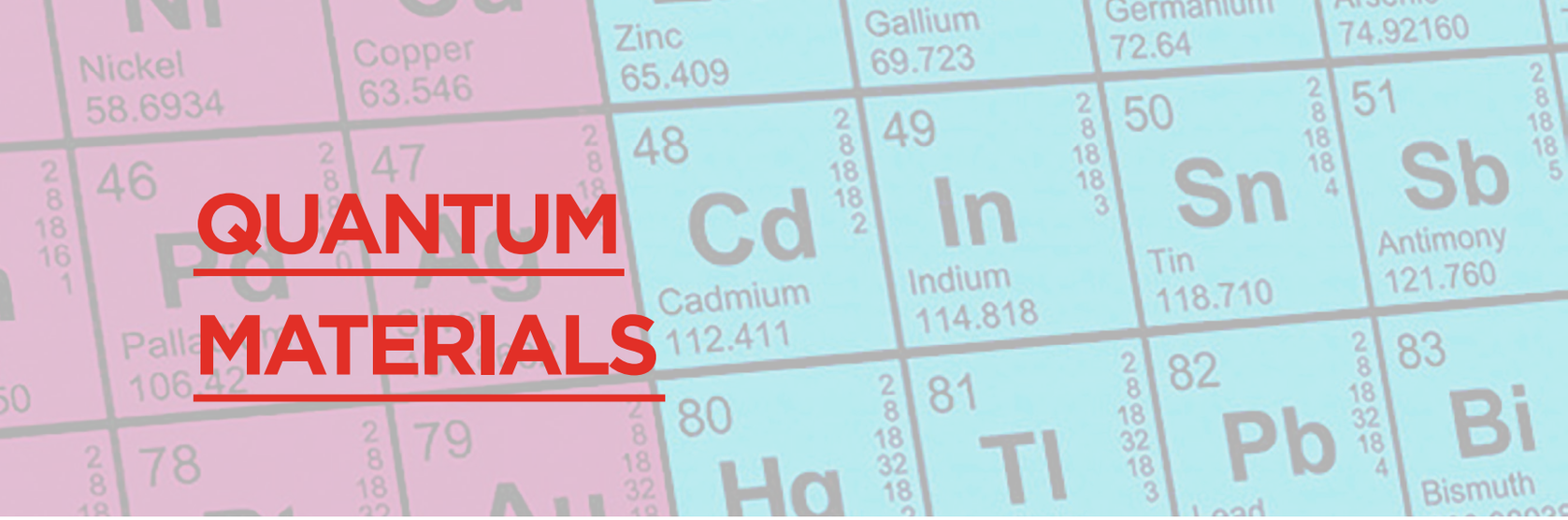

QUANTUM MATERIALS

Invents and explores materials whose novel and unusual electronic properties, like superconductivity, could revolutionize technology.

This year, the program saw an outpouring of research breakthroughs and publications, undertook numerous collaborative projects and organized a wide range of partnered events. Now in its 30th year, the program continues to explore new materials that exhibit high-temperature superconductivity, topological quantum properties and quantum spin liquid states. Iron-based superconductors including iron selenide (FeSe) and lithium iron arsenide (LiFeAs) are being investigated in detail, and new X-ray scattering methods are being developed by program fellows to better understand the distribution of electrons and superconductivity inside new composite materials and heterostructures.

The Fall program meeting took place at the Collège de France in Paris. CIFAR fellows and researchers from the Emergent Phenomena in Quantum Systems (EPiQS) program at the Gordon and Betty Moore Foundation (GBMF) in the United States met with quantum researchers from various institutions in France for two days of presentations and discussions. This resulted in an important discussion on superfluid density in lanthanum strontium copper oxide (LSCO) superconductors, which continued at the Spring 2017 meeting in Vancouver, along with new discussions and theoretical insights on the fascinating Kondo insulator samarium hexaboride (SmB6).

An additional workshop, Cracking the Enigma of Cuprate Superconductors, organized by Senior Fellows **André-Marie Tremblay** and **Louis Taillefer** (both Université de Sherbrooke), took place in Jouvence, QC, in May 2017 and involved 35 top researchers from around the world, including 14 CIFAR fellows. Supported by CIFAR and GBMF, the workshop did not have any formal presentations; instead, it focused on three full days of informal discussions about copper oxide–based superconductors.

This internationally recognized program is committed to making Canada an international leader in quantum-based technologies — with an existing partnership with GBMF, a new partnership with the Centre national de la recherche scientifique (CNRS) in France, a partnership with the Canada First Research Excellence Fund (CFREF) projects at the University of British Columbia and Université de Sherbrooke, and a potential new collaboration with The Simons Foundation based in New York.

RESEARCH HIGHLIGHTS

CIFAR researchers **Doug Bonn** (University of British Columbia), **David Broun** (Simon Fraser University), **Walter Hardy** (University of British Columbia), **Ruixing Liang** (University of British Columbia) and **Louis Taillefer** (Université de Sherbrooke) published their results on the physical properties of a new superconducting iron-based compound known as iron selenide (FeSe). The new material is important not only because it is a high-temperature superconductor, but also because it exhibits this property at a thickness of only one atomic layer. The research team resolved a long-standing debate as to whether the material's energetic properties were similar to the traditional copper oxide–based superconductors. Through the combined synthetic efforts of the researchers at the University of British Columbia, the microwave measurements performed at Simon Fraser University and the heat transport measurements performed at Université de Sherbrooke, the CIFAR program members helped establish important distinctions between the two types of materials.

- Li M et al. 2016. Superfluid density and microwave conductivity of FeSe superconductor: ultra-long-lived quasiparticles and extended s-wave energy gap. New J Phys. 18: 082001.

Postdoctoral fellow **Sebastian Macke**, jointly supervised by program members **Bernhard Keimer** (Max Planck Institute for Solid State Research) and **George Sawatzky** (University of British Columbia), developed a new technique for probing the spatial distribution of electrons at the interfaces between materials. The technique uses resonant X-ray scattering to probe these electrons and a new "dynamic" analysis method to describe the data more accurately than

AT A GLANCE

FOUNDED: 1987

MOST RECENT RENEWAL: 2012

PROGRAM DIRECTOR: Louis Taillefer, Université de Sherbrooke

FELLOWS, ADVISORS AND CIFAR AZRIELI GLOBAL SCHOLARS: 68

INSTITUTIONS REPRESENTED: 32, in 7 countries

FIELDS AND SUBFIELDS REPRESENTED: condensed matter and quantum physics; atomic, chemical and computational physics; nanomaterials and materials engineering

MEETINGS: 2; in Paris, France, and Vancouver, Canada

RELEVANT KNOWLEDGE USERS: industry (e.g., quantum computing, power transmission, transportation, magnetic medical imaging, wireless communications)

PARTNER: Gordon & Betty Moore Foundation

TO LEARN MORE: www.cifar.ca/research/quantum-materials/

traditional methods. It will be an important resource for future X-ray scattering experiments.

- Macke S et al. 2016. Dynamical effects in resonant X-ray diffraction. Phys Rev Lett. 117: 115501.

Strontium ruthenate (Sr_2RuO_4) is an important and rare type of superconductor believed to have p-wave symmetry — a state in which the paired electrons in the material that give rise to the observed superconductivity have spins aligned in the same direction. Such a material is of potentially great interest in quantum computing; however, recent work by Global Scholar Alumni **Elena Hassinger** (Max Planck Institute for Chemical Physics of Solids), Program Director **Louis Taillefer** (Université de Sherbrooke) and Associate Fellow **Yoshiteru Maeno** (Kyoto University) has raised questions about the nature of the symmetry in Sr_2RuO_4. By measuring heat conduction in different directions through a crystal of Sr_2RuO_4, the research team found that the unpaired electrons in the material behaved more like a typical d-wave state rather than a p-wave state, contradicting previous experimental observations.

- Hassinger E et al. 2017. Vertical line nodes in the superconducting gap structure of Sr_2RuO_4. Phys Rev X. 7: 011032.

Program Director Louis Taillefer speaking at the Paris program meeting.

Other Notable Publications and Outputs

- Li F-Y, Kim YB, Balents L et al. 2016. Weyl magnons in breathing pyrochlore antiferromagnets. Nat Commun. 7: 12691.
- Jang H, Bonn DA, Hardy WN, Kivelson SA, Liang R et al. 2016. Ideal charge density wave order in the high-field state of YBCO. Proc Natl Acad Sci U S A. 113: 14645.
- Nourafkan R, Kotliar G, Tremblay A-MS. 2016. Correlation-enhanced odd-parity inter-orbital singlet pairing in the iron-pnictide superconductor LiFeAs. Phys Rev Lett. 117: 137001.

GLOBAL ACADEMY

Two new CIFAR Azrieli Global Scholars joined the program for a two-year term, as part of the inaugural cohort appointed in 2016/2017. **Kate Ross** (Colorado State University) and **Luyi Yang** (University of Toronto) both presented their work at program meetings during the year.

The program's annual summer school took place in Vancouver on April 24-26, 2017. Organized by trainees from the University of British Columbia, Simon Fraser University and Université de Sherbrooke, the school drew over 80 participants and focused on experimental techniques in the synthesis and study of novel phases of matter. Ten guest lecturers took part, including three CIFAR fellows and the Quantum Materials CIFAR Azrieli Global Scholars.