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Research Interests & Expertise

My current research interests focus on the engineering of novel states of matter in two-dimensional materials. I currently work on the strongly-correlated flat bands of twisted multilayers of graphene, studying their properties through electrical and optical methods. During my PhD and MSc, I gained expertise in the fabrication of complex vdW heterostructures, correlated and topological properties of flat band systems, two-dimensional superconductivity, thermoelectricity, quantum transport and optoelectronics. I have over 6 years of expertise in nanofabrication techniques, including standard cleanroom processes (e-beam and laser lithography, etching, metal deposition, sputtering), fabrication of 2D materials (exfoliation, stacking), fabrication in inert atmosphere (glovebox systems) and advanced patterning techniques (including He-FIB). My key scientific contributions include the demonstration of heavy-fermion physics in MATBG, the observation of ultrafast carrier dynamics and novel e-ph cooling mechanism and the first demonstration of single-photon detection on a high- T_C superconductor.

Research Experience

16/09/19 – 02/09/24

PhD in Photonics, Advisor: Prof. Dr. Dmitri K. Efetov
“*Optoelectronic studies of strongly correlated 2D materials*”
LMU, Munich, Germany & ICFO, Barcelona, Spain

- Correlated transport and optoelectronic properties of moiré materials
- Study of the thermoelectric effect in magic-angle twisted bilayer graphene
- Study of the cooling dynamics of hot carriers in magic-angle twisted bilayer graphene
- Developing a high-temperature single-photon detector based on 2D superconductor
- Fabrication of waveguide-integrated, high- T_C superconducting bolometers
- Fabrication of nanostructures in cleanroom environment & other fabrication tools
- Glovebox assembly of vdW heterostructures for air-sensitive materials
- Low-temperature transport and optoelectronic studies of vdW heterostructures
- Data analysis, scientific writing, teaching & mentorship skills

15/02/19 - 15/08/19

Master Thesis project, Advisor: Dr. Pol Forn Díaz
“*Coherent control of superconducting quantum bits*”

Barcelona Supercomputing Centre, Barcelona, Spain

- Dispersive readout of a capacitively-coupled transmon qubit @ 4.8 GHz
- Calibration of IQ Mixers for heterodyne detection of qubit resonances
- Concepts of quantum optics & circuit quantum electrodynamics

10/12/18 - 15/02/19

Research Internship, Advisor: Dr. Sandra Bermejo

“Electro-sprayed nanostructures for thin silicon solar cells”

Universitat Politècnica de Catalunya (UPC) – Barcelona, Spain

- Fabrication of electro-sprayed colloidal crystals based on polystyrene nanospheres
- Characterization of the efficiency for a solar cell (spectro-photometry)
- Concepts on photovoltaic response and solar cell operation

15/08/17 - 15/12/17

Bachelor Thesis project, Advisor: Prof. Dr. Michiel de Dood

“Characterizing MoSi superconducting single photon detectors”

Universiteit Leiden – Leiden, The Netherlands

- Transport in crystalline & amorphous superconducting thin films
- Free-space near-infrared optics at low temperatures ($T = 3.3$ K)
- Counting statistics and quantum detector tomography for single-photon detection

Education

01/08/2022 – present **PhD in Photonics (continuation-group move)**

Ludwig Maximilians Universität (LMU) – Munich, Germany

16/09/2019 – 01/08/2022 **PhD in Photonics**

Institute of Photonic Sciences (ICFO) – Barcelona, Spain

12/09/2018 – 24/07/2019 **M.Sc. in Photonics (M2)**

Universitat Politècnica de Catalunya – Barcelona, Spain

11/09/2015 – 10/07/2018 **B.Sc. in Physics**

Universidad de La Laguna – Tenerife, Spain

15/09/2013 – 30/08/2015 **B.Sc. in Physics & Mathematics**

Universidad Complutense – Madrid, Spain

Awards & Scholarships

2022 FI AGAUR National Fellowship for PhD candidates (Catalan Government)

2022 FI AGAUR National Fellowship for PhD candidates (Catalan Government)

Fully-funded fellowship for excellent doctoral candidates.

2018 National Fellowship for Post-Bachelor studies (Spanish Government)

Full tuition of M2 master studies for excellence at the Bachelor level.

2018 Highest honors for Bachelor thesis (Universidad de La Laguna)

2017 Erasmus + Grant (European Union)

Funding for research stay in Leiden, The Netherlands for Bachelor Thesis.

2013 Fellowship for Bachelor studies (Spanish government)

Full tuition for 1st year of B.Sc. in Physics & Mathematics on the basis of excellence.

Publications in peer-reviewed journals

1. **R. L. Merino**, D. Călugăru, H. Hu, J. Díez-Mérida, A. Díez-Carlón, T. Taniguchi, K. Watanabe, P. Seifert, B. A. Bernevig and D. K. Efetov. Interplay of light and heavy electron bands in the thermoelectric transport of magic-angle twisted bilayer graphene, *under review Nature Physics*. (2024), arXiv:2402.11749

- Key observations: First demonstration of heavy-fermion physics in the Seebeck coefficient of MATBG, demonstration of the photo-thermoelectric effect in MATBG
- Acquired skills: Thermoelectric transport, optoelectronics and transport characterization in graphene p-n junctions, Seebeck coefficient in moiré graphene.

2. D. Călugăru, H. Hu, **R. L. Merino**, N. Regnault, D. K. Efetov and B. A. Bernevig. The Thermoelectric Effect and Its Natural Heavy Fermion Explanation in Twisted Bilayer and Trilayer Graphene, *under review Phys. Rev. Lett.* (2024), arXiv:2402.14057

- Key observations: Modelling the Seebeck coefficient in the correlated ground states of MATBG, predicting anomalous Seebeck coefficient due to light-heavy insulators.
- Acquired skills: Concepts on microscopic modelling of MATBG flat bands, concepts on strongly-correlated physics in heavy fermion materials.

3. J. D. Mehew, **R. L. Merino**, H. Ishizuka, A. Block, J. Díez-Mérida, A. Díez-Carlón, K. Watanabe, T. Taniguchi, L. Levitov, D. K. Efetov and K. J. Tielrooij. Ultrafast Umklapp-assisted electron-phonon cooling in magic-angle twisted bilayer graphene, *Sci. Adv.* **10** adj1361, (2024)

- Key observations: Discovery of a novel, moiré-induced mechanism for cooling of hot carriers in MATBG, first study of light-matter interaction in MATBG p-n junctions
- Acquired skills: Techniques to resolve hot carrier dynamics: CW photomixing and time-resolved photovoltage. Light-matter interaction and e-ph coupling in MATBG.

4. **R. L. Merino**, P. Seifert, J. R. Durán-Retamal, R. K. Mech, T. Taniguchi, K. Watanabe, K. Kadowaki, R. H. Hadfield and D. K. Efetov. Two-dimensional cuprate nanodetector with single telecom photon sensitivity at $T = 20$ K, *2D Materials*. **10**, 021001 (2023)

- Key observations: Demonstration of high- T_C single-photon detector with record operating temperature of $T = 20$ K. Non-invasive fabrication of cuprate nanowires.
- Acquired skills: Fabrication in glovebox environment, fabrication using focused-ion beams (Ga-FIB, He-FIB). Transport and optical characterization of high- T_C nanowires.

5. S. Yang, A. Díez-Carlón, J. Díez-Mérida, A. Jaoui, I. Das, G. di Battista, **R. L. Merino**, R. K. Mech and D.K. Efetov. Plethora of many body ground states in magic angle twisted bilayer graphene, *Low. Temp. Phys.*, **49**, 631 (2023)

- Key observations: Review on the various condensed matter phases found in MATBG.
- Acquired skills: Phenomenology of MATBG and other strongly-correlated systems.

6. P. Seifert, J. R. Durán-Retamal, **R. L. Merino**, H. H. Sheinflux, J. Díez-Mérida, J. N. Moore, M. A. Aamir, T. Taniguchi, K. Watanabe, M. Artiglia, M. Romagnoli and D.K. Efetov. A high- T_C van der

Waaals superconductor based photodetector with ultra-high responsivity and nanosecond relaxation time, *2D Materials*. **8**, 035053 (2021)

- Key observations: Bolometers based on 2D, high- T_C superconductor. Record detection speed (ns) and responsivity (10^7 V/W). Integration on SiN planar waveguides.
- Acquired skills: Cleanroom fabrication, vdW assembly, optoelectronic techniques

Scientific talks

Invited

1. Swabian Summer School – Stuttgart, Germany September 2024
“Harnessing 2D superconductivity for quantum sensing”
2. Blas Cabrera Seminar – ULL, Tenerife, Spain September 2024
“Estudios optoelectrónicos de materiales 2D fuertemente correlacionados”
3. Superconducting Quantum Devices – ARC, Glasgow, UK July 2023
“Detecting telecom photons using a 2D high-TC superconductor”

Contributed

4. APS March Meeting – Minneapolis, USA March 2024
“Signatures of heavy electron bands in the thermoelectric response of MATBG pn-junctions”
5. CLEO Europe – Munich, Germany June 2023
“2D high-temperature superconducting nanodetectors”
6. Internal Seminar CeNS– Munich, Germany June 2023
“Intrinsic and synthetic correlated electrons in 2D materials and how to use them”
7. ICFO – IMPRS Workshop – Barcelona, Spain April 2023
“Twist angle control of hot carrier relaxation in magic angle twisted bilayer graphene”
8. APS March Meeting – Chicago, USA March 2022
“Single-photon detection at $T = 20$ K in an exfoliated 2D cuprate superconductor”
9. Quantum201 – Bilbao, Spain November 2021
“Photodetection on an exfoliated two-dimensional cuprate superconductor”
10. COEFIS XII – Tenerife, Spain March 2019
“Quantum computing: Exploiting quantum properties to solve hard problem”

Internal

11. Visit to Klaus Ensslin’s group @ ETH – Zurich, Switzerland November 2022
“Two-dimensional superconducting bolometers for ultra-sensitive photodetection”
12. Visit to Philip Walther’s group @ UniVie – Vienna, Austria May 2019
“Characterizing an SNSPD based on amorphous MoSi thin films”

Prizes

- Best Poster prize at Graphene2024, Madrid, Spain June 2024

Other conference contributions

- Poster contribution at Graphene2024, Madrid, Spain June 2024

Research stays with collaborators

2024 Short research stay at Klaas-Jan Tielrooij's group at TU/Eindhoven, The Netherlands

- *Acquired skills: Operation of time-resolved optoelectronic setup using pulsed lasers and optothermal methods for the characterization of 2D materials.*

2020 Short research stay at Marco Romagnoli's group at CNIT, Pisa, Italy

- *Acquired skills: Operation and testing of integrated photonic circuits. Fabrication of 2D devices coupled to planar photonic waveguides.*

Teaching experience

2023 Winter Semester Tutorials in Advanced Solid State Physics, 80 total students M1 level,
M.Sc. in Physics, Ludwig Maximilian University (LMU), Munich, Germany

- *Acquired skills: Preparation of classes & exercises, communication & dissemination skills, mentorship skills.*

Supervision

23/04/24 - present M.Sc. student - Egor Agapov: Study of hot carrier response in moiré
graphene *p-n* junctions

10/02/24 - 10/06/24 Intern – Lorenzo Volta: Assembly of Ar-filled glovebox setup for
vdW assembly and electrical testing

Participation in International Projects

ERC Starting Grant SuperTwist – Ref: 852927

Funding agency: European Research Council

Total funds: 1.780.000 €

Tasks: Develop novel thermal probes for correlated 2D materials based on the photo-thermoelectric effect

2D-SIPC, Graphene Flagship (2018-2022) – Ref: 820378

Funding agency: European Commission

Total funds: 530.000 €

Tasks: Develop the key enabling technology of high-temperature superconducting single-photon detectors