International Workshop

“Dzyaloshinskii-Moriya Interaction and Exotic Spin Structures”

Abstracts and programme

8-12 July 2019
Petrozavodsk, Russia

DMI 2019 WORKSHOP

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International Workshop

"Dzyaloshinskii-Moriya Interaction and Exotic Spin Structures"

TOPICS

- Monoaxial chiral helimagnets.
- DMI effect on the magnetic structure.
- Exotic spin structures (skyrmions).
- Evolution of the magnetic structure in helimagnets under high pressure.
- Spin excitations in helimagnets with DM interaction.
- Neutron scattering for non-collinear magnetism.
- Thin films and surface effects in cubic ferromagnets without center of symmetry

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Programme

Monday. 8 July 2019		
9.00 – 9.30	**Opening ceremony**	
Session 1. Monoaxial chiral helimagnets Chair: **Kazuhisa Kakurai**		
9.30 – 10.15	**Jun-ichiro Kishine** Prof., The Open University of Japan, Japan	Highly nonlinear dynamics of chiral solitons in a mono-axial helimagnet
10.15 – 11.00	**Yoshihiko Togawa,** Dr., Osaka Prefecture University, Japan	Anomalous physical responses on chiral magnetic materials
11.00 -11.30	**Coffee break**	
11.30 – 12.00	**Alexander S. Ovchinnikov** Prof., Ural Federal University Ekaterinburg, Russia	Theory of standing waves in finite-size soliton lattice
12.00 – 12.15	**Alexey Tereschenko,** Mr., Institute of Natural Sciences and Mathematics of Ural Federal University, Ekaterinburg, Russia	Magnitostriction effects in thin flims of monoaxial chiral helimagnets: double sine-Gordon model
12.15– 12.30	**Alexey Bykov,** Dr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Magnetic phase diagram of the uniaxial helimagnet $Cr_{1/3}NbS_2$: evidence from small angle neutron scattering
12.30 – 13.00	**Oleg Utesov** Dr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Spiral plane flops in frustrated helimagnets in external magnetic field
13.00 – 14.00	**Lunch**	
Session 2. DMI effect on the magnetic structure Chair: **Alexander S. Ovchinnikov**		
14:00 – 14:30	**Igor Lyubutin,** Prof., Shubnikov Institute of Crystallography of FSRC “Crystallography and Photonics” RAS	Helical Magnetic Structures in the Langasite Family Crystals Related to the Dzyaloshinskii-Morya Effect
14:30-15:00	**Tetsuya Takeuchi,** Dr. Low Temperature Center, Osaka University	Unique Magnetic Field versus Temperature Phase Diagrams in Cubic Chiral Antiferromagnet

		EuPtSi
15:00-15:30	**Alexander Smirnov,** Prof. P. L. Kapitza Institute for Physical Problems RAS	Spinons modified by uniform Dzyaloshinskii-Moriya interaction
15.30 -16.00	**Coffee break**	
16:00-16:30	**Hisatomo Harima,** Prof., Kobe University, Japan	Fermi surfaces of cubic chiral ullmannite-type compounds
16:30-17:00	**Andrey Rogalev,** Dr., ESRF, France	X-ray spectroscopy of chiral molecular magnets
17:00-17:30	**Roman Morgunov,** Prof. Dr., Institute of Problems of Chemical Physics, Russia	Magnetization reversal in K0.4(Cr(CN)6)(Mn(S)-pn)(S)-pnH0.6 chiral molecular ferrimagnet by FORC
17:30-17:15	**Naoto Tsuchiya,** Mr., Hiroshima University, Japan	Magneto-elastic coupling in Organic-Inorganic Materials having Ferroelasticity and Magnetic Long Range Order
17:15-18:15	**Jun Akimitsu,** Prof., Okayama University, Japan	Trial to carrier-doping in Sr_2IrO_4 with strong spin-orbit coupling
19.00	**Welcome party**	
Tuesday. 9 July 2019		
Session 3. Exotic spin structures (skyrmions). Chairman **Javier Campo**		
9.30 – 10.00	**Isabelle Mirebeau** Prof., LLB, Saclay, France	Spin textures induced by quenched disorder in a reentrant spin glass: vortices versus frustrated skyrmions
10:00-10:30	**Kazuhisa Kakurai,** Prof. Dr., Comprehensive Research Organization for Science and Society (CROSS), Japan	Skyrmion related neutron scattering research activities on TAIKAN in collaboration with RIKEN CEMS
10:30-11:00	**Victor Ukleev** Dr., Paul Scherrer Institute,	Element-specific soft X-ray spectroscopy, scattering and imaging studies of skyrmion-hosting compound $Co_8Zn_8Mn_4$
11.00– 11.30	**Coffee break**	
11:30-12:00.	**Evgeny Altynbaev,** Dr., Petersburg Nuclear Physics Institute, Gatchina,	Appearance of the skyrmion lattice in Fe-doped MnGe compounds

	Russia	
12.00 – 12.30	**Tobias Weber** Dr., Institut Laue-Langevin (ILL), France	Polarisation Analysis of the Nonreciprocal Skyrmion Dynamics in MnSi
12.30 – 12.45	**Andrey Tsypilnikov**, Mr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Calculation of the spectrum of magnons on the skyrmion lattice in the Landau functions basis
12.45 – 13.00	**Ankit Labh** Mr., TUDelft, Delft, Netherlands	Magnetic correlations in the frustrated antiferromagnet $FeCl_3$
13.00 – 14.00	**Lunch**	
Session 4. Evolution of the magnetic structure in helimagnets under high pressure. Chairman **Jun–ichiro Kishine**		
14:00-14:20	**Denis Salamatin,** Dr.,Vereshchagin Institute for High Pressure Physics, RAS, Moscow, Troitsk, Russia	Magnetic ordering above 30 K in noncentrosymmetric $YbCoC_2$
14:20-14:40	**Vladimir Sidorov**, Dr.,Vereshchagin Institute for High Pressure Physics, RAS, Moscow, Troitsk, Russia	Anomalous magnetism and Kondo-lattice state in noncentrosymmetric $YbNiC_2$ and their evolution at high pressure.
14:40-15:05	**Shigeo Ohara,** Prof., Nagoya Institute of Technology, Nagoya, Japan	Single Crystal Growth of Chiral Magnet $YbNi_3Al_9$ using Flux Method in a Temperature Gradient
15:05-15:30	**Kazunori Umeo,** Dr., N-BARD, Hiroshima University, Japan	Pressure-induced magnetic ordered phase in the chiral compound $YbNi_3Ga_9$ studied by Hall effect and magneto-resistance under pressures up to 12 GPa
15:30-16:00	Coffee break	
16:00-16:20	**Yusuke Kousaka,** Dr., Okayama University, Japan	Neutron Scattering Experiments of $CsCuCl_3$ under High Magnetic Field and High Pressure
16:20-16:40	**Hiroyasu Matsuura,** Dr., The University of Tokyo, Japan	Theory of Magnetic Phase Diagram in Chiral Magnet $CsCuCl_3$ under High Pressures

17.00	**Excursion through the down-town Petrozavodsk**	
Wednesday. 10 July 2019		
Session 5. Spin excitations in helimagnets with DM interaction Chairman: **Sergey Grigoriev**		
9:30-10:00	**Javier Campo** Prof., Instituto de Ciencia de Materiales de Aragón – Universidad de Zaragoza, Zaragoza, Spain	The role of the thermal fluctuations in cubic helimagnets: stabilization of new phases at low temperature
10:00-10:25	**Alla Petrova** Dr., Institute for High Pressure Physics of RAS, Moscow, Russia	The physical properties of $(Mn_{0.85}Fe_{0.15})Si$ along the critical trajectory
	5 minutes break	
10:30-11:00	**Nicolas Martin** Dr., LLB, Saclay, France	Liquid crystalline structures and elasticity in a cubic chiral helimagnet
11:00-11:15	**Ekaterina Iashina** Mrs., Petersburg Nuclear Physics Institute, Gatchina, Russia	Three-dimensional neutron polarization analysis of the small-angle scattering from helimagnetic fluctuations
11:15-11:45	**Homma Yoshiya,** Dr., IMR, Tohoku University, Japan	Magnetic Fluctuation and First-Order Transition in Trillium Lattice of EuPtSi Observed by 151Eu Mossbauer Spectroscopy
11.45 – 12.15	**Coffee break**	
12.30-20.00	**Excursion to the Museum – Island "Kizhi"**	
Thursday. 11 July 2019		
Session 6. Neutron scattering for non-collinear magnetism Chairperson: **Isabelle Mirebeau**		
9:30-10:00	**Arsene Goukassov,** Dr., LLB CEA-CNRS, Saclay, France	Polarized Neutrons studies of weak magnetization densities
10:00-10:30	**Vladimir Hutanu,** Dr., RWTH Aachen University, Institute of	Determining the sign of DMI in $MnCO_3$ by polarised neutron diffraction.

	Crystallography, Germany	
10:30-11:00	**Yusuke Araki,** Mr., The University of Tokyo, Japan	High-field optical study of metamagnetic transitions in a chiral polar magnet Ni_2InSbO_6
11:00-11:15	**Kirill Pschenichnyi** Mr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Spin-wave stiffness of Dzyaloshinskii-Moriya helimagnets $Fe_{1-x}Co_xSi$ studied by small-angle neutron scattering
11.15– 11.30	**Coffee break**	
11:30-12:00	**Catherine Pappas** Prof., TUDelft, Delft, Netherlands	Tilted conical phase and multiple skyrmionic phases in Cu_2OSeO_3
12:00-12:15	**Mikhail Chuev,** Mr., Valiev Institute of Physics and Technology of RAS, Russia	The Morin Transition and Dzyaloshinskii-Morya Effect in Hematite Nanoparticles
12:15-12:30	**Miguel Pardo,** Mr., Instituto de Ciencia de Materiales de Aragón (ICMA), Spain	Non collinear magnetic phases in spinel $MnCr_2O_4$
12:30-13:00	**Igor Zobkalo,** Dr., Petersburg Nuclear Physics Institute, Gatchina, Russia	On the 4f-3d coupling in orthomanganites $Dy_{1-x}Ho_xMnO_3$
13.00 – 14.00	**Lunch**	
Session 7. Thin films and surface effects in cubic ferromagnets without center of symmetry Chairman: **Yoshihiko Togawa**		
14:00-14:30	**Sergey Maleyev,** Prof. Dr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Surface magnetic layer and magnetic field
14:30-15:00	**Alexey Ognev,** Dr., Far Eastern Federal University, Russia	Effect of focused ion beam irradiation on the interface DMI and magnetic anisotropy thin films
15:00-15:20	**Oksana Koplak,** Dr., IPCP RAS, Russia	Magnetic refrigeration by tuning of exchange spring, helix, fan in Ho/W films

15:20-15:40	**Dmitriy Tatarskiy** Dr., Institute for physics of microstructures RAS, Russia	Nanofabrication of Bloch and Néel skyrmions in Co/Pt multilayers
15:40-16:00	**Ksenia Chichay** Immanuel Kant Baltic Federal University, 236004, Kaliningrad, Russia	Effect of interplay of Dzyaloshinskii-Moria and dipolar interactions on internal skyrmion structure in magnetic mulilayers.
16.00 – 17.00	**Poster session and Coffee break**	
17:00-17:30	**K. Sharma** Dr., Laboratory of Information Technology, JINR, Dubna, Russia.	«Dzyaloshinskii-Moriya interaction as an agent to free the bound entangled states »
17:30-18:00	**P. Kizhe** Dr., Grad-Kitezh University, Grad-Kitezh, Russia	«Signs of life in terms of the fractal concept»
19:00-22-00	**Gala dinner**	
Friday 12 July 2019		
9:30-12:00	**Departure from Petrozavodsk**	

Poster session (16:00 -18:00 Thursday 11 July 2019)	
Anatoly Tsvyashchenko, Dr., HPPI RAS, Russia	Quadrupole and magnetic hyperfine interaction arising on nuclei of 181Ta and 111Cd in noncentrosymmetric RhGe
Daria Skanchenko, Ms., Petersburg Nuclear Physics Institute, Gatchina, Russia	Investigation of the magnetic structure of $Rh_{1-x}Fe_xGe$ by small-angle neutron diffraction.
Denis Salamatin, Dr.,Vereshchagin Institute for High Pressure Physics, RAS, Moscow, Troitsk, Russia	Magnetic properties and Phase Separation in the noncentrosymmetric narrow band semiconductors Ru1-xCoxGe (B20), synthesized under high pressure
Alexander Ovsyanikov, Mr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Spin waves in the high-temperature phase in a rare-earth orthoferrite $HoFeO_3$
Okumura Shun, Mr., The University of Tokyo, Japan	Numerical study of magnetic hedgehog lattices in itinerant electron systems
Viktor Timofeev, Mr., Petersburg Nuclear Physics Institute, Gatchina, Russia	Comparative study of skyrmion crystal and triple helix states in non-centrosymmetric magnets
Anna Matveeva, Ms., Petersburg Nuclear Physics Institute, Gatchina, Russia	Evolution of magnetic structure in NdMn2O5 and Nd0.8Tb0.2Mn2O5

Session 1. Monoaxial chiral helimagnets

Chairman: Kazuhisa Kakurai

Highly Nonlinear Dynamics of Chiral Solitons in a Mono-axial Helimagnet

Jun-ichiro Kishine[1,2] and Alexander S. Ovchinnikov[3,4]

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[2]*Institute for Molecular Science, Okazaki, 444-8585, Japan;*
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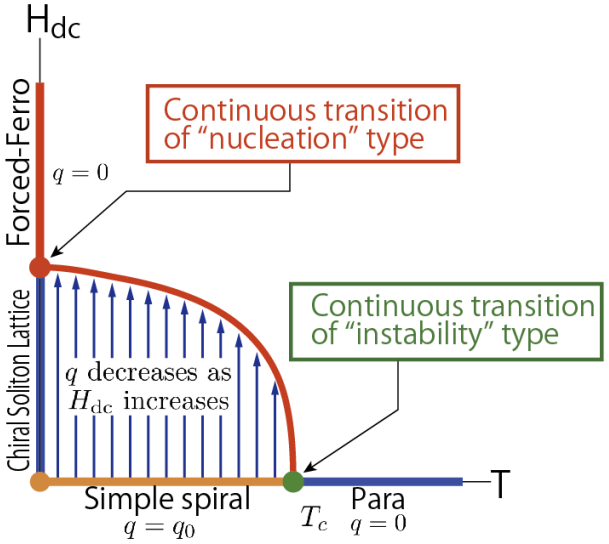
Since theoretical prediction [1] and experimental verification [2] met together in 2012, so called chiral a soliton lattice (CSL) in a mono-axial chiral helimagnet such as $CrNb_3S_6$ has attracted much attention. Honestly, physics contained in this incommensurate non-linear magnetic order is much richer than we expected [3]. This richness comes from its coherent nature with nonlinear and asymmetric structure.

It is also a surprise that a global phase diagram of $CrNb_3S_6$ has become clearer only recently [4,5,6]. A conceptual diagram is shown in the figure. In Ref.[6], Laliena and Campo first paid attention to a classification of the continuous transitions in chiral helimagnet. According to De Gennes [7], there are two types of transitions, i.e., "nucleation transitions" and "instability transitions." In the former case, the period of the incommensurate modulated state diverges at the transition point being approached from the modulated phase. In the latter case, the phase transition takes place in such a manner that the intensity of the Fourier component with nonzero wave vector tends to zero. The instability transition is usual Landau-type continuous transition.



The mechanisms for these two kinds of transitions are qualitatively different. In the monoaxial helimagnet, the transition between the CSL and the forced-ferromagnetic (FFM) states where a perpendicular magnetic field increases at sufficiently low temperature is of nucleation type. On the other hand, a mean-field theory predicts an instability type continuous transition at the ordering temperature. The transition to the FFM in presence of a parallel magnetic field is also of second-order instability type phase transition. It is quite a challenging topic to fully understand global nature of the phase diagram of mono-axial chiral helimagnet on the H-T plane. For example, nucleation of a soliton share physical origins with superconductive vortex [8]. This fact suggests this problem may play universal roles in condensed matter physics.

Apart from thermodynamic properties, its dynamical responses to external probes disclose the nature of collective excitations in condensed matters. In this respect, we expect the nucleation of solitons may cause peculiar nonlinear response, which has not been found in conventional Landau-type phase transition. Nonlinear responses of materials to an external field manifest hidden richness of their internal degrees of freedom. In condensed matter physics, generally, there may be two sources of nonlinear responses. One is large amplitude fluctuations around the long-range-ordered state such as soliton or domain wall motion. Another is higher-order many-body correlation such as three body or four body correlations of microscopic quantities.

Actually, there have been some important reports on nonlinear responses of $CrNb_3S_6$[]. In this presentation, we will make a report on the above-mentioned topics, including,

1. Global phase diagram of a mono-axial chiral helimagnet

2. Universality of nucleation processes
3. Highly nonlinear regime and soliton dynamics
4. Domain formation and slow dynamics in broader viewpoints.

We put stress on a single soliton dynamics by taking account of its internal deformation. As a result, we will show that the highly nonlinear response naturally appears. We will show theoretical frame work of how to solve an equation of motion for a single soliton and make comparison with recent experimental findings.

Acknowledgement: This work was supported by a Grant-in-Aid for Scientific Research (B) (No. 17H02923) from the MEXT of the Japanese Government and the JSPS Core-to-Core Program, A. Advanced Research Networks. A.S.O. acknowledges funding by the RFBR, Grant No. 17-52-50013, by the Foundation for the Advancement of Theoretical Physics and Mathematics BASIS Grant No. 17-11-107, and by Act 211 Government of the Russian Federation, contract No. 02.A03.21.0006. A.S.O. thanks the Ministry of Education and Science of the Russian Federation, Project No. 3.2916.2017/4.6.

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Anomalous Physical Responses on Chiral Magnetic Materials

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Chiral crystalline and magnetic structures provide a variety of striking physical responses. These phenomena are triggered by the coupling with electromagnetic fields or conduction electrons and the influence of thermal fluctuations. In this presentation, we discuss melting phenomena of chiral magnetic order in thin-film lamellae of a chiral monoaxial $CrNb_3S_6$ crystal [1] together with nontrivial transport phenomena on it [2]. The experimental data were obtained by means of electrical transport and magnetic resonance measurements as well as magnetic imaging using electron beams.

$CrNb_3S_6$ crystals show magnetic phase transitions among several kinds of chiral magnetic order [3]. A chiral helimagnetic order exhibits a cascade of transitions of its periodicity as a function of temperature, which is worth discussing in terms of melting in two dimensions [1]. The chiral soliton lattice appears under a magnetic field perpendicular to the helical principal axis. It is very robust and stable with phase coherence on macroscopic lengthscale [4]. The tunable and topological nature of the chiral soliton lattice give rise to discretized responses of the interlayer magnetoresistance [5,6] and magnetic resonance frequency [7]. These responses are strongly influenced by the existence of a surface barrier against the chiral soliton penetration [8] accompanying a surface twist structure at the boundary [6].

Chiral magnetic materials exhibit nonreciprocal transport properties of the conduction electrons, frequently called the electrical magnetochiral (EMC) effect. Interestingly, in addition to the conventional EMC signals due to structural chirality being dominant in a paramagnetic state above the magnetic phase transition temperature, an anomalous enhancement of the EMC response occurs upon the formation of the chiral magnetic phase [2]. The magnetic coefficient of the EMC turns out to be about 3 orders of magnitude larger than the crystalline counterpart.

These observations will provide a new insight on the interplay between structural and magnetic chirality on nontrivial transport phenomena and lead to further understanding of a wide variety of chirality-related phenomena in chiral materials.

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Theory of standing spin waves in finite-size chiral spin soliton lattice

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We present a theory of standing spin wave (SSW) in a monoaxial chiral helimagnet. Motivated by experimental findings on the magnetic field-dependence of the resonance frequency in thin films of $CrNb_3S_6$ [1], we examine the SSW over a chiral soliton lattice (CSL) excited by an ac magnetic field applied parallel and perpendicular to the chiral axis. For this purpose, we generalize Kittel-Pincus theories [2,3] of the SSW in ferromagnetic thin films to the case of non-collinear helimagnet with the surface end spins which are softly pinned by an anisotropy field. Consequently, we found there appear two types of modes. One is a Pincus mode which is composed of a long-period Bloch wave and a short-period ripple originated from the periodic structure of the CSL (Fig. 1). Another is a short-period Kittel ripple excited by space-periodic perturbation which exists only in the case where the ac field is applied perpendicular the chiral axis.

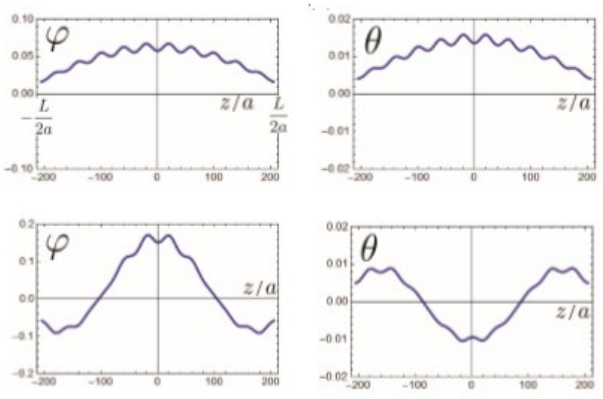

Fig. 1: The spatial profiles of φ and θ associated with the standing waves when the ac-field is applied parallel to the chiral axis.

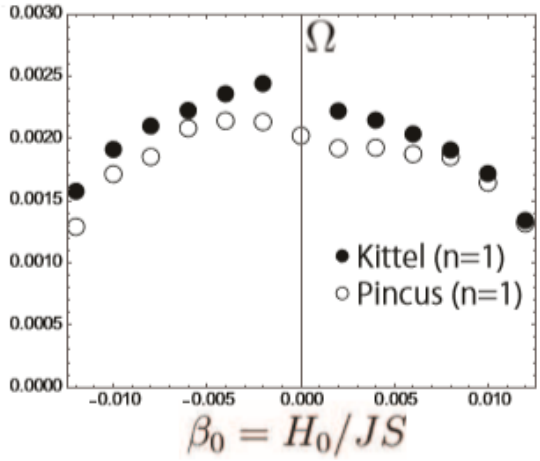

Fig. 2: H-dependencies of the lowest antisymmetric (○) and the n=1 ripple (●) mode.

We demonstrate that the existence of the Pincus mode and the Kittel ripple is consistent with experimentally found double resonance profile (Fig.2).

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Effects of magnetostriction in a uniaxial chiral helimagnet: a double sine-Gordon model

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Uniaxial chiral helimagnets are of interest for potential applications in spintronics due to ability to control magnetic chirality by external forces. For example, collective action of an external magnetic field and mechanical stress can lead to essential rearrangement of a magnetic background. There remains a need for deep understanding of the process.

We consider a problem of a soliton lattice deformation caused by a stretch applied perpendicular to the helicoidal axis in a framework of the phenomenological approach. The model free energy includes the Heisenberg exchange interaction, the Dzyaloshinskii-Moriya antisymmetric exchange and the Zeeman coupling with the external magnetic field *H* along with the magnetoelastic interactions admitted by the hexagonal crystal symmetry

$$\mathrm{F} = \int \mathrm{dV}\left[\frac{\mathrm{J}}{2}\left(\frac{\partial \mathbf{M}}{\partial \mathrm{z}}\right)^2 + \mathrm{D}\hat{\mathrm{z}}\cdot\left[\mathbf{M}\times\frac{\partial \mathbf{M}}{\partial \mathrm{z}}\right] + \mathrm{HM_x} + (\mathrm{b_{11}} - \mathrm{b_{12}})\left(\mathrm{u_{xx}M_x^2} + \mathrm{u_{yy}M_y^2}\right)\right].$$

Here, **M** is the magnetization vector, and u_{ij} is the strain tensor and b_{ij} are the magnetoelastic constants. Minimization of the free energy leads to the double sine-Gordon model, which has been previously used to analyze second-order anisotropy effects in the uniaxial helimagnets [1, 2]. A solution shows an existence of two spatially inhomogeneous phases: the phase where there is spin polarization along the applied magnetic field, "modified sine-Gordon" phase (MSG), and the phase with the "packed" structure (PS), where spins are aligned under a finite angle with respect to the field. A presence of the two phases is explained by an appearance of the effective magnetoelastic anisotropy caused either by the stretch deformations parallel or perpendicularly to the magnetic field, when both forces are perpendicularly applied to the chiral axis. We build the phase diagram of the found phases in the "stress-field" axes. In addition, the Lorentz diffractograms are calculated to identify the found phases in experiments (Fig. 1). The results obtained may serve as foundation for spin valve devices on the base of thin films of $CrNb_3S_6$.

This work was supported by the RFBR grant 18-32-00769 mol_a and the Foundation for Assistance to the Development of Theoretical Physics and Mathematics BASIS 17-11-107.

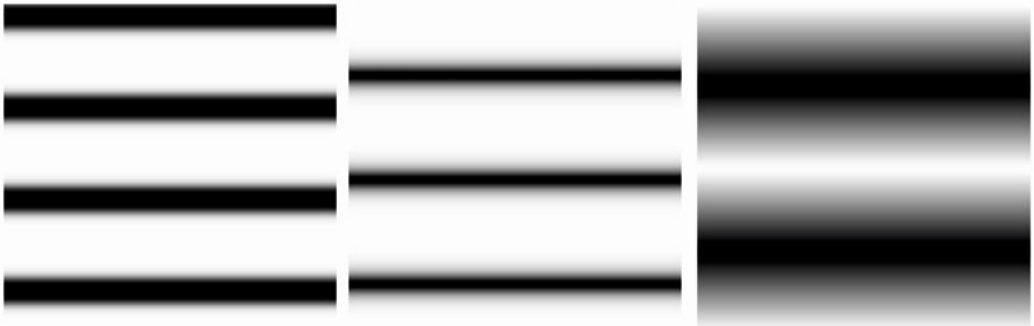

Fig. 1. Lorentz diffractograms for the MSG phase (left), the usual soliton lattice (center) and the PS phase (right).

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Magnetic phase diagram of the uniaxial helimagnet $Cr_{1/3}NbS_2$: evidence from small angle neutron scattering

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The magnetic structure of the $Cr_{1/3}NbS_2$ compound was studied by small angle neutron scattering (SANS) under applied magnetic field in the wide temperature range below T_N = 130 K. The magnetic spiral of Cr^{3+} ions is built along the c-axis of the structure belonging to the $P6_322$ space group at zero field [1-3]. As the sample under study is in the powder form, the diffraction ring is detected that is interpreted as scattering on the magnetic spiral with the period of 485 Å at low temperatures (fig. 1).

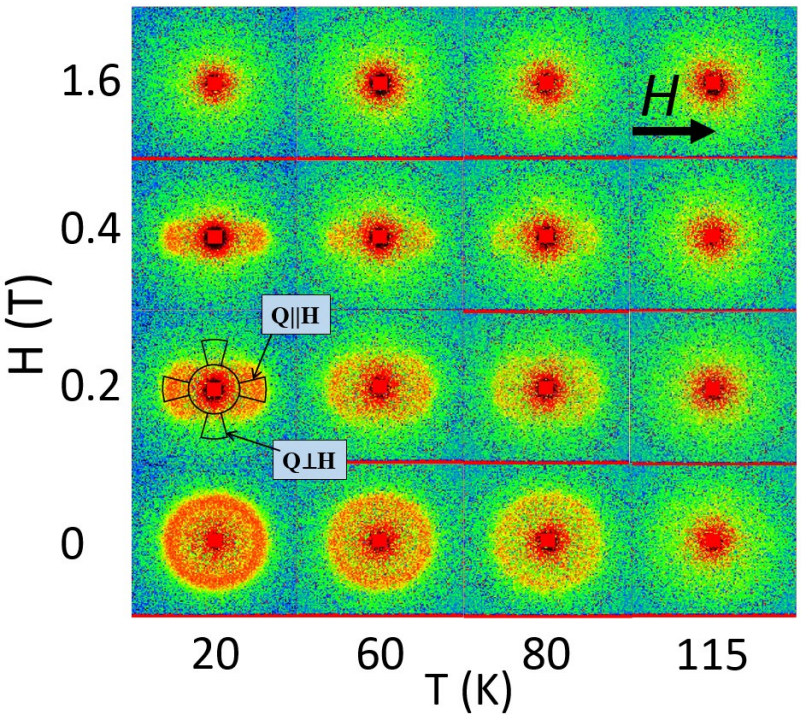

Fig. 1. A set of the SANS maps of the *H*-scan for the different magnetic fields and temperatures.

The intensity of the diffraction peak decreases with *T* and vanishes completely at *T* = 115 K. Being applied perpendicular to the neutron beam, the magnetic field affects differently the samples grains with helix wave vector **k** along the field and those with **k** perpendicular to the field. The magnetic field, when applied, leads to emergency of the chiral soliton lattice (CSL) for the grains with **k** perpendicular to the field. The period of the CSL increases rapidly as H approaches H_{C1} = 0.25 T. The transition from CSL to the field-induced ferromagnet, however, is not homogeneously smooth but is accompanied by the strong ferromagnetic fluctuations in the wide

field range around H_{C1}. These fluctuations are well visible in SANS experiment as scattering at Q = 0. For the grains with **k** parallel to the field systems undergoes a series of the transitions from helimagnet to the conical state, and then to the field-induced ferromagnet at H_{C2} = 1.25 T. The period of the cone increases slightly (for 5 %) with increase of the field, while the transition to the field – induced ferromagnetic state is again accompanied by strong ferromagnetic fluctuations. Magnetic field - Temperature (*H-T)* phase diagram was drown on the basis of the obtained SANS data (fig. 2).

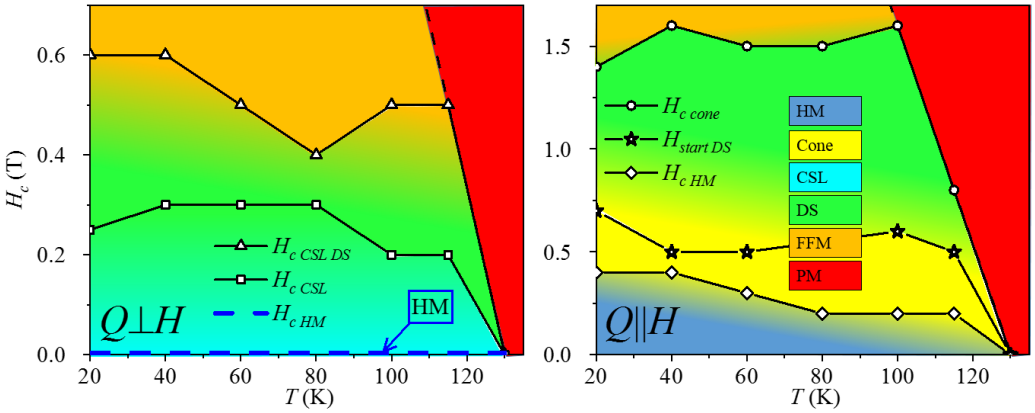

Fig. 2. HT phase diagrams of magnetic spiral in $Cr_{1/3}NbS_2$.

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Spiral plane flops in frustrated helimagnets in external magnetic field

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Multiferroics with coexisting magnetic and ferroelectric orders have attracted a lot of attention recently. The possibility to realize cross control between magnetism and electricity in such compounds would lead to many desirable applications. For instance, strong enough magnetoelectric coupling would allow us to manage magnetic memory by electric field. In so-called multiferroics of spin origin ferroelectricity is induced by some types of magnetic ordering and magnetoelectric coupling in such compounds is discovered to be strong. There are three main mechanisms of ferroelectricity of spin origin: exchange-striction mechanism, inverse Dzyaloshinskii-Moriya (DM) mechanism, and spindependent p-d hybridization mechanism [1]. Noncollinear spin ordering induced, e.g., by frustration is indispensable for the second and the third mechanisms.

We discuss theoretically frustrated Heisenberg spiral magnets in magnetic field **H**. We demonstrate that small anisotropic spin interactions (single-ion biaxial anisotropy or dipolar forces) select the plane in which spins rotate (spiral plane) and can lead to the spiral plane flop upon in-plane field increasing. Expressions for the critical fields H_{flop} are derived [2]. It is shown that measuring of H_{flop} is an efficient and simple method of quantifying the anisotropy in the system (as the measurement of spin-flop fields in collinear magnets with axial anisotropy [3]). Corresponding recent experiments are considered in spiral magnets some of which are multiferroics of spin origin.

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Session 2. DMI effect on the magnetic structure

Chairman: Alexander S. Ovchinnikov

Helical Magnetic Structures in the Langasite Family Crystals Related to the Dzyaloshinskii-Morya Effect

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The langasite structure with a general formula $A_3BC_3D_2O_{14}$ belongs to the trigonal non-centrosymmetrical space group *P321*, Z = 1. The A and B cations occupy the dodecahedral and octahedral oxygen sites, respectively, and C and D cations are located in the tetrahedral sites. Based on the langasite ($La_3Ga_5SiO_{14}$) structure a series of crystals containing paramagnetic iron ions $A_3MFe_3X_2O_{14}$ (A = Ba, Sr; M = Sb, Nb, Ta; X = Si, Ge) was synthesized. The low-temperature magnetic properties of these compounds were studied by Mössbauer spectroscopy, and a long-range 3D magnetic order with a Neel point in the range 27-37 K was found [1,2]. It was shown that magnetic ordering induces a structural transition, which creates conditions for the ferroelectric state. Thus, the iron-containing langasites are a new class of multiferroics in which ferroelectricity can be induced by magnetic ordering [3,4].

Below the Neel temperature T_N, the moments of Fe^{3+} cations in C-sites (3*f*) form a triangular magnetic lattice in the *xy* (*ab*) plane (Fig. 1a). The magnetic moments of Fe^{3+} in each triangle are oriented at an angle of 120° relative to each other (Fig. 1b) [5-7] Moreover, this antiferromagnetic spructure in langasites $Ba_3NbFe_3Si_2O_{14}$ and $Ba_3TaFe_3Si_2O_{14}$ gained a helicoidal twist of the iron moments in triangles at their translation along the *z (c)* axis and, possibly, along a certain axis in the *xy* plane (Fig. 2) [3,5,8].

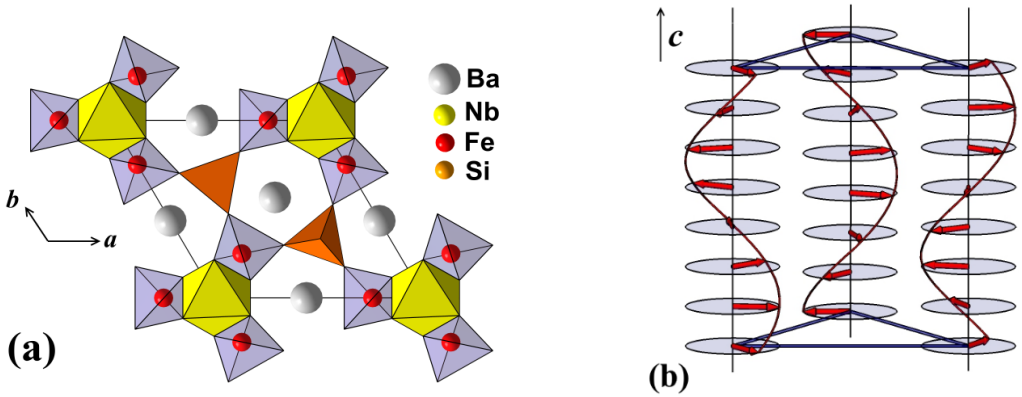


Fig. 1. (a) Projection of the crystal structure of $Ba_3NbFe_3Si_2O_{14}$ on the *(ab)* plane. The Fe^{3+} ions are located in the oxygen tetrahedra 3*f* and form a triangular magnetic lattice in the (*ab*) plane. (b) Helical spin ordering of the Fe magnetic moments during synchronous rotation of three spins of Fe by an angle of about 51° in neighboring layers when translating along the *c* axis. Seven steps along of rotation result in the period of the magnetic spiral.

Based on experimental data, a phenomenological theory explaining the properties of such systems has been proposed [3,4]. Symmetry aspects were analyzed and phase transitions in frustrated magnets, leading to magnetoelectric effects, were described. It was shown that the iron-containing langasites with a triangular magnetic lattice may have piezoelectric properties above the Neel temperature T_N, but they are not ferroelectrics. Occurrence of either ferroelectric or both ferroelectric and piezoelectric states is possible below T_N, and these crystals can be considered as multiferroics with a helicoid of magnetic moments oriented along the *c* axis. In particular, for the helicoidal structure of langasite, the effects of magnetic chirality associated with the sign of the spin-orbit interaction (the Dzyaloshinskii effect) were considered. Depending on the filling of the 3*d* shells, there can be a change in the sign of the spin-orbit interaction constant, which leads to a

change in the sign of the propagation vector q_z along the threefold axis *c*. This corresponds to the opposite sign in rotations of the triangular magnetic lattice of Fe ions (change of the sign of chirality) in the *xy* plane (Fig. 1b). This effect was observed experimentally in $Ba_3NbFe_3Si_2O_{14}$ and $Ba_3TaFe_3Si_2O_{14}$ langasites [8]. The observation of electric polarization at $T < T_N$ is possible at large values of piezo-coefficients and at mechanical deformations. Because of magneto-elastic interactions (appearing due to lowering symmetry $P321 \rightarrow P3$ below T_N), the electric polarization and the axis of the magnetic helicoid can both be parallel to the *z* axis even in the absence of the Dzyaloshinskii-Moriya (DM) effect. The magnetic helicoid with its axis in the *ab* plane may appear due to the spin-orbit interaction (DM effect). In this case, electric polarization must appear also in the *ab* plane (Fig. 3).

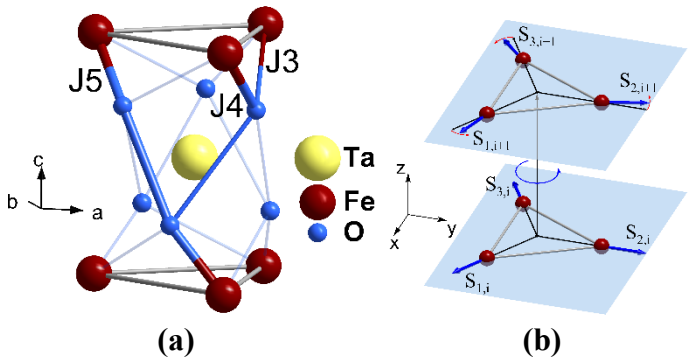
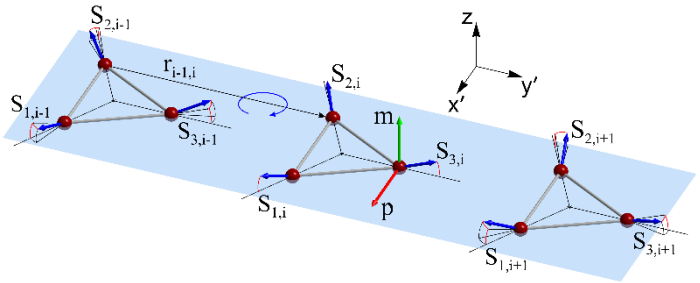


Fig. 2. **(a)** Triangular clusters of Fe^{3+} and the interlayer super-exchange Fe-O-O-Fe interactions *J*3, *J*4 and *J*5 between Fe^{3+} ions situated in nearest layers are shown. **(b)** Triangular magnetic lattice of Fe ions with the 120°- spin packing in the plane perpendicular to the *c (z)* axis. Iron spins ***S*** in the sublattices 1, 2, and 3 rotate upon translation from the layer *i* to the layer (*i*+1) forming a helicoid along the *c (z)* axis.



Rotation of spins ***S*** upon translation from the cluster *i* to the cluster (*i*+1) in the *xy* plane leads to a spiral twist of spins along the ***r*** vectors lying in the *xy* plane. The moment value ***m*** in each triangle cluster remains constant at the spiral twist of spins ***S*** in the *xy* plane along the ***r*** vectors. The electric polarization ***p*** (red arrow) perpendicular to both the ***r*** and ***m*** vectors appears in the *xy* plane of such a structure.

Fig. 3. An appearance of the multiferroic state in the triangular magnetic lattice of langasite is shown. Spins ***S*** of the sublattices 1, 2, and 3 forming triangular 120°-clusters deviate from the *xy* plane at an identical angle due to the **DM** effect. A week ferromagnetic moment ***m*** (green arrow) appears along the *c*(*z*) axis.

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Unique Magnetic Field versus Temperature Phase Diagrams in Cubic Chiral Antiferromagnet EuPtSi

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EuPtSi is most likely the first rare-earth based intermetallic compound in which the skyrmion lattice is recognized. This compound has the cubic LaIrSi-type crystal structure with the space group $P2_13$ as in B20 compounds.[1] The divalent Eu ions form a trillium lattice, which is a three-dimensional network of corner-sharing triangles similar to the network of Mn atoms in MnSi. Franco *et al.* measured the magnetic susceptibility and specific heat on polycrystalline samples and found that EuPtSi shows an antiferromagnetic ordering below T_N =4.1 K.[2]

Recently, Kakihana *et al.* succeeded in growing single crystals of EuPtSi and found that the characteristic field-induced phase, which is reminiscent of the A-phase in MnSi, appears in the magnetic fields along the [111] direction, as shown in Fig. 1(b).[3] For example, the observed distinct additional Hall resistivity and pronounced magnetoresistance in the field-induced phase (A-phase) strongly suggest the formation of the skyrmion lattice. In fact, the very recent neutron scattering experiment revealed that the ground state is herimagnetic phase.[4] In addition, when entering the A-phase, magnetic peaks form characteristic hexagonal patterns in the equatorial scattering plane around nuclear peaks. The A-phase for H // [111] was observed in the restricted temperature and magnetic field region, indicating that this phase is closed in the H - T plane. The A-phase was also observed for H // [001], as shown in Fig. 1(a). In addition, a new phase was found just above the A-phase in the H - T plane. The A-phase in EuPtSi was observed for H // [001] and [111] but not for H // [110] and [112].

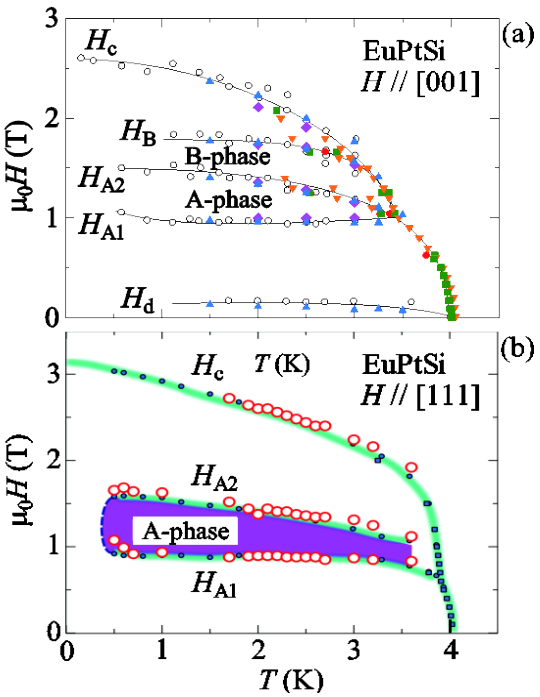

Figure 1 : Magnetic field versus temperature phase diagrams of EuPtSi for (a) H // [001] and (b) [111].

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Spinons modified by uniform Dzyaloshinskii-Moriya interaction

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One-dimensional S=1/2 Heisenberg antiferromagnets demonstrate a variety of collective quantum effects, such as a spin-liquid behavior at zero temperature and fractionalized spin S=1/2 excitations (spinons), which result in a two-particle continuum of S=1 excitations (see, e.g., [1]). In a magnetic field the continua of transverse and longitudinal fluctuations are split and the longitudinal continuum develops a fine structure near a Brillouin zone boundary (**q**=π/a). This fine structure was observed by neutron scattering [2]. Typically, the continuum structure is undetectable at zero wave vector (**q**=0), where the continuum width is zero. In a magnetic field the frequency at **q**=0 just takes a Larmor value.

We address now to a fine structure of the two-spinon continuum, appearing at **q**=0 in S=1/2 chains with the so-called *uniform* Dzyaloshinskii--Moriya interaction (DMI). In contrast to a conventional *staggered* (or alternating) DMI, causing a tilting of magnetic sublattices in a classical antiferromagnet, the *uniform* DMI interaction would stabilize a spiral spin structure. The *uniform* DMI is not wide spread among antiferromagnetic crystals, only several rare examples are known. In case of a quantum spin chain, which has a disordered ground state, the *uniform* DMI was predicted to change essentially the excitation spectrum [3]. In particular, spinons with the same momentum, but moving in opposite directions, were predicted to have different energies. This effect results in a shift of the two-spinon continuum in **q**-space by a wavevector $q_{DM}=D/(Ja)$ (here D is the DMI energy, J - exchange integral and a - interspin distance, $D << J$) [3]. As a result, in a magnetic field **H** || **D**, the ESR line should split into a doublet with the frequencies at the upper and lower boundaries of the unshifted transversal continuum at the wavevector q_{DM}.

We describe electron spin resonance (ESR) experiments on S=1/2 quasi-1D antiferromagnets $K_2CuSO_4Br_2$[4], $K_2CuSO_4Cl_2$ [5], and quasi-2D magnet Cs_2CuCl_4 [6], which all allow *uniform* DMI. We observe the predicted spinon doublet and a specific soft mode, induced by uniform DMI, using ESR in a frequency range of 0.5-300 GHz. This range is rising from sub-D to over-J domains. Cooling down to temperature below J/k_B is necessary, therefore we use a cryostat providing 0.1 K. Besides, we detect a collapse of the spinon doublet in a high magnetic field, suppressing quantum fluctuations and, hence, the continuum. In the ordered phase, well below J/k_B, the coexistence of spinon modes and low-frequency antiferromagnetic magnon modes is observed [7].

Thus, we have observed a fine structure of the spectrum of fractionalised excitations at **q**=0, this fine structure is induced by the uniform Dzyaloshinskii-Moriya interaction in a quantum antiferromagnet.

Support of ESR work by RSF project 17-12-01505 is acknowledged.

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Fermi Surfaces of the Ullmannite-type Cubic Chiral Compounds

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Fermi surfaces of non-centrosymmetric compounds have been widely investigated, then the splitting strengths and spin textures of the Fermi surfaces have been discussed [1-12]. Among them, the characteristic property originating in the spin textures has been discussed as the orbital crossing on split Fermi surfaces in Yb_4Sb_3[12]. However, the relation between the spin textures and the magnetic properties has not yet discussed well so far, as most of the compounds are paramagnetic.

Recently, the unique magnetic properties of cubic chiral compound EuPtSi have been reported, suggesting the presence of a magnetic skyrmion lattice in *f*-electron system [13-15]. EuPtSi crystalizes in the ullmannite-type structure, which space group #198 ($P2_13$, T^4) is cubic chiral as the same as for MnSi, where a magnetic skyrmion lattice has been reported in the first time [16]. Dzyaloshinskii-Moriya interaction (DMI) should plays crucial role in those compounds, but the origin of the DMI is different. The localized $4f^7$ electrons of Eu^{2+} ion in EuPtSi interact though RKKY interaction, where the DMI should be involved. Thus, the spin-textures of the Fermi surfaces determine the DMI.

The Fermi surfaces of the ullmannite-type compounds have been investigated well for NiSbS and PdBiSe [7-9, 11]. The Fermi surfaces of EuPtSi in a high magnetic field limit are now in investigating.

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X-ray Spectroscopy of Chiral Molecular Magnets

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Systems, in which fundamental symmetries of nature are broken, play a fascinating role not only in physics but also in chemistry and in life sciences. A symmetry breaking manifests itself in various optical phenomena and therefore interaction of light with matter is the most powerful tool to deepen our understanding of complex matter. Two most vivid examples are magneto-optical and natural optical activity. The former is associated with the breaking of time-reversal symmetry by a magnetic field. It arises as a consequence of frequency dispersion: the magnetic field cause a relative shift of the levels involved into optical transitions induced by right- and left-polarized light. The observation of magneto-optical activity does not require the sample to satisfy any specific symmetry condition because the effect involves pure electric dipole (E1.E1) or quadrupole (E2.E2) transitions. Natural optical activity is manifestation of spatial dispersion, i.e. the fact that the transition probabilities also depend on the light wavevector k. Natural optical activity refers to the first order terms (linear in k) and require the transition probabilities to mix multipoles of opposite parity, e.g., electric dipole and magnetic dipole (E1.M1) or electric dipole and electric quadrupole (E1.E2). The Curie symmetry principle states that this is only possible in systems with broken inversion symmetry, like in chiral media.

Although the underlying physics is fundamentally different, the two phenomena manifest themselves quite similarly in homogeneous media: a rotation of the polarization plane of light or a difference in absorption of circularly polarized light (circular dichroism). This resemblance has motivated many eminent scientists, starting from Pasteur himself, to look for a link between magnetism and optical activity, but in vain. The corresponding optical manifestation is magneto-chiral effect which was first predicted in 1962 [1]. It may only occur in systems where both inversion and time-reversal symmetries are simultaneously broken. These symmetry conditions are satisfied in magneto-electric media and chiral molecular magnets. The striking features of this effect can be derived from the symmetry considerations. It is a property of unpolarized light and its sign depends on the relative orientation of k and B as well as it has opposite for two different chiral enantiomeres. As such magnetochiral effect has been speculated to be at the origin of the homochirality of life [2]. The first experimental evidence of the magneto-chiral effect has been given only in 1997 by G. Rikken and E. Raupach [3] using visible light. In the X-ray range, the effect was discovered soon after in magnetoelectric Cr_2O_3 single crystal at ID12 beamline [4] following the discovery of natural optical activity in the X-ray range [5].

A fascinating interplay of magnetism and structural chirality is reported here with two representative examples. The first one deals with the archetypal Single Chain Magnets M(hfac)2NITPhOMe where M is bipositive 3d transition metal ions (Mn^{2+} or Co^{2+}) [6]. For the first time, all the three dichroism spectra (X-ray magnetic circular dichroism (XMCD), X-ray natural circular dichroism (XNCD) and X-ray magnetochiral dichroism (XMχD)) have been measured at the K-edges of transition metals on pairs of opposite enantiomers, using single crystals with volume of the order of the mm^3. For the Co crystals, the amplitude of all three effects were found to be comparable in amplitude but differs dramatically in the spectral shape. The effect is more than merely the product of natural circular dichroism and magnetic circular dichroism. The effect is more than merely the addition of natural circular dichroism and magnetic circular dichroism. For the Mn crystals the same hard X-ray investigation revealed comparable natural and magnetic dichroisms, but a vanishingly small magneto-chiral contribution. The combination of helical structure with a large atomic orbital moment resulting in a non-collinear spin arrangement seems the key for a strong magnetochiral effect.

The second example concerns more recent detection of XMχD signal in a mononuclear paramagnetic lanthanide coordination complex, namely, $Na_5[Ho(ODA)_3](BF_4)_2(H_2O)_6$ at low

temperatures and under high magnetic field [7]. The magnetochiral dichroism signal was found to be much weaker than XMCD and XNCD signals despite a large orbital moment carried by Ho^{3+} ion. This is due to a very weak hybridization of the strongly localized 4f states of the lantanides which are responsible for magnetism in these ions.

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Magnetization reversal in $K_{0.4}(Cr(CN)_6)(Mn(S)\text{-}pn)(S)\text{-}pnH_{0.6}$ chiral molecular ferrimagnet by FORC

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The existence and evolution of the nonlinear spin ensembles (domain walls, spin solitons, etc.) in molecular based-magnets cause to unusual macroscopic response of magnetization [1, 2]. We present the researching of magnetization reversal in $K_{0.4}Cr(CN)_6)(Mn(S)\text{-}pn)(S)\text{-}pnH_{0.6}$ chiral molecular ferrimagnet by First Order Reversal Curves (FORC) method. FORC diagram recorded in standard conditions as well as the delayed FORC diagram recorded after pause between magnetic field switching and magnetic moment measurements in metal–organic chiral magnet.

Time domain analysis of the FORC diagram revealed the effect of continuous magnetic relaxation on reversal magnetization. The FORC diagram contains two maxima corresponding to two types of nonlinear spin configurations with different interaction fields and similar switching fields. The changes in the FORC diagram caused by time delay were observed due to excluding the contribution of spin configuration, which magnetic relaxation is faster at 2 K. The temperature decrease from 20 K down to 2 K causes changes in the FORC diagram similar to those caused by time delay. The FORC map as well as reversal magnetization is governed by magnetic anisotropy analyzed in our work. Experimental results were discussed in the frame of Callen-Callen formalism applied for temperature dependence of magnetic anisotropy governing by non linear spin excitations.

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Magnetelastic Coupling in Organic-Inorganic Materials having Ferroelasticity and Magnetic Long Range Order

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Category : Antiferromagnets and multiferroics

Multiferroics means the materials in which at least two of ferroic long range orders, such as ferromagnetism, ferroelectricity and ferroelasticity, etc., coexist at same time. Magnetic field can induce electric polarization or electric field can induced magnetization in the case of coupling between magnetic and electric order parameters. These properties are called magnetoelectric (M-E) effect. This effect has been reported in experimental and theoretical aspects[1,2]. While it is not clear magnetoelastic effect which means ferromagnetism and ferroelasticity coexist. Ferroelasticity was defined it has two or more orientation states in the absence of mechanical stress and can be shifted from one to another of these states by a mechanical stress[3].

Recently, we found that the magnetization of $(C_6H_5C_2H_4NH_3)_2Fe^{II}Cl_4$ single crystal was changed by applying mechanical stress[4]. However this compound requires to be heated up to the ferroelastic transition temperature in order to control the ferroelastic domains, which makes quantification of magnetoelastic effect difficult. Therefore, we explore the another organic-inorganic material which shows movable domain walls without heating. Here, we report the magnetoelastic effect of $H_3NC_3H_6NH_3Mn^{II}Cl_4$ that exhibits structural phase transitions a little bit higher than room temperature[5] (Fig.1)

As shown in Fig. 2, the characteristic domain structure due to the ferroelasticity was observed at room temperature under the polarized microscope by applying mechanical stress from *c*- axis. Magnetic field-dependent magnetization measurements were showed the direction of spin canting was changed due to changing the crystal axis by applying mechanical stress at room temperature. The specific jump of magnetization was observed around 25 kOe at isothermal magnetization curve along *b*- axis. These phenomena indicate the magnetoelastic coupling.

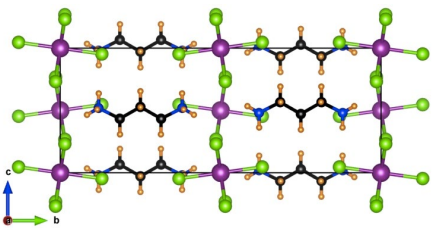

Fig.1 Crystal structure for $H_3NC_3H_6NH_3Mn^{II}Cl_4$ at 293 K

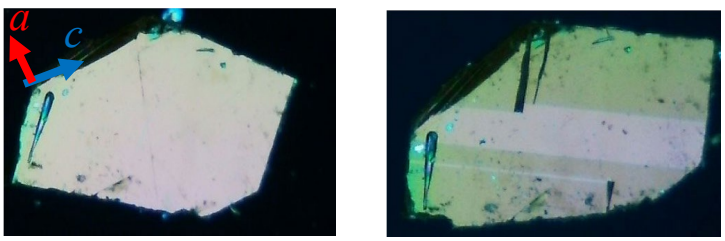

Fig.2 Ferroelastic domains structure for $H_3NC_3H_6NH_3Mn^{II}Cl_4$ at r.t. (left : before stress, right : after stress)

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Trial to Carrier-doping in Sr_2IrO_4 with Strong Spin-orbit Coupling

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Recently, much attention has been paid to the superconductivity in the Iridate system. If the superconductivity is realized in the Iridate system with the strong spin-orbit coupling, it will open the new world in the condensed matter physics. In particular, Sr_2IrO_4/Ba_2IrO_4 has been predicted to be a high-temperature superconductor upon electron doping since it highly resembles the cuprate in crystal structure and magnetic coupling constant. Particularly, the remarkable resemblance between Sr_2IrO_4/ Ba_2IrO_4 and La_2CuO_4 makes a good candidate to expect the unconventional HTSC in the Sr_2IrO_4/Ba_2IrO_4.

Indeed,

1) A low temperature STM study [1)] on the K-doping (effectively election doping) in the clean surface of Sr_2IrO_4 demonstrates the clear spin gap state.
2) Moreover, Y. K. Kim *et.al*. observed the low temperature nodal Fermi surface and high-temperature Fermi arcs[2)].

These experimental results suggest the clear evidence of the d-wave pairing correlation. However, the direct evidence of the superconductivity such as zero resistivity (E=0) and Meisser effect (B=0) can not be observed in the bulk system. We have tried to observe the evidence of superconductivity in the carrier doped bulk material. Recently, we published our present experimental data for this problem to the following paper [3),4)]

In particular, Terashima et al. demonstrated that the d-wave gapped state approaches the Fermi energy as the doped carrier increases, which show the striking similarity with those observed for underdoped cuprate, suggesting that superconductivity can be realized with increasing the carrier concentration.

At present stage, however, we can not obtain a bulk superconductivity, probably due to the insufficient carriers in the IrO_2 planes.

At conference, we show the present situation of "how to dope the carrier" and discuss its experimental results of system.

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Session 3. Exotic spin structures (skyrmions)

Chairman: Javier Campo

Spin textures induced by quenched disorder in a reentrant spin glass: vortices versus frustrated skyrmions

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Disorder plays a central role in the advent of the most spectacular quantum phenomena observed in condensed matter. Reentrant spin glasses (RSG's) are nice playground to study the influence of disorder on frustrated ferromagnets, and see how it affects topological defects. RSG's develop vortex-like textures under magnetic field [1,2], which we investigate in comparison with the frustrated skyrmions predicted by theory [3,4].

Our recent study of a $Ni_{1-x}Mn_x$ single crystal by small angle neutron scattering [5] clarifies their internal structure and shows that these textures are randomly distributed. Using two magnetic field geometries, we found that transverse spin components rotate over length scales of 3-15 nm, decreasing as field increases from 0 up to 8 T according to a scaling law.

Monte-Carlo simulations reveal that the internal structure of the vortices is strongly distorted and differs from that assumed for frustrated skyrmions. The pattern of topological charge density depends on the bond distribution. The vortices keep an anisotropic shape on a 3 dimensional lattice, recalling "croutons" in a "ferromagnetic soup". The size and number of these metastable textures can be tuned by the magnetic field and concentration x (or heat treatment), respectively.

Our results may be extended to other frustrated metallic systems, independently of the crystal structure. Preliminary data [6] in amorphous a-$Fe_{1-x}Mn_x$, measured across the quantum critical point which separates RSG from a true spin glass phase, show that the key parameter which controls the occurrence of such metastable vortices is the average exchange interaction. This confirms the validity of the mean field picture to simulate the magnetic phase diagram.

The whole study opens an original route to understand and control the effect of quenched disorder in systems hosting non trivial spin textures.

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Skyrmion related neutron scattering research activities on TAIKAN in collaboration with RIKEN CEMS

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We report on skyrmion physics related experiments performed on the neutron small- and wide-angle scattering instrument TAIKAN. The instrument is installed on the beam line (BL) 15 of the J-PARC MLF spallation source looking at the cold moderator [1]. It covers the wide Q range from 0.005 to 17 $Å^{-1}$ and it is reflected in the epithet 'TAIKAN' meaning 'Overarching viewpoint' in Japanese.

The wide-Q coverage of the instrument allows to microscopically determine varieties of topological spin textures. As an example the microscopic observation of transitions of topological spin textures between skyrmion- and hedgehog-lattice states in cubic chiral magnets $MnSi_{1-x}Ge_x$ with variation of lattice constant controlled by Si/Ge substitution will be presented [2].

Due to the pulsed nature of the neutron spallation source the TOF experimental data are taken in the event recording mode, where every detected neutron is archived with its TOF with respect to its creation at the source and detector position information. Thus by synchronizing outer stimuli, such as electric current pulses, with the neutron pulses, one can introduce a stroboscopic observation of SANS patterns with a temporal resolution of tens of milliseconds (ms). Here the stroboscopic small-angle neutron scattering investigation on the kinetics of the metastable supercooled magnetic skyrmion lattice (SkL) formation in MnSi upon rapid cooling will be reported [3].

These experiments have been performed in the framework of the Long Term Proposal beam time allocation in the J-PARC MLF Users Program.

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Soft X-ray spectroscopy, scattering and imaging studies of skyrmion-hosting compound $Co_8Zn_8Mn_4$

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A room-temperature skyrmion-hosting compound $Co_8Zn_8Mn_4$ has been examined by means of soft X-ray absorption spectroscopy, resonant small-angle scattering and extended reference holography. An element-selective study was performed by exciting the *2p*-to-*3d* transitions near Co and Mn $L_{2,3}$ absorption edges. By utilizing the coherence of soft X-ray beams the element-specific real-space distribution of local magnetization at different temperatures has been reconstructed using iterative phase retrieval and holography with extended reference. It was shown that the magnetic moments of Co and Mn are ferromagnetically coupled and exhibit similar magnetic patterns. Both imaging methods provide a real-space resolution of 30 nm and allowed to record a magnetic texture in the temperature range between T = 20 K and T = 120 K, demonstrating the elongation of the skyrmions along the principal crystallographic axes at low temperatures. Micromagnetic simulations have shown that such deformation is driven by decreasing ratio of symmetric exchange interaction to antisymmetric Dzyaloshinskii-Moriya interaction in the system and effect of the cubic anisotropy (Fig. 1).

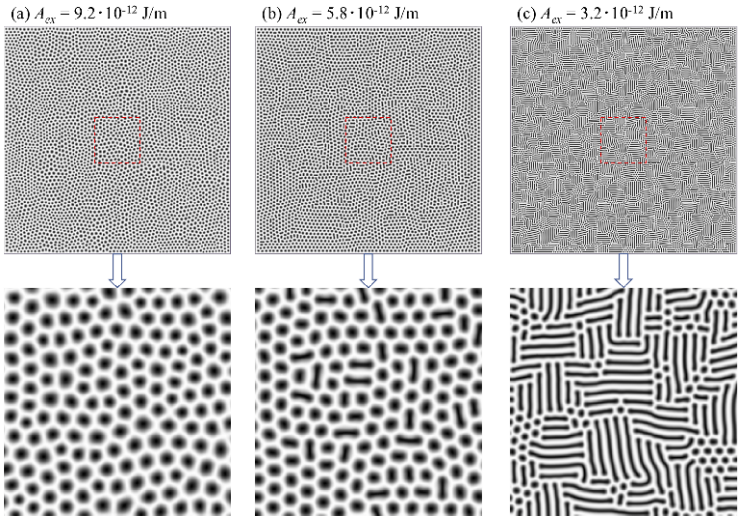

Figure 2 Micromagnetic simulations of $Co_8Zn_8Mn_4$ 10 × 10 μm^2 thin plate: *z*-projection of the magnetic texture is shown for various exchange from stiffness parameters A_{ex}. Bottom panels show magnification of the rectangular regions highlighted by the corresponding red boxes.

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NanoSkyrmionics.

Appearance of the skyrmion lattice in MnGe compound with Fe-doping

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We have grown $Mn_{1-x}Fe_xGe$ compounds with $x = 0.0$, 0.1, 0.2 and 0.3 using high pressure synthesis [1]. It is well known that the magnetic system of $Mn_{1-x}Fe_xGe$ B20-type solid solutions with $x < 0.4$ orders into helical structure with a wave vector $k \approx 2$ nm^{-1} at low temperatures [2]. The formation of the skyrmion lattice (SkX) is found to be an inherent feature of all helical magnets based on Dzyaloshinsky-Moriya interaction (DMI) studied up to now. For the FeGe compound the SkX was observed under external magnetic field within the specific field range at temperatures close to T_C [3]. However the presence of the SkX in pure bulk MnGe has not been clearly established yet.

The evolution of the magnetic system of the $Mn_{1-x}Fe_xGe$ compounds with x = 0.0, 0.1, 0.2 and 0.3 under external magnetic field has been studied using small-angle neutron scattering. As the result the (H-T) phase diagram has been plotted for each compound (Fig.1a-d). The skyrmion lattice (SkX) was not found for MnGe compound within the range 0 T < H < 10 T and 5 K < T < 200 K. However the A-phase has been observed for compounds with x = 0.1, 0.2 and 0.3 from very low temperatures almost up to T_N. As to the field range, the existence of the SkX increases linearly with x up to 1.5 T for $Mn_{0.7}Fe_{0.3}Ge$.

We suggest that the appearance of the SkX and the increase of the field range of its presence is connected to the linear increase of the DMI in $Mn_{1-x}Fe_xGe$ with increase of Fe concentration [4-6]. The *ab*-initio calculations predict almost zero value of the DMI for pure MnGe that, to our opinion, correlates with the absence of SkX for pure compound. The temperature range of the presence of the SkX is most likely connected to the intrinsic instability of the magnetic structure found for MnGe and Fe-doped compounds [7]. We suggest the DMI serves as an instrument for destabilization of the ordered helical structure upon increase of x and as the main reason for the appearance of the A-phase in $Mn_{1-x}Fe_xGe$ solid solutions with $x > 0.1$.

Authors thank for support the Russian Scientific Foundation (Grant No 17-12-01050).

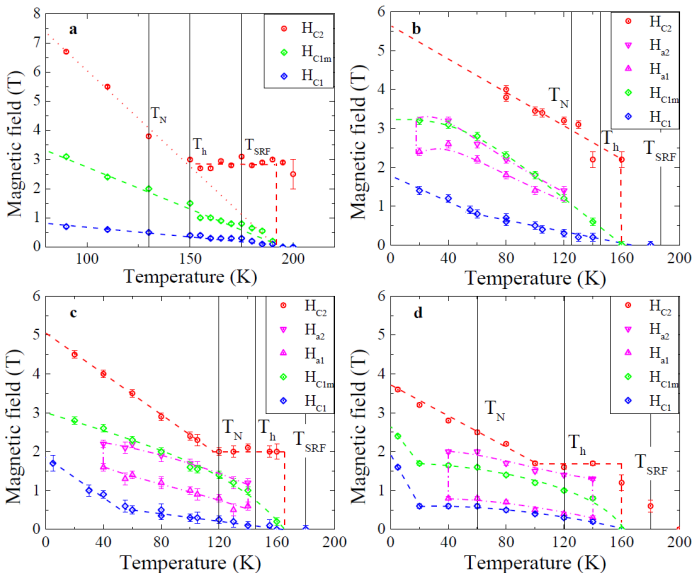

Figure 1: *(H-T) phase diagrams of $Mn_{1-x}Fe_xGe$, with x = 0.0* ***(a)****, 0.1* ***(b)****, 0.2* ***(c)*** *and 0.3* ***(d)****.*

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Polarization analysis of the skyrmion dynamics in MnSi

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The itinerant-electron compound MnSi features a skyrmion order [1] for temperatures in the range $T \approx 28 - 29$ K and for magnetic fields $B \approx 0.16 - 0.21$ T. Its non-centrosymmetric $P2_13$ space group has profound consequences for spin-wave dynamics in all ordered magnetic phases of MnSi. Namely, it introduces a Dzyaloshinskii-Moriya term which – at reduced momentum transfers parallel to the skyrmion axis – leads to magnon creation at energies that are different from the energies for magnon annihilation at the same momentum transfer q. The dynamical magnetic structure factor $S(\boldsymbol{q}, E, \boldsymbol{B})$, with $\boldsymbol{q} = \boldsymbol{Q} - \boldsymbol{G}$ and lattice vector $\boldsymbol{G}$, is thus asymmetric ("non-reciprocal") with respect to changing the sign of either the reduced momentum transfer $\boldsymbol{q}$, the energy transfer E, or the magnetic field $\boldsymbol{B}$, but is symmetric upon interchanging the signs of any two of these variables [2]. Such an asymmetric behavior could be observed for the field-polarized [3, 4], the paramagnetic [5], the conical [6], and the skyrmion [2] phase of MnSi.

In a recent series of experiments at the instrument ThALES [7], we investigated the separation of the non-reciprocal skyrmion dynamics into different polarization channels. These channels signify a flip from spin-down to spin-up ("SF-+"), from up to down ("SF+-") or no spin-flip ("NSF"). Selected experimental results are shown in the bottom panels of the figure. Theoretically, we succeeded to describe our results utilizing a mean-field linear spin-wave model, whose predictions are depicted in the top panel of the figure. The probability for creating or annihilating magnons is given as the line widths of the individual curves. A correction of the theory for instrumental resolution yields the solid curves in the bottom panels and confirms an excellent agreement between experiment and theory.

Our new results are intriguing, as they not only confirm the previously determined [2] asymmetric nature of the skyrmion dynamical structure factor with respect to $\boldsymbol{q}$, E, and $\boldsymbol{B}$, but furthermore extend the asymmetry to the flipping direction of the spin. We could furthermore show a close relationship between dynamics in the skyrmion phase and the other ordered magnetic phases in MnSi.

Upcoming publication: T. Weber, D. Fobes, J. Waizner, L. Beddrich, P. Steffens, G. Tucker, R. Bewley, M. Skoulatos, R. Georgii, P. Link, G. Ehlers, A. Bauer, C. Pfleiderer, P. Böni, M. Janoschek, and M. Garst, in preparation. (The present work will be published as part of that general investigation into skyrmion dynamics.)

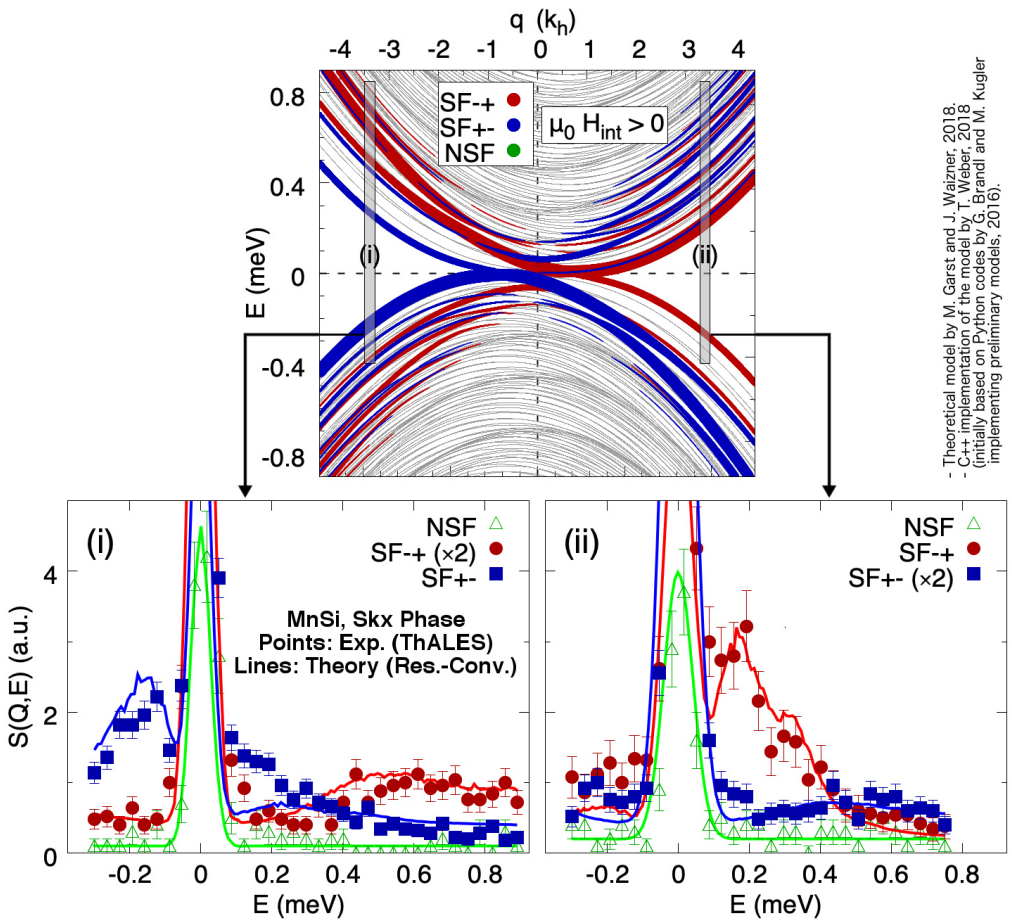

Figure: The theoretical linear spin-wave model (top panel and lines in bottom panels), which describes the polarization dependence of the skyrmion dynamics, excellently and quantitatively agrees with our recent experimental data (bottom panels). Description: see text.

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Magnon spectrum and magnetic susceptibility of skyrmion crystal

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Vortex structures are observed in thin films of magnetic materials under certain conditions. These structures, called skyrmions, attract much interest both in terms of their basic physics as well as the possibility of technological applications [1,2]. A classical skyrmion configuration becomes energetically favorable in presence of Dzyaloshinskii-Moriya interaction and external magnetic field. The extensive analysis of the magnon spectrum in this case for a single skyrmion was done in works [3].

We study the low-energy magnon spectrum in the skyrmion crystal (SkX) formed in two-dimensional ferromagnet with Dzyaloshinskii-Moriya interaction and magnetic field. Equations on the spectrum of magnons is obtained in semi-classical quantization appeoach. SkX hexagonal superlattice is approximated by a set of overlapping disks with optimal radius. One way of calculation is to first determine the spectrum of magnons on one disk. The hybridization of magnons belonging to different discs provides a description of the lowest bands of magnons in SkX.

Another way of calculation is to represent the appearing Schroedinger equation for SkX as quantum mechanical problem for a particle moving in a periodic potential and subject to periodic gauge field. The uniform component of the latter field corresponds to non-zero density of topological charge, and makes the problem similar to Landau quantization.

The oscillating part of the field is zero on the average. The uniform part of Hamiltonian is diagonalized by using Laguerre polynomials, which are further used for the analysis of the periodic part of Hamiltonian. This method gives the spectrum, and the values of wave-vectors may be found from the periodicity of wave functions.

The spectrum and the wave functions define the non-uniform dynamic magnetic susceptibility of the system. The latter quantity is observable in inelastic neutron scattering experiments which should provide further insights into the physics of such materials.

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Magnetic correlations in the frustrated antiferromagnet $FeCl_3$

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Magnetic skyrmions are topological protected spin textures with particle-like properties, stabilized by the DMI interaction in non-centrosymmetric crystal lattices(1). However, theory predicts skyrmions to also exist in frustrated magnets even with conventional centrosymmetric crystal structure (2, 3). $FeCl_3$ is such a frustrated magnetic system, which crystallizes in a hexagonal structure(4, 5). The anisotropy of the lattice parameters, with c = 17.4 Å, about three times a = b = 6.04 Å leads to a weak two dimensional behaviour. Previous experiments indicated that below $T_N \approx 8.2$ K, the Fe moments are helically modulated along the $[14\bar{5}0]$ direction of the ab-plane and coupled antiferromagnetically between adjacent planes(4, 5, 6).

We present neutron diffraction and magnetic susceptibility results on powder and single crystals of $FeCl_3$, which reveal a complex magnetic phase diagram. The susceptibility measurements provide indications for short range order at temperatures as high as $3T_N$. The combination of small angle neutron scattering and neutron powder diffraction shows that the magnetic Bragg peaks appear below T_N, and at low temperatures the sub lattice magnetisation, M, follows a power law $M \propto (T_N - T)^{\beta}$ with $\beta = 0.19 \pm 0.01$ and $T_N = 8.3 \pm 0.1$ K. The low value of critical exponent β is consistent with previous results (6) and hints to a weak 2D behaviour. With SANS we have followed the evolution of the magnetic scattering as a function of magnetic field and temperature searching for skyrmionic correlations and we will discuss the resulting phase diagram.

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Session 4. Evolution of the magnetic structure in helimagnets under high pressure.

Chairman: Jun–ichiro Kishine

Magnetic ordering above 30 K in noncentrosymmetric $YbCoC_2$

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The compounds $RCoC_2$ (R = Tb, Dy, Ho, Er, Tm) possess the noncentrosymmetric orthorhombic structure of $CeNiC_2$-type (space group *Amm2*). According to magnetic measurements and neutron diffraction experiments they all orders ferromagnetically at temperatures T_c in the range 9-30 K depending on rare earth element [1-3]. The information on the physical properties and possible magnetic ordering in $YbCoC_2$ is missing though this compound was synthesized at ambient pressure long time ago [4]. We have successively synthesized $YbCoC_2$ by melting of the mixture of constituent elements at high pressure (8 GPa) [5] and studied its magnetic, thermodynamic and electronic transport properties at normal and high pressure.

Synthesized polycrystalline $YbCoC_2$ sample has the orthorhombic structure of $CeNiC_2$-type and the structural parameters obtained by Reitveld refinement of x-ray powder diffraction spectrum at 300 K are presented in the table. Measurements of the magnetic susceptibility and heat capacity revealed the magnetic transition at T_m = 26.5 K. Above the transition susceptibility follows the modified Curie-Weiss law and the effective magnetic moment μ_{eff} is equal to 4.42 μ_B - the value close to that for Yb^{+3} ion (4.53 μ_B). From the behavior of the magnetic susceptibility below T_m and the field dependence of the magnetization at T = 2 K was concluded that $YbCoC_2$ is antiferromagnet. At T = 2 K the field-induced transition to the ferromagnetic state takes place in the range of fields 6-8 T with hysteresis 0.2 T. Both antiferromagnetic properties and the high value of T_m are anomalous compared to the nearest trivalent rare earth compounds $ErNiC_2$ and $TmNiC_2$ which are ferromagnets (T_c = 14 K for $ErNiC_2$ and 9 K for $TmNiC_2$ [2]). Heat capacity measurements indicate on the moderate heavy fermions in $YbCoC_2$ (C/T extrapolated from above T_m to T = 0 is 190 mJ/mol K^2). The magnetic entropy at T_m is close to Rln2 that indicate the doublet ground state of Yb-ion. The temperature dependence of the electrical resistivity of $YbCoC_2$ is of metallic type and the resistivity exhibits the fast drop at the magnetic transition temperature T_m. To explore the effect of pressure on the magnetic transition we have measured the electrical resistivity of $YbCoC_2$ at high hydrostatic pressure up to 5 GPa with Toroid-type pressure cell in a liquid pressure medium and up to 13 GPa with the Diamond Anvil Cell (DAC) in NaCl pressure medium. The experiments in both types of pressure cells showed consistent results. The transition temperature T_m increases up to T_m = 33 K at 13 GPa. The magnetic ordering temperature above 30 K is the highest for any known Yb-based compound. *Ab initio* calculations based on the density functional theory (DFT) with the use of QUANTUM ESPRESSO package have shown that the ground state of $YbCoC_2$ at T=0 is ferromagnetic with the magnetic moment on the Co atom M_{Co} = 0.79 μ_B. The results of experiments and calculations allow one to assume the formation of the complex magnetic structure in $YbCoC_2$ resulted from the interaction of localized Yb moments and itinerant magnetism of d-electrons of Co. This interaction is probably the origin of a high value of the magnetic ordering temperature in $YbCoC_2$. In other $RCoC_2$ the cobalt atoms have no magnetic moment [1,2].

This work was supported by the Russian Science Foundation (grant 17-12-01050 and 18-12-00438) and by the Russian Foundation for Basic Research (grant 17-02-00064).

Space group	*Amm2* (No. 38), $Z = 2$		
Lattice constants	$a = 3.43908(2)$ Å, $b = 4.\ 49479(3)$ Å, $c = 5.99866(4)$ Å		
Atom	Yb	Co	C
x	0.0	1/2	1/2
y	0.0	0.0	0.1719(19)
z	-0.0433(5)	0.5713(4)	0.2876(9)
R_{wp}, χ^2	3.70, 1.66		

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Anomalous magnetism and Kondo-lattice state in noncentrosymmetric $YbNiC_2$ and their evolution at high pressure.

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The compounds $RNiC_2$ (R = La-Lu) possess the noncentrosymmetric orthorhombic structure of $CeNiC_2$-type (space group *Amm2*) and exhibit a variety of transitions at decreasing temperature – charge density waves (CDW) and magnetic. These compounds are the convenient platform for studies of interplay between CDW and magnetism [1]. Very recently the unconventional superconductivity was found in $CeNiC_2$ near the quantum critical point at high pressure [2]. Contrary to others $RNiC_2$ the physical properties of $YbNiC_2$ have never been studied though it was synthesized many years ago at normal [3] and high pressure [4]. We have successively synthesized $YbNiC_2$ by melting of the mixture of constituent elements at high pressure (8 GPa) [5] and studied its magnetic, thermodynamic and electronic transport properties at normal and high pressure.

Synthesized polycrystalline $YbNiC_2$ sample has the orthorhombic structure of $CeNiC_2$-type and the structural parameters obtained by Reitveld refinement of x-ray powder diffraction spectrum at 300 K are presented in the table. Measurements of the magnetic susceptibility and heat capacity revealed the magnetic transition at T_m = 17 K. Above the transition susceptibility follows the Curie-Weiss law and the effective magnetic moment μ_{eff} is equal to 4.59 μ_B - the value close to that for for Yb^{+3} ion (4.53 μ_B). The behavior of the magnetic susceptibility below T_m and the field dependence of the magnetic moment at T = 2 K are consistent with the ferromagnetic component of the ordered magnetic moment, though the large negative value of the Weiss temperature (-180 K) indicate on the dominant antiferromagnetic interactions. Both ferromagnetic properties and relatively high value of T_m are anomalous compared to the nearest trivalent rare earth compounds $ErNiC_2$ and $TmNiC_2$ which are antiferromagnets (T_N = 8.5 K for $ErNiC_2$ and 5.5 K for $TmNiC_2$ [6]). Heat capacity measurements indicate on the moderate heavy fermions in $YbNiC_2$ (C/T extrapolated from above T_m to T = 0 is 170 mJ/mol K^2). The temperature dependence of the electrical resistivity of $YbNiC_2$ is characteristic of the dense Kondo-lattice compounds. It exhibits a shallow minimum at about 100 K and a sharp maximum at 18 K followed by a rapid decrease of resistivity. The magnetically ordered state in $YbNiC_2$ starts just below the peak of the electrical resistivity. In order to explore the effect of pressure on the magnetic transition and Kondo-state we have measured the electrical resistivity and heat capacity of $YbNiC_2$ at high hydrostatic and quasi-hydrostatic pressures. Resistivity and ac-calorimetry measurements at hydrostatic pressure up to 5 GPa were performed with Toroid-type pressure cell in a liquid pressure medium. Diamond Anvil Cell was used for resistivity measurements up to 25 GPa and a pressure medium around the sample was NaCl in this case. The temperature of the magnetic transition T_m increases slightly up to 3 GPa but then starts to decrease rapidly at higher pressure. However, the projected quantum critical point at $P_c \sim 10$ GPa is not realized in $YbNiC_2$. Instead, T_m is stabilized near 10 K at $P \sim 9$ GPa and then is nearly pressure independent up to 25 GPa. This unusual behavior of T_m may be related with the appearance of resistivity anomaly typical for CDW at T ~200 K at pressures above 6 GPa which becomes more pronounced at higher pressures. Concurrently the resistivity peak characteristic of the Kondo-lattice state decreases gradually and disappears. Apparently, the appearance of CDW and the suppression of the Kondo state results in stabilization of the magnetically ordered state in $YbNiC_2$ at high pressure. *Ab initio* calculations based on the density functional theory (DFT) with the use of QUANTUM ESPRESSO package have shown

that the ground state of $YbNiC_2$ at T=0 is the state without the band magnetism related with d-electrons of nickel. Thus the magnetic order in $YbNiC_2$ is completely due to the 4f-electrons of ytterbium.

This work was supported by the Russian Science Foundation (grants 17-12-01050 and 18-12-00438) and by the Russian Foundation for Basic Research (grant 17-02-00064).

Space group	*Amm2* (No. 38), $Z = 2$		
Lattice constants	a = 3.47648 (7) Å, b = 4.49354 (9) Å, c = 5.99719 (10) Å		
Atom	Yb	Ni	C
x	0.0	1/2	1/2
y	0.0	0.0	0.15677
z	0.0	0.60325	0.29472
R_{wp}, χ^2	4.71, 1.44		

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Single Crystal Growth of Chiral Magnet $YbNi_3Al_9$ by Flux Method with a Temperature Gradient

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Crystal structure of rare-earth intermetallic compound $YbNi_3Al_9$ has a chirality. $YbNi_3Al_9$ crystallizes in $ErNi_3Al_9$-type structure with the space group of *R*32 [1]. The crystal symmetry belongs to a Sohncke type, which means that the crystal can be in two enantiomorphic structures. Using a flux method, we can obtain both enantiopure crystals as a racemic conglomerate, and racemic twin crystals. Because of the high vapor pressure of ytterbium, the flux method is almost the only way of synthesizing ytterbium compounds. In the flux method, it is possible to prevent the evaporation of ytterbium by dissolving it in flux.

In $YbNi_3Al_9$, Yb-ions are magnetic, but Ni are not. The Yb-valence is +2.97 which is slightly smaller than +3 due to Kondo-effect [2,3]. Figure 1(a) shows the unit cell of $YbNi_3Al_9$ and (b) Yb_2Al_3-layer. The magnetic Yb-ions form a honeycomb-network in Yb_2Al_3-layer perpendicular to *c*-axis. Non-magnetic seven monoatomic layers of Ni or Al-ions separate Yb_2Al_3-layers along *c*-axis. The lattice parameters are a=0.7260nm, c=2.7307nm [2].

Below the magnetic ordering temperature of 3.4K, $YbNi_3Al_9$ is a chiral helical magnet [2,4,5]. Figure 2 shows magnetic structure of $YbNi_3Al_9$. The wavelength of the helix is 3.4nm with the magnetic propagation vector q=(0 0 0.8). The relatively short wavelength is characteristic of *f*-electron chiral magnets [6]. The size of the Yb magnetic moment is 1.2μ_B with an orientation perpendicular to *c*-axis. One to one relationship between the crystallographic chirality and magnetic helicity is proved by resonant circularly-polarized X-ray diffraction measurement [5]. It is also established that the chiral soliton lattice is formed in the magnetic field applied perpendicular to the helical axis [5].

Our next goal is to measure the inelastic neutron scattering of $YbNi_3Al_9$. However, the size and quality of the obtained crystals were not sufficient. In this study, we aimed to improve the flux

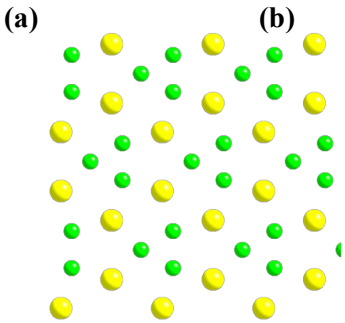

Figure 1. (a) Unit cell of trigonal $YbNi_3Al_9$. Yellow circles correspond to Yb, red circles to Ni, and green circles to Ga atoms. (b) Yb_2Al_3- layer. Yb-ions form a two-dimensional honeycomb-network.

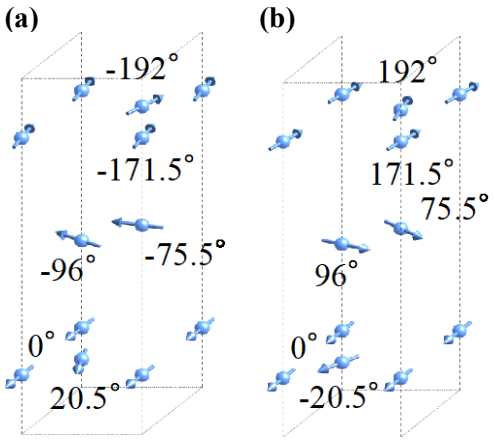

Figure 2. Helical magnetic structure of $YbNi_3Al_9$. (a) Clockwise and (b) counterclockwise helix. The magnetic moment of Yb is 1.2μ_B.

method to obtain larger and highly enantiopure crystal.

We have used a self-flux method to synthesize $YbNi_3Al_9$. Starting material was

stoichiometric mixture of high purity ytterbium, nickel and aluminum. Excess aluminum was added as the flux. These were put in the alumina crucible and sealed in vacuum in a quartz tube. We have used the alumina crucible with an inner diameter of 9 mm.

In usual, we put the crucible in a uniform temperature region and cool it slowly, as schematically shown in Fig. 3(a). In this setting, a lot of crystals of different sizes grew, because crystal nucleation occurs at various locations within the crucible. To narrow the area where crystal nucleation occurred, we performed the flux method with a temperature gradient. As shown in Fig. 3(b), the crucible was placed on a temperature gradient and cooled from the bottom.

As a result, we succeeded in growing the crystal to three times or more the size. Figure 4(a) and (b) are examples of the largest crystal obtained by flux method in a uniform and a gradient temperature, respectively. The mass of the obtained crystals increased from 60mg to 200mg. This result indicates that the temperature gradient can reduce the number of crystal nucleation. Currently, we are trying to grow the crystal from the tip of a conical crucible.

This work is supported by Grants-in-Aid for Scientific Research on Innovative Areas "J-Physics" (Grants No. 18H04315) from MEXT, and KAKENHI (18K03539, 17H02815) from JSPS.

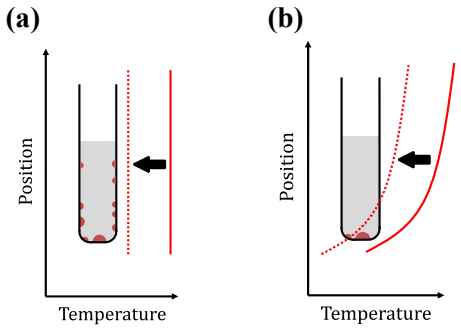

Figure 3. The relationship between crucible and temperature. (a) usual flux-method and (b) with a temperature gradient.

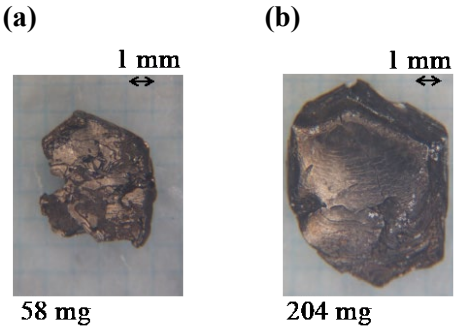

Figure 4. Typical result of obtained crystal by flux-method. (a) in a uniform temperature and (b) with a temperature gradient.

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Possible Formation of a Chiral Soliton Lattice in the Pressure-Induced Magnetic Phase in the Chiral Compound $YbNi_3Ga_9$

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Chiral magnets such as $Cr_{1/3}NbS_2$ with a chiral soliton lattice (CSL) have received much interests [1]. An Yb-based compound $YbNi_3Al_9$ crystallizing into a chiral structure (trigonal space group $R32$) exhibits a chiral helical magnetic order at T_M = 3.4 K [2]. By substituting Cu for Ni by 6% in $YbNi_3Al_9$, T_M increases up to 6.4 K [3], and a CSL is realized when magnetic fields up to B_c = 1 T are applied perpendicular to the helical axis ($B \perp c$) [4]. On the other hand, in the isostructural compound $YbNi_3Ga_9$, a magnetic order is induced by applying the pressure P above 9 GPa [5]. Our specific-heat measurements revealed that T_M and B_c for $P \geq 11$ GPa increase up to 5 K and 1.3 T, respectively [6], whose values are similar to those for $Yb(Ni_{0.94}Cu_{0.06})_3Al_9$ with CSL [3]. Furthermore, a field-induced ordered phase (phase II) appears only for $B \perp c$ as shown in Fig. 1 [6].

In order to investigate the feasibility of CSL in the pressure-induced magnetic phases in $YbNi_3Ga_9$, we have measured the Hall resistivity $\rho_H(B)$ and the magnetoresistance $R(B)$ for $B \perp c$ under P up to 12.6 GPa. As shown in Fig. 2, the slope of $\rho_H(B)$ changes between the phase I and phase II. The Hall coefficient $R_H(B) = \rho_H(B)/B$ displayed in Fig. 3 increases near the phase the boundary between the phase II and paramagnetic (PM) phase. Furthermore, the field dependence of $R(B)$ having a maximum near the boundary between phase II and PM phase is similar to that for $Yb(Ni_{0.94}Cu_{0.06})_3Al_9$ as shown in Fig. 4 [7]. The close resemblance in $R(B)$ suggests the formation of CSL in the phase I of $YbNi_3Ga_9$.

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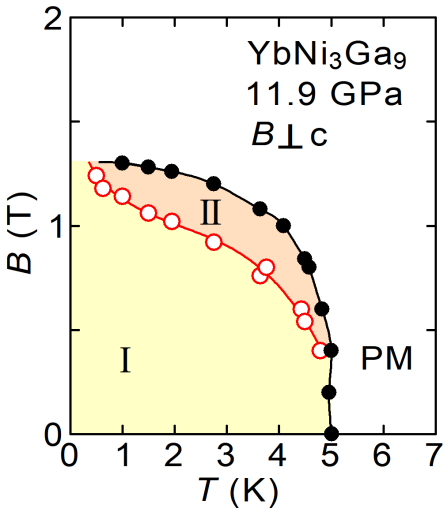

Fig. 1. *B*-*T* phase diagram of $YbNi_3Ga_9$ for $B \perp c$ at 11.9 GPa determined by specific-heat measurements [6].

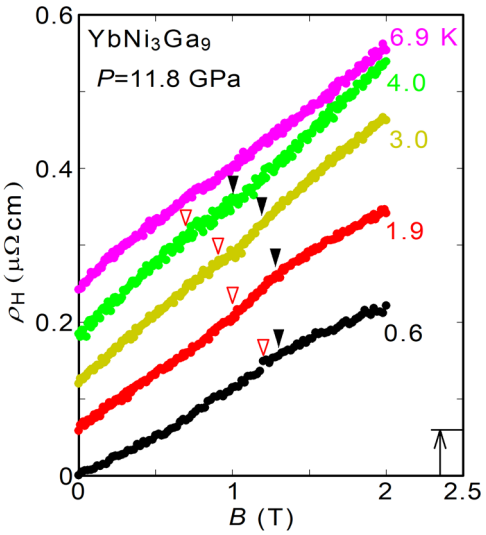

Fig. 2. Field dependence of ρ_H for $YbNi_3Ga_9$ at 11.8 GPa and various temperatures. The red open arrows and black closed arrows show the fields at the boundary between phase I and II and phase II and paramagnetic phase, respectively.

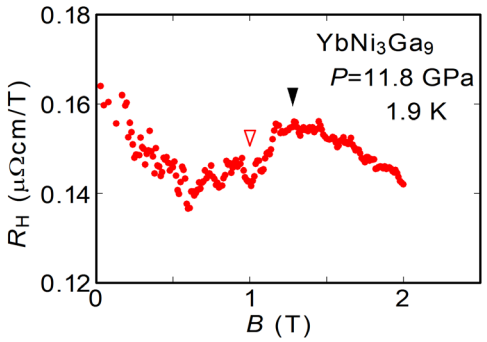

Fig. 3. Field dependence of $R_H = \rho_H / B$ for $YbNi_3Ga_9$ at 11.8 GPa.

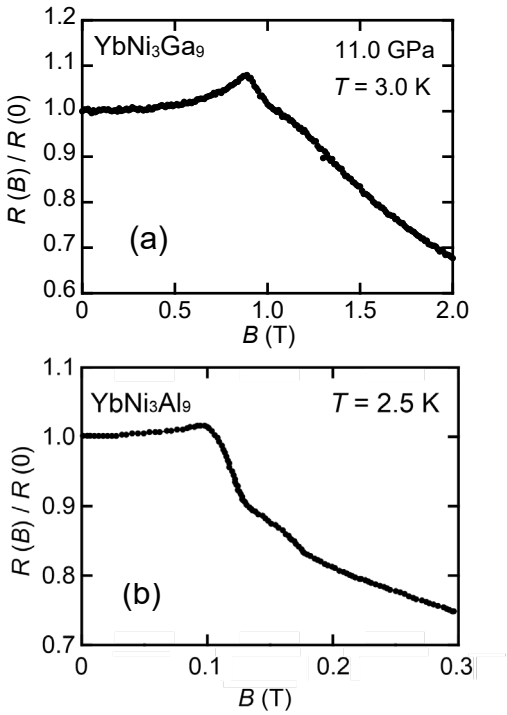

Fig. 4. Magnetoresistance of (a) $YbNi_3Ga_9$ at 11.8 GPa and (b) $YbNi_3Al_9$ at ambient pressure [7].

Pressure Induced New Magnetic Phases in $CsCuCl_3$ Probed by Neutron Diffraction Technique

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The ground state of frustrated quantum magnets has been studied as one of important issues in the condensed matter physics. In case of $S = 1/2$, the exotic ground states could be induced by the quantum spin fluctuation. The up-up-down (*uud*) spin state providing 1/3 magnetization plateau is well known as a typical exotic ground state dominated by such fluctuation effects. However, there have been few experimental results of the *uud* ground state.

$CsCuCl_3$ crystallizes in right-handed ($P6_122$) and left-handed ($P6_522$) chiral space groups which allow Dzyaloshinskii-Moriya interaction. The compound has attracted much attention from two-dimensional triangular antiferromagnetic state and chiral helimagnetic ordering with the magnetic propagation vector $\boldsymbol{k}_{mag} = (1/3, 1/3, \delta)$ [1]. The 1/3 magnetization plateau is induced by applying high pressure and magnetic field along the *c*-axis [2]. Theoretical studies indicate that high pressure induces new magnetic phases as *uud* and Y phases [3].

In order to determine the magnetic structures in the new magnetic phases, we performed neutron diffraction experiments on the E4 thermal neutron diffractometer at HZB in Germany. When we applied pressure of 0.7 GPa and magnetic field along the *c*-axis, the magnetic satellite peaks of (1/3, 1/3, δ) were observed at H = 12 T and H = 14.2 T, indicating umbrella and 2-1-coplanar structures, respectively. However, at H = 13 T, where the 1/3 magnetization plateau was observed, the magnetic signals were observed only at (1/3, 1/3, 0). The magnetic structure of the new phase is interpreted as the *uud* structure.

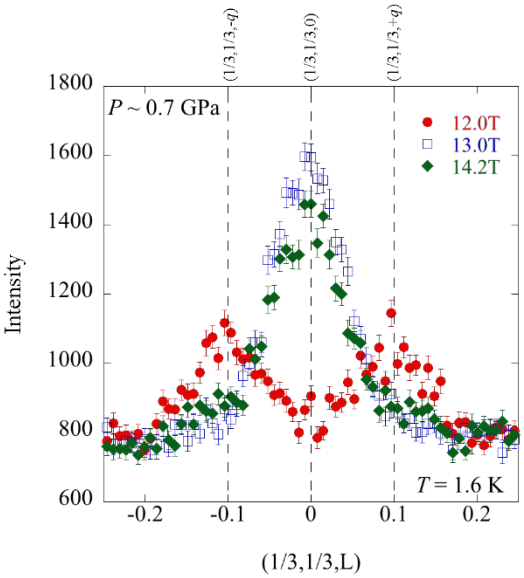

Figure 1: Neutron diffraction profile of the (1/3, 1/3, *l*) reflections.

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Theory of Magnetic Phase Diagram in Chiral Magnet $CsCuCl_3$ under High Pressures

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ABX_3 type compounds (A=Rb, Cs; B=Mn, Fe, Co, Ni, Cu, V; X=Cl, Br, I) are the ideal field to investigate the phase transition in low-dimensional systems. In that family, $CsCuCl_3$ attracts much attention in terms of two-dimensional triangular antiferromagnets and chirality. The crystal structure of $CsCuCl_3$ in the low temperature (below 423K) is hexagonal with space group $P6_122$ or $P6_522$. In this phase, Cu chains form the helices along the c axis, and these chains form the triangle lattice in ab plane. The main exchange interactions between Cu ions are intra-chain ferromagnetic interaction J_0 ~28K, inter-chain antiferromagnetic interaction J_1 ~4.9K, and Dzyaloshinskii-Moriya (DM) interaction with D vector along c axis (D ~5K). Due to these interactions, below T_N = 10.7K, this compound shows the helical spin structure along c axis [1].

The ground state of $CsCuCl_3$ in longitudinal magnetic field (the magnetic field is parallel to c axis) at low temperature of ambient pressure is well understood by using a spin wave theory [2]. Nikuni and Shiba showed that the quantum phase transition from an umbrella phase to 2-1 coplanar phase occurs when the magnetic field increases. The theoretical prediction was confirmed by experiments. Recently, the new magnetization plateau was found under the high pressure [3]. Although this plateau is expected to be "up-up-down" (uud) phase showing the 1/3 plateau of saturation magnetic field, the existence has not been explained by the spin wave theory.

In this talk, we clarify the existence of uud phase by considering the pressure dependence of model parameters on the basis of the spin wave theory (See Fig.1) [4]. We also find the Y coplanar phase, which has not been confirmed by the experiments, under the high pressure.

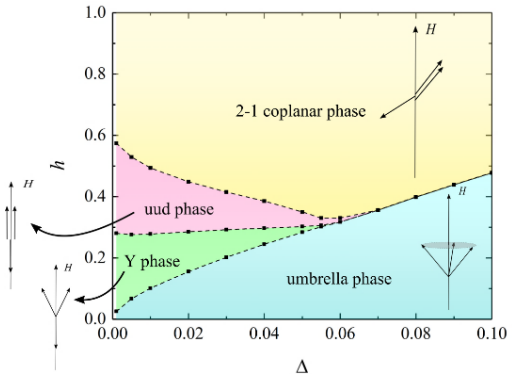

Fig1. Magnetic Phase diagram of $CsCuCl_3$. Δ depends to the pressure. The ambient pressure is Δ~0.07.

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Session 5. Spin excitations in helimagnets with DM interaction

Chairman: Sergey Grigoriev

The role of the thermal fluctuations in cubic helimagnets: stabilization of new phases at low temperature

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The role of thermal fluctuations in the stabilization of the magnetic states that appear in cubic helimagnets is theoretically analyzed, using a saddle point expansion to obtain the free energy. It is shown that in the low temperature region thermal fluctuations destabilize the conical state and stabilize the skyrmion lattice (SKL) near the transition to the forced ferromagnetic state. Also, a new phase, whose features cannot be determined with our method, appears in this region of the phase diagram (Figure left) [1]. This new state, and the SKL at low temperature, have been recently found in Cu_2OSeO_3 [2, 3]. It is also shown that at high temperature and low field, near the phase boundary, thermal fluctuations stabilize the SKL, which becomes the equilibrium state (Figure right) [4]. Comparisons with recent experimental results [2, 3] and with the computations of Mühlbauer et al. [5] are given.

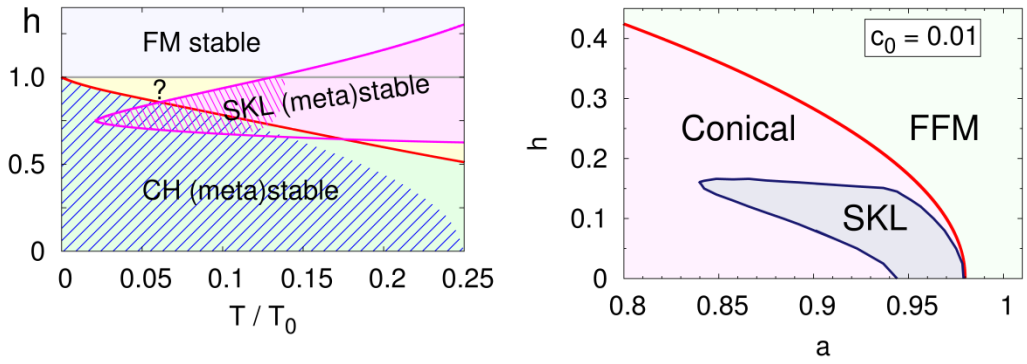

Figure: left, theoretical phase diagram of the cubic helimagnet, including the effect of Gaussian fluctuations, in the low T region; right, same in the high T region (the parameter *a* controls the variation of temperature)

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Physical properties of $(Mn_{0.85}Fe_{0.15})Si$ along the critical trajectory

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The phase transition temperature in the helical magnet MnSi decreased with pressure and reached the zero value at ~15 kbar. However a nature of this transition at zero temperature and high pressure and an existence of quantum critical point in MnSi are still a subject of controversial interpretations. In this situation it would be appealing to use a different approach to discover a quantum criticality in MnSi, for instance, making use doping as a control parameter. In case of Fe doping a critical concentration consist about 15% (actually different estimates vary from 0.10 to 0.19) [1-3].

We report results of studying the magnetization, specific heat and thermal expansion of a single crystal with nominal composition $(Mn_{0.85}Fe_{0.15})Si$. Magnetic susceptibility in the form $(1/\chi - 1/\chi_0)^{-1}$ and Gruneisen parameter β/Cp in $(Mn_{0.85}Fe_{0.15})Si$ show diverging behavior, which is interrupted at about 5 K by factors linked somehow with spin fluctuations analogues to ones preceding the phase transition in MnSi. Specific heat divided by temperature Cp/T of $(Mn_{0.85}Fe_{0.15})Si$ clearly demonstrate diverging behavior to 2 K. The electrical resistivity of $(Mn_{0.85}Fe_{0.15})Si$ exhibits non Fermi liquid character.

We found no thermodynamic evidences in favor of a second order phase transition in the 15% Fe substituted MnSi. The trajectory corresponding to the present composition of $(Mn_{0.85}Fe_{0.15})Si$ is a critical one, i.e. approaching quantum critical point at lowering temperature, which agrees with conclusions made in [2,4]. However, the critical trajectory in fact is a tangent to the phase transition line and therefore this situation produces some sort of a mixed state instead of a pure quantum critical one that probably was seen in the experiments [5].

AEP and SMS greatly appreciate financial support of the Russian Science Foundation (grant 17-12-01050).

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Liquid crystalline structures and elasticity in a cubic chiral helimagnet

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Condensed matter provides convenient ways to observe and manipulate a large variety of complex long-range orders. Currently, a strong focus is put on the study of chiral magnets belonging to the so-called B20 family, such as MnSi, FeGe, MnGe, etc. These alloys indeed display a plethora of multiply modulated phases, including the topologically non-trivial skyrmion (SK) lattice, and a constantly improved understanding of their microscopic properties is required.

Using small-angle neutron scattering on $Mn_{1-x}(Co,Rh)_xGe$ solid solutions, we have recently discovered that MnGe undergoes a doping-induced transition from helimagnetism to weak ferromagnetism through a mixed-state. Within this intermediate phase, topological defects –akin to SK-anti SK pairs- proliferate, even in zero field [1]. The formal equivalence between the latter and the "*twist-grain boundary*" (TGB) phase already evidenced in certain chiral liquid crystals [2] underscores the deep connections between the two classes of systems.

In turn, this analogy implies that the helimagnetic (HM) ground state should support low energy *phason* modes [3], but their observation has remained elusive in B20 compounds. We have used a cutting-edge quasi-elastic scattering method, the so-called MIEZE spectroscopy [4], to verify this prediction. Our study of the temperature-dependence of the HM order lifetime in pure MnGe revealed that it is *finite* in a large temperature interval below the macroscopic ordering temperature $T_N \approx 170$ K down to $T_{com} \approx 30$ K [5]. This finding suggests that the ground state is dominated by non-linear excitations, which destabilize the long-range order. They could be connected to the large topological Hall effect observed in this compound [6].

Altogether, our work shows that there still exists an amazing landscape to be explored in chiral magnets, beyond the physics of skyrmions. Neutron scattering will keep on playing a key role in this adventure.

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Three-dimensional neutron polarization analysis of the small-angle scattering from helimagnets

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The three-dimensional neutron polarization analysis (3D analysis) is based on the fact that the polarization of the neutrons scattered by a magnetically isotropic sample is described by the Haldpern-Jonson equation [1]. Previously it was demonstrated that the 3D analysis allows one to investigate critical scattering where direct measurement of the magnetic scattering is impossible, to determine the correlation length of the critical fluctuation very close to the Curie temperature where the inelasticity and multiple scattering spoil the results of the study [2].

To investigate helimagnetics properties in the vicinity of T_C the 3D analysis can be applied to characterize the inelastic component in the small-angle neutron scattering on helimagnets. The analysis reveals 100% chilarity of the spin helix in the ordered phase at $T<T_C$ with no possibility to detect any inelastic component of the scattering. The inelastic scattering is well registered via the non-zero projection of the polarization along the neutron wave vector as part of the scattering on the spin helix fluctuations above T_C. These spin helix fluctuations are characterized by the correlation length ξ and the life time τ. These two quantities are related to the widths of the scattering peak in the momentum transfer Q and in the energy space ω, its shape is being Lorentzian function in both spaces. It is shown that the ratio of two projections of the neutron scattering polarization along and perpendicular to the neutron wave vector $\alpha = (P^{\parallel}/P^{\perp})$ is proportional to the inverse life time of the spin helix fluctuation $\Gamma=1/\tau$. Moreover α is inversely proportional to incident neutron energy that gives possibility to tune the range of the measured inverse life time. The method is applicable for the detection of the neutron energy transfer in the range from 1 to 100 μeV, or, for the life time from 100 ps to 10 ns. Being the integrative method the 3D analysis is clearly complementing the neutron spin-echo method in the asymptotic of the large ω range.

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Magnetic Fluctuation around First-Order Transition in Trillium Lattice of EuPtSi Observed by ^{151}Eu Mössbauer Spectroscopy

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A new type of topological magnetic texture so called the magnetic skyrmion was discovered in the A-phase under the magnetic fields just below the Néel temperature T_N of the B20-type helimagnets such as MnSi and FeGe having the trillium lattice. The trillium lattice is also realized in EuPtSi intermetallic compounds of LaIrSi type structure. Recently, the first-order like antiferromagnetic ordering of EuPtSi at T_N=4.0 K, which is small in magnitude compared with ordering temperatures of 10–100 K in the usual divalent Eu compounds, reflecting the frustration of spins in the chiral structure [1],[2]. Very recently, the magnetic structure of EuPtSi has been investigated by neutron diffraction measurement [3].

We report the results of ^{151}Eu Mössbauer spectroscopy on EuPtSi with a chiral structure belonging to the $P2_13$ (#198) space group at zero magnetic fields. The paramagnetic single absorption forms a magnetic splitting profile directly below T_N=4.0 K and the spectrum at 3.9 K consists of the sum of the paramagnetic single absorption and the magnetic splitting absorption, which indicates a first-order transition at T_N=4.0 K. The temperature dependence of the effective hyperfine fields H_{hf} at the Eu nucleus follows a power law of $H_{hf} = H_0(1-T/T_N)^{\beta}$ with H_0 = 25.6±0.4 T and β = 0.16±0.01 indicates a full moment of Eu^{2+} ions. The relative integral intensity I of the ^{151}Eu Mössbauer spectroscopy for EuPtSi is enhanced using a Debye calculation below $T_0 \simeq 15$ K, which indicates the development of magnetic correlations. The line width Γ of the ^{151}Eu Mössbauer spectra increases below T_{FD} ($\simeq$8 K) close to the Weiss temperature θ_p and shows a sharp peak at T_N. The magnetic behavior of EuPtSi can be divided into three magnetic regions: the paramagnetic (PM) phase, the fluctuation-disordered (FD) phase and the antiferromagnetic phase with fluctuation disordering (AF with FD). The magnetic fluctuation is realized around the first-order transition between the paramagnetic and helimagnetic states in EuPtSi.

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Session 6. Neutron scattering for non-collinear magnetism

Chairperson: Isabelle Mirebeau

Polarized Neutrons studies of weak magnetization densities

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Strong sensitivity of polarized neutrons to weak magnetic signals, allows very precise determination of magnetization distribution maps. In the talk the results of recent polarized neutron diffraction experiments on ruthenate and irridate compounds will be presented, giving access to the weak (Dzyaloshinsky-Mori) magnetization density spatial distribution.

High-field optical study of metamagnetic transitions in a chiral polar magnet Ni_2InSbO_6

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Ni_2InSbO_6 crystallizes in a corundum-related trigonal structure with a chiral polar space group $R3$ (Fig. 1). This compound undergoes a transition to a long-period helimagnet with the propagation vector $\boldsymbol{q} \perp \boldsymbol{c}$ below T_N = 77 K [1]. The helicoid is approximately of proper-screw type driven by Dzyaloshinskii-Moriya interaction. We have studied the magnetoelectric effect and found metamagnetic transitions so far [2]. However, the spin configurations in high-field phases were unknown in detail.

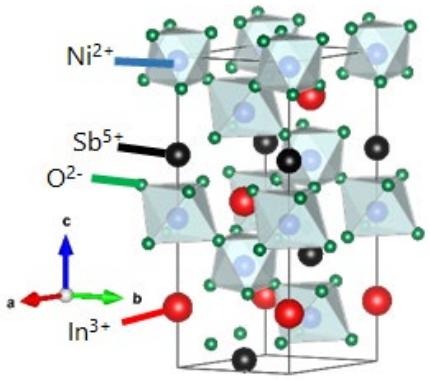

Fig. 1 Crystal structure of Ni_2InSbO_6.

In this study, we explore high-field magnetic phases by measuring optical absorption spectra in Ni_2InSbO_6 in high magnetic fields to obtain the detailed information on the direction of Ni^{2+} magnetic moments. For Voigt configuration ($\boldsymbol{k} \parallel \boldsymbol{c}$, $\boldsymbol{B} \parallel \boldsymbol{a}^*$), the absorption spectra do not show any clear difference between light polarizations $\boldsymbol{E}^{\omega} \parallel \boldsymbol{B}$ and $\boldsymbol{E}^{\omega} \perp \boldsymbol{B}$, suggesting that the light polarization should not affect the selective rule of the *d-d* excitation in a Ni-O octahedral cluster. By applying a magnetic field, the absorption intensities at E = 1.56 eV and 1.76 eV show field dependence well-corresponding to the magnetization which implies the modulation of the soliton state (Fig. 2(a)). For Faraday configuration ($\boldsymbol{k} \parallel \boldsymbol{B} \parallel \boldsymbol{c}$), the absorption intensities at E = 1.56 eV and 1.75 eV show a hysteresis loop like the magnetization curve as described in Fig. 2(b). These behaviors are attributable to the field-induced change in the direction of Ni^{2+} magnetic moments.

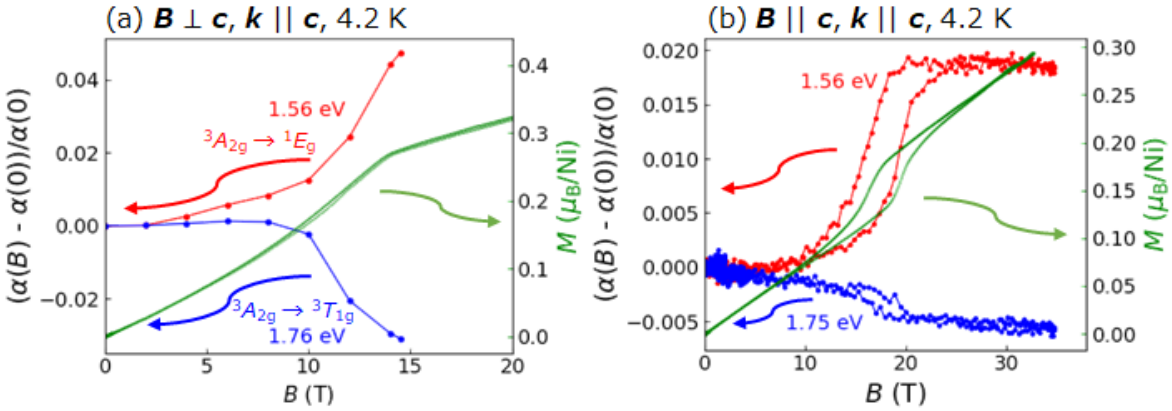

Fig. 2 Magnetic-field dependence of the absorption intensity for (a) $\boldsymbol{k} \parallel \boldsymbol{c}$, $\boldsymbol{B} \parallel \boldsymbol{a}^*$ and (b) $\boldsymbol{k} \parallel \boldsymbol{B} \parallel \boldsymbol{c}$ configurations. Red and blue dots show the absorption at 1.56 eV and 1.75 (1.76) eV, respectively. Green lines show magnetization curves.

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Spin-wave stiffness of Dzyaloshinskii-Moriya helimagnets $Fe_{1-x}Co_xSi$ studied by small-angle neutron scattering

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The spin wave stiffness was measured by small-angle neutron scattering method in the Dzyaloshinskii-Moriya helimagnets $Fe_{1-x}Co_xSi$ with x = 0.25; 0.30; 0.50. It has been shown that the spin wave dispersion in the fully polarized state is anisotropic due to Dzyaloshinskii-Moriya interaction. It is reflected in the neutron scattering pattern as two circles for neutrons obtaining and losing the magnon energy, respectively. The centers of the circles are shifted by the momentum transfer oriented along the applied magnetic field H and equal to the wave vector of the spiral ± $\mathbf{k}_S$. The radius of the circles is directly related to the stiffness of spin waves and depends on the magnetic field. We have found that the spin-wave stiffness A changes weakly with temperature for each individual compound. On the other hand, the spin-wave stiffness A increases linearly with x in contrast to the x dependences of the critical temperature T_C and the low-temperature ordered spin S.

It has been demonstrated that in the B20 compounds, the magnetism correlates closely with the structure, and the DM interaction in $Fe_{1-x}Co_xSi$ and $Fe_{1-x}Co_xGe$ can be effectively controlled by the Co composition. It is instructive to compare the magnetic properties of the $Fe_{1-x}Co_xSi$ [1,2] compounds with those of $Fe_{1-x}Co_xGe$ compounds [3]. In the Co-rich compounds the magnetic properties duplicate each other: the CoGe and CoSi are both nonmagnetic isolators, the ordered magnetism emerges with 80% of the Co content, the sign of the DM interaction changes at x = 0.6 in $Fe_{1-x}Co_xGe$ [3] and at x = 0.65 in $Fe_{1-x}Co_xSi$ [2], the critical temperature decreases monotonously with increase of x from 0.4 to 0.8.

On contrary, the Fe-rich compounds are different: FeGe is helimagnetic metal with very high T_C =278 K, while FeSi is nonmagnetic semiconductor. The Co doping results in the decrease of the critical temperature and the average spin S for the $Fe_{1-x}Co_xGe$ compounds, while 5-10% of Co doping results in appearance of the helimagnetic structure in the $Fe_{1-x}Co_xSi$ compounds. Nevertheless the magnetic structure of the Fe-rich part of the $Fe_{1-x}Co_xSi$ phase diagram are rather well understood being described by the Bak-Jensen model, but the Co-rich part remains a puzzle.

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Tilted conical and multiple skyrmionic phases in Cu_2OSeO_3

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Skyrmion-hosting materials, and in particular the archetype cubic chiral magnets, show the same generic behaviour, which was so far assumed to be universal. Recent experiments on the insulator Cu_2OSeO_3, however, show remarkable deviations from this universal behavior, with far-reaching implications. A new phase occurs when it is the least expected, at low temperatures and high magnetic fields, but only when the field is applied along the [001] easy crystallographic axis [1]. Furthermore, extremely robust skyrmionic states, can be produced in large areas of the magnetic phase diagram [2, 3]. Nascent and disappearing spiral states near critical lines catalyze topological charge changing processes, leading to the formation and destruction of skyrmionic states at low temperatures, which are thermodynamically stable or metastable depending on the orientation and strength of the magnetic field. The metastable low temperature skyrmions are surprisingly resilient to high magnetic fields and their memory persists in the field polarized state, even when the skyrmion lattice signal has disappeared [3]. These results hint to novel routes for skyrmion nucleation [4] and highlight the paramount role of magnetic anisotropies in stabilizing exotic chiral magnetic states.

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The Morin Transition and Dzyaloshinskii-Morya Effect in Hematite Nanoparticles

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An alternative treatment of the well-known effect of a decrease in the Morin transition temperature in hematite with a decrease in the size of crystallites to the complete disappearance of the transition for nanoparticles smaller than 20 nm is proposed [1]. In contrast to the standard speculative explanation of this effect in terms of the effect of surface and defectiveness of grains, we suggest that the decisive factor is an increase in the contribution of the shape anisotropy of particles with a decrease in their size, which is responsible for the spread of orientations of the axes of the resulting magnetic anisotropy with respect to the crystallographic axes. Three types of the magnetic structure of hematite nanoparticles with various sizes are found by Mössbauer spectroscopy: coexistence of the well pronounced antiferromagnetic and weakly ferromagnetic phases for particles with average diameters of about 55 nm, non-uniform distribution of the magnetization axes which concentrate on the vicinity of the basal plane (111) for prolonged particles with cross sections of about 20 nm, and uniform distribution of the easy axes in regard to the crystalline directions for 3-nm particles [2]. Our reasons are confirmed by a numerical analysis of Mössbauer spectra of hematite nanoparticles within the continuous model of magnetic dynamics of an ensemble of antiferromagnetic nanoparticles in the two-sublattice approximation [3] generalized to the existence of weak ferromagnetism (Dzyaloshinskii-Morya interaction).

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Non-collinear magnetic phases in the spinel $MnCr_2O_4$

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The cubic spinels AB_2O_4, where the tetrahedral A-sites are occupied by magnetic A^{2+} ions and the octahedral B-sites are occupied by Cr^{3+} ions, are model systems to study magnetic geometrical frustration (MGF) [1,2]. These compounds could exhibit both ferromagnetic and ferroelectric polarizations, induced by conical spin structures [3].

In particular, in the $MnCr_2O_4$, the MGF still survives if the Cr-Mn exchange interaction is smaller than the Cr-Cr one [4]. Neutron diffraction studies reported that below T_F = 41 K the system presents ferrimagnetic order with an easy axis parallel to the [110] direction [5, 6]. When the temperature decreases below T_H = 18 K, this magnetic phase coexists with short-range spiral order.

We reinvestigate the nuclear and magnetic structure of the $MnCr_2O_4$ for different temperatures by means of magnetization, specific heat and neutron powder diffraction techniques for three samples with different preparation methods.

Through these experiments we determined the temperatures: T_{S1}=20 K corresponding to the transition from ferrimagnetic to a spiral order phase with propagation vector Q_{S1}=(0.62, 0.62, 0.00); and T_{S2} = 18 K, corresponding to the transition to a helical phase characterized by a propagation vector Q_{S2} = (0.60, 0.66, 0.20).

The results suggest that a new non-collinear magnetic phase, not previously reported, is developed under 18 K.

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On the 4f-3d coupling in orthomanganites $Dy_{1-x}Ho_xMnO_3$.

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The perovskite-like manganites $RMnO_3$ (R = Dy, Ho) belong to magnetic multiferroics (or multiferroics type-II). The magnetic origin of ferroelectric polarization in the compounds $DyMnO_3$, $HoMnO_3$ is described by different microscopic mechanisms: by Dzyaloshinskii-Moriya interaction and the exchange striction respectively [1, 2]. Ferroelectric polarization in $DyMnO_3$ rises with the increase of dysprosium moment ordered in cycloidal structure (polarized by manganese subsystem) and falls down when Dy subsystem orders in its independent commensurate structure [3].

The studies of $DyMnO_3$ (DMO) and $Dy_{0.8}Ho_{0.2}MnO_3$ (DHMO) single crystals were carried out by neutron scattering, including the diffraction of polarized neutrons and spherical neutron polarimetry technique.

Temperature of the magnetic ordering for both compounds was observed about the same: T_N = 39 K and 38 K for DMO and DHMO respectively. And the magnetic structure both of them is described by the same type of propagation vector $\boldsymbol{k}$ = (0 k_y 0). Magnetic order of DMO has transverse spin wave structure down to ~ 19 K, and then transition to cycloidal type takes place [4], which is considered to be due to the influence of polarized rare earth subsystem. Our results witness that considerable induced ordered moment of Dy subsystem occurs already at temperatures higher than 30 K. The magnetic structure of DMO at 4 K represents a spin cycloid with $\boldsymbol{k}_{Mn}$ = (0 k_y 0) and configuration of magnetic moments of manganese subsystem has type A_yA_z and for dysprosium subsystem - G_xA_y. Along with the incommensurate structure, below $T_{NR} \approx 7$ K subsystem Dy^{3+} is ordered into the collinear magnetic structure of type G_xA_y with the propagation

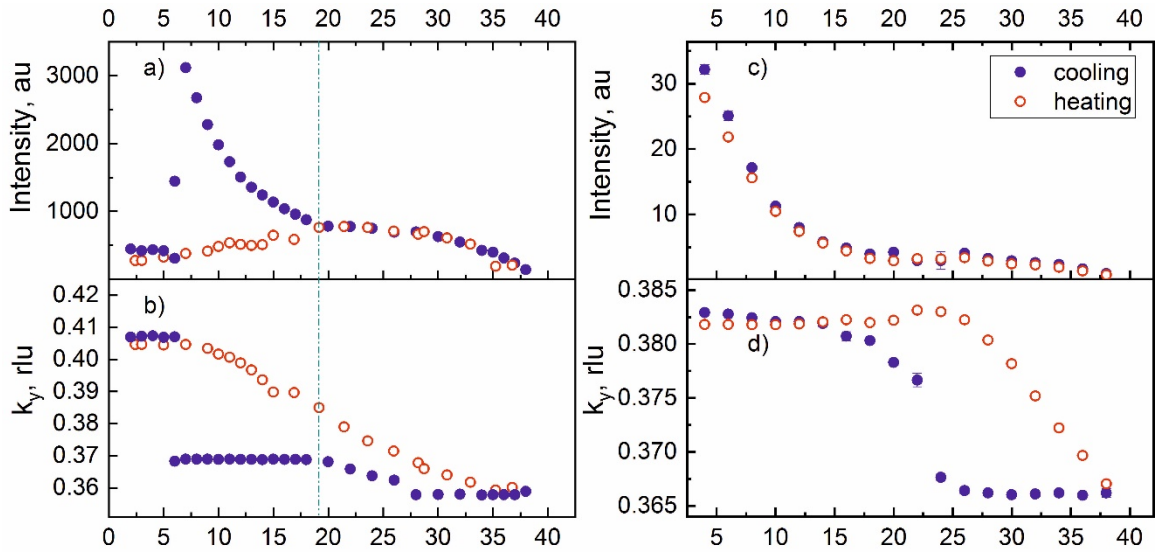

Fig. 1. Temperature dependencies of magnetic satellites (0 0 1)+ for $DyMnO_3$ (left panel) and $Dy_{0.8}Ho_{0.2}MnO_3$ (right panel) measured in cooling and heating modes: a), d) – satellites intensities; b), e) – propagation vectors; c), f) – peak widths.

vector $\boldsymbol{k}_{Dy}$ = (0 0.5 0). The magnetic structure of the substituted compound inherits the type of

magnetic configuration from parent compound DMO. We reveal that manganese subsystem of DHMO at 4 K is ordered in the cycloidal structure with configuration of type A_yA_z, and the magnetic structure of the rare-earth subsystem also represent a spin cycloid of G_xA_y type. The results of the magnetic structure refinement are in good agreement with the measurements of the magnetization.

Temperature evolution of the magnetic structures parameters of both investigated compounds demonstrate a significant dependence on the measurement mode — whether measurements were made during heating or cooling the crystal (Fig.1). The origin of this effect certainly connected with the strong interaction of two magnetic subsystems, 3d manganese and 4f rare-earth ones. However, the type of such hysteresis is different for DMO and DHMO, which indicates that in the dysprosium compound rare-earth magnetic subsystem has a stronger influence on the manganese than in the substituted one. Indeed, in DMO below 7 K, there is abrupt decrease of the incommensurate satellite intensity and sharp change of the incommensurate propagation vector. This is connected with ordering of rare-earth magnetic system into an independent antiferromagnetic structure. In a contrast, there is rather smooth behavior of such parameters at DHMO. And also one can see no evidences about independent ordering of rare earth subsystem. Replacement dysprosium with holmium leads to suppression of the ordering of the rare-earth subsystem with its own wave vector.

The refinement of the magnetic structures of DMO, which are realized at different modes – heating/cooling – has been carried out at T = 12 K. It reveals that for both cases the magnetic structure and moment values are the same. Thus the considerable difference in the satellite intensities in temperature region 7 K – 19 K for DMO (Fig.1a) originates from unusually very slow relaxation of the magnetic structure, that occurs due to the peculiarities of exchange interactions in Dy-sublattice.

The chiral scattering at DHMO demonstrate weak dependence from external electric field (Fig.2). In the critical region, near the transition from the spin wave to the cycloid, one can see the similarity to the classical hysteresis loops.

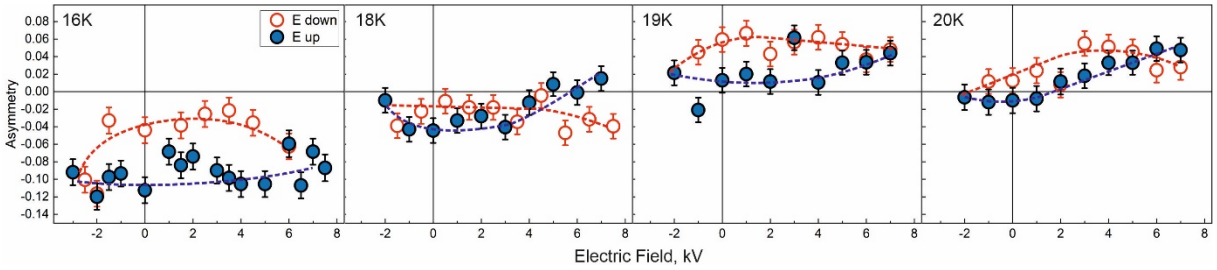

Fig. 2. Field dependence asymmetry (difference between “left” and “right” chiral domains at $Dy_{0.8}Ho_{0.2}MnO_3$ for different temperatures.

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Session 7. Thin films and surface effects in cubic ferromagnets without center of symmetry

Chairman: Yoshihiko Togawa

Surface magnetic layer and magnetic field

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In the magnetic layers the Dzyaloshinskii-Moriya interaction (DMI) is a result of the mirror symmetry breaking. It leads to a cycloid for both types of the exchange interaction. General expressions for the cycloid energy in magnetic field are derived. In zero field the cycloid orientation is determined by the DM induced anisotropy. There are the uniaxial, square and hexagonal anisotropy in the layers with corresponding symmetry. So we have one, two or three chiral domains. The in-plane magnetic field rotates them. For some field directions the spin flops are predicted. In the out-of-of-plane field there is a conical cycloid which magnetization tends to be along the field and the cycloid wave-vector decreases. In the perpendicular field there is the spin flop to the collinear state. Developed method allows studying the magnetic field behavior and spinning flops in other DM magnets such as multiferroics.

Effect of focused ion beam irradiation on the interface DMI and magnetic anisotropy thin films

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In this paper, we report the effects of focused Ga^+ ion beam (FIB) fluence on the magnetic properties and domain structure in ultrathin Ru/Co/W/Ru films with strong iDMI and PMA. The polycrystalline Ru(10)/Co(1)/W(0.25)/Ru(2) films (all thicknesses are denoted in nm) were prepared by UHV magnetrons sputtering. The as-grown films have PMA and dendritic domain structure [1]. The effective iDMI value for the non-irradiated film was measured by Brillouin Light Scattering (BLS) Spectroscopy: D_{eff} = -3.1 erg/cm^2 [2]. Energy of the effective magnetic anisotropy (K_{eff}) was estimated from the initial magnetization curves: K_{eff}=0.75×10^6 erg/cm^3.

The films were irradiated by FIB with the constant Ga^+ ion energy E_{FIB}=30 keV. Doses were varied from 4.0×10^{12} up to 6.5×10^{13} ions/cm^2. Both iDMI and K_{eff} sharp decrease with the increasing dose (fig. 1a). The simulations at TRIDYN software [3] show that low dose of irradiation intermixed the interfaces in films. This confirm that PMA and DMI has the interface quality depending nature. The observation of the magnetic structure by a polar magneto-optical Kerr microscope showed the formation of structures like a skyrmion-bubbles. The experimental findings are explained with help of micromagnetic simulations.

The presented spatially resolved modification of ultrathin films can be potentially used for creations of artificial neuromorphic devises and skyrmion-based logics exploiting the locally gradient-tuned PMA and/or DMI. Moreover, the FIB modification can be used for formation of narrow magnetic nanotracks with desired properties for skyrmion propagation and operation.

This work was supported by the Russian Foundation for Basic Research (grant 19-02-00530) and by the Russian Ministry of Education and Science under the state task (3.5178.2017 and 3.4956.2017).

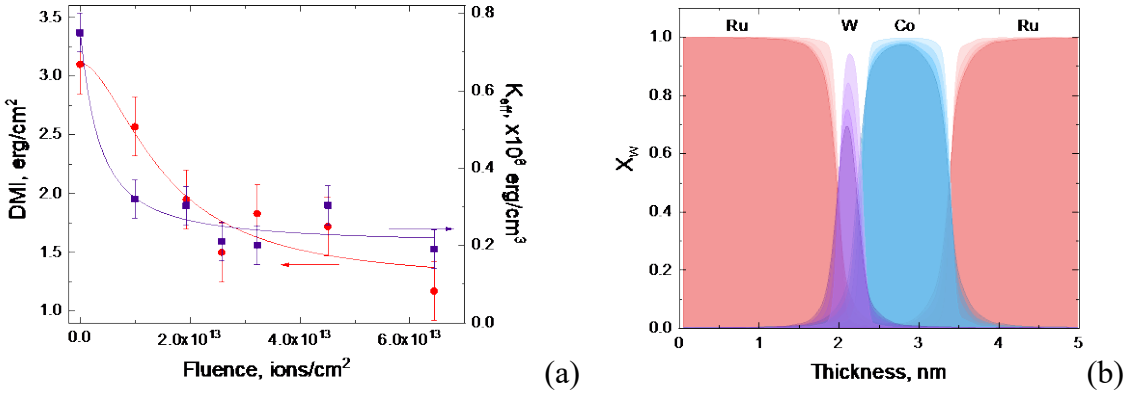

Fig. 1. The dependence of DMI and PMA energies vs. ions fluence (a); the simulated profiles for Ru(10)/Co(1)/W(0.25)/Ru(2) film after fluence by 5.8x10^{12}, 2.6x10^{13}, 4.5x10^{13}, 6.4x10^{13} ions/cm^2.

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Magnetic refrigeration by tuning of exchange spring, helix, fan in Ho/W films

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Modern magnetic refrigeration technologies require large isothermal magnetic entropy change during magnetic phase transitions. Most of known technologies explore variation of magnetic field in the vicinity of the Curie point. Nevertheless, non collinear magnetic materials possess multiply spin transitions convenient for large variation of entropy S caused by magnetic field sweeping. The Ho thin films possess multiple magnetic phase transitions observed when tuning temperature and applied magnetic field. Exchange spring, fan, helix and other spin states are present in Ho film. The MgO/W/Ho(400nm)/W films of 400 nm thickness were used in our experiments. Geometry of Ho/W sandwich was aimed to finding and analysis of anisotropic magnetocaloric effect. Extension of the Ho film under interface internal stresses provides anisotropy of the magnetic refrigeration. Series of the field dependences around the Curie temperature 130 K for “in-plane” and “out-of-plane” field orientations were recorded and analyzed. Transition from spin helix to paramagnetic state takes place near 130 K. Easy magnetization axis lies in plane of the film. Calculation of the magnetic part of entropy results in maximal value ΔS = -16 J/kg K for “out-of-plane” magnetic field direction, while in the “in plane” orientation ΔS = -35 J/kg K at 5 T. Maximum of the entropy on temperature dependence S(T) was broader in the “in-plane” orientation. The anisotropy of magnetocaloric effect can be explained by mixing of the energy levels of the Ho^{3+} ions controlled by internal stresses and depending on orientation. Few additional entropy peaks were distinguished in the S(T) dependence. Most probably these peaks are provided by transitions between low temperature intermediate spin states, which are spin-slip at 95-110 K, helifan to helix continuous transition at 40-120 K and transition of the spin-slip phase to the “40 degree” spin spring phase at 78 K. The Ho/W films were investigated in paramagnetic state at 300 K by electron spin resonance technique. There are three octets of the resonant lines. Lines within each octet are split by hyperfine interaction, while difference between central fields of octets corresponds to fine interaction depending on local crystal field. Non equivalency of the spins in paramagnetic state indicates mechanical stresses sorting local amorphous–crystalline areas in the film.

Nanofabrication of Bloch and Néel skyrmions in Co/Pt multilayers

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Absence of the inversion symmetry in ferromagnetic materials may lead to the antisymmetric exchange interaction – Dzyaloshinskii-Moriya interaction (DMI) [1,2]. It can exist both in bulk materials [3,4] and thin films [5,6] (so-called iDMI). The significant fact is that the DMI makes more favorable homochiral inhomogeneous magnetization distributions: helices & Bloch skyrmions for bulk materials and cycloids & Néel skyrmions in thin films. The most qualitative and quantitative method to investigate inhomogeneous states in thin films is the Lorentz transmission electron microscopy[7]. The existence of iDMI has been shown in a wide range of ferromagnetic (Co, Fe, Ni) multilayers with different interlayer materials: metals (Pt, Ta, Pd, Cu, Au) or oxides (AlO_x, MgO_x) [8-12].

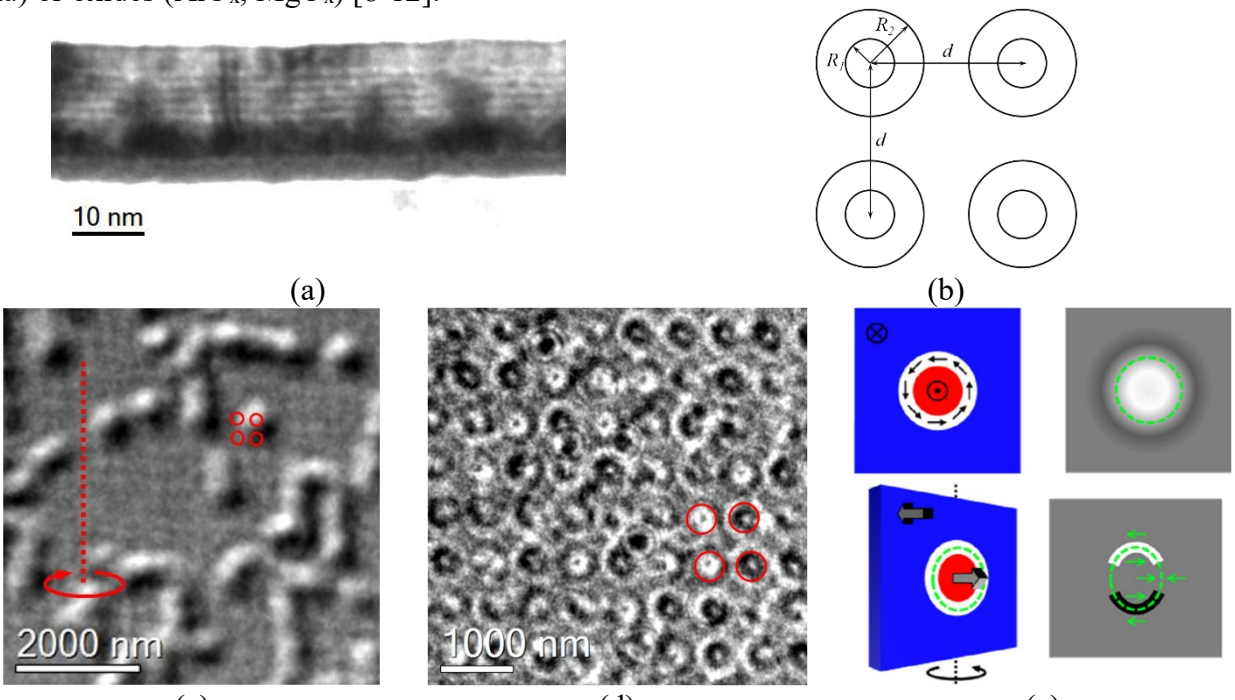

Figure 1. Cross-sectional TEM micrograph of Co/Pt multilayer (a); Scheme of He^+ ions irradiation (b); Dipole Fresnel contrast in TEM of artificial Néel-type skyrmion lattice, the specimen tilted along vertical axis on the 30 degrees (c); Focusing/defocusing Fresnel contrast of artificial Bloch-type skyrmion lattice (d); Fresnel contrast for Bloch skyrmion and tilted Néel skyrmion (e) (from Ref. [11]).

The most part of such heterogeneous multilayers have the strong enough iDMI to stabilize a Néel domain walls and corresponding skyrmions at room temperatures [8-11]. Nanofabrication by focused ion irradiation is a way to pin skyrmions in multilayers at the desired place in the material. In Ref.[13] the modification by focused Ga^+ beam was done. The interaction of Ga^+ ions with multilayer is very strong and the Co/Pt were totally intermixed. Thus there was no iDMI and only the Bloch skyrmions were observed. Still there is no method of nanofabrication to observe in the same film both type of skyrmions. The He^+ ions interacts with matter much weaker [14]. That makes possible very precise nanomodification of multiayers. We expect that the proper fluencies

and exposition areas of focused He^+ beams will allow us to control the type of skyrmions in Co/Pt multilayers.

We prepare the following multilayered structure (ML) on the 30 nm thick amorphous SiN_4 membrane: Ta 10 nm layer, Pt 10 nm layer, periodical structure [Co 0.5 nm/Pt 1.0 nm]×5 and Pt 2 nm cap. The growth of layers was done by magnetron sputtering. Typical cross-sectional TEM bright field micrograph is shown on Fig.1a. Such Co/Pt multilayer seems to have symmetrical Co-on-Pt and Pt-on-Co interfaces and is not expected to have the iDMI. Our observations contradicts and shows the existence of the Néel and 360º Néel domain walls [9]. That is the sing of presence of rather strong iDMI. The origin of it is that fact that the Co-on-Pt interface growth is not equal to the growth of Pt-on-Co interface. The ML is locally irradiated by focused 30 keV He^+ beams by Carl Zeiss ORION NanoFab with fluencies $0.8–10.0\times10^{15}$ ions/cm^2. The scheme of the exposition is shown on Fig.1b. The central part of the ring with radius R_1 is exposed with fluence D_1, the outer part with radius R_2 is exposed with fluency D_2. The rings are formed in a square 50×50 μm lattice with period d. The fluency D_1 is always smaller than the D_2. Our aim is to investigate how the fluencies and radii of exposed areas connected with types of inhomogeneous magnetization textures. We use the Lorentz mode of FEI Titan TEM to investigate magnetization distribution. We observe two types of the Fresnel contrast: the dipole contrast in case of the Néel-type skyrmions (Fig. 1c) and bright/dark dotted contrast in case of the Bloch-type skyrmions (Fig. 1d). The typical contrasts for Bloch and Néel skyrmions are shown on Fig. 1e (from Ref.[11]).

Our fluencies of He^+ in the ring areas destroys the iDMI locally. The magnetostatic energy makes more preferable Bloch-type skyrmions in rings. The observed distribution is determined by the competition of the magnetostatic energy and the iDMI energy. When the radiate radius R_2 of the ring is about 200 nm the Bloch skyrmion is more preferable. When the radius R_2 is less than 100 nm, the Néel skyrmion is observed. The observed results are in a good agreement with micromagnetic modeling. We developed a new precise method for nanofabrication and controlling the type of skyrmions in the Co/Pt periodical multilayers.

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Effect of interplay of Dzyaloshinskii-Moria and dipolar interactions on internal skyrmion structure in magnetic multilayers

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Magnetic Skyrmions are one of the fascinating and promising objects because of their small size and stability to perturbations such as electric currents and magnetic fields [1-4]. The major mechanism to stabilize small Skyrmions in ferromagnet/heavy metal bilayers is the presence of Dzyaloshinskii-Moriya interaction (DMI). In thin films, the DMI arises at the interface of ferromagnetic material and heavy metal due to the presence of spin-orbit interaction and broken inversion symmetry [4, 5].

In this work we investigate the stability and internal structure of an isolated Skyrmion in bilayer (ferromagnet/heavy metal) and trilayer (heavy metal 1/ferromagnet/heavy metal 2) nanodisks. We study the static properties of the Skyrmions and obtain the phase diagrams of the Skyrmion existence depending on the thickness of the ferromagnetic layer and the DMI strength. We demonstrate the importance of fully taking into account the dipolar interaction even for a few atomic layers thin nanodisk and that together with DMI it has the stabilizing effect and defines the Skyrmion configuration. For the trilayer structures with two heavy-metal interfaces (corresponding to two interfacial DMIs), we show that the type and configuration of the Skyrmion can be controlled by the thickness of ferromagnetic, and interplay of two interfacial DMIs can lead to formation of magnetic structures with higher winding number.

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Dzyaloshinskii-Moriya interaction as an agent to free the bound entangled states

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In this work, we investigate the efficacy of Dzyaloshinskii–Moriya (DM) interaction to convert the bound entangled states into free entangled states. We consider the tripartite hybrid system as a pair of non interacting two qutrits initially prepared in bound entangled states and one auxiliary qubit. Here, we consider two types of bound entangled states investigated by Horodecki. The auxiliary qubit interacts with any one of the qutrit of the pair through DM interaction. We show that by tuning the probability amplitude of auxiliary qubit and DM interaction strength, one can free the bound entangled states, which can be further distilled. This method can be useful in quantum information and computation.

POSTER SESSION

Quadrupole and magnetic hyperfine interaction arising on nuclei of ^{181}Ta and ^{111}Cd in noncentrosymmetric RhGe

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The coexistence of weak ferromagnetism (T_m = 140 K) and superconductivity (T_c = 4.3 K) has recently been observed in the cubic B20-type high-pressure phase of RhGe with lattice parameter a = 4.860 Å [1]. Time differential perturbed angular correlation (TDPAC) method with ^{111}Cd and ^{181}Ta probes inserted in the RhGe lattice was used to study the electric field gradient (EFG) and hyperfine magnetic fields (MHF) of the compound in temperature region 4-300 K. In the paramagnetic region, the EFG measured on the ^{111}Cd probe nuclei is equal to 6.7×10^{17} V/cm^2 with asymmetry parameter η = 0 and EFG on Ge lattice site obtained from *ab initio* DFT computations is -7.4×10^{17} V/cm^2 [2]. This points out that the ^{111}Cd nuclei localized in Ge lattice sites. At T = 90 K about 80 % of RhGe volume stay paramagnetic while 20 % of nuclei feel single MHF B_{hf} = 0.55 T.

The EFGs measured on the ^{181}Ta probe nuclei in RhGe at room temperature are equal to $V_{zz1} = 2.0\times10^{17}$ V/cm^2 with η_1 = 1.0(2) and $V_{zz2} = 1.5\times10^{17}$ V/cm^2 with η_2 = 0.66(8). For both probes nuclei the EFGs are weakly depend on the temperature. ^{181}Ta-TDPAC measurements performed at 4 K showed that the full volume is magnetic and the MHFs at ^{181}Ta are B_{hf1} = 0.8 T and B_{hf2} = 3.2 T. We also observed the change of asymmetry parameters in magnetic state: η_1 =0.5(1) and η_2 = 0.7(1).

In the ^{181}Ta-TDPAC experiments the Ta concentration was about 2% this may lead to the distortion of the crystal lattice. We modelled this situation by using 2x2x2 supercell containing 64 atoms. For the case of $Rh_{30}Ta_2Ge_{32}$ compound (when two Rh atoms replaced by Ta) the initial B20 structure is distorted and becomes triclinic with all Rh and Ge sites in nonequivalent positions. Actually, instead of two V_{zz}(Rh) and V_{zz}(Ge) values obtained previously for pure RhGe, we found the whole spectrum of V_{zz} values with two distinct distributions for Rh and Ge atoms with average EFGs V_{zz}(Rh) = 2.7×10^{17} V/cm^2 and V_{zz}(Ge) = 8.7×10^{17} V/cm^2 . The calculation performed for four different pairs of Ta atoms showed that V_{zz} and η values are close for all pairs and equal to $V_{zz}(Ta_1) = 2.5\times10^{17}$ V/cm^2 with η = 0.75 and $V_{zz}(Ta_2) = 5.0\times10^{17}$ V/cm^2 with η = 0.4.

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Investigation of the magnetic structure of $Rh_{1-x}Fe_xGe$ by small-angle neutron diffraction.

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The temperature evolution of the magnetic structure of the $Rh_{1-x}Fe_xGe$ compounds was studied by the small-angle neutron scattering (SANS) method. These compounds, synthesized at high pressure, crystallize into a non-centrosymmetric B20 cubic structure [1], which results in the appearance of the antisymmetric Dzyaloshinsky-Moriya interaction (DMI) and the formation of a magnetic spiral [2, 3]. However the RhGe compound exhibits a superconducting state below Tc = 4.5 K and weak ferromagnetism below Tm = 140 K [4] and does not possess any traces of the helical structure. It turned out that the replacement of Rh atoms by Fe in $Rh_{1-x}Fe_xGe$ compounds leads to helical magnetic ordering. The temperature of the transition from paramagnetic to helical state Tc increases with x from zero for RhGe to 278 K for FeGe [5]. At the same time, in the $Rh_{1-x}Fe_xGe$ compounds with iron concentrations $0 < x \leq 0.3$, the helicoidal magnetic structure is observed only at temperatures below 30 K. For compounds with x = 0.4 and 0.5 the scattering from the helical magnetic state was not registered with SANS. That indicates that the value of k_s is less 0.01 nm^{-1} for compounds with x = 0.4 and 0.5 and the transition of the magnetic system into the ferromagnetic state appears. The value of the wave vector at concentrations of $0.6 \leq x \leq 1.0$, increases with x up to $k_s = 0.09 \pm 0.005$ nm^{-1} at x = 1.0 [5]. Since the helical wave vector k_s is small and is almost constant with temperature for concentrations of $0.6 \leq x \leq 1.0$, it can be considered that the helical structure of these compounds is satisfactorily described by the model developed for FeGe [3]. Similar conversion of the wave vector to zero for intermediate concentrations was found in the study the magnetic structure of the compounds $Fe_{1-x}Mn_xGe$ and $Fe_{1-x}Co_xGe$ [5, 6]. This phenomenon was interpreted as a reversal of magnetic chirality with a change in concentration x and later confirmed by the theoretical calculations [7]. The question of the nature of the helicoidal magnetic structure in compounds with a large content of Rh ($0.0 < x \leq 0.3$) requires additional theoretical and experimental studies.

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Magnetic properties and Phase Separation in the noncentrosymmetric narrow band semiconductors $Ru_{1-x}Co_xGe$ (B20), synthesized under high pressure

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It is known that strong spin-orbit interactions which arises in solids that lack a center of inversion symmetry can lead to the formation of Weyl fermions open in the topological insulators [1] or to topological skyrmions observed in metal chiral magnets B20 [2-3].

Despite the well-known fact that the RuGe is a diamagnetic [2] small-band gap semiconductor and CoGe is a Pauli paramagnet semimetal [3] recently the weak magnetism was found in the system $Ru_{1-x}Co_xGe$ with x <= 0.046 [4]. These compounds have cubic B20 crystal structure (space group $P2_13$).

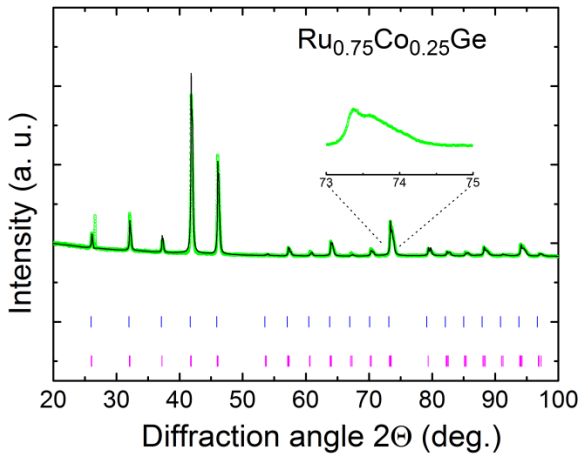

Fig. 1. The x-ray powder diffraction pattern of $Ru_{0.75}Co_{0.25}Ge$ ($x = 0.25$). The splitting of the peaks near 74 degrees is shown. The ticks at the bottom: blue from cubic B20 structure and pink from trigonal *R3* structure.

By the high pressure and temperature synthesis [5] we got $Ru_{1-x}Co_xGe$ samples with higher x (Co concentration). At low Co concentration x = 0.025; 0.05 and 0.1 the visual and Rietveld analyses of x-ray powder diffraction patterns showed that the $Ru_{1-x}Co_xGe$ samples are single phase with B20 crystal structure. At higher Co concentration x = 0.15; 0.25; 0.5 and 0.75 the new satellites appeared in x-ray powder diffraction patterns (see Fig. 1). These peaks could not be fitted with two B20 phases. The best fits of these patterns was achieved with two crystallographic phases: cubic B20 and trigonal *R3* (No. 146, $Z = 3$). At $x = 0.25$ the lattice parameters of R3 phase are a =

6.80421(9) Å, c = 8.2871(2) Å and its volume is approximately 75 % (the B20 cubic structure have the volume of 25 %). The Ru atoms are in *9b* Wyckoff positions, Co atoms are in *3a*, and Ge atoms are in *9b* and *3a* positions.

Magnetic properties were measured with VSM inserted in the PPMS. The measurements of the electrical resistivity and the magnetic susceptibilities at high pressure were performed on bulk polycrystalline samples.

To identify the magnetic structure of each compound, SANS measurements were carried out using the SANS-1 instrument at the FRM II reactor in Garching (Germany).

The measurements of electrical resistivity show that with the increasing of Co concentration the temperature dependence of resistivity change behavior from semiconductor to weak semiconductor and to metallic for x = 0.25. The value of the band gap E_g decreases from 0.16 eV for pure RuGe to 0.04 eV for sample with x = 0.1 and 0.03 eV for sample with x = 0.15.

The dependence of magnetic susceptibility versus temperature has a wide peak for samples with x = 0.025 and 0.05 with maximum at approximately 7 and 8 K, respectively. The magnitude of this peak noticeably increases for samples with x = 0.1 and 0.15 but the position of the maximum almost does not change.

The measurements of pressure dependence of the susceptibility peak measured for the sample $Ru_{0.9}Co_{0.1}Ge$ reveal the linear shift of the peak to the lower temperature with increasing the pressure from 9 K at 0 GPa to 5 K at 4.67 GPa. The intensity of the peak also decreases with the hydrostatic pressure.

The magnetization of the $Ru_{1-x}Co_xGe$ compounds with x = 0.05 - 0.75 is not saturated in the magnetic field up to 9 T at temperature T = 2 K.

The small angle neutron scattering patterns did not reveal static helical magnetic order in samples with x = 0.025, 0.05 and 0.1. But the samples with x = 0.025 and 0.1 contain ferromagnetic inclusions with the sizes approximately 200 and 125 nm. This may indicate to the formation of ferromagnetic droplet lattice in these compounds [6].

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Spin waves in the high-temperature phase in a rare-earth orthoferrite HoFeO3

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The multiferroic properties of rare-earth orthoferrites $RFeO_3$ (R is a rare-earth ion) have been discovered in recent years and the ferroelectric polarization was observed at rather high temperatures [1]. This can bring $RFeO_3$ closer to use as a new functional materials of advanced technologies. The coexistence of two magnetic subsystems - iron and rare-earth ones leads to a complex structure of magnetic interactions. The role of the Fe-R or R-R interactions increases with temperature decrease, leading to spin-orientational transitions [2]. An antisymmetric Dzyaloshinsky-Moria interaction (DMI) makes a significant contribution to magnetic interaction scheme, providing the weak ferromagnetic component. It is assumed that magnetic interactions in $RFeO_3$, and, apparently, DMI, are the origin of the ferroelectric polarization. According to recent precise single-crystal neutron diffraction studies the magnetic structure at $HoFeO_3$ below $T_N = 647$ K has weak ferromagnetic order with representation Γ_4 [3], the spin-reorientation phase transition to antiferromagnetic order Γ_1 takes place at $T_{SR1} = 55$ K and second reorientation transition $\Gamma_1 - \Gamma_2$ is at $T_{SR2} = 35$ K [4].

This work presents the results of experiments on inelastic neutron scattering on the holmium orthoferrite $HoFeO_3$, which were performed at ILL on the spectrometers IN12 and IN20. The measured dispersion maps are presented at Fig. 1.

For the description of magnetic excitations in $HoFeO_3$ the standard spin-wave approach was used. In the general case, a Hamiltonian must contain the following terms:

$$H = H^{Fe-Fe} + H^{Ho-Ho} + H^{Fe-Ho} \qquad (1)$$

where the first two terms describe exchange interactions and single-ion anisotropies within Fe and Ho subsystems, respectively. The third term describes the interaction between the Fe and Ho subsystems.

In our experiment energy maps were obtained at a temperature of T=65K, when Ho has zero magnetic moment and the second and third terms in the Hamiltonian are zero. Then dispersion curves can be described using interactions inside the Fe sublattice:

$$H^{Fe-Fe} = \sum_{ij} S_i^{Fe} \cdot J_{ij}^{Fe} \cdot S_j^{Fe} + \sum_i S_i^{Fe} \cdot A_i^{Fe} \cdot S_i^{Fe} + \sum_{mn} S_m^{Fe} \cdot D_{mn}^{Fe} \cdot S_n^{Fe} \qquad (2)$$

where S – spin operator, J - exchange interactions, A - single ion anisotropy, D - DM interaction parameter. In the calculations, the parameters of exchange interactions, anisotropy and DM are written as a 3x3 matrix. In this Hamiltonian, the first term dictates an overall shape and maximum energy of the Fe excitations.

The anisotropy determines a magnetic ground state [5] and gives rise to the gap in the Fe magnon spectrum [6]. Due to the orthorhombic symmetry of the Fe environment, the anisotropy anisotropy must be described two nonequivalent constants A_{ab} and A_c. In $RFeO_3$ with nonmagnetic R-ions, a dominating term A_{ab} stabilizes the $\Gamma 4$ phase. In $HoFeO_3$, the Ho-Fe interaction induces renormalization of the effective anisotropy constants. At $T \approx T_{SR2}$, A_{ab} and A_c become approximately equal [5]. Below T_{SR2} $A_c > A_{ab}$ stabilizes the $\Gamma 2$ phase.

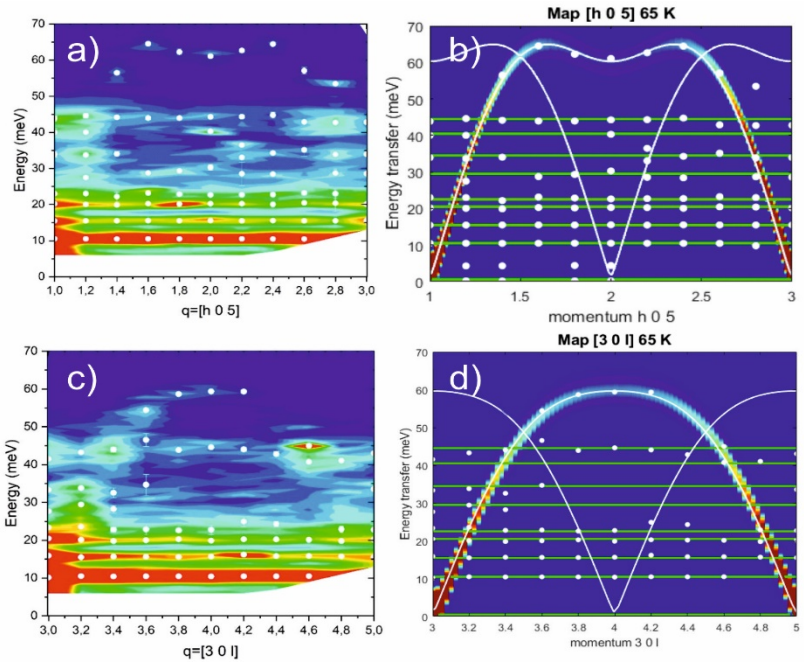

Fig. 1. Measured spin wave dispersion at 65 K along a) *h* direction; c) *l* direction; and calculated spin wave dispersion along b) *h* direction; d) *l* direction. Dots -positions of inelastic peaks. Green lines - energy levels of Ho^{3+}.

At temperatures above T_{SR1} = 55 K the moments of Fe are directed along *a* axis and are ordered antiferromagnetically with magnetic propagation vector $\boldsymbol{k}$ = (0 0 0). The antisymmetric DM interaction leads to a weak canting of the sublattices, which is described by two constants D1 and D2, responsible for the canting along the c and b axes, respectively.

The exchange interaction parameters were obtained which show that the main contribution to the formation of the magnetic structure is provided by the super exchange inside the Fe^{3+} subsystem. The exchange parameters were found to be $J_c^{Fe} = 4.901(5)$ meV along the axis *c* and in the plane *ab* to be $J_{ab}^{Fe} = 4.764(2)$ meV, and the next-nearest neighbors exchange is $J_{nnn}^{Fe} = 0.1507(3)$ meV. The distortion of the collinear structure is caused by the interaction of the DMI with the components *D1* = -0.12(2) meV and *D2* = -0.08(2) meV. These parameter values are in a good agreement with the data obtained by optical spectroscopy [7] and Raman spectroscopy [8].

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Comparative study of skyrmion crystal and triple helix states in non-centrosymmetric magnets.

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Skyrmion crystal (SkX) state in systems with Dzyaloshinskii-Moriya interaction (DMI) continues to attract an interest of researchers [1]. There are two different approaches to consideration of such configuration: as superposition of three helixes [2] or as densely packed skyrmions. These two kind of configurations give similar lattice of vortexes, with unit topological charge per cell.

We consider Belavin-Polyakov-like [3] skyrmions within stereographic projection approach. This approach represents multi-skyrmion configurations as a sum of stereographic projections of solitary skyrmions. Assuming that the shape of single skyrmions doesn't change crucially, we consider pairwise and non-pairwise interactions between skyrmions, that allow us to calculate the density of classical energy [4].

We further consider the normalized sum of three helices with additional magnetization parallel to external magnetic field, we parametrize helices by Jacobi elliptic functions instead of simple trigonometrical ones. Thus we have three variational parameters to minimize the energy: the helical pitch which is the lattice parameter of SkX, additional magnetization and elliptic parameter defining the shape and the size of skyrmions.

We compare the ground state energy in these two variational approaches at different values of external magnetic field, B. We find that the stereographic approach is a better description at larger B, when skyrmions are well separated, and the triple helix better describes the ground state configuration at smaller B, when individual skyrmions are deformed due to their interaction.

The predictions of these two variational approaches can be tested by the elastic magnetic scattering. We show that the two configurations have different intensities of second and third Bragg reflections from the helical crystal structure.

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Numerical study of magnetic hedgehog lattices in itinerant electron systems

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Chiral magnets have attracted much attention due to the interesting properties associated with their peculiar spin structures originating from the antisymmetric exchange interaction called the Dzyaloshinkii-Moriya interaction. For example, among the *B*20-type compounds, MnSi and MnGe show 2D skyrmion and 3D hedgehog lattices, respectively, both of which are characterized by three wave numbers (3Q). These peculiar spin structures induce an interesting quantum transport called the topological Hall effect [1]. In addition, a new chiral spin texture characterized by four wave numbers, the 4Q hedgehog lattice, has been recently reported in $MnSi_{1-x}Ge_x$ [2]. Although these systems are metallic and the coupling between spin and charge should be important, the effect of itinerant electrons on the chiral multiple-Q states has not been fully understood thus far.

In the present study, in order to clarify the stability of the chiral multiple-Q states in the 3D systems, we study an effective spin model including the coupling to itinerant electrons and the spin-orbit interaction by variational calculations and Monte Carlo simulations. We find several 3D chiral spin textures, including the skyrmion and hedgehog lattices with the 3Q and 4Q vectors shown in Fig. 1. These chiral multiple-Q states are stabilized due to the effective RKKY interaction, the effective biquadratic interaction, and the Dzyaloshinskii-Moriya interaction. We also discuss the behaviors of such multiple-Q spin textures in a magnetic field in comparison with the experimental data.

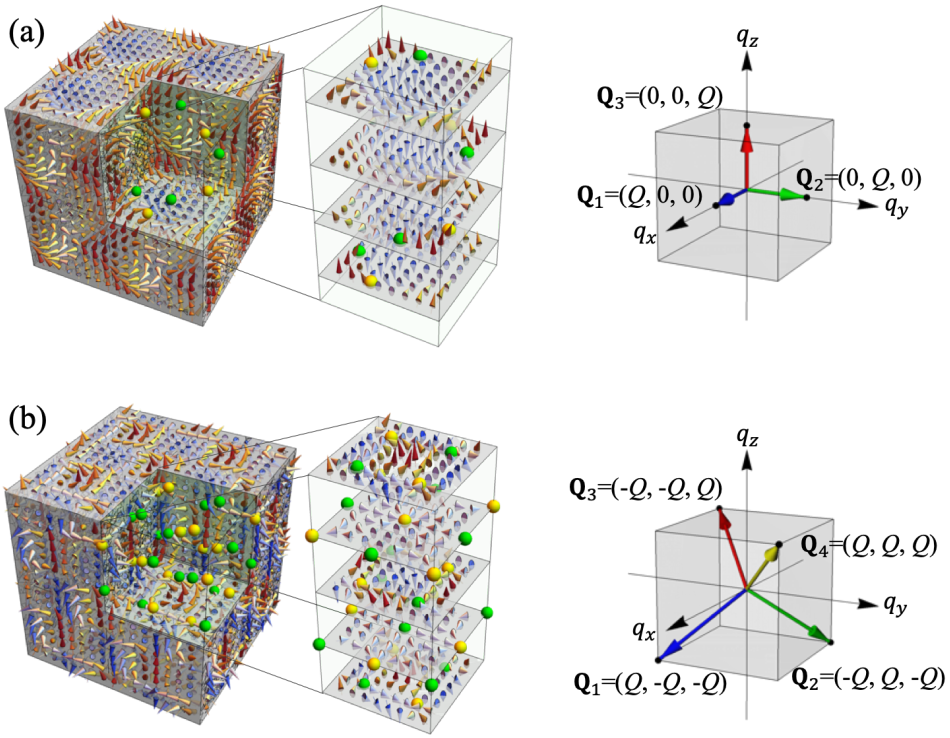

Fig. 1: Schematic pictures of (a) 3Q and (b) 4Q hedgehog lattices. The middle panels show the enlarged pictures of the magnetic unit cell. The yellow (green) balls represent the positions of hedgehogs (anti-hedgehogs). The right panels show the examples of the ordering vectors for the (a) 3Q and (b) 4Q cases.

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Participants

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