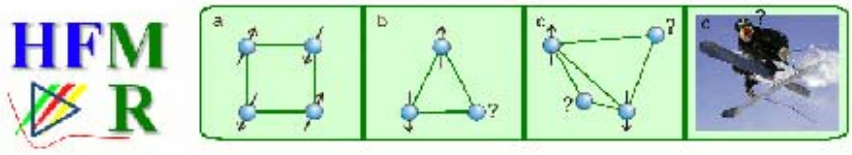

Magnetic Resonance in Highly Frustrated Magnetic Systems

HFMR 2010

February 1 – 4, 2010, Kranjska Gora, Slovenia

"Jožef Stefan" Institute

Faculty of Mathematics and Physics

1. Summary

The workshop "Magnetic resonance in highly frustrated magnetic systems" was organized to bring together leading European scientists (with prominent guests from overseas) in the field of magnetic resonance of frustrated magnetic systems. The workshop took place in Kranjska Gora, strating on February 1st, and finishing on February 4th, 2010. All together 51 participants attended the workshop from as many as 15 different countries. We heard 28 talks mainly divided into introductionary (more tutorial oriented) lectures (40 minutes) and a number of research lectures (20 minutes). The program and the book of abstracts can be downloaded from the workshop home-page http://titan.ijs.si/Pulsed_ESR/HFMR_2010/ .

The program was formally divided into four sessions: nuclear magnetic resonance, electron paramagnetic resonance, muon spin relaxation and theory of magnetic resonance in frustrated systems. The first lecture with the title "High-field NMR in Frustrated Quantum Antiferromagnets" was given by professor Claude Berthier from the Laboratorie National des Champs Magnetiques Intenses, Grenoble, France. Professor Berthier gave an excellent introduction to demonstrate the power of nuclear magnetic resonance in the study of quantum spin liquids especially at high magnetic fields and presented several examples, such as $SrCu(BO_3)_2$ or azurite diamond chain system. The other two introductionary lectures in the NMR session were given by professor Philippe Mendels ("NMR in triangular-based antiferromagnets") and professor Pietro Carretta ("Los-energy excitations in S=1/2 frustrated systems on a square lattice"). Muon spin relaxation session was introduced by professor Delmas de Reotier, CEA, France ("Muon spin relaxation studies of pyrochlore and triangular geometrically frustrated magnets") and professor Amit Keren, Technion, Israel ("Investigating distortions and correlations in frustrated magnets with muons"). Professor Sergei Zvyagin, Dresden High Magnetic Field Laboratory, gave an excellent demonstration for the application of Affleck-Oshikawa theory in 1-dimensional S=1/2 antiferromagnetic systems, while professor Ohta, Kobe University, Japan demonstrated that new detection of EPR signal using simple cantilevers can significantly improve the sensitivity if high-field EPR spectrometers and thus opens the possibility for studying the Kagome lattice antiferromagnets. Finally, professor Frederic Mila, EPFL, Switzerland discussed the

phase diagram of $SrCu(BO_3)_2$ in detail while professor Masaki Oshikawa presented his theory of ESR frequency shifts in antiferromagnetic chains. A number of young researchers also presented their work in the form of research lectures or during the poster session, which proved that groups participating in the ESF Network "Highly frustrated magnetism" strongly benefited from the mutual collaboration. Possible future actions to continue with the network activities were discussed during the conference.

2. Description of the scientific content of and discussion at the event

Since the discovery of High Tc Superconductivity, the idea of stabilizing new quantum states in correlated systems has been investigated both from the theoretical and the experimental directions. Frustration of antiferromagnetic interactions has been singled out as being a dominant ingredient in this quest for novel states, as proposed initially by Anderson in 1973 in his "resonating valence bond" model (RVB) of the triangular lattice. In the past decade, frustration in lattices that are less coordinated than the triangular one has been shown to lead to a possible stabilization of new states, including the RVB state. Such magnetic networks are observed in kagomé and pyrochlore systems (lattices of corner sharing triangles and tetrahedra respectively) and beyond. In fact stabilization of such exotic and intriguing ground states as spin liquids, orbital liquids, spin-ice systems has been found to occur when there is a competition between various degrees of freedom (magnetic, charge, orbital, elastic…) which turns out to lead to unusual effects when lattice frustration is present. Frustration is also of major importance in the physics of correlated fermions. High Tc superconductors were one example of this. The recently discovered superconducting and magnetic cobaltites present another system of growing importance, since frustration of the magnetic interactions is inherent to the triangular structure of the Co network. Furthermore, it has been shown that in magnetically frustrated systems very complex magnetic orders with incommensurate magnetic structure can develop at low temperatures. These systems in principle can allow for a simultaneous development of a ferroelectric order since the main symmetry restriction (center of inversion) has been removed by the incommensurate magnetic order. This new

class of multiferroic compounds has attracted a great deal of interest in the last few years and has been also a subject of research in the Network.

Magnetic resonance techniques, i.e. solid state nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR) or muon spin relaxation (muSR), are key experimental techniques for study of magnetically frustrated systems. Magnetic resonance probes are local, real-space probes, where the behavior of nuclear/electronic/muon spins can be monitored on a site-by-site basis. They provide a unique insight into the local static and dynamic magnetic structure and can thus as such compete with neutron diffraction techniques, for instance. As it has been discussed by professor Claude Berthier in his opening lecture, NMR still has certain advantage over neutron diffraction techniques; namely in NMR experiments unconventional quantum states at very high magnetic fields can be studied (present experimental setups for neutron diffraction experiments still does not allow for such experiments). All these arguments stimulated us to organize a workshop entitled “Magnetic resonance in highly frustrated systems” in Kranjska Gora, Slovenia. It should be stressed that Slovenia has a long tradition of magnetic resonance and Josef Stefan Institute has been for many years one of the leading European magnetic resonance laboratories.

Two-dimensional dimer system $SrCu(BO_3)_2$ has been discussed in a number of talks both from the experimental and theoretical point of view. In an opening lecture professor Berthier very low temperature (40 mK) and very high-magnetic field (up to 28 T) NMR experiments on this compound. A very complex phase diagram arises from all these experiments, which is composed of special “plateous” where a particular order of triplets is realized. It should be stressed that these experiments were strongly coupled to theoretical work of professor Frederic Mila, dr. Kai P. Schmidt and dr. Karlo Penc. It seems that after these experiments the physics of this very unique quantum magnetic system is being finally fully understood.

Being up-to-date, we had also a couple of lectures devoted to newly discovered iron-based superconductors. Nic Shannon addressed their magnetic properties from the geometrically frustrated point of view and compared them with the general J_1/J_2 phase diagram. His main conclusion was that 3D magnon theory is needed to explain the experimental data. Similar questions were posed by dr. Peter Jeglic, who focused on the

deviations from the simple Korringa relation in several pnictide systems, such as NdOFeAs, LiFeAs and $SrFe_2As_2$. The analysis, which closely follows the previous work on cuprates, seems to prove the existence of strong antiferromagnetic fluctuations.

Frustration, ground states and low-energy excitations in quasi-one-dimensional antiferromagnetic systems were also addressed in several lectures. Dr. Martin Klanjsek treated the so-called BPCB system in terms of Luttinger liquid theory and demonstrated that low-temperature NMR can be extremely powerfull and precise tool to determine main parameters in the Luttinger liquid theory. On the other hand, Sergei Zvyagin and Masaki Oshikawa analyzed temperature dependence of the ESR linewidth and lineshift in organic spin-1/2 chains, which present a test for the recent Affleck-Oshikawa theory of ESR.

A new multiferroic system, $FeTe_2O_5Br$ discovered by a close ESF network collaboration between the groups of Professor Helmuth Berger, EPFL, Lausanne, dr. Oksana Zaharko, PSI, Switzerland, and professor Denis Arčon, Institute Jozef Stefan, Ljubljana, Slovenia, has been reported by Matej Pregelj. Extensive NQR, μSR and neutron diffraction data allowed for the determination of the magnetic structure (which proved to be amplitude modulated incommensurate) and lead to the discovery of low-temperature ferroelectric transition. Multiferroicity in $YMnO_3$ was also discussed by Sergei Zvyagin.

3. Assessment of the results and impact of the event on the future direction of the field

Our main motivation to organize the workshop "Magnetic resonance in highly frustrated magnetic systems" was to:

a) Bring together leading European solid state magnetic resonance laboratories that are working in the field of frustrated magnetism,

b) Give the opportunity to young researchers to present their recent results and discuss these results in a friendly atmosphere,

c) Establish new collaborations with the aim to allow the access to some of the best European research infrastructure,

d) Discuss the future of the Network.

Looking back at the Workshop we can say that we largely succeeded to reach the above mentioned goals. As an organizer I was especially pleased to see many smaller groups discussing science during the lunch breaks meaning that we managed to bring together a small but very coherent group of scientists being interested in similar subjects. From my experience for a good conference such personal contacts are as important as good lectures.

Let us now assess in detail the above mentioned goals:

a) For many years European solid state magnetic resonance groups were linked together through the AMPERE society. This society organized regular schools, workshops, conferences and fostered know-how exchange. Unfortunately, this society has recently shifted its interest more towards other areas of physics and chemistry and we (especially groups coming from the former eastern countries) feel that these activities need to be reanimated. For this reasons, ESF network "Highly Frustrated Magnetism" is of extreme importance and we hope that workshop, such as "Magnetic resonance in highly frustrated magnetic systems", represent a first step in this direction. How successful we were in bringing excellent European groups together is seen only at looking at participating from the European high-magnetic-field laboratories. We had representatives from the Grenoble High Magnetic field Laboratory (prof. Claude Berthier), Dresden High Magnetic Field Laboratory (prof. Sergei Zvyagin) and CNRS & Universite Paul Sabatier; Toulouse, France. In addition many high-magnetic field groups from Russian Federation (prof. Sergei Sosin) or Japan (prof. Hitoshi Ohta or dr. Yugo Oshima) also participated. In addition we have also managed to geographically cover almost all countries participating in the ESF Network, which includes also Eastern European Countries (Czech Republic, Croatia, Russia, …).

b) We had a number of contributions from a post-doctoral researchers or PhD students. The reason for their participation is probably the fact that thanks to ESF and Slovenian Research Agency grants we were able to cover all local

expenses for the participants. In order to promote this exciting field of physics, this is probably the way to go in the future.

c) It is almost impossible to track all ideas for future collaborations that emerged during the conference. Speaking for the Institute Jozef Stefan group, we are happy to stress, that the collaboration with the Orsay group (collaboration between professor Philippe Mendels and dr. Andrej Zorko) as well as with the Grenoble group (Professor Claude Berthier and dr. Martin Klanjšek) is developing very well. In addition we were discussing possible experiments in Dresden (high-field ESR experiments together with professor Sergey Zvyagin) and in Tallinn (low-temperature MAS experiments together with professor Raivo Stern).

d) The future of the network was mainly discussed informally during the breaks. There is a common opinion that Network activities should continue in the future but that we still need to find a suitable framework for this.

4. Final programme of the meeting

Program - HFMR 2010, Kranjska Gora, 1.-4. February 2010

Monday, February 1, 2010 **NMR Session**

8.25-8.30 Opening (D. Arčon)

Chair: P. Carretta

8.30-9.10	Claude Berthier	High Field NMR Study of Field Induced Exotic Ground States in Frustrated Quantum Spin Systems
9.10-9.30	Raivo Stern	Frustration and Bose-Einstein Condensation in Oxide Dimer Systems Investigated by NMR
9.30-9.50	Martin Klanjšek	From Luttinger liquids to exotic field induced phases in coupled spin chains and ladders

Chair: A. Keren

10.30-11.10	Philippe Mendels	NMR in triangular-based antiferromagnets
11.10-11.30	Andrej Zorko	Magnetism of rare-earth based Langasites
11.30-11.50	M. Sato	Field and temperature dependence of NMR relaxation rate for multi-polar liquid phases in frustrated spin chains

Chair: A. Zorko

18.30-19.10	Pietro Carretta	Low energy excitations in *S*=1/2 frustrated systems on a square lattice
19.10-19.30	Matej Pregelj	Magnetoelectric Effect in Oxohalide Tellurites: a New Family of Multiferroics Emerging from the Amplitude Modulated Magnetic Structure
19.30-19.50	Magdalena Wencka	Electronic transport and NMR study of the YbCu4.25 heavy-fermion intermetallic compound

Tueasday, February 2, 2010 **mSR Session**

Chair: P. Mendels

8.30-9.10	P. Dalmas de Reotier	Muon spin relaxation studies of pyrochlore and triangular geometrically frustrated magnets
9.10-9.30	Alexandros Lappas	Muons see the Order in the Frustrated spin-2 Triangular Lattice α-NaMnO2
9.30-9.50	H. Nakamura	Spin and lattice dynamics of correlated tetrahedral clusters in GaNb$_4$S$_8$

Chair: R. Stern

10.30-11.10	Amit Keren	Investigating distortions and correlations in frustrated magnets with muons
11.10-11.30	Nic Shannon	Are iron-pnictides frustrated magnets ?

11.30-11.50	Peter Jeglič	Antiferromagnetic correlations in iron-pnictide superconductors

18.30-20.00	POSTER SESSION

Wednesday, February 3, 2010 **EPR Session**

Chair: H. Ohta

8.30-9.10	Sergei Zvyagin	High-Field ESR in Spin Systems with Competing Magnetic Interactions
9.10-9.30	Yugo Oshima	High-Frequency ESR studies on frustrated molecular systems - application to Keplerates
9.30-9.50	Karlo Penc	Bond-wave calculation of the ESR spectra in SrCu$_2$(BO$_3$)$_2$

Chair: S. Sosin

10.30-11.10	H-A. Krug von Nidda	Electron Spin Resonance in Frustrated Magnets
11.10-11.30	S. C. Furuya	ESR of quantum spin chain in the classical limit
11.30-11.50	Yutaka Fujii	Magnetic property of 2D triangular lattice antiferromagnet HCrO$\bm{_2}$

Chair: S. Zvyagin

18.30-19.10	H. Ohta	Spin Liquid State observed in S=1/2 Kagome Lattice Antiferromagnet BaCu3V2O8(OH)2 by High-Field ESR
19.10-19.30	Sergey Sosin	Magnetic resonance study of pyrochlore antiferromagnets Gd$_2$Sn$_2$O$_7$ and Er$_2$Ti$_2$O$_7$

20.00 Conference Dinner

Thursday, February 4, 2010 **Theory Session**

Chair: A. Lappas

8.30-9.10	Frederic Mila	Theory of high magnetic-field phases of frustrated magnets revealed by NMR
9.10-9.30	Kai P. Schmidt	Plateaux and Supersolid Phases in SrCu$_2$(BO$_3$)$_2$
9.30-9.50	Samir El Shawish	Spin Hamiltonian of the triangular layered α-NaMnO$_2$ system

Chair: H-A. Krug von Nidda

10.30-11.10	Masaki Oshikawa	Perturbation theory of the ESR frequency shift
11.10-11.30	Alexander Tsirlin	Comparing experiment and theory for spin-$\frac12$ frustrated square lattice model
11.30-11.50	Closing remarks (P. Mendels)	

POSTER SESSION

Anja Wolter	Magnetic-field induced phases in the frustrated ferromagnetic S = 1/2 Heisenberg chain linarite
Alireza Akbari	Evidence for gap symmetry and the impurity effect on the Fe-pnictide
Andrew Smerald	What can magnetic resonance tell us about square lattice frustrated magnets?
K. Belakroum	ESR Measurements of Frustrated Spinel System Cu}}$_{{\Large y%}}${\Large \textbf{Cr}}$_{{\Large y}}${\Large \textbf{Zr}}$_{{\Large 2-y}}$%{\Large \textbf{Se}}$_{{\Large 4}}
Prando Giacomo	Anomalous low-frequency fluctuations in the itinerant pyrochlore Sm2Mo2O7
O. Janson	Volborthite Cu$_3$V$_2$O$_7$(OH)$_2\cdot$2H$_2$O: Orbital ordering \newline on a distorted kagom\'e geometry
Judit Romhanyi	Bond-wave calculation of the ESR spectra in the 1/3 magnetization plateau state of the SrCu$_2$(BO$_3$)$_2$
Federico Becca	Spin-liquid and magnetic phases in the anisotropic triangular lattice: the case of κ-(ET)$_2$X
Vadim Ohanyan	Exact solution of the model of sawtooth chain with Ising and Heisenberg bonds and lattice distortions.
Jorge Lago	CdEr2Se4: A new Erbium spin ice system in a spinel structure
Karel Kouril	Magnetic axis switching in magnetite studied by NMR
Peter Jeglič	NMR of Cs3C60 - role of frustrated lattice on high-T superconductivity in fullerides
Peter Jeglič	NMR Study of LiFeAs
Anton Potočnik	High-pressure EPR and NMR Study of (CH3NH2)K3C60
Anton Potočnik	EPR Study of Vanadium Oxobenzoate
Ana Smontara	High-pressure transport study of Co1/3NbS2
Dejan Djokić	High field ESR temperature study of (EDT-TTF-CONH)$_{6}$Re$_{8}$Se$_{6}$(CN)$_{6}$ under pressure