# Mott physics beyond the Heisenberg model

**Oriel College, Oxford, 16–18 September, 2014**

**Abstracts**

## Wednesday 17 September, 2014

### 09.30 Giniyat Khaliullin (MPI, Stuttgart)

*Magnetism and doping effects in spin-orbit coupled $d^4$ and $d^5$ Mott insulators*

After a brief introduction to transition metal compounds with strong spin-orbit coupling, I will present our recent theoretical work addressing magnetic order and doping effects in $d^4$ and $d^5$ Mott insulators (such as ruthenates, osmates, iridates).

### 10.00 Kazunari Yamaura (National Institute for Materials Science, Japan)

*High-pressure and high-temperature synthesis of 5d oxides: perovskite and related materials*

Materials containing $5d$ element have recently attracted increasing attention owing to their potential significance in advanced applications in a field of such as spintronics, topological insulator, and unconventional superconductivity. In general, $5d$ atoms exhibit significant radially extended valence orbitals and large spin-orbit couplings, which distinguish their correlated electrons behavior from that of $3d$ material. Unexpected discovery of a Slater-like transition in a perovskite oxide $NaOsO_3$, and a ferroelectric-like transition in a metallic oxide $LiOsO_3$ represent unique features of the $5d$ oxides. Recently, we have successfully prepared $5d$ compounds $Ca_2MOsO_6$ ($M$ = Ca, In, Zn, Fe, Mn) under a certain high-pressure and high-temperature condition, allowing investigation of newly compositional $5d$ oxides. In this talk, we report progress of our studies on the osmium oxides and related materials.

### 10.30 – 11.00 Coffee/Tea

### 11.00 George Jackeli (MPI, Stuttgart)

*Spin-orbit induced magnetic order and dynamics in insulating iridates*

I will review recent theoretical and experimental results on the effects of spin-orbit coupling in the insulating iridium oxides. Three representative examples will be discussed: (i) single-layer $Sr_2IrO_4$, with nearly isotropic magnetic dynamics of Heisenberg-type; (ii) double-layer $Sr_3Ir_2O_7$, with large anisotropy gap of Ising-type; and (iii) hexagonal iridates $A_2IrO_3$ ($A$ = Li, Na), hosting large bond-directional magnetic anisotropies of Kitaev-type.

### 11.30 Radu Coldea (University of Oxford)

*Unconventional magnetic order stabilized by Kitaev interactions in the three-dimensional honeycomb polytypes of $Li_2IrO_3$*

The recently-synthesized iridates $\beta$- and $\gamma$-$Li_2IrO_3$ have been proposed as candidates to display novel magnetic behaviour stabilized by frustration effects from bond-dependent, anisotropic interactions (Kitaev model) in three-dimensional generalizations of a honeycomb lattice. Using single-crystal resonant magnetic x-ray diffraction we find in both cases a surprisingly complex, yet highly symmetric, incommensurate magnetic structure with non-coplanar and counter-rotating Ir moments [1,2]. Our experimental results combined with a theoretical analysis [3] of candidate spin Hamiltonians provide strong evidence that both $\beta$ and $\gamma$-$Li_2IrO_3$ realize a spin Hamiltonian with dominant Kitaev interactions.

[1] A. Biffin, R.D. Johnson, I. Kimchi, R. Morris, A. Bombardi, J.G. Analytis, A. Vishwanath, and R. Coldea, arXiv:1407.3954 (2014).

[2] A. Biffin, R.D. Johnson, Sungkyun Choi, F. Freund, S. Manni, A. Bombardi, P. Manuel, P. Gegenwart, R. Coldea, arXiv:1408.0246 (2014).

[3] I. Kimchi, R. Coldea and A. Vishawanath, arXiv:1408.3640 (2014).

**12.00 Maria Daghofer (IFW Dresden/ University of Stuttgart)**

*Spin-orbital excitations of square-lattice and exotic ground states of hexagonal-symmetry iridates*

We investigate excitations of the low-energy $j = 1/2$ system stabilized by spin-orbit coupling in square-lattice iridates, in particular spin-orbital excitons into the $j = 3/2$ states. The analysis supports the interpretation as a spin-orbit-assisted Mott insulator and reveals a sharp quasi- particle-like peak as expected for a hole in a Mott insulator, even though the spin-orbit excitation is charge neutral. We then investigate potential ground states of frustrated Kitaev-Heisenberg models in hexagonal symmetry and find a persistent tendency towards incommensurate non-coplanar patterns. Both on triangular and honeycomb lattices, we find regular lattices of topological defects, somewhat similar to skyrmion lattices, in the ground state.

**12.30 Silke Biermann (École Polytechnique, Paris)**

*Interplay of spin-orbit coupling and Coulomb correlations: a "first principles" dynamical mean field perspective*

We will discuss the Mott transition in multi-orbital Hubbard systems, with particular emphasis on the notion of an effective orbital degeneracy found to be crucial not only in $3d$ transition metal oxides [1], but also in $4d$ rhodates and $5d$ iridates [2]. Dynamical mean field theory will be introduced as a tool for describing the interplay of correlations, crystal fields, and spin-orbit interactions from first principles, that is, without adjustable parameters. For $Sr_2IrO_4$, we will also comment on the role of non-local Coulomb correlations, shown to be crucial for understanding the spectral properties [3]. Finally, we will end with a discussion of the general prospects of electronic structure calculations for correlated materials.

[1] E. Pavarini, S. Biermann, A.I. Poteryaev, A.I. Lichtenstein, A. Georges, O.K. Andersen, Phys. Rev. Lett. **92** 176403 (2004).

[2] C. Martins, M. Aichhorn, L. Vaugier, S. Biermann, Phys. Rev. Lett. **107** 266404 (2011).

[3] C. Martins, L. Perfetti, S. Biermann, in preparation.

**13.00 – 14.30 Lunch**

### 14.30 Jeroen van den Brink (IFW and Technische Universität, Dresden)

*Resonant Inelastic X-ray Scattering on high $T_c$ cuprates and magnetic iridates*

Resonant Inelastic X-ray Scattering (RIXS) provides direct access to elementary charge, spin and orbital excitations in complex oxides. As a technique it has made tremendous progress with the advent high-brilliance synchrotron X-ray sources. From the theoretical perspective the fundamental question is to precisely which low-energy correlation functions RIXS is sensitive. Depending on the experimental RIXS setup, the measured charge dynamics can include charge-transfer, phonon, *d*–*d* and orbital excitations [1]. The focus of this talk will be on RIXS as a probe of spin dynamics and superconducting gap of high-$T_c$ cuprates [2–4] and the combined magnetic and orbital modes in strongly spin-orbit coupled iridium-oxides [5–7].

[1] L. Ament *et al.*, Rev. Mod. Phys. **83**, 705 (2011).
[2] L. Braicovich *et al.*, Phys. Rev. Lett. **104**, 077002 (2010).
[3] M. Dean *et al.* Nature Materials **11**, 850 (2012).
[4] P. Marra *et al.*, Phys. Rev. Lett. **110**, 117005 (2013).
[5] L. Ament *et al.*, Phys. Rev. B **84**, 020403 (2011).
[6] J. Kim *et al.*, Phys. Rev. Lett. **108**, 177003 (2012).
[7] H. Gretarsson *et al.*, Phys. Rev. Lett. **110**, 076402 (2013).

### 15.00 Daigorou Hirai (University of Tokyo)

*Exploration of exotic phases produced by strong spin-orbit coupling in Ir oxide thin films*

In 5*d* iridium oxides, a large spin-orbit coupling (SOC) of $\sim$0.5 eV, inherent to heavy 5*d* elements, is not small as compared with other relevant electronic parameters, including Coulomb $U$, transfer $t$ and crystal field splitting $D$, which gives rise to a variety of exotic ground states. In the layered perovskite $Sr_2IrO_4$, spin-orbital Mott state with $J_{\text{eff}} = 1/2$ is realized due to the novel interplay of those energy scales [1,2]. Another example can be seen in orthorhombic perovskite $SrIrO_3$ and $CaIrO_3$, where a semi-metallic state originating from a combination of its lattice structure and a large SOC is observed [3]. Recent technical advances in the atomic-scale fabrication of oxide heterostructures have enabled us to create novel ground states of matter. Utilizing subtle competition of the ground states in iridium oxides, we successfully tailor a spin-orbital magnetic insulator out of a semi-metal $SrIrO_3$ by controlling dimensionality using $SrIrO_3/SrTiO_3$ super-lattice structure [4]. This is an important step towards the realization of topological phased in complex iridates with very strong SOC. The bilayers of perovskite iridate grown along the [111] crystallographic axis are theoretically predicted to be a candidate for a topological insulator [5]. However, unlike (001) crystallographic surface, polarity of (111) surface make it difficult to obtain well-defined atomically flat surface. We recently overcame the difficulties and realized iridate superlattice structure along the [111] axis. In this presentation, I focus on those exotic phases realized in Ir oxides thin films.

### 15.30 Hae-Young Kee (University of Toronto)

*Generic spin model for the honeycomb Iridates and effects of trigonal distortion*

Recently, realizations of Kitaev physics have been sought in the $A_2IrO_3$ family of honeycomb iridates, originating from oxygen-mediated exchange through edge-shared octahedra. However, for the $j_{\text{eff}} = 1/2$ Mott insulator in these materials exchange from direct *d*-orbital overlap is relevant, and it was proposed that a Heisenberg term should be added to the Kitaev model.

Here we provide the generic nearest-neighbour spin Hamiltonian for ideal honeycomb lattice, when both oxygen-mediated and direct overlap are present, containing a bond dependent off-diagonal exchange in addition to Heisenberg and Kitaev terms. We analyze this complete model using a combination of classical techniques and exact diagonalization. Near the Kitaev limit, we find new magnetic phases, 120 degree and incommensurate spiral order, as well as extended regions of zigzag and stripy order. We further show that near the ferromagnetic Kitaev limit, a small trigonal distortion turns the spiral- into a zigzag-phase, which may be relevant for understanding $Na_2IrO_3$ and $Li_2IrO_3$.

Ref: J. Rau and H.-Y. Kee, Phys. Rev. Lett. **112**, 077204 (2014).

**16.00 – 16.30 Tea/Coffee**

**16.30 James Vale (University College, London)**

*Emergent magnetic excitation in the pyrochlore osmate $Cd_2Os_2O_7$*

$5d$ TMOs exhibit a number of exotic electronic and magnetic phenomena, as a consequence of the interplay between the electron correlation energy, $U$, the bandwidth $W$, and the spin-orbit coupling, all of which are of similar energy in these compounds. Osmate compounds provide a particularly interesting route to unusual electronic phases and metal-insulator transitions, for example $NaOsO_3$, an example of a Slater insulator; and $LiOsO_3$, recently reported as a type of 'ferroelectric metal'.

The pyrochlore osmate $Cd_2Os_2O_7$ undergoes a metal-insulator transition (MIT) which is concomitant with the onset of all-in, all-out antiferromagnetic order (stabilised by the strong single-ion anisotropy), and is notable since no structural distortion is associated with it. Recent resonant inelastic X-ray scattering (RIXS) measurements of the electronic and magnetic excitations reveal the presence of an emergent excitation which disappears at the Néel temperature / MIT, and is attributed to a local spin-flip process which breaks the all-in, all-out magnetic structure.

**16.45 Marein Rahn (University of Oxford)**

*Magnetic structure of the unconventional insulator $Ca_2Os_2O_7$ (Imma)*

The "weberite structure of orthorhombic calcium osmate is a variation of the pyrochlore in which only half of the osmium ions are magnetically frustrated. The material is a poor metal at high temperatures, but evolves into an unconventional insulating state below 327 K. The opening of the gap also sees a continuous magnetic ordering process, atypical of the traditional Mott scenario. In order to clarify the role of electronic correlation and spin orbit interaction in this strange phase transition, we are presently performing a comprehensive study comprising neutron and x-ray scattering on poly- and single-crystalline samples. In my presentation, I will focus on the microscopic evidence on the magnetic ordering process obtained from neutron powder diffraction.

**17.00 Yahua Yuan (National Institute for Materials Science, Japan)**

*High pressure synthesis, crystal structure, and magnetic properties of the $KOsO_3$*

Recently, oxides containing 5d transition metals have attracted great interest. For instance, $KOs_2O_6$ shows superconductivity [1]. Metal-insulator transition was observed for $Ln_2Ir_2O_7$ ($Ln$ = Nd–Ho) [2]. Our group synthesized $Ca_3LiOsO_6$ which shows an antiferromagnetic transition at the remarkable high temperature 117 K [3]. So far, little is known about the nature and properties of 5$d$ oxides. Single crystal of the osmium-containing compound $KOsO_3$ with hexagonal structure has been successfully grown under high-pressure condition, for the first time. The crystal structure of $KOsO_3$ was characterized as an order cubic structure of space group $Im\overline{3}$. The electromagnetic analysis shows that the crystal exhibits a metal-like behavior below 184 K and undergoes antiferromagnetic transition at 24 K.


[1] S. Yonezawa *et al.*, Superconductivity in a pyrochlore-related oxide $KOs_2O_6$, J. Phys. Condens. Matter **16**, L9 (2004);

[2] K. Matsuhira, M. Wakeshima, Y. Hinatsu, and S. Takagi, Metal-Insulator Transitions in Pyrochlore Oxides $Ln_2Ir_2O_7$. J. Phys. Soc. Jpn **80**, 094701 (2011);

[3] Y.-G. Shi *et al.*, Crystal Growth and Structure and Magnetic Properties of the 5$d$ Oxide $Ca_3LiOsO_6$: Extended Superexchange Magnetic Interaction in Oxide, J. Am. Chem. Soc. **132**, 8474 (2010).


**17.15 Amir Haghighirad (University of Oxford)**

*Magnetism in the S=2 frustrated spinel $GeFe_2O_4$*

$GeFe_2O_4$ is a cubic spinel $AB_2O_4$ with magnetic $Fe^{2+}(3d^6)$ ions located on the octahedral B-sites and non-magnetic $Ge^{4+}$ ions sitting on the tetrahedral A-sites. This material is interesting in the field of magnetic frustration that has similar lattice to pyrochlores, but is populated with a magnetic 3$d$ transition metal ion, $Fe^{2+}$, rather than a rare earth ion. $Fe^{2+}$ is expected to have much smaller magnetic anisotropy, and exchange interactions are likely to dominate over dipolar ones, which would lead to a very different magnetic state that can be compared to the well-studied "spin-ice" materials. We have synthesized polycrystalline as well as single crystals of $GeFe_2O_4$ and have performed structural characterisation, magnetometry experiments, SR experiments, thermodynamic investigations and neutron diffraction. Our studies reveal in $GeFe_2O_4$ two successive magnetic anomalies attributed tentatively to the onset of distinct magnetic orders near 6.5 and 7.6 K. These anomalies are supported by recent neutron diffraction experiments indicating magnetic diffraction peaks at low temperatures, but surprisingly the data suggest the co-existence of two propagation wave vectors. The presence of two magnetic propagation vectors is surprising and indicates a rather unusual magnetic order pattern.

**17.30 Zhuo Feng (University College, London)**

*High pressure studies of 5d transition metal oxides*

The 5$d$ transition metal oxides (TMOs) have attracted a lot of interest recently as their crystal field, Coulomb repulsion and spin-orbit coupling are all competing at an equal level. The electronic ground states are believed to be highly sensitive to structural distortion by pressure, and hence, we have carried out intensive x-ray diffraction (XRD) experiments on the perovskite $Sr_3Ir_2O_7$ and pyrochlore $Eu_2Ir_2O_7$, by using a diamond anvil cell to 60 GPa. An emergent structure transition is identified in $Sr_3Ir_2O_7$ at about 53 GPa, while this material still remains insulating at this pressure [1]. On the other hand, for $Eu_2Ir_2O_7$, there is no obvious structural change up to 25 GPa, while a MIT occurs at a low pressure of 7 GPa [2].

In parallel with x-ray diffraction, we will also show our developed new patterned diamond/moissanite anvil cell (DAC/MAC) by introducing cleanroom fabrication facilities at UCL. With this new technique, we are able to perform *in-situ* transport measurement within hydrostatic high pressure environment, and search for the novel metal-insulation transition or quantum critical point in potential systems.

[1] Zocco *et al.*, J. Phys.: Condens. Matter **26** (2014) 255603.

[2] Tafti *et al.*, Phys. Rev. B **85**, 205104 (2012).

**19.30 Workshop banquet**

## Thursday 18 September, 2014

### 09.00 Philipp Gegenwart (University of Augsburg)

*Electronic and magnetic properties of honeycomb iridates*

Honeycomb iridates $A_2IrO_3$ recently attracted considerable interest due to proposed topological phases and frustrated magnetism related to the interplay of large spin-orbit coupling, crystal field splitting and electronic correlations. We report bulk and spectroscopic measurements on different members of this family with $A$ = Na or Li (and various substitutions) probing the electronic and magnetic properties.

Work in collaboration with S. Manni, F. Freund, Y. Singh, S. Choi, R. Coldea, F. Luepke, M. Wenderoth, M. Altmeyer, H. O. Jeschke, I. Mazin and R. Valenti. Financial support through DFG SPP 1666 and the Helmholtz virtual institute 521 is acknowledged.

### 09.30 Amalia Coldea (Oxford University)

*Quantum oscillations in a metallic pyrochlore iridate, $Bi_2Ir_2O_7$*

We report quantum oscillations observed in single crystals of $Bi_2Ir_2O_7$ using torque magnetometry in high magnetic fields up to 33 T and low temperatures to 0.3 K. Quantum oscillations allow to determine the extremal areas of the Fermi surface perpendicular to the magnetic field, the quasiparticle masses and also the scattering time. Our results are compared with first-principle band structure calculations that take into account the effects of the spin-orbit coupling. We find evidence both for small and large Fermi surfaces and the effective masses are unexpectedly light. The effect of the magnetic field on the electronic structure of $Bi_2Ir_2O_7$ will be also discussed.

### 10.00 Andrew Princep (University of Oxford)

*Novel electronic phenomena in 5d osmium oxides*

The 5$d$ transition metal oxides host a wide range of physical phenomena due to the interplay between the electron correlation, $U$, the crystal field energy and the spin-orbit coupling, which are of similar magnitude in these compounds. Osmium presents both synthetic challenges and intriguing opportunities owing to the ready adoption of $d^1$, $d^2$, $d^3$, and $d^4$ configurations in oxides, which has a profound impact on the single-ion properties.

Recently the investigation of osmate materials have revealed an array of phenomena comparable to that found in the iridates. For example: metal-insulator transitions have been observed in both the slater [1] and mott limits [2], "ferroelectric-like" structural transitions [3] have been reported, as have unconventional superconductivity and remarkably high temperature half-metallic ferromagnetism (730 K). We have recently synthesised several new osmates using high pressure methods, and in addition to presenting an overview of the pyrochlore, perovskite, and spin-chain osmate materials I will describe these newly synthesised materials and present the results of diffraction and bulk property measurements designed to determine the structural and electronic ordering they exhibit.

[1] S. Calder *et al.*, Phys. Rev. Lett. **108**, 257209 (2012).
[2] O. N. Meetei *et al.*, Phys. Rev. Lett. **110**, 087203 (2013).
[3] Y. Shi *et al.*, Nature Materials **12**, 1028 (2013).

[4] Galati *et al.*, J. Mater. Chem. **17**, 160 (2007).
[5] Y. Krockenberger *et al.*, Phys. Rev. B **75**, 020404(R) (2007).

**10.30 – 11.00 Coffee/Tea**

**11.00 Matthias Vojta (Technische Universität, Dresden)**

*Magnetism in spin models for depleted honeycomb-lattice iridates: Spin-glass order towards percolation*

Iridates are characterized by a fascinating interplay of spin-orbit and electron-electron interactions. The honeycomb-lattice materials $A_2IrO_3$ ($A$ = Na, Li) have been proposed to realize pseudospin-1/2 Mott insulating states with strongly anisotropic exchange interactions, described by the Heisenberg-Kitaev model, but other scenarios involving longer-range exchange interactions or more delocalized electrons have been put forward as well. Here we study the influence of non-magnetic doping, i.e., depleted moments, on the magnetic properties of experimentally relevant variants of the Heisenberg-Kitaev and Heisenberg $J_1 - J_2 - J_3$ models. We generically find that the zigzag order of the clean system is replaced, upon doping, by a spin-glass state with short-ranged zigzag correlations. We determine the spin-glass temperature as function of the doping level and argue that this quantity allows to experimentally distinguish the different proposed spin models when the doping is driven across the site percolation threshold of the honeycomb lattice.

**11.30 Félix Baumberger (University of Geneva)**

*Doping evolution of the correlated insulator $Sr_3Ir_2O_7$*

The layered perovskite iridates share key structural and electronic properties with the cuprates. Intriguingly, recent angle-resolved photoemission (ARPES) data from lightly doped $Sr_2IrO_4$ reproduced much of the unique phenomenology observed in underdoped cuprates, including open Fermi arcs and a temperature dependent pseudogap. Evidence for strong correlations were also reported for Ru-doped. Here we use ARPES to characterize the electron doping evolution of $(Sr_{1-x}La_x)_3Ir_2O_7$. Concomitant with the metal insulator transition around $x \approx 0.05$ we find the emergence of coherent quasiparticle states forming a closed small Fermi surface of volume $3x/2$, where $x$ is the independently measured La concentration. The quasiparticle weight $Z$ remains large along the entire Fermi surface, consistent with the moderate renormalization of the low-energy dispersion. This indicates a conventional, weakly correlated Fermi liquid state with a momentum independent residue $Z \approx 0.4$ in lightly doped $Sr_3Ir_2O_7$.

**12.00 Youguo Shi (Institute of Physics, Beijing)**

*New materials research on 5d osmium oxide systems*

$5d$ transition metal oxides may display physical properties very different from $3d$ transition metal compounds due to the reduced electronic correlation strength and enhanced spin-orbit coupling (SOC) effect. Their competition or cooperation can result in exotic properties. In recent years our main focus of our research is to search for new materials in $5d$ osmium oxide materials: the exploration of novel and high quality osmium oxides; the investigation structure and physical properties of these new materials. We succeeded to prepare several new compounds from osmium oxides, and studied their structure and physical properties. We found some very interesting results from these osmium oxide materials, such as: 1. Perovskite structure $NaOsO_3$ undergoes a metal-insulator transition (MIT) near 410 K, suggesting it should be a "Slater insulator" transition; 2. $Ca_3LiOsO_6$ shows exotic superexchange magnetic interaction (Os–O)-(O–Os); 3. $LiOsO_3$ remains a metal down to the 2 K and yet undergoes a structural transition that is identical to the ferroelectric transition, which discovery represents the first clear-cut example of a "ferroelectric" metal proposed by Anderson and Blount; and so on. All these studies on 5*d* osmium oxides help us understand the 5*d* electrons well.

### 12.30 Stephan Rachel (Technische Universität, Dresden)

*Spiral order in the honeycomb iridate* $Li_2IrO_3$

The honeycomb iridates $A_2IrO_3$ ($A$ = Na, Li) constitute promising candidate materials to realize the Heisenberg-Kitaev model (HKM) in nature, hosting unconventional magnetic as well as spin liquid phases. Recent experiments suggest, however, that $Li_2IrO_3$ exhibits a magnetically ordered state of incommensurate spiral type which has not been identified in the HKM. We show that these findings can be understood in the context of an extended Heisenberg-Kitaev scenario satisfying all tentative experimental evidence: (i) the maximum of the magnetic susceptibility is located inside the first Brillouin zone, (ii) the Curie-Weiss temperature is negative relating to dominant antiferromagnetic fluctuations, and (iii) significant second-neighbor spin-exchange is involved.

### 13.00 – 14.30 Lunch

### 14.30 Alberto de la Torre (University of Geneva)

*Doping evolution of the strong spin-orbit insulator* $Sr_3Ir_2O_7$ *from angle-resolved photoemission*

We report angle resolved photoemission data characterizing the doping evolution of the correlated insulator $(Sr_{1-x}La_x)_3Ir_2O_7$. For La concentrations $x > 0.05$ coherent quasiparticles with light effective masses emerge along the $(\pi, \pi)$ direction, while the spectral weight around $(\pi, 0)$ is suppressed,reminiscent of the pseudogap phase in cuprates. However, we show that carriers doped into $Sr_3Ir_2O_7$ form a closed Fermi surface pocket with an area corresponding to the doping $x$, consistent with the formation of a weakly correlated conventional Fermi liquid state for $x > 0.05$. In the metallic phase,the spectra show a peak-dip-hump line shape, indicative of coupling to bosonic modes.

### 14.45 Paul Freeman (EPFL, Lausanne)

*CAMEA: The Continuous Angle Multiple Energy Analysis Instrument*

The CAMEA is a neutron secondary spectrometer designed for optimal efficiency in the horizontal scattering plane to enable detailed and/or rapid mapping of excitations. A spectrometer thus optimized is ideally suited to studies of materials under extreme environments, the complex sample environs of *in-situ* experiments, or where neutron studies of specific region of reciprocal space are required.

This instrument is based on a secondary spectrometer using a series of analyser arrays being placed behind each other to simultaneously analyse different final energies of scattered neutrons over a wide pseudo-continuous angular range. The analyser arrays of CAMEA scatter vertically into position sensitive detector arrays, in a geometry similar to the flatcone concept. By scanning the excitations as a function of the sample rotation CAMEA maps the excitation spectrum of single crystals.

In this presentation we present the status of CAMEA as an indirect spectrometer for the European Spallation Source [1], and as a multiplexed triple axis spectrometer for RITA-II at SINQ, Paul Scherrer Institut.

[1] P. G. Freeman, *et. al.*, arXiv:1406.5945.

**15.00 Emily Hunter (University of Edinburgh)**

*The evolution of the ground state of lanthanum doped $Sr_3Ir_2O_7$*

Though originally thought to be only weakly correlated, oxide materials containing iridium (IV) show a variety of interesting properties such as long-range magnetic order, metal-insulator transitions and non-fermi liquid behaviour. These unusual electronic properties arise from a delicate balance of competing interactions such as the Coulombic repulsion, crystal field strength and the magnitude of the spin-orbit coupling.

$Sr_3Ir_2O_7$ is one such compound and exhibits long-range antiferromagnetic order below 287 K that is thought to be facilitated by the presence of a spin-orbit assisted $J_{\text{eff}} = 1/2$ Mott-insulating state. This presentation explores the effect of lanthanum doping on the ground state of $Sr_3Ir_2O_7$ by using bulk measurements such as resistivity, magnetic susceptibility and heat capacity to monitor changes to the electronic properties. Powder and single crystal x-ray diffraction measurements will also be drawn upon to discuss the effect of lanthanum doping on the structure of $Sr_3Ir_2O_7$ and whether the observed insulator to metal transition can be explained by a rigid band shift.

**15.15 Alun Biffen (University of Oxford)**

*Dynamics of the Spin-Orbital Singlet state in $FeSc_2S_4$ probed via Neutron Scattering*

In systems where both spin and orbital frustration are present, an intriguing Spin Orbital Liquid (SOL) state is believed to occur where spin and orbital moments remain disordered down to the lowest measurable temperatures. The A-site spinel $FeSc_2S_4$ is believed to form a Spin Orbital Singlet ground state closely related to the SOL, with its undistorted cubic structure and diamond lattice of Fe2+ sites providing the ingredients for orbital and spin frustration, respectively. The system displays Curie–Weiss behaviour indicative of strong exchange between $S = 2$, $L = 2$ $Fe^{2+}$ ions, though it does not order down to the lowest measurable temperatures. Here I will present the results of inelastic, time-of-flight neutron scattering experiments that probe the full bandwidth of the magnetic excitations in a powder sample of $FeSc_2S_4$, and provide a consistent model of the observed dynamics in terms of spin-orbital excitations, in both zero-field and infield measurements. I will discuss in particular how the application of a magnetic field elucidates the spin and orbital nature of these excitations, as the system shows behaviour drastically contrary to its spin-only analogue.

**15.45 – 16.15 Tea/Coffee**

**16.15 - 17.15 Review Session**