Organization committee

Christophe Berthod
Stefano Gariglio
Ignacio Gutiérrez Lezama
Anna Tamai

Adriana Bonito Aleman
Pierre Bouillot
Pascal Cugni
Gregory Manfrini
Natacha Triscone

contact: qma-dqmp@unige.ch
SANITARY RULES

You will be hosted at Eurotel Victoria, where all meals will be served; the talks and the poster session will take place at the conference center, a 5-minute walk from the hotel.

At the hotel, the current sanitary rules apply: a mask must be worn indoor, social distancing of 1.5 meters must be maintained, and consumption at the bar and the restaurant is possible only seated. The hotel follows strict rules for the disinfection of the rooms and the common spaces.

At the conference center, the sanitary restrictions will be partially lifted: masks will not be required, standing coffee breaks and drinks during the poster session will be allowed. We nevertheless encourage the participants to self-organize in the conference room for maximal distancing.

In order to make this possible, you need to have a valid COVID certificate for the entire duration of the workshop. The organizers will check the QR code of your certificate on Monday at registration time. Swiss and EU vaccine certificates are accepted. Negative PCR and antigen tests are accepted as well. Quick self-tests are not accepted. Note that antigen tests have a short validity period of 48 hours and will need to be repeated in the course of the conference, for instance during the free time on Tuesday. You may contact the medical center in Les Diablerets (024 492 30 41) for information. Otherwise, the closest place where tests can be done is Montreux [https://www.onedoc.ch/en/covid-testing-center/montreux].

Please note that the same rules apply for adult accompanying persons if they want to join some of the activities at the conference center.

You may contact the organizers if you have questions or need additional information.

contact: qma-dqmp@unige.ch
# PROGRAM OVERVIEW

## Monday August 30th

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00</td>
<td>Registration at Eurotel Victoria</td>
</tr>
<tr>
<td>12:15</td>
<td>Lunch</td>
</tr>
<tr>
<td>13:00</td>
<td>Registration at the Congress-Center</td>
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<tr>
<td>13:50</td>
<td>Welcome</td>
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</table>

### 2D materials

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00</td>
<td>Alberto Morpurgo</td>
</tr>
<tr>
<td>14:25</td>
<td>Giulia Tenasini</td>
</tr>
<tr>
<td>14:45</td>
<td>Florian Margot</td>
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<tr>
<td>15:05</td>
<td>Lihuan Sun</td>
</tr>
<tr>
<td>15:25</td>
<td>Nicolas Ubrig</td>
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<tr>
<td>15:45</td>
<td>Break</td>
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### Material design

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker(s)</th>
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<tbody>
<tr>
<td>16:05</td>
<td>Carmine Senatore</td>
</tr>
<tr>
<td>16:30</td>
<td>Gianmarco Bovone</td>
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<tr>
<td>16:50</td>
<td>Robin Lefevre</td>
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<tr>
<td>17:10</td>
<td>Radovan Černý</td>
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### Special session

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker(s)</th>
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<tbody>
<tr>
<td>17:40</td>
<td>Jean-Marc Triscone</td>
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<tr>
<td>17:45</td>
<td>Antoine Georges</td>
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<tr>
<td>18:10</td>
<td>Jan Zaamen</td>
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<tr>
<td>18:35</td>
<td>Dirk van der Marel</td>
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<tr>
<td>19:30</td>
<td>Special dinner</td>
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</tbody>
</table>

## Tuesday August 31st

### Low-dimensional systems

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Jean-Marc Triscone</td>
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<tr>
<td>09:25</td>
<td>Claribel Dominguez</td>
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<tr>
<td>09:45</td>
<td>Louk Rademaker</td>
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<tr>
<td>10:05</td>
<td>Giacomo Morpurgo</td>
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<tr>
<td>10:25</td>
<td>Break</td>
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#### Spatially-resolved spectroscopies

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>10:45</td>
<td>Christoph Renner</td>
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<tr>
<td>11:10</td>
<td>Árpád Pásztor</td>
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<tr>
<td>11:30</td>
<td>Andrew Hunter</td>
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<td>11:50</td>
<td>Alexey Kuzmenko</td>
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### Quantum Magnetism

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Ignacio Gutiérrez-Lezama</td>
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<tr>
<td>09:20</td>
<td>Johannes Motruk</td>
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### Non-equilibrium phenomena

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>10:45</td>
<td>Philippe Jacquod</td>
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<tr>
<td>11:10</td>
<td>Giacomo Mazza</td>
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<tr>
<td>11:30</td>
<td>Flavio Giorgianni</td>
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<tr>
<td>11:50</td>
<td>Javier del Valle</td>
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</table>

## Wednesday September 1st

### Quantum magnetism

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Patrycja Paruch</td>
</tr>
<tr>
<td>10:05</td>
<td>Nirvana Caballero</td>
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<tr>
<td>10:25</td>
<td>Break</td>
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</table>

### Free time

### Poster Prize

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>17:00</td>
<td>Christian Rüegg</td>
</tr>
<tr>
<td>17:25</td>
<td>Poster session &amp; Aperitif</td>
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<tr>
<td>20:00</td>
<td>Dinner</td>
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</tbody>
</table>
# Detailed Program

## Monday August 30th

<table>
<thead>
<tr>
<th>Activity</th>
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</tr>
<tr>
<td>Welcome</td>
<td>13:50 – 14:00</td>
</tr>
</tbody>
</table>

### Session 1: 2D Materials
Chair: Michele Filippone

<table>
<thead>
<tr>
<th>Time</th>
<th>Presentation</th>
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</thead>
<tbody>
<tr>
<td>14:00 – 14:25</td>
<td><strong>2D materials and heterostructures</strong></td>
</tr>
<tr>
<td></td>
<td>Alberto Morpurgo</td>
</tr>
<tr>
<td>14:25 – 14:45</td>
<td><strong>Bandgap opening in bilayer graphene and 2D magnetic insulators van der Waals interfaces</strong></td>
</tr>
<tr>
<td></td>
<td>Giulia Tenasini</td>
</tr>
<tr>
<td>14:45 – 15:05</td>
<td><strong>Quantum size effects and electron-phonon coupling in exfoliated black phosphorus and black arsenic</strong></td>
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<tr>
<td></td>
<td>Florian Margot</td>
</tr>
<tr>
<td>15:05 – 15:25</td>
<td><strong>Tunable spin orbit coupling in twisted graphene/WSe₂ heterostructures</strong></td>
</tr>
<tr>
<td></td>
<td>Lihuan Sun</td>
</tr>
<tr>
<td>15:25 – 15:45</td>
<td><strong>Optical spectroscopy of atomically thin quantum materials</strong></td>
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<td>Nicolas Ubrig</td>
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</tbody>
</table>

### Session 2: Material Design
Chair: Fabian von Rohr

<table>
<thead>
<tr>
<th>Time</th>
<th>Presentation</th>
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</thead>
<tbody>
<tr>
<td>16:05 – 16:30</td>
<td><strong>Advanced design and control of superconducting materials for applications</strong></td>
</tr>
<tr>
<td></td>
<td>Carmine Senatore</td>
</tr>
<tr>
<td>16:30 – 16:50</td>
<td><strong>Recent innovations in Nb₃Sn wire technology for the next generation of accelerator magnets</strong></td>
</tr>
<tr>
<td></td>
<td>Gianmarco Bovone</td>
</tr>
<tr>
<td>16:50 – 17:10</td>
<td><strong>CeZn₂₋₅Ge₂: New Zn-deficient CaBe₂Ge₂-type phase with rare Ce-based ferromagnetism and large magnetoresistance</strong></td>
</tr>
<tr>
<td></td>
<td>Robin Lefevre</td>
</tr>
<tr>
<td>17:10 – 17:35</td>
<td><strong>Complex hydrides as electrolytes for Na solid-state batteries: From boosted characterizations techniques towards better performance</strong></td>
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<tr>
<td></td>
<td>Radovan Černý</td>
</tr>
</tbody>
</table>
Session 3: **Special session**
Chair: Jean-Marc Triscone

17:40 – 17:45  **Introduction**

17:45 – 18:10  **Quantum criticality, skewed Planckian metals and the Seebeck effect**  
Antoine Georges

18:10 – 18:35  **Observing the propagation of shear in heavy electron Fermi-liquids**  
Jan Zaanen

18:35 – 19:00  **Superconductivity mediated by charged phonons**  
Dirk van der Marel

**Special dinner**  
19:30
## Tuesday August 31st

### Session 4: **Low-dimensional systems**
Chair: Céline Lichtensteiger

- **9:00 – 9:25** Structural and electronic coupling at oxide interfaces
  Jean-Marc Triscone
- **9:25 – 9:45** Coupling of magnetic phases at nickelate interfaces
  Claribel Dominguez
- **9:45 – 10:05** Symmetry breaking and Chern insulators in twisted graphene structures
  Louk Rademaker
- **10:05 – 10:25** Effects of disorder in singlet/triplet quasi-1d superconductors
  Giacomo Morpurgo

**Break**  
10:25 – 10:45

### Session 5: **Spatially-resolved spectroscopies**
Chair: Anna Tamai

- **10:45 – 11:10** Scanning probe imaging and spectroscopy of correlated electron materials and devices
  Christoph Renner
- **11:10 – 11:30** Unveiling multiband charge density waves in NbSe$_2$
  Árpád Pásztor
- **11:30 – 11:50** Laser-ARPES measurements of Sr$_2$RuO$_4$ under uniaxial strain
  Andrew Hunter
- **11:50 – 12:15** Variable-temperature infrared nanoscopy of quantum materials
  Alexey Kuzmenko

**Lunch**  
12:30 – 13:30

**Free time**  
13:30 – 17:00

### Session 6: **Quantum magnetism**
Chair: Thierry Giamarchi

- **17:00 – 17:25** Quantum materials in and beyond equilibrium
  Christian Rüegg

**Poster session & Aperitif**  
17:25 – 20:00

**Dinner**  
20:00
**Wednesday September 1st**

### Session 7: Quantum magnetism
Chair: Thierry Giamarchi

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 9:20</td>
<td>Determining the phase diagram of 2D van der Waals magnets</td>
<td>Ignacio Gutiérrez-Lezama</td>
</tr>
<tr>
<td>9:20 – 9:40</td>
<td>Four-spin terms and the origin of the chiral spin liquid in Mott insulators on the triangular lattice</td>
<td>Johannes Motruk</td>
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</tbody>
</table>

### Session 8: Domain walls
Chair: Thierry Giamarchi

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:40 – 10:05</td>
<td>Ferroelectricity at the nanoscale: complex polarisation textures and emergent functionalities</td>
<td>Patrycja Paruch</td>
</tr>
<tr>
<td>10:05 – 10:25</td>
<td>Domain walls in ferroic materials: a statistical physics approach to predicting the static and dynamic behaviour of interfaces</td>
<td>Nirvana Caballero</td>
</tr>
</tbody>
</table>

**Break**

### Session 9: Non-equilibrium phenomena
Chair: Andrea Caviglia

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
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</thead>
<tbody>
<tr>
<td>10:45 – 11:10</td>
<td>Wave coherence in the physics of AC electric power grids</td>
<td>Philippe Jacquod</td>
</tr>
<tr>
<td>11:10 – 11:30</td>
<td>Photon dressing of the electronic response of two-dimensional semiconductors in cavity electrodynamics</td>
<td>Giacomo Mazza</td>
</tr>
<tr>
<td>11:30 – 11:50</td>
<td>Nonlinear magnetophononics in a frustrated quantum antiferromagnet</td>
<td>Flavio Giorgianni</td>
</tr>
<tr>
<td>11:50 – 12:10</td>
<td>Filament nucleation and growth in MIT materials</td>
<td>Javier del Valle</td>
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**Poster Prize 12:10–12:30**

**Lunch**

12:30–13:30

**End of the Conference**
<table>
<thead>
<tr>
<th>Poster Session</th>
<th>Title</th>
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<tbody>
<tr>
<td>Stephan Allenspach</td>
<td>Bayesian investigation of quantum criticality in spin dimer systems</td>
</tr>
<tr>
<td>Francesco Barantani</td>
<td>Experimental observation of electron-exciton coupling in high-$T_c$ cuprates</td>
</tr>
<tr>
<td>Adrien Bercher</td>
<td>Near field imaging of metallic filaments in NdNiO$_3$ (NNO)</td>
</tr>
<tr>
<td>Marco Bonura</td>
<td>Record-high upper critical field in MgB$_2$ bulk samples prepared by a non-conventional rapid synthesis route</td>
</tr>
<tr>
<td>Chuanwu Cao</td>
<td>Gate-induced hole superconductivity in transition-metal dichalcogenide</td>
</tr>
<tr>
<td>Edoardo Cappelli</td>
<td>Fermi surface and quasiparticle dispersion of the highly-conductive perovskite oxide SrMoO$_3$</td>
</tr>
<tr>
<td>Pablo Cayado</td>
<td>Study of the oxygen diffusion process in commercial REBCO-based coated conductors</td>
</tr>
<tr>
<td>Kumara Cordero-Edwards</td>
<td>Novel functionalities at twin domain crossings</td>
</tr>
<tr>
<td>Daniil Domaretsky</td>
<td>Identifying atomically thin crystals with diffusively reflected light</td>
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<tr>
<td>Julian Fritzsch</td>
<td>Long wavelength coherence in networks of coupled oscillators</td>
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<tr>
<td>Stefano Gariglio</td>
<td>Octahedra rotations coupling in perovskite vanadate heterostructures</td>
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<tr>
<td>Gianmarco Gatti</td>
<td>Electronic structure of few-layer crystals of the magnetic topological insulator MnBi$_2$Te$_4$</td>
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<tr>
<td>Hugo Henck</td>
<td>Electroluminescent Γ point interlayer excitons</td>
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<tr>
<td>Julia Issing</td>
<td>First micro-ARPES measurements of encapsulated few-layer Td-MoTe$_2$</td>
</tr>
<tr>
<td>Lukas Korosec</td>
<td>Perturbed angular correlation spectroscopy of complex oxide heterostructures</td>
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<tr>
<td>Menghan Liao</td>
<td>Magnetoresistance oscillations in superconducting films with coexisting charge orders</td>
</tr>
<tr>
<td>Céline Lichtensteiger</td>
<td>Domain scaling and coupling of structural distortions in tensile-strained PbTiO$_3$ heterostructures</td>
</tr>
<tr>
<td>S. A. Lopez-Paz</td>
<td>Magnetism and superconductivity in iron substituted FeSr$_2$YCu$_2$O$_y$ cuprates</td>
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<tr>
<td>KeYuan Ma</td>
<td>New oxide group-9 transition metal superconductors in the filled-T$_3$Ni type structure</td>
</tr>
<tr>
<td>Alexander Madsen</td>
<td>Automatic signal-background decomposition of multidimensional data</td>
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<tr>
<td>Ivan Maggio-Aprie</td>
<td>Wang-McDonald vortex core states in heavily-overdoped Bi$_2$Sr$_2$CaCu$<em>2$O$</em>{8+δ}$</td>
</tr>
<tr>
<td>Siobhan Mckeeown Walker</td>
<td>The Laboratory of Advanced Technology: collaborations within the DQMP and beyond</td>
</tr>
<tr>
<td>Bastien Michon</td>
<td>The spectral weight of hole doped cuprates across the pseudogap critical point</td>
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<tr>
<td>Bernat Mundet</td>
<td>Mapping electronic phase coexistence in nickelate superlattices by STEM-EELS</td>
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<tr>
<td>Pavel Naumov</td>
<td>Neutron scattering under multi-extreme conditions</td>
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<tr>
<td>S. E. Nikitin</td>
<td>Field-induced spin dynamics in triangular-lattice antiferromagnet CsYbSe$_2$</td>
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<tr>
<td>Bruce Normand</td>
<td>Tricriticality, BKT multicriticality and proximate deconfined quantum criticality in fully frustrated quantum antiferromagnets</td>
</tr>
<tr>
<td>Andreas Ørsted</td>
<td>Tuneable space-charge-doping for scanning tunnelling microscopy investigations</td>
</tr>
</tbody>
</table>
Vincent Pasquier Tunable biaxial strain device for low dimensional materials
Marc Philippi Quenching the band gap of 2D semiconductors with an electric field
Lorenzo Pizzino Dimensional crossover in weakly-coupled chains
Dorota Pulmannova Crystal structure of new polymorph of Sr₂TiO₄ with tetrahedral titanium
Ishita Pushkarna Thickness dependent properties of transition metal dichalcogenides using gold-assisted exfoliation
Willem Rischau Ferroelectricity and superconductivity in 18O-substituted SrTiO₃−δ
Alessandro Scarfato Surface density of states in Pt₂HgSe₃ investigated by quasiparticle interference
Tejas Parasram Singar Revisiting the electronic and structural properties of heavily under-doped Bi₂Sr₂CaCu₂O₈+δ high Tc cuprate superconductor by STM/STS
David Soler-Delgado Multiple ferromagnetic states revealed by transport experiments in the van der Waals ferromagnet VI₃
Michael Sonner Influence functional of many-body systems: temporal entanglement and matrix-product state representation
Leonie Spitz Slow dynamics from ultrafast coherent phononic driving in CuGeO₃
Julian Thoenniss Reconstruction of the influence matrix from Keldysh correlation functions
Koen van Walstijn Probabilistic forecasting of nodal high-voltage electric loads using a variational autoencoder
Adrien Waelchli Growth and oxygenation of infinite-layer CaCuO₂ and SrCuO₂ thin films
Dorota Walicka Structure-property relationships in superconductors with honeycomb layers
Wei Wang Magnetostuctural transition of two-dimensional antiferromagnetic materials under electric field
Catherine Witteveen Polytipism and superconductivity in the NbS₂ system
Fan Wu Electric field effect in few layers antiferromagnetic CrSBr
Yixi Zhou Variable-temperature SNOM imaging of long-propagating phonon-polaritons in strontium titanate
Marios Hadjimichael Searching for superconductivity in SrCuO₂ heterostructures
João S. Ferreira Exact description of quantum stochastic models as quantum resistors
POSSIBLE ACTIVITIES

The KML files can be opened in Google Earth or drag&dropped on the Swisstopo map.

Easy walks
- Vers Champ (+/-250m, 7.5km, 2h) [KML file]
- Col du Pillon - Lac Retaud (bus 20 min, +/-200m, 4.5km, 1h30) [KML file]
- Col du Pillon - Cascade du Dar (bus 20 min, -400m, 5km, 1h20) [KML file]
- See also: Hiking in Les Diablerets, Les Diablerets wonders

Longer walks
- Les Crêtes (bus 10 min, +450m/-600m, 8km, 2h45) [KML file]
- Cabane des Diablerets (bus 20 min, +950m, 3.2km, 2h45, return by cable car) [KML file]
  For well-trained walkers not prone to vertigo; requires good shoes

Via Ferrata de la cascade
- Intermediate level, don’t go if unsure [KML file]
- Website
- Renting equipment

Glacier 3000
- Beautiful view in case of good weather, but expensive
- Website
- Peak walk
- Alpine coaster
ABSTRACTS
of the
oral presentations
2D materials and heterostructures

Alberto Morpurgo\textsuperscript{1,2}

\textsuperscript{1} DQMP, University of Geneva
\textsuperscript{2} GAP, University of Geneva

Exfoliation of layered, van der Waals bonded materials is a very effective strategy to easily produce high-quality, atomically thin crystals of a broad variety of compounds. These so-called 2D materials allow the exploration of a multitude of physical phenomena and regimes, never investigated earlier. Additionally, 2D materials can be controlled in ways that have no analog for conventional bulk crystals. When embedded in an interface or exposed to a perpendicular electric field, for instance, an entire 2D material is modified, whereas in a bulk crystal only the surface is affected. Hence, 2D materials exhibit new phenomena that can be controlled—or engineered—to produce new properties and functionalities. Exploring these phenomena and mechanisms in device structures is the core of the research of the Quantum Electronics group, which I will briefly introduce in my talk.
Bandgap opening in bilayer graphene and 2D magnetic insulators van der Waals interfaces

Giulia Tenasini,1,2 David Soler Delgado,1,2 Zhe Wang,1,3 Enrico Giannini,1 Ignacio Gutiérrez-Lezama,1,2 and Alberto F. Morpurgo1,2

1 Department of Quantum Matter Physics, University of Geneva, 24 Quai Ernest Ansermet, CH-1211 Geneva, Switzerland
2 Group of Applied Physics, University of Geneva, 24 Quai Ernest Ansermet, CH-1211 Geneva, Switzerland
3 MOE Key Laboratory for Nonequilibrium Synthesis and Modulation of Condensed Matter, School of Physics, Xi’an Jiaotong University, Xi’an, 710049, China

The application of a perpendicular electric field can controllably tune bilayer graphene (BLG) into an insulating state, disclosing the possibility of tailoring the material bandstructure with sufficiently large electric fields [1, 2]. Van der Waals (vdW) interfaces can naturally host built-in electric fields perpendicular to the layers, whenever the band alignment between the constituent two-dimensional (2D) materials is such to favor a significant charge transfer. Here, we report the observation of a bandgap in BLG when placed in contact with a 2D magnetic insulator, specifically a chromium tri-halide CrX₃ (X = Cl, Br, I). By means of field-effect measurements in BLG/CrX₃ heterostructures we detect a sharp conductance suppression of over five order of magnitude in the transfer curves below 50 K, indicative of the presence of a robust insulating state in BLG. We attribute the bandgap opening to the considerable charge transfer—as high as 10¹³ cm⁻²—occurring from BLG to the localized d-bands of CrX₃, that induces a strong hole doping in graphene and generates an electric field at the interface. From the Arrhenius dependence we can extract the activation energies and the corresponding bandgaps for the three vdW heterostructures, which result in good agreement with the theoretical prediction for the displacement fields inferred from the doping charge density measured in BLG. Furthermore, the geometry of our devices allows us to relate a gate voltage change to a shift in chemical potential and to independently estimate the bandgap values from transfer curves. Despite this simple picture works remarkably well for BLG/CrCl₃ where the bandgap is ~ 170 meV, the detailed electrostatic equilibrium at the interface has to be considered for a reliable modeling of the gap in the three heterostructures. Our results pave the way for engineering an insulating state in BLG by assembling vdW interfaces of suitably chosen 2D materials.

Quantum size effects and electron-phonon coupling in exfoliated black phosphorus and black arsenic

Florian Margot, Simone Lisi, Irène Cucchi, Edoardo Cappelli, Andrew Hunter, Ignacio Gutiérrez-Lezama, KeYuhan Ma, Fabian von Rohr, Christophe Berthod, Marco Gibertini, Samuel Poncé, Nicolas Marzari, Anna Tamai, Alberto Morpurgo, and Felix Baumberger

Quantum confinement profoundly affects the electronic structure of 2D materials as their thickness is reduced down to the atomic limit. Prominent examples include the transition from an indirect to a direct bandgap in transition metal dichalcogenides and the marked increase of the band gap in black phosphorus (BP). Here we present direct measurements of quantum size effects in black phosphorus and black arsenic (BAs), topical 2D semiconductors characterized by a puckered honeycomb crystal structure. Both of these semiconductors offer promising electronic and optoelectronic properties for applications, primarily due to their direct gap and high mobility. Our ARPES measurements map the quantum well state (QWS) dispersion in the valence band of few layer BP and BA. This is achieved by fabricating multiple devices with exfoliated flakes of 2–9 layers thickness encapsulated between graphene and graphite. Based on these measurements, we quantify the anisotropy of the valence band edge and we determine the splitting of the QWS. We find that the splittings differ markedly from the picture of a particle in a box that is used for conventional semiconductor quantum wells (GaAs, Si), but are well described by a tight-binding model. Our ARPES spectra also reveal distinct signatures of electron-phonon coupling, a phenomenon that remained elusive in previous ARPES studies of exfoliated 2D semiconductors but plays a crucial role in the transport properties at elevated temperature.
The spin-orbit interaction (SOI) in graphene can be strongly enhanced by proximity to transition-metal dichalcogenides (TMD) [1, 2]. However, the strength of SOI varies by an order of magnitude according to the measurements from different research groups. The reasons for this spread are still not very clear. Some theoretical calculations predict that the twist angle could probably influence the strength of the different types of SOI [3]. Here, we studied the intra-valley scattering of graphene/WSe₂ by scanning tunneling microscopy, which implies enhanced SOI. We found that backscattering appears on the monolayer graphene/WSe₂ heterostructure for twist angle of 16 and 24 degrees. However, it disappears at a twist angle of 7 degrees. Theoretical calculations suggest that backscattering is allowed when SOI is enhanced, and its strength depends on twist angle. Our results give direct knowledge of the scattering mechanism of graphene/WSe₂ and pave the way for the angle tuning of the proximity engineering.

Optical spectroscopy of atomically thin quantum materials

Nicolas Ubrig

DQMB, Université de Genève

In this talk, we will review past success stories of investigating atomically thin van der Waals materials by optical means, with a particular focus on artificially designed interfaces, and give a bright outlook on exciting phenomena that are likely to be discovered.
Advanced design and control of superconducting materials for applications

Carmine Senatore,1 Tommaso Bagni,1 Marco Bonura,1 Gianmarco Bovone,1 Florin Buta,1 Pablo Cayado,1 Jose Ferradas,1,2 Davide Matera,1 and Damien Zurmuehle1

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The grand challenges that are being faced by scientists developing superconductors for applications are driven by a number of projects and proposals, from those with the aim of expanding the frontiers of human knowledge, e.g. the studies for next generation hadron colliders, to those with a direct societal impact, including innovative gantries for the hadron therapy of cancer, NMR spectrometers at the highest resolution, compact fusion devices, and novel applications in the electric infrastructure and in the field of hydrogen-based mobility. Each of these technologies calls for superconductor R&D tailored to its specific operating conditions—temperature, magnetic field, mechanical stresses, radiation environment. This requires the development of processing routes with a full control of the nanoscale dimensions and scalable at the industrial level. Among the main research directions, two are the most prominent nowadays: (1) a strong focus on pushing the low temperature superconductor Nb3Sn towards its ultimate performance, mainly driven by the high-energy physics programs; (2) some innovative and more fundamental rethinking about YBa2Cu3O7−x conductors that may bring revolution in magnet engineering. The corresponding research activities must (i) build on fundamental material science, a vast range of experimental investigations, from low temperature/high magnetic field measurements to advanced analytical tools, eventually accompanied by machine learning data processing (ii) have pilot production capability to drive and accompany the transition to technical superconductors relevant for industrialization. The aim of this talk is to introduce some examples of the activities running in the Group of Applied Superconductivity at DQMP to provide scope and motivation for targeted R&D in various domains of superconductor technology.
Recent innovations in Nb$_3$Sn wire technology for the next generation of accelerator magnets

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The aim of our research is to push Nb$_3$Sn wires towards their ultimate performance in view of future particle-physics experiments at the energy frontier. In particular, the design of 16 T dipole magnets for the CERN Future Circular Collider (FCC) relies on the development of next-generation Nb$_3$Sn wires with outstanding properties in terms of critical-current density and mechanical strength. Our contribution to the advancement of the Nb$_3$Sn technology relies on two pillars: at the nanoscale level, tailoring the vortex-pinning landscape and enhance $J_c$; at the microscale level, predicting the properties of the conductor under large stress. The first focus is on inhibiting the Nb$_3$Sn-grain growth by means of nanoparticles (typically ZrO$_2$) that form through internal-oxidation processes during the reaction heat treatment. Grain boundaries act as pinning centers in Nb$_3$Sn, therefore smaller Nb$_3$Sn grains enhance $J_c$. We are currently manufacturing internally-oxidized rod-type multi-filamentary wires made from binary and ternary Nb-alloys. Beyond an improved $J_c$, our wires exhibit record-high upper critical fields above 29 T at 4.2 K [1]. At the microscale level, we developed a method to characterize the wires’ internal voids and cracks, which play a crucial role for the electromechanical properties [2]. X-Ray tomographies were acquired at the European Synchrotron Radiation Facility (ESRF) on Nb$_3$Sn wires used for prototype accelerator magnets. Samples were submitted to mechanical load, simulating real conditions during magnet operation. Convolutional Neural Network (CNN) analyses allowed us to identify wire components (Nb$_3$Sn sub-elements, copper matrix) and defects (voids, cracks). The trained CNN was able to analyze, quickly and autonomously, large volumes of tomographic images, thus enabling a systematic investigation of the mechanical damages in Nb$_3$Sn wires and, eventually, the development of reinforcement strategies.

CeZn$_{2-\delta}$Ge$_2$: New Zn-deficient CaBe$_2$Ge$_2$-type phase with rare Ce-based ferromagnetism and large magnetoresistance

Robin Lefevre and Fabian Von Rohr

University of Zurich, Department of Chemistry

We report on a new compound CeZn$_{2-\delta}$Ge$_2$ which crystallizes in a CaBe$_2$Ge$_2$-type structure. The phase only forms Zn-deficient on only one crystallographic site. This reduces the number of excess electron per unit-cell stabilizing the unusual compound. This new phase is metallic, displaying uncommon Ce-based ferromagnetism with a critical temperature of $T_c = 6.7$ K as confirmed by magnetic susceptibility measurement in form of an Arrott plot. We find this material to exhibit a large positive magnetoresistance of approximately 30% below 50 K a temperature much higher than the Curie temperature hence the magnetoresistance is not only linked to the ordering of the magnetic moments, but likely connected to enhanced spin-fluctuations.
Complex hydrides were deeply investigated for solid-state hydrogen storage, and since few years also as solid-electrolytes [1]. Elevated ionic motion occurs only after a structural phase transition, which generally occurs beyond room temperature (rt). The transition temperature depends on the charge, size and shape of the hydride’s polyanion. Frustrating the anion sublattice, either by anion replacing or anion mixing, is an effective strategy to stabilize down to rt the conductive phase. Following this approach, we studied a group of fast Na\(^+\) conductors, obtained by mechanical mixing of different closo-hydroborates and carboranates. Among them, Na\(_4\)(CB\(_{11}\)H\(_{12}\))\(_2\)(B\(_{12}\)H\(_{12}\)) features a superior ionic conductivity of 2 mS cm\(^{-1}\) at rt, with a low activation energy of 314 meV [2]. Electrochemical stability of 4.1 V vs. Na\(^+\)/Na is compatible with high-voltage operating positive electrodes [3, 4]. It is limited by the electrochemical stability of less stable anion, confirming that [CB\(_{11}\)H\(_{12}\)]\(^-\) is the more robust anion of the pool [5]. Such evidence has motivated the search for alternative strategies to frustrate the anion landscape in NaCB\(_{11}\)H\(_{12}\). High-energy mechanical milling stabilized a new conductive phase at rt (\(\sigma = 3.4\) mS cm\(^{-1}\)), featuring a bcc anion sublattice, different from the fcc packing in the high-temperature polymorph. IR, XPS and MS analysis have been carried out, to get further insights. The critical current density will be discussed, underlying the crucial role of stacking pressure for targeting enhanced electrochemical performance.

Quantum criticality, skewed Planckian metals and the Seebeck effect

Antoine Georges$^{1,2,3}$

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$^3$ University of Geneva, DQMP

I will review recent works which support the existence of a quantum phase transition at a critical doping between two metallic phases in a random $t$–$J$ model related to Sachdev-Ye-Kitaev models. The Fermi surface undergoes a volume change at the quantum critical point, and transport displays ‘Planckian’ behaviour with linear resistivity. I will emphasize that such non Fermi liquids may naturally host a strong particle-hole asymmetry (skewness) which has surprising consequences for the sign and temperature dependence of the Seebeck effect. Connections with the phenomenology of cuprates will be discussed in light of recent experiments.
Observing the propagation of shear in heavy electron Fermi-liquids

Jan Zaanen
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The zero temperature Fermi-liquid is a remarkable affair—although it is a liquid not breaking the symmetry of space when the Landau parameter $F_1$ governing the mass of the quasiparticles becomes larger than a critical value it supports propagating shear modes. These were observed in $^3$He in the 1970’s but the question arises whether such a propagating shear also exists in the heavy fermion metals. Only photons couple to these modes with the implication that one can only probe them at very small momenta. But there is a way: we predict that gigantic oscillations occur in the transmission through thin slabs as function of frequency.

Superconductivity mediated by charged phonons

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Strontium titanate is a semiconducting material, which can be tuned to become ferro-electric by substituting the heavier $^{18}$O isotope for the natural $^{16}$O isotope. When doped, the material becomes superconducting already at extremely low carrier densities [1, 2]. The proximity to a ferro-electric instability is peculiar and has lead to the suggestion that the pairing is mediated by ferro-electric soft modes. This model has lead to the prediction of a strong increase of the superconducting $T_c$ with $^{18}$O isotope substitution [3], which has been confirmed by our experimental studies and those from a group in Tokyo [4–6]. From our optical studies we can moreover show that the main channel for pairing is the exchange of pairs of ferro-electric modes. Using the optical sumrule for coupling to charged phonons, and another one relating the electronic polarizability to interband transitions, we can determine the strength of the pairing interaction [7], which is consistent with the $T_c$ of these materials. Applying the same arguments to doped KTaO$_3$ [8], the coupling is even stronger in this material, for which $T_c$ has recently been found to be 5 times higher than in doped SrTiO$_3$. These observations imply an interesting possibility, namely that superconducting pairing can be mediated by pairs of so-called “charged phonons”, i.e. optical phonons coupled to electronic modes. This type of pairing is particularly relevant when the carrier concentration is low and may be relevant in other cases of interest such as twisted bilayer graphene.

Structural and electronic coupling at oxide interfaces

Margherita Boselli,1 Claribel Dominguez,1 Jennifer Fowlie,1 Stefano Gariglio,1 Marta Gibert,2 Marios Hadjimichael,1 Lukas Korosec,1 Celine Lichtensteiger,1 Giacomo Mazza,1 Hugo Meley,1 Bernat Mundet,1,3 Gernot Scheerer,1 Javier del Valle,1 Lucia Varbaro,1 Adrien Waelchli,1 and Jean-Marc Triscone1

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In this talk, I will discuss several interfacial couplings that occur in oxide heterostructures and some exciting developments. The talk will be a broad introduction to more focused presentations of the group members. First, polar discontinuities can lead to 2-dimensional conduction between insulating materials—an example is the celebrated LaAlO3/SrTiO3 system [1, 2]; Structural and electronic coupling at oxide interfaces can also lead to interesting phenomena that we investigated in perovskite nickelates [3, 4]—well-known for their metal to insulator transition (MIT) and unique antiferromagnetic (AFM) ground state [5–7]; I will also mention vanadate-based heterostructures where we aimed at designing an artificial ferroelectric material [8, 9]; Finally, I will end by discussing exciting recent developments that might lead to a control of high \( T_c \) superconductivity and the realization of distinct phases with different oxygen contents.

Perovskite rare earth nickelates (with chemical formula $\text{RENiO}_3$, $\text{RE} =$ Rare Earth, $\text{RE} \neq \text{La}$) are fascinating materials, well-known, for their metal to insulator transition (MIT) and unique antiferromagnetic ground state [1–3]. Due to the lack of sizeable single crystals, heterostructures constitute the best system to study the fascinating properties of these materials. Pursuant to this, we have grown superlattices made of $\text{SmNiO}_3$ and $\text{NdNiO}_3$ layers. When these two compounds are brought together at an interface the stability of a metal-insulator phase separation can be controlled by the thickness of the individual layers, giving a critical length scale below which, a single metal-to-insulator transition occurs. We have demonstrated that this behavior is set by the balance between the energy of the interfacial phase-boundary and the bulk phase energies [4]. As the ground state of this materials is not only insulating but also antiferromagnetic, by combining a probe of long-range magnetic order—resonant x-ray magnetic scattering—and a highly sensitive probe of local magnetism—muon spin relaxation—we study how the magnetic order evolves in this complex multicomponent system. We find that similar to what is observed in the resistivity measurements, these superlattices display either two magnetic transitions or one depending on the superlattice wavelength. The critical length scale over which antiferromagnetic-paramagnetic phase coexistence can occur is found to be greater than the critical length scale for insulating-metallic phase coexistence, indicating that, relative to the bulk phase energies, the magnetic phase boundary is more costly. The results of this study offer a complete picture of how distinct phases couple at interfaces and may carry implications for ultrathin oxide devices.

Symmetry breaking and Chern insulators in twisted graphene structures

Louk Rademaker

Department of Theoretical Physics, Université de Genève

Twisted bilayer graphene (tBG) and variants like twisted monolayer-bilayer graphene (tMBG) were proposed to be a platform for strongly correlated physics akin to the cuprate family. However, I will show that many of the observed interacting phenomena can be explained in terms of breaking of spin/valley symmetry. This can lead to a quantum anomalous Hall effect in the absence of a field, as I will show for tMBG [1]. In large magnetic fields the same spin-valley symmetry breaking leads to a series of Chern insulator states [2]. Finally, I will briefly discuss the possibility of genuine strong correlated physics in Moiré structures.

Effects of disorder in singlet/triplet quasi-1d superconductors

Giacomo Morpurgo and Thierry Giamarchi

Department of Quantum Matter Physics, University of Geneva

We look at the combined effects of disorder and interactions in low dimensional quantum systems and in particular at the effect of disorder on the critical temperature towards superconductivity in a system with attractive interactions. For three dimensional materials the celebrated Anderson theorem [1–3] states that superconductivity is resistant to non-magnetic disorder because time-reversal invariance is still preserved, and thus $T_c$ is unchanged. However, for quasi-one-dimensional systems, made of weakly coupled chains, it was shown [4] that the Anderson theorem is not valid because of Anderson localization. In that case $T_c$ is weakened even by non-magnetic impurities.

We further investigate this issue, using field theory and renormalization group techniques both for magnetic disorder on s-wave quasi-1D superconductors and for triplet superconductors in presence of non-magnetic disorder. We compute the dependence in disorder of the superconducting transition temperature and analyze the competition between superconductivity and localization for these various cases.

Scanning probe imaging and spectroscopy of correlated electron materials and devices

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The scanning probe imaging and spectroscopy team [1] is investigating the electronic properties of low dimensional correlated electron materials and devices. The focus is on charge density wave (CDW) systems, high temperature superconductivity, topological insulators and spin orbit coupling. We will provide a glimpse of some recent achievements in characterizing the genuine vortex core structure in a high temperature superconductor [2] and exposing the multiband nature of the CDW in NbSe$_2$ [3]. We will provide some insight into challenges ahead and introduce ongoing efforts to achieve doping and strain dependent scanning tunneling microscopy and spectroscopy of a range of low dimensional materials and devices.

Unveiling multiband charge density waves in NbSe$_2$

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The charge density wave (CDW) state is an electronic order where the charge density develops a spatial modulation concomitantly to a periodic distortion of the atomic lattice. The new periodicity leads to the reorganization of the electronic bands of the parent compound through their back-folding on the new Brillouin-zone. Although a gap in the energy spectrum should open at all crossings of the folded bands, previous studies only focused on the primary CDW gap around the Fermi-level, which leads to the highest energy gain of the reconstructed system. The existence of secondary gaps and associated charge modulations in charge ordered materials remains largely unexplored.

We show that combining energy dependent scanning tunneling microscopy (STM) topography with a simple model of the charge modulations and a self-consistent calculation of the CDW gap, we find evidence for a multiband CDW in 2H-NbSe$_2$ [1]. This CDW not only involves the opening of a gap on the inner band around the K-point, but also on the outer band. This leads to spatially out-of-phase charge modulations from electrons on these two bands, which we detect through a characteristic energy dependence of the CDW contrast in topographic STM images. As an ongoing follow-up of this work we will also discuss an alternative spectroscopic approach to unravel the gaps associated to these charge modulations.

Laser-ARPES measurements of $\text{Sr}_2\text{RuO}_4$ under uniaxial strain

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Sr$_2$RuO$_4$ has evolved into a key-model system for correlated electron physics following the discovery of its superconductivity—long believed to harbour $p$-wave triplet pairing—27 years ago. The normal state of Sr$_2$RuO$_4$ is exceptionally well characterized and is generally regarded as the cleanest Fermi-liquid system amongst all transition metal oxides. Recent transport experiments discovered that a compressive strain of $\sim 0.6\%$ causes the superconducting transition temperature of Sr$_2$RuO$_4$ to increase from 1.5 K to 3.4 K concomitant with the development of a pronounced non-Fermi-liquid behaviour in the normal state. This behaviour is commonly attributed to a Lifshitz transition in one of the three Fermi surface sheets [1–3].

Here, we report a new generation of ARPES experiments under strain based on a thermally actuated strain cell and a micro-structured tapered sample prepared with focused ion beam milling. Coupled with a micro-focused laser source, this allows the measurement of the quasi-continuous variation of strain on a single sample. We use this new capability to image the Lifshitz transition and to monitor the evolution of the quasiparticle dispersion and self-energy upon approaching the non-Fermi-liquid regime.

Variable-temperature infrared nanoscopy of quantum materials

Yixi Zhou, Adrien Bercher, Iris Crassee, and Alexey Kuzmenko

Nano-optics group, DQMP, University of Geneva

Our group focuses on research of quantum materials using scattering-type scanning near-field optical microscopy (s-SNOM), in combination with conventional (far-field) optical and Raman measurements. In this presentation, I will give a brief introduction to the s-SNOM technique, overview our current projects and mention open questions, future goals, challenges and collaborations within the Department. A significant part of our research is devoted to functional oxides and interfaces, in a close collaboration with the Oxide interfaces group (Prof. J.-M. Triscone) at the DQMP. Specifically, we study the electromagnetic response of the 2D electron gas (2DEG) created the LAO/STO interfaces, the propagation of surface phonon polaritons (PhPs) and phase separation at metal-insulator transitions induced by temperature and/or electric current. In collaboration with several other groups, we focus on investigating plasmons and phonon polaritons at low temperatures (and in magnetic field) in 2D van der Waals materials: graphene, hBN, jacutingaite, MoO$_3$ and others. Additionally, we develop new physical models for quantitative analysis of s-SNOM spectra and plasmon interference maps.
Quantum materials in and beyond equilibrium

Christian Rüegg\textsuperscript{1,2,3,4}

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Spins form well-defined lattices in many quantum materials and serve as model systems to study many-body states such as interacting quantum dimers, Luttinger liquids, or magnon Bose-Einstein condensates. Neutrons and photons are unique tools for high-precision studies of such states in and beyond equilibrium. An overview of current frontiers in the field will be presented with special focus on exciting new opportunities that free electron lasers like SwissFEL and ultra-fast lasers offer to study out-of-equilibrium quantum phenomena.
Determining the phase diagram of 2D van der Waals magnets

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The arrival of 2D magnets in the form of atomically thin van der Waals (vdW) crystals [1] has open the possibility to explore a plethora of different magnetic states hosting novel interesting phenomena, and to control the magnetic properties of these materials, for instance, via an electric field. Probing magnetism in these systems is however challenging because experimental methods commonly used to study bulk compounds are not sufficiently sensitive to detect signals emerging from micron-sized structures with a diminutive amount of material. Here, we give an overview of recent experiments in which we map the phase diagram of 2D antiferromagnets [2, 3] and ferromagnets via magneto transport measurements performed on vdW heterostructures, in which insulating 2D magnets are used as tunnel barriers. Indeed, the tunneling conductance of the devices evolves as a function of temperature and magnetic field, providing a means to trace the spin configuration in these materials. In antiferromagnets the tunneling conductance changes in response to an abrupt change in the alignment of the spins in the tunnel barriers (and the associated tunneling probability) when the temperature and field are varied across a magnetic transition. Instead, in ferromagnets, where no magnetic boundaries are present below the Curie temperature, the tunneling conductance depends on temperature and magnetic field via the magnetization of the material, a link that has been established only recently. Our results also highlight the coupling between transport and magnetism in vdW magnets, and enable the determination of microscopic information regarding the magnetic state of the material, such as the strength of the interlayer exchange coupling and the energy difference between the spin up and spin down bands.

Four-spin terms and the origin of the chiral spin liquid in Mott insulators on the triangular lattice

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At strong repulsion, the triangular-lattice Hubbard model is described by $s = 1/2$ spins with nearest-neighbor antiferromagnetic Heisenberg interactions and exhibits conventional $120^\circ$ order. Using a combination of infinite density matrix renormalization group and exact diagonalization, we study the effect of the additional four-spin interactions naturally generated from the underlying Mott-insulator physics of electrons as the repulsion decreases. Although these interactions have historically been connected with a gapless ground state with emergent spinon Fermi surface, we find that at physically relevant parameters, they stabilize a chiral spin-liquid (CSL) of Kalmeyer-Laughlin (KL) type, clarifying observations in recent studies of the Hubbard model. We also present a self-consistent solution based on a mean-field rewriting of the four-spin interaction to obtain a Hamiltonian with similarities to the parent Hamiltonian of the KL state, providing a physical understanding for the origin of the CSL. This model is relevant to the theoretical description of several spin liquid candidate materials and we will comment on the implications for experiments.
Ferroelectricity at the nanoscale: complex polarisation textures and emergent functionalities

Patrycja Paruch

DQMP, University of Geneva

Ferroelectric materials can host a wide range of novel functional properties as well as unusual structural features, potentially useful for nanoelectronics applications. At domain walls or in regions with high strain gradients, in particular, the complex interaction between polarisation, electrostatics, and strain can lead to localised chiral polarisation textures, electrical conductivity, local mechanical responses, and charge or chemical segregation. At surfaces, meanwhile, the inherent polarisation discontinuity promotes especially strong and polarisation dependent interactions with adsorbates, of significant interest in catalysis and electrochemistry. My group uses a broad spectrum of primarily scanning probe microscopy techniques, coupled with machine learning analysis to investigate and disentangle the many complex and correlated physical phenomena in these materials. We focus in particular on the functional properties of twin domains, the growth of ice-like water layers on ferroelectric surfaces, and potential applications in catalysis and nanotribology patterning of ferroelectrics, as well as on the fundamental understanding of the structure, geometry and dynamics of domain walls.
Domain walls in ferroic materials: a statistical physics approach to predicting the static and dynamic behaviour of interfaces

Nirvana Caballero, Patrycja Paruch, and Thierry Giamarchi

Department of Quantum Matter Physics, University of Geneva

Ferroic materials are characterized by having regions (domains) with different homogeneous properties that lead to the existence of structures at the nanoscale in the form of interfaces (domain walls). The high-speed manipulation of these nanostructures is the prime factor for the development of the next generation of new and low-power functional devices for computation and communication. Controlling these nanostructures is challenging since their behaviour is governed by the competition between their elastic energy and the varying potential landscape which allows pinning, leading to characteristic roughening and complex dynamic response. The framework of disordered elastic systems is a powerful tool that allows us to unravel the physics of interfaces and has served to understand many of their properties. However, this approach is severely limited by its formal applicability only to univalued and smooth interfaces, thus inducing uncontrolled approximations. Solving interface dynamics and statics in more realistic systems beyond the elastic approximation is still a largely open theoretical/analytical problem. We address this problem by analyzing a Ginzburg-Landau model that allows us to extend the theory of disordered elastic systems, clearly demonstrating the connection between our approach and disordered elastic systems theory. In addition, we show how through this connection it is possible to explain otherwise not-understood experimental results in ferromagnetic interfaces. Our approach is readily applicable to study interfaces in ferroelectric materials.
Wave coherence in the physics of AC electric power grids

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Covering areas as large as entire continents, high-voltage power grids have a priori little to do with quantum mechanics. Yet, upon closer inspection, interesting analogies emerge with quantum / wave-coherent phenomena such as the Josephson effect, vortices in superfluids or multiple coherent scattering. This is so, because the operational state of AC power grids is determined by complex voltages at buses on a two-dimensional network.

In this talk I will give an introduction to the equations describing the dynamics and the operational steady-state of AC power grids. Josephson physics directly emerges from the steady-state equations in the limit of very high voltages. When considering a power grid on a meshed network, this raises the possibility of vortex formation with associated persistent power currents. I will discuss four dynamical mechanisms for vortex formation and their connection to quantum phase slips in superconducting nanorings. Time pending, I may briefly discuss multiple scattering of frequency-disturbances and how they can give rise to wave-coherent phenomena over thousands of miles in continental grids. I will conclude with assessing how much of these analogies are relevant to today’s power grid operation.

Photon dressing of the electronic response of two-dimensional semiconductors in cavity electrodynamics

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Cavity electrodynamics has been recently proposed as a novel platform for controlling properties of matter by exploiting strong light-matter interaction. In particular, this new perspective focuses on the light-matter interaction in the so-called vacuum regime, i.e. in the absence of external sources, in which the coupling is entirely determined by intrinsic fluctuations of electromagnetic fields in the cavity. Despite several proposals for cavity control of collective phases of matter, as e.g. superconductivity and ferroelectricity, the understanding of the fundamental effects of the vacuum light-matter interaction on some material property remains at an early stage. In this talk I will discuss the effects of the vacuum light-matter interaction on the electronic response of two-dimensional semiconductors embedded in an electromagnetic environment made of two planar mirrors [1]. I will describe shifts of the spectral weight for optical absorption due to photon dressing of the electronic response following the evolution from the cavity limit, characterised by a strong effects of the confinement, to the free-space limit in which the effects of the light-matter interaction become independent of the environment. I will therefore discuss the comparison between the quantum and classical treatment of the light-matter interaction and show that, while the electromagnetic environment can be used to control the gap for optical absorption it weakly affects the single-particle electronic band gap. Eventually, I will discuss extension to systems of finite thickness.

Nonlinear magnetophononics in a frustrated quantum antiferromagnet

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Quantum magnetic materials are valuable model systems for realizing intriguing phenomena ranging from quantum phase transitions to magnon condensation and fractionalization, topological orders, and entanglement on macroscopic length scales [1, 2]. The ground state of these materials is dictated by superexchange interactions between neighboring spins, which can be controlled via the crystal lattice through external pressure [3, 4]. However, possible strategies to achieve dynamical control, for example, by ultrafast light pulses, remain relatively unexplored. Here we perform terahertz (THz) pump-probe spectroscopy on the quantum antiferromagnet SrCu2(BO3)2 [5]. By using intense terahertz pulses [6] resonantly tuned to lattice modes, we show coherent excitation of a two-triplet bound state, which is a fundamental quantum spin mode in this material. We explain the observed spin dynamics by nonlinear magnetophononics, which arises from the dynamical modulation of the superexchange interaction at the difference frequency mixing of two primary terahertz-driven phonons that break the geometrical frustration. The observed nonlinear magnetophononic effect is analyzed through first principle calculations of the phonon modes and symmetries.

Our results demonstrate a new and attractive route for ultrafast manipulation of superexchange interactions, ground states, and elementary excitations in quantum spin systems, wherein exciting physics in out-of-equilibrium conditions has high potential for major discoveries and applications.

Filament nucleation and growth in MIT materials

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Certain correlated oxides feature an insulator-to-metal transition which can be triggered by applying an external voltage: the material becomes conducting if a threshold electric field is exceeded. This phenomenon is known as voltage-driven IMT, and it has very promising applications in emerging technologies such as optoelectronics and neuromorphic computing. While it is known that this process takes place in a filamentary way, it is not yet known how these filaments nucleate, grow and relax. We combine reflectivity and transport measurements to image metallization with spatial and temporal resolution. Five systems featuring an IMT from two different families are analyzed: VO₂, V₂O₃, V₃O₅, NdNiO₃ and SmNiO₃, finding remarkable differences in the filament expansion process. By comparing these systems and with the insight of numerical simulations and high resolution SNOM we identify the key parameters that govern the dynamics of the voltage-driven IMT.
ABSTRACTS

of the

poster presentations
Bayesian investigation of quantum criticality in spin dimer systems

Stephan Allenspach,1,2 Alexander Madsen,1,3 Pascal Puphal,4 Steffen Krämer,5 Mladen Horvatić,5 Raivo Stern,6 Maciej Bartkowiak,7 Oleksandr Prokhnenko,7 Nicolas Laflorencie,8 Frédéric Mila,9 Bruce Normand,1,9,10 and Christian Rüegg1,2,9,11

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Phase transitions and their accompanying concepts of criticality and universality are a foundation stone of statistical physics. In gapped spin dimer systems a quantum phase transition can be induced by applying a magnetic field. At this transition U(1) symmetry is broken and the resulting field-induced phase corresponds to a Bose-Einstein condensate (BEC) of magnetic quasi-particles. The phase boundary takes the functional form

\[ T_c(H) = \alpha \left[ \mu_0 H - \mu_0 H_{c1} \right]^{\frac{2}{d}} \]

in the critical regime for these systems and the exponent \( \phi = \frac{2}{d} \) can be used to determine the dimensionality, \( d \), of the BEC. However, determining \( \phi \) from data is challenging due to the high correlation between the parameters (\( \phi \), \( H_{c1} \), \( \alpha \)) and because the size of the critical regime is non-universal and unknown.

Bayesian Inference (BI) is a statistical method used in various areas of physics [1]. The result of BI is not a point estimate but a probability distribution, called the posterior distribution, of the model parameters given the data. BI provides a systematic framework to estimate the value and uncertainty of any single parameter independently from all the other parameters by integrating them out of the posterior distribution. In addition, correlations between parameters are directly visible in the joint posterior distribution of these parameters. Thus using BI in an analysis of the phase boundary, the first problem of independently determining \( \phi \) is solved.

We use BI to determine \( \phi \) from Nuclear Magnetic Resonance spectra measured for the quasi-2D spin dimer compound Ba_{0.9}Sr_{0.1}CuSi_2O_6 [2]. By varying the range of the data included in the analysis, we tackle the second problem and find a value of \( \phi = 2/3 \) (3D). Additionally, we employ BI for the analysis of neutron diffraction data measured for the parent compound BaSrCuSi_2O_6 at magnetic fields up to 25.9 T.

Experimental observation of electron-exciton coupling in high-$T_c$ cuprates

Francesco Barantani,$^{1,2}$ Michael K. Tran,$^1$ Ivan Madan,$^1$ Itzik Kapon,$^1$ Nimrod Bachar,$^1$ Adrien Bercher,$^2$ Teguh Citra Asmara,$^3$ Eugenio Paris,$^3$ Yi Tseng,$^3$ Wenliang Zhang,$^3$ Yi Hu,$^{4,5}$ Xuxin Huang,$^{4,5}$ Enrico Giannini,$^1$ Genda Gu,$^6$ Thomas P. Devereaux,$^{5,7,8}$ Christophe Berthod,$^1$ Fabrizio Carbone,$^2$ Thorsten Schmitt,$^5$ and Dirk van der Marel$^1$

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Explaining the mechanism of superconductivity in the high-$T_c$ cuprates requires an understanding of what causes electrons to form Cooper pairs. Pairing can be mediated by phonons, the screened Coulomb force, spin or charge fluctuations, excitons, or by a combination of these. An excitonic pairing mechanism has been postulated, but experimental evidence for coupling between conduction electrons and excitons in the cuprates is sporadic. Here we use resonant inelastic x-ray scattering (RIXS) to monitor the temperature dependence of the $dd$ exciton spectrum of Bi$_2$Sr$_2$CaCu$_2$O$_{8-x}$ (Bi-2212) crystals with different charge carrier concentrations. We observe a significant change of the $dd$ exciton spectra when the materials pass from the normal state into the superconductor state. From theoretical modeling, we determine the strength of the coupling between the electrons and the excitons. Our observations show that the coupling to excitons can be strong enough to play an important role in stabilizing the superconducting state.
Near field imaging of metallic filaments in NdNiO$_3$ (NNO)

Adrien Bercher, Javier del Valle Granda, Claribel Dominguez, Jennifer Fowlie, Stefano Gariglio, Jean-Marc Triscone, and Alexey Kuzmenko

DQMP

Temperature- and current-controlled metal-insulator transitions (MIT) in rare-earth nickelates attract much attention nowadays. We employed scattering-type scanning near-field optical microscopy (s-SNOM) to investigate the formation of electric-current filaments in NNO thin film grown on LaAlO$_3$ (LAO) with a short separation between the electrodes (10 microns). The current and temperature dependence of the metallic filaments were highlighted in this experiment. We obtain good correlation between the spatial profile of the filaments and changes in the $I/V$ curve of the device.
Record-high upper critical field in MgB$_2$ bulk samples prepared by a non-conventional rapid synthesis route

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The upper critical field ($B_{c2}$) sets the thermodynamic limit to the superconductivity. In the case of the MgB$_2$ superconductor, a big gap is present between $B_{c2}$ values measured in bulk samples and in thin films, where $B_{c2}$ can be as high as $\sim 50$ T at 4.2 K. Filling this gap would unlock the potential of MgB$_2$ for magnet applications, which is much wished by the applied-superconductivity community because of its low cost and relatively high critical temperature, close to 40 K. This work presents the results of an extensive experimental campaign that was guided by a Design of Experiment and demanded the preparation and characterization of $\sim 50$ samples. We measured and modeled the dependence of the upper critical field on the main synthesis parameters and established a new record for $B_{c2}$ ($\sim 35$ T measured at 4.2 K) by tuning the structural disorder in C-doped samples prepared by a non-conventional rapid synthesis route [1]. The idea behind is that rapid heating and cooling may freeze the system in configurations with high structural disorder as in the case of thin films. Indeed, X-ray diffraction and X-ray photoelectron spectroscopy analyses demonstrate that the rapid-synthesis route allows levels of C substitution in the B sites not attainable with conventional manufacturing routes for bulk samples. However, the achieved record appears to be an upper boundary for $B_{c2}$ in bulk samples. Structural disorder in films seems to be able to act selectively on one of the two bands where the superconductivity in MgB$_2$ takes place: this enhances $B_{c2}$ while reducing $T_c$ only by a few Kelvins. On the other hand, the critical temperature in bulk samples decreases monotonically when the structural disorder increases, and this imposes a limit to the maximum achievable $B_{c2}$.

Gate-induced hole superconductivity in transition-metal dichalcogenide

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Few-atoms-thick semiconducting transition-metal dichalcogenides (TMDs) attracted great research interest and showed a variety of promising phenomena. Most of these TMDs show superconducting behaviour when a large amount of carriers are induced by ionic liquid gating [1–3]. Ionic liquid gating is a powerful tool to accumulate high carrier density of the order of $10^{14} \text{cm}^{-2}$ for both electrons and holes. However, all these superconducting behaviours are reported in the conduction band only. Recently, a new gating method, which uses lithium-ion conducting glass ceramic (LICGC) as a substrate for electrostatic gating, was developed [4]. LICGC has a good gating ability which is comparable with ionic liquid. By combining LICGC gating and ionic liquid gating, one can induce larger amount of holes into a 2-dimensional sample than using ionic liquid only. Moreover, this method can provide a tunable perpendicular electric field through the sample which is much larger than any other gating method [5]. In this poster, we show transport studies on the valence band of TMDs using this double gating technique. We searched hole superconductivity by accumulating a higher density of holes and tuning its band structure by a strong perpendicular electric field.

Fermi surface and quasiparticle dispersion of the highly-conductive perovskite oxide SrMoO$_3$

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SrMoO$_3$ single-crystals have the lowest room-temperature resistivity of any transition-metal oxide [1]. This remarkable material has therefore attracted substantial interest for its possible uses as an electrode in oxide-electronics applications [2–5]. Electrical conduction in SrMoO$_3$ arises from the 2 itinerant electrons in the Mo 4$d$ $t_{2g}$ shell [6]. This makes SrMoO$_3$ the particle-hole-symmetric counterpart to the ruthenate SrRuO$_3$, with 2 holes in the Ru 4$d$ $t_{2g}$ shell. The room-temperature resistivity of the latter is, however, more than one order of magnitude higher [7] and existing estimates for the effective masses hint to a markedly different strength of correlations in these two compounds. The reason for this remarkable difference is not known. Here, I will present our ARPES investigation of bulk-like SrMoO$_3$ thin films grown by pulsed-laser deposition. Our synchrotron measurements establish the full 3D electronic structure of SrMoO$_3$ and yield quantitative information about the quasi-particle (QP) band dispersion. We determine QP self-energies and compare our results to dynamical mean-field calculations, which provides new insight into the puzzle of the low resistivity of SrMoO$_3$.

Study of the oxygen diffusion process in commercial REBCO-based coated conductors

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The performance of REBa2Cu3O7−x-based coated conductors (REBCO CCs, RE = rare earth element) has improved considerably in the last years, making them strong candidates for multiple applications like compact fusion machines, high-field dipoles for future accelerators, ultra-high-resolution NMR, motors or generators. The oxygen stoichiometry in the REBCO layer is one of the main parameters that define the superconducting properties of the CC. Multiple studies have been carried out on this topic in laboratory scale REBCO films, whilst there is not much knowledge in the case of commercial CCs, for which differences in the microstructure are expected to affect the oxygen diffusion. In this work, we introduce general aspects of the oxygen diffusion processes in REBCO films and present the results of an experimental campaign focused on the oxygenation/deoxygenation of commercial REBCO tapes in the range of temperatures 150°C–750°C. We combined X-ray diffraction, magnetization and current-transport measurements to study the evolution of the superconducting and structural properties of the CCs as a function of the heat treatment parameters. We paid special attention to the low temperature regime (T < 250°C), which covers also the temperature range used e.g. for soldering, where we found an early degradation of the critical current due to oxygen out-diffusion from the REBCO grain boundaries. No significant decrease of the critical temperature occurs at such low temperatures, indicating that the out-diffusion of oxygen from the grain cores starts taking place only at temperatures above 250°C. Our observations define a double-channel diffusion process for REBCO CCs, one associated with the grain boundaries, with a lower activation energy, and a second one, with a larger activation energy, related to the grains. The study sheds light on the basic mechanisms that rule the oxygenation/deoxygenation processes in coated conductors, but also provides valuable information for many practical applications.
Novel functionalities at twin domain crossings

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In ferroelectrics, domain walls are thin interfaces separating regions with different orientations of electric polarization, either along the same crystalline axis (180° domain walls), or as ferroelastic twins. The domain walls can present physical properties quite different from the surrounding domains, allowing them to be used as active components in future device applications. Recent studies of domain walls using scanning probe microscopy have focused on mapping their response to different parameters such as temperature, applied pressure and electric field, in order to understand their structure-property relationships. In particular, the role of high strain gradients present at ferroelectric twins has been shown to enhance their electrical conduction [1] and can lead to complex rotational polarization textures [2, 3].

Here, I will present our investigation of ferroelastic twin domains (90° domain walls) in epitaxial PbTiO3 thin films grown on SrTiO3, explored with scanning probe microscopy. Our results suggest a complex polarization structure, with unique mechanical response distinct from the surrounding ferroelectric phase, and enhanced electrical conduction.

Identifying atomically thin crystals with diffusively reflected light

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The field of 2D materials has been developing at an impressive pace, with atomically thin crystals of an increasing number of different compounds that have become available, together with techniques enabling their assembly into functional heterostructures. The strategy to detect these atomically thin crystals—based on optical contrast enhanced by Fabry-Pérot interference—has however remained unchanged since the discovery of graphene. Such an absence of evolution is starting to pose problems because for many of the 2D materials of current interest the optical contrast provided by the commonly used detection procedure is insufficient to identify the presence of individual monolayers or to determine unambiguously the thickness of atomically thin multilayers. Here we explore an alternative detection strategy, in which the enhancement of optical contrast originates from the use of optically inhomogeneous substrates, leading to diffusively reflected light. Owing to its peculiar polarization properties and to its angular distribution, diffusively reflected light allows a strong contrast enhancement to be achieved through the implementation of suitable illumination-detection schemes. We validate this conclusion by carrying out a detailed quantitative analysis of optical contrast, which fully reproduces our experimental observations on over 60 WSe$_2$ mono-, bi-, and trilayers. We further validate the proposed strategy by extending our analysis to atomically thin phosphorene, InSe, and graphene crystals. Our conclusion is that the use of diffusively reflected light to detect and identify atomically thin layers is an interesting alternative to the common detection scheme based on Fabry-Perot interference, because it enables atomically thin layers to be detected on substrates others than the commonly used Si/SiO$_2$, and it may offer higher sensitivity depending on the specific 2D material considered.

Long wavelength coherence in networks of coupled oscillators

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It has been observed that in networks of coupled oscillators groups of different oscillators start to coherently oscillate against each other. Such long wavelength coherent effects are well-understood in networks that consist of weakly-coupled well-defined areas. However, these oscillations have also been observed in well-connected large-scale networks. We are using tools from quantum mechanics such as matrix perturbation theory and phenomena like avoided crossings to show how these modes arise from the hybridization of the zero modes of each group and are protected against the influence of the higher modes. Finally, we are applying these techniques to real world applications such as inter-area oscillations in power grids, where groups of generators are oscillating against each other. These inter-area oscillations are problematic because they can lead to grid instabilities. It is therefore of utmost importance to understand better their properties, how they emerge, and how they can be controlled.
Octahedra rotations coupling in perovskite vanadate heterostructures

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Octahedral rotations patterns in transition metal perovskites affect their physical properties due to the strong coupling between the lattice and the electronic degrees of freedom. Across an interface in an epitaxial heterostructure, the corner sharing of the oxygen octahedra has been shown to modify the rotation pattern of the layer; the extent and the structural details of the affected region are currently at the focus of several studies. Theoretical work indicates that such coupling could be at the origin of novel properties and functionalities.

In this work, we investigate by X-ray diffraction and scanning transmission electron microscopy (STEM) the interface between two orthorhombic materials, a LaVO₃ thin film epitaxially grown by pulsed laser deposition onto a (110) DyScO₃ substrate. STEM imaging reveals that the interface is chemically sharp at the atomic scale while the layer possesses a pattern of rotations that depends on and evolves across the thickness of the layer.
Electronic structure of few-layer crystals of the magnetic topological insulator \textbf{MnBi$_2$Te$_4$}

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The interplay between non-trivial topology and magnetism in layered materials is fertile ground for the discovery of novel interesting phenomena. MnBi$_2$Te$_4$ (MBT) is a topological insulator with antiferromagnetic ordering below $\approx 24$ K [1, 2]. Upon exfoliation MBT can be thinned down to few septuple layers and exhibits exotic transport properties. In its six-septuple-layers form, MBT is an axionic insulator and the application of a magnetic field drives a transition to a Chern insulator with quantized Hall resistance [3]. Five-septuple-layers MBT shows the quantum anomalous Hall effect below 1.4 K, a phase previously reported only for non-stoichiometric crystals [4]. Despite the large interest in the ground state of MBT in its two-dimensional limit, little is known from experiments about its electronic structure. Here, we show preliminary results electronic structure measurements of few-layer MBT. We discuss its fabrication and compare our measurements to bulk MBT.

Electroluminescent $\Gamma$ point interlayer excitons

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Assembling semiconductors in type-II interfaces is promising for optoelectronics as the spectral response of the interlayer excitons can be tailored over a broad range by changing the constituents of the heterostructure. Recent works have shown that engineering van der Waals (vdW) heterostructures based on crystals that have the bottom of the conduction band and the top of the valence band at the $\Gamma$ point provide a robust method to tune photoluminescence at various energies depending on the constituents and their thicknesses [1]. Here we fabricated and investigated the first electrical devices of this type of interfaces (i.e. InSe/TMD bilayer). By operating the devices such that a $p$-$i$-$n$ junction forms in the interfacial channel, we observe bright electroluminescence (EL) from interlayer excitons. By tuning the voltage across the interface we are able to modulate the emission energy of the EL over several hundreds of meV. This illustrates that tailored vdW interfaces provide a very attractive platform for tunable radiation sources that cover a very broad frequency spectrum as well as for the study of excitonic dynamic [2–4].

First micro-ARPES measurements of encapsulated few-layer T$_d$-MoTe$_2$

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Thinning a bulk material down to few atomic layers or even to a monolayer influences its physical properties considerably. In this project, we plan to study the thickness dependent electronic structure of MoTe$_2$ in its orthorhombic T$_d$ phase with broken inversion symmetry. Bulk T$_d$-MoTe$_2$ is a type-II Weyl semimetal with topological Fermi arc surface states and becomes superconducting at a low critical temperature of $T_c = 0.1$ K. Remarkably, superconductivity becomes far more robust in the 2D limit, contrary to generic models and the established trend in ultrathin metal films [1]. Recent transport measurements reported an increase in $T_c$ for decreasing thickness with $T_c$ reaching 7.6 K in the monolayer [2]. The reasons for the strong increase in $T_c$ as well as the nature of the superconducting state remain unknown. Here, we will present preliminary micro-focus ARPES measurements of exfoliated few-layer MoTe$_2$ encapsulated between graphite and graphene to protect the flakes from degradation. We will discuss the device fabrication technique as well as first insights into the thickness dependent electronic structure.

Perturbed angular correlation spectroscopy of complex oxide heterostructures

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Perturbed angular correlation spectroscopy (PAC) measures the local magnetic field and electric field gradient (EFG) in materials by introducing radioactive nuclei and observing their emitted radiation [1]. The sensitivity to the EFG can be a crucial advantage of PAC over other local hyperfine probe techniques such as muon spin rotation and relaxation (µSR). The EFG provides spectroscopic access to lattice distortions (e.g. in ferroelectrics) as well as the local chemical environment (e.g. in heterostructures). We will study the magnetic phase diagram of ((SmNiO₃)ₘ/(NdNiO₃)ₘ)₁ superlattices grown epitaxially on [001] pc-oriented LaAlO₃ by ¹¹¹In/¹¹¹Cd-PAC measurements. Using µSR, we have found that two distinct magnetic phase transitions occur in this system only if \( m > 17 \) [2, 3]. Based on DFT simulations, we expect that the difference in EFG between SmNiO₃ and NdNiO₃ is sufficiently large to be resolved in a PAC measurement. Thus, each spectral line in the paramagnetic state can be assigned to one compound. If the two magnetic transitions correspond to separate transitions of the SmNiO₃ and NdNiO₃ layers, this will appear in PAC as a splitting of different lines at different temperatures. We expect that this work will enable future PAC experiments on other complex oxide heterostructures. This is an ongoing project. We hope to obtain first PAC data by the end of June and to show preliminary experimental results in this presentation.

Magnetoresistance oscillations in superconducting films with coexisting charge orders

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Understanding the interplay between superconductivity and charge orders may provide important insights to the mechanism of novel superconductors. Here, I will introduce a distinct type of ordering in two superconducting systems: lithium intercalated TiSe$_2$ and lightly doped Bi$_2$Sr$_2$CaCu$_2$O$_{8+x}$ (Bi-2212). The ordering manifests itself as the magnetoresistance (MR) oscillations at low magnetic fields and at temperatures around the superconducting transition.

In TiSe$_2$, we realize a superconducting dome by lithium intercalation via back gating with solid ion conductor substrates. MR oscillations are observed in the nearly optimal-doped states where the charge density wave (CDW) and superconductivity coexist. In the over-doped regime where the CDW is fully suppressed, the MR oscillations disappear. The oscillations can be attributed to the flux effects in a periodic superconducting matrix, which forms because of the interaction between commensurate and incommensurate CDW. In Bi-2212 films, we control the carrier density continuously in a wide range by lithium intercalation or by varying the oxygen content directly. In the extremely under-doped states which exhibit coexisting superconductivity and charge orders, we observe MR oscillations at low magnetic fields and at temperatures around the superconducting transition. The oscillations can be explained by the Little-Parks effect if we assume spontaneously formed periodic structures with mesh size of about 50 nm.

The ordering we observed is distinctly different from well-established ones such as CDW or pair density wave, which seems to be a more intriguing piece of puzzle in novel superconductors.
Domain scaling and coupling of structural distortions in tensile-strained PbTiO$_3$ heterostructures

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DQMP - University of Geneva

In ferroelectric thin films, the complex interplay between mechanical and electrostatic boundary conditions allows for the formation of a large variety of domain structures with fascinating properties. Heterostructuring and careful tuning of the epitaxial strain allow for precise control of these boundary conditions, leading to the formation of novel domain structures such as polar merons in tensile-strained PbTiO$_3$ films and skyrmions in PbTiO$_3$/SrTiO$_3$ superlattices. The structural coupling across PbTiO$_3$ layers in these systems can also lead to the formation of complex three-dimensionally ordered supercrystal structures, recently observed in tensile-strained PbTiO$_3$/SrTiO$_3$ and PbTiO$_3$/SrRuO$_3$ superlattices. Domain structures in ferroelectric systems not only change the properties of the ferroelectric itself, but can also be used to change the properties of other materials through electrostatic and structural coupling.

Here, we study heterostructures of PbTiO$_3$ under tensile strain, deposited using off-axis RF magnetron sputtering. The films are epitaxially grown on (110)-oriented DyScO$_3$ substrates and are sandwiched between top and bottom 55 unit cell-thick SrRuO$_3$ layers. The tensile strain imposed by the substrate favours a ferroelastic domain structure, with PbTiO$_3$ adopting both in-plane and out-of-plane polarization orientations. Using a combination of x-ray diffraction (XRD) and atomic force microscopy (AFM), we study the domain structure in these systems as a function of PbTiO$_3$ layer thickness. We find that the anisotropic strain imposed by the orthorhombic substrate creates a large asymmetry in the domain configuration, with domain walls macroscopically aligned along one of the two in-plane directions. We show that the periodicity estimated by XRD as a function of the film thickness deviates from the Kittel law. Above a certain critical thickness, the large structural distortions associated with the ferroelastic domains propagate through the top SrRuO$_3$ layer, creating a modulated structure that extends beyond the ferroelectric layer thickness, with signatures observed both in XRD and AFM.

Our results shine light on the complexity of ferroelastic domain structures in PbTiO$_3$-based multilayers and their sensitivity to both electrostatic and mechanical boundary conditions.
Magnetism and superconductivity in iron substituted FeSr$_2$YCu$_2$O$_y$ cuprates

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Substitution of copper by iron in the charge reservoir block of the YSCO cuprate superconductor brings out an appealing insight on the interplay between superconductivity and magnetism $^{[1, 2]}$. The resulting FeSr$_2$YCu$_2$O$_{7+y}$ compounds are composed of [FeO$_1+y$] layers and CuO$_2$ bi-layers which alternate along the stacking direction, making them potential layered magnetic superconductors $^{[3]}$. Indeed, by modifying the hole doping level in FeSr$_2$YCu$_2$O$_{7+y}$, we have explored the evolution from a non-superconducting phase with long-range antiferromagnetic order involving both Fe$^{3+}$ and Cu$^{2+}$ cations for $y = 0.08$, to a superconducting sample with $T_c = 70$ K for $y = 0.85$, in which superconductivity coexists with Fe$^{4+}$ long-range magnetic ordering ($T_N = 110$ K $>$ $T_c$) $^{[4]}$. An intermediate-doped sample, with $y = 0.56$, present a mixed valent Fe$^{3.5+}$ state and superconductivity at a lower $T_c = 30$ K $^{[5]}$. The delicate charge balance between iron and copper is characterized by combining Mossbauer, X-Ray absorption and electron-energy loss spectroscopies and the novel magnetic structures are characterized by means of neutron diffraction and magnetization measurements. We get a further insight on the eventual interplay between the magnetic and the superconducting interactions in these iron-containing cuprates by means of muon spin relaxation spectroscopy measurements.

New oxide group-9 transition metal superconductors in the filled-Ti$_2$Ni type structure

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The Ti$_2$Ni and the related eta-carbide-type structures are known to exhibit various interesting physical properties. The Ti$_2$Ni structure is surprisingly complex for an intermetallic structure-type crystallizing in the space group Fd-3m with a unit cell containing of 96 metal atoms [1, 2]. The related eta-carbide-type compounds of the general formula A$_4$B$_2$X or A$_3$B$_3$X correspond to filled version of the Ti$_2$Ni structure [2]. The role of the void filling light atom X, which can be carbon, oxygen, or nitrogen, has so far been unclear for the overall physical properties of these materials. Herein, we have successfully synthesized single crystals of Ti$_2$Co with the Ti$_2$Ni-type structure and single crystals of eta-carbide-type oxide Ti$_4$Co$_2$O.

We show that while Ti$_2$Co is a semiconductor, while its filled-version Ti$_4$Co$_2$O is a bulk superconductor with a critical temperature of 2.7 K. We find that the interstitial oxygen plays a crucial role for the overall physical properties. By extending this concept to the other group 9 transition metals, we have successfully synthesized the two new compounds Ti$_4$Rh$_2$O and Ti$_4$Ir$_2$O. We, furthermore, show that both are new bulk type-II superconductors with superconducting transitions at 2.8 K and 5.3 K, respectively.

We present detailed measurements on all three superconductors, showing that all three have remarkably high upper critical field in comparison with their critical temperature. Most noteworthy Ti$_4$Ir$_2$O has an upper critical field of 16.06 T, which is exceeding by far the weak-coupling BCS Pauli paramagnetic limit of 9.86 T.


Automatic signal-background decomposition of multidimensional data

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Thanks to the commodification of techniques like automatic differentiation [1] and probabilistic programming [2], data scientists are successfully fitting increasingly complex models to very large datasets. These same tools can be leveraged for the analysis of physics experiments. In this talk I will demonstrate the use of a generic, nonparametric background model in the form of a Markov Random Field with applications for denoising, probabilistic interpolation of gaps in data coverage, and fitting of a signal model directly to a high-dimensional dataset without making cuts or projections, including in the presence of spurions and other background features. The focus is on practical methods that can be immediately employed by non-expert users for rapid analysis of their experiments. I will show applications to time-of-flight neutron spectroscopy but the technique is general and can be adapted to other data-intensive experimental techniques including light scattering and electron spectroscopy.


Wang-McDonald vortex core states in heavily-overdoped Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

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The electronic signature of vortex cores in high-temperature cuprate superconductors has been challenging the scientific community for decades. Early experiments were suggesting that the cores in these materials were not matching the BCS expectations, one of the main argument being that the zero-bias conductance anomaly predicted for d-wave superconductors by Wang and MacDonald in 1995$^1$ was absent. In 2016, we found that the previously reported subgap states in YBa$_2$Cu$_3$O$_{7-\delta}$ (Y123) were belonging to an electronic background uniformly measured across the surface$^2$, and could demonstrate that the vortex cores in Y123 do really present the expected BCS quasiparticle LDOS$^3$. From recent scanning tunneling microscopy data$^4$, we show that vortices observed at very low magnetic field in heavily overdoped Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ do exhibit a clear d-wave electronic structure, with a zero-bias conductance peak at the vortex center that splits with increasing distance from the core. We stress that previously reported unconventional electronic structures, like the low energy conductance modulations in the vortex halo and the absence of a zero-bias conductance peak at the vortex center, are direct consequences of short inter-vortex distance and vortex-vortex interactions prevailing in earlier experiments. Whether these characteristics are restricted to strong overdoping is the focus of ongoing measurements on heavily underdoped samples, where the electronic signatures are significantly dominated by the pseudogap regime. We also aim at studying the widely debated topic of charge density modulations as well as the theoretically predicted pair density waves, in order to confirm their existence or absence at the various doping regimes.

The Laboratory of Advanced Technology: collaborations within the DQMP and beyond

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The Laboratory of Advanced Technology (LTA) is a partnership between the University of Geneva and HES-SO Geneva to support research at both institutions by facilitating resource sharing. In practice, the LTA makes it easy for you to find and access equipment in other sections or faculties without needing a formal collaboration. Here we will show how this works, and how resource sharing can be beneficial to your research activity. The LTA has also launched its own Chemical Analysis and Imaging Platform, with two techniques not previously available at the University of Geneva: XPS and TOF-SIMS. These are both surface sensitive probes of composition and chemistry. We will give a few examples of this platform’s projects within the DQMP and the University, and discuss the scope of these techniques, so you can see how they could be applicable to your research. The LTA is also a bridge between research labs and industry. We will tell you more about how such collaborations work and what benefits they can have for both industrial and academic partners.
The spectral weight of hole doped cuprates across the pseudogap critical point


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The mysterious phase diagram of hole doped cuprates is a big puzzle for researchers in condensed matter physics. This phase complexity in cuprates encloses the highest \( T_c \) at ambient pressure (\( T_c \sim 100 \) K). Recent experiments have highlighted the interplay of the pseudogap phase and superconductivity: the pseudogap vanishes at a critical carrier concentration \( p^* \), constituting a quantum critical point around which the superconducting \( T_c \) forms a dome. At this critical doping \( p^* \), two important breakthroughs were exhibited: (i) A drop in carrier density \( n \) from \( 1 + p \) to \( p \) as the system enters the pseudogap phase observed by Hall effect \([1, 2]\) indicating a sudden Fermi surface reconstruction. (ii) A dramatic effective mass enhancement at \( p^* \) observed by specific heat \([3]\), believed to result from enhanced fluctuations of the pseudogap at the quantum critical point.

In our study, we used infrared optics to measure the free carrier spectral weight. This quantity, expressed in appropriate units represents the kinetic energy of the charge carriers per primitive cell. The spectra exhibit a narrow coherent zero energy mode and a broad incoherent mid-infrared band. The total (coherent + incoherent) spectral weight represents the unrenormalized kinetic energy \( K \) of the charge carriers per primitive cell, and the spectral weight of the narrow zero energy mode is the renormalized kinetic energy \( K^* \) \([4]\).

We demonstrate that in the normal state of LSCO and Eu-LSCO cuprates \( K \) and \( K^* \) are significantly influenced by the behavior of \( n \) and \( m^* \), as their values remain extremely small (3 to 4 times smaller) compared to the band calculation. If we compare \( K^* \) with the superconducting penetration depth \( 1/\lambda^2 \), we show that superconductivity could be a BEC (Bose-Einstein condensate) in the underdoped region. In addition, the spectral weight enclosed inside the MIR band \( K_{MIR} = K - K^* \) tracks the superconducting critical temperature \( T_c \), suggesting a candidate for the pairing mechanism.

Mapping electronic phase coexistence in nickelate superlattices by STEM-EELS

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To study the electronic couplings that are established at the coherent interfaces of epitaxial heterostructures, and their characteristic length-scales, novel characterization techniques capable of mapping electronic phase coexistence at the atomic-scale level are required. Here, we show that scanning transmission electron microscopy in combination with electron energy-loss spectroscopy (STEM-EELS) can be used to map electronic phase coexistence in rare-earth nickelate materials, a system whose physical properties are determined by a strong interplay between its structural, magnetic and electronic properties [1]. The feasibility of the experiment is demonstrated by using two (NdNiO3/SmNiO3) superlattices (SLs) whose constituent SmNiO3 layers are either insulating or metallic at room temperature depending on their corresponding layer thickness [2]. By tracing the changes appearing in the O K and Ni L edge fine structures across both SL, we are able to map their metallic and insulating regions, and to further estimate the width associated to the metallic/insulating boundaries [3].

Neutron scattering under multi-extreme conditions

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Modern neutron scattering investigations require a wide range of sample environments. High-pressure techniques are particularly valuable for controlling the microscopic interactions within the system. Used in combination with magnetic fields and at low temperatures, they provide unique information about the magnetic states, transitions and excitations of materials under extreme conditions. Developing a cryomagnetic system for high-pressure research is a complex engineering challenge with multiple contradictory requirements. A strong magnetic field is achieved most easily in a small volume, but a wide bore is needed to accommodate the pressure cell and cooling system. Effective cooling requires a small sample mass, while high pressures require thick cell walls. Our new cryomagnetic system is based on a superconducting magnet providing a vertical field of 11 T over a very large sample space (100 mm). We have combined this magnet with a large 3He/4He dilution refrigerator (base temperature 20 mK) and two types of pressure cell, a He gas cell (up to 0.5 GPa) and a double-wall clamp cell (up to 1 GPa). For test measurements we used a high-quality single crystal of the spatially anisotropic triangular-lattice material Cs2CuCl4, which displays a cascade of phase transitions at T = 0.05 K and fields up to 11.5 T [1, 2]. Working on the triple-axis spectrometer TASP (PSI), we exploited the high cold-neutron flux to explore the novel field-induced phases. In our first trials at the target temperature, pressure and field parameters, the measured signal-to-noise ratio was sufficient to resolve only structural but not magnetic features, and thus we are changing the pressure cell to increase the sample volume. In developing this uniquely flexible facility for neutron scattering with wide-ranging coverage of the multi-extreme (P, H, T) parameter space, we aim to unveil and understand new physics in a broad spectrum of metallic and insulating quantum magnetic materials [3–5].

Field-induced spin dynamics in triangular-lattice antiferromagnet CsYbSe$_2$

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Geometrically frustrated magnets provide an intriguing playground for the investigation of novel phenomena in condensed matter physics. Among these, one of the most intensively studied models is the triangular-lattice antiferromagnet (AFM) with nearest-neighbour coupling, which shows different ordered and quantum disordered ground states, depending on the interaction symmetry and the applied magnetic field [1, 2]. Recent theoretical progress has made it possible to compute the full excitation spectrum at zero field [3, 4], but good model materials with no disorder or distortions, and only weak interlayer coupling remain, rare. As a result, the rare-earth-based delafossite compounds have attracted considerable recent attention because of their potential for realising the triangular-lattice AFM [5, 6]. In this work we studied CsYbSe$_2$, one member of the delafossite family, by means of inelastic neutron scattering (INS) in fields up to 5 T, as well as by ESR and complementary thermodynamic probes. We found that the zero-field ground state exhibits incipient magnetic order at our lowest temperatures (40 mK), in contrast to theoretical and experimental claims of a quantum spin-liquid state, albeit with a spectrum of highly damped, continuum-like excitations. The applied magnetic field produces a long-range ordered phase over the range, 3–5 T, of the collinear $M_S/3$ plateau state, where the INS spectrum evolves into relatively sharp spin-wave modes. We performed large-cluster DMRG calculations of the Heisenberg model on the triangular lattice in a magnetic field, which reproduce all the essential features of the observed spectra, including damping of the magnon modes in the non-collinear, low-field states and multiple sharp magnon modes in the field-induced plateau state. Our results indicate that the rare-earth delafossites do constitute a faithful realisation of the triangular-lattice AFM with only weak spin anisotropies, and we provide a comprehensive theoretical and experimental overview of the field-induced spin dynamics in this system.

Tricriticality, BKT multicriticality and proximate deconfined quantum criticality in fully frustrated quantum antiferromagnets

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Fully frustrated quantum antiferromagnetic models exhibit a wealth of novel phenomena, including strongly bound multiparticle excitations whose proliferation assures anomalous thermodynamic properties [1, 2 and references therein]. A common feature of these models is a first-order quantum phase transition, which persists to finite temperatures before terminating at a thermal critical point [1, 2]. Major advances in numerical techniques, including quantum Monte Carlo (QMC) in arbitrary bases [1, 2] and finite-temperature tensor-network methods [3], have provided unprecedented insight into the physics of these models.

The Shastry-Sutherland model provides one paradigm for a fully frustrated system that is realised quite faithfully in the material SrCu$_2$(BO$_3$)$_2$ (SCBO). It was shown recently by specific-heat measurements and tensor-network modelling [3] that the pressure-temperature phase diagram of SCBO is dominated by a thermal critical point, occurring at approximately 19 kbar and 3.2 K, which extends with little alteration to finite magnetic fields.

Here we report further theoretical and experimental progress. By QMC simulations of the fully frustrated bilayer model [1] in an applied magnetic field, we show that the line of thermal critical points between the dimer-singlet (DS) and -triplet antiferromagnetic (DTAF) phases becomes a line of finite-temperature tricritical points once the DS phase is replaced by a field-induced checkerboard triplon-crystal (TC) state [4]. The tricritical TC-DTAF line displays emergent $Z_4$ symmetry, delimits the BKT regime of the DTAF state and terminates at a quantum critical endpoint. By nuclear magnetic resonance (NMR) measurements in the plaquette phase of SCBO, we demonstrate that the field-induced transition to the AF phase occurring around 6 T is a “weakly first-order” bicritical point with matching critical exponents, a gapless spin excitation and an emergent O(3) symmetry [5]. These results provide strong experimental evidence for close proximity to a deconfined quantum critical point in SCBO [6].

Tuneable space-charge-doping for scanning tunnelling microscopy investigations

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Doping dependency of 2D materials has in recent years caught much attention, as doping can induce novel physics, such as insulator to superconductor transitions [2] and new charge density wave phases. The nature of these phases is not fully understood, and an in-depth study of tuneable doped systems is therefore of high interest. Scanning tunnelling microscopy (STM) provides the perfect tool to investigate and analyse these novel phases with the ability to resolve structural and electronic properties at an atomic scale. The newly emerged technique, space-charge-doping (SCD) [1], has been found to provide extremely high doping levels (> $10^{14}$ cm$^{-2}$), high tunability while preserving the high surface quality necessary for STM without having any of the downsides of the standard doping methods. This project aims to study doping dependent behaviour of 2D materials through STM and the SCD method. Through the anodic bonding technique, we bind few-layer crystal flakes to a glass wafer. This technique automatically induces electrostatic doping of the flakes through space-charge-doping. Once bound to the glass wafer, the doping level of the flake can be tuned freely and repeatedly through reheating of the glass while applying various electric fields. This is the basis of the SCD method. The combination of SCD and STM allows us to study the same sample at multiple doping levels, providing valuable insight into the nature of purely doping induced phases at the atomic level.

Tunable biaxial strain device for low dimensional materials

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University of Geneva

Strain is attracting much interest as a mean to tune the properties of thin exfoliated two-dimensional materials and their heterostructures. While tunable uniaxial strain has been demonstrated in a range of devices, tunable biaxial strain is yet to be implemented. Here we present a device allowing the controlled application of uniaxial as well as biaxial in-plane strain. We demonstrate their performance on exfoliated 2H-MoS$_2$, characterizing the response of this material to up to 1.6% strain using Raman spectroscopy. We model the devices using finite element analysis to understand the strain response, in particular its uniformity over the sample area.
Quenching the band gap of 2D semiconductors with an electric field

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The electronic band structure of atomically thin semiconductors can be tuned continuously by the application of a perpendicular electric field. Shortly after the discovery of graphene, this principle was demonstrated experimentally by opening a finite band gap in graphene bilayers which naturally are zero-gap semiconductors [1, 2]. So far, however, the same principle could not be employed to control a broader class of materials because the required electric fields are too large. Indeed, whereas top gates with high capacitance were readily available in the form of ionic liquids, the lack of high capacitance back gate restricted the maximum electric field that could be applied. A solution to this problem was brought by our recent study where we used Li-ion conducting glass ceramics for electrostatic gating [3]. In it, we showed that these ionic ceramics had a capacitance similar to that of ionic liquids and could therefore be used in conjunction with them in double gating measurements. As such, we present in this work an experimental strategy using double ionic gated devices, which enables very large electric fields to be applied perpendicularly to atomically thin crystals. Using these devices, we show that the band gap of few-layer semiconducting transition metal dichalcogenides can be continuously suppressed from 1.5 eV to zero. This unprecedented level of control of the band structures has important implications for both future research and applications of atomically thin crystals.

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Dimensional crossover in weakly-coupled chains

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We study the dimensional crossover from one dimension (1D) to quasi-1D that occurs, as a function of temperature, if we weakly couple 1D chains made of interacting particles, bosons or fermions. If temperature is too high, the effect of a small transverse coupling is washed out, meanwhile, for small temperatures, it affects the system. The situation in enriched by the presence of interactions and by meaning of Tomonaga-Luttinger theory we completely describe the low-energy excitations of any 1D interacting system. Moreover, we also consider a Renormalization group approach to address the interplay of interactions and the small inter-chain coupling.
Crystal structure of new polymorph of $\text{Sr}_2\text{TiO}_4$ with tetrahedral titanium

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$\text{Sr}_2\text{TiO}_4$, first member of the Ruddlesden-Popper series $\text{Sr}_{n+1}\text{Ti}_n\text{O}_{n+1}$, has been long known to undergo a phase transition at 1550 °C. This transition makes the growth of single crystals of this material highly challenging, because it usually breaks the crystal into a periodic array of uneven lamellae. While the low temperature tetragonal phase is widely studied due to its close connection to the famous perovskite $\text{SrTiO}_3$, there is little information about the high temperature $\alpha$—phase.

We stabilized the high-temperature $\alpha$—$\text{Sr}_2\text{TiO}_4$ crystals by rapid cooling of the melt from temperature above the structural transition. The $\alpha$—phase crystallizes in the orthorhombic Pna2$_1$ group and is isostructural to the orthorhombic forms of $\text{Sr}_2\text{VO}_4$ and $\text{Sr}_2\text{CrO}_4$. Its structure is formed by a complicated framework of large $\text{SrO}_x$ polyhedra with tetrahedral cavities occupied by the transition metal. The tetrahedral coordination of Ti$^{IV}$ makes the $\alpha$—$\text{Sr}_2\text{TiO}_4$ quite a rare case among titanate compounds, the only other known example being the barium orthotitanate Ba$_2\text{TiO}_4$ [1].

In this work, we report the crystal structure of the high-temperature phase of $\text{Sr}_2\text{TiO}_4$. We compare the optical properties of related compounds and discuss possible mechanism driving the structural transition.

Thickness dependent properties of transition metal dichalcogenides using gold-assisted exfoliation

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Scanning tunneling microscopy (STM) and spectroscopy experiments of transition metal dichalcogenides (TMDs) as function of their thicknesses hold promise for uncovering interesting physical properties. Thickness dependent properties can be very efficiently addressed in mechanically exfoliated bulk crystals. However, the original exfoliation on silicon-oxide substrates often fails to give thin flakes of materials with strong interlayer coupling. Gold substrates, owing to the strong chemical interaction of chalcogens with noble metals like gold, offer an attractive alternative for the exfoliation of TMDs into thin layers (including monolayers) [1]. We will present preliminary results using ultra-flat template stripped gold surfaces [2] in place of freshly prepared surfaces for exfoliating selected TMDs. They are appealing due to their simple preparation techniques and their ability to be stored for long time without being exposed to the environment and hence contamination. Furthermore, they also provide a suitable base for STM experiments.

Ferroelectricity and superconductivity in $^{18}$O-substituted SrTiO$_{3-\delta}$

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SrTiO$_3$ (STO) is an insulator and quantum paraelectric with a remarkably high dielectric constant. A long-range ferroelectric order can be induced by $^{18}$O-isotope substitution above a quantum critical point (QCP) located at 0.33 at. % $^{18}$O. On the other hand, SrTiO$_3$ becomes a metal with a superconducting ground state after the removal of an extremely small number of oxygen atoms making it one of the most dilute superconductors known today. Although superconductivity in this material has been discovered already half a century ago, the pairing mechanism leading to the superconducting dome is still under debate. The superconducting and ferroelectric orders may be accidental neighbors or intimately connected, as in a recently proposed quantum critical scenario where pairing is mediated by the ferroelectric soft mode $^{[1, 2]}$.

We developed a $^{18}$O substitution process to control substitution levels beyond the quantum critical point in bulk STO. In these samples, dielectric and Raman measurements evidence a ferroelectric order below the Curie temperature. Upon electron-doping by oxygen removal, we find that a polar order coexists with the induced metallicity up to a critical doping threshold. In oxygen deficient samples with $^{18}$O-substitution levels close and beyond the QCP, the superconducting critical temperature is strongly enhanced. This supports the role played by the ferroelectric vicinity in the precocious emergence of superconductivity, restricting possible theoretical scenarios for pairing.

Surface density of states in $\text{Pt}_2\text{HgSe}_3$ investigated by quasiparticle interference

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Jacutingaite, with chemical formula $\text{Pt}_2\text{HgSe}_3$, is a layered material that in bulk form manifests a dual topological character by hosting a weak topological phase and a mirror-protected topological crystalline phase. This topological duality has been investigated theoretically \cite{Marrazzo2020, Facio2019} and experimentally by high-resolution angle-resolved photoemission spectroscopy (ARPES) \cite{Cucchi2020}. Here, we extend the experimental investigation to the conduction band—not accessible by ARPES—by means of scanning tunneling spectroscopy (STS), Fourier transform STS, and density functional theory (DFT) calculations. The experiments have been performed at low temperatures and in UHV on high quality single crystals grown at the DQMP. Despite its semimetallic character, at high junction resistances ($R_J$) the spectroscopy curves appear insulating with a large gap $\sim 0.8$ eV, while they have metallic behavior in the limit of low $R_J$. Our DFT calculations explain this behavior with a reconstruction of the surface crystal structure leading to insulating behavior at the topmost layer. We identify several robust spectroscopic features in the density of states in both the conduction and valence band. Quasiparticle interference allows to track their origin to the existence of surface states. We discuss the observed dispersive character and the possible topological nature with the support of DFT calculations.

\cite{Marrazzo2020, Facio2019, Cucchi2020}
Revisiting the electronic and structural properties of heavily underdoped Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ high $T_c$ cuprate superconductor by STM/STS

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Decades after the discovery of high $T_c$ superconductors, there is still some scope to delve deeper into the physics of many poorly understood phenomena such as the pairing mechanism, pseudogap, ordered electronic phases, vortices, and quasiparticle interference present in these compounds. Here, we revisit some of these features in highly underdoped single crystals ($T_c \approx 50$ K) of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (Bi2212) by STM/STS following recent findings in heavily overdoped specimen [1]. STM offers immense spatial and energy resolution for resolving structural and electronic features down to the atomic scale in real space.

The goal of our present work is to understand the ordered phases and the vortex core structures in Bi2212 in the heavily underdoped region. Recent findings from low field vortex imaging studies in overdoped samples has revealed a d-wave electronic core structure with a zero-bias conductance peak at the vortex center which splits upon moving away from the core center [1, 2]. These observations are clearly in contrast with vortex signatures at high fields where low energy checkerboard charge order is observed inside a vortex core and the zero-bias peak is absent. However, underdoped Bi2212 is known to be challenging for STM experiments due to strong local inhomogeneities and pseudogap related features. In our data, we observe some of the recently reported features such as the crystal stripe phase [3], and other well-known features like periodic $\approx 4a_0 \times 4a_0$ and $\approx (3/4)a_0 \times (3/4)a_0$ electronic modulations, where $a_0$ is the crystallographic unit cell. The major focus of our work is to study the intrinsic vortex core electronic structure and ordered phases at low fields in underdoped Bi2212 and possibly detect the pair density waves around the cores in real space from topographic imaging at very low energies close to the superconducting gap.

Multiple ferromagnetic states revealed by transport experiments in the van der Waals ferromagnet VI$_3$

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Magnetic layered van der Waals materials (vdW) is an emergent platform to study and engineer novel phenomena in the 2D limit, however, detecting magnetism at this scale remains extremely challenging. While transport experiments have been vital in investigating the magnetic structure of this class of materials, the information withdrawn from these experiments was limited to certain cases. For instance, the magnetic phase diagram of vdW anti-ferromagnets was successfully determined employing simple conductance measurements [1, 2].

In this work, we report transport experiments performed on thin flakes of VI$_3$: a newly discovered vdW ferromagnet. In particular, our magneto-resistance measurements show distinctive features which demonstrate that VI$_3$ undergoes two ferromagnetic transitions at temperatures $T_{FM1} \approx 58$ K, and $T_{FM2} \approx 36$ K, in agreement with magnetization and specific heat measurements previously reported for bulk samples [3]. Our results show the possibility to realize field-effect transistors based on magnetic vdW materials and demonstrate that magneto-transport measurements are a powerful tool to determine the peculiar phase diagram of atomically thin VI$_3$.

Influence functional of many-body systems: temporal entanglement and matrix-product state representation

Michael Sonner, Alessio Lerose, and Dmitry Abanin

Despite recent experimental and theoretical progress, predicting local dynamics of out of equilibrium many-body systems remains a challenge of computational physics. While in thermalizing systems information about the initial state is quickly forgotten locally, it remains encoded in nonlocal correlations of the entire quantum state. The complexity of the time evolved quantum state severely limits traditional numerical approaches based on the global wavefunction. To circumvent this difficulty we view local dynamics as evolution of a small subsystem subjected to a dissipative quantum bath which represents the rest of the system. This way any spatial correlations which do not contribute to local dynamics do not need to be considered. The action of a quantum bath can be described by the Influence Matrix, a discrete version of the celebrated Feynman-Vernon influence functional. For one dimensional geometries, it is possible to iteratively construct the Influence Matrix corresponding to a longer chain from that of a shorter chain. Instead of spatial entanglement, this method is limited by temporal entanglement. We found several parameter regimes where temporal entanglement is low, even in thermalizing system, where spatial entanglement is high and traditional methods are unfeasible.

Slow dynamics from ultrafast coherent phononic driving in CuGeO$_3$

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Advances in ultrafast light sources allow the targeted modulation of magnetic interactions through selective excitation of infrared-active phonons [1–4], a mechanism known as magnetophononics. The opportunity to probe dynamical magnetic properties out of equilibrium opens new possibilities for finding both novel phenomena and novel solutions to old but unresolved problems. An example of the latter is the spin-Peierls transition in CuGeO$_3$. This material hosts quasi-1D antiferromagnetic $S = \frac{1}{2}$ chains, which are unstable towards a lattice distortion that promotes the formation of a gapped, non-magnetic, collective singlet ground state of spin dimers below a transition temperature of $T_{SP} = 14$ K [5]. Despite intensive research into the magnetoelastic coupling mechanism [6–11], neither a soft mode nor the precise phonon or phonons driving the dimerization of the 1D electronic system has ever been identified.

We apply intense THz pulses to pump a number of phonon modes that modulate the superexchange paths between neighbouring Cu atoms. We identify extremely slow dynamics triggered by the light pulses when measuring on resonance with the onsite Cu d-d transitions. These dynamics are unique to the spin-Peierls phase and represent the first observation of a distinct difference between the uniform and the spin-Peierls phase in a pump-probe experiment. We investigate the origin of this slow timescale (150 ps) within the physics of the spin-Peierls transition and use the example of CuGeO$_3$ to discuss the new possibilities that coherent phononic control of magnetic interactions by THz pulses can offer to the field of quantum magnetism.

Reconstruction of the influence matrix from Keldysh correlation functions

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In the study of quantum thermalisation in isolated quantum many-body systems, the recently developed influence matrix (IM) approach has opened new doors for the efficient simulation of quantum many-body dynamics [1-4]. This approach is inspired by the Feynman–Vernon influence functional which encodes the dynamical influence of a many-body bath on a local subsystem [5]. While a self-consistent approach to the computation of the IM has been proven extremely versatile for the efficient application of MPS algorithms, this technique is not applicable to arbitrary initial states. I will present a complementary perspective in which the IM is viewed as generating functional for Keldysh correlation functions in the bath. By computing these correlation functions explicitly, the IM can be reconstructed for a large range of initial states and certain types of Floquet dynamics. Moreover, this perspective can serve as useful starting point for approximations and renormalisation group approaches which may help to shed new light on the mechanisms governing out-of-equilibrium quantum many-body dynamics.

Probabilistic forecasting of nodal high-voltage electric loads using a variational autoencoder

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High-voltage electric power grids face an increasing amount of uncertainty in their operating state. Aside from component failures, there is growing uncertainty in the in and outflows at grid nodes, caused by fluctuating renewables, electric vehicles, intra-day trading, unscheduled foreign transit flows and more. As these in and outflows depend on complicated human and economic interactions, a data-driven forecasting approach is natural, which can subsequently be combined with the known physics of power flow to form a full probabilistic forecast of the grid state.

This work uses a variational autoencoder (VAE)\textsuperscript{[1, 2]} to learn the joint probability density of hourly nodal loads in the Swiss transmission grid, as a function of time and weather features. The VAE learns a Bayesian network representation of the joint density, making it possible to use ancestral Monte Carlo sampling of complete and coherent ‘load snapshots’ for a given context.

The benefits of this approach are multiple. Firstly, the load distributions are highly correlated and non-Gaussian: the VAE makes it possible to learn flexible marginal distributions depending in a non-linear way on the context, and to model the correlations by sampling the load snapshots for the grid as a whole. Secondly, the ancestral sampling approach makes it possible to form a picture of uncertainty given how much is known at the time: unknown inputs can be sampled, for example from an external probabilistic weather forecast, leading to a wider picture of uncertainty that narrows over time. Lastly, the resulting sampled load snapshots can directly be used in a power flow analysis, leading to a joint distribution over the line flows that can be used to obtain risk measures: examples include the probability of exceeding the thermal limit of a line, and if exceeded, the expectation value of by how much.

Growth and oxygenation of infinite-layer CaCuO$_2$ and SrCuO$_2$ thin films

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The discovery of high-$T_c$ superconductivity in cuprates and the central role of the CuO$_2$ planes for superconductivity in these materials have triggered a large effort in studying the infinite-layer compounds, ACuO$_2$; these systems have a layered structure composed of CuO$_2$ planes and separated by alkaline metal (A = Ca, Sr, Ba) planes [1].

The infinite-layer compounds are insulating when A is an alkaline metal, but can be doped with electrons or holes, leading to the appearance of superconductivity. Hole doping in these systems is usually associated with the appearance of apical oxygens, both in bulk crystals [2] and in multilayer thin films [3–5]. Controlling the oxygen content in these systems is therefore crucial to determine their properties and eventually induce high-$T_c$ superconductivity. Previous works indicate that the infinite-layer structure is modified in presence of highly oxidising atmosphere, with an expansion of the c-axis parameter [6]. In this work, we study this high c-axis phase and more generally the oxygenation of infinite-layer films of CaCuO$_2$ and SrCuO$_2$ deposited using pulsed laser deposition. Our experimental observations from X-ray diffraction and X-ray absorption spectroscopy indicate that under highly oxidising growth condition, additional oxygens are indeed incorporated in the structure, probably at the apical site of copper, as suggested in [6]. Moreover, we demonstrate that three key parameters should be consider in order to control the oxygen content in these compounds: the size of the A-cation, the oxidising power of the growth atmosphere and the strain state induced by the substrate. A careful choice of these parameters leads to the formation of a doped compounds ACuO$_{2+\delta}$, confirmed by first principle and bond valance sum calculations.

Structure-property relationships in superconductors with honeycomb layers

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In this work we successfully synthetized Ca$_{1-x}$Sr$_x$AlSi and Ca$_{1-x}$Sr$_x$GaGe solid solutions and investigated the structural and superconducting properties of these systems. Both CaAlSi and CaGaGe crystallize in 6-folded layered structures with slightly buckled Al-Si and Ga-Ge honeycomb layers. The end members, SrAlSi and SrGaGe, crystallize in prototypical AlB$_2$-type structures with planar Al-Si and Ga-Ge honeycomb layers, respectively. We observed how structure and electronic properties change with chemical substitution, and we find that with an increasing Sr content the Al-Si and Ga-Ge layers become planar in both solid solutions. Interestingly, while the two systems behave chemically very similar, they display very different electronic properties. We find that the buckling of the honeycomb layers in Ca$_{1-x}$Sr$_x$AlSi enhances the superconducting critical temperature across the solid solution, while it decreases it in the Ca$_{1-x}$Sr$_x$GaGe system.
Magneetostructural transition of two-dimensional antiferromagnetic materials under electric field

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The two-dimensional layered antiferromagnetic material MnPS$_3$ had attracted considerable attention for their significant potential application in catalysis, ultraviolet photoelectric detection and spintronics. However, compared with ferromagnetic materials, there are some limitations in application of antiferromagnetic materials. Thus, the modification of magnetic properties of MnPS$_3$ is of great importance. Recently, theoretical calculations show that it could realize the transformation of antiferromagnetic to ferromagnetic order in MnPS$_3$ by adjust the carrier concentration. Because it is difficult to directly detect the magnetism of MnPS$_3$ flakes, we designed and constructed MnPS$_3$/graphene heterojunction to detect the magnetic structure changes of MnPS$_3$ under various gate voltage by measuring the Hall resistance of graphene at low temperature. Through the analysis of the anomalous Hall effect, we can observe the antiferromagnetic state to ferromagnetic state transition, and identify other magnetostructural transition, such as spin-flop and spin-flip transition etc.
Polytypism and superconductivity in the NbS$_2$ system

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NbS$_2$ is a metallic layered transition metal dichalcogenide. While the layers consist of covalently bound atoms, weak van der Waals forces hold the layers together. NbS$_2$ can have two different stacking sequences, resulting in two different stable polytypes: 2H- and 3R-NbS$_2$. We report on the phase formation and the superconducting properties in the NbS$_2$ system. Specifically, we have performed a series of standardized solid-state syntheses in this system, which allow us to establish a comprehensive synthesis map for the formation of the two polytypes 2H-NbS$_2$ and 3R-NbS$_2$, respectively. We show that the identification of two polytypes by means of X-ray diffraction is not always unambiguous. Our physical property measurements on a phase-pure sample of 3R-NbS$_2$, on a phase-pure sample of 2H-NbS$_2$, and a mixed phase sample confirm earlier reports that 2H-NbS$_2$ is a bulk superconductor and that 3R-NbS$_2$ is not a superconductor above $T = 1.75$ K. Our results clearly show that specific heat measurements, as true bulk measurements, are crucial for the identification of superconducting materials in this and related systems.
Electric field effect in few layers antiferromagnetic CrSBr

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Low dimensional magnetic material with weak interlayer electronic coupling and high electrical field tunability provide a great platform for developing modern spintronic technologies. Van der Waals materials CrSBr has been recently reported to be an A-type antiferromagnetic structure below 132 K with each layer aligned ferromagnetically in plane yet coupled antiferromagnetically along the stacking direction [1–4]. To investigate its magnetic tunability with field-effect, we report the in-plane transport and optical study on first successfully fabricated 6–12 layers CrSBr field effect transistor (FET). The FET devices show n-type semiconducting behavior with on/off current ratio of 10³ to 10⁵ from room temperature down to liquid Helium temperatures respectively. The field effect mobility evaluated from the gate capacitance is around 8 cm²/Vs, comparable to the previously reported 2D magnetic van der Waals materials, such as NiPS₃ [5]. Furthermore, we found the finite density of states even at zero backgate voltage which could possibly be attributed to impurity doping with density around 8 × 10¹² cm⁻². Meanwhile, based on thermally activated model, the activation energy at different silicon back gate voltages is estimated and experience a change from 33 to 277 meV revealing the appearance of impurity in gap states below the conduction band. This is consistent with the photoluminescence (PL) spectra, which show the direct gap recombination at 1.35 meV and a low energy peak (1.25 meV) attributed to the presence of impurities in the materials. To explore the magnetic tunability of CrSBr, the magnetic phase diagram versus temperature and magnetic field is studied in detail. Further investigation also reveals a close relation between negative magnetoresistance and applied gate voltage. These results demonstrate the great potential of semiconducting CrSBr as a promising candidate for exploring electrical field effect on 2D magnetism down to low temperature with defects playing a role.

Variable-temperature SNOM imaging of long-propagating phonon-polaritons in strontium titanate

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Surface phonon polaritons—light coupled to lattice vibrations—in polar crystals offer an opportunity to achieve low optical losses and enhanced photonic density of states in the mid-IR to THz spectral ranges, which are of great importance for the applications of biosensing, optical imaging and energy harvesting. Here we firstly report a cryogenic near-field spectroscopic study of phonon polaritonic response at the interface of SrTiO$_3$. We observe a temperature dependence of far-infrared phonon polaritons. Specifically, the phonon polariton propagation length can exceed 100 micrometers at liquid nitrogen temperatures. More importantly, by fabricating LaAlO$_3$/SrTiO$_3$ heterostructure, we observe a blue-shift of the phonon peak comparing with pure SrTiO$_3$. Our experimental findings are accurately supported with theory. Thus, SrTiO$_3$ is confirmed as a new and potential polaritonic material of the perovskite family, which would be beneficial for the understanding and design of future polaritonic devices.
Searching for superconductivity in SrCuO$_2$ heterostructures

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The discovery of high-$T_c$ superconductivity has led to the intensive study of the infinite-layer parent compounds of the superconducting cuprates. These compounds, whilst insulating when grown in the purely infinite-layer phase (ACuO$_2$), can be made superconducting via electron or hole doping, through chemical substitution or defect-layer formation. The research activity focused on these materials has intensified with progress in thin-film deposition techniques, which allowed for the straightforward stabilization of the infinite-layer phases. Consequently, this progress has led to a plethora of discoveries, including superconductivity in artificially layered cuprates $^1$, interface superconductivity between the infinite layer CaCuO$_2$ and the perovskite SrTiO$_3$ $^2,3$, and complete structural reconstructions led by the polar nature of the planes in SrCuO$_2$ $^4,5$.

The rich physics that can be explored in an otherwise simple structure can therefore be utilized for material control through heterostructure engineering $^6$.

Here, we present results on SrCuO$_2$+$\delta$ thin films grown by pulsed laser deposition in a highly oxidizing atmosphere. Using a combination of x-ray diffraction, x-ray absorption spectroscopy and x-ray photoelectron spectroscopy we find that highly oxidizing growth conditions can be employed to stabilize a structure with high oxygen content, where additional oxygens are incorporated in the SrO$\delta$ planes (SrCuO$_2$+$\delta$). Our measurements indicate that the valence of Cu in the structure increases, with additional oxygen atoms leading to hole doping. Therefore, controlling the oxygen content in the structure can lead to precise control of the doping in these systems and may lead to superconductivity.

Exact description of quantum stochastic models as quantum resistors

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We study the transport properties of generic out-of-equilibrium quantum systems connected to fermionic reservoirs. We develop a new method, based on an expansion of the current in terms of the inverse system size and out of equilibrium formulations such as the Keldysh technique and the Meir-Wingreen formula. Our method allows a simple and compact derivation of the current for a large class of systems showing diffusive/ohmic behavior. In addition, we obtain exact solutions for a large class of quantum stochastic Hamiltonians (QSHs) with time and space dependent noise, using a self consistent Born diagrammatic method in the Keldysh representation. We show that these QSHs exhibit diffusive regimes which are encoded in the Keldysh component of the single particle Green’s function. The exact solution for these QSHs models confirms the validity of our system size expansion ansatz, and its efficiency in capturing the transport properties.