Quantum theory of light and matter and complex systems

Condensed Matter Physics

V. Falko

A. Principi

N. Walet

Y. Xian

M. S. Bahramy

Non-equilibrium quantum physics

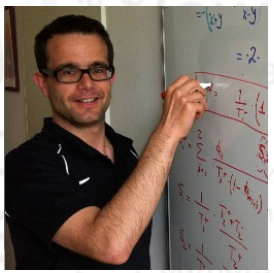
A. Nazir

J. Iles-Smith

T. Elliot

Complex Systems and Statistical Physics

M. Godfrey



T. Galla

Theory of Quantum Nanomaterials

V. Falko

Electronic and optical properties of 2D materials and heterostructures, dominated by quantum physics:

- many-body phases of electronic liquids in 2D materials
- quantum properties of minibands generated by moiré superlattices
- modelling optical properties of 2D materials
- Modelling heat transport in 2D materials

Methods: field theory in condensed matter theory; analytical and computational quantum transport theory; group theory and symmetry applications in solid state physics

Quantum theory of strong interactions in low-dimensional systems

A. Principi

Impact of interactions on equilibrium and non-equilibrium properties of 2D systems:

- **Quantum magnetism and topological order**
- Finding new ways to detect, address and control emergent quasiparticles with anyonic statistics
- The charge, thermal, and thermoelectric transport in strongly correlated systems
- The complex interplay between topology and interactions

Methods: mainly analytical; quantum field theory (Feynman diagrams, path integrals, non-equilibrium Green's functions, quantum kinetic equation, etc.)

Theoretical and computational approaches to 2D materials

N. Walet

Broad interest in condensed matter physics:

- the study of Majorana edge states in novels devices
- the development of practical approaches for quantum information processing with such devices
- A description of the distortion of layered materials with approximate alignment
- a correct description of flat bands and twisted bilayer graphene
- the nature of topological effects in graphene heterostructures,
- electronic structure of superconductivity in 2D materials
- development of many-body theory (coupled cluster and the functional renormalisation group) for the study of strongly interacting systems.

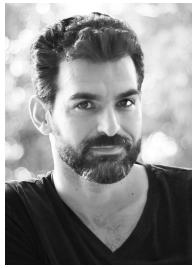
Quantum many-body theories and their applications in condensed matter physics

Y. Xian

Physical phenomena resulting from the combination of **dynamic interaction between particles and their quantum mechanical nature**:

- Applications of quantum many-body theories to the ground and excited states of strongly correlated systems such as high-Tc superconductors and quantum spin liquids;
- Dynamics of strongly correlated systems such as low-dimensional antiferromagnetic lattices, graphene ribbons and allied materials, with particular emphasis on their longitudinal modes;
- Topological properties, including the thermal Hall effect, of two-dimensional layered ferromagnets and antiferromagnets with a Dzyaloshinskii-Moriya interaction and/or Kekule distortions.

Computational modelling and design of next generation quantum materials



S. Bahramy

Development and application of advanced computational methods to predict, design and study non-trivial quantum materials:

- machine-learning-based methods for designing artificial two-dimensional materials and superstructures.
- ab-initio methods to study superconductivity and magnetism in low-dimensional systems
- First-principles modelling of topological quantum phenomena in structurally-frustrated heavy fermion systems.
- Thermopower generation and manipulation in materials.
- Magnetic generation and switching of topological phases through proximity effect.

Theory of open quantum systems: Non-equilibrium dynamics and Thermodynamics

A. Nazir

New theoretical techniques to understand the behaviour of **open quantum systems both in and out of equilibrium**:

- fundamental developments in the theory of open quantum systems and applications to many-body systems
- the impact of quantum correlations on the laws of thermodynamics and quantum scale thermal machines
- the effects of environmental interactions in solid-state quantum technology (with established experimental collaborations)
- strong light-matter interactions in quantum electrodynamics
- vibrational influences in the optical and electronic properties of natural and artificial molecular aggregates, with applications to solar energy harvesting.

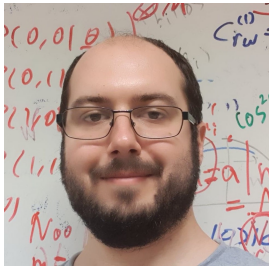
Open quantum systems theory and quantum technologies

J. Iles-Smith

Novel analytic and computational methods for **open quantum systems strongly coupled to their environment**:

- Development of analytic methods to describe open quantum systems in strong coupling regimes.
- Tensor network methods for describing nonequilibrium open quantum systems.
- Developing new quantum optics methods for solid-state quantum emitters (with established experimental collaborations).
- Methods to engineer an environment to enhance quantum technologies.

Complex structure in quantum dynamics



T. J. Elliott

Understanding what makes **complex quantum systems** *complex*…
…and how this complexity can be put to use

- Using quantum information theory to uncover and classify structure and memory in quantum stochastic processes
- Exploring the interplay between quantum memory advantages in stochastic simulation and increased thermal efficiency
- Improving and extending the design of quantum-enhanced adaptive agents, and/or developing their applications
- Using tools from quantum many-body physics and/or quantum machine learning to enhance quantum memory advantages
- Adapting quantum compression algorithms for implementation with near-future quantum technologies

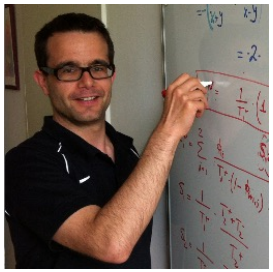
Glassy materials

M. Godfrey

Fundamental unsolved problem in physics, which also has practical importance for many technologies:

- Investigation of the connections between local microscopic **structure and dynamics in glasses**.
- Development and application of linear algebra techniques for computing the properties of disordered materials in low dimensions.
- Study of the so-called “Gardner transition”, which has been predicted to exist deep inside the glass phase, and at which glasses might lose their brittleness and become malleable, like metals.

Statistical Mechanics and Complex Systems



T. Galla

Applications of statistical mechanics to questions in biology, the social sciences, and medicine:

- stability of eco-systems
- spread of epidemics
- pattern formation in developmental biology
- topics in evolutionary game theory,
- modelling of cancer and problems in medical statistics.

Methods: stochastic differential equations, path integrals and master equations, Bayesian statistics and maximum likelihood methods, combined with algorithms for fast numerical simulations.

Technical info - application

Required documents:

- Potential supervisor
- Transcript and degree certificates
- Two academic references
- Personal statement
- Research proposal
- CV

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Technical info - funding

Funding from EPSRC (Department/NowNano CDT)

- Home students: cover all fees + stipend (details online)
- International students: cover fees up to home level + stipend.

  Requires a second step, faculty has to waive fees above home level (internal process, no action from the applicant)

Ranked by a Department/CDT panel

Technical info - funding

Funding from University (Presidential/Dean's scholarship)

- Covers all fees and stipend
- Very competitive
- You cannot apply for this: must be submitted by supervisor as different process

Ranked by a Department panel + Faculty panel + interview