Erwin Schrödinger International Institute
for Mathematics and Physics

ANNUAL REPORT 2021

THE INSTITUTE PURSUES ITS MISSION THROUGH A VARIETY OF PROGRAMMES

THE ERWIN SCHRÖDINGER INTERNATIONAL INSTITUTE FOR MATHEMATICS AND PHYSICS (ESI), founded in 1993 and part of the University of Vienna since 2011, is dedicated to the advancement of scholarly research in all areas of mathematics and physics and, in particular, to the promotion of exchange between these disciplines.

THEMATIC PROGRAMMES offer the opportunity for a large number of scientists at all career stages to come together for discussions, brainstorming, seminars and collaboration. They typically last between 4 and 12 weeks, and are structured to cover several topical focus areas connected by a main theme. A programme may also include shorter workshop-like periods.

WORKSHOPS with a duration of up to two weeks focus on a specific scientific topic in mathematics or physics with an emphasis on communication and seminar style presentations.

THE JUNIOR RESEARCH FELLOWSHIP PROGRAMME supports external or local graduate students and recent postdocs to work on a project of their own.

THE SENIOR RESEARCH FELLOWSHIP PROGRAMME aims at attracting internationally renowned scientists to Vienna for visits to the ESI for up to several months. Senior Research Fellows contribute to the scientific training of graduate students and postdocs of Vienna's research institutions by teaching a course and by giving scientific seminars.

THE ESI FREQUENTLY HOSTS GRADUATE SCHOOLS organized by research groups at the University of Vienna on topics in mathematics or physics aimed at local as well as external PhD students.

THE RESEARCH IN TEAMS PROGRAMME offers support for research teams to carry out collaborative work on specific projects at the ESI in Vienna for periods of one to four months.

DETAILED INFORMATION about all ESI programmes and the respective application procedures and deadlines are available on the ESI website **www.esi.ac.at**

ESI Annual Report 2021

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Preface

Message of the Director

As Director of the ESI, I am very pleased to present the annual report which gives an overview of all activities that took place at the institute in 2021. Of course, like in 2020 also in 2021 life at the ESI was dominated by the COVID-19 pandemic. Despite the immense progress made in the development of vaccines and other measures to mitigate the effects of the pandemic, the year 2021 was still rather difficult and as a visitors-oriented research institute focusing on the exchange of ideas and international communication, the ESI was affected particularly strongly. In the first part of 2021 high infection rates made it impossible to carry out on-site activities at the ESI, situation normalized a bit in early summer such that an almost normal programme of activities could take place at the ESI in the summer and early autumn. In November, however, a huge wave of infections in Austria and other parts of the world made it necessary to shut down the institute again forcing us into virtual space until early 2022. While in a regular year 4 - 5 thematic programmes take place at the ESI, there was only one such programme in 2021, which was made possible by the low infection numbers in the summer. Of the many workshops planned at the ESI in 2021 only two could take place on-site while most of them were carried out online. Fortunately, a number of individual researchers and small groups of researcher in our Research in Teams programme were able to visit the ESI as these activities were easier to plan and shift in time when necessary.

At the time of writing, the COVID-19 pandemic is not over yet and the world is in the grip of more than one crisis. In February 2022, people at the ESI were shocked by the brutal attack of Russia on Ukraine. In order to support Ukrainian scientists, the ESI started a special fellowship programme for research stays of up to four months. This initiative was also supported by the Faculties of Mathematics and Physics of the University of Vienna and from the Association Erwin Schrödinger Institute, to which I would like to express my gratitude. A detailed report on this special programme will be included in the annual report 2022.

Since it started in early 2020, the pandemic was a learning experience for all people involved in the ESI both in terms of communication technology and organization. The ESI has now accumulated the know-how and installed the equipment required to carry out hybrid events that combine on-site and online participation. While some of the virtual communication elements introduced at the ESI in the last two years will certainly stay, the countless virtual meetings all of us had to endure have highlighted how important physical proximity, such as a chat in the coffee break or a discussion over dinner, is for developing ideas, engage in discussions and forge new collaborations. At the ESI, we will continue to work with the community to find a good balance of real-world and virtual interactions in all ESI activities. In this process the ESI can rely on excellent staff who have responded to the challenges of the pandemic with optimism, energy and great dedication. Despite the challenges we are currently facing worldwide, I am confident that the ESI will continue to thrive and play an important role in promoting research and the global exchange of ideas in all areas of mathematics and physics. I look forward to welcome many old and new visitors at the ESI in the years to come.

Christoph Dellago
Director of the ESI
September 2022

The Institute and its Mission

The Erwin Schrödinger International Institute for Mathematics anond Physics (ESI), founded in 1993 and part of the University of Vienna since 2011, is committed to the promotion of scholarly research in mathematics and physics, with an emphasis on the interface between them.

It is the Institute's foremost objective to advance scientific knowledge in all areas of mathematics and physics and to create an environment where scientists can exchange ideas and fruitful collaborations can unfold. The Institute provides a place for focused collaborative research and interweaves leading international scholars, both in mathematics and physics, with the local scientific community. In particular, the research and the interactions that take place at the Institute are meant to have a lasting impact on those who pursue their scientific education in Vienna.

In the following, we will give a brief overview of the institutional structure of the ESI and the various programmatic pillars of its scientific activities. Thematic programmes form their core, supplemented by workshops, graduate schools and lecture courses given by Senior Research Fellows at the ESI. All activities include strong educational components. Guided by strict scientific criteria and supported by an international Scientific Advisory Board (SAB), the various actual components of the scientific activities of the ESI are chosen on a competitive basis.

The Institute currently pursues its mission in several ways:

(a) primarily, by running four to six *thematic programmes* each year, selected about two years in advance on the basis of the advice of the international ESI Scientific Advisory Board;

(b) by organizing additional *workshops* which focus on topical recent developments;

(c) by a programme of *Senior Research Fellows* (SRF), who give lecture courses at the ESI for graduate students and post-docs;

(d) by setting up *summer/winter schools* for graduate students and postdocs;

(e) by a programme of *Junior Research Fellows* (JRF), which supports graduate students or recent postdocs to work on a project of their own that is either connected to a research direction carried out at the University of Vienna or to an ESI thematic programme;

(f) by a programme of *Research in Teams* (RiT), which offers groups of two to four *Erwin Schrödinger Institute Scholars* the opportunity to work at the Institute for periods of one to four months;

(g) by inviting *individual scientists* who collaborate with members of the local scientific community.

Scientific Activities in 2021

In 2021, the following thematic programme took place at the ESI:

- *Geometry for Higher Spin Gravity: Conformal Structures, PDEs, and Q-manifolds*
  August 23 – September 17, 2021
  (org.: Xavier Bekaert (U Tours), Andreas Cap (U Vienna), Stefan Fredenhagen (U Vienna), Maxim Grigoriev (Lebedev Inst. & Lomonosov Moscow SU), Alexei Kotov (U Hradec Králové))

The following thematic programmes, scheduled for 2021, could not take place due to the spread of the COVID-19 pandemic. All these programmes have either been cancelled or postponed to the year 2022.

- *Mathematical Perspectives of Gravitation beyond the Vacuum Regime*
  February 1 – March 12, 2021
  (org.: Håkan Andréasson (CUT, Gothenburg), David Fajman (U Vienna), Jérémie Joudioux (MPIGP, Potsdam), Todd Oliynyk (Monash U, Melbourne))

- *Applied Functional Analysis and High-Dimensional Approximation*
  April 19 – May 28, 2021
  (org.: Aicke Hinrichs (JKU, Linz), Boris Kashin (RAS, Moscow), Denka Kutzarova (U Illinois), Vladimir Temlyakov (U of South Carolina, Columbia), Sergey Tikhonov (CRM, Barcelona))

- *The Landscape vs. the Swampland*
  May 31 – July 9, 2021
  (org.: Gary Shiu (U of Wisconsin-Madison), Washington Taylor (MIT, Cambridge), Irene Valenzuela (Harvard U, Cambridge), Timm Wrase (Lehigh U, Bethlehem))

- *Quantum Field Theory at the Frontiers of the Strong Interaction*
  July 19 – August 20, 2021
  (org.: André H. Hoang (U Vienna), Simon Plätzer (U Graz), Massimiliano Procura (U Vienna), Malin Sjödahl (Lund U), Iain Stewart (MIT, Cambridge))

A detailed account of the thematic programme that could take place is given in subsequent sections of this report.

In addition to this thematic programme, one workshop, one graduate school and workshop, the ESI Medal Award Ceremony 2021 and the IMO-Training were carried out on-site at the ESI in 2021, complemented by visits of several individual scholars who collaborated with scientists of the University of Vienna and the local community. In addition, many organizers agreed to organize pure online workshops to share their current scientific work with each other and to stay in touch. Here is a list of these activities:

- *Online-Workshop: Mathematical Perspectives of Gravitation beyond the Vacuum Regime*
  February 22 – 25, 2021
  (org.: Håkan Andréasson (CUT, Gothenburg), David Fajman (U Vienna), Jérémie Joudioux (MPIGP, Potsdam), Todd Oliynyk (Monash U, Melbourne))

- *Online-Workshop: Tomographic Reconstructions and their Startling Applications*
  March 15 – 25, 2021
  (org.: Wolfgang Drexler (Med U Vienna), Peter Elbau (U Vienna), Ronny Ramlau (RICAM, Linz), Monika Ritsch-Marte (Med Uni Innsbruck), Otmar Scherzer (U Vienna), Gerhard Schütz (TU Vienna))
- *Online-Workshop: Interdisciplinary Challenges in Nonequilibrium Physics*
  April 12 – 16, 2021
  (org.: Demian Levis (U Barcelona), Emanuele Locatelli (U Vienna), Jan Smrek (U Vienna), Francesco Turci (U Bristol))
- *Online-Workshop: Memory Effects in Dynamical Processes: Theory and Computational Implementation*
  June 23 – 25, 2021
  (org.: Christoph Dellago (U Vienna), Anja Kuhnhold (U of Freiburg), Hugues Meyer (U of Saarland), Tanja Schilling (U of Freiburg))
- *International Mathematical Olympiad Training 2021*
  June 28 – July 4 and October 27 – 29, 2021
  (org.: Michael Drmota (TU Vienna), Theresia Eisenkölbl (U Lyon), Michael Eichmair (U Vienna))
- *Online-School: DARK MATTER: From Theory to Detection*
  July 7 – 16, 2021
  (org.: Markus Arndt (U Vienna), Josef Pradler (HEPHY Vienna), Massimiliano Procura (U Vienna), Jochen Schieck (OEAW, Vienna), Armin Shayeghi (U Vienna), Fedor Simkovic (Comenius U, Bratislava))
- *Arithmetic Statistics and Local-Global Principles*
  September 20 – 24, 2021
  (org.: Tim Browning (ISTA, Klosterneuburg), Daniel Loughran (U Bath), Rachel Newton (KCL, London))
- *Symposium: ESI Medal Award Ceremony 2021*
  November 5, 2021
  (org.: Christoph Dellago (U Vienna, ESI Director))
- *School and Workshop: Higher Structures Emerging from Renormalisation*
  November 8 – 19, 2021
  (org.: Pierre Clavier (U of Haut-Alsace), Kurusch Ebrahimi-Fard (NTNU, Trondheim), Peter K. Friz (TU Berlin), Harald Grosse (U Vienna), Dominique Manchon (U of Clerment Auvergne), Sylvie Paycha (U of Potsdam))
- *Online-Workshop: Topology, Disorder, and Hydrodynamics in Non-equilibrium Quantum Matter*
  November 29 – December 3, 2021
  (org.: Jörg Schmiedmayer (TU Vienna), Maksym Serbyn (ISTA, Klosterneuburg), Romain Vasseur (U Massachusetts, Amherst))

The following workshops, scheduled for 2021, could not take place due to the COVID-19 pandemic. The workshops scheduled for spring were postponed to 2022. The workshops from May on were cancelled according to the new Covid-strategy of the ESI, if the event could not be hold at least in hybrid format and the organizers did not agree to hold them purely online.

- *Optimal Point Configurations on Manifolds*
  January 10 – 21, 2021
  (org.: Christine Bachoc (U Bordeaux), Henry Cohn (Microsoft, Redmond), Peter Grabner (TU Graz), Douglas Hardin (Vanderbilt U, Nashville), Edward Saff (Vanderbilt U, Nashville), Achill Schürmann (U of Rostock), Robert Womersley (UNSW, Sydney))

- *Stochastic Partial Differential Equations*
  February 8 – 12, 2021
  (org.: Sandra Cerrai (U of Maryland), Martin Hairer (Imperial College, London), Carlo Marinelli (IRIS) Eulalia Nualart (UPF), Luca Scarpa (Politecnico Milano), Ulisse Stefanelli (U Vienna))

- *Non-regular Spacetime Geometry*
  May 3 – 7, 2021
  (org.: Piotr T. Chrusciel (U Vienna), Michael Kunzinger (U Vienna), Ettore Minguzzi (U Florence), Roland Steinbauer (U Vienna))

- *Spectral Theory of Differential Operators in Quantum Theory*
  October 4 – 8, 2021
  (org.: Jussi Behrndt (TU Graz), Fritz Gesztesy (Baylor U, Waco), Ari Laptev (Imperial College, London), Christiane Tretter (U Bern))

- *Black-body Radiation Induced Effects and Phenomena*
  October 18 – 22, 2021
  (org.: Philipp Haslinger (TU Vienna), Francesco Intravaia (HU Berlin), Dennis Rätzel (HU Berlin), Matthias Sonnleitner (U Innsbruck))

As in previous years, within the *Senior Research Fellows* programme, the ESI offered a lecture course on an advanced graduate level.

In the summer term 2021 Pierre Germain (Courant Institute, New York U) gave a course on *Stability in nonlinear dispersive PDEs set on the line*. The course had to be held as a pure online course. Videos of the lectures are available on the ESI YouTube channel:

Established in 2012, the *Research in Teams Programme* provides the opportunity for research teams of a few people to work at the Institute in order to concentrate on new collaborative research in mathematics and physics. The interaction between the team members is a central component of this programme. The following research teams worked at the ESI in 2021. Despite the Covid-pandemic it was possible to host small research teams to work together on-site at the ESI:

- Robert Koenig (TU Munich), Kristan Temme (IBM T.J. Watson Research Center), *Simulability-versus-Noise Tradeoffs for Restricted Quantum Circuits*, August 8 – 22, 2021.

- Jeffrey Forshaw (U of Manchester), Patrick Kirchgässer (Lund U), Maximilian Löschner (KIT, Karlsruhe), Simon Plätzer (U Vienna), *Amplitude Evolution I: Initial State Evolution*, August 23 – September 17, 2021.

- Judith Alcock-Zeilinger (U Tübingen), Malin Sjödahl (Lund U), Stefan Keppeler (U Tübingen), Simon Plätzer (U Vienna), *Amplitude Evolution II: Cracking Down on Colour Bases*, September 13 – 24, 2021.

– Robert Kurinczuk (Imperial College London), Nadir Matringe (U of Poitiers), Alberto Mínguez (U of Vienna), Vincent Sécherre (Versailles U), *l-modular Langlands Quotient Theorem and Applications*, September 12 – 27, 2020, June 2 – July 4, 2021, September 19 – October 1, 2021, October 10 - 14, 2021.

– Philipp Haslinger (TU Vienna), Francesco Intravaia (Humboldt University Berlin), Dennis Rätzel (Humbolt University Berlin), Matthias Sonnleitner (U Innsbruck), *Blackbody Radiation induced inertial Effects and collective Phenomena - Theoretical Basis and Experimental Feasibility*, February 25 – March 1, June 2 – 8, November 18 – 22, 2019. September 22 - 25, 2021.

– Yacin Ameur (Lund U), Naomi Feldheim (Bar Ilan U), Antti Haimi (Acoustics Research Institute, Vienna), Günther Koliander (Acoustics Research Institute, Vienna), José Luis Romero (U of Vienna), *Time-Frequency Analysis of Random Point Processes*, January 9 – 18, 2020, October 23 – 31, 2021 and November 19 – 25, 2021.

– Athanasios Chatzistavrakidis (Ruđer Bošković Institute, Zagreb, Croatia), Jan Rosseel (U of Vienna), *Higher Global Symmetries and Geometry in (non-)relativistic QFTs*, November 1 – December 22, 2021 and January 9 – February 10, 2022.

The following Research in Teams Projects that were accepted for 2021 had to be postponed to the years 2022 due to worldwide travel restrictions.

– Arjun Bagchi (IIT Kanpur), Stefan Fredenhagen (U of Vienna), Daniel Grumiller (TU Vienna), *Chaos, Butterflies, and Entanglement in Flat Space*, May 1 – July 31, 2021.

– Anna Geyer (Delft U of Technology), Guilong Gui (Northwest University, Xian), Yue Liu (U of Texas at Arlington), Dmitry Pelinovsky (McMaster U, Hamilton), *Anna Geyer (Delft U of Technology), Guilong Gui (Northwest University, Xian), Yue Liu (U of Texas at Arlington), Dmitry Pelinovsky (McMaster U, Hamilton)*, May 10 – June 11, 2021.

– Chiara Marletto (Wolfson College, U of Oxford), Vlatko Vedral (Wolfson College, U of Oxford), Markus Arndt (U of Vienna), Caslav Brukner (U of Vienna), *From micro-to-macro: testing scale-independent, dynamics-independent laws*, October 1 – December 21, 2021.

In the year 2021 the following Junior Research Fellows visited the ESI to work on their research projects:

– Francesco Cattafi (KU Leuven), *Cartan geometries via Pfaffian groupoids*, January 11 – May 11, 2021.

– Paola Rioseco (ULS, Chile), *Dynamics and Stabilities in the Accretion Disk of Relativistic Kinetic Gas Particles in Kerr Geometry*, September 1 – December 31, 2021.

– Marius A. Oancea (U of Potsdam), *Polarization-Dependent Gravitational Lensing*, September 1 – December 31, 2021.

– Davide Pradovera (CSQI, EPFL, Lausanne), *Model Order Reduction of parametric PDEs with meromorphic structure based on minimal rational approximation*, October 20 – November 20, 2021.

– Hamed Barzegar (U Vienna), *Mathematical Analysis of Dark Matter*, October 1 – November 30, 2021 and January 1 – March 1, 2022.

– Stephan Eckstein (U of Hamburg), *Numerics of Adapted Transport and Applications to Mathematical Finance*, November 29, 2021 – January 31, 2022.

The reports of Hamed Barzegar and Stephan Eckstein will be part of the annual report 2022, since substantial parts of their research stays took place in 2022.

The following Junior Research Fellows accepted for 2020 or 2021 had to decline their invitations to work at the ESI in 2021 due to COVID-19. According to the Covid-strategy of the ESI a postponement would have been only possible until June 2022. It was decided that if a Junior Fellow or a Research in Teams group would like to come at a later period they would have to apply again for the fellowship.

– Alessandra Pluda (U of Pisa), *Nonlocal Minimal Partitions*, March 1 – April 30, 2020.

– Saurabh Singh (Ben-Gurion U), *Topological Quantum Field Theory*, October 1, 2020 – January 31, 2021.

– Hung D. Le (U of Missouri), *Orbital Stability or Instability of Capillary-Gravity Traveling Water Waves with a Point Dipole*, November 1, 2020 – February 28, 2021.

Other activities

The COVID-19 pandemic also made it impossible to host any events of the Vienna Doctoral School, or to hold an Erwin Schrödinger Lecture or an Erwin Schrödinger Colloquium.

The Institute's Management

Kollegium

The ESI is governed at the organizational and scientific level by a board ('Kollegium') of six scholars, all faculty members of the University of Vienna. Their term of office is three years. The members of this board are appointed by the Rector of the University after consultations with the Deans of the Faculties of Physics and Mathematics. There was no change in the composition of the Kollegium of the ESI in 2021. Hence, in the period January 1 - December 31, 2021, the Kollegium consisted of A. Constantin (Mathematics), C. Dellago (Physics), M. Eichmair (Mathematics), S. Fredenhagen (Physics), A. Hoang (Physics), I. Perugia (Mathematics). All members of the Kollegium act as professors at the University of Vienna.

At the operational level, the ESI is managed by the director supported by two deputy directors. This team of directors is proposed by the Kollegium and appointed by the Rector of the University. Currently, the ESI is managed by Christoph Dellago (Director), Stefan Fredenhagen (Deputy Director) and Ilaria Perugia (Deputy Director).

Scientific Advisory Board

The scientific activities of the ESI are supervised by the Scientific Advisory Board (SAB), composed of eminent scholars in mathematics and physics. The SAB also reflects the international ties which are essential for the ESI. In 2021, the SAB consisted of: Douglas N. Arnold (U Minnesota), Alberto Bressan (Penn State U), Mirjam Cvetic (U of Pennsylvania, Philadelphia) [chair], Sandra Di Rocco (KTH, Stockholm), Domenico Giulini (U Hannover), Gerhard Huisken (U Tübingen), Stefano Ruffo (SISSA, Trieste), and Martin Zirnbauer (U Cologne).

Administration

Isabella Janger left the administration by the end of June 2021. We would like to thank her for her valuable work for the ESI and her support of the administrative team. Unfortunately, her position could only be replaced until the beginning of 2022 due to the restrictions of the University to hire new staff in summer and autumn 2021. The administration team continued its work with customary efficiency for our visitors, research fellows and board. Through the COVID-19 pandemic it was forced to work from home office during a large part of the year. Also the IT-support of the Institute, Sascha Biberhofer, left the ESI by December 2021 since he moved abroad. Our special thanks go to him for his valuable support for over 10 year and the creation of our new website with the integrated database.

Christoph Dellago — October 1, 2022
ESI Director

The ESI in 2021: facts and figures

Management and Administration:

Director: Christoph Dellago

Kollegium: Christoph Dellago (Director), Stefan Fredenhagen (Deputy Director), Ilaria Perugia (Deputy Director), Adrian Constantin, Michael Eichmair, André H. Hoang

Administration: Isabella Janger (until June 2021), Maria Marouschek, Beatrix Wolf (Head)

Computing and networking support: Sascha Biberhofer, Thomas Leitner

Video recording and publishing: Sophie Kurzmann

International Scientific Advisory Board in 2021:

Douglas N. Arnold (U Minnesota)
Alberto Bressan (Penn State U)
Sandra Di Rocco (KTH, Stockholm)
Miriam Cvetic (U Pennsylvania, Philadelphia) [chair]
Domenico Giulini (U Hannover
Gerhard Huisken (U Tübingen)
Stefano Ruffo (SISSA, Trieste)
Martin Zirnbauer (U Cologne)

Budget and visitors: In 2021 the support of ESI received from the University of Vienna amounted to **€ 790 000** plus extra budget of € 100,000 to increase the visibility of the Institute. In addition, the ESI obtained a total of € 39 626 in third party funds from external sources for the support of the various activities.

The total amount spent in 2021 on scientific activities was € 134 341 (ESI budget) plus the external third party funds, while the expenditures for administration (mainly salaries) and infrastructure (mainly rent) amounted to € 458 490.

The total number of scientists visiting the Erwin Schrödinger Institute in 2021 was 244, see pages 88 – 92. Gender ratio: male: 176 (72,1 %), female: 38 (15,6 %), non-binary: 1 (0,4 %), prefer not to disclose or unspecified 29 (11,9 %). Moreover, 546 registered people participated online in various activities of the ESI. Here the gender ratio was as follows: male: 392 (71,8 %), female: 105 (19,2 %), prefer not to disclose or unspecified: 49 (9,0 %). Thus, online activities attract a notably higher fraction of female participants compared to on-site activities.

ESI research documentation:

Starting from January 2013, the ESI research output is tracked using the published articles and the arXiv database. The ESI website provides web links to these arXiv preprints and to the local ESI preprints collected until December 2013. It also contains the bibliographical data of the already published articles. Moreover, publications which appeared in 2021 but are related to past ESI activities, starting from 2011, have been tracked as well in order to provide a long-term evidence of the ESI research outcome success.

The total number of preprints and publications contributed to the ESI research documentation database in 2021 is 29, see pages 84 – 86 for details.

Since the summer of 2019, lectures given at the ESI are routinely recorded and the videos are published on the ESI Youtube-Channel. In total 230 videos were recorded in 2021 amounting to more than 188 hours of video material. These videos have been accessed 47.109 times in 2021 alone. Currently, the number of views is growing quickly indicating the strong interest for recorded ESI lectures in the community.

Scientific Reports

Main Research Programmes

Geometry for Higher Spin Gravity: Conformal Structures, PDEs, and Q-manifolds

Organizers: Xavier Bekaert (U Tours), Andreas Cap (U Vienna), Stefan Fredenhagen (U Vienna), Maxim Grigoriev (Lebedev Inst. & Lomonosov Moscow SU), Alexei Kotov (U Hradec Králové)

Dates: August 23 – September 17, 2021

Budget: ESI € 29 891
Lomonosov MSU, € 2 800 (travel expenses of Maxim Grigoriev)
Tours University, € 2 400 (travel expenses of Xavier Bekaert)

Report on the thematic programme

The idea of the programme was to bring together people studying mathematical aspects of higher-spin gravity, and mathematicians studying geometrical structures emerging in this context. These include conformal geometry, the geometry of partial differential equations, and differential graded geometry.

The construction of consistent interactions among gauge fields of spin higher than two is a notoriously difficult challenge. Each time some of the obstacles were overcome, various modern mathematical notions played a crucial role in the construction. In particular, this refers to structures known in the context of conformal geometry (Cartan connections, tractor bundles, Fefferman-Graham ambient metric, etc), the geometry of Partial Differential Equations (e.g. infinite jet bundles and their Cartan distributions), differential graded geometry (such as Q-manifolds, Batalin-Vilkovisky and Becchi-Rouet-Stora-Tyutin formalisms, Alexandrov-Kontsevich-Schwarz-Zaboronsky sigma models) and deformation quantization (for instance Fedosov-like connection, formality theorems, deformation theory, etc).

The deep relation between higher-spin gravity and important topics of contemporary mathematics is an active area of research and the programme has brought together experts from higher spin gravity and the aforementioned geometries. This has resulted in a fruitful exchange between different communities, new research projects, and collaborations.

Among the highlights of the programme were a number of introductory mini-courses meant for non-experts and young researchers. The idea was to foster the inter disciplinary communication and to help young researcher to enter this quickly developing field. In total there were about 14 mini-courses of 2-3 lectures each. Due to the interdisciplinary nature of the programme, all the speakers and lecturers were asked to be pedagogical and make their talks accessible to a wide audience.

Activities

The programme consisted of four weeks and was held in the hybrid format. Unfortunately, due to the COVID situation many speakers were not able to come in person. At the same time, because of the hybrid format many researchers, especially students, who initially would not have had an opportunity to participate, were able to follow the talks online. The total number of participants registered for the programme was over 100, with about 60 people participating in person.

Despite the fact that the programme was not specifically divided into parts devoted to one or another field of research the first two weeks had certain focus on higher spin gravity and quantum field theory while the third and the fourth weeks had an accent on geometry.

On the first week we had lectures by Andreas Cap introducing Cartan geometry and elements of the conformal geometry and lectures by Eugene Skvortsov on conformal higher spin gravity. These lectures initiated a series of informal discussion on higher spin geometry from the Cartan geometry point of view. Another mini course of the first week was the one by Ian Anderson who gave an introduction to the variational bicomplex, the subject deeply related to both conformal geometry and the formalism of higher spin gravity not to mention conventional applications to Lagrangian formalism in field theory. An interesting research talk by Kirill Krasnov also took place on the first week, where the Lagrangian of selfdual gravity and its higher spin generalization was presented.

The mini-course on BV/BFV formalims by Alberto Cattaneo took place in the end of the first and the beginning of the second weeks. It was devoted to the extension of Batalin-Vilkovisky formalism to the case of gauge theories on manifolds with boundaries. Such theories naturally arise in the context of AdS/CFT correspondence, including higher spin holography, as well as in the study of asymptotic symmetries of gravity and its extensions. The applications of this approach to general relativity were discussed in the research talk by Michele Schiavina.

On the second week, the mini-course that attracted considerable attention was the introduction to asymptotic symmetries by Marc Henneaux. This subject has given rise to much interest over the last few decades as it is deeply related to many subjects in mathematics and theoretical physics, including AdS/CFT correspondence, conformal compactifications, gravitational memory effect, and gauge fields on manifolds with boundaries. Another remarkable course on interacting higher spin gauge theories in AdS space was delivered by Mikhail Vasiliev and covered both the foundations of the theory and the recent develpments.

In week two Tim Adamo gave a mini-course on twistors, ambitwistors and amplitudes. On top of its applications to the conventional QFT models the twistor theory can be used to describe massless free fields of any integer or half-integer spin. The lectures also covered ambitwistor strings which are expected to be deeply related to higher spin gauge theories. Amplitudes in higher spin gauge theories were also discussed on the same week in the the research talk by Dmitri Ponomarev.

The mini-course of Micheal Eastwood took place in the end of week two and the beginning of week three and discussed core techniques of conformal geometry. The first lecture was devoted to the conformal version of the ambient metric construction due to Fefferman and Graham. The second lecture discussed the direct approach to tractor bundles and tractor connections. In both lectures applications to the construction of conformally invariant differential operators and of conformal invariants were outlined and examples were discussed in detail.

In week four, Rod Gover delivered a mini-course on boundary calculus in conformal geometry followed by a research talk on a closely related topic. These introduced the necessary tools for the study of conformally compact metrics and in particular of Poincaré-Einstein metrics using conformal geometry and tractors and discussed several applications.

In week four we also had a mini-course by Glenn Barnich devoted to quantum field theory on manifolds with boundaries. The topic covered included finite temperature Casimir effect, modular covariance, and the entropy for photons in a Casimir box. Another mini-course of the fourth week was devoted to Lie equations, Cartan bundles, Tanaka theory and differential invariants. It was given by Boris Kruglikov and covered various algebraic methods in the theory of PDEs. A particular attention was paid to the geometric theory of consistency of PDE.

Specific information on the thematic programme

Among the onsite participants there were more than 20 young researchers including PHD students and postdocs. Some of them gave research talks or participated in the poster session. The poster session took place during the second week of the program and attracted considerable attention of more senior participants. Yannick Herfray, a postdoc from Mons, even gave an informal lecture on the geometrical approach to asymptotic symmetries in gravity, including BMS symmetries which attract considerable attention recently in the context of flat space holography.

Outcomes and achievements

The program brought together researched from different areas of theoretical physics and mathematics. For several of these areas there is a substantial language-barrier which make communication and scientific exchange very difficult. The program at the ESI that extended over a longer period provided a perfect opportunity to find a common language and initiate more substantial discussions. In fact, a large number of discussions between scientists with different background took place during the program. We are sure that these will result in new developments and scientific results in the future.

In particular,

- higher spin geometry from the conformal geometry standpoint have been started with the program. Among the active participants are A. Cap, X. Bekaert, Y. Herfray, E. Skvortsov.

- Inverse problem of the calculus of variation in the context of higher spin theories was discussed among: B. Kruglikov, I. Khavkine, M. Grigoriev, and V.Gritsaenko. In particular, within this discussion one of the young participant, V. Gritsaenko, has presented results of his work, which was then published on ArXiv during the programme.

- The structure of Z-graded manifolds in the context of the program topics was discussed among A. Kotov, V. Salnikov, T. Strobl, A. Voronov, and J. Vysoky. A preprint on this subject was published by A. Kotov and V. Salnikov on ArXiv during the programme.

- An application of Dirac structures in constrained systems was discussed among O. Cosserat, C. Laurent-Gengoux, A. Kotov, L. Ryvkin, and V. Salnikov. A preprint on this topic was finished and published by the above participants on ArXiv during the programme.

- Relations between the topics of the program and geometric compactifications (in particular conformal and projective compactifications) and applications of these ideas to general relativity were discussed in depth among A. Cap, Y. Herfray, K. Krasnov, and J. Slovak.

- The comparison between different approaches to the construction and classification of conformal invariants and the role of generalizations of the calculus introduced by W. Wünsch and his collaborators were discussed among N. Boulanger, A. Cap, and J. Slovak.

- Algebraic structure relevant for background-independent BV-BRST formulation of string-field-theory like models were discussed by I. Sachs and M. Grigoriev. The respective paper was finalized during the program and sent to the journal.

List of mini-lectures

Tim Adamo (U Edinburgh)	Twistors, ambitwistors and amplitudes
Ian Anderson (Utah State U)	Variational Bicomplexes
Glenn Barnich (ULB, Brussels)	Photons and gravitons in a Casimir box
Andreas Cap (U Vienna)	Cartan Geometries
Alberto Cattaneo (U Zurich)	An introduction to the BV-BFV formalism
Michael Eastwood (Adelaide U)	Conformal differential geometry
Rod Gover (U Auckland)	Boundary calculus in conformal geometry
Marc Henneaux (ULB, Brussels)	Introduction to asymptotic symmetries
Yannick Herfray (ULB, Brussels)	Intro to BMS symmetries and asymptotic gravity vacua
Joseph Krasil'shchik (IUM, Moscow)	Geometry of PDEs: an overview
Boris Kruglikov (UiT)	Lie equations, Cartan bundles, Tanaka theory
Andrei Mikhailov (UNESP (Sao Paolo)	Q-manifolds and pure spinors
Eugene Skvortsov (U Mons)	Conformal higher spin gravities and holography
Mikhail Vasiliev (LPI, Moscow)	Introduction to HS fields and interactions in AdS
Alexander Verbovetsky (IUM, Moscow)	Geometry of PDEs: an overview

List of talks

Nicolas Boulanger (U Mons)	Algebraic classification of conformal invariants and conformal anomalies in arbitrary dimension
Andrea Campoleoni (U Mons)	On Carrollian and Galilean higher-spin algebras
Boris Doubrov (BSU)	Non-regular parabolic geometries via the notion of bi-filtered manifolds
Dario Francia (U Roma III)	Lagrangian double copy to cubic order
Rod Gover (U of Auckland)	Higher conformal fundamental forms and the asymptotically Poincare-Einstein Condition
Daniel Grumiller (TU Vienna)	Higher spins and non-AdS holography in lower dimensions
Marc Henneaux (ULB, Brussels)	The BMS (super)algebra at spatial infinity
Yannick Herfray (ULB, Brussels)	Tractor geometry of null-Infinity and gravitational radiations
Branislav Jurco (Charles U, Prague)	Homological perturbation lemma and homotopy transfer
Euihun Joung (Kyung Hee U, Seou)	Unfolding Conformal Geometry
Igor Khavkine (IM CAS)	Homotopy transfer for conserved currents and rigid symmetries in gauge theories
Niels Kowalzig (U Napoli)	Calculi, cohomology, and Hopf algebroids
Kirill Krasnov (U of Nottingham)	Self-dual Yang-Mills and self-dual gravity
Boris Kruglikov (UiT)	Super-symmetry of geometric structures
Svatopluk Krysl (Charles U, Prague)	Differential operators on bundles invariant with respect to compact operators
Sergei Kuzenko (UWA, Perth)	Duality-invariant conformal higher-spin models
Iva Lovrekovic (TU Vienna)	Holography of new conformal higher spin theories in three dimensions

Omid Makhmali (Polish Ac Sci. Warsaw)	Einstein-Weyl-like conditions and causal structures in dimension three
Chrysoula Markou (MPP, Munich)	Extracting Bigravity from String Amplitudes
Karapet Mkrtchyan (Imperial College, London)	Democratic (N)ED
Pavel Mnev (Notre Dame)	Effective BV action for Chern-Simons theory on cylinders
Stefan Prohazka (U Edinburgh)	Maximally symmetric spacetimes and their lower dimensional theories
Vladimir Salnikov (CNRS, Paris)	Some constructions from graded geometry
Henning Samtleben (ENS Lyon)	Introduction to exceptional field theory
Paolo Saracco (ULB, Brussels)	A mathematical overview of universal enveloping algebras and their universal properties
Michele Schiavina (ETH Zürich)	BV-BFV Approach to General Relativity
Eugene Skvortsov (U Mons)	Higher spin gravities and holography
Jan Slovak (Masaryk U, Brno)	Calculus on Symplectic Manifolds
Harold Steinacker (U Vienna)	(Higher-spin) gravity as a quantum effect on quantum space-time
Thomas Strobl (U Lyon)	Gauge theories with and without group actions and equivalences between them
Per Sundell (UNAB, Santiago)	Quantum field theory as a topological sigma.model
Mikhail Vasiliev (Lebedev Phys. Inst., Moscow)	Recent results in higher-spin gauge theory
Luca Vitagliano (UNISA)	Multiplicative Connections on Lie Groupoids
Alexander Voronov (U of Minnesota)	NQ-manifolds and homotopy Lie bialgebroids
Jan Vysoky (CTU Prague)	Graded Courant Algebroids
Andrew Waldron (UC Davis)	Quantization of Contact Structures

Publications and preprints contributed

X. Bekaert, *Notes on higher-spin diffeomorphisms*, arXiv:2108.09263 [hep-th].

O. Cosserat, C. Laurent-Gengoux, A. Kotov, L. Ryvkin, V. Salnikov, *On Dirac structures admitting a variational approach,*, arXiv:2109.00313v2 [math.DG].

M. Grigoriev and V. Gritzaenko, *Presymplectic structures and intrinsic Lagrangians for massive fields*, arXiv:2109.05596 [hep-th].

M. Grigoriev, A. Meyer, I. Sachs, *A toy model for background independent string field theory,*, arXiv:2106.07966 [hep-th].

M. Henneaux, P. Salgado-Rebolledo, *Carroll contractions of Lorentz-invariant theories*, JHEP **11** (2021), 180, doi:10.1007/JHEP11(2021)180, arXiv:2109.06708 [hep-th].

A.A. Tarusov, M.A. Vasiliev, *On the variational principle in the unfolded dynamics*, Phys.Lett.B 825 (2022) 136882, arXiv:2111.12691 [hep-th].

Participants (on-site and online)

Tim Adamo	U Edinburgh	online
Konstantin Alkalaev	Lebedev Inst. & Lomonosov Moscow SU	online
Ian Anderson	Utah State U	online
Glenn Barnich	ULB, Brussels	on-site
Thomas Basile	Kyung Hee U, Seoul	online
Xavier Bekaert	U Tours	Organizer
Klaus Bering	Masaryk U, Brno	online
Nicolas Boulanger	U Mons	on-site
Andrea Campoleoni	U Mons	on-site

Andreas Cap	U Vienna	Organizer
Alberto Cattaneo	U Zürich	on-site
Luca Ciambelli	ULB, Brussels	online
Oscar Cosserat	U of La Rochelle	on-site
David De Filippi	U Mons	on-site
Arnaud Delfante	U Mons	on-site
Ivan Dneprov	Lomonosov Moscow SU	on-site
Laura Donnay	TU Vienna	on-site
Boris Doubrov	BSU	on-site
Cristina Draper Fontanals	Malaga U	on-site
Michael Eastwood	Adelaide U	online
Dario Francia	U Roma III	on-site
Jordan Francois	U Mons	on-site
Stefan Fredenhagen	U Vienna	Organizer
Jordi Frias	Lomonosov Moscow SU	on-site
Oscar Fuentealba	ULB, Brussels	on-site
Olga Gelfond	Lebedev Physical Institute, Moscow	online
Rod Gover	U Auckland	online
Maxim Grigoriev	Lebedev Inst. & Lomonosov Moscow SU	Organizer
Vyacheslav Gritsaenko	MIPT	on-site
Daniel Grumiller	TU Vienna	on-site
Aliaksandr Hancharuk	U Lyon	on-site
Christoph Harrach	U Vienna	on-site
Marc Henneaux	ULB, Brussels	on-site
Yannick Herfray	ULB, Brussels	on-site
Daniel Hutchings	UWA, Perth	online
Carlo Iazeolla	G. Marconi U	online
Noriaki Ikeda	Ritsumeikan U, Kusatsu	online
Euihun Joung	Kyung Hee U, Seoul	online
Branislav Jurco	Charles U, Prague	on-site
Igor Khavkine	IM CAS	on-site
Yvette Kosmann-Schwarzbach	retired	on-site
Alexei Kotov	U Hradec Králové	Organizer
Niels Kowalzig	U Napoli	on-site
Joseph Krasil'shchik	IUM	online
Kirill Krasnov	U of Nottingham	on-site
Olaf Krüger	U Vienna	on-site
Boris Kruglikov	UiT	on-site
Svatopluk Krysl	Charles U, Prague	on-site
Sergei Kuzenko	UWA, Perth	online
Kristiansen Lara	U de Chile, Santiago	online
Camille Laurent-Gengoux	U Lorraine	on-site
Rob Leigh	U Illinois	online
Thomas Leistner	Adelaide U	online
Iva Lovrekovic	TU Vienna	on-site
Sucheta Majumdar	ULB, Brussels	on-site
Omid Makhmali	Polish Academy of Science, Warsaw	on-site
Chrysoula Markou	MPP, Munich	on-site
Mikhail Markov	Lomonosov Moscow SU	online
Javier Matulich Fabres	ULB, Brussels	onsite
Ruslan Metsaev	Lebedev Physical Institute, Moscow	online
Andrei Mikhailov	IFT UNESP, Sao Paolo	online
Nikita Misuna	AEI Golm	on-site
Karapet Mkrtchyan	Imperial College, London	on-site
Pavel Mnev	Notre Dame	online

Kevin Morand	Sogang U	online
Timothy Moy	Adelaide U	online
Turmoli Neogi	ULB, Brussels	onsite
Katharina Neusser	Masaryk U, Brno	online
Francisco José Palomo	Malaga U	on-site
Enrico Parisini	U Southampton	online
Noémie Parrini	U Mons	on-site
Mateo Paulišić	U Rijeka	on-site
Simon Pekar	U Mons	on-site
Alfredo Perez	CECS, Valdivia	on-site
Michael Ponds	UWA, Perth	online
Dmitry Ponomarev	Lomonosov Moscow SU	on-site
Stefan Prohazka	U Edinburgh	on-site
Nicolai Reshetikhin	UC, Berkeley	online
Jan Rosseel	U Vienna	on-site
Dmitrii Rudinskii	Lomonosov Moscow SU	online
Romain Ruzziconi	TU Vienna	on-site
Leonid Ryvkin	U Göttingen	on-site
Ivo Sachs	LMU Munich	on-site
Katja Sagerschnig	Polish Academy of Science, Warsaw	on-site
Vladimir Salnikov	CNRS, Paris	on-site
Jakob Salzer	Harvard U, Cambridge	on-site
Henning Samtleben	ENS Lyon	on-site
Andrea Santi	Arctic U	online
Paolo Saracco	ULB, Brussels	on-site
Michele Schiavina	ETH Zürich	on-site
Pavel Sereda	Lomonosov Moscow SU	online
Alexey Sharapov	Tomsk State U	online
Georgy Sharygin	Lomonosov Moscow SU	online
Ekaterina Shemyakova	UToledo	online
Eugene Skvortsov	U Mons	on-site
Jan Slovak	Masaryk U, Brno	on-site
Harold Steinacker	U Vienna	on-site
Thomas Strobl	U Lyon	on-site
Per Sundell	UNAB, Santiago	online
Tom Sutherland	U Vienna	on-site
Arman Taghavi-Chabert	U Warsaw	online
Dennis The	UiT	online
Ricardo Troncoso	CECS, Valdivia	online
Arkady Tseytlin	Imperial College, London	online
Mirian Tsulaia	OIST	online
Mikhail Vasiliev	Lebedev Physical Institute, Moscow	online
Alexander Verbovetsky	IUM	online
Luca Vitagliano	UNISA	online
Alexander Voronov	U of Minnesota	on-site
Theodore Voronov	U Manchester	online
Ivan Vuković	U Rijeka	on-site
Jan Vysoky	CTU Prague	on-site
Andrew Waldron	UC Davis	online
Raphaela Wutte	TU Vienna	on-site
Alexander Yan	Lomonosov Moscow SU	online
Yihao Yin	NUAA, Nanjing	online
Lenka Zalabová	South Bohemia U	online

Workshops organized independently of the main programmes

Online-Workshop: Mathematical Perspectives of Gravitation beyond the Vacuum Regime

Organizers: Håkan Andréasson (CUT, Gothenburg), David Fajman (U Vienna), Jérémie Joudioux (MPIGP, Potsdam), Todd Oliynyk (Monash U, Melbourne)

Dates: February 22 – 25, 2021

Budget: No budget was needed since the workshop was held online.

Report on the workshop

The mathematical studies of Einstein's equations have been flourishing during the last two decades, and many important achievements were reached. The near completion of one of the major problems of these last two decades, the expected monumental proof of the stability of stationary black holes, is certainly a milestone in the understanding of Einstein's equations in vacuum. Parallel to this work, there has been a growing interest to couplings between Einstein's equations with various matter models. Basic problems, such as well-posedness and local existence, as well as more advanced questions, such as existence of steady states, and their stability, formation of black holes, have been addressed for matter models such as collisionless matter, elastic matter or fluids. Furthermore, plasma physics, using collisioneless matter or magneto-hydro-dynamics, is at the center of the contemporary research in astrophysics.

In February 2017, we have organised a workshop, taking place at the Erwin Schrödinger international institute for Mathematics and Physics, centered on questions related to collisionless matter models. The six-week program "Mathematical Perspectives of Gravitation beyond the Vacuum Regime", originally scheduled early 2021, is the continuation of this workshop. The scope of the matter models has been enlarged to all matter models, with an emphasis on collisionless matter, fluids and elastic matter. Open questions regarding Einstein's equations in vacuum are also considered. The Covid-19 pandemic led to the postponement of this program, rescheduled early 2022, and we have suggested to the ESI the organisation of substitute online program.

The online workshop "Mathematical Perspectives of Gravitation beyond the Vacuum Regime", organised thanks to the support of the ESI, was a substitute while waiting for the longer six-week program. The purpose of the online workshop is the same as the online program, and served as a warm-up. We have gathered experts to present their results involving different matter models, with or without gravity. We have explicitly required from speakers also involved in research on vacuum Einstein equations to focus their talks on the topic of the workshop. This led to a series of lectures covering Klein-Gordon equations, Vlasov equations, Boltzmann equations, and Euler equations. The attendance for the workshop was open to all researchers.

Activities

The workshop consisted in a series of one-hour-long lectures, scheduled in the afternoon to allow the attendance of researchers in the US. The lectures were followed by discussion sessions. Long breaks were organised during two lectures to allow researchers to meet more individually in a virtual ESI.

Specific information on the workshop

Most of the colleagues who presented their works were senior researchers. Two more junior researchers presented their works:

- Léo Bigorgne, post-doc at Cambridge University.
- Fatima Ezzahra Jabiri, doctoral student at Paris Sorbonnes University, under the supervision of Jacques Smulevici.

We actively advertised the workshop in various networks of researchers. The following younger researchers (not yet graduated, or recently graduated) participated in the workshop:

- Nikolaos Athanasiou (Imperial College, London)
- Hamed Barzegar (U Vienna)
- Leo Bigorgne (U Cambridge)
- Xuantao Chen (Johns Hopkins U, Baltimore)
- Armand Coudray (U Brest)
- Allen Fang (Sorbonne U, Paris)
- Joachim Frenkler (U Bayreuth)
- Carlos Eduardo Gabarrete Fajardo (UMICH)
- Edgar Gasperin (U Bourgogne)
- Shalabh Gautam (IUCAA)
- Sari Ghanem (U of Lübeck)
- Irfan Glogic (U Vienna)
- Mateja Gosenca (U Vienna)
- Sebastian Günther (U Bayreuth)
- Lili He (Johns Hopkins U, Baltimore)
- Fatima-Ezzahra Jabiri (Sorbonne U, Paris)
- Joel Kurzweil (U Vienna)
- Timo Lebeda (U Bayreuth)
- Siyuan Ma (Sorbonne U, Paris)
- King Ming Lam (University College London)
- Marica Minucci (QMU London)
- Mariem Magdy Ali Mohamed (QMU London)
- Mikael Normann (QMU London)

- Matthias Ostermann (U Vienna)
- Johannes Oude Groeniger (KTH Stockholm)
- Shrish Parmeshwar (U Bath)
- Oliver Petersen (SU)
- Cornelius Rampf (U Vienna)
- Christopher Straub (U Bayreuth)
- Jörg Weber (U Lund)
- Max Weissenbacher (Imperial College, London)
- Zoe Wyatt (U Cambridge)
- Xiaoyi Xie (U Southampton)

Outcomes and achievements

Firstly, we have received many very positive feedbacks for the organisation of the workshop as well as the quality of the talks. Combined with a very large attendance, this workshop was a major event in the GR community. Various attendants were grateful to the opportunity to interact and update each other on the new developments in the field.

The online nature of the workshop led regrettably to less interaction as usual between the participants. The virtual ESI, though thoroughly advertised, was not as frequented as the online meeting. The following collaborations were fuelled by the virtual meeting:

- The group of Gerhard Rein and his students, as well as Mahir Hadzic, interacted to continue their research efforts to understand the stability of steady states of the Vlasov-Poisson system. A publication (see below) was released in relation to this collaboration.

In total, we expect that this virtual meeting was a very successful online meeting, which was reflected in particular by the large number of participants and the level of excellence of the speakers.

List of talks

Mahir Hadzic (UCL)	Instability of selfgravitating galaxies and stars
Robert Strain (UPenn)	On the relativistic Boltzmann equation with long range interactions
Jared Speck (Vanderbilt U)	A new formulation of relativistic Euler Flow: Miraculous Geo-Analytic structures and applications
Juhi Jang (USC)	Dynamics of Newtonian stars
Leo Bigorgne (Cambridge)	Stability of Minkowski spacetime for the massless Einstein-Vlasov system
Alexandru Ionescu (Princeton)	On the global regularity for the Einstein-Klein-Gordon coupled system
Olivier Sarbach (Michoacan)	Phase space mixing in an external gravitational potential

Jonathan Luk (Stanford)	High-frequency limit in general relativity and a conjecture of Burnett
Lavi Karp (Braude)	The continuity of the flow map with applications to Euler-Poisson equation
Jeremie Szeftel (Sorbonnes)	Finite time blow up for focussing supercritical NLS and compressible fluids
Simone Calogero (Gothenburg)	On self-gravitating polytropic elastic balls
Sijue Wu (Michigan)	On the free boundary hard phase fluid in Minkowski spacetime
Fatima-Ezzahra Jabiri (Sorbonnes)	On stationary black hole solutions of the Einstein-Vlasov system
Gerhard Rein (Bayreuth)	Can galaxies oscillate?
Oliver Rinne (Berlin)	Dynamics of gravitational collapse in the axisymmetric Einstein-Vlasov system
Ellery Ames (HSU)	Stability of Axisymmetric Stationary Einstein-Vlasov Bodies

Publications and preprints contributed

M. Hadzic, G. Rein, C. Straub, *On the existence of Linearly Oscillating Galaxies*, Archive for Rational Mechanics and Analysis, (2021)

Invited scientists

Peter C. Aichelburg (U Vienna), Ellery Ames (HSU), Håkan Andréasson (CUT, Gothenburg), Nikolaos Athanasiou (Imperial College, London), Hamed Barzegar (U Vienna), Robert Beig (U Vienna), Leo Bigorgne (U Cambridge), Volker Branding (U Vienna), Uwe Brauer (U Complutense de Madrid), Annegret Burtscher (Radboud U), Simone Calogero (CUT, Gothenburg), Xuantao Chen (Johns Hopkins U, Baltimore), Piotr T. Chrusciel (U Vienna), Armand Coudray (U Brest), Marcelo Disconzi (Vanderbilt U, Nashville), Roland Donninger (U Vienna), David Fajman (U Vienna), Allen Fang (Sorbonne U, Paris), Felix Finster (U Regensburg), Joachim Frenkler (U Bayreuth), Carlos Eduardo Gabarrete Fajardo (UMICH), Edgar Gasperin (U Bourgogne), Shalabh Gautam (IUCAA), Sari Ghanem (U Lübeck), Elena Giorgi (Princeton U), Irfan Glogic (U Vienna), Mateja Gosenca (U Vienna), Sebastian Günther (U Bayreuth), Mahir Hadzic (University College London), Lili He (Johns Hopkins U, Baltimore), Peter Hintz (MIT, Cambridge), Alexandru Ionescu (Princeton U), Fatima-Ezzahra Jabiri (Sorbonne U, Paris), Juhi Jang (U of Southern California, Los Angeles), Jose-Luis Jaramillo (UB), Jérémie Joudioux (MPIGP, Potsdam), Lavi Karp (Braude College), Joel Kurzweil (U Vienna), Timo Lebeda (U Bayreuth), Philippe G. LeFloch (Sorbonne U, Paris), Mohammed Lemou (U Rennes 1), Jonathan Luk (SU), Siyuan Ma (Sorbonne U, Paris), Maciej Maliborski (U Vienna), Florian Méhats (U Rennes 1), Filipe Mena (U Lisbon), King Ming Lam (University College London), Marica Minucci (QMU London), Mariem Magdy Ali Mohamed (QMU London), Georgios Moschidis (UC, Berkeley), José Natário (IST), Gustav Nilsson (AEI Golm), Brien Nolan (DCU), Mikael Normann (QMU London), Todd Oliynyk (Monash U, Melbourne), Matthias Ostermann (U Vienna), Johannes Oude Groeniger (KTH Stockholm), Shrish Parmeshwar (U Bath), Oliver Petersen (SU), Cornelius Rampf (U Vienna), Gerhard Rein (U Bayreuth), Natascha Riahi (U Vienna), Hans Ringström (KTH Stockholm), Oliver Rinne (HTW Berlin), Paola Rioseco (U de Chile, Santiago), Hannes Rueter (AEI Golm), Olivier Sarbach (UMICH), Bernd Schmidt (MPIGP, Potsdam), Jacques Smulevici (University Paris Sorbonnes), Jared Speck (Vanderbilt U, Nashville), Robert Strain (UPenn, Philadelphia), Christopher Straub (U Bayreuth), Martin Taylor (Imperial College, London), Juan A. Valiente Kroon (QMU London), Andras Vasy (SU), Jinhua Wang (Xiamen U), Jörg Weber (U Lund), Max Weissenbacher (Imperial College, London), Sijue Wu (U of Michigan, Ann Arbor), Zoe Wyatt (U Cambridge), Xiaoyi Xie (U Southampton).

Online-Workshop: Tomographic Reconstructions and their Startling Application

Organizers: Wolfgang Drexler (Med U Vienna), Peter Elbau (U Vienna), Ronny Ramlau (RICAM, Linz), Monika Ritsch-Marte (Med Uni Innsbruck), Otmar Scherzer (U Vienna), Gerhard Schütz (TU Vienna)

Dates: March 15 – 25, 2021

Budget: No budget was needed since the workshop was held online.

Report on the workshop

This workshop was intended to bring together scientist who are working on topics related to the Special Research Programme SFB F68 “Tomography Across the Scales” funded by the FWF. The focus was hereby on applications where tomographic reconstruction methods can be applied: Examples are ranging form adaptive optics techniques, which are not only used for telescopes recording astronomical data, but have also proved to yield good results in medical applications; the studying of wave propagation in biological samples to obtain quantitative reconstructions of material parameters (such as in computer tomography, sonography, optical coherence tomography, photoacoustic imaging, or elastography) up to super-resolution microscopy where localisations of blinking fluorescent molecules below the diffraction limit can be realised.

Due to the interdisciplinary nature of the research programme, where mathematicians are working together with applied scientists from physics, biology, and medicine, we tried to explore the various applications from the experimental and from the mathematical side by having presentations from researchers from different fields.

Activities

Since the workshop sadly could only be held online, we decided to shorten the two weeks to four and three days, respectively. Because of the internationality of the workshop, we tried to use time slots which were accessible as best as possible to most of the participants, which, of course, had the drawback of a slightly inconvenient schedule for everyone. To compensate for this, we attempted to dedicate each day to a certain topic, where the first week was mainly focused on the mathematical problems and the second week revolved around the experimental challenges.

The mathematical week started

- on Monday, March 15, with problems on how to invert from various tomographical data,
- on Tuesday, March 16, we revisited inverse scattering theory,
- on Wednesday, March 17, we focused on problems related to coupled physics imaging, and
- we concluded the first week on Thursday, March 18, with probabilistic and stochastic approaches for tomographical problems,

with the usual deviations according to the personal time restrictions of the speakers.
We continued in the second week with the experimental topics;

- on Tuesday, March 23, with a day on the use of adaptive optics in astronomy,
- discussed on Wednesday, March 24, the biological and medical applications of optical coherence tomography, photoacoustic tomography, and ultrasound tomography, and
- ended with a discussion of super-resolution fluorescence microscopy on Thursday, March 25.

Hereby, all the talks have been given via Zoom which was working flawlessly throughout the workshop and also the recording of the presentations was mostly granted by the speakers so that a lot of the talks could be made available online. The main disadvantage of the conference taking place virtually only, however, is that outside of the presentations, there are much less opportunities for enganging in a conversation. To facilitate this, we encouraged the use of the suggested gather town application for the virtual coffee breaks to stimulate some discussions amongst the participants, but the resonance was sadly not that great, although for the small groups who have been using it, it was working very nicely.

Specific information on the workshop

This workshop gave the PhD students and postdocs working in the research programme the chance to present their research to some of the leading experts working in their fields and establishing contacts with some of them and, on the other hand, also get a broader view on the applications connected to their work from an experimental and mathematical point of view. In particular, these were the talks by Fabian Parzer, Lisa Krainz, Ekaterina Sherina, Montserrat Lopez, Fabian Hinterer, and Magdalena Schneider. Additionally, there have been some young researchers among the external speakers: Bryn Davies, Felix Bartel, Tram Do, Bochra Mejri, Alina Böcker, and Edward Lilley. In partiucular, Bochra Mejri became very interested in the topic and stated that she intended to submit an ESPRIT-project to join our group in Vienna.

Outcomes and achievements

Sadly, the online format makes it rather difficult to initiate an interaction between the participants during the conference. Although there were interesting discussions with the speakers after the talks, where especially the interaction between the different communities led to sometimes surprising connections, and which indicated some possible cooperations; the further communications have been out of reach so that we are not aware of any concrete collaborations which were established at that event. And to our regret, we have not been informed of any articles going back to that workshop.

List of talks

First Week (Mathematics): March 15 – 18, 2021

Kim Knudsen (Technical U Denmark, Kongens Lyngby)	Feasibility of Acousto-Electric Tomography
Bryn Davies (ETH Zürich)	Discrete approximations of subwavelength resonator systems
Maxence Cassier (Institut Fresnel)	Imaging small polarizable scatterers with polarization data

Bernadette Hahn (U Stuttgart)	Implicit and explicit motion compensation strategies in tomography
Fabian Parzer (U Vienna)	Ensemble Kalman inversion and regularization:
Peter Kuchment (Texas A & M U)	Deep Learning Networks for Detecting Presence of Low-Emission Radiation Sources
Roman Novikov (Ecole Polytechnique, Palaiseau)	Phaseless inverse scattering problem
José A. Iglesias (RICAM, Linz)	Geometric convergence in total variation regularization
Todd Quinto (Tufts University)	Microlocal Analysis of Joint Reconstruction in X-ray+Compton Tomography
Günther Uhlmann (U of Washington)	40 Years of Calderón's Problem
Fioralba Cakoni (Rutgers U)	Spectral Problems in Inverse Scattering Theory
Thomas Schuster (U of Saarland)	Diffractive tensor field tomography as an inverse problem for a transport equation
Otmar Scherzer (U Vienna)	Reconstructions in Coupled Physics Imaging
Thorsten Hohage (U Göttingen)	On phase contrast X-ray tomography
Felix Bartel (TU Chemnitz)	Optimality of Cross-validation in Scattered Data Approximation
Giovanni S. Alberti (U of Genoa)	Compressed sensing photoacoustic tomography reduces to compressed sensing for undersampled Fourier measurements
Alexander Katsevich (UCF, Orlando)	Resolution analysis of inverting the generalized N-dimensional Radon transform in $\mathbb{R}^n$ from discrete data
Adel Faridani (Oregon State U, Corvallis)	Uniform and nonuniform sampling of bandlimited functions with faster convergence
Raymond Chan (City U of Hong Kong)	High-Resolution Phase Reconstruction in Ground-based Astronomy
Tapio Helin (LUT U, Lappeenranta)	Bayesian optimal experimental design in X-ray tomography
Tanja Tarvainen (U of Eastern Finland, Joensuu)	Bayesian approach to quantitative photoacoustic tomography
Russell Luke (U Göttingen)	Inconsistent Stochastic Feasibility: the Case of Stochastic Tomography
Larisa Beilina (CUT, Gothenburg)	Application of an adaptive finite element method in non-invasive monitoring of hyperthermia
Peter Maaß (U Bremen)	Regularization by architecture: Learning with few data and applications to CT
Tram Do (U Hamburg)	Multibang regularization for parameter identification problems
Bochra Mejri (Laboratoire J.A. Dieudonné)	Rock mass properties by the stochastic homogenization method

Second Week (Physics): March 23 – 25, 2021

Alina Böcker (MPIA, Heidelberg)	Reconstructing a galaxy's accretion history from integrated spectra
Tobias Buck (Leibniz Institute for Astrophysics Potsdam)	Reconstructing galaxy properties from multi-band images
Edward Lilley (U Vienna)	Is photometric deprojection possible without symmetry assumptions?
Miska Le Louarn (ESO, Garching)	Adaptive Optics in astronomy: an introduction to tomography
Lorenzo Busoni	Multi Conjugate Adaptive Optics for Extremely

(Arcetri Astrophysical Obervatory)	Large Telescopes: design, challenges and future developments.
Liliana Borcea (U of Michigan, Ann Arbor)	Reduced order model approach for inverse scattering
Kui Ren (Columbia U)	Inversion via Optimization: a Revisit to the Least-Squares Formulation
Brendan Kennedy (U of Western Australia)	Optical coherence elastography: imaging mechanical properties on the micro-scale
Lisa Krainz and Ekaterina Sherina (U Vienna)	Quantifying Minimal Strain in Intensity-based Optical Coherence Elastography
David Sampson (U Surrey)	Polarisation-sensitive optical coherence tomography —a window into the sub-wavelength, volumetric world — of fibrillar structures in biology
Manmohan Singh (U of Houston)	Structural and Functional Imaging with Optical Coherence Tomography and Optical Coherence Elastography
Sarah Patch (U of Wisconsin-Milwaukee)	Thermoacoustic Emissions Generated During Particle Therapy - analysis and applications
Michael Jaeger (U Bern)	Bayesian reconstruction for pulse-echo speed-of-sound imaging of human tissue
Lihong Wang (Caltech, Pasadena)	Photoacoustic Tomography and Compressed Ultrafast Photography
Robert Nuster (U Graz)	Photoacoustic and Speed of Sound Imaging with Camera-based Ultrasound Detection
Rainer Kaufmann (CSSB, Hamburg)	Correlative cryo super-resolution fluorescence microscopy and cryo electron tomography
Montserrat Lopez Martinez (TU Vienna) and Arjun Sharma (TU Vienna)	Setting up a Cryo - Single Molecule Localization Microscope
Jörg Enderlein (U Göttingen)	Metal-Indced Energy Transfer Imaging
Fabian Hinterer (Johannes Kepler U)	A robust method for bias-free localization of individual fixed dipole emitters achieving the Cramér Rao bound
Magdalena Schneider (TU Vienna)	A workflow for sizing oligomeric biomolecules based on cryo single molecule localization microscopy
Alexander Jesacher (Med Uni Innsbruck)	Localizing single molecules in 3D close to a dielectric interface
Lukas Velas (TU Vienna)	Applying 3D superresolution microscopy to T-cells
Francisco Balzarotti (Research Institute of Molecular Pathology)	Efficient use of emitted photons with MINFLUX

Publications and preprints contributed

So far, we are not aware of any publications directly resulting from this workshop.

Invited scientists

Giovanni S. Alberti, Andrea Aspri, Felix Bartel, Larisa Beilina, Stephanie Blanke, Alina Böcker, Liliana Borcea, Tobias Buck, Lorenzo Busoni, Fioralba Cakoni, Maxence Cassier, Raymond Chan, Bryn Davies, Shiyu Deng, Louis Detweiler, Tram Do, Jörg Enderlein, Simone Esposito, Jesus Falcon-Barroso, Adel Faridani, Florian Faucher, Alvaro Hacar, Bernadette Hahn, Pavol Harar, Tapio Helin, Thorsten Hohage, Simon Hubmer, Victoria Hutterer, José A. Iglesias, Kevin Islami, Michael Jaeger, Alexander Jesacher, Prashin Jethwa, Mirza Karamehmedovic, Ahmad Karimi, Alexander Katsevich, Rainer Kaufmann, Mengyuan Ke, Brendan Kennedy, Clemens Kirisits, Kim Knudsen, Lisa Krainz, Remo Kretschmann, Miska Le Louarn, Edward Lilley, Montserrat Lopez Martinez, Mia Kvåle Løvmo, Russell Luke, Peter Maaß, Thomas Mach, Marie Martig, Bochra Mejri, Gwenael Mercier, Leonidas Mindrinos, Roman Novikov, Robert Nuster, David Omogbhe, Günther Paltauf, Fabian Parzer, Sarah Patch, Juha-Pekka Puska, Michael Quellmalz, Todd Quinto, Aksel Rasmussen, Kui Ren, Kamran Sadiq, David Sampson, Hjørdis Amanda Schlüter, Magdalena Schneider, John Schotland, Thomas Schuster, Eric Setterqvist, Julia Shatokhina, Ekaterina Sherina, Cong Shi, Manmohan Singh, Patrick Stähli, Gabriele Steidl, Leila Taghizadeh, Tanja Tarvainen, Gunther Uhlmann, Glenn van de Ven, Leopold Veselka, Lihong Wang.

Online Workshop: Interdisciplinary Challenges in Nonequilibrium Physics

Organizers: Demian Levis (U Barcelona), Emanuele Locatelli (TU Vienna), Jan Smrek (U Vienna), Francesco Turci (U Bristol)

Dates: April 12 – 16, 2021

Budget: ESI € 1 037

Report on the workshop

Non-equilibrium processes play important and often vital roles at many length- and time-scales, ranging from those characteristic of the organisation of the cell nucleus to those relevant for the flocking of birds. Non-equilibrium statistical mechanics encompasses fundamental tools that are actively being developed and refined to understand such complex phenomena. A crucial factor that has hindered, so far, the formulation of a unified approach to nonequilibrium is the variety of different ways in which various systems can be out of equilibrium. Biological living complexes, glasses or active matter, represent such different systems and pose different challenges that are generally approached from different perspectives.

A key step to improve our understanding of universal non-equilibrium mechanisms at play across scales is to discuss and compare different ideas coming from all different research fields. The meeting focused on finding a common denominator for theoretical, computational and experimental approaches, so to maximally promote collaborations and knowledge exchange among early career researchers.

We organised 4 sessions focusing on the following topics:

1. biophysics and polymers
2. active matter
3. non-equilibrium statistical mechanics
4. glasses and disordered systems.

Activities

Due to the constraints imposed by the evolution of the COVID-19 pandemic, all of the activities took place online.

The workshop was structured as follows:

- Talk sessions on Zoom: with the exception of the first day, the workshop was composed by two zoom sessions per day, the first 75 minutes (3 talks) the second 50 minutes long (2 talks). On the first day, a “meet and greet” presentation session was organized on Zoom, where participants voluntarily presented themselves and their research: 46 participants accepted to introduce themselves in this way. After this session, a 50 minutes (2 talks) session was held.

- Poster session on the website Gather.town: the poster session was held every day after the Zoom sessions. It featured 19 posters. The participation was substantial, with more than 30 active participants every day. During the workshop a poster prize was announced; the three most-like posters were selected by the participants though an online voting system (Google forms). The session was open-ended, with a typical activity of about one hour and a half.

The key online tools used during the workshop were Zoom and Gather.town. The experience with Zoom was very positive. The livestream was basically flawless and rather uneventful; the audience (constantly 40-50 participants throughout the workshop) participated actively, asking questions and feeding into the discussion. The experience with Gather.town was also very positive: the session featured a good number of posters (19), which were thoroughly discussed during the week. The participation was substantial (constantly around 30 participants throughout the workshop). In addition to the poster session, Gather.town has hosted spontaneous discussions on various topics relevant for the meeting, similarly to ordinary, on-site workshop. Typically, these discussions continued beyond the official end of the poster session, which highlights the success of the format.

In order to make the workshop more engaging, we also invited different participants to chair the several sessions, mixing competences and backgrounds in order to have more inter-disciplinary and lively discussions. Again, the participants have been very receptive and seven of them accepted to chair the respective sessions.

Most of the talks were recorded with the permission from the speakers. The talks were then made available on the ESI website dedicated to the workshop, and on YouTube. While most speakers had no concerns regarding the recording, some of them have been uncomfortable with their broadcasting on YouTube.

Specific information on the workshop

The workshop was tailored to bring together early career researchers (PhD students, postdoctoral researchers and junior group leaders) working on interdisciplinary topics addressing issues in non-equilibrium physics and who are at the verge of, or have just made, the transition to independence. Indeed, 12 over 22 invited speakers were postdocs in April 2021 but, most remarkably, 20 over 25 of the original speakers did not have a permanent position in 2020, which is a proof of the quality of the speakers chosen. In addition, of the 19 posters, 14 were submitted by Ph.D. students and postdocs. Furthermore, from the 80 confirmed participants, the vast majority (65) do not currently have currently a permanent position, which demonstrates the format of the workshop is indeed very attractive for young researchers, notwithstanding the difficulties posed by the online format on the networking opportunities.

We further collected via email some spontaneous feedback from the participants, some of which we report here below:

- *It was a great workshop and I can say only positive things. The organization was fantastic; the format was very good; I liked gather.town very much. I particularly liked it that none of the talks was longer than 25 minutes (which I think is highly beneficial for the quality of the talks).*

- *I'd like to thank you once again for the invitation to the workshop and congratulate with you for the successful organization. Despite the hard times we are living, you have managed to bring forward a very nice initiative... and that's definitely not trivial.*

- *I just wanted to thank you all and the Institute, for organizing the Workshop "Interdisciplinary challenges in non-equilibrium physics" and giving us chance to participate in it, and I could present a poster also. I am sure that this workshop will have key influence in shaping my career.*

- *One [thing] which I think is nice about this kind of meeting is that although people are talking about many different topics or application, actually similar physics is cropping up in all these different places.*

Outcomes and achievements

The workshop has been the occasion of multiple informal contacts among the researchers, discussions around the posters and brainstorming on several problems of nonequilibrium physics. While it is too early to know whether collaborations emerged from these discussions, we have received positive feedback regarding the high degree of interdisciplinary nature of the topics treated, making such collaborations possible. The workshop also did not plan the production of dedicated articles. However, the online format and the technical support of ESI has produced very valuable registrations of the talks. These are videos (also accessible on YouTube) of a typical duration of 20-25 minutes which is exceptionally suitable for online fruition. Several talks (e.g. on Gatien Verley on stochastic thermodynamics or Valentina Ros on high-dimensional energy landscapes) have an exquisitely didactic nature which makes them suitable for a broader public of non-specialist researchers.

Finally, the success of the workshop has motivated some of the participants to continue the initiative in 2022, putting in place a new organising committee for the third iteration during the last days of the workshop itself, taking advantage of the Gather.town platform that was put in place. This is a very valuable outcome, as it establishes the Interdisciplinary Challenges in Nonequilibrium Physics as a high-quality, high-impact recurring event for a broad community of genuinely curious early-career researchers.

List of talks

Andreas Zöttl (U Vienna)	Microswimmer reinforcement learning with genetic algorithms
Helena Massana-Cid (U Roma 1, Sapienza)	Guiding photokinetic bacteria with dynamic light patterns
Fischer-Friedrich (TU Dresden)	The Poisson ratio of the cellular actin cortex is frequency-dependent
Elisabeth Chris Brackley (U Edinburgh)	Physical Mechanisms of Chromosome Organisation
Flavia Corsi (IMBA)	Understanding the spatial organisation of replicated human chromosomes
Paolo Malgaretti (HI-ERN)	Confinement as a control parameter

Patrick Pietzonka (U Cambridge)	Constraints on power and efficiency in heat engines and active engines
Eric De Giuli (Ryerson University)	What is the simplest model of an amorphous solid?
Domenico Truzzolillo (U Montpellier)	Vitrification and yielding of soft colloids
Priya Subramanian (U Oxford)	Looking at nucleation and non-topological defects through the lens of spatial localisation
Sophie Ramananarivo (Ecole Polytechnique, Palaiseau)	Boosted annealing of colloidal monolayers driven by active dopants
Joost de Graaf (Utrecht U)	Probing glassy colloidal systems with active particles
Izaak Neri (KCL, London)	Dissipation bounds the moments of first-passage times of dissipative currents in nonequilibrium stationary states
Gianmaria Falasco (U of Luxembourg)	A thermodynamic approach to mesoscopic complexity far from equilibrium
Gatien Verley (Université Paris-Saclay)	Insight into stochastic thermodynamics
Camille Scalliet (U Cambridge)	Microscopic origin of excess wings in the relaxation spectra of deeply supercooled liquids
Valentina Ros (CNRS, Paris)	Finding saddles in a complex landscape: a large deviation calculation
Anton Souslov (U Bath)	Active elastocapillarity
Pau Guillamat (U Genève)	Integer topological defects direct supracellular organization in nematic tissues
Benno Liebchen (TU Darmstadt)	Optimal Navigation of Microswimmers
Thomas O'Connor (Sandia National Laboratories)	The Outlier Dominant Rheology of Ring Polymers In Elongational Flow Recording
Davide Michieletto (U Edinburgh)	Topologically Active Polymers

Publications and preprints contributed

The workshop did not include the publication of research articles.

Invited scientists

Kishor Acharya, Natasa Adzic, Elisabeth Agoritsas, Alejandro Almodóvar, Katarina Bodova, Chris Brackley, Stanislav Burov, Francesco Cagnetta, Carles Calero, Claudio Caporusso, Roberto Cerbino, Iurii Chubak, Joan Codina, Flavia Corsi, Sara Dal Cengio, Eric De Giuli, Joost de Graaf, Pasquale Digregorio, Sudheesh Kumar Ethirajan, Gianmaria Falasco, Elisabeth Fischer-Friedrich, Giada Forte, Guram Gogia, Anton Goloborodko, Galien Grosjean, Pau Guillamat, Deepak Gupta, Arthur Hardiagon, Moshir Harsh, Ilin Karagjozov, Richard Kollàr, Zaida Zuleica Lara Chavero, Demian Levis, Benno Liebchen, Christos Likos, Emanuele Locatelli, Paolo Malgaretti, Alessandro Manacorda, Helena Massana-Cid, Sara Merino-Aceituno, Davide Michieletto, Juan Pablo Miranda, Izaak Neri, Thomas O'Connor, Antonio Ortiz Ambriz, Masoumeh Ozmaeian, Jack Thomas Parley, Charlotte Petersen, Patrick Pietzonka, Fahad Puthalath, Dusan Racko, Sophie Ramananarivo, Valentina Ros, Ylann Rouzaire, Jose Manuel Ruiz Franco, Renata Ruskova, Marks Ruziboev, Camille Scalliet, Deborah Schwarcz, Elena Sesé Sansa, Syed Hashim Shah, Gaurav Prakash Shrivastav, David Sivak, Jan Smrek, Juan Carlos Sobarzo Ponce, Anton Souslov, Vittoria Sposini, Alessio Squarcini, Aparna Sreekumari, Priya Subramanian, Diego Tapias, Domenico Truzzolillo, Francesco Turci, Mattia Alberto Ubertini, Pierfrancesco Urbani, Ivonne Elizabeth Ventura Rosales, Gatien Verley, Susanne Wagner, Scott Waitukaitis, Andreas Zöttl.

Online-Workshop: CHEBYSHEV-200

Organizers: Aicke Hinrichs (JKU, Linz), Boris Kashin (RAS, Moscow), Denka Kutzarova (U Illinois), Vladimir Temlyakov (U of South Carolina, Columbia), Sergey Tikhonov (CRM, Barcelona)

Dates: May 17 – 18, 2021

Budget: No budget was needed since the workshop was held online.

Report on the workshop

Activities

The Thematic Programme "Applied Functional Analysis and High-Dimensional Approximation" was cancelled due to COVID 19 pandemic.

Nevertheless, at least an online workshop "CHEBYSHEV-200" was held on May 17 - 18, 2021.

The programme included 4 talk by the following speakers:

Ron DeVore from Texas A&M University (USA), Aleksander Aptekarev from Keldysh Institute for Applied Mathematics and Moscow State University (Russia), Andrey Bogatyrev from Institute of Numerical Mathematics (Russia), and Vladimir M. Tikhomirov from Moscow State University (Russia).

Outcomes and achievements

The main goal of the workshop was to bring together specialists in approximation theory, harmonic analysis and functional analysis. The talks were given by the well-known experts in these fields. The workshop received substantial attention – on average, 45 people participated (online) per session.

List of talks

Ron DeVore	Learning from Data: From Chebyshev to Deep Learning
Aleksander Aptekarev	On the Sharp Constants in the Rate of Convergence of the Tchebyshev Rational Approximation for Analytic Functions
Andrey Bogatyrev	Chebyshev heritage in new Millennium
Vladimir M. Tikhomirov	Chebyshev's life and ideas

Publications and preprints contributed

F. Albiac, J. L. Ansorena, M. Berasategui, P. M. Berna, S. Lassalle, *Weaker forms of unconditionality of bases in greedy approximation*, arXiv:2106.00975 [math.FA].

F. Albiac, J. L. Ansorena, M. Berasategui, P. M. Berna, S. Lassalle, *Bidemocratic bases and their connections with other greedy-type bases*, arXiv:2105.15177 [math.FA].

Invited scientists

Christoph Aistleitner, Fernando Albiac, Jose Ansorena, Alexander I. Aptekarev Sergey Astashkin, Xandro Bayer, Pablo Berna, Dmitriy Bilyk, Peter Binev, Andrey Bogatyrev, Andrii Bondarenko, Petr Borodin, Anna Breger, Leyla Burusheva, Feng Dai, Alberto Debernardi, Ronald DeVore, Stephen Dilworth, Oscar Dominguez, Mikhail Dyachenko, Denis Filatov, Simon Foucart, Daniel Freeman, Dmitry Gorbachev, Philipp Grohs, Aicke Hinrichs, Clemens Karner, Boris Kashin, Vladimir Kazeev, Gerard Kerkyacharian, Yurii Kolomoitsev, Eva Kopecka, David Krieg, Peter Kritzer, Alexandr Kuleshov, Denka Kutzarova, Irina Limonova, Thomas Mejstrik, Yuri Malykhin, Yuri Matiyasevich, Thomas Mejstrik, Erich Novak, Kristina Oganesyan, Timur Oikhberg, Alexander Olevskii, Philipp Petersen, Dominique Picard, Friedrich Pillichshammer, Joscha Prochno, Vladimir Protasov, Oleg Reinov, Konstantin Ryutin, Thomas Schlumprecht, Alexei Shadrin, Mathias Sonnleitner, Vladimir Temlyakov, Vladimir M. Tikhomirov, Sergey Tikhonov, Mario Ullrich, Jan Vybiral.

Online-Workshop: Memory Effects in Dynamical Processes: Theory and Computational Implementation

Organizers: Christoph Dellago (U Vienna), Anja Kuhnhold (U of Freiburg), Hugues Meyer (U of Saarland), Tanja Schilling (U of Freiburg)

Dates: June 23 – 25, 2021

Budget: ESI € 1 305

Report on the workshop

In statistical physics, one frequently deals with processes that involve a very large number of degrees of freedom, implying significant computational cost if one needs to resolve all microscopic trajectories. However, there is a wide class of dynamical phenomena that can be described by the evolution of a reduced set of variables. In order to derive equations of motion for such quantities, one has to develop and apply coarse-graining procedures. If one develops a coarse-grained model of a complex system by systematically integrating out degrees of freedom, in general the resulting equations of motion are non-local in time, an aspect that is often referred to as *memory effects*. Neglecting these effects by using Markovian models can sometimes be meaningful, but this method has shown its limitations when modeling complex many-body processes. A lot of research and theoretical tools were introduced in the 1960's and 1970's to go beyond the Markovian approximation and to properly account for memory effects in coarse-graining procedures, but these were of no practical use without substantial computing power. Thanks to the massive improvement of computing resources in recent years, this research topic attracts now a considerable interest.

There is as of yet no deep understanding, general consensus and widely accepted methods on three main aspects:

- How to systematically derive equations of motion for reaction coordinates or coarse-grained degrees of freedom, and models for memory functions for systems that are out of thermal equilibrium.
- How to numerically deal with complex integro-differential equations of motion in an efficient way.

- How to consistently establish a link between a Langevin description, on the level of the single experiment, and a Fokker-Planck description for the probability density of the reaction coordinates.

In this meeting speakers reviewed recent advancements in the study of coarse-grained models and they discussed the impact of memory effects on the system dynamics. Several facets of the field have been presented and discussed. First, new theoretical elements were introduced, whose main goals were to investigate the mathematical structure of memory effects in non-equilibrium physics, such as recent advancements in time-dependent projection operator techniques, mode coupling theory and power-functional theory.

Then, a large part of the meeting was dedicated to numerical methods. The main challenge in the field consists in developing systematic and reliable methods to evaluate memory effects, in order either to handle them properly or to assess whether they can be neglected. Multiple new methods, such as iterative memory reconstruction, Volterra-like inversion, or noise reconstruction were presented, discussed and compared.

Finally, many practical examples from various fields of research were shown, e.g. biological reaction networks, phase transition kinetics, glasses physics and mechanical properties of soft materials. The wide range of applications presented in this workshop shows the current great interest for memory effects. In addition, the topic was addressed by physicists, mathematicians and chemists which lead to a lively interdisciplinary discourse.

Activities

The online workshop was held in the course of the Thematic Programme "Applied Functional Analysis and High-Dimensional Approximation".

The organization of this workshop was not clear for a long time, as it was originally postponed because of the COVID-19 pandemic, and was then planned as a hybrid online/on-site event. Finally, only the organizers and two other participants traveled to Vienna but all other participants participated online.

As most of the speakers were invited, we shared evenly the talk slots. More precisely, there were six sessions of 3-4 talks, for which we used the Zoom conference platform, and each talk had a duration of about 30 minutes including a discussion part. The set of speakers were composed of well-established professors as well as young researchers, which ensured a friendly and positive atmosphere throughout the workshop.

For further discussions, we had coffee breaks of 30 minutes between the sessions, for which we met in the ESI Gather.Town. Because it was not clear whether the workshop format could be hybrid, we kept the mornings free of talks to provide further time for discussions between the on-site participants. In addition, we had a poster session via Gather.Town after the second session on the second day.

Specific information on the workshop

The talks were given by experienced researchers and experts in the field and we also had contributions by young researchers (5 talks, 2 posters). The audience included further PhD students and postdoctoral researchers. A list of participating young researchers is given below.

Post-docs:

B. Bishnoi, A. Chanana, D. de las Heras, G. Jung, A. Kuhnhold, R. Mandal, H. Meyer (talk), S. Mandal, B. Rotenberg (talk), D. Tapias, M. Tripathy, H. Vroylandt (talk)

PhD students:

M. Bültmann, F. Glatzel, M. Harsh, J. Jin (poster), V. Klippenstein (talk), K. Palacio-Rodríguez (talk), P. Pelagejcev, J. Shea (poster), M. Spinaci

Undergraduate students:

M. Mathes

Outcomes and achievements

We are aware of the following collaborations and other outcomes:

T. Voigtmann and S. Mandal continued their collaboration on active colloidal systems.

M. Schmidt and T. Schilling will start a collaboration on the combination of projection operators and power functionals.

F. Pietrucci and S. Bonella invited T. Schilling, C. Dellago and H. Meyer to a conference in Paris to continue discussing on coarse-graining.

We would also like to stress that there has been a vivid discussion between the participants about the very structure of the equations of motion used in many studies by the community. This topic is still heavily debated as the current theories used in most cases are not derived under controlled approximations. As the workshop was relatively short and the online format is not the best way to discuss theoretical physics, we think that this topic should still be tackled in a later meeting. Our event definitely launched some fruitful discussions for future research.

List of talks

Angelo Vulpiani (U Roma 1)	Understanding causation via correlations and linear response theory
Hugues Meyer (U of Saarland) 7 contexts	Generalized langevin equation in time-dependent
Raphael Wittkowski (U Münster)	Jerky active matter model: particle dynamics with translational and orientational memory
Karen Palacio-Rodriguez (Sorbonne U, Paris)	Data-driven langevin equations from transition path sampling trajectories
Viktor Klippenstein (TU Darmstadt)	Cross-correlation corrected friction in (generalized) langevin models
Benjamin Rotenberg (CNRS, Paris)	Computing memory kernels from noise reconstruction by a deterministic approach
Hadrien Vroylandt (Sorbonne U, Paris)	Computing memory kernels from noise reconstruction by a stochastic approach
Julia Yeomans (U Oxford)	Active matter: from 2d to 3d
Martin Hanke-Bourgeois (U Mainz)	Model reduction techniques for the computation of extended markov parameterizations for generalized langevin equations
Thomas Franosch (U Innsbruck)	Persistent correlations in colloidal suspensions – noise cancellation algorithm
Thomas Voigtmann (DLR, Köln)	Aging in glasses: generalized langevin equations and scaling laws

Friederike Schmid (U Mainz)	Memory kernels and fluctuation-dissipation relations far from equilibrium
Felix Höfling (FU Berlin)	Spectral approaches to memory: friction in liquids and a generalised master equation
Matthias Schmidt (U Bayreuth)	Power functional perspective on memory in liquids
Peter Sollich (Georg-August-U, Göttingen)	Memory in subnetwork dynamics
Marcus Müller (U Göttingen)	Kinetics of structure formation in multicomponent polymer systems
Sara Jabbari Farouji (U Amsterdam)	Mechanical memory effects in solid-like polymers
Suzanne Fielding (Durham U)	Ductile and brittle yielding in amorphous materials
Marjolein Dijkstra (Utrecht U)	Machine-learning many-body potentials for colloidal systems
Sara Bonella (EPFL Lausanne)	Generalized langevin equations for simulating nuclear quantum effects

Invited scientists

Sara Bonella, Moritz Bültmann, Daniel de las Heras, Christoph Dellago, Marjolein Dijkstra, Suzanne Fielding, Thomas Franosch, Fabian Glatzel, Martin Hanke, Felix Höfling, Sara Jabbari-Farouji, Jaehyeok Jin, Gerhard Jung, Péter Király, Viktor Klippenstein, Anja Kuhnhold, Rituparno Mandal, Moritz Mathes, Hugues Meyer, Marcus Müller, Martin Oettel, Karen Palacio-Rodríguez, Harald Posch, Benjamin Rotenberg, Tanja Schilling, Friederike Schmid, Matthias Schmidt, Jeanine Shea, Peter Sollich, Marco Spinaci, Diego Tapias, Gergely Tóth, Madhusmita Tripathy, Thomas Voigtmann, Hadrien Vroylandt, Rodolphe Vuilleumier, Angelo Vulpiani, Raphael Wittkowski, Julia Yeomans.

International Mathematical Olympiad Training 2021

Organizers: Michael Drmota (TU of Vienna), Michael Eichmair (U of Vienna), Theresia Eisenkölbl (U of Lyon and U of Vienna)

Dates: Part I: June 28 – July 4, 2021, Part II: October 27 – October 29, 2021

Budget: ESI € 5 406
Federal Ministry of Education, Science and Research (BMBWF) € 1 344

Report on the workshop

The International Mathematical Olympiad (IMO) is the most prestigious mathematics competition for secondary school students. The Erwin Schrödinger International Institute for Mathematics and Physics (ESI) in cooperation with the joint project Mathematik macht Freu(n)de (MmF) of the University of Vienna and the University College of Teacher Education in Lower Austria organized a training week in July and three training days in October for the Mathematical Olympiad teams representing Austria. The training focused on the core subject areas of the IMO, Algebra, Combinatorics, Geometry, and Number Theory.

After all competitions of this Austrian Mathematics Olympiad year had taken place online, all participants were very happy that the IMO training could be held in presence in Vienna.

The Austrian Mathematical Olympiad is very thankful to the ESI and MmF for all their initiative and support.

Further links to these event:
`https://oemo.at/OeMO/News/imo-training-und-cpsa-match-2021/`
`https://oemo.at/OeMO/News/62-internationale-mathematik-olympiade-2021/`

Activities

Part I.
Subject-specific lectures in the fields of algebra, geometry, combinatorics and number theory were given by Theresia Eisenkölbl, Josef Greilhuber, Daniel Holmes, Moritz Hiebler, Lorenz Hübel, Morteza Saghafian, and Veronika Schreitter. In addition to that some new formats were tried outin order to make the training more diverse and effective in the future. For example, the students prepared an exercise competition for the other team in advance in two teams, which was then carried out in the course of the training and also corrected by the students themselves. Also new was a unit in which the strategic approach to difficult competition tasks was discussed.

During the week a visit from the Federal Ministry of Education, Science and Research (BMBWF) was received. Section head Doris Wagner (BMBWF, Section 1) personally got a picture of the IMO training and met the students briefly. She was welcomed by Michael Eichmair (Project Manager MmF), Radu Bot (Dean of the Faculty of Mathematics at the University of Vienna) and Michael Drmota (Scientific Director of the ÖMO).

Finally, at the end of the intensive training week, the CPSA match took place on July 3 and 4, which this year was again held online under Slovakian organization with support from all four countries. The competition is intended as a friendly competition between the countries as a preparatory competition for the IMO. Accordingly, Austria was also represented by the IMO participants present; the competition was accompanied and organized from the Austrian side by Daniel Holmes and Moritz Hiebler. Thanks to the foresighted organization, this competition could take place for the first time in presence form, namely at the University of Vienna, which we would like to thank again at this point.

Apart from the mathematical part, the IMO training gave all participants - students as well as presenters - the opportunity to get to know each other personally, to exchange ideas while eating, talking and playing cards together and to strengthen the team spirit.

Part II.
A second special training for students who have already qualified for an international competition took place from Oct. 27–29, 2021 (during the Austrian autumn vacations). The lectures on combinatorics and geometry were given by Florian Aigner, Theresia Eisenkölbl, Robert Geretschläger, Moritz Hiebler and Ivan Izmestiev. The topics covered ranged from graph coloring and marriage theorems, inversions and isognal conjugation to tasks from various international competitions.

There was also plenty of social interaction. Outside the lectures there was not only time for mathematical discussions, but also for community games and conversations. Friday afternoon there was also an excursion to the Technical Museum Vienna.

Specific information on the workshop

It should be emphasized that several young students and researchers gave training courses:

- Florian Aigner

- Josef Greilhuber
- Daniel Holmes
- Moritz Hiebler
- Lorenz Hübel
- Veronika Schreitter

This led to several fruitful discussions and interactions with the students. We are convinced that this will have a lasting positive effect on ÖMO.

Outcomes and achievements

Since the two workshops were of a training nature, no scientific collaborations are expected. Due to the involvement of young scientists as lecturers and the possible networking, later collaborations are very likely. The students also had the opportunity to make contacts that may prove very beneficial in the years to come, both for their choice of studies and for their possible future scientific careers.

Participants

Part I. Martin Bierbaumer, David Blassnig, Zirui Deng, Michael Drmota, Michael Eichmair, Theresia Eisenkölbl, Lukas Ginter, Josef Greilhuber, Paul Hametner, Moritz Hiebler, Michael Hollnbuchner, Daniel Holmes, Lorenz Hübel, Tristan Löb, Doris Obermaier, Gabriel Pflügl, Morteza Saghafian, Jan Schiller, Janina Schneeweiss, Veronika Schreitter, Georg Weisbier.

Part II. Florian Aigner, Martin Bierbaumer, David Blassnig, Michael Eichmair, Theresia Eisenkölbl Robert Geretschläger, Lukas Ginter, Paul Hametner, Moritz Hiebler, Jakob Kapelari, Tristan Löb, Doris Obermaier, Gabriel Pflügl, Jan Schiller, Janina Schneeweiss, Georg Weisbier.

Online-School: DARK MATTER: From Theory to Detection

Organizers: Markus Arndt (U Vienna), Josef Pradler (HEPHY, Vienna), Massimiliano Procura (U Vienna), Jochen Schieck (HEPHY, Vienna), Armin Shayeghi (U Vienna), Fedor Simkovic (Comenius U, Bratislava)

Dates: July 7 – 15, 2021

Budget: ESI € 624

Report on the school

The International School on AstroParticle Physics (ISAPP) "*DARK MATTER: from theory to detection*" covered important and timely topics that are connected to the Dark Matter (DM) problem, taught by internationally renowned experts. A primary focus of the school was on the direct detection of dark matter in rare-event searches. The theoretical background, observational motivation, and experimental avenues to observe dark matter signatures in the laboratory was covered. ISAPP is a consortium of over 30 European Institutions that organize Doctorate Schools on Astroparticle Physics for almost 20 years; the Institute of High Energy Physics (HEPHY) is a member. The key topics and associated questions that were covered at the school were:

- New observational and astrophysical insights into DM: what is known about DM observationally and what are the expected advances in the coming years?
- Light dark sectors: new particles and interactions at or below the GeV-scale have rich implications for cosmology and astrophysics and in experiment such as at high-intensity beams.
- Direct detection of dark matter: an extensive overview over the theoretical description of low-energy DM scattering on various targets will be given, including novel search strategies such as e.g. utilizing acoustic and optical phonons or the Migdal effect.
- Table-top DM searches: ultralight bosonic DM fields such as axions or dark photons with masses well below the eV-scale require dedicated detection schemes; low-energy tests of the Standard Model provide additional insights.
- Statistics for rare-event searches: introduction to statistical inference related to low-number statistics and difficult-to-model signal and backgrounds will be given. Limit-setting procedures as well as hypothesis testing for discoveries will be introduced.

Activities

The in-person event was canceled one month before the school, due to the pandemic situation. The online version was condensed to afternoons and one morning session, starting with a series of lectures, followed by discussion sessions moderated by the lecturers. A poster session was hosted through ESI's virtual space provided by gather.town.

Specific information on the school

For the originally planned on-site event, we selected about 40 excellent students — in part vetted by contacting their Ph.D. supervisors — and who were willing to travel to Vienna. However, we could not bring enough lecturers on-site out of a variety of reasons (their Universities would not allow travel, pending vaccination appointments and so forth), so that we had to switch to an online version. For this we opened up the school to *all* original registrants. In total, we had 108 registrations (24 of which were female), broken down in terms of country of affiliation as: Argentina (1), Austria (13), Canada (1), China (7), Cyprus (1), Czechia (4), France (5), Germany (17), India (12), Iran (1), Italy (17), Mexico (1), Morocco (1), Netherlands (1), Peru (1), Poland (5), Russia (5), Slovakia (1), Spain (4), Sweden (2), Switzerland (2), Ukraine (1), UAE (1), USA (5).

Outcomes and achievements

Lectures and exercise sessions were attended by a steady number of over 50 students throughout both weeks. We used the "Zoom Reports"-feature to monitor attendance. This allowed us to hand out attendance certificates for individuals with significant attendance. Recordings of most lectures are now available on the ESI YouTube channel.

List of lectures

Achim Schwenk (TU Darmstadt)	Nuclear physics of dark matter direct detection I and II
Maxim Pospelov (U of Minnesota, Minneapolis)	Dark sector theory overview I and II
Tien-Tien Yu (U of Oregon, Eugene)	Atomic physics for dark matter direct detection I and II
Ranny Budnik (Weizman Institute, Rehovot)	Liquid scintillator dark matter detectors
Jules Gascon (IPNL, Lyon)	Cryogenic dark matter detectors
Sara Algeri (U of Minnesota, Minneapolis)	Statistics for rare-event searches I and II
Simon Knapen (CERN Geneva)	Theory advances in direct detection I and II
Andreas Ringwald (DESY Hamburg)	Ultralight dark sectors theory
Dmitry Budker (U Mainz)	Ultralight dark sectors in experiment I and II
Andreas Ringwald (DESY Hamburg)	Theory of ultralight dark sectors
Vera Gluscevic (U of Southern California)	Observational insights into dark matter I and II

Publications and preprints contributed

We had in total 20 posters presented at a session that was hosted through gather.town. Posters were made available there.

Invited scientists

Iftikhar Ahmad, Sid El Moctar Ahmed Maouloud, Sara Algeri, Emanuele Angelino, Markus Arndt, Hamed Barzegar, Anna Bertolini, Mukund Bharadwaj, Julian Bollig, Aridai Bordón, Alexis Boudon, Dmitry Budker, Ranny Budnik, Emanuela Celi, Ting Cheng, Mar Ciscar, Sukeerthi Dharani, Johannes Diehl, Jules Gascon, Vera Gluscevic, Jonathan Gosling, Michal Iglicki, Aliaksei Kachanovich, Melih Kara, Margarita Kaznacheeva, Moritz Kellermann, Simon Knapen, Pawel Kozow, Agustin Lantero Barreda, Jeffrey Lazar, Miroslav Macko, David José Gaspar Marques, Peter Matak, Martin Mauser, Krzysztof Mekala, Julia Müller, Tobias Ortmann, Georgios Papadopoulos, Ricardo Peres, Maxim Pospelov, Josef Pradler, Massimiliano Procura, Francesca Pucci, Markus Rademacher, Florian Reindl, Alberto Ressa, Alessio Rettaroli, Andreas Ringwald, Jochen Schieck, Achim Schwenk, Armin Shayeghi, Fedor Simkovic, Adam Smetana, Anastasia Sokolenko, Florian Steininger, Gaurav Tomar, Samuele Torelli, Michelangelo Traina, Einar Urdshals, Sonali Verma, Tien-Tien Yu, Paules Zakhary.

Arithmetic Statistics and Local-Global Principles

Organizers: Tim Browning (ISTA, Klosterneuburg), Daniel Loughran (U Bath), Rachel Newton (King's College, London)

Dates: September 20 – 24, 2021

Budget: ESI € 12 560
ESRPC EP/R021422/2 of Daniel Loughran €1 000

Report on the workshop

The study of rational and integral points on algebraic varieties cut out by systems of polynomial equations is profoundly ancient and broad. In the setting of algebraic varieties of dimension at least 2 there has been a particular emphasis on questions concerning the existence of points, and the distribution of points with respect to heights. There are two central conjectures that have shaped modern research. The first is a famous conjecture of Colliot-Thélène and Sansuc from the 1970s that the (cohomological) Brauer–Manin obstruction controls the Hasse principle for rational surfaces. The second emerged in 1989 in work of Franke, Manin and Tschinkel and concerns a precise prediction (the Manin conjecture) for the number of rational points of bounded height on Fano varieties defined over a number field.

Led by Fields medallist Bhargava and his school, the rapidly growing research area of arithmetic statistics is concerned with the study of number-theoretic objects in families. Although some of the major problems in the field (such as Gauss's class number one problem) go back centuries, there has been a flurry of recent breakthroughs around Malle's conjecture on the distribution of number fields with bounded discriminant (or conductor) and given Galois group. Closely connected to this is the vibrant area surrounding the Cohen–Lenstra heuristics, which gives a probabilistic model to explain numerous phenomena in the statistical behaviour of class groups.

The principal aim of this workshop was to bring together leading researchers interested in the quantitative arithmetic of higher-dimensional varieties on the one hand, and those working on the statistics of algebraic number fields on the other hand. These two areas have operated more or less independently over the last twenty years, but their borders share an increasingly rich seam of mathematics.

Activities

We took the early decision to make this conference fully in person and to not have a hybrid format. This was greatly appreciated by the participants, since it was possible to informally speak with any of the speakers during the coffee breaks, rather than only via a zoom link directly after the talk. For many participants this was the first in person conference since the COVID-19 pandemic began. We therefore decided to keep the schedule of the workshop fairly light to ensure that the informal coffee and lunch break discussions, so difficult to replicate in an online format, were given proper emphasis. We achieved this by scheduling at most four talks a day and organising a conference hike to Kahlenberg on Wednesday afternoon. Mindful of the importance to promote women in mathematics, we prioritised a healthy percentage of female speakers (24%) in preparing the schedule.

Specific information on the workshop

During the pandemic it has been harder than usual for junior researchers to present their work to the broader community. In the light of this we deliberately saved talk slots for 2 Phd students (Ross Paterson and Margherita Pagano) and 9 postdocs (Carlo Pagano, Vlad Matei, Adam Morgan, Florian Wilsch, Beth Romano, Sam Streeter, Damián Gvirtz, Simon Rydin Myerson, Tal Horesh).

Outcomes and achievements

The participants universally enjoyed the workshop and thanked us all for being able to put on an in-person conference. These are some of the specific outcomes:

- Jakob Glas and Leo Hochfilzer initiated a collaboration about counting $\mathbb{F}_q(t)$-points on smooth cubic surfaces.

- Julian Lyczak and Harkaran Uppal discussed and made progress on questions about the Brauer groups of affine cubic surfaces of the form $ax^3 + by^3 + cz^3 = d$, for given $a, b, c, d \in \mathbb{Z}$.
- Tim Browning and Efthymios Sofos discussed a natural extension of the work presented by Skorobogatov and Sofos, with the hope of dealing with the Hasse principle for arbitrary norm form equations $\mathrm{N}_{K/\mathbb{Q}}(x_1, \ldots, x_n) = f(t)$, in which the assumption that $K/\mathbb{Q}$ is cyclic is removed.
- Kevin Destagnol and Zhizhong Huang discussed their forthcoming paper on the local distribution of rational points and the circle method, together with potential further directions.
- Kevin Destagnol and Julian Lyczak revisited their long term project of studying Manin's conjecture for symmetric powers of singular del Pezzo surfaces that arise as equivariant compactifications of $\mathbb{G}_a^2$.
- Martin Bright and Rachel Newton discussed a geometric approach to generalising their work on evaluating the wild Brauer group to elements of prime-power order.
- Alexei Skorobogatov had useful discussions with Margherita Pagano which helped him to construct a family of products of elliptic curves over $\mathbb{Q}$ with good ordinary reduction at 2 and a Brauer class with non-constant 2-adic evaluation map, similar to Margherita's K3 surface example.
- Christopher Frei, Daniel Loughran, and Rachel Newton continued their collaboration on the Hasse Norm Principle for abelian extensions.
- Tim Browning, Florian Wilsch and Kevin Destagnol discussed families of Pell equations and how current conjectures might shed light on the behaviour of integral points on affine cubic surfaces.

List of talks

Florian Wilsch (ISTA, Klosterneuburg)	Integral points of bounded height on a certain toric variety
Margherita Pagano (Leiden U)	An example of a Brauer-Manin obstruction to weak approximation at a prime with good reduction
Beth Romano (U Oxford)	Arithmetic statistics via graded Lie algebras
Marta Pieropan (Utrecht U)	Hyperbola method and Campana points on toric varieties
Tal Horesh (ISTA, Klosterneuburg)	Distribution of primitive lattices and free rational points on the Grassmannian
Alex Bartel (University of Glasgow)	Statistics of ray class groups of quadratic number fields
Vlad Matei (Tel Aviv U)	Probabilistic Galois Theory - The Square Discriminant Case
Adam Morgan (University of Glasgow)	Integral Galois module structure of Mordell–Weil groups
Martin Widmer (RHUL)	Northcott numbers for the house and Weil height

Efthymios Sofos (University of Glasgow)	Schinzel's Hypothesis with probability 1 and rational points on varieties in families (in two parts)
Alexei Skorobogatov (Imperial College London)	Schinzel's Hypothesis with probability 1 and rational points on varieties in families (in two parts)
Ross Paterson (University of Glasgow)	Average Ranks of Elliptic Curves after p-Extension
Carlo Pagano (University of Glasgow)	Statistics of integral points on conics
Kevin Destagnol (U Paris Sud, Orsay)	Local distribution of rational points and the circle method
Damián Gvirtz (University College London)	The Hilbert Property for Enriques surfaces
Simon Rydin Myerson (U Warwick)	Fibrations over elliptic curves, Brauer groups and the elliptic sieve
Sam Streeter (U Bath)	Weak approximation for del Pezzo surfaces of low degree

Publications and preprints contributed

Many of the discussions were at a preliminary stage and it is too early to see precisely which publications will emerge from the workshop.

Invited scientists

Alex Bartel, Dante Bonolis, Martin Bright, Tim Browning, Ulrich Derenthal, Kevin Destagnol, Daniel El-Baz, Christopher Frei, Jakob Glas, Damián Gvirtz, Leonhard Hochfilzer, Tal Horesh, Zhizhong Huang, Jef Laga, Daniel Loughran, Julian Lyczak, Oscar Marmon, Vlad Matei, Vladimir Mitankin, Adam Morgan, Rachel Newton, Otto Overkamp, Carlo Pagano, Margherita Pagano, Ross Paterson, Marta Pieropan, Beth Romano, Simon Rydin Myerson, Tim Santens, Alec Shute, Alexei Skorobogatov, Efthymios Sofos, Sam Streeter, Lola Thompson, Magdaléna Tinková, Harkaran Uppal, Martin Widmer, Florian Wilsch.

ESI Medal Award Ceremony 2021

Organizer: Christoph Dellago, ESI Director (U Vienna)

Dates: November 5, 2021

ESI Medal

The *Medal of the Erwin Schrödinger Institute for Mathematics and Physics*, in short ESI-Medal, has been created to recognize outstanding achievements in any area of mathematics or physics, including contributions at the interface of the two fields.

The ESI-Medal is awarded annually and emphasis is generally given to recent achievements not older than ten years. There is no age limitation for the recipient and ordinarily the ESI-Medal is awarded to one person only.

The recipient of the ESI-Medal receives a medal, a certificate and a monetary award of € 4 000.

Nominations for the ESI-Medal can be made by organizers of ESI Thematic Programmes taking place in the year of the award and in the four previous years, former members of the Scientific Advisory Board of the ESI, former recipients of the ESI-Medal, former Directors of the ESI and the President of the ESI Association. The recipient is selected by the Scientific Advisory Board of the ESI.

Winner of the ESI Medal 2021

The winner of the the *Medal of the Erwin Schrödinger Institute for Mathematics and Physics* for the year 2021 is Elliott Lieb, Professor Emeritus at Princeton University.

Professor Lieb has been honoured for his deep and groundbreaking mathematical analysis of fundamental problems and models of many-body physics, foremost his works of recent years, which continue to be outstanding and inspiring to a new generation of mathematical physicists. Two highlights in the realm of Coulomb systems are a mathematically rigorous justification of the Local Density Approximation in Density Functional Theory, and a proof of the equivalence in the thermodynamic limit of three different definitions of the minimum energy of a homogeneous electron gas (joint work with M. Lewin and R. Seiringer).

Award Ceremony

The award ceremony took place on November 5, 2021 at the ESI Boltzmann Lecture Hall. While some people attended the ceremony on-site, others (including the awardee) participated online.

Schedule of the Ceremony

Christoph Dellago, ESI Director (U of Vienna)	Welcome
Robert Seiring (IST Austria)	Recent (mathematical) results on Density Functional Theory
Jan Philip Solovej (U of Copenhagen)	On the Wehrl entropy - online
Christoph Dellago, ESI Director (U of Vienna)	Award of the ESI Medal
Jakob Yngvason (U of Vienna)	Laudatio
Elliott Lieb (Princeton U)	Award Lecture - online
Christoph Dellago, ESI Director (U of Vienna)	Closing

School and Workshop: Higher Structures Emerging from Renormalisation

> *Renormalization, writes David Tong, a theorist at the University of Cambridge, is “arguably the single most important advance in theoretical physics in the past 50 years.”*[1]

Organizers: Pierre Clavier (U of Haute-Alsace, Mulhouse, France), Kurusch Ebrahimi-Fard (NTNU, Trondheim, Norway), Peter K. Friz (TU Berlin, Germany), Harald Grosse (U of Vienna, Austria), Dominique Manchon (CNRS, U Clermont Auvergne, France), Sylvie Paycha (U of Potsdam, Germany)

[1] Charlie Wood, *How Mathematical ‘Hocus-Pocus’ Saved Particle Physics*, in Quanta Magazine, September 17, 2020.

Dates: November 8 – 19, 2021

Budget:	ESI	€ 18 552
	CNRS GDR Renormalisation	€ 13 000
	TU Berlin	€ 5 000
	IRIMAS (Mulhouse)	€ 1 700
	NTNU (Trondheim)	€ 4 500
	Compositio Mathematica	€ 7 500

Report on the Graduate School and Workshop

Introduction

The school and the workshop were follow-up events of the online meeting on ”Higher Structures Emerging from Renormalisation”, that took place in October 2020. The purpose was to create and enhance existing interactions between the following main topics:

T1) Rough analysis, regularity structures, mould calculus and renormalisation

T2) Algebraic and combinatorial structures in renormalisation and Quantum Field Theory

T3) Renormalisation in Quantum Field Theory

Beyond these topics, there was a cross-fertilisation between (stochastic) analytic and algebraic approaches to renormalisation in the theory of (singular) stochastic partial differential equations (SPDEs) and associated aspects in constructive approaches to Quantum Field Theory (QFT) and related questions.

The central notion underlying (almost) all contributions was **Renormalisation**:

The concept of renormalisability and the process of renormalisation are cornerstones of (the perturbative approach to) quantum field theory (QFT). Proving renormalisability of a QFT model is largely an analytic problem, whereas its renormalisation is of a more combinatorial nature. The conceptional and computational challenges in renormalisation of perturbative QFT models have been well-documented, for instance, in Quantum Electrodynamics (QED), the relativistic QFT of electrodynamics, and its so-called overlapping divergences[2]. Historically, the concept of renormalisation entered already in classical electrodynamics: approximating the self-energy of a point-like charge by the self-energy of a charged ball of finite radius, one observes a linear divergence if one sends the radius to zero. After addressing this problem via a simple subtraction from the (in the limit infinite) self-energy the remaining equations for the particle and the electromagnetic field show an a-causal behaviour, like pre-acceleration and existence of run away solutions. In QED, that is, at the quantum level, a logarithmic divergence remains. These divergences in QED puzzled many people for a long time. In a nutshell, the process of renormalisation in perturbative QFT is essentially (or mathematically speaking) a reparametrisation problem that relies on the availability of a finite number of –experimentally–

[2]“Renormalization theory has a history of egregious errors by distinguished savants. It has a justified reputation for perversity; a method that works up to 13th order in the perturbation series fails in the 14th order. Arguments that sound plausible often dissolve into mush when examined closely. The worst that can happen often happens.”. Quote from A.S. Wightman’s contribution (page 16) in *Renormalization Theory*, Proceedings of the NATO Advanced Study Institute held at the International School of Mathematical Physics at the ’Ettore Majorana’ Centre for Scientific Culture in Erice (Sicily) Italy, 1975.

fixed numbers relevant for the (re)parametrisation of the QFT model (Lagrangian, which is defined using so-called bare parameters/quantities to begin with). Indeed, after an appropriate reparametrisation of the model Lagrangian (in terms of the physical quantities, which are defined by the full interacting system and will differ in general from the bare ones), the renormalised Feynman (Stückelberg) graph expansion led to (formal) perturbative expansions, which are finite order by order. Those renormalised expansions permit to approximate physical quantities to a high precision. The combinatorics of renormalisation at the Feynman graph level can be deduced inductively (in loop order) from Faà di Bruno's (Hopf algebra) formula. That these results are independent of the regularisation scheme follows from the Epstein–Glaser work, as long as the axioms of Wightman are fulfilled. That method relies on the analytic continuation of distributions to regions of coinciding points, avoiding problems like overlapping divergences.

In the last 25 years, substantial progress has been made in the mathematical understanding of the process of renormalisation and its ramifications in various areas of modern mathematics, ranging from algebra and combinatorics to algebraic geometry and number theory. Key is a seminal finding due to A. Connes and D. Kreimer, which formulates the Bogoliubov–Parasiuk–Hepp–Zimmermann (BPHZ) renormalisation method as an algebraic-combinatorial factorisation problem in the group of characters over the combinatorial Hopf algebra of Feynman graphs. This insight led to many new developments and made it possible to transfer the concept of renormalisation to other mathematical problems, opening new interweaving paths between analysis, algebra, combinatorics and number theory. For instance, renormalisation methods reach out to number theory when extending multiple zeta values (MZVs) to negative integers. Sophisticated analytical and algebraic tools intermingle in K. Rejzner et al.'s perturbative approach to algebraic QFT, which fruitfully merges with higher structures such as K. Costello's and O. Gwilliam's so-called factorisation algebras. Analysis intertwines with combinatorics in G. Dunne et al.'s exciting program which aims at linking K. Yeats' work on combinatorial Dyson–Schwinger equations with J. Ecalle's analytic resurgence theory. Certain Hopf algebras on (planar and non-planar) rooted trees, a class of combinatorial Hopf algebras which also prove to be useful tools for renormalisation purposes, surprisingly share a common mathematical structure with J. Butcher's B-series. The latter being a cornerstone of the modern analysis of numerical integration methods. All these ramifications of the concept of renormalisation triggered an avalanche of results. Most spectacularly, the developments leading from T. Lyons' geometric rough paths to M. Gubinelli's branched rough paths, which culminated in M. Hairer's celebrated regularity structures (Fields Medal 2014), build up on a highly sophisticated scaffolding of algebraic and analytic techniques. In providing remarkable solutions to open problems in the theory of (singular) stochastic partial differential equations (SPDEs), they fostered cross-fertilisation between (stochastic) analytic and algebraic approaches to renormalisation in the constructive approach to QFT and related mathematical questions.

The meeting offered an ideal place to discuss the many similarities between 'classical' renormalisation methods in QFT and more recent treatments of (singular) SPDEs. Indeed, A. Chandra's exposition showed how symmetry and renormalisation play together in Hairer's regularity structures. This interdisciplinarity across mathematical fields and reaching out to physics, together with the resulting interactions are reflected in the contents of this meeting.

Let us name a few.

Lower dimensional QFT models were constructed (Glimm, Jaffe, and others), which are super renormalisable, meaning that only a finite number of divergences occur in the Feynman graph expansion. This case is also considered in the context of SPDEs where it is referred to as subcritical.

The renormalisable (but not super renormalisable) limit case is called critical for SPDEs. The fourth power interaction in four space-time dimensions for a scalar Boson field belongs to this class. The standard BPHZ method within the QFT formalism allows to show renormalisability, yet the question of non-triviality remains open.

Zimmermann's famous forest formula and subtraction procedure was finally put by Connes–Kreimer into an adequate combinatorial Hopf algebra framework. Similar algebraic structures defined on vertex and edge decorated rooted trees appear extensively in the studies of SPDEs, and many contributions to this meeting discussed results and ideas in this direction.

The renormalisation group (RG) is a central concept to renormalisation techniques in QFT. Historically, after the original work of Stückelberg and Peterman in 1953 (see also Gell-Mann and Low, 1954), many contributions followed in the decades to come. Culminating in K. Wilson's seminal work which turned the RG into an extraordinarily powerful tool in statistical physics, where he used it to evaluate (approximately) critical exponents in the context of the problem of critical phenomena. This method was also discussed in the SPDE.

Activities

The **first week** of the meeting (November 8 - 12) was dedicated to a Master Class which comprised four introductory 4 hrs mini-courses given by Ilya Chevyrev (U of Edinburgh, UK), Kasia Rejzner (U of York, UK), Frédéric Patras (CNRS, U Côte d'Azur, Nice, France) and Lorenzo Zambotti (Sorbonne U, Paris, France).

In addition, we had 15 short communications by young researchers. As testified by the titles listed below, the level of these contributions was extremely high, covering a variety of aspects of renormalisation across the whole spectrum.

The young researchers came from various fields of research in mathematics and physics. They were able to benefit both from presenting their results to a broad and rather receptive audience and from learning about other topics from the other talks.

Each day, we had three lectures in the morning and three to four presentations (primarily short contributions) in the afternoon.

The **second week** (November 15 - 19) was organised in the classical workshop format. However, as a novelty, talks were given 'in pairs', that is, a 40 min presentation by an invited speaker was followed by a 15 min discussion on the presentation by an invited *discussant*.

The talks on Monday were done in a hybrid format, with most of the participants being present at the ESI. Unfortunately, due to a covid-19 incidence among the workshop participants, we had to change the format of the whole meeting (starting on Tuesday morning) by moving it to an online platform. The regulations at the ESI required an additional test to be allowed to enter the premises. Consequently, fewer people were present at the ESI, which forced us to cancel the eagerly anticipated Round Table discussion group on Foundations of QFT.

Additionally to the talks in mathematics and physics, we had two research talks by two philosophers of science (M. Miller and J. Dougherty) accompanied by a general audience lecture given by M. Miller on Monday evening. These contributions aimed at fostering discussions of aspects of more fundamental nature regarding the role of renormalisation in modern QFT. For instance, the 'classical' question of why one is able to describe and understand physical systems all the way from the classical to the quantum realm using (abstract) mathematics.

Specific information on the school and workshop

The four introductory 4 hrs mini-courses during the first week were given by:

Ilya Chevyrev (U of Edinburgh, UK)
Hopf and pre-Lie algebras in regularity structures, T1 & T2

> The focus was on algebraic aspects of Hairer's regularity structures and the role of pre-Lie algebras in renormalisation of SPDEs.

Kasia Rejzner (U of York, UK)
Renormalization in perturbative algebraic quantum field theory, T3

> The perturbative renormalisation à la Epstein–Glaser was used within the algebraic QFT framework.

Frédéric Patras (CNRS, U Côte d'Azur, Nice, France)
Renormalization à la Wick, T2

> The theory of Wick polynomials and Wick products, examples of a renormalisation procedure and the relation to Hopf algebraic structures as well as quasi-shuffle products were explained.

Lorenzo Zambotti (Sorbonne U, Paris, France)
Analytic aspects of regularity structures, T1

> The main analytic tools of Hairer's regularity structures, i.e., the reconstruction theorem and Schauder estimates were revisited and presented in a simplified and more accessible way. It was shown how regularity structures can be viewed as an abstract theory of Taylor expansions.

Each day consisted of three lectures in the morning and three to four short communications by young researchers in the afternoon.

Regarding the latter, there were a number of young researchers from various fields of mathematics and physics who benefited both from presenting their results to a broad and rather receptive audience and from learning about recent developments in other topics. We had explicitly asked the speakers to make a special pedagogical effort by keeping in mind that the audience was rather mixed including a number of non-experts.

Here is the list of young researchers who delivered short communications:

David Prinz (HU Berlin, Germany)	Hopf Ideals for General Relativity
Victor Nador (U Bordeaux, France)	Double scaling limit of the quartic $O(N)^3$-tensor model
Rosa Preiß (U of Potsdam, Germany)	Adding rough paths: no problem as long as they are smooth
Albin Grataloup (U Montpellier, France)	A derived geometric perspective on the BV complex
Adrián Celestino Rodriguez (NTNU, Trondheim, Norway)	Relations between cumulants from Magnus' expansion

Nicolas Gilliers (NTNU, Trondheim, Norway)	Post-Lie algebras and operator-valued Dykema's T-transform in Free Probability
Adrien Laurent (U of Bergen, Norway	Exotic aromatic B-series for the long time integration of ergodic stochastic differential equations
Ludwig Rahm (NTNU, Trondheim, Norway)	Substitution in Lie–Butcher Series
Pablo Linares (MPI Leipzig, Germany)	A multiindex-based regularity structure for quasilinear SPDEs
Pawel Duch (U Adam Mickiewicz, Poznan, Poland)	Flow equation approach to singular stochastic PDEs
Eugenia Boffo (Charles U, Prague, Czech Republic)	BRST of the N=2 superparticle and R-R fields
Yannic Vargas (U of Potsdam, Germany)	New formulas for cumulant-to-moment relations
Diego Lopez Valenci (U of Potsdam, Germany)	Pole Structure of Shintani zeta functions and Newton Polytopes
Toni Kodžoman (Institut Ruđer Bošković, Croatia)	On Hopf and L-infinity Algebras
Carlo Bellingeri (TU Berlin, Germany)	A geometric approach to renormalisation on ”smooth rough paths”

The titles of these short contributions hint at the relations to the three mentioned topics, T1, T2, T3. They also reflect the fruitful interactions that arose between renormalisation in perturbative QFT and in the theory of (singular) SPDEs, over the past decade (thanks to, among others, M. Hairer, M. Gubinelli, L. Zambotti, A. Kupiainen, A. Chandra), resulting in a fascinating cross-fertilisation between (stochastic) analytic and algebraic approaches to renormalisation in QFT and related questions.

The Master Class was followed by a research workshop structured around the ‘talks in pairs’ format. The latter consists of a 40 min presentation by a speaker followed by a 15 min discussion on the presentation by a discussant. This format was borrowed from meetings in Oberwolfach. It has shown to lead to fruitful interactions. The role of a discussant included highlighting and possibly complementing the contribution of a speaker. They also provided short summaries and general comments together with a brief explorations of how the presented results contribute to advances in the topic.

This format was appreciated: the discussant often gave a (second) explanation to the presented subject, allowing non-experts in the audience to have another chance to develop some understanding of the general motivation as well as the context of the talk. Another positive aspect is to see the experts discussing other points of view on the results.

The following speakers gave seminars at the workshop:

Y. Bruned (Edinburgh, UK), A. Chandra (London, UK), J. Dougherty (Munich, Germany), G. Dunne (Connecticut, USA), L. Foissy (Calais, France), A. Frabetti (Lyon, France), E. Garcia Failde (Paris, France), J. Gracia-Bondia (San José, Costa Rica), O. GWilliams (Massachussets, USA), E. Herscovich (Grenoble, France), M. Hoshino (Osaka, Japan), F. Lehner (Graz, Austria), F. Otto (Leipzig, Germany), E. Panzer (Oxford, UK), J. Thürigen (Münster, Germany), V. Vargas (Genève, Switzerland), K. Yeats (Waterloo, Canada), M. Miller (Toronto, Canada), R. Zhu (and X. Zhu) (Beijing, China & Bielefeld, Germany)

The titles of their contributions (to be mentioned at the end of the report) reflect once again the two main subjects, the theory of SPDEs and (perturbative) QFT. The talks on combinatorics and algebraic structures underlying approaches to both SPDEs and QFT served as a common thread to these two topics and provided a sound basis for interesting discussions.

The schedule comprised also two research talks and a public lecture by philosophers of science, who addressed philosophical aspects of the renormalisation of gauge theories as well as the classical work by Epstein-Glaser on renormalisation. The public lecture addressed one of the most central questions in philosophy of science, namely why mathematics is key to formulating, studying and understanding theories of physical systems; the lecture was based – as one might expect,– on Eugene Wigner’s 1960 classical article on “The Unreasonable Effectiveness of Mathematics in the Natural Sciences”.

Outcomes and achievements

Although developments in local quantum field theory started 90 years ago, and many aspects are by now well understood, there is still no nontrivial QFT model in 4 space-time dimensions constructed.

That quantum physics is closely related to stochastic problems is well-known from the early days, when it became clear that the unitary time evolution can be analytically continued to the semi-group of the heat kernel for lower bounded self-adjoint Hamilton operators. This way, the quantum physics could be reformulated in a stochastic language, with the Wiener measure playing a central role.

Both subjects have evolved rapidly and led to many open questions and new ideas. This meeting has shown, how much one can learn from studying both subjects closely. In fact, future developments in both QFT as well as SPDEs will profit from these common events.

We mention here the start of discussions between two young researchers, Dr. Rosa Preiß (U of Potsdam, Germany) and Ludwig Rahm (NTNU, Trondheim, Norway), on algebraic and operadic structures related to the notion of smooth rough paths and the concept of translation/substitution for rough paths (L. Rahm will present his work in a seminar at the U of Potsdam, in February).

List of talks

Vincent Vargas (U Genève) Discussant: Nathanael Berestycki (U Vienna)	Liouville conformal field theory: from probability theory to the conformal
Erik Panzer (U Oxford) Discussant: Oliver Schnetz (U Erlangen–Nürmberg)	Tropical field theory
Estanislao Herscovich (U Grenoble) Discussant: Kasia Rejzner (U of York)	Quantum field theory and vertex algebras within 2-monoidal categories
Gerald Dunne (U of Connecticut) Discussant: Frédéric Fauvet (U Strasbourg)	Non-Perturbative Physics from Perturbative Hopf-Algebraic Dyson–Schwinger Equations
Michael Miller (U Toronto) Moderator: Frédéric Patras (CNRS, U Côte d’Azur, Nice)	The (un?)reasonable effectiveness of mathematics in the natural sciences
Felix Otto (MPI Leipzig) Discussant: Rosa Preiß (U of Potsdam)	The structure group in regularity structures: avoiding trees
José M. Gracia-Bondìa (Universidad de Costa Rica, San José) Discussant: Pawel Duch (U Adam Mickiewicz, Poznan)	Revisiting the Okubo–Marshak Argument
Ajay Chandra (Imperial College, London) Discussant: Hendrik Weber (U Bath)	Symmetry and renormalisation in regularity structures
Owen Gwilliam (UMass Amherst) Discussant: Claudia Scheimbauer (TU Munich,	From Feynman diagrams to commutative diagrams)

Franz Lehner (TU Graz) Discussant: Frédéric Patras (CNRS, U Côte d'Azur, Nice)	Cumulants, Spreadability and Quasisymmetric functions
Elba Garcia Failde (Sorbonne U, Paris) Discussant: Raimar Wulkenhaar (U Münster),	Topological recursion, discrete surfaces and cohomological field theories)
Loic Foissy (U of Littoral Côte d'Opale) Discussant: Joscha Diehl (U Greifswald)	Cointeracting bialgebras
Yvain Bruned (U Edinburgh) Discussant: Tom Klose (TU Berlin)	Locality for singular stochastic PDEs
Rongchan Zhu (AMSS, Beijing, China) Discussant: Nils Berglund (U d'Orléans)	Singular kinetic equations and applications
Michael Miller (U Toronto) Discussant: José M. Gracia-Bondía (U Costa Rica,	A Philosopher Looks at Epstein–Glaser Renormalization)
John Dougherty (LMU Munich) Discussant: Frédéric Patras (CNRS, U Côte d'Azur, Nize)	Some philosophical aspects of the renormalization of gauge theories
Karen Yeats (U Waterloo) Discussant: Michael Borinsky (ETH Zurich)	Combinatorics of higher order renormalization group equations
Masato Hoshino (U Osaka) Discussant: Nicolas Perkowski (FU Berlin)	Paracontrolled calculus and regularity structures
Johannes Thürigen (U Müster) Discussant: Alexander Hock (U Oxford)	Combinatorial Dyson–Schwinger equations in tensorial field theory
Alessandra Frabetti (U Lyon) Discussant: Maria Immaculada Galvez Carrillo (U Politècnica de Catalunya)	Direct connections on jet groupoids

Publications and preprints contributed

We are considering the publication of the contributions in a proceedings volume.

N. Berglund, *An Introduction to Singular Stochastic PDEs. Allen–Cahn Equations, Metastability, and Regularity Structures*, ems.press:10.4171.

Invited scientists

Carlo Bellingeri, Nathanael Berestycki, Marko Berghoff, Nils Berglund, Eugenia Boffo, Michael Borinsky, Lucas Broux, Yvain Bruned, Diego de Jesus Caudillo Amador, Adrián Celestino Rodriguez, Ajay Chandra, Ilya Chevyrev, Pierre Clavier, Jacky Cresson, Joscha Diehl, John Dougherty, Pawel Duch, Gerald Dunne, Kurusch Ebrahimi-Fard, Quentin Ehret, Hugo Eulry, Frederic Fauvet, Léonard Ferdinand, Julian Fischer, Loic Foissy, Alessandra Frabetti, Peter K. Friz, Maria Immaculada Gálvez Carrillo, Elba Garcia Failde, Nicolas Gilliers, José M. Gracia-Bondía, Albin Grataloup, Harald Grosse, Subbarao Venkatesh Guggilam, Owen Gwilliam, Paul Hager, Florian Hanisch, Fabian Harang, Estanislao Herscovich, Alexander Hock, Masato Hoshino, Florian Huber, Jean-David Jacques, Tajron Juric, Foivos Katsetsiadis, Tom Klose, Joachim Kock, Toni Kodžoman, Olaf Krüger, Adrien Laurent, David Lee, Imene Lehbab, Franz Lehner, Pablo Linares, Chong Liu, Diego Lopez Valenci, Ihsane Malass, Dominique Manchon, Michael Miller, Muhammad Usama Nadeem, Rita Nader, Victor Nador, Thanh Loan Nguyen, Vu Nguyen Dinh, Felix Otto, Erik Panzer, Frederic Patras, Sylvie Paycha, Nicolas Perkowski, Sylke Pfeiffer, Rosa Preiß, David Prinz, Ludwig Rahm, Kasia Rejzner, Vincent Rivasseau, Claude Roger, William Salkeld, Claudia Scheimbauer, Leonard Schmitz, Oliver Schnetz, Adrian Tanasa, Markus Tempelmayr, Johannes Thürigen, Andrew Tonks, Vincent Vargas, Yannic Vargas, Emanuele Verri, Fabien Vignes-Tourneret, Hendrik Weber, Raimar Wulkenhaar, Karen Yeats, Lorenzo Zambotti, Rongchan Zhu, Xiangchan Zhu.

Online-Workshop: Topology, Disorder, and Hydrodynamics in Non-equilibrium Quantum Matter

Organizers: Jörg Schmiedmayer (TU Vienna), Maksym Serbyn (ISTA, Klosterneuburg), Romain Vasseur (U Mass Amherst)

Dates: November 29 – December 3, 2021

Budget: No budget was needed since the workshop was held online.

Report on the workshop

The SVS21 workshop aimed to bring together leading experts working on the *topology*, *disorder*, and *hydrodynamics* aspects of non-equilibrium quantum systems. Although the above three themes are apparently unrelated and span very different areas of Physics, they recently became intertwined in studies of highly non-equilibrium quantum systems. Understanding universal features in interacting out-of-equilibrium quantum matter is an extremely challenging conundrum and the SVS21 workshop brought these communities together, facilitating synergy between leading experts and enable progress on these topics. To this end, the particular attention was devoted to attracting leading experimental groups in these fields.

Activities

The workshop was planned in a hybrid format, however the development of COVID pandemic and declared lockdown forced the switch to online format. In order to better accommodate the speakers from different time zones, in the online format talks were shifted to later times. In addition, all talks were given in Zoom, using an infrastructure provided by the ESI and were recorded to the cloud. The recordings of the talks were posted online on the next day, which enabled participants from countries with a large time difference (i.e. USA West coast) to follow talks on their own schedule. Online availability of talks recordings allowed to broaden the outreach of the workshop. In about a month after the workshop some talks are viewed already more than 100 times. Finally, the gather.town platform provided an opportunity for informal discussions, that was used by workshop participants during breaks.

The online program consisted of five days, with 6-7 talks per days. In total, the even hosted 10 experimental talks, successfully attracting the significant number of prominent experimental groups, including those lead by senior and also by junior PIs. Remaining talks were theoretical, and were also delivered by physicist working at different career stages, ranging from postdocs to full professors. In addition to the formal talks, the workshop allowed for a significant post-talk discussion time. In addition, the long lunch break and coffee breaks enabled follow-up discussions and more informal interactions using gather.town platform.

Specific information on the workshop

The young researchers that took part in the workshop were:
Dr. Ivan Khaymovich (MPI Dresden, Germany)
Dr. Zala Lenarcic (Jozef Stefan Institute, Slovenia)
Dr. Jacopo De Nardis (Ghent Univ., Belgium)
Dr. Philipp Dumitrescu (Flatiron, USA)
Dr. Adam Nahum (ENS, France)

Dr. Matteo Ippoliti (Stanford Univ., USA)
Dr. Maximilian Pruefer (TU Vienna, Austria)
Dr. Wen Wei Ho (Stanford Univ., USA)

Outcomes and achievements

The goal of this workshop was to bring together leading experts working on topological properties and Floquet dynamics, dynamics of disordered systems, and, finally, quantum hydrodynamics; and to generate a stimulating atmosphere in which new ideas and approaches for dealing with these complex systems can be developed. Explicit examples of interfaces between these three fields include:

- Protection of Floquet topological phases from heating by MBL
- Hydrodynamics and prethermalization in Floquet systems, quasi-conserved quantities
- Hydrodynamic description of operators in (integrable) Floquet systems and thermalization
- Emergent integrability from disorder: hydrodynamics and its failure at the MBL transition
- Quantum information spreading and its “hydrodynamics”

In the longer term, we expect that the impact of this workshop will allow development of new approaches to nonequilibrium quantum dynamics. In addition, the event provided a snapshot of the current activities in the field of nonequilibrium quantum dynamics.

Researchers from all around the world attended the workshop, with a size of audience approaching 100 participants for some talks. In addition, a significant number of scientists from Vienna and Innsbruck participated in this event, making positive impact on the Austrian research landscape. The event atmosphere was positive and included a number of constructive discussions.

From the positive feedback received by the workshop participants, we believe that the objectives of the workshop were fulfilled and we hope that inspired synergies and collaborations would lead to joint publications in the near future. At the same time participants gave an explicit feedback that encouraged the next event to be held in in-person format. As a particular limitation of the online format, junior participants mentioned the limited ability of informal interactions especially between theoretical and experimental physicists. Moreover, it was repeatedly mentioned that organizing similar event using in-person format within 1-2 years would be highly desirable and would be appreciated.

List of talks

Benjamin Doyon (KCL, London)	Emergent hydrodynamics in many-body systems
David Weiss (Penn State)	Experiments with out of equilibrium 1D Bose gases
Dmitry Abanin (U Genève)	Influence matrix approach to quantum many-body dynamics

Pasquale Calabrese (SISSA, Trieste)	Quantum generalized hydrodynamics
Isabelle Bouchoule (U Paris-Saclay)	Losses in 1D Bose gases
Zoran Hadzibabic (U Cambridge)	Two sounds and turbulence in shaken 2D Bose gases
Ivan Khaymovich (MPI Dresden)	Localization beyond convergence of locator expansion in correlated long-range systems
Wen Wei Ho (SU)	Exact emergent quantum state designs from quantum chaotic dynamics
Frank Pollmann (TU Munich)	Efficient Simulation of Quantum Transport in 1D
Jens H Bardarson (KTH Stockholm)	Time-evolution of local information: thermalization dynamics of local observables
Ulrich Schneider (U Cambridge)	Observing novel phase transitions with Bosons in optical lattices
Siddharth Parameswaran (U Oxford)	Asymptotically exact nonlinear responses in interacting many-body systems (virtual)
Michael Knap (TU Munich)	Anomalous transport and operator growth in constrained quantum matter
Marco Schiro (CNRS, Paris)	Unraveling Quantum Many Body Dynamics
Sarang Gopalakrishnan (CUNY, New York)	Entanglement transitions and symmetries
Monika Aidelsburger (LMU Munich)	Non-ergodicity and emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains
Rahul Nandkishore (U of Colorado, Boulder)	Fracton dynamics
Adam Nahum (ENS Paris)	Entanglement membrane in chaotic many-body systems
Zala Lenarcic (Jozef Stefan Institute, Ljubljana)	Extracting complexity of quantum dynamics using machine learning
Jacopo De Nardis (Ghent U)	Subdiffusive hydrodynamics of nearly-integrable anisotropic spin chains
Cheng Chin (U of Chicago)	Dynamics of topological defects driven by density-dependent gauge field
Marko Znidaric (U Ljubljana)	Non-Hermitian phantoms in random circuits
Maximilian Pruefer (TU Vienna)	Probing emergent universal phenomena with one-dimensional Bose gases
Christoph Naegerl (U Innsbruck)	Dynamics of impurities in strongly interacting one-dimensional quantum gases
Gil Refael (Caltech, Pasadena)	Topological two frequency conversion in doubly driven Weyl semimetal
Matteo Ippoliti (SU)	Monitored quantum dynamics via spacetime duality
Immanuel Bloch (MPI Quantum Optics, Garching)	Quantum Gas Microscopy of Kardar-Parisi-Zhang Superdiffusion
Philipp Dumitrescu (Flatiron)	Dynamic phases in quasiperiodically driven quantum many-body systems
Roderich Moessner (MPI Dresden)	Topological Route to New and Unusual Coulomb Spin Liquids
Hannes Pichler (IQOQI, Innsbruck)	Probing Quantum Spin Liquids with Rydberg Atom Arrays
Norbert Schuch (U Vienna)	Matrix product state algorithms for free fermions in and out of equilibrium
Tomaz Prosen (U Ljubljana)	Exact results on dynamics of dual unitary circuits and their perturbations

Invited scientists

Dmitry Abanin, Monika Aidelsburger, Soumik Bandyopadhyay, Jens H. Bardarson, Nicolo Beato, Immanuel Bloch, Isabelle Bouchoule, Pietro Brighi, Pasquale Calabrese, Alec Cao, Alberto Cappellaro, Federica Cataldini, Cheng Chin, Giuseppe Del Vecchio Del Vecchio, Jacopo De Nardis, Benjamin Doyon, Philipp Dumitrescu, Paul Fendley, Christoph Fleckenstein, Jose Garre, Fotios Ioannis Giasemis, Marek Gluza, Sarang Gopalakrishnan, Zoran Hadzibabic, Wen Wei Ho, Friedrich Hübner, Matteo Ippoliti, Ivan Khaymovich, Vedika Khemani, Michael Knap, Marton Kormos, Soumya Kumar, Ancel Larzul, Achilleas Lazarides, Maciej Łebek, Zala Lenarcic, Alessio Lerose, Shuwei Liu, Marko Ljubotina, Maximilian Lock, Mahdi Mashkoori, Oles Matsyshyn, Raimel Medina, Roderich Moessner, Frederik Møller, Per Moosavi, Christoph Naegerl, Adam Nahum, Rahul Nandkishore, Sourav Nandy, Siddharth Parameswaran, Hannes Pichler, Lorenzo Piroli, Frank Pollmann, Tomaz Prosen, Maximilian Prüfer, Gil Refael, Paola Ruggiero, Colin Rylands, Gopal Chandra Santra, Marco Schiro, Jörg Schmiedmayer, Ulrich Schneider, Norbert Schuch, Philipp Schüttelkopf, Maksym Serbyn, Jeongrak Son, Michael Sonner, Spyros Sotiriadis, Jan Suntajs, Kuldeep Suthar, Rafal Swietek, Steven Thomson, Xhek Turkeshi Loredana Mihaela Vasiloiu, Romain Vasseur, Lev Vidmar, Artem Volosniev, David Weiss, Marko Znidaric.

Research in Teams

Research in Teams Project 1: Simulability-versus-Noise Tradeoffs for Restricted Quantum Circuits

Collaborators: Robert Koenig (TU Munich), Kristan Temme (IBM T.J. Watson Research Center)

Dates: August 8 - 22, 2021

Budget: ESI € 2 240

Report on the project

Scientific Background

Our project idea revolved around the question of how to characterise the difference between purely classical and quantum computational resources. Central to such a characterisation is the fact that sufficiently noisy quantum computations are typically accessible to classical simulation methods. For example, it is known that quantum circuits with a high level of noise (as modelled for example by a depolarising channel acting on each wire) can be efficiently simulated using classical computational resources, e.g., relying on tensor networks. As a consequence, such noisy circuits cannot provide a quantum advantage. For experimental design considerations, it is essential to know at what noise level this breakdown or "phase transition" of quantum computational power occurs. Surprisingly, very little is known about this question, and it is yet to be completely resolved in general (but see, e.g., [1, 2]). Our research project set out to shed more light on this question by extending the reach of existing classical simulation methods, and working towards a more quantitative understanding of this boundary between quantum and classical computational power.

Project aims and scope

In the initial discussion phase at the ESI, we laid the ground work and discussed potential approaches to characterise the transition towards classical simulability. Typically, each approach to establish classical approximation methods is highly noise-model dependent. For examples, one can seek to establish classical simulation techniques for certain noise models based on the decomposition of general channels into convex combinations of Gaussian maps. An observation that became already apparent in the very early stages of the project is that such a transition from quantum hardness to classical simulability strongly depends on the specific form of the noise. It is therefore central to understand how to quantify the noise in a quantum circuit given by a quantum channel $\mathcal{N}$. The quantum capacity of a channel is the rate at which quantum information can be transmitted through the channel without incurring loss. The capacity serves as the universally accepted quantity to establish the noise and information loss in noisy quantum processes. Our effort therefore focused first on quantifying the noise in the quantum circuit.

Characterisation of noise in terms of the quantum capacity: The question of whether noise introduced by a quantum channel $\mathcal{N}$ can be dealt with by means of introduction of suitable redundancy (error-correcting codes, encoding maps and decoders, as well as protected logical gates) takes a particularly elegant form when the computation to be performed is simply given by a qudit identity map. Such a "trivial" computation is highly non-trivial to achieve experimentally, and raises challenging mathematical questions. In an asymptotic setting, the usefulness of a quantum channel $\mathcal{N} : \mathcal{B}(\mathcal{H}_A) \to \mathcal{B}(\mathcal{H}_B)$ for achieving such a "quantum memory simulation" is simply given by its quantum (information-carrying) capacity $Q(\mathcal{N})$ (defined operationally). The Lloyd-Shor-Devetak theorem [3, 4, 5] provides a formula for this quantity in terms of the coherent information, i.e.,

$$Q(\mathcal{N}) = \limsup_{n\to\infty} I_c(\mathcal{N}^{\otimes n}) \qquad \text{where} \qquad I_c(\mathcal{N}) = \max_{\rho_A} S(\mathcal{N}(\rho_A)) - S(\mathcal{N}^c(\rho_A)) \ , \tag{1}$$

and where $\mathcal{N}^c$ is a complementary channel (defined using an isometric extension of $\mathcal{N}$). The quantity $Q(\mathcal{N})$ gives a clear measure of how detrimental the noise $\mathcal{N}$ is for quantum information-processing. In particular, any upper bound $Q(\mathcal{N})$ indicates a noise regime where coherence (for a system dimension determined by the rate) cannot be maintained because of the noise $\mathcal{N}$. However, it is well known that the evaluation of the regularised coherent information, and therefore the only known expression for the quantum capacity is not feasible in general.

Problem statement : The quantity $Q(\mathcal{N})$ cannot be evaluated in closed form for general quantum channels $\mathcal{N}$ because of the regularisation appearing in its definition. Its evaluation "single-letterises" only in cases where the coherent information is additive, i.e., for channels $\mathcal{N}_1, \mathcal{N}_2$ such that

$$I_c(\mathcal{N}_1 \otimes \mathcal{N}_2) = I_c(\mathcal{N}_1) + I_c(\mathcal{N}_2) \ . \tag{2}$$

However, the addivity property (2) does not hold in general: *"superactivation"* is the striking phenomenon that there are channels $\mathcal{N}_1$ and $\mathcal{N}_2$ for which $Q(\mathcal{N}_1) = Q(\mathcal{N}_2) = 0$ yet $Q(\mathcal{N}_1 \otimes \mathcal{N}_2) > 0$: here (2) is violated [6].

Given the difficulty of evaluating (1), it is natural to ask for bounds on $Q(\mathcal{N})$. Here we are interested in upper bounds that are easily computable and do not involve a regularisation. More specifically, our goal can be phrased as follows: find functionals f of quantum channels such that

$$Q(\mathcal{N}) \leq f(\mathcal{N}) \qquad \text{for any channel } \mathcal{N} \ , \tag{3}$$

i.e., f provides (an ideally non-trivial) upper bound on the quantum capacity $Q(\mathcal{N})$, and

$$f(\mathcal{N}_1 \otimes \mathcal{N}_2) = f(\mathcal{N}_1) + f(\mathcal{N}_2) \qquad \text{for any two quantum channels } \mathcal{N}_1, \mathcal{N}_2 \ . \tag{4}$$

Outcomes and achievements

Methodology: The discussion during our stay at ESI was focused on formulating and identifying an approach towards obtaining and classifying strong, novel upper-bounds. We have been able to execute the first significant steps in this program. We have devised an approach to obtain entropic bounds on the quantum capacity satisfying our constraints. In pioneering work, Cross, Li and Smith [7] characterised a certain subset of functionals satisfying the additivity property (4): They constitute a set called the *uniform additivity polytope*. Likewise, we have derived a characterisation of a polytope to identify good upper bounds on the quantum capacitity. A crucial tool hereby has been the strong subadditivity property of the von Neumann entropy.

It is possible to define this polytope following the approach by Yeung in classical information theory [9] and pioneered by Pippenger in the quantum context [10]. Using these polytopes, we obtain a systematic way of generating new upper bounds on the quantum capacity in the form of polytopes in the space of generalised information measures. To identify "good" candidate upper bounds on the quantum capacity, we have devised specific instances where we can evaluate the deviation from the quantum capacity and determine the strength of the bounds. A systematic search for upper bounds on $Q(\mathcal{N})$ has already led to at least one particularly interesting quantity satisfying all our criteria; to our knowledge, the corresponding quantity has not been considered before in quantum information theory. We are currently studying the implications of this result. Furthermore, we plan to systematically consider more general cases. In this case, the search should reproduce one of the known additive upper bounds on the quantum capacity, the symmetric side-channel assisted capacity [11]. We think that identifying this quantity (and possibly others) would provide a good validation of the approach taken here.

Publications and preprints contributed

At present, this is still work in progress, but we expect it to result in a publication in the near future.

References

[1] A. A. Razborov, *An upper bound on the threshold quantum decoherence rate*, arXiv preprint quant-ph/0310136, 2003.

[2] J. Kempe, O. Regev, F. Uunger, and R. de Wolf, *Upper bounds on the noise threshold for fault-tolerant quantum computing*, Quantum Information & Computation **10** (2010), no. 5 361–376.

[3] S. Lloyd, *Capacity of the noisy quantum channel*, Phys. Rev. A **55**, Mar, (1997), 1613–1622.

[4] P. Shor, *The quantum channel capacity and coherent information*, 2002.

[5] I. Devetak, *The private classical capacity and quantum capacity of a quantum channel*, IEEE Transactions on Information Theory **51** (2005), no. 1 44–55.

[6] G. Smith and J. Yard, *Quantum communication with zero-capacity channels*, Science **321** (2008), no. 5897 1812–1815.

[7] A. Cross, K. Li, and G. Smith, *Uniform additivity in classical and quantum information*, Phys. Rev. Lett. **118** (Jan, 2017) 040501.

[8] M. A. Alhejji and G. Smith, *Monotonicity under local operations: Linear entropic formulas*, IEEE Transactions on Information Theory **66** (2020), no. 8 5055–5060.

[9] R. Yeung, *A framework for linear information inequalities*, IEEE Transactions on Information Theory **43** (1997), no. 6 1924–1934.

[10] N. Pippenger, *The inequalities of quantum information theory*, IEEE Transactions on Information Theory **49** (2003), no. 4 773–789.

[11] G. Smith, *Private classical capacity with a symmetric side channel and its application to quantum cryptography*, Phys. Rev. A **78** (Aug, 2008) 022306.

Research in Teams Project 2: Amplitude Evolution I: Initial State Evolution

Collaborators: Jeffrey Forshaw (U Manchester), Patrick Kirchgässer (Lund U), Maximilian Löschner (Karlsruher IT), Simon Plätzer (U Graz / U Vienna)

Dates: August 23 - September 17, 2021

Budget: ESI € 3 280

Report on the project

Scientific Background

Precise quantum field theory calculations need to re-arrange the perturbative series to include logarithmically enhanced terms to all perturbative orders. For gauge theories like the strong interactions described by Quantum Chromodynamics (QCD), this re-summation can be carried out thanks to universal properties of infrared divergences. These divergences occur in the limits of low-energy or (quasi-)collinear emission of additional partons, the fundamental quarks and gluons, and cancel against universal singularities from loop corrections, leading to a logarithmic enhancement in infrared sensitive observables which probe final state jets of hadrons – bound systems of quarks and gluons – emerging from parton radiation. Parton branching at the amplitude level (PBAL) [1, 2] is based on a direct analysis of QCD scattering amplitudes and has proven to provide a powerful framework to improve existing resummation algorithms and event generator simulations. It also provides an entirely new paradigm and a method in its own right to address parton evolution beyond the limit of a large number of colour charges, and including quantum mechanical interference from a first-principles approach. Recent work in this context has mainly been focusing on final state radiation of gluons with an energy much less than the typical momentum transfers (so-called "soft" gluons).

Project aims and scope

The main aim of the present project was to extend PBAL to include higher-order branching kernels of collinear origin, the evolution of initial state partons, and to possibly address the physics of multi-parton interaction in between many constituents of protons or ions entering a high energy collision.

Outcomes and achievements

One of the central activities of the programme actually concerned the systematic derivation of parton branching amplitudes which cover many different soft and collinear limits. This understanding is key to address the initial state evolution, and to extend the final state evolution beyond the physics of soft gluons and single-emission collinear branchings. In collaborative work finalised within the research teams we have achieved this within a general formalism which will impact the further development of PBAL beyond leading order and beyond final state radiation, with a publication currently under review by the *Journal of High Energy Physics* (JHEP)[3]. The question of how a physical initial and final state of the collision is defined, and how this definition enters in the evolution is equally relevant to address final state structures beyond jets. We have extensively worked on this question, with a preprint submitted to JHEP soon [4]. The findings reported in this paper might be immediately relevant to the physics of so-called super-leading logarithms and the breakdown of QCD coherence [5]. The latter is probably connected to multi-parton interactions, which have been addressed during the program in the numerical `CVolver` simulation [6], which has been extended to cover processes with incoming partons and the physics of the JIMWLK evolution equation [7]. Work is in progress to summarise the results in upcoming publications.

Publications and preprints contributed

Two main publications have been moved to their final stages in the course of the programme (all submitted to JHEP):

M. Löschner, S. Plätzer and E. S. Dore, *Multi-Emission Kernels for Parton Branching Algorithms*, arXiv:2112.14454 [hep-ph].

S. Plätzer, *Colour Evolution and Infrared Physics*, arXiv:2204.06956 [hep-ph].

Though Prof. Forshaw could not attend the programme in person due to the pandemic, we have actually also finalised significant parts of the following work (which, topically, rather belongs to the sibling prgramme "Amplitude Evolution II", see this report):

J. R. Forshaw, J. Holguin and S. Plätzer, *Rings and strings: a basis for understanding subleading colour and QCD coherence beyond the two-jet limit*, arXiv:2112.13124 [hep-ph].

References

[1] R. Ángeles Martínez, M. De Angelis, J. R. Forshaw, S. Plätzer and M. H. Seymour, *Soft gluon evolution and non-global logarithms*, JHEP **05** (2018), 044, doi:10.1007/JHEP05(2018)044 [arXiv:1802.08531 [hep-ph]].

[2] J. R. Forshaw, J. Holguin and S. Plätzer, *Parton branching at amplitude level*, JHEP **08** (2019), 145 doi:10.1007/JHEP08(2019)145 [arXiv:1905.08686 [hep-ph]].

[3] M. Löschner, S. Plätzer and E. S. Dore, *Multi-Emission Kernels for Parton Branching Algorithms*, [arXiv:2112.14454 [hep-ph]].

[4] S. Plätzer, *Colour Evolution and Infrared Physics*, [arXiv:2204.06956 [hep-ph]].

[5] J. R. Forshaw and J. Holguin, *Coulomb gluons will generally destroy coherence*, JHEP **12** (2021), 084 doi:10.1007/JHEP12(2021)084 [arXiv:2109.03665 [hep-ph]].

[6] M. De Angelis, J. R. Forshaw and S. Plätzer, *Resummation and Simulation of Soft Gluon Effects beyond Leading Color*, Phys. Rev. Lett. **126** (2021) no.11, 112001 doi:10.1103/PhysRevLett.126.112001 [arXiv:2007.09648 [hep-ph]].

[7] J. Jalilian-Marian, A. Kovner, A. Leonidov and H. Weigert, *The Wilson renormalization group for low x physics: Towards the high density regime*, Phys. Rev. D **59** (1998), 014014 doi:10.1103/PhysRevD.59.014014 [arXiv:hep-ph/9706377 [hep-ph]].

Research in Teams Project 3: Amplitude Evolution II: Cracking Down on Colour Bases

Collaborators: Judith Alcock-Zeilinger (U Tübingen), Malin Sjödahl (Lund U), Stefan Keppeler (U Tübingen), Simon Plätzer (U Vienna)

Dates: September 13 - 24, 2021

Budget: ESI € 880

Report on the project

Scientific Background

This programme is a sibling programme of "Amplitude Evolution I", (see this report) and shares the same background. Its main focus is, however, more on the group-theoretical aspects of parton branching at the amplitude level (PBAL), which are needed to uncover the theoretical structures as well as efficient algorithms for numerical simulation.

Project aims and scope

The original aim of the project was to use multiplet bases [6], a set of $SU(N)$ tensor structures forming high-degree irreducible representations, to express the underlying structures such as anomalous dimensions, emission kernels, and density operators appearing in PBAL. These should then also be used to identify how physical measurements need to be translated to the computationally more handy colour flow basis [1, 2] used in the `CVolver` simulation[3].

Outcomes and achievements

Due to the pandemic and other unforeseen reasons, unfortunately neither Dr. Alcock-Zeilinger nor Dr. Keppeler could take part in the programme in person. Both have attended several online meetings though and the programme has yet achieved significant steps towards its main goal, though no results are publicly available yet. During the programme we have also made significant progress on related aspects of spin structure and electroweak interactions in PBAL [5]. Also, the structure of contributions suppressed by the number of colour charges in QCD has been uncovered from a new point of view, as already advertised in the report on the sibling programme[4].

Publications and preprints contributed

Two publications have been prepared with significant contributions achieved during the program:

J. R. Forshaw, J. Holguin, S. Plätzer, *Rings and strings: a basis for understanding subleading colour and QCD coherence beyond the two-jet limit*, arXiv:2112.13124 [hep-ph] (submitted to JHEP).

S. Plätzer, M. Sjodahl, *Amplitude Factorization in the Electroweak Standard Model*, arXiv:2204.03258 [hep-ph] (submitted to PRL).

References

1. S. Plätzer, *Summing Large-N Towers in Colour Flow Evolution*, Eur. Phys. J. C **74** (2014) no.6, 2907 doi:10.1140/epjc/s10052-014-2907-2 [arXiv:1312.2448 [hep-ph]].
2. S. Plätzer and I. Ruffa, *Towards Colour Flow Evolution at Two Loops*, JHEP **06** (2021), 007, doi:10.1007/JHEP06(2021)007 [arXiv:2012.15215 [hep-ph]].
3. M. De Angelis, J. R. Forshaw and S. Plätzer, *Resummation and Simulation of Soft Gluon Effects beyond Leading Color*, Phys. Rev. Lett. **126** (2021) no.11, 112001, doi:10.1103/ PhysRevLett.126.112001 [arXiv:2007.09648 [hep-ph]].
4. J. R. Forshaw, J. Holguin and S. Plätzer, *Rings and strings: a basis for understanding subleading colour and QCD coherence beyond the two-jet limit*, [arXiv:2112.13124 [hep-ph]].
5. S. Plätzer and M. Sjodahl, *Amplitude Factorization in the Electroweak Standard Model*, [arXiv: 2204.03258 [hep-ph]].
6. S. Keppeler and M. Sjodahl, *Orthogonal multiplet bases in SU(Nc) color space*, JHEP **09** (2012), 124 doi:10.1007/JHEP09(2012)124 [arXiv:1207.0609 [hep-ph]].

Research in Teams Project 3/2020: ℓ-modular Langlands Quotient Theorem and Applications

Collaborators: Robert Kurinczuk (Imperial College London), Nadir Matringe (U of Paris), Alberto Mínguez (U of Vienna), Vincent Sécherre (Versailles U)

Dates: September 12 – 27, 2020, June 2 - July 4, 2021, September 19 – October 1, 2021 and October 10 – 14, 2021, Mai 27 - June 10, 2022, one further stay in autumn 2022

Budget: ESI € 7 200

Report on the project

The aim of our project was to establish a modular analogue of the Langlands quotient theorem for p-adic GL_n. Because of the sanitary situation all members could not be present at the same time, which led to three related but distinct projects.

Scientific Background

This project fits into the ℓ-modular Langlands program, initiated by M.-F. Vignéras at the intersection of number theory and representation theory of reductive groups over local fields and adeles of global fields. The modular local Langlands program in particular aims to understand if the ℓ-adic LLC (Local Langlands Correspondence, known for classical groups including GL_n) preserves integrality, and then congruences between integral representations. Some parts of our project exactly fits into this picture, namely preservation of integrality and congruences under some important correspondences and functorialities of the Langlands pogramme. On the other hand, the fundamental Langlands quotient theorem for ℓ-adic representations of reductive p-adic groups (which is always part of the proof of the LLC when established) states that any irreducible representation of such a group is the unique irreducible quotient of a unique standard module. An analogue of such a theorem in the modular case is a very subtle (and long standing) question, which is not only hard to prove, but also very difficult to state as there is no obvious analogue of standard modules modulo ℓ.

Project aims and scope

The project, initially addressing a modular version of the Langlands quotient theorem for the general linear group over a p-adic field, has evolved in three directions. The first is the initial one, the modular Langlands quotient Theorem, and involves N. Matringe and A. Mínguez. The second is preservation of congruences under functoriality from classical groups to GL_n involving A. Mínguez and V. Sécherre. The third direction, involving R. Kurinczuk and A. Mínguez, is concerned with preservation congruences under the Howe correspondence. All three projects are central problems in the field of modular representation theory of p-adic groups, and each progress will lead with no doubt to important publications in the field.

The modular Lanlglands quotient theorem for GL_n

During Matringe's visit, Matringe and Mínguez worked on the following projects. By Vignéras and Mínguez-Sécherre, the modular representations of p-adic GL_n are parametrised by aperiodic multisegments (see [6]), and we denote by $\mathfrak{m} \mapsto Z(\mathfrak{m})$ this parametrisation. In [5] Kurinczuk and Matringe defined a class of modular Galois parameters called C- parameters, which can also be naturally parametrised by aperiodic multisegments thanks to Vignéras semi-simple LLC ([7]): we denote by $\mathfrak{m} \to C(\mathfrak{m})$ this parametrisation. They also gave a bijection $\pi \to C(\pi)$ between irreducible representations of p-adic GL_n and C-parameters, preserving local factors for generic representations (see [4] and [5]). Firstly, we will associate to each aperiodic multisegment $\mathfrak{m}$ an essentially AIG representation $S(\mathfrak{m})$ in the sense of Emerton-Helm, and we will prove that this representation has a unique irreducible quotient equal to $L(\mathfrak{m}) := Z(\mathfrak{m})^*$ where * stands for the ℓ-modular Aubert-Zelevinsky involution. The representation $S(\mathfrak{m})$ will be defined as an intersection of a finite number of essentially AIG representations, each of which obtained as the reduction modulo ℓ of a certain lattice in an ℓ-adic standard module attached to a multisegment lifting $\mathfrak{m}$.

Secondly, we will prove that $C(\mathfrak{m}) = C(L(\mathfrak{m}))$ for any aperiodic cuspidal multi-segment, and from this we will deduce that the correspondence C defined in [5] preserves local constants not only for generic, but for all irreducible representations.

Functorial lifting for classical groups

V. Sécherre came to ESI three times to work with A. Mínguez on the project *Congruence properties of the local functorial lifting for classical groups*. Given two congruent ℓ-adic discrete series representations of a classical (that is, symplectic, special orthogonal or unitary) p-adic group, this project aims at describing the congruence properties of their functorial lifts to the corresponding general linear group (see [1], [3]).

This project has been divided into three steps: (1) Globalisation, (2) Global transfer and (3) ℓ-modular strong multiplicity 1.

The Howe correspondence and congruences

R. Kurinczuk visited the ESI in autumn 2021 to work on the following with A. Mínguez. Let $(\mathrm{G}, \mathrm{G}')$ be a *dual pair* of classical p-adic groups in a p-adic symplectic group $\mathrm{Sp}(W)$. Write $\mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(\mathrm{G})$ for the set of irreducible representations of G. We denote by θ the *Howe correspondence* (see [2], [8]) which associates to a representation $\pi \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(\mathrm{G})$ either the zero representation, or an element $\theta(\pi) \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(\mathrm{G}')$. The representation $\theta(\pi)$ is by definition the unique irreducible quotient of the big Θ-lift $\Theta(\pi)$ for $\pi \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(\mathrm{G})$ (where by abuse of language $\{0\}$ is the unique irreducible quotient of $\{0\}$ only).

Write $\mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(\mathrm{G})$ for the subset of integral representations of G. Kudla's work allows Kurinczuk and Mínguez to deduce that if $\pi \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(\mathrm{G})$ and $\Theta(\pi) \neq 0$, then $\theta(\pi) \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(\mathrm{G}')$.

Naive Conjecture 0.1 *Let* $\pi_1, \pi_2 \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(\mathrm{G})$ *and* $\theta : \mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(\mathrm{G}) \to \mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(\mathrm{G}')$ *denote the Howe correspondence for the dual pair* $(\mathrm{G}, \mathrm{G}')$. *Then* $\pi_1 \equiv \pi_2[\ell] \Rightarrow \theta(\pi_1) \equiv \theta(\pi_2)[\ell]$.

This turns out to be false in general, and they built counterexamples with one-dimensional and three dimensional unitary groups using that the "first occurrence indices" $\mu_{\min}(\pi_1)$ and $\mu_{\min}(\pi_2)$ of congruent integral representations π_1 and π_2 are not in general the same, and compatibilities with parabolic induction. Thus one needs to add hypotheses (for example $\mu_{\min}(\pi_1) = \mu_{\min}(\pi_2)$) or ask for a weaker conclusion.

Naive Conjecture 0.2 *Let* $\pi_1, \pi_2 \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(\mathrm{G})$ *(and suppose* G' *lies above the first occurence isometry groups for* π_1 *and* π_2 *in its Witt tower). Then* π_1 *and* π_2 *are in the same block mod* $\ell \Rightarrow$ $\theta(\pi_1)$ *and* $\theta(\pi_2)$ *are in the same block mod* ℓ.

The plan is now to study both naive conjectures using results of Kudla to reduce to the supercuspidal case, results of Loke–Ma (for p large enough) to reduce to an analogous question for finite groups, which they plan to study using Pan's parameterisation of the finite Howe correspondence and known compatibilities between Lusztig's classification and Brauer theory.

Outcomes and achievements

During Matringe's visit, Matringe and Mínguez defined modular standard modules, and checked the Langlands quotient conjecture for GL_2 and GL_3. They also entirely resolved the conjecture on preservation of local constants under the C-correspondence in the important case of standard Artin local constants (i.e. for the pair $(\mathrm{GL}_n, \mathrm{GL}_1)$).

During the first two stays of Sécherre at ESI, Mínguez and Sécherre focused on the first two steps, relying on previous works of Scharlau (globalisation of quadratic and Hermitian forms), Taibi (global functorial lift for inner forms of classical groups that are compact at infinity) and Khare-Vignéras (double globalisation process). These first two steps are now almost completely achieved. During the last stay at ESI, they focused on the third step, aiming at adapting the classical argument of Piatetski-Shapiro to our ℓ-adic setting. They are currently encountering convergence issues of a Fourier transform in this third step, which once solved will finish the project.

Kurinczuk and Mínguez during Kurinczuk's stay formulated questions and a strategy to study the "theta correspondence and congruences". They established the first naive conjecture in the very special case of "ℓ-regular" supercuspidals (with p large enough) in the equal rank symplectic-orthogonal Howe correspondence. This general cases will be the subject of another visit.

Publications and preprints contributed

In preparation

References

[1] J. Arthur, *The endoscopic classification of representations. Orthogonal and symplectic groups*, American Mathematical Society Colloquium Publications, 61. American Mathematical Society,

Providence, RI, 2013.

[2] W.-T. Gan, S. Takeda, *A proof of the Howe duality conjecture*, J. Amer. Math. Soc. 29 (2016), no. 2, 473–493.

[3] C.P. Mok, *Endoscopic classification of representations of quasi-split unitary groups*, Mem. Amer. Math. Soc. 235 (2015), no. 1108.

[4] R. Kurinczuk, N. Matringe, *Rankin-Selberg local factors modulo ℓ*, Selecta Math. (N.S.) 23 (2017), no. 1, 767-811

[5] R. Kurinczuk, N. Matringe, *The ℓ-modular local Langlands correspondence and local constants*, J. Inst. Math. Jussieu 20 (2021), no. 5, 1585-1635.

[6] A. Mínguez, V. Sécherre, *Représentations lisses modulo-ℓ de GLm(D)*, Duke Math. J. 163 (2014), no. 4, 795-887.

[7] M.-F. Vignéras, *Correspondance de Langlands semi-simple pour GL(n,F) modulo $\ell \neq p$*, Invent. Math. 144 (2001), no. 1, 177-223.

[8] J.-L. Waldspurger, *Démonstration d'une conjecture de dualité de Howe dans le cas p-adique, $p \neq 2$*, 267-324, Israel Math. Conf. Proc., 2, Weizmann, Jerusalem, 1990.

Research in Teams Project 4: Blackbody Radiation induced inertial Effects and collective Phenomena - Theoretical Basis and Experimental Feasibility - Part 4

Collaborators: Philipp Haslinger (TU Vienna), Francesco Intravaia (Humboldt University Berlin), Dennis Rätzel (Humbolt University Berlin), Matthias Sonnleitner (U Innsbruck)

Dates: February 25 – March 1, 2019, June 2 – 8, 2019, November 18 – 22, 2019, September 23 – 24, 2021

Budget: ESI € 2 480

Report on the project

Scientific Background

Blackbody radiation is omnipresent. It is emitted by objects at finite temperature with an outward energy-momentum flow, which exerts an outward radiation pressure. For example, in a radiation field at room temperature, a caesium atom would scatter less than one thermal photon every 10^8 years on average. Thus, it is generally assumed that any scattering force exerted on atoms by such radiation is negligible. In 2013, Sonnleitner et al. theoretically predicted that particles should also interact coherently with the thermal electromagnetic field due to their polarisability [2]. This can lead to a surprisingly strong force that is attractive in contrast to radiation pressure. This prediction has sparked a hot debate in the related scientific community.

The quantum mechanical phase of massive particles enables us to sense accelerations and potential energy differences with unprecedented accuracy using matter-wave interferometry. Atoms provide nearly perfect test-particle properties as they can be selected isotopically pure, cooled down to nano-Kelvin temperatures, and have well understood and easily tunable magnetic and electric properties. Atom interferometric methods have been used to measure local gravity, gravitational gradients, the gravitational constant, and the fine-structure constant. Furthermore, atom interferometry has been employed to test the universality of free fall and to search for dark energy. Due to recent experimental improvements in the Müller group at UC Berkeley, Philipp Haslinger and coworkers reached the needed sensitivity to search for the theoretically predicted attractive blackbody radiation force using an optical cavity enhanced atom interferometer. The observed force [1] agrees perfectly with the theoretical predictions of Sonnleitner et al. [2].

Blackbody radiation also induces a thermal friction force on neutral particles, which is related to the Einstein-Hopf drag on harmonic oscillators in thermal baths. The thermal friction force exists independently of any gradient of the radiation field. In analogy to the velocity-independent case, inhomogeneities in the radiation in space modify the frictional force, in particular when the atom moves near macroscopic objects.

Most of the effects described above apply to individual atoms interacting with external (thermal) radiation. However, a dense ensemble of atoms will react to external radiation in unison and this gives way to collective effects. For atoms or (sub-)micron-sized scatterers, interparticle effects, such as optical binding, have been studied mostly using coherent laser beams. Recently, in addition to van der Waals/Casimir-Polder forces, artificial dispersion forces generated by random fields have become a focus of growing interest. In general, the low polarisability of individual atoms makes it difficult to measure collective motional effects without a cavity or other setups. One therefore usually expects that intense fields are required to generate measurable effects such as self-organisation or deformation of a trapped atomic cloud. However, the improvements achieved in the experimental techniques involving atom-interferometry and the present ability of creating and controlling very dense clouds, can be used to measure light induced dipole-dipole interactions with a high degree of precision and accuracy also in weak radiation fields.

Project aims and scope

The focus of this project is to derive the results of Haslinger et al. [1] with the elaborate and highly accurate quantum field theoretical methods of the Casimir-Polder force community represented by Francesco Intravaia in this collaboration [3]. The comparison to the results of Sonnleitner et al. [2] is expected to lead to a common theoretical basis for the description of the effect and, consequently, to the resolution of present disagreements. Furthermore, an advantage of the methods used by the Casimir-Polder force community is that the material properties of the sources of thermal radiation are taken into account from first principles and do not need, as it is done presently, to be introduced by hand later. Also, retardation and distance dependence are treated explicitly in that framework. Therefore, the significance of the increased accuracy can be evaluated by comparison to the geometrical approach of Sonnleitner et al. [2].

Since the attractive blackbody radiation force dominates for a large temperature range over both gravity and radiation pressure, it may significantly affect the ultimate accuracy of atom interferometric metrology (as it already does for optical clocks), and it may have implications for astrophysical scenarios. Therefore, a high accuracy of theoretical predictions is desirable, which could be supplied by the theoretical framework that is being developed during this project. Based on the insights from the theoretical work, further experiments to investigate the attractive blackbody radiation force are being considered.

Another goal of this project is to evaluate the feasibility of an experimental detection of (thermal) frictional forces using interferometric methods. We are estimating the strength of the frictional force for different experimental configurations and the feasibility of its measurement as well as its relative size compared to other interactions present in the system. During this project, we are developing new experimental proposals to measure the predicted thermal friction and a possible accelerating thermal force due to the dynamical Stark shift.

We are also developing the theoretical and experimental tools to investigate inter-atomic forces induced by blackbody radiation using atom-interferometry.

Outcomes and achievements

Due to the Covid-19 pandemic, this project was not continued as planned in 2020 and 2021 and has not finished yet. Therefore, only intermediate results can be reported here.

The theoretical description of the effect highlighted in Ref. [2] and experimentally measured in Ref. [1] is being developed mostly by Francesco Intravaia and his student Daniel Reiche. Results are likely to be presented and discussed during the RIT meetings in 2022. Recently, they have also co-authored a perspective paper reviewing the physics of the frictional interaction between objects in relative motion [4].

During the first RIT meetings, estimates where made of the size of the effects of frictional forces on moving cold atoms in vacuum or a thermal field. Discussions between the theoreticians and the experimentalist Philipp Haslinger showed that their detection is challenging. Further considerations will also involve nano-particles instead of atoms and elaborate geometries and material properties to enhance the effects significantly. This is planned for the upcoming meetings in 2022.

Philipp Haslinger, Matthias Sonnleitner and Dennis Rätzel are participating in a project in collaboration with Jörg Schmiedmayer at the Atominstitut, TU Wien, to test for black-body-radiation-induced collective effects in cold atomic clouds. The experimental setup is capable of producing very dense and ultra-cold atomic samples (Rb-BEC), and it is highly sensitive to measure potential energy differences between the separated atomic wave functions. It is a perfect testbed to sense for blackbody-radiation induced interactions. During this RIT project, Matthias Sonnleitner derived a full theoretical description for the experiments and predicted an attractive force between the atoms that should be visible in the experiments. This effort was supported by Matthias Sonnleitner regularly reporting and discussing his results at the RIT meetings with the three collaborators. A preprint of this work has been published on the arXiv-server [5].

Discussions during the first meetings also involved the project "Quantum Klystron" by Philipp Haslinger and Dennis Rätzel which was reported on in a paper in Physical Review Research [6]. At the last meetings, we also discussed with Stefan Nimmrichter, Uni Siegen, diffraction effects of atoms by blackbody-radiation retro-reflected from a nearby mirror. Atoms whose internal resonances define the best-known frequency standards filter out most of the blackbody-radiation and interact mainly with structured light (standing waves due to retro-reflection) near their resonances. At the moment, some of us are preparing a paper to present the results of this research.

Publications and preprints contributed

D. Reiche, F. Intravaia and K. Busch, *Wading through the void: Exploring quantum friction and nonequilibrium fluctuations*, arXiv preprint arXiv:2112.12195, 2021.

M. Maiwöger, M. Sonnleitner, T. Zhang, I. Mazets, M. Mallweger, D. Rätzel, F. Borselli, S. Erne, J. Schmiedmayer, P. Haslinger, *Observation of Light-Induced Dipole-Dipole Forces in Ultracold Atomic Gases* , arXiv preprint arXiv:2202.00562, [cond-mat.quant-gas], 2022.

D. Rätzel, D. Hartley, O. Schwartz, P. Haslinger, *Controlling Quantum Systems with Modulated Electron Beams*, Physical Review Research 3 (2021), 023247.s, https://doi.org/10.1103/PhysRevResearch.3.023247.

References

[1] P. Haslinger, M. Jaffe, V. Xu, O. Schwartz, M. Sonnleitner, M. Ritsch-Marte, H. Ritsch, H. Müller, *Attractive force on atoms due to blackbody radiation*, Nature Physics, 14, 3, (2018) 257–260.

[2] M. Sonnleitner, M. Ritsch-Marte, H. Ritsch, *Attractive optical forces from blackbody radiation*, Physical Review Letters, 111, 2, 023601, (2013)

[3] F. Intravaia, C. Henkel, and M. Antezza. *Fluctuation-Induced Forces Between Atoms and Surfaces: The Casimir-Polder Interaction*, volume **834** of Lecture Notes in Physics, 345 (Springer, Berlin / Heidelberg), 2011.

Research in Teams Project 2/2020: Time-Frequency Analysis of Random Point Processes

Collaborators: Yacin Ameur (Lund U), Naomi Feldheim (Bar Ilan U), Antti Haimi (U of Vienna, Vienna), Günther Koliander (Austrian Academy of Sciences, Vienna), José Luis Romero (U of Vienna)

Dates: January 9 – 18, 2020, October 23 – 31, 2021 (second part), November 19 - 24, 2021 (third part)

(The schedule was significantly impacted by the covid pandemic.)

Budget: ESI € 1 680
We also kindly acknowledge support from the Austrian Science Fund Y 1199.

Report on the project

In time-frequency analysis a real-variable function or signal is studied by means of a two-dimensional representation, called the *short-time Fourier transform* (STFT). The STFT shows how the various oscillatory components of a signal evolve with time, much in analogy with a music score. Time-frequency analysis is at the core of audio processing and wireless communications, and is also the language of quantum physics. As such, time-frequency analysis finds the most diverse applications, including statistics and data analysis.

Random point processes are ubiquitous is statistical mechanics and have more recently attracted significant attention in data science.

This project explores interactions between time-frequency analysis and random point processes to derive new results in mathematical signal processing and statistical physics.

Scientific Background

We are mainly interested in the following random point processes

- Coulomb gases

The Coulomb gas consists of a large number of repelling point charges confined by an external potential. Particles follow the Boltzmann-Gibbs distribution and concentrate on a compact set known as droplet. One is interested in the statistical properties of the interacting particles as a function of the confining potential and the temperature. [C]

- Zeros of the short-time Fourier transform of a signal impacted by noise:

  It has been recently shown that the zero set of the STFT encodes rich information and exhibits a rather rigid pattern as soon as the analysed signal is impacted by even a moderate amount of noise. This insight has been successfully exploited in statistical signal processing by means of algorithms partially motivated by statistical mechanics. [A,B]

Project aims and scope

[O1] *Statistics of Coulomb gases at low temperature*
At very low temperatures the Coulomb gas is expected to exhibit a certain almost deterministic pattern; a so-called *freezing regime* emerges. We aimed to formally describe this phenomenon.

[O2] *Analysis of algorithms for the computation of zeros of the short-time Fourier transform*
The accurate computation of zeros of the short-time Fourier transform of an analog signal from finitely given data is challenging. Certain very effective algorithms have recently appeared in the signal processing literature, but our current understanding of them is only heuristic [B,C]. We aimed to derive formal and quantitative performance guarantees.

Outcomes and achievements

[O1] We proved results on the plane consistent with the intuition of a freezing regime for Coulomb gases. Specifically, under a mild freezing assumption, we showed that samples of the Coulomb gas are:

a) asymptotically separated in the sense that with growing probability there is a minimal distance between different points (with the appropriate scalings).

b) the random particles are equidistributed at microscopic scale, and their density is precisely given by the so-called equilibrium density (or half of it at the boundary of the droplet).

To prove these results, we investigated the condition number of the problem of interpolating univariate complex polynomials on a random sample of the Coulomb gas. More precisely, we showed that with high probability, a random sample of the Coulomb gas solves certain sampling and intepolation problems [1].

[O2] We studied the computation of the zero set of the Bargmann transform of a signal contaminated with complex white noise, or, equivalently, the computation of the zeros of its short-time Fourier transform with Gaussian window. We introduced the *adaptive minimal grid neighbors* algorithm (AMN), a variant of a method that has recently appeared in the signal processing literature, and proved that with high probability it computes the desired zero set. More precisely, given samples of the Bargmann transform of a signal on a finite grid with spacing δ, AMN was shown to compute the desired zero set up to a factor of δ in the Wasserstein error metric, with failure probability $O(\delta^4 \log^2(1/\delta))$ [2].

Further work on O1 and O2 is still in progress.

Publications and preprints contributed

[1] Y. Ameur and J. L. Romero. The planar low temperature coulomb gas: separation and equidistribution. *Revista Matemática Iberoamericana. To appear. ArXiv:2010.10179*.

[2] L. A. Escudero, N. Feldheim, G. Koliander, and J. L. Romero. Efficient computation of the zeros of the Bargmann transform under additive white noise. Preprint. *ArXiv:2108.12921*.

References

[A] R. Bardenet, J. Flamant, and P. Chainais. On the zeros of the spectrogram of white noise. *Appl. Comput. Harmon. Anal.*, 48(2):682–705, 2020.

[B] P. Flandrin. Time–frequency filtering based on spectrogram zeros. *IEEE Signal Processing Letters*, 22(11):2137–2141, 2015.

[C] Forrester, P. J., *Log-gases and random matrices*, Princeton 2010.

Research in Teams Project 5: Higher Global Symmetries and Geometry in (non-) relativistic QFTs

Collaborators: Athanasios Chatzistavrakidis (Ruder Bošković Institute, Zagreb, Croatia), Jan Rosseel (University of Vienna)

Dates: November 1 – December 22, 2021 and January 9 - February 6, 2022

Budget: ESI € 6 400
Croatian Science Foundation approx. € 700 (5 371 HRK)

Report on the project

Scientific Background

Quantum Field Theory (QFT) is the language of all physical phenomena in high energy and condensed matter physics. An important feature of QFTs is their global and local symmetry structure. In recent years, effort has been devoted to systematically describing symmetries that lead to conservation laws for currents that are higher degree differential forms. Such symmetries are called higher global symmetries and they are used to study dualities and the classification of phases in QFT. They have interesting geometric underpinnings and a close relation to higher *gauge* theories, which is a more widely studied topic of mathematical physics.

Like their ordinary counterparts, higher global symmetries can be spontaneously broken or gauged. For spontaneously broken ones, the Nambu-Goldstone bosons (NGBs) are not spin-0 fields but instead fields of higher spin. For example, the photon is a NGB of the broken global electric symmetry in Maxwell theory in this sense. Moreover, higher global symmetries often exhibit 't Hooft anomalies that (partially) prevent their gauging.

Higher global symmetries have also been uncovered recently in the non-relativistic context of condensed matter physics. This includes models of fractons and subdimensional particles, symmetry-protected immobile excitations that lead to the preservation of dipole or other multipole moments. An exciting development was the construction of nonrelativistic fractonic gauge theories that serve as models for this physical behaviour.

Project aims and scope

The scope of the project was to start developing a new viewpoint on higher global symmetries and their properties (such as their anomalies, their breaking and their gauging) in a general setting and understand the geometrical structures underlying them.

Our first goal was to provide answers to the following questions: (i) under which geometrical conditions does a higher global symmetry exist, and (ii) what is their relation to 't Hooft anomalies. In this respect, we planned to approach this problem not only in its generality but also through examples, studying these questions for specific non-linear theories, such as gauge field theories with additional scalar fields, Born-Infeld electrodynamics and the recently found ModMax theory of electromagnetism.

The second goal was to take a step towards understanding further the structure and geometry of *non-relativistic* QFTs with higher global symmetries. In this respect, we aimed at finding a systematic way to construct gauge theories with so-called subsystem symmetries building upon their structural similarity to relativistic tensor gauge theories. Another question was whether such non-relativistic QFTs can be supersymmetrised, especially in view of the fact that non-relativistic supersymmetry is an underdeveloped topic, in which the team members have previous experience and collaboration record.

Outcomes and achievements

The two main collaborators of the project have worked together in two directions during the visit. The first concerns nonrelativistic gauge theories with subsystem symmetries, for example fracton gauge theories. This work started with a joint effort to understand the recent relevant literature and single out open problems and possible new research directions. Realising that the variety of models that exhibit subsystem symmetries are related to tensor gauge theories (often for higher spin fields), we began exploring whether a common relativistic origin for different types of such theories can be found. This is an ongoing project, which starts from theories such as linearised general relativity, generalized gauge theories for mixed symmetry tensor fields and Fronsdal theory for higher spins and uses a systematic truncation method to construct gauge invariant nonrelativistic theories with fractonic or higher gauge symmetries. This work will result in a joint publication, which is currently under preparation.

A second direction which the two collaborators have pursued, this time together with a PhD student (G. Karagiannis) and a postdoc (A. Ranjbar) from RBI in Zagreb, regards two intriguing questions: (a) does linearised gravity have a 't Hooft anomaly? and (b) can a spin-2 particle (e.g. the graviton) be viewed as a NGB? These questions are strongly related to the previously described work but they can also be independently posed and answered. Regarding the 't Hooft anomaly, one recalls that at the linearised level, gravity has a electric/magnetic duality symmetry, exchanging the graviton with the so-called dual graviton in any dimension. A careful study of the shift symmetries of spin-2 fields reveals that indeed there exist two different dual currents and a mixed 't Hooft anomaly between the corresponding higher symmetries. Moreover, there are clear indications that when such symmetries are spontaneously broken, then the graviton appears as the NGB. The latter statement can be confirmed by calculating the behaviour of the vacuum expectation value of loop operators in the theory. This project is also ongoing and we expect to have a joint publication on it in due time.

Aside from the above joint works, the two members of the project have contributed independently in project-related goals that resulted in two published articles and two arXiv preprints with ESI affiliation and/or acknowledgement to the project. Article [1] contains a study of the physical consequences of a potential gravitational θ-term in gravity with torsion. The main outcome is that such a term can modify the gravitomagnetic field around rotating bodies such as planets and lead to a potentially observable new component. We note that one of the collaborators (A. Ch.) gave a talk in the Mathematical Physics group meeting of the University of Vienna on this topic.

In [2], which is a precursor to our joint work described above and it is at the core of the project, the geometry of higher global symmetries was investigated. The main result is that any higher global symmetry can be interpreted as a generalised isometry along a graded Killing vector field on the jet space of a graded target space that encodes the fields of a given field theory. This is true not only for linear theories but also for a large class of nonlinear ones with higher derivatives, such as of Born-Infeld type or the "ModMax" conformal nonlinear electrodynamics.

In [3] T-duality in string theory is studied in a particular limit in which the compactification circle becomes lightlike. It has been argued that the T-dual theory is then given by non-relativistic string theory, i.e. a limit in which the string spectrum exhibits non-relativistic dispersion relations. In [3], this duality is studied from the viewpoint of the low energy effective equations of motion for the target space background fields that strings couple to and is used to derive the basic Neveu-Schwarz brane solutions of non-relativistic string theory.

Finally, in [4] the first example of a solution to the classical master equation for a 3D topological field theory with Wess-Zumino term and no QP structure on the target space was described in the framework of the Batalin-Vilkovisky formalism beyond the AKSZ construction.

Publications and preprints contributed

[1] A. Chatzistavrakidis, G. Karagiannis, G. Manolakos and P. Schupp, *Axion gravitodynamics, Lense-Thirring effect, and gravitational waves*, Phys. Rev. D **105** (2022) no.10, 104029, doi:10.1103/PhysRevD.105.104029, arXiv:2111.04388 [gr-qc].

[2] A. Chatzistavrakidis, G. Karagiannis and A. Ranjbar, *Duality, Generalized Global Symmetries and Jet Space Isometries*, Universe **8** (2021) no.1, 10, doi:10.3390/universe8010010, arXiv:2112.00441 [hep-th].

[3] E. Bergshoeff, J. Lahnsteiner, L. Romano and J. Rosseel, *The Supersymmetric Neveu-Schwarz Branes of Non-Relativistic String Theory*, arXiv:2204.04089 [hep-th].

[4] A. Chatzistavrakidis, N. Ikeda and G. Šimunić, *The BV action of 3D twisted R-Poisson sigma models*, arXiv:2206.03683 [hep-th]].

Senior Research Fellows Programme

To stimulate the interaction with the local scientific community the ESI offers regular lecture courses on an advanced graduate level. These courses are taught by Senior Research Fellows of the ESI. In exceptional cases this programme also includes long-term research stays of small groups or individual distinguished researchers. These lecture courses are highly appreciated by Vienna's students and researchers.

This year's programme covered the following online Lecture Course:

Pierre Germain: Soliton stability in nonlinear dispersive PDEs set on the line

Lecture Courses, Summer Term 2021:

Pierre Germain (Courant Institute, New York U):
Soliton stability in nonlinear dispersive PDEs set on the line
Lecture Course 250 072 VO: April 13 – June 1, 2021
Tuesday: 13:30 - 15:00

Course

This class provided an overview of the subject of soliton stability in dimension one. Solitons are fundamental objects in nonlinear wave equations, or nonlinear physics in general, and the question of their stability is the first one to ask. Much progress has been made since the 70's, but much remains to be done in this exciting field! The mathematical tools which come into play are nonlinear functional analysis and Fourier analysis.

The course was very well attended, between 20 and 30 students in average, who were very motivated and eager to participate - I always had many insightful questions, in spite of the virtual setup, which can discourage some students. The topics I covered were

- Introduction to nonlinear dispersie PDEs set on the line
- Local and global well-posedness
- Dispersive and Strichartz estimates
- Distorted Fourier transform
- Scattering for small solutions
- Orbital stability of solitons
- Asymptotic stability of solitons through improved local decay
- Asymptotic stability of solitons through resonances

Research

During my stay at ESI, I worked on the following projects

- Stability of kinks in nonlinear Klein-Gordon equations, in collaboration with F. Pusateri (Toronto).
- Boundedness of spectral projectors on Riemannian manifolds, in collaboration with T. Leger (Princeton) and S. Myerson (Warwick).
- Euler equation set on the sphere: orbital stability, Arnold's method, and bifurcation, in collaboration with A. Constantin (Vienna).

Publications and preprints contributed

P. Germain, T. Léger, *Spectral projectors, resolvent, and Fourier restriction on the hyperbolic space*, 2104.04126 [math.AP].

P. Germain, S. L. R. Myerson, *Bounds for spectral projectors on tori*, 2104.13274 [math.AP].

A. Constantin, P. Germain, *Stratospheric planetary flows from the perspective of the Euler equation on a rotating sphere*, arXiv:2109.08797 [math.AP].

Junior Research Fellows Programme

Francesco Cattafi (KU Leuven, WPI Vienna, JMU Würzburg): Cartan geometries via Pfaffian groupoids

Dates of stay: January 11 – May 11, 2021

Report

The history of Cartan geometries dates back to the pioneering studies of the XIX century on non-euclidean geometries, and to the famous Erlangen programme by Felix Klein. This layed the ground for Élie Cartan to define his *espaces généralisés*, i.e. abstract spaces modelled on a Klein geometry, which become locally flat under a suitable integrability condition, in the same way that Riemannian manifolds whose curvature vanish are locally the flat Euclidean model. In modern language, a **Cartan geometry** (P,θ) consists of a principal bundle P together with a vector-valued differential form θ satisfying certain connection-like properties [9].

I have developed myself a new approach to this topic by using **Lie groupoids**, i.e. more general versions of Lie groups with many unit elements and a partially defined multiplication. Indeed, a well-known construction establishes a 1-1 correspondence between principal bundles and *transitive* Lie groupoids. It is therefore natural to wonder if further structures on principal bundles, such as Cartan geometries, have a counterpart in the world of (transitive) Lie groupoids. This would allow one to solve a problem in one setting by translating it into an equivalent problem in the other setting.

In my paper [4] I have indeed proved a bijective correspondence between transitive *Pfaffian* Lie groupoids and a unifying class of structures (which I called Cartan bundles) on principal bundles, including as extreme cases Cartan geometries and G-structures. The notion of **Pfaffian groupoid** has been recently introduced to encode pseudogroups of symmetries [8] and differential equations on jet bundles [2], and was further developed in my PhD thesis [3] to solve an integrability problem. It consists of a Lie groupoid together with a special **multiplicative form** [5], i.e. a differential form compatible with the groupoid multiplication. In turn, multiplicative structures are well-established objects which have been crucial in the development of the modern Poisson geometry, and which are turning out to be useful in many other fields of geometry and mathematical physics [6].

During the first part of my stay at the ESI I have been exploring, in collaboration with Andreas Čap, various possible applications of Pfaffian groupoids to several aspects of Cartan geometries, as well as their relations with G-structures, their prolongations and deformations.

In particular, I have spent some time learning the general construction to prolong *filtered* G-structures to *parabolic* Cartan geometries, as this is the main source of examples for Cartan geometries which do not reduce to ordinary G-structures with connections [1].

I have therefore developed a theory of **filtered Pfaffian groupoids** and investigated their prolongations, with the aim of recovering the above construction in the transitive case and obtain new examples in the intransitive one.

While this approach gave us a clear direction and future conjectures to tackle, it also proved to be too hard to be faced in its full generality, due to several Lie-algebraic and representation-theoretic subtleties (which are not easily visible in the setting of Pfaffian groupoids, but are crucial for Cartan geometries).

Accordingly, in the second part of my stay at the ESI we have decided to focus on an important class of examples, namely **subriemannian structures on bracket-generating distributions**. Such example is general enough to include many interesting geometric structures (e.g. contact subriemannians structures) which have never been interpreted as Cartan geometries, but it is also simple enough to allow down-to-earth computations. Moreover, it will shed light on the general theory and help prove the conjectures mentioned above.

Any subriemannian structure on a bracket-generating distribution has a point-dependent invariant, its **symbol algebra**. When such algebra is constant at any point, one can construct a principal bundle and a Cartan connection with ordinary methods [7]; this can be equivalently described using *transitive* filtered Pfaffian groupoids.

The groupoid point of view becomes particularly convenient in the general case, when the symbol algebra is not constant, and the traditional approach with principal bundles is not effective. I was therefore able to describe explicitly the non-transitive Lie groupoid encoding such objects and its filtered Pfaffian structure. We are currently investigating the precise normalising conditions needed to complete the associated prolongation construction.

During my stay at the ESI I also benefitted from interactions with the research group of Andreas Čap, including his postdoc Christoph Harrach and his PhD students Zhangwen Guo and Michal Wasilewicz. I have also given a 6-hours minicourse for them, the topics of which included an introduction to Lie groupoids, Lie algebroids and their integrability, as well as their applications to Cartan geometries.

Last, while at the ESI, I continued working on my ongoing project with Luca Accornero (Universiteit Utrecht), which is related to Cartan geometries as well. Indeed, after adapting the notion of Morita equivalence to the context of Pfaffian groupoids, we were able to give a general definition of integrability for the Cartan bundle associated to a transitive Pfaffian groupoid which I described in [4]. On one extreme, this recovers the classical flatness for Cartan geometries, while on the other extreme we obtain a notion of integrability for G-structures, which takes into account a “twist” given by a Lie algebra $\mathfrak{h}$. For the Heisenberg Lie algebra, one obtains the integrability of almost-contact structures (which cannot be described by the standard theory). We are currently investigating intermediate examples between these extreme cases, and relating them with higher order G-structures.

Publications and preprints contributed

Currently in progress

References

[1] Andreas Čap, Jan Slovák, *Parabolic Geometries: Background and general theory*, American Mathematical Society, 2009.

[2] Francesco Cattafi, Marius Crainic, María Amelia Salazar, *From PDEs to Pfaffian fibration*, Enseign. Math. 66 (2020), no. 1-2, 187–250.

[3] Francesco Cattafi, *A general approach to almost structures in geometry*, PhD thesis, Universiteit Utrecht, 2020.

[4] Francesco Cattafi, *Cartan geometries and multiplicative forms*, Differential Geom. Appl. 75 (2021), 101722, 20 pp.

[5] Marius Crainic, María Amelia Salazar, Ivan Struchiner *Multiplicative forms and Spencer operators*, Math. Z. 279, 939–979, 2015

[6] Yvette Kosmann-Schwarzbach, *Multiplicativity, from Lie groups to generalized geometry*, Banach Center Publ., 110, Polish Acad. Sci. Inst. Math., Warsaw, 2016.

[7] Tohru Morimoto, *Cartan connection associated with a subriemannian structure*, Differential Geom. Appl. 26 (2008), no. 1, 75–78.

[8] María Amelia Salazar, *Pfaffian Groupoids*, PhD Thesis, Universiteit Utrecht, 2013.

[9] Richard W. Sharpe, *Differential Geometry: Cartan's generalisation of Klein's Erlangen program*, Springer-Verlag, 1997.

Paola Rioseco (CMM, Chile): Dynamics and Stabilities in the Accretion Disk of Relativistic Kinetic Gas Particles in Kerr Geometry

Dates of stay: September 1 – December 31, 2021

Report

The long term goal is to study aspects of the mathematical modelling of the accretion disk around a Kerr Black Hole using a relativistic kinetic gas.
One of the intermediate goals I am working on is to answer the following question:
Does the phase space mixing still drive a system such as an accretion to equilibrium if its self-gravity is taken into account? In order to solve this question, it is necessary to first explore the fixed background case considering the thick accretion disk and, parallelly, explore the self-gravity behaviour in a simpler model than the relativistic case (1 dim on space, 2 dim on phase space), where we consider the effects of the particles over the potential by means of the Poisson equation.
Mixing on a fixed background model of kinetic gas particles in Kerr accretion thick disk: In order to describe this problem, it was necessary to construct the corresponding action angle variables for a fixed background model of kinetic gas particles in a Kerr accretion thick disk in the way described my previous work [5].

We find that the phase space mixing properties still hold in the thick disk, since the system has enough conserved quantities (i.e. ℓ_z, ℓ, E, m) to ensure an integrable system and also the phase space mixing occurs. For this ongoing work, the next step is to extend the formal result of the phase space mixing theorem that should be done during the ESI program *Mathematical Perspectives of Gravitation beyond the Vacuum Regime* in which my collaborator Dr. O. Sarbach will participate. This work will be finished before June 2022.

Some of the questions behind the phase space mixing that concentrate interest are related with the relaxation time—how fast is this relaxation process? This seems to be particularly important in the neighbourhood of a particular curve where the determinant condition is zero (The determinant of the area function is the same as in [5]). In this direction the open questions to solve are:

- How can we physically characterise these orbits?
- How can we find the relaxation time for the phase space mixing?
- How does the relaxation time change near these particular orbits?

Toy model of self gravitation kinetic gas particles on Vlasov-Poisson system: Physically, the model consists of a set of particles in an harmonic oscillator (the simplest case) or a generic background potential, e.g. the perturbed harmonic oscillator with a confined potential. Regarding this background, we can consider that the particles modify the potential through the force induced by the Poisson equation.

This means that initially we have a Hamiltonian $H_0(x,p)$ and the solution of the Vlasov equation $L_{H_0}[f_0]=0$ will be found using the action angle variables. Here, we note that the phase space mixing occurs in any case where the frequencies are different than zero (anharmonic potential); also the distribution will be time dependent. With this distribution we compute the corresponding particle density function $\rho(t,x)$ and the corresponding force that comes from the Poisson equation given by $\mathcal{F}(t,x) = \int_{-\infty}^{x} \rho(t,y)dy$. Now the question is how this term that arises from the kinetic gas particles can modify the behaviour of the particles. Can this new term be considered as a collision term? This question is not answered easily.

While I was reviewing this question, I found a paper on the same topic [1] in which they explore the same model using a quadratic perturbation on the harmonic oscillator, they study the mixing and a quantitative decay.

This paper was in the same direction of my previous research for the toy model. Because this the paper gave me the idea to explore the mixing theorem and the points where the frequencies are constant. I started to study the vector field method widely known for the works of Klainerman [3] and [2, 7]. This vector field $W := \omega'(J)t\partial_Q - \partial_J$ commutates with the Liouville operator $L := \partial_t - w(J)\partial_Q$ and satisfies properties that are useful to prove the phase space mixing theorem in a different way than in my previous work [6]. But this case is a bit different because it only considers a Newtonian setting. Thanks to the vector field method it was also possible to find a time relaxation; this result was obtained in collaboration with H. Van Den Bosch and M. Moreno from U. Chile [4] finished during my stay in ESI.

Future directions of the research are related to using the vector field method to find a quantitative decay in the same way I did in the Newtonian case, but for the relativistic Kerr one.

During my time at ESI, I was able to study the vector field method thanks to the comments and work of Dr. David Fajman (University of Vienna, Austria), and reviewed his extended results on this topic [2]. I also spent time progressing a project that addresses the same issue - a joint work with Dr. H. Van Den Bosch and M. Moreno (all Center of Mathematical Modeling, Chile) to find new results for the Newtonian time decay for the mixing process. I made advances in the results for the studies of the potential and his description in action angle variables on a thick Kerr disk in the same way that the previous work [5] with Dr. O. Sarbach (Universidad Michoacana de San Nicolás de Hidalgo, Mexico).

I participated in the seminar and discussions in Physics Talks Vienna organised by TU Wien. I also attended the meeting (virtually, due to Covid restrictions in UK) *Frontiers in analysis of kinetic equations* and *Kinetic Theory: old and new tutorial*, organised by Isaac Newton Institute (UK) the topics of which were strongly related to my recent results and interests.

Publications and preprints contributed

M. Moreno, P. Rioseco, H. Van Den Bosch, *Mixing in an anharmonic potential well*, arXiv:2201.07019 [math-ph].

P. Rioseco, O. Sarbach, *Dynamics of collisionless thick discs on a Kerr black hole background exterior*, In preparation May 2022.

References

[1] S. Chaturvedi and J. Luk, *Phase mixing for solutions to 1D transport equation in a confining potential*, 2022 preprint, arXiv:2109.12402.

[2] Fajman, D. and Joudioux, J. and Smulevici, J., *A vector field method for relativistic transport equations with applications*, Analysis & PDE, 2017.

[3] Klainerman, S., *Uniform decay estimates and the Lorentz invariance of the classical wave equation*, Communications in Pure & Applied Mathematics, 1985.

[4] Moreno, M. and Rioseco, P. and Van Den Bosch, H., *Mixing in an anharmonic potential well*, 2022 preprint, arXiv:2201.07019.

[5] P. Rioseco and O. Sarbach, *Phase space mixing in the equatorial plane of a Kerr black hole*, Phys. Rev. D, 2018.

[6] P. Rioseco and O. Sarbach, *Phase space mixing in external gravitational potentials*, Classical and Quantum Gravity, 2020.

[7] Wong, W. W. Y., *A commuting-vector-field approach to some dispersive estimates*, Archiv der Mathematik, 2018.

Marius A. Oancea (U of Potsdam): Polarization-Dependent Gravitational Lensing

Dates of stay: September 1 – December 31, 2021

Report

This project was dedicated to the study of gravitational lensing phenomena beyond the standard geometrical optics approximation. By considering higher-order corrections to the geometrical optics approximation, the propagation of waves of finite frequency becomes polarization dependent [1, 2, 3, 4]. This is called the gravitational spin Hall effect, in analogy with other similar spin Hall effects that can be observed in optics and condensed matter physics. The main goal of this project was to study polarization-dependent effects in the gravitational lensing of electromagnetic and gravitational waves.

The propagation of electromagnetic and gravitational waves in curved spacetime can be described by the polarization-dependent ray equations derived in [1, 2]. As a first step towards the goal of the present project, the properties of these equations were studied in order to understand their limitations and how they could be applied in the case of gravitational lensing phenomena. In particular, a simplified, more compact form of the equations originally derived in [1, 2] was obtained, and the relation with the well-known Mathisson-Papapetrou equations for spinning objects was discussed. This allowed the derivation of conservation laws, which can be used to improve the numerical integration of the ray equations. This work was done in collaboration with Abraham I. Harte (Dublin City University) and will soon be available as preprint.

Based on the results mentioned above, a Mathematica/Python code was developed. The ray equations are integrated numerically, and ray-tracing simulations can be performed. This allows us to study polarization-dependent gravitational lensing phenomena in any spacetime of physical interest. Preliminary results allowed us to estimate the magnitude of polarization-dependent effects in several scenarios: In the case of far field lensing (when the lensed light rays pass far away from the source of gravity) the polarization-dependent effects are very small and could probably not be detected in the foreseeable future. However, the strong field regime (when rays pass close to the source of gravity) seems to be much more promising. In particular, preliminary results suggest that strong field lensing of gravitational waves could produce polarization-dependent time delays of significant magnitude. This is currently ongoing work, in collaboration with Miguel Zumalacarregui (Max Planck Institute for Gravitational Physics) and Richard Stiskalek (LMU Munich).

Publications and preprints contributed

Currently in preparation.

References

[1] M. A. Oancea, J. Joudioux, I. Y. Dodin, D. E. Ruiz, C. F. Paganini, L. Andersson, *Gravitational spin Hall effect of light*, Physical Review D 102, 024075 (2020), `https://doi.org/10.1103/PhysRevD.102.024075`

[2] L. Andersson, J. Joudioux, M. A. Oancea, A. Raj, *Propagation of polarized gravitational waves*, Physical Review D 103, 044053 (2021), `https://doi.org/10.1103/PhysRevD.103.044053`

[3] M. A. Oancea, C. F. Paganini, J. Joudioux, and L. Andersson, *An overview of the gravitational spin Hall effect*, arXiv:1904.09963, `https://arxiv.org/abs/1904.09963`

[4] M. A. Oancea, *Spin Hall effects in General Relativity*, PhD thesis, University of Potsdam (2021) `https://doi.org/10.25932/publishup-50229`

Davide Pradovera (CSQI, EPFL, Lausanne): Model Order Reduction of parametric PDEs with meromorphic structure based on minimal rational approximation

Dates of stay: October 20 – November 20, 2021

Report

The aim of this project, originally planned for the year 2020, was the development and analysis of model order reduction (MOR) approaches for a certain class of parametric PDEs. Specifically, one could consider the Helmholtz equation with parametric (angular) frequency ω *and* parametric wave-speed field $c = c(\theta)$:

$$-c(\theta)^2\Delta u - \omega^2 u = f, \tag{1}$$

endowed with suitable boundary conditions, which may also depend on ω and θ in some cases. The solution u (if it exists uniquely) defines, with respect to frequency and other parameters, the so-called *solution map*

$$u : \mathbb{C} \times \mathbb{R}^n \ni (\omega, \theta) \mapsto u(\omega, \theta) \in H^1(\Omega),$$

with n being the dimension of the parameter vector θ and Ω the spatial domain where (1) is set. Note that evaluating u requires the solution of the PDE (1). Numerically, this step is carried out by introducing a discretisation of Ω, Δ, and (if necessary) c, e.g., by finite elements or finite differences. Accordingly, computing $u(\omega,\theta)$ for arbitrary values of ω and θ has the potential of being quite expensive, especially when the numerical mesh is very fine (which is a necessity for large frequencies ω).

In this framework, the purpose of MOR is finding an approximation of u, the evaluation of which is much cheaper than (building and) solving the discretised version of (1). Some popular MOR approaches are the reduced basis family [1], based on (Petrov-)Galerkin projection, and the parametric Loewner framework [2], based on (multivariate) rational approximation. More recently, the (parametric) minimal rational interpolation was proposed in [3]. Notably, differently from reduced basis, minimal rational interpolation is *non-intrusive*, i.e., the PDE (1) may be considered as a "black box" for the sake of MOR. Moreover, it is capable of handling even modest numbers of parameters ($n \gtrsim 10$), as opposed to the parametric Loewner framework ($n \lesssim 5$).

During my one-month stay at ESI, I worked on the following related topics:

- In some cases, it proves useful to carry out the discretisation of the Helmholtz equation (1) via (h-, p-, or hp-)adaptive approaches, so that the discretised space where the solution u is sought may be properly adapted "on-the-fly" to the features of u. For instance, localised singularities may appear as a result of the properties of Ω. Moreover, depending on the value of ω, u may display resonant behaviour, which could (potentially) be more easily resolved using adaptivity. In collaboration with F. Bonizzoni (U Augsburg) and M. Ruggeri (TUW), I have developed an extended version of the (non-parametric) minimal rational interpolation method that accepts adapted snapshots as input. This allows one to build a surrogate model starting from samples of u that live in different discrete spaces. This work can be found in the preprint [I].

- Several extensions of the methods and results presented in [I] are under way. Notably, we plan to employ our approach in the parametric setting, in the wake of [3]. Moreover, we envision extensions of minimal rational interpolation that allow for adaptivity both in the solution of (1) *and* in the sampling of the solution map u for the construction of the surrogate.

- In collaboration with I. Perugia and M. Nonino (U Vienna), I started to investigate MOR approaches for the time-domain version of (1), namely, the wave equation

$$-c(\theta)^2\Delta u + \partial_{tt}u = f. \tag{2}$$

  Several results in the recent years, see, e.g., [4] and the references therein, have shown that standard *linear* MOR methods, e.g., reduced basis, are not ideal for problems like (2). Indeed, (2) is used to model advection phenomena, with moving wave fronts that are difficult to represent (or, more properly, "compress") in an inexpensive way. This often results in the lack of so-called *online efficiency*, since the surrogate model is not that much cheaper than the original one (if at all). In this field, our endeavour is the development of non-linear MOR approaches, able to represent the travelling wave in a "more compressible" format via space-time transformations. Some works in this direction are already available, see, e.g., [4]. However, our focus is on the mostly unexplored approximation of more complex (i.e., not just transport-based) interactions, e.g., refraction and reflection. This work is still under way.

Publications and preprints contributed

[I] F. Bonizzoni, D. Pradovera, and M. Ruggeri. *Rational-based model order reduction of Helmholtz frequency response problems with adaptive finite element snapshots*. ArXiv preprint: 2112.04302, 2021.

References

[1] A. Quarteroni, A. Manzoni, and F. Negri. “Reduced basis methods for partial differential equations: An introduction”. Springer International Publishing. 2015.

[2] A.C. Ionita and A.C. Antoulas. *Data-driven parametrized model reduction in the Loewner framework*. SIAM J. Sci. Comput., 36(3), 2014.

[3] F. Nobile and D. Pradovera. *Non-intrusive double-greedy parametric model reduction by interpolation of frequency-domain rational surrogates*. ESAIM: M2AN, 55(5), 2021.

[4] N. Cagniart, Y. Maday, and B. Stamm, *Model Order Reduction for Problems with Large Convection Effects*. In: “Contributions to Partial Differential Equations and Applications”, Comput. Meth. in Appl. Sc., 47, 2019.

Seminars and colloquia outside main programmes and workshops

270 seminar and colloquia talks have taken place at the ESI in 2021 including the following individual talk.

2021 10 12 , Detlev Buchholz (U Göttingen): "Classical dynamics, arrow of time, and the origin of Heisenberg's commutation relations"

ESI Research Documentation

ESI research in 2021: publications and arXiv preprints

THEMATIC PROGRAMMES

Geometry for Higher Spin Gravity: Conformal Structures, PDEs, and Q-manifolds (FGC)

X. Bekaert, *Notes on higher-spin diffeomorphisms*, arXiv:2108.09263 [hep-th].

O. Cosserat, C. Laurent-Gengoux, A. Kotov, L. Ryvkin, V. Salnikov, *On Dirac structures admitting a variational approach,*, arXiv:2109.00313v2 [math.DG].

M. Grigoriev and V. Gritzaenko, *Presymplectic structures and intrinsic Lagrangians for massive fields*, arXiv:2109.05596 [hep-th].

M. Grigoriev, A. Meyer, I. Sachs, *A toy model for background independent string field theory,*, arXiv:2106.07966 [hep-th].

M. Henneaux, P. Salgado-Rebolledo, *Carroll contractions of Lorentz-invariant theories*, JHEP **11** (2021), 180, doi:10.1007/JHEP11(2021)180, arXiv:2109.06708 [hep-th].

A.A. Tarusov, M.A. Vasiliev, *On the variational principle in the unfolded dynamics*, Phys.Lett.B 825 (2022) 136882, arXiv:2111.12691 [hep-th].

WORKSHOPS

Online-Workshop: Mathematical Perspectives of Gravitation beyond the Vacuum Regime (FAO)

M. Hadzic, G. Rein, C. Straub, *On the existence of Linearly Oscillating Galaxies*, Archive for Rational Mechanics and Analysis, (2021)

Applied Functional Analysis and High-Dimensional Approximation (HKT)

F. Albiac, J. L. Ansorena, M. Berasategui, P. M. Berna, S. Lassalle, *Weaker forms of unconditionality of bases in greedy approximation*, arXiv:2106.00975 [math.FA].

F. Albiac, J. L. Ansorena, M. Berasategui, P. M. Berna, S. Lassalle, *Bidemocratic bases and their connections with other greedy-type bases*, arXiv:2105.15177 [math.FA].

Graduate School: Higher Structures Emerging from Renormalisation (EGP)

N. Berglund, *An Introduction to Singular Stochastic PDEs. Allen–Cahn Equations, Metastability, and Regularity Structures*, ems.press:10.4171.

RESEARCH IN TEAMS (RIT)

Y. Ameur and J. L. Romero, *The planar low temperature coulomb gas: separation and equidistribution*, Revista Matemática Iberoamericana, to appear. arXiv:2010.10179 [math.PR].

E. Bergshoeff, J. Lahnsteiner, L. Romano and J. Rosseel, *The Supersymmetric Neveu-Schwarz Branes of Non-Relativistic String Theory*, arXiv:2204.04089 [hep-th].

A. Chatzistavrakidis, G. Karagiannis and A. Ranjbar, *Duality, Generalized Global Symmetries and Jet Space Isometries*, Universe **8** (2021) no.1, 10, doi:10.3390/ universe8010010, arXiv:2204.04089 [hep-th].

A. Chatzistavrakidis, G. Karagiannis, A. Ranjbar, *Duality, Generalized Global Symmetries and Jet Space Isometries*, Universe 8 (2021) 1, 10, arXiv: 2206.03683 [hep-th].

A. Chatzistavrakidis, G. Karagiannis, G. Manolakos, P. Schupp, *Axion Gravitodynamics, geodetic effects and gravitational waves*, arXiv:2111.04388 [gr-gc].

L. A. Escudero, N. Feldheim, G. Koliander, and J. L. Romero, *Efficient computation of the zeros of the Bargmann transform under additive white noise*, preprint, arXiv:2108.12921 [math.NA].

J. R. Forshaw, J. Holguin and S. Plätzer, *Rings and strings: a basis for understanding subleading colour and QCD coherence beyond the two-jet limit*, arXiv:2112.13124 [hep-ph].

M. Löschner, S. Plätzer and E. S. Dore, *Multi-Emission Kernels for Parton Branching Algorithms*, arXiv:2112.14454 [hep-ph], (submitted to JHEP).

M. Maiwöger, M. Sonnleitner, T. Zhang, I. Mazets, M. Mallweger, D. Rätzel, F. Borselli, S. Erne, J. Schmiedmayer, P. Haslinger *Observation of Light-Induced Dipole-Dipole Forces in Ultracold Atomic Gases*, arXiv:2202.00562 [cond-mat.quant-gas].

S. Plätzer, *Colour Evolution and Infrared Physics*, arXiv:2204.06956 [hep-ph], (submitted to JHEP).

D. Rätzel, D. Hartley, O. Schwartz, P. Haslinger, *Controlling Quantum Systems with Modulated Electron Beams*, Physical Review Research 3 (2021), 023247.s, https://doi.org/10.1103/PhysRevResearch.3.023247.

D. Reiche, F. Intravaia and K. Busch, *Wading through the void: Exploring quantum friction and nonequilibrium fluctuations*, arXiv preprint arXiv:2112.12195, 2021.

SENIOR RESEARCH FELLOWS PROGRAMME (SRF)

P. Germain, T. Léger, *Spectral projectors, resolvent, and Fourier restriction on the hyperbolic space*, 2104.04126 [math.AP].

P. Germain, S. L. R. Myerson, *Bounds for spectral projectors on tori*, 2104.13274 [math.AP].

A. Constantin, P. Germain, *Stratospheric planetary flows from the perspective of the Euler equation on a rotating sphere*, arXiv:2109.08797 [math.AP].

JUNIOR RESEARCH FELLOWS PROGRAMME (JRF)

F. Bonizzoni, D. Pradovera, M. Ruggeri, *Rational-based model order reduction of Helmholtz frequency response problems with adaptive finite element snapshots*, arXiv:2112.04302 [math.NA].

A. I. Harte, M. A. Oancea, *Spin Hall effects and the localization of massless spinning particles*, arXiv:2203.01753 [gr-qc].

M. Moreno, P. Rioseco, H. Van den Bosch, *Mixing in an anharmonic potential well*, arXiv:2201.07019 [math-ph].

P. Rioseco, O. Sarbach, *Dynamics of collisionless thick discs on a Kerr black hole background exterior*, In preparation May 2022.

List of all visitors in 2021

A total of 244 scientist visited the ESI in 2021.

The gender distribution is as follows:
male: 176
female: 38
prefer not to disclose: 3
non-binary: 1
unspecified: 26

Affiliation by country:
AUT, Austria: 67
BLR, Belarus: 1
BEL, Belgium: 16
CAN, Canada: 1
CHL, Chile: 2
CRI, Costa Rica: 1
HRV, Croatia: 5
CZE, Czech Republic: 8
FRA, France: 37
DEU, Germany: 37
ISR, Israel: 2
ITA, Italy: 2
NLD, Netherlands: 4
NOR, Norway: 7
POL, Poland: 3
RUS, Russian Federation: 5
ESP, Spain: 5
SWE, Sweden: 6
CHE, Switzerland: 4
GBR, United Kingdom of Great Britain and Northern Ireland: 26
USA, United States of America: 5

The following codes indicate the association of visitors with specific ESI events:

NLB21 = Arithmetic Statistics and Local-Global Principles
EM2021 = ESI Medal Award Ceremony 2021
FGC21 = Geometry for Higher Spin Gravity: Conformal Structures, PDEs, and Q-manifolds
EGP21 = Higher Structures Emerging from Renormalisation
IMO21 = IMO-Training 2021

IMO21-2 = IMO-Training 2021, part 2
IS-21 = Individual Visiting Scientists 2021
LTL21 = Interdisciplinary Challenges in Nonequilibrium Physics
MKS21ON = Memory Effects in Dynamical Processes: Theory and Computational Implementation
JRF = Junior Research Fellows
SRF = Senior Research Fellow
RIT = Research in Teams Project
SAB = Scientific Advisory Board Meeting 2021

Aigner Florian, U Vienna; 2021-10-28 - 2021-10-28, IMO21
Alekseev Anton, U Genève; 2021-11-05 - 2021-11-06, EM2021
Ameur Yacin, U Lund; 2021-10-23 - 2021-10-31, RIT
Barnich Glenn, ULB, Brussels; 2021-09-12 - 2021-09-17, FGC21
Bartel Alex, U of Glasgow; 2021-09-19 - 2021-09-25, NLB21
Barzegar Hamed, U Vienna; 2021-10-01 - 2021-11-30, 2022-01-01 - 2022-03-01, JRF
Bekaert Xavier, U Tours; 2021-08-21 - 2021-09-19, FGC21
Bellingeri Carlo, TU Berlin; 2021-11-07 - 2021-11-20, EGP21
Berestycki Nathanael, U Vienna; 2021-11-15 - 2021-11-19, EGP21
Berglund Nils, U of Orléans; 2021-11-14 - 2021-11-19, EGP21
Bierbaumer Martin, HTL3R, Vienna; 2021-06-28 - 2021-07-02, IMO21
Bierbaumer Martin, HTL3R, Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Blassnig David, High School Vienna; 2021-06-28 - 2021-07-02, IMO21
Blassnig David, High School Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Boffo Eugenia, Charles U, Prague; 2021-11-07 - 2021-11-12, EGP21
Bonolis Dante, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Borinsky Michael, ETH Zürich; 2021-11-14 - 2021-11-20, EGP21
Boulanger Nicolas, U Mons; 2021-09-12 - 2021-09-17, 2021-08-22 - 2021-08-28, FGC21
Bright Martin, Leiden U; 2021-09-19 - 2021-09-24, NLB21
Broux Lucas, Sorbonne U, Paris; 2021-11-07 - 2021-11-13, EGP21
Browning Tim, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Bruned Yvain, U Edinburgh; 2021-11-14 - 2021-11-21, EGP21
Buchholz Detlev, U Göttingen; 2021-10-09 - 2021-10-18, IS-21
Burde Dietrich, U Vienna; 2021-09-13 - 2021-09-17, IS-21
Campoleoni Andrea, U Mons; 2021-08-22 - 2021-09-04, FGC21
Cap Andreas, U Vienna; 2021-08-23 - 2021-09-17, FGC21
Cattafi Francesco, U Vienna; 2021-01-11 - 2021-05-11, JRF
Cattaneo Alberto, U Zürich; 2021-08-26 - 2021-08-30, FGC21
Caudillo Amador Diego de Jesus, NTNU, Trondheim; 2021-11-07 - 2021-11-21, EGP21
Celestino Rodriguez Adrián, NTNU, Trondheim; 2021-11-07 - 2021-11-19, EGP21
Chatzistavrakidis Athanasios, RBI, Zagreb; 2021-11-01 - 2021-12-22, 2022-01-10 - 2022-02-10, RIT
Chevyrev Ilya, U Edinburgh; 2021-11-09 - 2021-11-12, EGP21
Clavier Pierre, U of Haut-Alsace; 2021-11-07 - 2021-11-20, EGP21
Cosserat Oscar, U of La Rochelle; 2021-08-21 - 2021-09-04, FGC21
Cresson Jacky, U of Pau et des Pays de l'Adour; 2021-11-14 - 2021-11-20, EGP21
Cronvall Joakim, Lund U; 2021-10-23 - 2021-10-31, RIT
Cvetic Mirjam, UPenn, Philadelphia; 2021-11-05 - 2021-11-08, SAB
De Filippi David, U Mons; 2021-08-30 - 2021-09-07, FGC21
Dekimpe Karel, KU Leuven; 2021-09-12 - 2021-09-17, IS-21
Delfante Arnaud, U Mons; 2021-08-23 - 2021-09-03, FGC21
Dellago Christoph, U Vienna; 2021-11-05 - 2021-11-05, EM2021
Dellago Christoph, U Vienna; 2021-11-05 - 2021-11-06, SAB2021
Deng Zirui, High School Vienna; 2021-06-28 - 2021-07-02, IMO21

Derenthal Ulrich, Leibniz U; 2021-09-19 - 2021-09-23, NLB21
Destagnol Kevin, U Paris Sud, Orsay; 2021-09-19 - 2021-09-25, NLB21
Diehl Joscha, U Greifswald; 2021-11-12 - 2021-11-20, EGP21
Di Rocco Sandra, KTH Stockholm; 2021-11-05 - 2021-11-07, SAB
Dneprov Ivan, Moscow; 2021-08-24 - 2021-09-10, FGC21
Donnay Laura, TU Vienna; 2021-08-25 - 2021-09-07, FGC21
Doubrov Boris, Belarusian State U; 2021-09-05 - 2021-09-17, FGC21
Dougherty John, LMU Munich; 2021-11-14 - 2021-11-17, EGP21
Draper Fontanals Cristina, Malaga U; 2021-08-22 - 2021-08-28, FGC21
Drmota Michael, TU Vienna; 2021-06-28 - 2021-07-02, IMO21
Duch Pawel, Adam Mickiewicz U Poznan; 2021-11-07 - 2021-11-20, EGP21
Ebrahimi-Fard Kurusch, NTNU, Trondheim; 2021-11-07 - 2021-11-20, EGP21
Eckstein Stephan, U Hamburg; 2021-11-29 - 2022-01-31, JRF
Ehret Quentin, U of Haut-Alsace; 2021-11-07 - 2021-11-14, EGP21
Eisenkölbl Theresia, U Vienna; 2021-06-28 - 2021-07-04, IMO21
Eisenkölbl Theresia, U Vienna; 2021-10-27 - 2021-10-29, IMO21-2
El-Baz Daniel, TU Graz; 2021-09-19 - 2021-09-24, NLB21
Eulry Hugo, U Rennes 1; 2021-11-07 - 2021-11-12, EGP21
Fauvet Frederic, U Strasbourg; 2021-11-14 - 2021-11-20, EGP21
Feldheim Naomi, Bar Ilan U; 2021-11-19 - 2021-11-24, RIT
Ferdinand Léonard, Paris-Saclay U; 2021-11-08 - 2021-11-19, EGP21
Foissy Loic, U of Littoral Côte d'Opale, Dunkerque; 2021-11-08 - 2021-11-19, EGP21
Frabetti Alessandra, U Lyon; 2021-11-14 - 2021-11-19, EGP21
Francia Dario, U Roma III; 2021-08-30 - 2021-09-11, FGC21
Francois Jordan, U Mons; 2021-08-30 - 2021-09-13, FGC21
Franosch Thomas, U Innsbruck; 2021-06-23 - 2021-06-26, MKS21ON
Fredenhagen Stefan, U Vienna; 2021-08-23 - 2021-09-17, FGC21
Frei Christopher, TU Graz; 2021-09-19 - 2021-09-24, NLB21
Frias Jordi, Lomonosov Moscow SU; 2021-08-22 - 2021-09-18, FGC21
Friz Peter K., TU Berlin; 2021-11-16 - 2021-11-20, EGP21
Fuentealba Oscar, ULB, Brussels; 2021-08-22 - 2021-09-03, FGC21
Gálvez Carrillo Maria Immaculada, U Politecnica de Catalunya; 2021-11-06 - 2021-11-21, EGP21
Geretschläger Robert, High School Vienna; 2021-10-27 - 2021-10-28, IMO21-2
Germain Pierre, CIMS, New York; 2021-04-01 - 2021-06-01, SRF
Gilliers Nicolas, NTNU, Trondheim; 2021-11-07 - 2021-11-18, EGP21
Ginter Lukas, High School Vienna; 2021-06-28 - 2021-07-04, IMO21
Ginter Lukas, High School Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Glas Jakob, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Glatzel Fabian, U of Freiburg; 2021-06-23 - 2021-06-26, MKS21ON
Gracia-Bondía José M., Universidad de Costa Rica; 2021-11-07 - 2021-11-19, EGP21
Grataloup Albin, U Montpellier; 2021-11-07 - 2021-11-13, EGP21
Greilhuber Josef, U Vienna; 2021-06-29 - 2021-07-02, IMO21
Grigoriev Maxim, Moscow; 2021-08-22 - 2021-09-18, FGC21
Gritsaenko Vyacheslav, MIPT, Moscow; 2021-09-02 - 2021-09-17, FGC21
Grosse Harald, U Vienna; 2021-11-08 - 2021-11-19, EGP21
Grumiller Daniel, TU Vienna; 2021-08-23 - 2021-09-17, FGC21
Gvirtz Damián, University College London; NLB21
Haimi Antti, OEAW, Vienna; 2021-10-25 - 2021-10-29, 2021-11-19 - 2021-11-24, RIT
Hametner Paul, HS Linz; 2021-06-28 - 2021-07-04, IMO21
Hametner Paul, HS Linz; 2021-10-27 - 2021-10-29, IMO21-2
Hancharuk Aliaksandr, U Lyon; 2021-08-23 - 2021-09-12, FGC21
Haslinger Philipp, TU Vienna; 2021-09-23 - 2021-09-24, RIT
Henneaux Marc, ULB, Brussels; 2021-08-23 - 2021-09-04, FGC21
Herfray Yannick, ULB, Brussels; 2021-08-22 - 2021-09-17, FGC21
Herscovich Estanislao, U Grenoble Alpes; 2021-11-14 - 2021-11-20, EGP21

Hiebler Moritz, AAU, Klagenfurt; 2021-06-27 - 2021-07-04, IMO21
Hiebler Moritz, AAU, Klagenfurt; 2021-10-27 - 2021-10-29, IMO21-2
Hochfilzer Leonhard, Georg-August-U, Göttingen; 2021-09-20 - 2021-10-01, NLB21
Hollnbuchner Michael, BRG Linz; 2021-06-27 - 2021-07-04, IMO21
Holmes Daniel, U Cambridge; 2021-07-02 - 2021-07-02, IMO21
Horesh Tal, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Huang Zhizhong, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Hübel Lorenz, U Vienna; 2021-06-29 - 2021-07-02, IMO21
Huber Florian, U Vienna; 2021-11-08 - 2021-11-20, EGP21
Huisken Gerhard, U Tübingen; 2021-11-04 - 2021-11-07, SAB
Jacques Jean-David, Sorbonne U, Paris; 2021-11-08 - 2021-11-12, EGP21
Jurco Branislav, Charles U, Prague; 2021-09-06 - 2021-09-10, FGC21
Juric Tajron, RBI, Zagreb; 2021-11-06 - 2021-11-14, EGP21
Kapelari Jakob, Akademisches Gymnasium Innsbruck; 2021-10-27 - 2021-10-29, IMO21-2
Katsetsiadis Foivos, U Edinburgh; 2021-11-07 - 2021-11-13, EGP21
Khavkine Igor, Czech Academy of Sciences, Prague; 2021-08-30 - 2021-09-15, FGC21
Kirchgaesser Patrick, Lund U; 2021-08-29 - 2021-09-18, RIT
Klose Tom, TU Berlin; 2021-11-07 - 2021-11-22, EGP21
Kock Joachim, U Autonoma, Barcelona; 2021-11-14 - 2021-11-20, EGP21
Kodžoman Toni, RBI, Zagreb; 2021-11-07 - 2021-11-13, EGP21
Koenig Robert, TU Munich; 2021-08-08 - 2021-08-22, RIT
Koliander Günther, U Vienna; 2021-10-25 - 2021-10-29, 2021-11-19 - 2021-11-24, RIT
Kosmann-Schwarzbach Yvette, retired; 2021-08-29 - 2021-09-19, FGC21
Kotov Alexei, U Hradec Králové; 2021-08-25 - 2021-09-17, FGC21
Kowalzig Niels, U Napoli; 2021-09-10 - 2021-09-18, FGC21
Krasnov Kirill, U of Nottingham; 2021-08-21 - 2021-08-31, FGC21
Kruglikov Boris, U of Tromsø; 2021-09-04 - 2021-09-19, FGC21
Krysl Svatopluk, Charles U, Prague; 2021-08-22 - 2021-09-04, FGC21
Kurinczuk Robert, U of Sheffield; 2021-10-10 - 2021-10-14, RIT
Laga Jef, U Cambridge; 2021-09-20 - 2021-09-24, NLB21
Laurent Adrien, U of Bergen; 2021-11-07 - 2021-11-20, EGP21
Laurent-Gengoux Camille, U Lorraine; 2021-08-23 - 2021-08-27, FGC21
Lee David, Sorbonne U, Paris; 2021-11-07 - 2021-11-13, EGP21
Lehbab Imene, U of Haut-Alsace; 2021-11-07 - 2021-11-14, EGP21
Lehner Franz, TU Graz; 2021-11-08 - 2021-11-12, 2021-11-15 - 2021-11-19, EGP21
Linares Pablo, MPI Leipzig; 2021-11-06 - 2021-11-19, EGP21
Löb Tristan, High School Vienna; 2021-06-28 - 2021-07-02, IMO21
Löb Tristan, High School Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Locatelli Emanuele, U Vienna; 2021-04-12 - 2021-04-16, LTL21
Lopez Valenci Diego, U of Potsdam; 2021-11-08 - 2021-11-12, EGP21
Löschner Maximilian, KIT, Karlsruhe; 2021-08-22 - 2021-09-12, RIT
Loughran Daniel, U Bath; 2021-09-19 - 2021-09-24, NLB21
Lovrekovic Iva, TU Vienna; 2021-08-23 - 2021-09-17, FGC21
Lyczak Julian, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Majcen Peter, U Vienna; 2021-08-23 - 2021-09-17, RIT
Majumdar Sucheta, ULB, Brussels; 2021-08-22 - 2021-09-03, FGC21
Makhmali Omid, Polish Academy of Science, Warsaw; 2021-08-23 - 2021-09-17, FGC21
Malass Ihsane, U of Potsdam; 2021-11-07 - 2021-11-12, EGP21
Manchon Dominique, U Clerment Auvergne; 2021-11-07 - 2021-11-19, EGP21
Marceca Felipe, U Vienna; 2021-10-25 - 2021-10-29, RIT
Markou Chrysoula, MPP, Munich; 2021-08-22 - 2021-09-03, FGC21
Marmon Oscar, Lund U; 2021-09-19 - 2021-09-24, NLB21
Matei Vlad, Tel Aviv U; 2021-09-19 - 2021-09-25, NLB21
Matringe Nadir, U Paris; 2021-06-02 - 2021-06-15, RIT
Meyer Hugues, U of Saarland; 2021-06-23 - 2021-06-25, MKS21ON

Miller Michael, U Toronto; 2021-11-15 - 2021-11-20, EGP21
Minguez Alberto, U Vienna; 2021-09-19 - 2021-10-14, 2021-06-02 - 2021-07-01, RIT
Misuna Nikita, AEI Golm; 2021-08-22 - 2021-09-04, FGC21
Mitankin Vladimir, Leibniz U; 2021-09-19 - 2021-09-26, NLB21
Mkrtchyan Karapet, Imperial College, London; 2021-09-05 - 2021-09-13, FGC21
Morgan Adam, U of Glasgow; 2021-09-19 - 2021-09-24, NLB21
Nader Rita, U of Orléans; 2021-11-07 - 2021-11-19, EGP21
Nador Victor, U Bordeaux; 2021-11-07 - 2021-11-12, EGP21
Neogi Turmoli, ULB, Brussels; 2021-08-29 - 2021-09-11, FGC21
Newton Rachel, KCL, London; 2021-09-19 - 2021-09-24, NLB21
Nguyen Thanh Loan, U Clerment Auvergne; 2021-11-07 - 2021-11-12, EGP21
Nguyen Dinh Vu, U Paris 13; 2021-11-07 - 2021-11-12, EGP21
Nimmrichter Stefan, Universität Siegen; 2021-09-23 - 2021-09-24, RIT
Oancea Marius A., U Vienna; 2021-09-01 - 2021-12-31, JRF
Obermaier Doris, BRG1 Vienna; 2021-06-28 - 2021-07-04, IMO21
Obermaier Doris, BRG1 Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Otto Felix, MPI Leipzig; 2021-11-14 - 2021-11-17, EGP21
Overkamp Otto, U Oxford; 2021-09-19 - 2021-09-24, NLB21
Pagano Carlo, U of Glasgow; 2021-09-19 - 2021-09-24, NLB21
Pagano Margherita, Leiden U; 2021-09-19 - 2021-09-26, NLB21
Palomo Francisco José, Malaga U; 2021-08-23 - 2021-08-27, FGC21
Panzer Erik, U Oxford; 2021-11-14 - 2021-11-19, EGP21
Parrini Noémie, U Mons; 2021-08-23 - 2021-09-10, FGC21
Paterson Ross, U of Glasgow; 2021-09-18 - 2021-09-25, NLB21
Patras Frederic, U Côte d'Azur, Nice; 2021-11-07 - 2021-11-20, EGP21
Paulišić Mateo, U Rijeka; 2021-08-29 - 2021-09-03, FGC21
Paycha Sylvie, U of Potsdam; 2021-11-10 - 2021-11-19, EGP21
Pekar Simon, U Mons; 2021-08-23 - 2021-09-11, FGC21
Perez Alfredo, CECS, Valdivia; 2021-09-08 - 2021-09-16, FGC21
Pflügl Gabriel, Petrinum Linz; 2021-06-27 - 2021-07-04, IMO21
Pflügl Gabriel, Petrinum Linz; 2021-10-27 - 2021-10-29, IMO21-2
Pieropan Marta, Utrecht U; 2021-09-19 - 2021-09-24, NLB21
Plätzer Simon, U Graz; 2021-08-23 - 2021-09-17, RIT0-1
Plätzer Simon, U Graz; 2021-09-13 - 2021-09-24, RIT0-2
Ponomarev Dmitry, Lomonosov Moscow SU; 2021-08-22 - 2021-09-18, FGC21
Pradovera Davide, U Vienna; 2021-10-21 - 2021-11-19, JRF1020
Preiß Rosa, U of Potsdam; 2021-11-07 - 2021-11-23, EGP21
Prinz David, HU Berlin; 2021-11-07 - 2021-11-14, EGP21
Prohazka Stefan, U Edinburgh; 2021-08-23 - 2021-09-17, FGC21
Rahm Ludwig, NTNU, Trondheim; 2021-11-07 - 2021-11-21, EGP21
Rätzel Dennis, U of Bremen; 2021-09-22 - 2021-09-25, RIT0119
Rejzner Kasia, U of York; 2021-11-07 - 2021-11-16, EGP21
Rioseco Paola, U of Chile, Santiago; 2021-08-28 - 2021-12-31, JRF
Rivasseau Vincent, U Paris Sud; 2021-11-14 - 2021-11-19, EGP21
Roger Claude, U Lyon; 2021-11-07 - 2021-11-19, EGP21
Romano Beth, U Oxford; 2021-09-19 - 2021-09-24, NLB21
Romero Jose Luis, U Vienna; 2021-10-25 - 2021-10-29, 2021-11-19 - 2021-11-24, RIT
Rosseel Jan, U Vienna; 2021-08-24 - 2021-09-17, FGC21
Rosseel Jan, U Vienna; 2021-11-02 - 2021-12-22, 2022-01-10 - 2022-02-10, RIT
Ruffa Ines, U Vienna; 2021-08-24 - 2021-09-17, RIT
Ruzziconi Romain, TU Vienna; 2021-08-24 - 2021-09-17, FGC21
Rydin Myerson Simon, U Warwick; 2021-09-17 - 2021-09-26, NLB21
Ryvkin Leonid, U Göttingen; 2021-08-15 - 2021-08-28, FGC21
Sachs Ivo, LMU Munich; 2021-09-13 - 2021-09-15, FGC21
Sagerschnig Katja, Polish Academy of Science, Warsaw; 2021-08-23 - 2021-09-17, FGC21

Saghafian Morteza, ISTA, Klosterneuburg; 2021-06-29 - 2021-07-02, IMO21
Salkeld William, U Côte d'Azur, Nice; 2021-11-07 - 2021-11-21, EGP21
Salnikov Vladimir, CNRS / U La Rochelle; 2021-08-20 - 2021-08-31, FGC21
Salzer Jakob, Harvard U, Cambridge; 2021-09-08 - 2021-09-16, FGC21
Samtleben Henning, ENS Lyon; 2021-08-22 - 2021-08-27, FGC21
Santens Tim, KU Leuven; 2021-09-19 - 2021-09-25, NLB21
Saracco Paolo, ULB, Brussels; 2021-09-10 - 2021-09-18, FGC21
Scheimbauer Claudia, TU Munich; 2021-11-15 - 2021-11-17, EGP21
Schiavina Michele, ETH Zürich; 2021-08-29 - 2021-09-03, FGC21
Schiller Jan, HTLWY, Waidhofen/Ybbs; 2021-06-27 - 2021-07-02, IMO21
Schiller Jan, HTLWY, Waidhofen/Ybbs; 2021-10-27 - 2021-10-29, IMO21-2
Schilling Tanja, U of Freiburg; 2021-06-23 - 2021-06-25, MKS21ON
Schmitz Leonard, U Greifswald; 2021-11-07 - 2021-11-12, EGP21
Schneeweiss Janina, High School Vienna; 2021-06-28 - 2021-07-02, IMO21
Schneeweiss Janina, High School Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Schnetz Oliver, FAU Erlangen-Nürnberg; 2021-11-14 - 2021-11-19, EGP21
Schreitter Veronika, U Vienna; 2021-06-28 - 2021-07-02, IMO21
Sécherre Vincent, U Versailles Saint-Quentin; 2021-09-19 - 2021-10-01, 2021-06-18 - 2021-07-04, RIT
Seiringer Robert, ISTA, Klosterneuburg; 2021-11-05 - 2021-11-05, EM2021
Shute Alec, ISTA, Klosterneuburg; 2021-09-20 - 2021-09-24, NLB21
Sjödahl Malin, Lund U; 2021-09-13 - 2021-09-24, RIT
Skorobogatov Alexei, Imperial College London/FRIAS University of Freiburg; 2021-09-19 - 2021-09-25, NLB21
Skvortsov Eugene, U Mons; 2021-08-21 - 2021-08-31, FGC21
Slovak Jan, Masaryk U, Brno; 2021-08-29 - 2021-09-11, FGC21
Sofos Efthymios, U of Glasgow; 2021-09-19 - 2021-09-25, NLB21
Sonnleitner Matthias, U Innsbruck; 2021-09-22 - 2021-09-24, RIT0119
Steinacker Harold, U Vienna; 2021-08-23 - 2021-09-15, FGC21
Streeter Sam, U Bath; 2021-09-19 - 2021-09-25, NLB21
Strobl Thomas, U Lyon; 2021-08-21 - 2021-09-14, FGC21
Sutherland Tom, U Vienna; 2021-08-23 - 2021-08-27, 2021-09-06 - 2021-09-17, FGC21
Temme Kristan, IBM, Yorktown Heights; 2021-08-08 - 2021-08-22, RIT
Tempelmayr Markus, MPI Leipzig; 2021-11-07 - 2021-11-19, EGP21
Thompson Lola, Utrecht U; 2021-09-19 - 2021-09-25, NLB21
Tinková Magdaléna, CTU Prague; 2021-09-19 - 2021-09-24, NLB21
Tonks Andrew, U Politecnica de Catalunya; 2021-11-06 - 2021-11-21, EGP21
Uppal Harkaran, U Bath; 2021-09-19 - 2021-09-25, NLB21
Vargas Yannic, U of Potsdam; 2021-11-07 - 2021-11-19, EGP21
Verri Emanuele, U Greifswald; 2021-11-07 - 2021-11-21, EGP21
Vignes-Tourneret Fabien, UCB Lyon; 2021-11-14 - 2021-11-19, EGP21
Voronov Alexander, U of Minnesota; 2021-08-22 - 2021-08-28, FGC21
Vuković Ivan, U Rijeka; 2021-08-29 - 2021-09-03, FGC21
Vysoky Jan, CTU Prague; 2021-09-12 - 2021-09-17, FGC21
Weber Hendrik, U Münster; 2021-11-14 - 2021-11-19, EGP21
Weisbier Georg, High School Vienna; 2021-06-28 - 2021-07-02, IMO21
Weisbier Georg, High School Vienna; 2021-10-27 - 2021-10-29, IMO21-2
Widmer Martin, RHUL London; 2021-09-19 - 2021-09-26, NLB21
Wilsch Florian, ISTA, Klosterneuburg; 2021-09-19 - 2021-09-24, NLB21
Wulkenhaar Raimar, U Münster; 2021-11-14 - 2021-11-17, EGP21
Wutte Raphaela, TU Vienna; 2021-08-23 - 2021-08-27, FGC21
Yngvason Jakob, U Vienna; 2021-11-05 - 2021-11-05, EM2021
Zambotti Lorenzo, Sorbonne U, Paris; 2021-11-09 - 2021-11-14, EGP21

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