excellent example of a quasi-2D easy-plane system, with multiple inter-plane exchange interactions which lead to stabilization of incommensurate phases. Using ultrasound velocity measurements, we constructed phase diagrams for $RbFe(MoO_4)_2$ with fields parallel and perpendicular to the basal plane and identified the nature of the phase transitions. The theoretical analysis was done using a 3D Heisenberg Hamiltonian with a biquadratic term which is known to stabilize the 1/3 magnetization plateau.

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