Erwin Schrödinger International Institute
for Mathematics and Physics

ESI / universität wien

ANNUAL REPORT 2022

ESI

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 2022

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Preface

Message of the Director

In my capacity as the Director of ESI, I am delighted to present to you the ESI Annual Report for the year 2022. Much like in the two preceding years, the ESI faced significant challenges due to the persistent impact of the COVID-19 pandemic. Nonetheless, the ESI was open for most of the year and we were able to carry out almost all of the planned activities. Many of them incorporated online components, allowing individuals to participate in workshops and other events even if they were prevented from visiting the ESI in person due to ongoing travelling restrictions. On the whole, the ESI has weathered the pandemic well, in no small part due to the dedicated work of the ESI administrative team. They showed remarkable flexibility in navigating the challenges of the pandemic, acquiring new technical skill, and, as always, efficiently managing the Institute's operations. At the same time, we gained a deeper appreciation for the value of personal interactions and live discussions. This became particularly evident during a summer school on machine learning in material science hosted at the ESI in the summer of 2022. It was heartening to witness over 60 participants from all over the world enjoying productive collaboration working with instructors and fellow participants, marking a return to in-person engagements after an extended period of virtual meetings. As is customary for ESI activities, the school included a relaxing and memorable evening at a traditional Viennese Heurigen. While the central goal of the ESI is to foster collaborative research, we recognize that science is done by people and so sometimes scientific gatherings result in enduring friendships, particularly after a joint visit to the Heurigen.

In February 2022, we were all shocked by the brutal attack of Russia on Ukraine, and the resulting war is still ongoing at the time of writing. The Governing Board of the ESI unequivocally condemned Russia's aggression and expressed profound solidarity with the people of Ukraine. In an effort to support Ukrainian scientists amidst this challenging period, the ESI initiated a Special Fellowship Programme for Ukrainian Scientists, facilitating research stays at the ESI lasting up to four months. Within this programme, which has also garnered support by the Faculties of Mathematics and Physics of the University of Vienna as well as by the Association *Erwin Schrödinger Institute*, ten Ukrainian researchers visited the ESI over the year and worked here, interacting with colleagues of the University of Vienna. Comprehensive accounts of the research conducted during these visits can be found later in this report.

In 2022, we had the privilege of welcoming new members to the Scientific Advisory Board (SAB) of the ESI. Francesco Sciortino and Julia Kempe have assumed their roles, succeeding Stefano Ruffo and Martin Zirnbauer. We extend our heartfelt gratitude to Stefano and Martin for their dedicated service to the ESI. A special expression of appreciation goes to Mirjam Cvetič, who, in 2022, completed her second three-year term on the SAB. Mirjam not only served as a valuable member but also chaired the board from 2019 to 2022. We are deeply thankful for her contributions. Fortunately, Sandra Di Rocco has graciously accepted the responsibility of succeeding Mirjam as the new chair, and for this, we are truly grateful. The SAB plays a pivotal role in the ESI, offering a global perspective and upholding the highest international scientific standards.

In 2023, we will celebrate the first 30 years of the ESI, which was established in 1993 in the wake of the fall of the Iron Curtain and the opening of Eastern Europe. We will mark this important milestone with a symposium that reflects the Institute's commitment to fostering research and collaboration in the diverse domains of mathematics and physics. At the time of writing we are in the middle of preparations for this celebration and we have put together an exciting programme. This will be a big party and we hope to see many of you there!

Christoph Dellago
Director of the ESI
September 2023

The Institute and its Mission

The Erwin Schrödinger International Institute for Mathematics and 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 2022

The list of research areas in mathematics and physics covered by the scientific activities of the Erwin Schrödinger Institute in 2022 shows a wide variety.

Thematic Programmes

In 2022, the following thematic programmes took place at the ESI: Organizers

- *Mathematical Perspectives of Gravitation beyond the Vacuum Regime*
  January 31 – March 11, 2022
  Organizers: Håkan Andréasson (CUT, Gothenburg), David Fajman (U of Vienna), Jérémie Joudioux (MPIGP, Potsdam), Todd Oliynyk (Monash U, Melbourne)
- *Computational Uncertainty Quantification: Mathematical Foundations, Methodology & Data*
  May 2 – June 24, 2022
  Organizers: Clemens Heitzinger (TU Vienna), Fabio Nobile (EPFL, Lausanne), Robert Scheichl (U Heidelberg), Christoph Schwab (ETH Zürich), Sara van de Geer (ETH Zürich), Karen Willcox (U of Texas, Austin)
- *Higher Structures and Field Theory*
  August 1 – 26, 2022
  Organizers: Anton Alekseev (U Genève), Stefan Fredenhagen (U of Vienna), Nicolai Reshetikhin (UC, Berkeley), Thomas Strobl (U Lyon), Chenchang Zhu (U Göttingen)
- *Tensor Networks: Mathematical Structures and Novel Algorithms*
  August 29 – October 21, 2022
  Organizers: Frank Pollmann (TU Munich), Norbert Schuch (U of Vienna), Frank Verstraete (Ghent U)
- *Large Deviations, Extremes and Anomalous Transport in Non-equilibrium Systems*
  September 19 – October 14, 2022
  Organizers: Christoph Dellago (U of Vienna), Satya Majumdar (U Paris Sud, Orsay), David Mukamel (Weizmann Institute, Rehovot), Harald Posch (U of Vienna), Gregory Schehr (U Paris Sud, Orsay)
- *Mathematical Methods for the Study of Self-organization in the Biological Sciences*
  November 14 – December 9, 2022
  Organizers: Pierre Degond (IMT), Marie Doumic (Sorbonne U, Paris), Anna Kicheva (ISTA, Klosterneuburg), Sara Merino-Aceituno (U of Vienna), Christian Schmeiser (U of Vienna)

A detailed account of the thematic programmes that took place is given in subsequent sections of this report.

Workshops

In addition to this thematic programmes, five workshops, one graduate school, the ESI Medal Award Ceremony 2022 and the IMO-Training and the IPhO-Training took place on-site at the ESI in 2022, complemented by visits of a some individual scholars who collaborated with scientists of the University of Vienna and the local community. Additionally, one pure online workshops took place. Here is a list of these activities:

– *Workshop and School: Optimal Point Configurations on Manifolds*
  January 10 – 21, 2022
  Organizers: 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)

– *Online-Workshop: Free Boundary Problems and Related Evolution Equations*
  February 21 – 25, 2022
  Organizers: Giovanni Bellettini (U Siena), Shokhrukh Kholmatov (U of Vienna), Paolo Piovano (Politecnico Milano)

– *Adaptivity, High Dimensionality and Randomness*
  April 4 – 8, 2022
  Organizers: Carsten Carstensen (HU Berlin), Albert Cohen (Sorbonne U, Paris), Michael Feischl (TU Vienna), Christoph Schwab (ETH Zürich)

– *Minimal Representations and Theta Correspondencen*
  April 11 – 15, 2022
  Organizers: Wee Teck Gan (U of Singapore), Marcela Hanzer (U Zagreb), Alberto Minguez (U of Vienna), Goran Muic (U Zagreb), Martin Weissman (UC Santa Cruz)

– *International Mathematical Olympiad and MEMO Training 2022*
  June 27 – July 1 and October 26 – 31, 2022
  Organizers: Michael Eichmair (U of Vienna), Theresia Eisenkölbl (U of Vienna)

– *IPhO and EuPhO Training 2022*
  June 27 – July 1, 2022
  Organizers: Marianne Korner (U of Vienna), Stefan Lorbek (BRG Mürzzuschlag)

– *Set-Theory*
  July 4 – 8, 2022
  Organizers: Jörg Brendle (Kobe U), Vera Fischer (U of Vienna), Sy David Friedman (U of Vienna)

– *ESI-DCAFM-TACO-VDSP Summer School on "Machine Learning for Materials Hard and Soft"*
  July 11 – 22, 2022
  Organizers: Christoph Dellago (U of Vienna), Ulrike Diebold (TU Vienna), Leticia Gonzalez Herrero (U of Vienna), Jani Kotakoski (U of Vienna), Christiane Losert-Valiente Kroon (U of Vienna)

– *Symposium: ESI Medal Award Ceremony 2022*
  November 4, 2022
  Organizers: Christoph Dellago (U Vienna, ESI Director)

– *Spectral Theory of Differential Operators in Quantum Theory*
  November 7 – 11, 2022
  Organizers: Jussi Behrndt (TU Graz), Fritz Gesztesy (Baylor U, Waco), Ari Laptev (Imperial College, London), Christiane Tretter (U Bern)

The following workshops, scheduled for 2022, did not take place due to the COVID19 pandemic:

– *Stochastic Partial Differential Equations*
  March 7 – 11, 2022
  Organizers: Sandra Cerrai (U of Maryland), Martin Hairer (Imperial College, London), Carlo Marinelli (IRIS) Eulalia Nualart (UPF), Luca Scarpa (Politecnico Milano), Ulisse Stefanelli (U Vienna)

– *Chromatin Modeling: Integrating Mathematics, Physics, and Computation for Advances in Biology and Medicine*
  March 21 – 24, 2022
  Organizers: Christos Likos (U of Vienna), Stephanie Portillo (NYU, New York), Tamar Schlick (NYU, New York)

Senior Research Fellows

As in previous years, within the *Senior Research Fellows* programme, the ESI offered lecture courses on an advanced graduate level. In 2022 the ESI offered three of them.

In the winter term 2021/22 Martin Kružík (Czech Academy of Sciences, Prague) gave a course on *Lower Semicontinuity of Integral Functionals and Applications*. In the summer term 2022 Sergei A. Egorov (Virginia U) gave a course on *Classical Density Functional Theory with applications to colloid/polymer systems in the bulk and under confinement* and John Barrett (U of Nottingham) gave a course on *Introduction to Non-commutative Geometry* in the winter term 2022/23.

Research in Teams Programme

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 2022.

– Nihat Sadik Deger (Bogazici University) and Jan Rosseel (University of Vienna), *Three-Dimensional Minimal Massive Supergravity*, January 31 – February 28 and May 22 – June 5, 2022.

– Wee Teck Gan (NU of Singapore), Nadya Gurevich (Ben-Gurion U of the Negev), Aaron Pollack (UC, San Diego), Gordan Savin (U of Utah, Saltlake City), *Modular Forms and Theta Correspondence for Exceptional Groups*, April 16 – 23, 2022.

– Anna Geyer (Delft U of Technology), Guilong Gui (Northwest University, Xian), Yue Liu (U of Texas at Arlington), Dmitry Pelinovsky (McMaster U, Hamilton), *A study of nonlinear nonlocal asymptotic shallow-water models, with an emphasis on wave breaking and stability of peaked waves*, May 9 – June 11, 2022.

- Martin Bauer (Florida State U), Philipp Harms (NTU Singapore), Peter W. Michor (U Vienna), *Infinite Dimensional Riemannian Geometry*, May 23 – July 1, 2022.
- 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*, May 27 - June 8, 2022, September 2 - 10, 2022 and December 9 - 22, 2022.
- Arjun Bagchi (IIT Kanpur), Stefan Fredenhagen (U of Vienna), Daniel Grumiller (TU Vienna), *Chaos, Butterflies, and Entanglement in Flat Space*, June 12 – July 23, 2022.
- Delia Ionescu-Kruse (Simon Stoilow Institute, Bucharest), Rossen I. Ivanov (TU Dublin), *Variational Approaches to Modelling Geophysical Waves and Flows*, July 1 – 31, 2022.
- Arkady Berenstein (U of Oregon), Vladimir Retakh (Rutgers U), *Noncommutative Cluster Structures and their Symmetries*, July 1 – August 31, 2022.
- Jinfeng Chu (Shanghai Normal U, China), Calin Martin (U Vienna), Kateryna Marynets (Technical University Delft), *Two-Layer Periodic Water Waves*, October 1 – 31, 2022.

The following Research in Teams project that was accepted for 2022 had to be cancelled due to travel restrictions connected to the COVID-19 pandemic still in place in some countries:

- Xiangke Chang (Chinese Academy of Sciences), Jonathan Eckhardt (Loughborough U), Aleksey Kostenko (U of Vienna/U of Ljubljana), Jacek Szmigielski (U of Saskatchewan), *Peakon Dynamics*, May 26 – July 6, 2022.

Junior Research Fellows

In the year 2022 the following Junior Research Fellows visited the ESI to work on their research projects:

- Stephan Eckstein (U Hamburg), *Numerics of Adapted Transport and Applications to Mathematical Finance*, November 29, 2021 – January 31, 2022.
- Hamed Barzegar (U of Vienna), *Mathematical Analysis of Dark Matter*, October 1 – November 30, 2021 -and January 1 – March 1, 2022.
- Alexander Evetts (Heriot-Watt U, Edinburgh), *Conjugacy growth in finitely generated nilpotent groups* , May 2 – 26, 2022.
- Lorenzo Del Re (Georgetown U), *Dimensional Crossover of Layered Strongly Correlated Ultracold Fermi Gases*, June 6 – June 20, 2022.
- Judith Alcock-Zeilinger (Independent Researcher), *Multiplet bases for resummation — understanding structures of color evolution*, July 11 – November 10, 2022.
- Aliaksandr Hancharuk (U Lyon), *Higher Gauge Theories*, July 31 – August 30, 2022.
- Sudipta Dutta (IIT Kanpur), *Holography of asymptotically flat spacetimes*, September 1, 2022 – December 31, 2022.

– Barbara Bošnjak (U Zagreb), *The unitarizability problem through Arthur packets*, April 4 – July 3 and September 1 – October 1, 2022.

– Vincentas Mulevicius (U Hamburg), *Defects in Douglas-Reutter 4-dimensional TQFT*, October 1, 2022 – December 21, 2022.

Ukrainian Research Fellows

After the brutal attack launched by Russia on Ukraine on February 24, 2022, the Governing Board of the ESI issued a statement strongly condemning Russia's actions. In order to support Ukrainian scientists, the ESI started a special fellowship programme for research stays of up to four months. At the ESI, research fellows from Ukraine could work on their research projects and interact with scientists of the Faculties of Mathematics and Physics of the University of Vienna. With support from the Faculties of Mathematics and Physics of the University of Vienna, and from the Association Erwin Schrödinger Institute 10 researchers from Ukraine visited the ESI in 2022:

– Vira Niestierkina (National Academy of Sciences of Ukraine, Kharkiv), *Influence of defects on radiative relaxation of halide and oxide scintillators*, April 1 – July 31, 2022.

– Ivan Kyrchei (National Academy of Sciences, Ukraine, Lviv), *Quaternion algebras and their application in the study of quaternion generalized inverse matrices*, April 12 – June 12, 2022.

– Volodimir Simulik (National Academy of Sciences Ukraine, Kiev), *New approach to relativistic quantum mechanics and field theory of arbitrary spin*, April 20 – June 20, 2022.

– Anna Kosogor (National Academy of Sciences of Ukraine, Kiev), *The spin-wave contribution to the specific heat of Heusler alloys*, May 23 – October 8, 2022.

– Valeri Lozovski (Taras Shevchenko National University Kiev), *The self-consistent description of plasmon-assisted Brillouin Light Scattering (BLS) spectroscopy*, June 6 – October 6, 2022.

– Yurii Sitenko (National Academy of Sciences, Ukraine, Kiev), *Quantum effects in the background of a topological defect*, June 30 – August 31, 2022.

– Yurii Zhuchok (Luhansk Taras Shevchenko National University), *Endomorphism semigroups and free Loday's structures*, July 11 – November 10, 2022.

– Yuliia V. Zhuchok (Luhansk Taras Shevchenko National University), *Free trioids*, August 15 – December 15, 2022.

– Anatolii V. Zhuchok (Luhansk Taras Shevchenko National University), *Relatively free trioids and generalized dimonoids*, August 15 – December 15, 2022.

– Oleg Korotchenkov (Kiev University), *Time-domain impedance analysis of carrier recombination in ZnO thin films grown on Si*, July 6 – August 6, December 10, 2022 – January 21, 2023, April 29 – June 1, 2023.

Other activities

After a break of two years, we arranged again an Erwin Schrödinger Lecture, held by Philip Walther (Faculty of Physics, U of Vienna) on the topic “Photonic quantum computing – a bright future for many applications”.

Finally, the Erwin Schrödinger Institute also hosted again an events of the Vienna Doctoral School in Physics (VDSP) and the Vienna School of Mathematics (VSM):

– *Does science always have to be sensational and/or educational?* on March 22, 2022. The meeting was jointly organized by students of the VSM and VDSP.

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 2022. Hence, in the period January 1 - December 31, 2022, 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 2022, 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), Julia Kempe (NYU), and Francesco Sciortino (U of Rome, La Sapienza).

The composition of the SAB of the ESI changed by the end of the year 2021. After two terms of office Stefano Ruffo (SISSA, Trieste) and Martin Zirnbauer (U Cologne) retired from the Board. The Institute is very grateful to them for many years of valuable advice and support. Julia Kempe (NYU) and Francesco Sciortino (U of Rome, La Sapienza) joined the Board on January 1, 2022, as new members.

Administration

With the beginning of 2022 the open position at the administration could be filled with Blanka Molnár. For the period August till December 2022 the ESI administration was supported by Helena Kempf to an extent of 10 hours per week. We would like to thank her for her valuable work for the ESI and her support of the administrative team in this period. The administration team continued its work with customary efficiency for our visitors, research fellows and board after having overcome most restrictions connected to the COVID pandemic in spring 2022.

Christoph Dellago October 11, 2023
ESI Director

The ESI in 2022: 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: Helena Kempf (August – December 2022), Blanka Molnár, Maria Marouschek, Beatrix Wolf (Head)

Computing and networking support: Marion Praschl (from Mai 2022 on), Thomas Leitner

Video recording and publishing: Sophie Kurzmann

International Scientific Advisory Board in 2022:

Douglas N. Arnold (U Minnesota)
Alberto Bressan (Penn State U)
Sandra Di Rocco (KTH, Stockholm)
Julia Kempe (NYU)
Domenico Giulini (U Hannover)
Gerhard Huisken (U Tübingen)
Miriam Cvetic (U Pennsylvania, Philadelphia) [chair]
Francesco Sciortino (U of Rome, La Sapienza)

Budget and visitors: In 2022 the support of ESI received from the University of Vienna amounted to **€ 790 000**. In addition, the ESI obtained a total of € 117 953 in third party funds from external sources for the support of the various activities.

The total amount spent in 2022 on scientific activities was € 576 977, € 459 024 from the ESI budget plus the external third party funds of € 117 953, while the expenditures for administration (mainly salaries) and infrastructure (mainly rent) amounted to € 491 462.

The total number of scientists visiting the Erwin Schrödinger Institute in 2022 was 815, see pages 149 – 166. Gender ratio: male: 602 (73,9 %), female: 157 (19,2 %), non-binary: 2 (0,2 %), prefer not to disclose or unspecified 54 (6,7 %). Moreover, 439 registered people participated online in various activities of the ESI. Here the gender ratio was as follows: male: 318 (72,4 %), female: 81 (18,5 %), prefer not to disclose or unspecified: 40 (9,1 %).

ESI research documentation:

Starting from January 2013, the ESI research output is tracked using the published articles and the arXiv database.

The total number of preprints and publications contributed to the ESI research documentation database in 2022 is 89 [related to the activities in 2022: 87, related to the activities in previous years: 2], see pages 142 – 147 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 339 videos were recorded in 2022 amounting to more than 250 hours of video material. These videos have been accessed 66.192 times in 2022 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

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: January 31 – March 11, 2022

Budget: ESI € 10 160

Report on the programme

In 2017 we organized the workshop "Geometric Transport Equations in General Relativity", which took place at the Erwin Schrödinger International Institute for Mathematics and Physics. This workshop was centered on questions related to collisionless matter models in general relativity. The six-week programme "Mathematical Perspectives of Gravitation beyond the Vacuum Regime" is the continuation of this workshop. The scope of the matter models were extended to all models which are considered serious in the sense that they satisfy important energy conditions. Examples of such models are collisionless matter, fluids and elastic matter. These models are called phenomenological matter models. A different type of matter models are field theoretical models such as scalar fields, electromagnetic fields, the Klein-Gordon model and the Dirac model. These models were also included in the programme. The main reason why the focus in our programme was on the coupling of Einstein's equations to matter is that the vacuum case has been a central theme of many conferences within the community during the last decade. We therefore found a programme as ours to be a natural complement to the many activities centered around the vacuum case. Indeed, many participants expressed their gratitude that we organized a programme focussing on the matter aspects.

An unfortunate consequence of the Covid-19 pandemic was that we had to use a hybrid format for the programme since many participants chose to stay at home and give their seminars online. The number of participants who took part in person at ESI varied, roughly, between 10 and 20 during the six weeks of the programme. Under normal circumstances these numbers had of course been considerably higher.

Four out of the six weeks were devoted to research collaborations among the participants but talks were also given during this period. The second and the third week were exceptions. The second week was devoted to a winter school covering four different topics and during the third week we organized a workshop where almost 20 talks were given. The details of these activities are given below.

During the programme we were asked by an editor of the journal Classical and Quantum Gravity if we were interested in editing a ”Focus Issue” based on the theme of the programme. We accepted this offer and presently several speakers and participants from the programme have agreed to write review papers on different topics on the coupling of matter models to the Einstein equations. We believe that this will be a valuable contribution to our research community.

Despite the problems caused by the Covid-19 pandemic we were very happy with the outcome of the programme and we have received many positive reactions from the participants. Hence, our original motivation and belief that there is a need for a programme focussing on matter models in the community seems to be shared by many of our colleagues.

Winter School on "Mathematical Perspectives of Gravitation beyond the Vacuum Regime", February 7 – 10, 2022

The second week of the programme was devoted to a Winter school covering four different topics in the field. Four lectures per topic were given. The speakers and the titles are given below.

Markus Kunze (University of Cologne)	A Birman-Schwinger principle in galactic dynamics (The Vlasov-Poisson system)
Jared Speck (Vanderbilt University)	The Relativistic Euler Equations: Remarkable Structures and Applications
Robert Beig (University of Vienna)	General relativistic elasticity
Olivier Sarbach (UMICH, Mexico)	The relativistic Boltzmann equation: geometric formulation and application

List of talks

Workshop on "Mathematical Perspectives of Gravitation beyond the Vacuum Regime", February 14 – 18, 2022

During the third week of the programme we organized a workshop with 18 talks. Several outstanding speakers from highly ranked universities took part, e.g. speakers from Princeton University, Stanford University and Sorbonne University to mention a few. The speakers and the corresponding titles were:

Hans Ringström (KTH Stockholm)	A geometric framework for anisotropic big bang singularities and initial data on the singularity
Philippe G. LeFloch (Sorbonne U, Paris)	Some advances on self-gravitating massive fields: nonlinear stability, asymptotic decay, and singularities
Igor Rodnianski (Princeton U)	Landau law and stability of 3D shocks
Robert Strain (UPenn, Philadelphia)	On the fully nonlinear 2D Peskin problem
Joachim Frenkler (U Bayreuth)	Self-consistent models for Spiral Galaxies - A new chapter in the discussion about Dark Matter
Sebastian Günther (U Bayreuth)	Collisionless equilibria in general relativity: stable configurations beyond the first binding energy maximum
Jonathan Luk (Stanford U)	From vacuum to dust to Vlasov
Juhi Jang (U of Southern California, Los Angeles)	Newtonian self-similar gravitational collapse
Sohrab Shahshahani (UMass Amherst)	The hard phase fluid with free boundary in relativity
William East (Perimeter Institute, Waterloo)	Cosmic Censorship, Black Holes, and Backreaction: Adventures in the Collapse of Collisionless Matter

Florian Beyer (U of Otago)	Fluids in the vicinity of Kasner big bang singularities
Zoe Wyatt (U Cambridge)	Stabilising relativistic fluids on slowly expanding cosmological spacetimes
Jeremie Szeftel (Sorbonne U, Paris)	The nonlinear stability of Kerr for small angular momentum
Mahir Hadzić (University College London)	Examples of naked singularities for the Einstein-Euler system
Hans Lindblad (Johns Hopkins U, Baltimore)	Global stability of Minkowski space for the Einstein-Maxwell-Klein-Gordon system in generalized wave coordinates
Markus Kunze (U Cologne)	Static solutions to the spherically symmetric Einstein-Vlasov system: a particle-number-Casimir approach
Lars Andersson (BIMSA)	The gravitational spin Hall effect
Alexandru Ionescu (Princeton U)	On the asymptotic behavior of solutions to the Vlasov-Poisson system in 3 dimensions

Collaborations and auxiliary talks

The first week together with weeks 4-6 were devoted to research exchanges and collaborations between participants. As a consequence of the Covid-19 pandemic there were less participants at the institute compared to what we originally planned for. Nevertheless constructive collaborations took place and in addition we organized a few talks during this period, namely:

Hanne Van den Bosch (U of Chile)	Mixing in an anharmonic potential well
Erik de Amorim (U Cologne)	The Maxwell-Bopp-Lande-Thomas-Podolsky-Einstein system for a static point source
Maciej Maliborski (U of Vienna)	Characteristic approach to the soliton resolution

Publications and preprints contributed

M. Kunze, *A Birman-Schwinger principle in galactic dynamics*, arXiv:2202.04555 [math-AP].

S. Günther, G. Rein, C. Straub, *A Birman-Schwinger Principle in General Relativity: Linearly Stable Shells of Collisionless Matter Surrounding a Black Hole*, arXiv:2204.10620 [math-AP].

Further forthcoming articles can be found here: https://iopscience.iop.org/collections/0264-9381_mathematics-of-gravitation

Invited scientists

Håkan Andréasson, David Fajman, Jérémie Joudioux, Todd Oliynyk, Rubén Omar Acuna Cárdenas, Peter C. Aichelburg, Artur Alho, Ellery Ames, Lars Andersson, Hamed Barzegar, Robert Beig, Florian Beyer, Léo Bigorgne, Piotr Bizón, Annegret Burtscher, Andreas Cap, Xuantao Chen, Piotr T. Chruściel, Wan Cong, Joao Lopes Costa, Mihalis Dafermos, Edvin Dapo, Erik de Amorim, Marcelo Disconzi, Roland Donninger, William East, Joerg Frauendiener, Joachim Frenkler, Carlos Eduardo Gabarrete Fajardo, David Garfinkle, Daniel Ginsberg, Sebastian Günther, Mahir Hadzić, Lili He, Gustav Holzegel, Kaibo Hu, Cécile Huneau, Alexandru Ionescu, Jim Isenberg, Fatima-Ezzahra Jabiri, Juhi Jang, Philip Karlsson, Lavi Karp, Elena Kopylova, Maximilian Kraft, Markus Kunze, Sergio Leal Gomez, Philippe G. LeFloch, Hans Lindblad, Chao Liu, Jiaqi Liu, Maximilian Lock, Jonathan Luk, Maciej Maliborski, Diego Martínez-Argüello, Alex McGill, Filipe Mena, Shuang Miao, Thomas Mieling, Mikhail Molodyk, Matías Moreno Bustamante, Georgios Moschidis, José Natário, Brien Nolan, Marius A. Oancea, Maximilian Ofner, Jose Arturo Olvera Santamaria, Matthias Ostermann, Johannes Oude Groeniger, Oliver Petersen, Stephen Plachta, Hans Ringström, Oliver Rinne, Paola Rioseco, Calum Robertson, Igor Rodnianski, Félix Salazar, Tony Salvi, Olivier Sarbach, Bernd Schmidt, Sohrab Shahshahani , Walter Simon, Jacques Smulevici, Jared Speck, Roland Steinbauer, Florian Steininger, Robert Strain, Christopher Straub, Jeremie Szeftel, Martin Taylor, Jessica Paola Trespalacios Julio, Liam Urban, Juan A. Valiente Kroon, Hanne Van den Bosch, David Wallauch, Jörg Weber, Sijue Wu, Zoe Wyatt, Weihang Zheng, Shengguo Zhu.

Computational Uncertainty Quantification: Mathematical Foundations, Methodology & Data

Organizers: Clemens Heitzinger (TU Vienna), Fabio Nobile (EPFL Lausanne), Robert Scheichl (U Heidelberg), Christoph Schwab (ETH Zürich), Sara van de Geer (ETH Zürich), Karen Willcox (U of Texas, Austin)

Dates: May 2 – June 24, 2022

Budget: ESI € 43 141

Report on the programme

The ESI TP on Computational Uncertainty Quantification (UQ for short) gathered leading experts in the field of computational UQ for partial differential equations. This TP had been scheduled originally in the spring of 2020, but had to be postponed due to CoV-related travel and conferencing restrictions. The ESI board subsequently decided to reschedule the TP in 2022, with an updated scientific agenda. Accordingly, the TP organizers slightly re-aligned the scientific agenda of the TP (as compared with the original, 2020 proposal) in the following points:

(i) Some titles of the proposed TP workshops were revised, to account for current scientific developments in the field. This pertained in particular to WS3 and WS4, where emphasis was now placed on the methodologies related to deep-learning and their impact on computational UQ.

(ii) The invitation list of TP participants was updated until rather close to the start of the TP. With overseas participants being in part constrained by CoV-related travel restrictions in various parts of the world (in particular in asia), new participants were invited. Emphasis was placed on young researchers from European academic institutions, with the expectation that they could realize in-person participation on site at ESI and would also benefit most form participating.

(iii) It was determined that all workshops should be held in hybrid format, from the venue of the Boltzmann Lecture Hall at ESI. Key to facilitating this was the high quality videoconferencing equipment available in ESI's Boltzmann Lecture Hall.

As precursor for this event in 2022, we also proposed to the Director of ESI to run a reduced version of the opening workshop on *"Multilevel and Multifidelity Sampling Methods in Uncertainty Quantification for PDEs"* online on May 4 and 5, 2020, with the aim to advertise the future TP and to initiate a 2-year collaborative research effort on this very active, specialist subtopic in Computational UQ. This proposal was enthusiastically supported by the Director of ESI and by the entire ESI team. Overall this proved to be a great success and the format of the online workshop offered sufficient interaction to achieve the goals and to initiate collaborations.

Activities

During the TP UQ programme, **five thematic workshops** took place. They were organized by one or two of the TP organizers, plus some further leading experts in the particular WS theme. All workshops were foreseen as in-person events, with the option, to participate and present from remote at short notice.

Titles and organizers of all TP UQ workshops are as follows:

- **Workshop 1:** *Multilevel and multifidelity sampling methods in UQ for PDEs*. Organizers: K. Law (U of Manchester), F. Nobile (EPF Lausanne), R. Scheichl (U of Heidelberg), K. Willcox (U of Texas, Austin).

- **Workshop 2:** *Approximation of high-dimensional parametric PDEs in forward UQ*. Organizers: A. Cohen (Sorbonne U, Paris), F. Nobile (EPF Lausanne), C. Powell (U of Manchester), Ch. Schwab (ETH Zürich), L. Tamellini (CNR-IMATI, Pavia).

- **Workshop 3:** *PDE-constrained Bayesian inverse problems: Interplay of spatial statistical models with Machine Learning in PDE discretizations*. Organizers: S. Reich (U of Potsdam), Ch. Schwab (ETH Zürich), A. M. Stuart (CalTech), S. van de Geer (ETH Zürich).

- **Workshop 4:** *Statistical estimation and deep learning in UQ for PDEs*. Organizers: F. Bach (Sorbonne U, Paris), C. Heitzinger (TU Wien) , Johannes Schmidt-Hieber (U of Darmstadt), S. van de Geer (ETH Zürich).

- **Workshop 5:** *UQ in kinetic and transport equations and in high-frequency wave propagation*. Organizers: L. Borcea (U of Michigan), G. Dimarco (U of Ferrara), C. Heitzinger (TU Wien), Shi Jin (Shanghai Jiao Tong U), R. Scheichl (U of Heidelberg), Euan Spence (U of Bath).

Specific information on the programme

The overall response for the general program has been positive. The TP attracted, in particular through the workshops, well-known, key researchers at the forefront of computational UQ, in particular from data assimilation, deep learing, inverse problems, statistics and numerical analysis. Although seemingly different themes in five workshops were covered, they complemented each other very well, and covered the entire spectrum of computational UQ research activities. A number of the participants requested to participate to two or more workshops and to stay in the week in between. The ESI hybrid format in the organization of the workshops, combined with the professional ESI staff handling of the videoequipment in the Boltzmann Lecture Hall at the ESI site, has been key for the success of this post-CoV research activity. In all workshops, at least half of the participants attended in person and could profit of the ESI's excellent facilities and ample free time left for discussions and collaborations.

Researchers from the different workshops interacted, which was one of the primary goals when designing the TP. In addition, young researchers had the opportunity to network to obtain e.g. valuable international connections or postdoctoral fellowships.

Workshop 1 [Co-ordinator: Robert Scheichl] was set up as a highly interactive workshop on a specialised and focused, yet hugely active research area in computational UQ: multilevel and multifidelity (ML/MF) sampling methods. As such, the researchers – while coming from a variety of academic fields – were able to interact and discuss rather easily on cutting-edge developments in the field.

Alongside over 20 insightful and stimulating research presentations by leading experts in the field, as well as by young researchers, the workshop contained round-table discussions and two entire mornings (Wed & Thu) of group work. This culminated in a series of short presentations from each of the working groups on their discussions and ideas on Friday morning. All the in-person participants and even some online-participants engaged and contributed enthusiastically to the activities. The feedback was extremely positive.

Developments showcased in the research talks ranged from novel application areas for ML/MF sampling methods (Lévy noise, SPDEs, nonlocal models, soft matter physics, naval engineering, fusion energy), over improved algorithms (adaptivity, branching, machine learning), to rare event simulation and a wide range of novel ideas in the context of ML/MF sampling for Bayesian inverse problems (Stein variational gradient descent, delayed acceptance, sequential Monte Carlo, optimal couplings).

Themes emerging from the working groups which led to ongoing collaborations include *“ML/MF for SPDEs”*, *“Beyond Gaussian Priors & Gaussian RFs”*, *“Extensions of Multilevel Delayed Acceptance”* and *“Software Benchmarking and Method Comparison”*.

Workshop 2 [Co-ordinator: Fabio Nobile] showcased several approaches and recent developments to approximate the parameter-to-solution map for high-dimensional parametric/random PDEs, including reduced basis methods (Ehrlacher, Uschmajev, Vidlickova, Rozza, Mula), kernel methods (Rieger), sparse approximations and compressed sensing (Dexter, Doostan), rational approximations (Pradovera), multilevel methods (Bespalov, Harbrecht), as well as more recent directions in machine learning and deep neural networks (Rauhut, Kutyniok). Other talks addressed the problem of approximating directly the probability distribution of output quantities (Sagiv, Ernst) or touched on more fundamental approximation theory questions on the optimality of certain representation/reconstruction algorithms (Dolbeault, Backmayr, Kazashi). Finally, some talks used hierarchical/sparse methods to address challenging applications (Farcas, Tamellini).

The rather relaxed schedule allocated coffee and free time in the morning before the first talk at 10:30, which was appreciated and used by the participants for individual discussions and interactions.

A one-hour group discussion has been organized on Wednesday morning. Topics for discussion were collected the day before and discussed in a plenary session. Several interesting challenges and research directions emerged from the discussion. These included: transferring and combining ideas between reduced basis methods and polynomial chaos approaches; studying reliability guarantees for training algorithms of new machine learning approaches to UQ; exploiting new hardware architectures that will become available in the machine learning field to improve the performance of established methods. Also, some discussion was initiated on the impact that the UQ community represented in the WS had and potentially will have on real world engineering/industrial applications.

Workshop 3 [Co-ordinator: Christoph Schwab] This WS explored numerical methods for UQ in *Bayesian Inverse Problems for Partial Differential Equations*. Here, the task is the inference of expected values of so-called *Quantities of Interest* (QoI's) for PDEs, subject to prior knowledge of a-priori unknown, hidden parameters in PDE inputs, and also subject to *noisy measurements*. Due to the strong impact of deep learning methodologies on the field of scientific computing during the past years, the theme of this WS was slightly re-aligned compared to the objective(s) in the original TP proposal.

The presentations focused on the one hand on *mathmatical formulation of Bayesian Inverse Problems* for various classes of PDEs, and on the other hand on the efficient numerical treatment of Bayesian Inversion, combined with advanced PDE discretization methods. Here, as in the other workshops, the dynamical development of deep neural network and tensor formatted techniques in step with model order reduction methods, during the past years was strongly reflected in the WS presentations. In this way, WS3 tied into scientific topics from WS1 and WS2, but also pointed forward to topics highlighted in WS4, later in the TP. Reduced models of PDE-based forward models were concluded to allow for a vast speedup in Markov-Chain Monte-Carlo methods for Bayesian Inversion and data assimilation.

Workshop 4 [Co-ordinator: Sara Van de Geer] This workshop brought together experts in theoretical statistics and numerical analysis. Combining these two communities was highly successful: workshop 4 was a unique opportunity to be exposed to an alternative way of thinking, an alternative way to put the emphasis, and also to see the relevance of strong results of another field to the WS theme. It is clear that the two fields statistics and numerical analysis complement each other and that knowledge transfer, on a high technical level, was extremely fruitful. This was also evident from the lively discussions that emerged! A multitude of themes were addressed, around neural networks, approximation, estimation and optimization. To give an impression of this let us present a brief summary.

Optimization of neural networks was for instance done exploiting fixed (sparse) support, or applying gradient descent methods or tensor-train reconstructions, as well as the use of sampling for incremental and provable learning of neural networks. The approximation properties were studied for Besov spaces and analytic functions, and via entropy numbers. The prediction of the flux of vehicles on a road was presented as well as the application of residual neural networks. Theory for data interpolation was presented not only for neural networks but also for random forests, for minimum-norm interpolation and for ada-boost. Several new statistical approaches were discussed, such as *minimum Wasserstein distance methods for deep generative networks*, estimation via measure transport, score-based methods, the MOM approach, and a new direct method for manifold learning. The Wasserstein distance also was invoked for studying robustness. There were new direct methods for image classification and results for distributional reinforcement learning. Finally, Bayesian inverse problems also had its share of attention, with special focus on the statistical inference.

Some of the talks in WS4 were online, and (hence) some of the participants also could participate only online, too. This worked very well, with an active online involvement in the discussions by these participants. The meeting of colleagues from another field paved the way to new collaborations. In short, it has been a very inspiring week with very nice people, notably including the ESI team.

Workshop 5 [Co-ordinator: Robert Scheichl] focused on two particularly interesting and challenging applications for UQ: kinetic and transport equations as well as high-frequency wave propagation. Due to the high computational cost and other numerical challenges, efficient UQ tools are still under active development in both those fields. The workshop schedule was deliberately kept relaxed with long coffee and lunch breaks to enable interaction among participants.

The presentations ranged from novel algorithmic developments for UQ in kinetic and transport equations, such as intrusive stochastic Galerkin, micro-macro generalized polynomial chaos, neural network based solvers, adaptive sparse polynomial interpolation, to more application-focused talks, e.g., on modelling coupled surface and body waves via the radiative transfer equation, the spread of epidemics such as Covid19, stochastic flocking, or the shallow water equations over uncertain bathymetry. Topics showcased in the context of high-frequency wave propagation focused on shape uncertainty in scattering and wave propagation in uncertain, hetertogeneous media; the range of numerical approaches included model order reduction, rational interpolation, first order moment approximation, multi-modes Monte Carlo, quasi-Monte Carlo, as well as multilevel Monte Carlo with local time-stepping. The workshop also contained more overarching and outlooking talks on the importance and range of scales and ill-posedness when considering numerical inversion from kinetic equations all the way to wave propagation models in the area of quantum computing.

TP Summary: The overall quality of the speakers and the presentations in all five workshops was very high. During the workshops, latest results, sometimes not yet published, were presented, and there has been a lot of interaction both during the talks and during the breaks. In the weeks in between the workshops, discussions and paper-writing took place at ESI. Collaborations among the participants have been advanced and new projects were initiated.

The excellent audiovisual support by ESI technical staff was a key ingredient in the success of the workshops, as oftentimes some participants were barred to participate in-person due to CoV-related travel restrictions.

The talks were also well-attended by “local” researchers from Vienna in particular around deep-learning themes and methods. Here, the hybrid-format was again extremely helpful to allow Vienna researchers to attend particular presentations “from (home-)office” when their regular academic schedules (research and teaching) precluded in-person attendance.

Outcomes and achievements

During the programme, TP participants started new projects and collaborations, and continued to work on ongoing projects. Some highlights are included here. A list of scientific talks is provided in the next section, with detailed information available under

`https://www.esi.ac.at/events/e426/`

Ch. Schwab (ETH) and J. Zech (U Heidelberg) have, during their stay at ESI, completed with L. Herrmann (RICAM, Linz) a paper on the expression rate analysis of so-called *deep Operator Networks*: these are deep neural networks which approximate maps between infinite-dimensional function spaces. The paper is submitted for publication and currently under review.

Yanchen He and Ch. Schwab (ETH) have, in joint work with C. Marcati (Uni Milano), in the ESI TP initiated work on analytic regularity of Leray-Hopf solutions to the Navier-Stokes equations in polygonal domains. A paper is completed and has been submitted.

F. Nobile (EPFL) and Y. Kazashi (U. Heidelberg), during their stay at ESI, have advanced on a work analyzing the formulation and well posedness of dynamical low rank equations for stochastic differential equations.

Following on from the group work in **WS1**, T. Cui (Monash U, Melbourne), A.-L. Haji-Ali (Heriot-Watt U, Edinburgh), F. Nobile (EPFL) and R. Scheichl (U Heidelberg) started a new collaboration on *Multi-index Delayed Acceptance MCMC*.

Another project emerging from **WS1**, initiated and driven by L. Seelinger (U Heidelberg) is related to setting up a suite of UQ benchmarks. It involves several other participants of the ESI TP, in particular N. Baumgarten (KIT Karlsruhe), T. Dodwell (U Exeter & Alan Turing Institute), J. Jakeman (Sandia National Labs, USA), R. Scheichl (U Heidelberg) and L. Tamelini (CNR-IMATI, Pavia), as well as further international researchers. A publication in a software journal is under preparation.

P. Rohrbach (U Cambridge) and R. Scheichl (U Heidelberg) finished at the ESI TP a paper on *"Multilevel simulation of hard-sphere mixtures"* in soft matter physics (with other co-authors). The paper is submitted for publication and under review.

T. Cui (Monash U) and R. Scheichl (U Heidelberg) spent an entire week at the ESI TP to finalise a paper on *"Deep importance sampling using tensor-trains with application to a priori and a posteriori rare event estimation"* jointly with S. Dolgov (U Bath), which is about to be submitted for publicaton.

K. Kirchner (TU Delft) and Ch. Schwab (ETH) worked during the TP on a longer term project related to MLMC convergence for statistical moments (2 and $k-$ point spatiotemporal correlation functions) of random solutions for PDEs. A key progress in this project was achieved during the discussions at ESI, and will be acknowledged in the paper (currently being finalized).

List of talks

Workshop 1 on "Multilevel and multifidelity sampling methods in UQ for PDEs", May 2 – 6, 2022

- Monday May 2, 2022

  1. Abdul-Lateef Haji-Ali (Heriot-Watt U, Edinburgh)
     Multilevel Path Branching for Digital Options
  2. Michael Feischl (TU Vienna)
     Convergence of adaptive stochastic collocation
  3. Tiangang Cui (Monash U, Melbourne)
     Multi-Level Optimization based Monte-Carlo Samplers for Large-Scale Inverse Problems
  4. Neil Chada (KAUST, Thuwal)
     Improved efficiency of multilevel Monte Carlo for stochastic PDE through strong pairwise coupling
  5. Lorenzo Tamellini (CNR-IMATI, Pavia)
     Comparing Multi-Index Stochastic Collocation and Multi-Fidelity Stochastic Radial Basis Functions for Forward Uncertainty Quantification of Ship Resistance

- Tuesday, May 3, 2022

  1. Andreas Stein (ETH Zurich)
     Multilevel Monte Carlo FEM for Elliptic PDEs with Besov Random Tree Priors Recording
  2. Niklas Baumgarten (KIT, Karlsruhe)
     A Non-Intrusive Multilevel Uncertainty Quantification (UQ) Framework for Wave Equations with Random Input Data
  3. Linus Seelinger (U Heidelberg)
     UM-Bridge: Bridging the Gap Between UQ and Model Software
  4. Paul Rohrbach (U Cambridge)
     Multilevel simulation of hard sphere mixtures
  5. Tim Dodwell (U of Exeter)
     Adaptive Multilevel Delayed Acceptance

6. Alex Gorodetsky (U of Michigan, Ann Arbor)
   MFNETS: Multifidelity surrogate modeling of ensembles of information sources through directed acyclic graphs

- Wednesday May 4, 2022

  1. Juan Pablo Madrigal Cianci (EPFL Lausanne)
     Multi-level Markov Chain Monte Carlo Methods for Bayesian Inverse Problems
  2. Andrea Barth (U Stuttgart)
     Uncertainty quantification and subordinated fields
  3. Parisa Khodabakhshi (U of Texas, Austin)
     Multifidelity Uncertainty Quantification for Nonlocal Models
  4. Ionut-Gabriel Farcas (U of Texas, Austin)
     Learning hierarchies of reduced-dimension and context-aware low-fidelity models for multi-fidelity Monte Carlo sampling

- Thursday, May 5, 2022

  1. Benjamin Peherstorfer (CIMS, New York)
     Multilevel Stein variational gradient descent with applications to Bayesian inverse problems
  2. Shangda Yang (U of Manchester)
     Multi-index Sequential Monte Carlo Ratio estimators for Bayesian Inverse problems
  3. Mikkel Lykkegaard (U of Exeter)
     Derivative-Free Thinning (DaFT) with Stochastic Kernel Embeddings
  4. Pieterjan Robbe (Sandia National Laboratories)
     Uncertainty Quantification in Computational Modeling of Plasma-Surface Interactions

- Friday May 6, 2022

  1. Hermann Matthies (TU Braunschweig)
     What is a Sample?
  2. Elisabeth Ullmann (TU Munich)
     Rare event estimation with PDE-based models

Workshop 2 on "Approximation of high-dimensional parametric PDEs in forward UQ" May 9 – 13, 2022

- Monday, 9 May, 2022

  1. Virginie Ehrlacher (ENPC, Paris)
     Influence of Monte-Carlo sampling on greedy algorithms for variance reduction
  2. André Uschmajew (MPI Leipzig)
     Dynamical low-rank approximation for parabolic problems
  3. Christian Rieger (Philipps U, Marburg)
     Kernel based reconstruction for Bayesian inverse problems
  4. Ionut-Gabriel Farcas (U of Texas, Austin)
     A general framework for quantifying uncertainty at scale and its application to fusion research

- Tuesday May 10, 2022

  1. Eva Vidlickova (EPFL Lausanne)
     Variational Formulation and Stability Properties of a Projector-Splitting Scheme for Dynamical Low Rank Approximation of Random Parabolic Equations

2. Gianluigi Rozza (SISSA, Trieste)
   Stabilized Reduced Order Methods for Transport Control Problems with Random Inputs
3. Matthieu Dolbeault (Sorbonne U, Paris)
   A sharp upper bound for sampling numbers in L_2
4. Amir Sagiv (Columbia University, New York)
   A Measure Perspective on Uncertainty Propagation
5. Nicholas Dexter (Simon Fraser U, Vancouver)
   Efficient algorithms for computing near-best polynomial approximations to high-dimensional, Hilbert-valued functions from limited samples

- Wednesday May 11, 2022

  1. Alex Bespalov (U of Birmingham)
     Multilevel and goal-oriented adaptivity for stochastic Galerkin FEM Recording
  2. Alireza Doostan (U of Colorado, Boulder)
     GenMod: A generative modeling approach for spectral representation of PDEs with random inputs
  3. Oliver Ernst (TU Chemnitz)
     Wasserstein Sensitivity of Risk and Uncertainty Propagation

- Thursday May 12, 2022

  1. Markus Bachmayr (U Mainz)
     Multilevel representations of random fields
  2. Helmut Harbrecht (University of Basel)
     Efficient discretization techniques of shape uncertainty problems
  3. Holger Rauhut (RWTH Aachen)
     The implicit bias of gradient descent for learning deep neural networks
  4. Yoshihito Kazashi (U Heidelberg)
     Sub-optimality of Gauss–Hermite quadrature and optimality of trapezoidal rule for functions with finite smoothness
  5. Davide Pradovera (U Vienna)
     Surrogate modeling of parametric frequency response problems via locally adaptive sparse grids

- Friday May 13, 2022

  1. Olga Mula Hernandez (Dauphine U, Paris)
     Sparse, Adaptive Interpolation of Measures with Wasserstein Barycenters. Application to Model Order Reduction.
  2. Gitta Kutyniok (LMU Munich)
     The Impact of Artificial Intelligence on Parametric Partial Differential Equations
  3. Lorenzo Tamellini (CNR-IMATI, Pavia)
     Multi-Index Stochastic Collocation for forward UQ of single- and multi-disciplinary systems

Workshop 3 on "PDE-constrained Bayesian inverse problems: Interplay of spatial statistical models with Machine Learning in PDE discretizations" May 16 – 20, 2022

- Monday, 16 May, 2022

  1. Viet-Ha Hoang (NTU Singapore)
     Bayesian inversion of log-normal eikonal equation
  2. Karen Veroy-Grepl (TU Eindhoven, The Netherlands)
     Optimal Experimental Design in the Deterministic and Bayesian Settings

3. Juan Pablo Madrigal Cianci (EPFL Lausanne, Switzerland)
   Generalized Parallel Tempering for Bayesian Inverse Problems
4. Qin Li (U of Wisconsin-Madison, USA)
   Mean field theory in Inverse Problems: from Bayesian inference to overparameterization of networks

- Tuesday, 17 May, 2022
  1. Simon Weissmann (U Heidelberg, FRG)
     Surrogate based one-shot formulation for inverse problems and optimization under uncertainty
  2. Björn Sprungk (TU Freiberg, FRG)
     Noise-level robust MCMC and pushforward Markov kernels
  3. Nikolas Nuesken (KCL, London, UK)
     Stein optimal transport for Bayesian inference
  4. Bjorn Engquist (U of Texas, Austin, USA)
     Seismic inversion in the presence of noise
  5. Franziska Weber (Carnegie Mellon U, Pittsburgh, USA)
     On Bayesian data assimilation for PDEs with ill-posed forward problems
  6. Nicholas Nelsen (CalTech)
     Noisy linear operator learning as an inverse problem
- Wednesday, 18 May, 2022
  1. Robert Scheichl (U Heidelberg, FRG)
     Multilevel Delayed Acceptance MCMC
  2. Kristin Kirchner (TU Delft, The Netherlands)
     When are linear predictions of random fields using wrong mean and covariance functions asymptotically optimal?
  3. Susana Gomes (U Warwick, UK)
     Parameter Estimation for Macroscopic Pedestrian Dynamics Models using Microscopic Data
  4. Marie-Therese Wolfram (U Warwick, UK)
     Ensemble Inference Methods for Models with Noisy and Expensive Likelihoods
  5. Hanne Kekkonen (TU Delft, The Netherlands)
     Consistency of Bayesian inference for a parabolic inverse problem
  6. Daniel Zhengyu Huang (Caltech, Pasadena, USA)
     Efficient Derivative-free Bayesian Inference for Large-Scale Inverse Problems
- Thursday, 19 May, 2022
  1. Urbain Vaes (INRIA Paris, France)
     Consensus-based sampling
  2. Jakob Zech (U Heidelberg, FRG)
     Approximation and computation of triangular transport maps
  3. Peng Chen (U of Texas, Austin, USA)
     Projected Variational Methods for High-dimensional Bayesian Inference
  4. Alexey Chernov (U of Oldenburg, FRG)
     Bayesian parameter identification of impedance boundary conditions for Helmholtz problems
  5. Omar Ghattas (U of Texas, Austin, USA)
     Reduced Basis Neural Network Surrogates for Bayesian Inversion and Optimal Experimental Design

6. Houman Owhadi (Caltech, Pasadena, USA)
   Computational Graph Completion

Workshop 4 on "Statistical estimation and deep learning in UQ for PDEs", May 30 –June 3, 2022

- Monday, 30 May, 2022
  1. Remi Gribonval (Inria Lyon, France)
     Rapture of the deep : highs and lows of sparsity in a world of depths
  2. Richard Nickl (University of Cambridge, UK)
     Bayesian non-linear inverse problems: Progress and Challenges
  3. Po-Ling Loh (University of Cambridge, UK)
     Robust W-GAN-Based Estimation Under Wasserstein Contamination
  4. Claire Boyer (Sorbonne University, Paris, France)
     Is interpolation benign for random forest regression?
- Tuesday, 31 May, 2022
  1. Helmut Bölcskei (ETH Zürich, Switzerland)
     Metric entropy limits on recurrent neural network learning of linear dynamical systems
  2. Andrew Barron (Yale University, New Haven, USA)
     Evolving posterior parameters for fitting mixture models and neural nets
  3. Pierre Alquier (RIKEN AIP, Japan)
     Robust estimation via minimum distance estimation
  4. Michael Kohler (TU Darmstadt, Germany)
     Estimation of multivariate regression functions by overparametrized deep neural networks
  5. Joost Opschoor (ETH Zürich, Switzerland)
     Constructive Deep ReLU Neural Network Approximation
- Wednesday, 1 June, 2022
  1. Petr Zamolodtchikov (University of Twente. The Netherlands)
     Local convergence rates of the least-squares estimator with applications to transfer learning
  2. Sven Wang (MIT, Cambridge, USA)
     Minimax density estimation via measure transport
  3. Alexis Derumigny (TU Delft, The Netherlands)
     Robust-to-outliers square-root Lasso, simultaneous inference with a MOM approach
- Thursday, 2 June, 2022
  1. Annika Lang (CUT, Gothenburg, Sweden)
     Short-term traffic prediction using physics-aware neural networks
  2. Geoffrey Chinot (ETH Zürich, Switzerland)
     Adaboost and robust 1-bit compressed sensing
  3. Carola-Bibiane Schönlieb (University of Cambridge, UK)
     Score based diffusion models for conditional generation
  4. Fan Yang (ETH Zürich, Switzerland)
     Generalization performance of interpolating models in high dimensions
  5. Sophie Langer (TU Darmstadt, Germany)
     Image classification: A (new) statistical viewpoint
  6. Hrushikesh Mhaskar (Claremont Graduate University, USA)
     A direct method for approximation on unknown manifolds
- Friday, 3 June, 2022

1. Clemens Heitzinger (TU Vienna, Austria)
   Convergence in distributional reinforcement learning and applications
2. Taiji Suzuki (University of Tokyo, Japan)
   Adaptivity of deep learning: Efficiency of function estimation and optimization guarantee from nonconvexity view-point
3. Tiangang Cui (Monash University, Melbourne, Australia)
   DIRT: a tensorised inverse Rosenblatt transport method

Workshop 5 on "UQ in kinetic and transport equations and in high-frequency wave propagation", June 13 – 17, 2022

- Monday June 13, 2022
  1. Shi Jin (Shanghai Jiao Tong University)
     Uncertain Quantification of ODEs/PDEs in quantum computing
  2. Josselin Garnier (Ecole Polytechnique, Palaiseau)
     Radiative transfer equation for surface and body waves
  3. Giacomo Dimarco (U of Ferrara)
     Micro-macro generalized polynomial chaos techniques for kinetic equations
  4. Martin Frank (KIT, Karlsruhe)
     Some Aspects of Uncertainty Quantification for Hyperbolic Conservation Laws
  5. Alina Chertock (North Carolina State U)
     Well-Balanced and Positivity Preserving Stochastic Galerkin Method for the Saint-Venant System with Uncertainty
  6. Li Wang (U of Minnesota)
     Neural network based solver for kinetic equations
- Tuesday June 14, 2022
  1. Lorenzo Pareschi (U of Ferrara)
     Stochastic Galerkin particle methods
  2. Francesca Bonizzoni (U Augsburg)
     Rational-based MOR methods for parametric-in-frequency Helmholtz problems with adapted snapshots
  3. Carlos Jerez-Hanckes (U Adolfo Ibanez)
     Helmholtz Scattering By Random Domains: First-Order Sparse Boundary Element Approximation
  4. Davide Pradovera (U Vienna)
     Can reliable surrogate models for frequency-domain problems be both non-intrusive and cheap to build?
  5. Qin Li (U of Wisconsin-Madison)
     Multiscale inverse problem, from Schroedinger to Newton to Boltzmann
  6. Jose Morales Escalante (UT San Antonio)
     Stochastic Galerkin Methods for the Boltzmann-Poisson system
- Wednesday June 15, 2022
  1. Xiaobing Feng (U of Tennessee, Knoxville)
     An efficient multi-modes Monte Carlo method for wave scattering in random media
  2. Giulia Bertaglia (U of Ferrara)
     Uncertainty quantification of the spatial spread of epidemics described through kinetic models
  3. Laura Scarabosio (Radboud U)
     Deep neural network surrogates for Helmholtz problems

4. Yuhua Zhu (SU)
   The Vlasov-Fokker-Planck Equation with High Dimensional Parametric Forcing Term

- Friday June 17, 2022

1. Ivan Graham (U Bath)
   The forward problem of UQ for the high-frequency Helmholtz equation
2. Mattia Zanella (U Pavia)
   Uncertainty quantification for kinetic equations of emergent phenomena
3. Simon Michel (U Zürich)
   Uncertainty Quantification by MLMC and Local Time-stepping For Wave Propagation
4. Seung-Yeal Ha (Seoul National U)
   Stochastic flocking of the Cucker-Smale flocking model
5. Ralf Hiptmair (ETH Zürich)
   Frequency-Explicit Shape Uncertainty Quantification for Acoustic Scattering

Publications and preprints contributed

L. Herrmann and Ch. Schwab, J. Zech, *Neural and gpc operator surrogates: construction and expression rate bounds*, Report number 2022-27, Seminar for Applied Mathematics, ETH Zürich.

T. Cui, S. Dolgov, R. Scheichl, *Deep importance sampling using tensor-trains with application to a priori and a posteriori rare event estimation*, arXiv:2209.01941 [stat.ML].

D. Elfverson, R. Scheichl, S. Weissmann, F.A. DiazDelaO, *Adaptive multilevel subset simulation with selective refinement for rare event probabilities*, arXiv:2208.05392 [math.NA].

P.B. Rohrbach, H. Kobayashi, R. Scheichl, N.B. Wilding, R.L. Jack, *Multilevel simulation of hard-sphere mixtures*, arXiv:2206.00974 [cond-mat.stat-mech].

List of participants

Anton Arnold, Francis Bach, Markus Bachmayr, Gichan Bae, Andrew Barron, Niklas Baumgarten, Giulia Bertaglia, Alex Bespalov, Helmut Bölcskei, Francesca Bonizzoni, Peng Chen, Alexey Chernov, Geoffrey Chinot, Andrés Christen, Albert Cohen, Tiangang Cui, Nada Cvetkovic, Masoumeh Dashti, Giacomo Dimarco, Matthieu Dolbeault, Virginie Ehrlacher, Bjorn Engquist, Oliver Ernst, Michael Feischl, Xiaobing Feng, Martin Frank, Josselin Garnier, Susana Gomes, Ivan Graham, Remi Gribonval, Elena Griniari, Philipp Grohs, Seung-Yeal Ha, Abdul-Lateef Haji-Ali, Helmut Harbrecht, Gottfried Hastermann, Yanchen He, Clemens Heitzinger, Lukas Herrmann, Ralf Hiptmair, Håkon Hoel, Gyuyoung Hwang, Carlos Jerez-Hanckes, Barbara Kaltenbacher, Clemens Karner, Yoshihito Kazashi, Vladimir Kazeev, Kristin Kirchner, Karina Koval, Peter Kritzer, Sophie Langer, Qin Li, Han Cheng Lie, Matthias Loeffler, Marcello Longo, Juan Pablo Madrigal Cianci, Carlo Marcati, Hermann Matthies, Simon Michel, Richard Nickl, Fabio Nobile, Joost Opschoor, Benjamin Peherstorfer, Ilaria Perugia, Philipp Petersen, Catherine Powell, Davide Pradovera, Dirk Praetorius, Sebastian Reich, Christian Rieger, Paul Rohrbach, Gianluigi Rozza, Michele Ruggeri, Andrea Scaglioni, Laura Scarabosio, Robert Scheichl, Claudia Schillings, Christoph Schwab, Linus Seelinger, Jonathan Spence, Björn Sprungk, Andreas Stein, Taiji Suzuki, Leila Taghizadeh, Lorenzo Tamellini, Raul Tempone, Elisabeth Ullmann, André Uschmajew, Sara van de Geer, Karen Veroy-Grepl, Eva Vidlickova, Sven Wang, Marie-Therese Wolfram, Fan Yang, Petr Zamolodtchikov, Mattia Zanella, Jakob Zech.

Invited scientists who participated online

Pierre Alquier, Hosseini Bamdad, Andrea Barth, Peter Bartlett, Liliana Borcea, Claire Boyer, Giuseppe Carere, Neil Chada, Alina Chertock, Colin Cotter, Matteo Croci, Alexis Derumigny, Nicholas Dexter, Josef Dick, Tim Dodwell, Alireza Doostan, Martin Eigel, Ionut-Gabriel Farcas, Sara Fraschini, Omar Ghattas, Alex Gorodetsky, Harshith Gowrachari, Diane Guignard, Eldad Haber, Viet-Ha Hoang, Thorsten Hohage, Gianluca Iaccarino, John Jakeman, Ajay Jasra, Shi Jin, Hanne Kekkonen, Parisa Khodabakhshi, Amirreza Khodadadian, Michael Kohler, Karl Kunisch, Gitta Kutyniok, Annika Lang, Jonas Latz, Kody Law, Liu Liu, Yuena Liu, Po-Ling Loh, Mikkel Lykkegaard, Youssef Marzouk, Hrushikesh Mhaskar, Giovanni Migliorati, Jose Morales Escalante, Mohammad Motamed, Olga Mula Hernandez, Nicholas Nelsen, Monica Nonino, Anthony Nouy, Nikolas Nuesken, Dirk Nuyens, Houman Owhadi, Iason Papaioannou, Andreas Postl, Elizabeth Qian, Holger Rauhut, Pieterjan Robbe, Olof Runborg, Amir Sagiv, Johannes Schmidt-Hieber, Sebastian Schmutzhard-Hoefler, Carola-Bibiane Schönlieb, Elnaz Seylabi, Aarti Singh, Ian Sloan, Euan Spence, Hans Peter Stimming, Urbain Vaes, Barbara Verfürth, Matti Vihola, Silvia Villa, Umberto Villa, Martin Wainwright, Li Wang, Gregor Wautischer, Franziska Weber, Clayton Webster, Simon Weissmann, Karen Willcox, Shangda Yang, Lexing Ying, Lenka Zdeborova, Daniel Zhengyu Huang, Yuhua Zhu.

Higher Structures and Field Theory

Organizers: Anton Alekseev (U Genève), Stefan Fredenhagen (U Vienna), Nicolai Reshetikhin (UC, Berkeley), Thomas Strobl (U Lyon), Chenchang Zhu (U Göttingen)

Dates: August 1 – 26, 2022

Budget: ESI € 49 723
U of Vienna, Faculty of Physics € 560 for travel costs for selected participants.

Report on the thematic programme

Field theories in their modern form connect more and more to higher structures. This applies in particular to quantum field theories, but also becomes increasingly true on the classical level as well. For example, classically the physics of a gauge field theory is described by the solutions of its Euler-Lagrange equations, where solutions connected to one another by a gauge symmetry transformation are identified as physically equivalent. This quotient by the gauge group is often singular and one is naturally led to consider stacks, groupoids up to Morita equivalence. But already before taking a potentially singular quotient, the restriction to classical solutions generally does not permit a sufficiently good description of the resulting space to compute questions of interest for physics.

Both steps, the restriction to solutions in the Lagrangian setting, which corresponds to the restriction to the constraint surface in the Hamiltonian setting, and the quotienting by the gauge symmetry group in the Lagrangian as well as the Hamiltonian setting, suggest to consider a cohomological approach: in the Lagrangian formulation of the field theory this is the BV formalism and in the Hamiltonian formulation the BFV formalism—invented by Batalin and Vilkovisky and Batalin, Fradkin and Vilkovisky, respectively. Here the space of fields is extended to include ghosts and ghosts for ghosts and the physics, on the classical as well as on the quantum level, is described by the cohomology of an operator squaring to zero.

Operators (or odd vector fields) squaring to zero also play an important role in describing higher versions of Lie algebras and Lie algebroids. They become omnipresent in gauge theories containing not only 1-form gauge fields, but also 2-form or higher form gauge fields. Bundle gerbes are examples. Such type of gauge theories are induced in the low energy limit of String Theory, for example, but also made their appearance in condensed matter physics recently. The bundles governing the geometry of higher gauge theories is subject of active research and the last word is not spoken here as it seems. One of the expected features in such a formulations is that 2-groups and n-groups replace the structure group of the usual principal bundles governing ordinary gauge theories.

Tackling quantum field theories in a categorical approach was particularly successful in the context of topological quantum field theories (TQFTs). In fact, TQFTs can be considered as functors from, on the one hand, the category of manifolds with cobordisms as its morphisms to, on the other hand, the category of vector spaces (with potentially additional structures, like equipping the vector spaces with scalar products turning them, for example, into Hilbert spaces).

Fully extended TQFTs go one step further here: they extend this idea to cases of manifolds with edges, i.e. whose boundaries can have boundaries themselves etc. One then considers functors in higher categories, in which one has 2-morphisms (morphisms between morphisms) and so on. This turns out to be an additional restriction and for some of the well-known TQFTs like the Chern-Simons theory it is not yet known if they are fully extended or fully extendable.

Recently there are, moreover, also attempts to define ordinary quantum field theories (QFTs), i.e. those which describe also propagating degrees of freedoms or particles, in a functorial way. One of the main guiding principles would be cutting and gluing rules for QFTs, also in their BV formulation in the case of gauge symmetries. One prominent approach in this direction is the BV-BVF formulation of Cattaneo, Mnev and Reshetikhin, but there are also other such attempts, in particular for defining QFTs on curved spacetimes.

All the above aspects of the interaction of field theories with higher structures were represented in this program. In addition, progress in both, field theory or higher structures by themselves, were covered as well—like, for example, the integration of higher Lie algebras to higher Lie groupds and the inverse operation, the differentiation of higher Lie group(oid)s to higher Lie algebras/oids.

The four weeks in 2022 were a continuation of the program from 2020 with the same title and was financed from the remaining funds of the first part—since then, due to the pandemic, the program was in part taking place online only. For this reason we also refer to the report on the first part of the program as a complement to the present one.

Activities

First week on dg Manifolds and Field Theory

Differential graded (dg) manifolds are some sort of higher and derived objects, which have appeared much in field theory in recent years. There are gradually rich math foundational works done for such objects. We aimed at linking the math foundational works and the field theoretical side in this week.

In the earlier part of this week, there were mostly mathematical talks focusing on foundational works around dg manifolds and similar objects. Del Hoyo talked about Lie bialgebroids and Kotov and Salnikov about their joint work on proper definitions of dg manifolds.

In the second part of this week, there were mostly talks on field theory with dg manifolds involved, as application. Blohmann talked about the appearance of multisymplectic geometry in field theory and Lazaroiu and Shahbazi about their joint work on supergravity and U-duality, for example.

There were quite a lot of interactions between mathematicians and mathematical physicists.

Second week on Higher Derived Structures and the B(F)V formalism for Field Theories

Higher/derived Structures is a vast topic which unifies modern approaches to homotopy theory and quantization and their links to quantum field theory.

There are recent break-throughs in 2-category setting with application to topological orders. Topological orders coming from physics in material science, related to the area of condensed matter (2016 Nobel Prize), now also combined with higher categorical theory, field theory. Many things come into play. Our trimester in 2020, which was in part moved online due to the pandemic, has contained a focus week on this topic, including two minicourses of Dirac Medal and Buckley Condensed Matter Prize winner Xiao-Gang Wen from MIT, together with Anton Kapustin from CalTech, respectively.

Two years have passed, we now see some following up foundational work in mathematics in representation theory with 2-category setting, such as the talk of Davydov and Nikshych. This is certainly very rewarding. In the third week, there were more talks in this direction.

In this week there were also several talks about Batalin-Vilkovisky (BV) and Batalin-Fradkin-Vilkovisky (BFV) formulations of field theories. Three of those were given by young participants, Dneprov, Hancharuk and Simunic. Hancharuk gave a beautiful talk about the construction of a Koszul-Tate resolution for ideals in Noetherian rings; this is one of the key steps in the construction of a BFV formulation for the case of singular reduction. Jurco reported about attemps of his research group to define a proper category of BV theories and Grigoriev summarized the progress he and his collaborators made on extending the AKSZ procedure to obtain BV formulations of a much larger class of field theories, like general relativity and the like.

Finally, it is worth mentioning the inspiring talk of Carchedi on the combination of derived geometry and quantum field theory, which he outlined at the example of a toy model. This is a vastly growing subject with more and more contributions in the recent years.

The last two weeks were maybe the most populated ones in the 2022 part of the programme and we had a variety of subjects which forbids attaching a single one as a title describing that week.

Third week

Due to a holiday, this week consisted only of four working days, all of which featured talks from various subjects: Hull explained how homotopy Lie structures appear naturally in field theories, Waldorf and Saemann dealt with T-duality and higher geometry, a subject reappearing in the fourth week by the talk of Valach, which advertised yet another prespective on it. The relation of BV structures and non-commutative geometry was subject of the talks by Szabo, an established researcher in the field, and Iseppi, a young postdoc. Skvortsov summarized some recent developments in higher spin theories, Ikeda related multisymplectic geometry to sigma models (some type of field theories), and Wagemann reported about the cohomolgy of Leibniz algebras, which play an increasingly important role in the context of supergravity theories due to their relation with embedding tensors. But also subjects such as non-standard space-times emerging in (non-standard) gravity theories (talk by Bojowald), the S-matrix in quantum field theories (talk by Reutter), and shifted geometry and groupoids (talk by Cueca) shaped this week to an interesting combination of a variety of interlinked topics, each of which relating to higher structures and field theories in their own way.

Fourth week

This week was the final week of the programme. It featured a number of inspiring talks by the leaders of the field and also by junior researchers.

To mention some of the highlights: Dmitry Roytenberg (one of the founders of the field of Higher Structures) presented a higher Lie theory, Maxim Zabzine (one of the leaders of the mathematical physics community) explained a new approach to equivariant integration on non-compact manifolds inspired by physics, Urs Schreiber (a charismatic researcher in the field of Higher Structures) made an unexpected link between twisted equivariant differential K-theory and topological orders, Francesco Bonechi explained the relation between quasi-Poisson groupoids and 1-shifted Poisson structures. Among other things, the talk of Bonechi makes a link to a non-standard model of equivariant cohomology due to Alekseev-Severa.

Among the talks by junior participants one should single out the following ones: Nils Carqueville explained the concepts of extended TQFTs and applied these principles to Rozansky-Witten models. Zoreh Ravanpak applied the idea of unimodularity to Poisson-Lie groups in a novel way, and Leonid Ryvkin showed some new results on the linearlization for singular foliations.

Specific information on the thematic programme

As already in the first part of the programme, much attention was given to inviting young researchers, giving them a stage for presenting their results and ideas, and providing ample space for more senior researchers to interact with them. For further details we refer to the previous report as well as to the examples provided in the previous subsection.

Outcomes and achievements

- Topological orders has recent emergent interaction with higher categorical theory, field theory. Many things come into play. Two years ago, in our trimester, Xiao-Gang Wen, a Dirac Medal and Buckley Condensed Matter Prize winner, has given a mini-course. There were more than 200 people attending online (and the trans-cast in China of Xiao-Gang's lecture, attracted around 2000 people attending online). Two years later, a rapid developing area in mathematics has been formed to host the physics phenomenon. People in representation theory, such as Nikshych, Davydov, and Reutter from the spectrum of young people, have reported their progress.

- Differential graded manifolds, and their global objects, (derived) Lie n-groupoids, are concrete models for derived and higher geometry. These objects, especially those with shifted Poisson or symplectic structures, are used widely in mathematical physics. We have invited people from the math side, focusing on the mathematical foundations of the theory of dg manifolds, and people from physics side, focused on field theory involving dg manifolds such as the Batalin-Vilkovisky formalism. The communication between both sides was lively and fruitful.

- Several ongoing discussions and collaborations were initiated or continued by the programme. To give some examples, Janssens, Ryvkin and Vizman could continue their discussions which they had already in the first part of the program and that had already led to a joint article also in the present part. They are now preparing a second article on their joint findings. Ikeda with Chatzistavrakidis on the one hand and with Hancharuk and Strobl on the other hand deepened their collaborations paving way to potential joint articles. Alekseev started discussing with Bonechi and Strobl collaborating with Ravanpak, both interactions leading to subsequent meetings after the programme ended.

List of talks

Matias L del Hoyo (UFF)	On double Lie bialgebroids
Vladimir Salnikov (CNRS / U La Rochelle), Alexei Kotov (U Hradec Králové)	Some constructions from graded geometry
Iuliu-Calin Lazaroiu (IFIN-HH, Bucharest)	The DSZ quantization and self-dual formulation of four-dimensional supergravity
Christian Blohmann (MPIM, Bonn)	Homotopy reduction of multisymplectic structures in field theory
Hadi Nahari (U Lyon)	Singular Riemannian foliations and I-Poisson manifolds
Carlos Shahbazi (UNED Madrid)	The differential geometry of arithmetic U-duality
Athanasios Chatzistavrakidis (RBI, Zagreb)	Twisted R-Poisson Sigma Models and Higher Geometry
David Carchedi (George Mason U, Fairfax)	Derived Manifolds in Quantum Field Theory
Alexei Davydov (Ohio State U, Columbus)	Deformation cohomology of tensor categories
Chenchang Zhu (U Göttingen)	Differentiation of higher Lie groupoid
Zoran Škoda (U Zadar)	Nonassociative deformations and Hopf algebroids
Martin Schlichenmaier (U of Luxembourg)	*N*-point Virasoro algebras are multi-point Krichever-Novikov type algebras
Dmitri Nikshych (U of New Hampshire)	Braided module categories, 2-centers, and higher Morita equivalences for braided tensor categories
Branislav Jurco (Charles U, Prague)	On the category of BV-theories (loop homotopy algebras)
Grgur Simunic (Institut Ruđer Bošković)	Classical BV action of topological Dirac sigma model
Jürgen Fuchs (U Karlstad)	String nets and universal RCFT correlators
Ivan Dneprov (Moscow)	Presymplectic BV-AKSZ formulation of Conformal Gravity
Aliaksandr Hancharuk (U Lyon)	On Koszul-Tate resolutions: an explicit construction using decorated trees
Maxim Grigoriev (Moscow)	Local gauge theories as presymplectic gauge PDEs
Chris Hull FRS (Imperial College, London)	The L-infinity Structure of Effective Field Theory
Konrad Waldorf (U Greifswald)	Geometric T-duality: Buscher rules in general topology
Miquel Cueca (U Göttingen)	Shifted lagrangian groupoids on BG
Christoph Schweigert (U Hamburg)	Traces and higher structures
Martin Bojowald (Penn State)	Hypersurface deformation structures and space-time models
Richard Szabo (Heriot-Watt U, Edinburgh)	BV quantization of noncommutative field theories
Eugene Skvortsov (U Mons)	Strong homotopy algebras for higher spin gravity and 3d bosonization duality
David Reutter (U Hamburg)	Higher S-matrices and a form of Poincare duality for anomalous TQFTs
Christian Saemann (Heriot-Watt U, Edinburgh)	Non-Geometric T-duality from Higher Groupoid Bundles with Connections
Noriaki Ikeda (Ritsumeikan U, Kusatsu)	Lie algebroids on (pre-mutli)symplectic manifolds and topological sigma models
Roberta Anna Iseppi (Georg-August-U, Göttingen)	The Batalin-Vilkovisky construction for finite spectral triples
Friedrich Wagemann (U Nantes)	Vanishing and nonvanishing theorems for the cohomology of nilpotent Leibniz algebras

Dmitry Roytenberg (U Amsterdam)	A homotopy theory for higher Lie theory
Fridrich Valach (Imperial College, London)	Exceptional generalised geometry, consistent truncations, and Poisson—Lie U-duality
Nils Carqueville (U Vienna)	Truncated Rozansky-Witten models as extended TQFTs
Olaf Hohm (HU Berlin)	Double Copy of Yang-Mills
Zohreh Ravanpak (IMPAN)	Unimodularity and invariant volume forms for Hamiltonian dynamics on Poisson-Lie groups
Oscar Cosserat (U of La Rochelle)	Symplectic groupoids for Poisson integrators
Maxim Zabzine (Uppsala U)	Equivariant partition functions and geometry
Allison Pinto (HU Berlin)	Homological Quantum Mechanics
Urs Schreiber (NYUAD)	TED K-theory of Cohomotopy moduli spaces and Anyonic Topological Order
Lukas Woike (U of Copenhagen)	Modular Functors and Factorization Homology
Antonio Miti (MPIM, Bonn)	Symmetries and Reduction of Multisymplectic Manifolds
Francesco Bonechi (INFN, Firenze)	Morita Invariance of Quasi Poisson Structures
Jiří Nárožný (Charles U, Prague)	Generalised Atiyah's Theory of Principal Connections
Leonid Ryvkin (U Göttingen)	Linearisation theorems for singular foliations

Publications and preprints contributed

B. Janssens, L. Ryvkin, C. Vizman, *The L_∞-algebra of a symplectic manifold*, Pacific J. Math. 314 (2021) 81-98.

A. Hancharuk, T. Strobl, *BFV extensions for mechanical systems with Lie-2 symmetry*, arXiv:2104.12257[hep-th].

H. Nahari, T. Strobl, *Singular Riemannian foliations and I-Poisson manifolds*, arXiv: 2210.17306[math.DG].

N. Ikeda, T. Strobl, *BV and BFV for the H-twisted Poisson sigma model*, arXiv: 1912.13511[hep-th].

Invited scientists

Anton Alekseev, Denis Bashkirov, Thomas Basile, Christian Blohmann, Martin Bojowald, Francesco Bonechi, Mark Bugden, Frédéric Butin, David Carchedi, Nils Carqueville, Athanasios Chatzistavrakidis, Oscar Cosserat, Miquel Cueca, Rea Dalipi, Alexei Davydov, Matias L del Hoyo, Ivan Dneprov, Sebastian Fertl, Alessandra Frabetti, Jordan François, Stefan Fredenhagen, Jürgen Fuchs, Maxim Grigoriev, Aliaksandr Hancharuk, Olaf Hohm, Chris Hull, Noriaki Ikeda, Nevena Ilieva, Roberta Anna Iseppi, Bas Janssens, Larisa Jonke, Branislav Jurco, Alexei Kotov, Iuliu-Calin Lazaroiu, Antonio Miti, Hadi Nahari, Jiří Nárožný, Milan Niestijl, Dmitri Nikshych, Allison Pinto, Zohreh Ravanpak, David Reutter, Vladimir Roubtsov, Dmitry Roytenberg, Leonid Ryvkin, Davide Saccardo, Christian Saemann, Vladimir Salnikov, Claudia Scheimbauer, Michele Schiavina, Martin Schlichenmaier, Urs Schreiber, Peter Schupp, Christoph Schweigert, Gabriel Sevestre, Carlos Shahbazi, Georgy Sharygin, Grgur Simunic, Zoran Škoda, Eugene Skvortsov, Thomas Strobl, RafałR. Suszek, Richard Szabo, Alice Barbara Tumpach, Fridrich Valach, Cornelia Vizman, Friedrich Wagemann, Konrad Waldorf, Lukas Woike, Hao Xu, Maxim Zabzine, Chenchang Zhu.

Tensor Networks: Mathematical Structures and Novel Algorithms

Organizers: Frank Pollmann (TU Munich), Norbert Schuch (U Vienna), Frank Verstraete (Ghent U)

Dates: August 29 – October 21, 2022

Budget: ESI € 54 880
European Research Council € 1 350
U of Vienna € 7 290

Report on the thematic programme

Context

Tensor networks provide a new paradigm for efficiently describing quantum many body systems. Since the early years of quantum mechanics, the quantum many body problem has been one of the main driving forces in theoretical physics. A lot of progress has been made in unravelling the entanglement structure of correlated systems, resulting in the study of quantum tensor networks which model the entanglement degrees by local tensors. This in turn has led to the development of new numerical methods for simulating complex quantum systems on one hand and to new analytic tools for classifying novel phases of matter on the other hand.

Tensor networks methods have seen advancements in various domains of physics, mathematics, and computer science. Some precursors of them already appeared in early works of Baxter when solving classical partition functions. In the late 80s, matrix product states (MPS) were discovered as powerful analytical tool to study the properties of quantum states. In this context, exact expressions of the seminal one-dimensional Affleck-Kennedy-Lieb-Tasaki (AKLT) state were found, which then gave rise to a broader class of so called finitely correlated states. Seemingly unrelated, a very important numerical development took place: White proposed in 1992 the famous density matrix renormalization group (DMRG) method, which quickly became the most powerful algorithm to simulate one-dimensional models. Only later on it was then realized that the computational power of DMRG can be understood in the framework of MPS representations, in particular, the DMRG algorithm variationally optimizes to quantum states in MPS form. The cross-fertilization between the development of numerical methods and the discovery of analytical structures in Tensor Network has since revolutionized our understanding of emergent phenomena in quantum many body physics. Recent examples include the development of projected entangled pair states (PEPS) that extend the variational power of MPS to higher dimensions and provide a framework for the classification of phases of matter, the Multi-scale Entanglement Renormalization Ansatz (MERA) that unravels the entanglement properties of critical states, and deep connections between tensor network states and the AdS/CFT correspondence in high energy physics.

At the same time, the rapid development of the field has given rise to a plethora of new questions, both on the fundamental mathematical level and relating to their utility in simulating physical systems, ranging from the structure theory of tensor networks and the classification of phases, their relation to conformal field theories (CFTs), or their ability to describe black hole dynamics, all the way to the development of increasingly powerful numerical methods to simulate systems in an as diverse as possible set of scenarios, including higher dimensions, excitations, in particular also anyonic ones in topological phases, topological spin liquids, or lattice gauge theories.

Goals of the programme

The goal of the programme was to tackle the relevant open problems in the field, by bringing together leading international experts from both mathematical and physical background who are working on the analytical and numerical aspects of tensor network states, and to foster collaborations and exchange between the different approaches and communities.

There were two key areas of questions which we wanted to tackle. First, the mathematical structure of Tensor Networks. Questions here ranged from the representation theory of tensor networks, the classification of phases, the relation of topological order with CFTs, categories, and Hopf algebras, higher-order symmetries and fractions all the way to lattice gauge theories and tensor networks for field theories. Second, the use of tensor networks for the efficient simulations of quantum many-body problems. This covered the search for the best simulation algorithms, their application to time evolutions, long-time behaviour, problems in high-energy physics, excitation dynamics, scaling exponents, the study of criticality, and their use in simulating quantum computers.

A key intention of the programme was to bring together researchers from different communities, with backgrounds in statistical mechanics (integrable systems, conformal field theory), condensed matter theory (strongly correlated systems), mathematical physics (quantum spin systems) and mathematics (category theory, tensors), as many of the problems to be tackled required the synergy between researchers from different backgrounds, and the structure of the programme was designed such as to facilitate those synergies.

Activities

The 8-week programme consisted of different types of activities.

On the one hand, there were two intense workshop weeks in weeks 3 and 6, with about 50-60 participants in each week. Each of the workshops hosted about 20 talks on current research topics. Between these talks, long breaks were scheduled, such as to allow for an intense exchange between the participants. A more detailed summary of each of the workshop weeks is given below.

Outside the workshop weeks, the programme was considerably lighter, with the idea of giving the participants ample of time to dicuss and collaborate. During those weeks, we had typically 3-5 self-organized discussions for all participants on topics of interest, which were led by one or two of the participants who were experts on the topic. An overview of these discussions is found in Section . These discussions were generally open-ended and served the purpose to stimulate scientific exchange and collaborations between the participants.

Finally, in the second week of the programme, we were organizing a school on tensor network methods, jointly with the European Tensor Network. This school hosted about 75 participants, and seven internationally renown lecturers which provided both introductory lectures to the field of tensor networks, as well as more specialized lectures on ongoing research topics. More details on the school are also given below.

Overall, the programme provided thus both opportunities for intensive long-term collaborations and intense workshops to bring many researchers together to exchange ideas, as well as the possibly for students to enter the field.

Specific information on the thematic programme

Let us briefly summarize the activities during the two workshop weeks, as well as the school.

The first workshop, “Computational aspects of Tensor Networks”, took place in the 3rd week of the program (September 12 - 16, 2022). It featured 22 talks by both senior and junior scientists, which covered a broad range of topics on numerical simulations with tensor networks, ranging from the study of critical systems with tensor networks, the study of systems with symmetries, the simulation of systems at finite temperature, systems in higher dimensions, all the way to the use of quantum computers to prepare tensor network states, and the use of tensor networks to solve classical constraint satisfaction problems. In addition, the workshop featured a poster session.

The second workshop, “Mathematical structure of Tensor Networks”, took place in the 6th week of the program (October 3-17, 2022). It featured 19 talks on a broad range of theoretical and mathematical aspects of tensor networks, given again by both senior and junior researchers, as well as a poster session. Topics included the classification of phases, representation theory of tensor networks, including for cagetories and Hopf algebras, the use of tensor networks to study thermalization, condensation of anyons, and phase transitions in the entanglement, as well as higher-order phases and the use of tensor networks in field theories and high-energy physics.

The school “Tensor Network based approaches to Quantum Many-Body Systems” was organized in the 2nd week of the programme (September 5-9, 2022), jointly with the European Tensor Network, which was aimed at PhD students entering the field. It featured a number of long lectures which introduced all students to the topic: Ian McCulloch introduced the students to Matrix Product States, Bruno Nachtergaele provided an introduction into the Mathematical Theory of Tensor Networks, and Jan von Delft lectured about Tensor Networks in Higher Dimensions, with a focus on symmetries. Moreover, McCulloch’s and von Delft’s lectures featured hands-on tutorials on the numerical implementation of PEPS algorithms. In addition, there were a number of shorter lectures on current research topics in the field, given by Maksym Serbyn, Andrew Green, Juraj Hasik, and Amanda Young. Finally, there were two poster sessions, in which the participants could present their work, and which were very well received, with almost 40 posters presented; additionally, participants had the opportunity to highlight their posters or their other work in short flash talks prior to the first poster session.

Outcomes and achievements

The ESI programme has initiated a large number of discussions which led to new collaborations. It has also allowed participants to follow up on and intensify existing collaborations and to complete joint projects. Below, we provide a sample of the activities carried out by participants during their stay at the ESI.

Jan von Delft and coworkers (Andreas Gleis, Jheng-Wei Li, Jeongmin Shim and Chang-Kai Zhang) had fruitful discussions with numerous participants of the workshop, including: Philippe Corboz regarding iPEPS studies of the t_1-t_2 doped Hubbard model and the role of implementing U(1) or SU(2) spin symmetry; Reinhard Noack and Markus Scheb about improving the convergence of fPEPS computations; Frank Pollmann about controlled bond expansion in DMRG computations; Jutho Haegeman about implementing non-Abelian symmetries in tensor network codes; Luca Tagliacozzo about iPEPS studies of lattice gauge theories; Natalia Chepiga about fork tensor networks for studying quantum impurity models; Miles Stoudenmire about tree tensor networks for studying models for heavy-fermion systems; and Ivan Oseledets about efficient parametrizations of multivariate functions using tensor trains. Aside from giving raise to several concrete ideas for future projects to be pursued in the group of Jan von Delft in Munich, these discussion also led to two concrete developments regarding personnel: Markus

Scheb will join the group of Jan von Delft as a postdoc, starting March 2023; and Luca Tagliacozzo and Jan von Delft decided to jointly supervise a Master's student in Munich, Manu Canals, on a project involving iPEPS studies of fermionic lattice gauge theories with U(1) and/or SU(2) symmetries.

Bruno Nachtergaele and Amanda Young collaborated on refining their stability result for the bulk gap for systems with gapless edges modes. This work is currently being prepared for publication. Nachtergaele enjoyed very much learning about new directions in TNS research, especially by junior members of the community. This included new results on canonical forms for TNS, genericity of nearest neighbor parent Hamiltonians for MPS, and the algebraic structures of MPO algebras to describe symmetry properties of TNS. Angelo Lucia and Amanda Young took advantage of their time at ESI to complete an on-going research project, also thanks to discussions with Bruno Natchergale, which resulted in the writing of the paper titled “A Nonvanishing Spectral Gap for AKLT Models on Generalized Decorated Graphs” (arXiv:2212.11872).

Zlatko Papic has used his stay at the ESI to study the applications of tensor networks to quantum transport, which resulted in publications arXiv:2210.01146 (jointly with participants Maksym Serbyn and Marko Ljubotina) and arXiv:2301.07717 (with participant Ian McCulloch). Zlatko Papic also completed the manuscripts arXiv:2210.02453 and arXiv:2301.03631 during the ESI programme. Finally, he had fruitful discussions throughout the programme on the applications of tensor networks to constrained systems (with Stefanos Kourtis, Natalia Chepiga), time dependent variational principle (Andrew Green, Luca Tagliacozzo) and variational quantum eigensolvers (Norbert Schuch, Laurens Vanderstraeten).

Ilya Kull and Norbert Schuch started a collaboration with Roger Mong on rigorous lower bounds for spectral gaps. In addition, they had fruitful discussions which contributed to a publication (arXiv:2212.03014). Through informal discussions with Ilya Kull, Antoine Tilloy got a first view of the tremendous progress done on energy lower bounds with tensor networks, something he was working on with outdated methods. Antoine Tilloy also enjoyed long discussions with Roger Mong on MPS/TNS approaches to the quantum Hall effect, that will likely spark a collaboration.

Thanks to participation in the workshop “Mathematical structure of Tensor Networks”, new research collaborations between Tobias Osborne, Paul Fendley, and Carolin Wille were initiated. In particular, these connections lead to a followup research visit to the University of Oxford where tensor-network methods for Yang-Baxter equations and holographic codes were studied. These results should appear in papers in the near future.

Luca Tagliacozzo and Natalia Chepiga progressed on their project on adapting constrained tensor networks to problems of a lattice gauge theory. After having discussions on the fermionic systems, Natalia Chepiga and Naoki Kawashima came to realize an exact mapping from the fermionic model to the XXZ spin chain (not just the 8-vertex model), on which they are planning to further clarify and extend the relation. Natalia Chepiga also finished the paper “From Kosterlitz-Thouless to Pokrovsky-Talapov transitions in spinless fermions and spin chains with next-nearest-neighbor interactions” [Phys. Rev. Research 4, 043225, (2022)] during her stay at the ESI.

Jürgen Fuchs and Christoph Schweigert worked on bicategorical string-net models which lead to the preprint arXiv:2302.01468. They had discussions with Laurens Lootens on criteria to detect the invertibility of bimodule categories in terms of 6j-symbols, with Hong-Hao Tu on the computation of Klein bottle amplitudes in conformal field theories and their use as invariants of condensed matter systems and with Yoshiko Ogata on topological field theory and the classification of topological phases of matter. Hong-Hao Tu and Wei Tang used their attendance of the programme to finalize a project on the universal scaling of the Klein bottle entropy near conformal critical points and prepared a preprint (arXiv:2211.09745).

David Perez-Garcia and Yoshiko Ogata started a collaboration to use Tensor Networks methods to provide new examples of systems fulfilling, and not fulfilling, the “weak Haag duality” property.

Dominic Williamson had a very productive visit to the ESI programme, as it allowed him to meet up with collaborators including David Stephen and Jose Garre Rubio and work on ongoing projects about anomalous subsystem symmetry fractionalization. He also had the chance to discuss potential new directions with other attendees including Adam Nahum, which has led to a potential new collaboration on quantum dynamics and error correction.

Hans Gerd Evertz worked on real time impurity solvers and on making them widely available, with fruitful discussions with Miles Stoudenmire (also on future student exchanges with the Flatiron Institute), Martin Ganahl, Salvatore Manmana, Jan von Delft, and others. He also had profitable discussions on tensor networks with Philippe Corboz, Naoki Kawashima, Reinhard Noack, and Bruno Nachtergaele. Viktor Eisler had a very stimulating discussion with Norbert Schuch which might lead to a new collaboration, as well as with with participants Matteo Rizzi, David Perez-Garcia and also Ohad Shpielberg, a participant of a parallel workshop at ESI.

List of talks

School on “Tensor Networks based approaches to Quantum Many-Body Systems”, September 5 –9, 2022

Ian McCulloch (U of Queensland)	Introduction to Matrix Product States I, II, III, IV
Bruno Nachtergaele (UC Davis)	Mathematical Theory of Tensor Networks I, II, III, IV
Maxym Serbyn (ISTA, Klosterneuburg)	Tensor networks and quantum many-body scars
Andrew Green (U College London)	Tensor Networks for Quantum Software and Simulation
Jan von Delft (LMU Munich)	PEPS & Tensor Networks in Higher Dimensions: Introduction, Algorithms, and Symmetries I, II
Juraj Hasik (U Amsterdam)	Simulating spin liquids with tensor networks
Amanda Young (TU Munich)	On Bounding Spectral Gaps for Quantum Lattice Models

Workshop 1 on “Computational aspects of Tensor Networks”, September 12 – 16, 2022

Natalia Chepiga (TU Delft)	Eight-vertex criticality in the interacting Kitaev chain
Örs Legeza (WIGNER RCP, Budapest)	Alternative/ab initio approach to target higher dimensional quantum lattice models via tensor product factorization
Andreas Weichselbaum (BNL, Upton)	Non-abelian symmetries in tensor networks: the open source QSpace tensor library
Ian McCulloch (U of Queensland, Brisbane)	Detecting and characterising dynamical quantum phase transitions through higher moments
Stefanos Kourtis (UdeS)	Fast counting with tensor networks
Ivan Oseledets (Moscow)	Tensor methods and their applications
Esperanza López Manzanares (UAM-CSIC, Madrid)	Algebraic Bethe Circuits

Miles Stoudenmire (Flatiron Inst., New York)	Disentangling Interacting Systems with Gaussian Tensor Networks
Luca Tagliacozzo (CSIC, Madrid)	Ablian LGT in 1D insights from MPS
Antoine Tilloy (MINES ParisTech)	Attacking 1+1 dimensional field theories with relativistic CMPS
Bram Vanhecke (U Vienna)	Continuous Tensor Networks for Lattice Models
Philippe Corboz (U Amsterdam)	iPEPS for 3D and layered quantum systems
Piotr Czarnik (Jagiellonian U, Krakow)	iPEPS simulations of strongly correlated systems at finite temperature
Didier Poilblanc (U Paul Sabatier, Toulouse)	Simulating chiral spin liquids with projected entangled-pair states
Naoki Kawashima (U Tokyo)	Tensor-network-representable quantum states
Anna Francuz (U Vienna)	Determining topological order with iPEPS
Andreas Läuchli (PSI, Villigen)	Accurate CFT data and velocities from iMPS simulations
Frederik Møller (TU Vienna)	Emergent hydrodynamics and Pauli blocking in a 1D Bose gas
Laurens Vanderstraeten (Ghent U)	Spectral functions of 2-D quantum spin liquids
Roger Mong (U Pittsburgh)	Mutual information and reflected entropies of random states
Simone Montangero (U Padova)	Tensor network algorithms for high-dimensional quantum many-body systems
Atsushi Ueda (ISSP, U of Tokyo)	Anatomy of 2D classical lattice models with TNR

Workshop 2 on “Mathematical structure of Tensor Networks”, October 3 – 7, 2022

Hong-Hao Tu (TU Dresden)	Tensor networks for fermionic parton wave functions
Paul Fendley (U Oxford)	Defects and Duality on the Lattice
Erez Zohar (HU Jerusalem)	Gauged Gaussian Fermionic PEPS: a tool for studying lattice gauge theories
Carolin Wille (U Oxford)	An effective field theory for (holographic) random matchgate tensor networks
Bruno Nachtergaele (UC Davis)	Ogata’s construction of an index for SPT phases of quantum spin chains
Angelo Lucia (U Complutense de Madrid)	Thermalization of quantum memories - a tensor networks approach
Yoshiko Ogata (U Tokyo)	A derivation of braided C^*-tensor categories from gapped ground states satisfying the approximate Haag duality
David Pérez-García (U Complutense de Madrid)	A canonical form for PEPS
Jürgen Fuchs (U Karlstad)	String nets and RCFT correlators
Christoph Schweigert (U Hamburg)	Tensors, state-sum TFTs and the evaluation of (extruded) graphs
Dominic Williamson (U Sydney)	Condensation and stability of topological order in tensor networks
Laurens Lootens (Ghent U)	Dualities in one-dimensional quantum lattice models: symmetric Hamiltonians and matrix product operator intertwiners
András Molnár (U Vienna)	Matrix product operator algebras
David T. Stephen (U of Colorado, Boulder)	Higher Chern number and matrix product state representations
Andreas Ludwig (UC, Santa Barbara)	Entanglement Transitions in Random Tensor Networks and Monitored Quantum Circuits

Adam Nahum (ENS Paris)	Entanglement transitions in tree tensor networks
Anne Nielsen (Aarhus U)	Inverted quantum many-body scars
Jens Eisert (FU Berlin)	Some new ideas on tensor networks to capture entanglement in quantum many-body systems
Tobias Osborne (ITP Hannover)	Quantum Simulation of Conformal Field Theory
Faedi Loulidi (U Paul Sabatier, Toulouse)	Measurement incompatibility vs. Bell non-locality: an approach via tensor norms

Publications and preprints contributed

M. V. Damme, J.-Y. Desaules, Z. Papić, J. C. Halimeh, *The Anatomy of Dynamical Quantum Phase Transitions*, arXiv:2210.02453 [quant-ph].

S. Bollmann, A. Osterkorn, E. J. König, S.R. Manmana, *Lifshitz transition in the phase diagram of two-leg t-J ladder systems at low filling*, arXiv:2211.13065 [cond-mat.str-el].

J. Fuchs, C. Schweigert, Y. Yang, *String-net models for pivotal bicategories*, arXiv:2302.01468 [math. QA].

M. Ljubotina, J.-Y. Desaules, M. Serbyn, Z. Papić, *The Anatomy of Dynamical Quantum Phase Transitions*, arXiv:2210.01146 [cond-mat.stat-mech].

P. Brighi, M. Ljubotina, M. Serbyn, *Hilbert space fragmentation and slow dynamics in particle-conserving East model* arXiv:2210.15607 [quant-ph].

M. Ljubotina, J.-Y. Desaules, M. Serbyn, Zl. Papić, *Superdiffusive Energy Transport in Kinetically Constrained Models*, arXiv:2210.01146 [cond-mat.stat-mech].

A. Lucia, A. Young, *A Nonvanishing Spectral Gap for AKLT Models on Generalized Decorated Graphs*, arXiv:2212.11872 [math-ph].

B. Nachtergaele, R. Sims, A. Young *Stability of the bulk gap for frustration-free topologically ordered quantum lattice systems*, arXiv:2102.07209 [math-ph].

Y. Zhang, A. Hulsch, H.-C .Zhang, W. Tang, L. Wang, H.-H. Tu, *Universal scaling of Klein bottle entropy near conformal critical points*, rXiv:2211.09745 [cond-mat.str-el].

Invited scientists

Juan Diego Arias Espinoza, Mark Arildsen, Mari Carmen Banuls, David Blanik, Pietro Brighi, Nick Bultinck, Angela Capel Cuevas, Natalia Chepiga, J. Ignacio Cirac, Philippe Corboz, Piotr Czarnik, Lukas Devos, Jerôme Dubail, Jens Eisert, Viktor Eisler, Hans-Gerd Evertz, Paul Fendley, Adrián Franco-Rubio, Anna Francuz, Jürgen Fuchs, Martin Ganahl, Juan Garrahan, José Garre Rubio, Albert Gasull, Andreas Gleis, Andrew Green, David Kenworthy Gunn, Jutho Haegeman, Juraj Hasik, Johannes Hauschild, Fabian Heidrich-Meisner, Michal P. Heller, Michael Kastoryano, Naoki Kawashima, Vladimir Kazeev, Stefanos Kourtis, Ilya Kull, Andreas Läuchli, Örs Legeza, Jheng-Wei Li, Jimin Li, Shenghsuan Lin, Marko Ljubotina, Laurens Lootens, Esperanza López Manzanares, Faedi Loulidi, Angelo Lucia, Andreas Ludwig, Salvatore Manmana, Ian McCulloch, Manuel Mekonnen, Frédéric Mila, Gunnar Möller, Frederik Møoller, András Molnár, Roger Mong, Simone Montangero, Bruno Nachtergaele, Adam Nahum, Anne Nielsen, Sen Niu, Reinhard Noack, Yoshiko Ogata, Tobias Osborne, Ivan Oseledets, Masaki Oshikawa, Zlatko Papic, David Pérez-García, Didier Poilblanc, Frank Pollmann, Cécile Repellin, Matteo Rizzi, Markus Scheb, Norbert Schuch, Christoph Schweigert, Maksym Serbyn, Jeongmin Shim, German Sierra Rodero, David T. Stephen, Miles Stoudenmire, Georgios Styliaris, Luca Tagliacozzo, Wei Tang, Jordan Taylor, Antoine Tilloy, Hong-Hao Tu, Atsushi Ueda, Laurens Vanderstraeten, Bram

Vanhecke, Frank Verstraete, Jan von Delft, Andreas Weichselbaum, Carolin Wille, Dominic Williamson, Wen-Tao Xu, Mingru Yang, Amanda Young, Changkai Zhang.

Large Deviations, Extremes and Anomalous Transport in Non-equilibrium Systems

Organizers: Christoph Dellago (U Vienna), Satya Majumdar (U Paris Sud, Orsay), David Mukamel (Weizmann Institute, Rehovot), Harald Posch (U Vienna), Grégory Schehr (Sorbonne U, Paris)

Dates: September 19 – October 14, 2022

Budget: ESI €39 590
CECAM, EPFL, Lausanne EUR € 8 918

Report on the thematic programme

Activities

This programme took place over four weeks, from September 19 to October 14, 2022. A workshop, which was supported also by CECAM (www.cecam.org), was held during the second week, from September 26 to 30, 2022.

Specific information on the thematic programme

Characterizing the steady-state and the dynamical properties of systems driven out of thermal equilibrium is currently a subject of intensive theoretical and experimental studies. Considerable theoretical progress in understanding various aspects of such non-equilibrium systems has been made recently and the aim of this Workshop was to bring together leading researchers, young scientists and students around three main themes which have been at the forefront of leading issues in non-equilibrium systems: (i) Theory of large deviations: large deviation functions have been considered as possible candidates for an effective free energy in out-of-equilibrium situations. In particular, the idea of detecting a phase transition by studying the singularities of the large deviation function has recently been extensively used in various areas ranging from anomalous transport and stochastic thermodynamics all the way to active matter and disordered systems. (ii) Rare events, extremes and first-passage properties in stochastic processes: Extreme value statistics plays an important role in statistical physics, e.g., in the context of disordered and non-equilibrium complex systems. One of the major current issues is to understand the role of correlations between different degrees of freedom in characterizing the universality classes of extreme value distributions. There has been some recent progress in calculating the extreme value distributions exactly in some strongly correlated systems such as in random matrix theory. (iii) Anomalous transport in low dimensional systems: Very recently an important progress has been made in this highly active area of research whereby a general framework has been proposed for understanding anomalous transport in a rather broad class of systems. This framework, referred to as non-linear fluctuating hydrodynamics, provides a rather successful theoretical approach. This has generated considerable activity in this field aiming at testing the general validity of this theory.

Outcomes and achievements

During the programme, there were typically two talks per day (one in the morning, one in the afternoon). During the workshop, which took place during the second week of the programme, there were four to seven talks per day, with a total of twenty-seven speakers – and more than fifty participants – from all over the world (Europe, India, Israel, South Korea and USA). Most of the talks have been recorded and can be viewed at https://www.esi.ac.at/events/e431/. Between the talks, there were many slots for discussions and the participants could enjoy the stimulating atmosphere provided by the ESI to share ideas and initiate collaborations. For many participants, this workshop was the first opportunity since the pandemic to meet colleagues in person, which was particularly appreciated.

The themes of the program, namely the theory of large deviations, rare events and extreme statistics as well as anomalous transport properties were discussed along the following main lines:

• *Active matter*

Active particles form a class of non-equilibrium systems which are able to generate dissipative directed motion through self-propulsion and consuming energy from their environment. The study of active particles is relevant in a wide variety of biological and soft matter systems ranging from bacterial motion, formation of fish schools and bird flocks, as well as granular matter and colloidal surfers. Recent years have seen a tremendous surge of research on active matter. This programme, and in particular the workshop, gathered many leading experts of this lively subject who presented recent developments in the field. These include theoretical as well as experimental progresses. On the theoretical side, on can mention the recent development of analytical tools to describe stochastic processes which are relevant for active systems as well as the characterization of the effects of quenched disorder in these systems. On the experimental side, recent progresses were reported on the detailed study of the motion of a single active particle in a viscoelastic (glassy) fluid.

• *Large deviations and their applications*

Large deviations were at the core of several talks and discussions during this workshop. Indeed, large deviations have recently found a lot of applications and several new results were presented during this workshop. This includes in particular macroscopic fluctuations in interacting particle systems (e.g., exclusion processes), applications in chemical physics or in the context of microbial growth or the development of new theoretical tools (e.g., tensor network techniques).

• *Stochastic thermodynamics*

Stochastic thermodynamics provides a universal framework for analysing nano- and micro-sized non-equilibrium systems. Prominent examples are single molecules, molecular machines, colloidal particles in time-dependent laser traps and biochemical networks. Thermodynamic notions like work, heat and entropy can then be identified on the level of individual fluctuating trajectories. They obey universal relations like fluctuation theorems, which have generated a lot of activities during the last two decades. This was also an important theme of this workshop during which several theoretical advances were presented, including in particular the concept of thermodynamic inference which uses consistency constraints derived from stochastic thermodynamics to infer otherwise hidden properties of non-equilibrium systems as well as the quantum extension of the classical fluctuation theorems.

• *Resetting dynamics*

During the last ten years, resetting of stochastic processes has become a major theme of study in non-equilibrium statistical physics, which has triggered of lot applications in various fields. An archetypal example of a stochastic process under resetting is a diffusing particle that is reset to the origin after random waiting times with exponential distribution. It has been shown that (i) the system reaches a non-equilibrium stationary state at large time and (ii) the mean first-passage time to some target is rendered finite, rather than infinite as in the absence of resetting. During this workshop, several new results on resetting were presented, in particular one of the very first experimental realization of this resetting protocol using optical tweezers.

List of talks

Sanjib Sabhapandit (RRI, Bangalore)	Direction reversing active Brownian particle
Rosemary Harris (QMU London)	Insights from non-Markovian random walks
Baruch Meerson (HU Jerusalem)	Negative autocorrelations of disorder potential strongly suppress thermally activated particle motion
Anupam Kundu (TIFR, Bangalore)	Super-diffusion and crossover from diffusive to anomalous transport in a 1d system
Francesco Mori (U Paris-Saclay)	The run-and-tumble particle: from universal properties to nonequilibrium phase transitions
Omer Granek (Technion Haifa)	The Anomalous Transport of Tracers in Active Baths
Bertrand Lacroix-À-Chez-Toine (KCL, London)	Survival probability and record statistics for random walks
Vivien Lecomte (U Grenoble Alpes)	Geometry of nonequilibrium reaction networks
Trevor GrandPre (Princeton U)	Entropy production fluctuations encode collective behavior in active matter
Clemens Bechinger (U of Konstanz)	Colloidal particles in non-Markovian fluids far from equilibrium
Robert Jack (U Cambridge)	Large deviations of time-integrated quantities in active (and passive) matter
Christian Maes (KU Leuven)	Nonequilibrium calorimetry
Urna Basu (SNBNCBS, Kolkata)	Activity driven transport in harmonic chains
Pierre Le Doussal (ENS Paris)	Large deviations for diffusion in random media: crossover from the macroscopic fluctuation theory to the KPZ equation
Benjamin De Bruyne (Paris-Saclay U)	Constrained stochastic processes
Olivier Benichou (Sorbonne U, Paris)	Generalized Density Profiles in Single-File Systems
Jae Dong Noh (U of Seoul)	Ordering of diffusing spins
Eli Barkai (Bar Ilan U)	Packets of diffusing particles exhibit universal exponential tails
Oren Raz (Weizmann Institute, Rehovot)	Fluctuations in the Fourier coefficient of the current in periodically driven systems
Marija Vucelja (U Virginia)	Anomalous thermal relaxation for over-damped Langevin dynamics
Stefan Thurner (Med U Vienna)	On the origin of fat tailed distribution functions in driven complex systems
Gianluca Teza (Weizmann Institute, Rehovot)	Anomalous dynamical scaling determines universal critical singularities
Sergio Ciliberto (CNRS, Paris)	Several applications of Engineered Swift Equilibration
Udo Seifert (U Stuttgart)	From stochastic thermodynamics to thermodynamic inference

David Limmer (UC, Berkeley)	A large deviation perspective on nanoscale transport phenomena
Juan Garrahan (U of Nottingham)	Tensor network methods and large deviations
Abhishek Dhar (TIFR, Bangalore)	Entropy growth during free expansion of an ideal gas
Jorge Kurchan (ENS Paris)	Quantum bounds and Fluctuation-Dissipation Relation
Ariel Amir (Harvard U, Cambridge)	Statistical physics of microbial growth: fluctuations, phase transitions and large deviations
Mustansir Barma (TIFR Hyderabad)	Coarsening, condensates and extremes in aggregation-fragmentation models
Stefano Lepri (ISC)	Anomalous transport in nonlinear lattices: quasi-integrability and long-range interactions
Andrea Gambassi (SISSA, Trieste)	A surprising centenarian: the Ising model and its (quantum) interface dynamics
Yariv Kafri (Technion Haifa)	The long-ranged influence of disorder on active systems
Shlomi Reuveni (Tel Aviv U)	Inspection Paradox Approach to Stochastic Resetting
Paul Krapivsky (U of Boston)	Large Deviations in Random Sequential Packing and Covering
Martin Evans (U Edinburgh)	Stochastic Resetting: Overview and Recent Developments
Roi Holtzman (Weizmann Institute, Rehovot)	The Hamiltonian bit: erasure with zero work by bypassing Liouville's theorem
Hyunggyu Park (KIAS, Seoul)	Speed Limit for a Highly Irreversible Process and Tight Finite-Time Landauer's Bound
Gunter Schuetz (IST)	Dynamical universality classes: Recent results and open questions
Alexander Hartmann (U Oldenburg)	Large deviations of work distributions for RNA secondary structures and for other distributions and models
Nicolo Defenu (ETH Zurich)	Quantum criticality and out-of-equilibrium scaling in long-range systems and beyond
Ludger Santen (U of Saarland)	Non-equilibrium fluctuations and twisting of a semi-flexible filament driven by active cross-linkers
Stefano Ruffo (SISSA, Trieste)	Thermodynamics of non additive systems: the example of the Thirring model of self-gravitating systems
Cecile Appert-Rolland (U Paris-Saclay)	Models for transport : road, pedestrian, and intracellular traffic
Tridib Sadhu (TIFR Mumbai)	Large deviations in the non-equilibrium stationary state of diffusive systems
Giacomo Gradenigo (Gran Sasso Science Institute, L'Aquila)	Localization transition in the Discrete Non-Linear Schrödinger Equation: ensembles inequivalence and negative temperatures
Alberto Rosso (U Paris Sud, Orsay)	Current fluctuations in noninteracting run-and-tumble particles in one dimension
Raphael Chetrite (CNRS Nice)	Homogenization of Markovian process and application to quantum continuous measurement
Ohad Shpielberg (Haifa U.)	Large deviations and large biasing of the ground state entanglement entropy

Publications and preprints contributed

A. Das, M. Barma, *Fluctuation dominated phase ordering in coarse-grained depth models: Domain wall structures, extreme values and coarsening*, arXiv:2212.07471 [cond-mat.stat-mech].

Invited scientists

Ariel Amir, Cecile Appert-Rolland, Eli Barkai, Mustansir Barma, Urna Basu, Clemens Bechinger, Olivier Benichou, Raphael Chetrite, Sergio Ciliberto, Benjamin De Bruyne, Nicolo Defenu, Christoph Dellago, Abhishek Dhar, Martin Evans, Simone Floreani, Andrea Gambassi, Juan Garrahan, Giacomo Gradenigo, Trevor GrandPre, Omer Granek, Rosemary Harris, Alexander Hartmann, Roi Holtzman, Robert Jack, Yariv Kafri, Paul Krapivsky, Anupam Kundu, Jorge Kurchan, Bertrand Lacroix-Á-Chez-Toine, Vivien Lecomte, Pierre Le Doussal, Stefano Lepri, Jimin Li, David Limmer, Christian Maes, Satya Majumdar, Baruch Meerson, Francesco Mori, David Mukamel, Jae Dong Noh, Hyunggyu Park, Harald Posch, Oren Raz, Shlomi Reuveni, Alberto Rosso, Stefano Ruffo, Sanjib Sabhapandit, Tridib Sadhu, Ludger Santen, Gregory Schehr, Gunter Schuetz, Udo Seifert, Ohad Shpielberg, Gianluca Teza, Stefan Thurner, Marija Vucelja, Michael Wassermair.

Mathematical Methods for the Study of Self-organization in the Biological Sciences

Organizers: Pierre Degond (IMT), Marie Doumic (Sorbonne U, Paris), Anna Kicheva (ISTA, Klosterneuburg), Sara Merino-Aceituno (U Vienna), Christian Schmeiser (U Vienna)

Dates: November 14 – December 9, 2022

Budget: ESI € 20 921
Funding provided by the Austrian Science Fund (FWF) through the project F65, € 500 of available budget to pay for food and drinks for the receptions that took place on the first days of the school and of the conference.
JP¥ 1 000 000 provided by the KU-UNIVIE Joint Grant Programme to invite guests from Kyoto University (Japan) and organize the Kyoto-Vienna biomath workshop.

Report on the thematic programme

Self-organization is pervasive in biology as living organisms are by essence systems that have self-assembled and self-organized in the course of their development. Self-organization refers to the ability of systems made of a large number of independent agents interacting through rather simple and local rules to generate large scale spatio-temporal coherent structures with typical dimensions orders of magnitude larger than those associated with each individual agent. Examples of self-organisation are natural network formation (like capillaries and leaf venation), collective dynamics (like flocking, herding and pedestrian dynamics), opinion dynamics, landscape formation, tissue and organ formation...

Self-organization occurs across all scales of biological structures from the molecular scale (DNA), the subcellular scale (the organites making the living cell), the organ scale, the organism scale (the cross-regulation between the various functions), the super-organism scale (as this includes all the bacteria and fungi that live in symbiotic fashion on a superior organism), the group scale (as social organization), the ecological niche scale (including various general populating a given environment) and finally the planet scale (including how the various animal societies share the limited available resources). Across this wide range of scales, spanning almost 20 orders of magnitude, a formidable variety of self-organization mechanisms can be found, but beyond this huge variety some common features emerge, leading to the possibility of classifying possible self-organization mechanisms in fundamental classes. This classification is important because it opens the way to analysing these mechanisms through a limited number of simple mathematical models exhibiting common features and structures. Crucially, mathematics provide the tools to link phenomena at different scales and, hence, to explain the emergence of self-organisation at larger scales. To establish the link across scales is essential to answering many scientific questions that cannot be answered just by knowledge constrained at each scale. Example of these questions are, how do tissues organise?, how affecting a tumour's micro-environment will affect its proliferation?, how do organs 'know' they have reached a mature state?, how does the nucleous of the cell self-organises?

In this programme we brought together mathematicians and biologists to provide a broad overview of the various self-organization mechanisms that prevail at the various scales and the mathematical models by which they can be described or even explained. Through this interaction between experts from different disciplines, we aimed to make progress towards determination of the key biological mechanisms that enable self-organisation at each scale and across the scales, and towards the derivation of suitable 'universal' mathematical models able to describe them across the scales. To achieve this, the thematic programme has included a school and a one week-workshop and a 2-day workshop.

Mathematically, the study of self-organisation is carried out using asymptotic approaches that encompass kinetic theory, hydrodynamic limits in probability, homogeneization, dynamical system.... For example, in kinetic theory, on a first step transport equations are derived from discrete models that describe the dynamics at the micro-scale. This first derivation is called mean-field limit and the transport equations correspond to kinetic equations giving the time-evolution of the distribution of particles or agents. On a second step, from these kinetic equations, continuum equations are derived for the time-evolution of statistics of the system like the density of the particles and their mean velocity. These continuum equations describe the large-scale dynamics. In this way, the derivation of the continuum equations from the discrete models allows us to explain how self-organisation arises. Something similar can be achieved using probabilistic approaches, where, through hydrodynamic limits, macroscopic equations can be derived directly from the particle dynamics, without passing through an intermediate step corresponding to kinetic equations.

Many of these asymptotic approaches were first developed for physical systems, but in the recent years they are finding an increasing number of applications in other fields like social sciences, finance, biology, geology and medicine. The application of these approaches to non-physical systems comes with many challenges since the particles and inter-particle interactions are more complex than in classical physical systems. In this thematic programme we will explore many of these challenges that include:

- the development of new hydrodynamic methodologies (e.g., when there are not conserved quantities);
- the determination of local equilibria (typically involving complex fixed-point problems);
- the convergence (and rate of convergence) to that equilibria (classical entropic methods tend to fail since the systems can be physically open);
- phase transitions at the macroscopic scale;
- development of new numerical methods (for phase transitions, for hyperbolic non-conservative systems,...);
- modelling and inter-disciplinary research with groups of experimentalists;
- analysis of inverse problems, data assimilation, model calibration.

Consequently, the study of emergence requires mathematicians to have a diversity of skills involving tools from probability (interacting particle systems, Markov processes, hydrodynamic limits), partial differential equations (specially transport and fluid equations, asymptotic limits, stability analysis), numerical analysis, modelling and the capacity to work in inter-disciplinary groups in the life sciences. With this in view we organised the school to provide a state of the art of current methodologies, challenges and open questions, to form multi-skilled young researchers.

The value of this thematic programme has been twofold. For the biologists, it has reinforced their link with mathematicians and enlarged the range of models that they can use to probe observed biological complexity. For the mathematicians, firstly, it has provided a state of the art of the challenges and methodologies in the field, and secondly, it has broaden the repertoire of case studies with which to confront their methodologies and practice. For the two communities (biologists and mathematicians), it has offered the opportunity of building trans-disciplinary teams.

Activities

The thematic programme lasted four weeks and consisted of one school, a one-week workshop, and a 2-day workshop.

The school, contents and purpose: The study of self-organisation demands a broad spectrum of mathematical tools, as well as, modelling and the capacity to work in inter-disciplinary groups that include biologists. Therefore, researchers must be multi-talented, as well as being able to work with researchers in complementary mathematical disciplines. In this school we put together all these skills by calling on experts in different topics that include:

- mean-field limits and hydrodynamic limits for interacting particle systems - a probabilistic approach;
- derivation of continuum equations from kinetic equations for models in biology;
- collective dynamics and self-organisation;
- modelling and working in inter-disciplinary groups with biologists;
- examples of systems from biology.

The Workshop: As mentioned before, we aimed, by bringing together mathematicians and biologists, to provide a broad overview of the various self-organization mechanisms that prevail at the various scales and the mathematical models by which they can be described or even explained.

More specifically some of the topics targeted at the workshop are listed below in a non-exhaustive way:

- collective dynamics from the cell-scale to the population-scale (collective cell migration, flocking, etc);
- spatio-temporal pattern formation and self-organization (cell sorting, developmental biology, tumour growth, epithelial-mesenchymal transition);
- pattern formation in gene expression regulation, control of stochasticity, cell-fate decision-making (e.g. in the maturation of immunity cells);
- mechanical regulation of collective dynamics (role of the congestion constraint, packing and jamming, cluster formation), particularly in cases coming from developmental biology and flocking behaviour;

- data analysis, model calibration, data-model coupling, inverse problems.

The 2-day workshop "Kyoto-Vienna Biomath workshop": We got funding to organise a 2-day event to invite researchers from Vienna and researchers from the group of Seirin-Lee (University of Kyoto), to establish new collaborations and future exchanges. Seirin-Lee is a bio-mathematician that leads a group of mathematical modellers embedded in a biology institute, the ASHBI (Kyoto University Institute for the Advanced Study of Human Biology).

Specific information on the thematic programme

List of young researchers, prae- and post-docs (indicated with 'Dr.')

Gaurav Athreya	Max Planck Institute for evolutionary biology (Plön, DE)
Olga Babadei	U of Vienna (Vienna, AT)
Cedrik Barutel	U Toulouse (Toulouse, FR)
Laura Bocanegra	ISTA, Klosterneuburg
Chloé Bucheron	U of Vienna (Vienna, AT)
Charles Elbar	Sorbonne U, Paris (Paris, FR)
Guillaume Garnier	INRIA, Rocquencourt
Kasumi Kishi	ISTA, Klosterneuburg
Salvo Danilo Lombardo	U of Vienna (Vienna, AT)
Annamaria Massimini	TU Vienna (Vienna, AT)
Carmela Moschella	U of Vienna (Vienna, AT)
Claudia Mussnig-Wytrzens	U of Vienna (Vienna, AT)
Sascha Ollertz	U Würzburg (Würzburg, DE)
Steffen Plunder	U of Vienna (Vienna, AT)
Simone Portaro	KAUST, Thuwal (Thuwal, SA)
Alex Richardson	U Edinburgh (Edinburgh, GB)
Stefanie Rus	ISTA, Klosterneuburg
Jakub Skrzeczkowski	U Warsaw (Warsaw, PL)
Samuel Stephan	U Toulouse (Toulouse, FR)
Madeleine Zillner	ISTA, Klosterneuburg
Dr. Farid Bozorgnia	IST (Lisboa, PT)
Dr. Chitaranjan Mahapatra	CNRS/Paris Saclay Institute of Neuroscience (Paris, FR)
Dr. Thomas Minchington	ISTA, Klosterneuburg
Dr. Purnedu Mishra	Norwegian University of Lif e Sciences (As, NO)
Dr. Celine Sin	U of Vienna (Vienna, AT)
Dr. Raphael Winter	U of Vienna (Vienna, AT)
Dr. Tobias Wöhrer	TU Munich (Munich, DE)

Young researchers benefited from a dedicated week to a school prior to the workshop. Both in the workshop and the school there was a poster session with a reception. They also could participate in the social dinner.

Outcomes and achievements

- Antoine Diez and Sara Merino-Aceituno started a collaboration during that week and now they have involved a master student at the University of Vienna.
- Eric Theveneau and Sara Merino-Aceituno discussed on future projects on collective dynamics.
- Marie Doumic and Christian Schmeiser will continue on-going collaborations. They consider involving participant Carmela Moschella on a project.
- Steffen Plunder met Seirin-Lee, who is going to be his new post-doc supervisor.

- New contacts were established between the Kyoto and Vienna community. Sara Merino-Aceituno and Carmela Moschella have been invited to a workshop in Kyoto at the end of this summer.
- There were discussions on cross interests between the talks of Human Rezeai and Klemens Fellner.

List of talks

School, November 14 – 18, 2022

Francis Filbet (U Paul Sabatier, Toulouse)	About kinetic theory for the study of self-organization in the biological science
Amandine Véber (U. Paris Cité)	Stochastic models of evolution in a population living in a continuum
Luigi Preziosi (Politecnico, Torino)	Modelling Cell Motility and the Physical Limits of Migration
Sascha Martens (U of Vienna)	Mechanisms of Cargo Selection and Autophagosome Biogenesis in Selective Autophagy
Kees Weijer (U Dundee)	Analysis and perturbation of cell behaviours controlling gastrulation in the chick embryo
Amic Frouvelle (CEREMADE, Paris)	Alignment of self-propelled particles: from microscopic to hydrodynamic models
Maria Romanova-Michaelides (U Genève)	Mechanism of Morphogen Gradient Scaling
Diana Pinheiro (Vienna Biocenter)	Morphogen gradient orchestrates pattern-preserving tissue morphogenesis via motility-driven unjamming
Rubén Pérez-Carrasco (Imperial College, London)	Effects of cell cycle variability on stochastic gene expression in a population of cells
Timothy Saunders (U Warwick)	Cell shape changes during tissue morphogenesis

Workshop, November 21 – 25, 2022

Vincent Calvez (UCB Lyon)	A simple go-or-grow model of aerotaxis along a self-generated gradient
Elly Tanaka	Scaling during axolotl organ regeneration
Katarina Wolf (Radboud U)	Collective cancer cell invasion in 3D tissue: plasticity, interconversions and jamming
Maria Bruna (U Cambridge)	Excluded volume and order in systems of Brownian needles
Patrick Müller (U of Konstanz)	Analysis and control of multicellular patterns
Sophie Hecht (Sorbonne U, Paris)	Micro to macro passage for growth-fragmentation equations with short-range interactions
Doron Levy (U of Maryland)	Group dynamics in phototaxis
Katharina Sonnen (Hubrecht Institute)	Signaling dynamics in the control of embryonic development and tissue homeostasis
Diane Peurichard (INRIA Paris)	Diffusion limit of a transport equation leading to volume-exclusion chemotaxis
Eric Theveneau (CBI, Toulouse)	Dynamics of epithelial-mesenchymal transition in the early embryo: how can modelling help an experimental biologist?
Zuzanna Szymanska (U Warsaw)	Bayesian inference of a non-local proliferation model
Alba Diz-Muñoz (EMBL, Heidelberg)	More than the sum: How does a composite interface govern function at the cell surface?
Raluca Eftimie (U Franche-Comte, Besancon)	Computational and analytical approaches for pattern formation in nonlocal mathematical models for biological aggregations: from animal movement to cell movement

Human Rezaei (INRAe, Jouy en Josas)	Dynamic of prion assemblies and the consequences of the coexistence of multiple prion conformations
Wei-Feng Xue (U of Kent)	Comparative analysis of the relative fragmentation stabilities of polymorphic amyloid fibrils
Daria Siekhaus (ISTA, Klosterneuburg)	The dynamic dance of immune cells and their environment that allows invasion
Klemens Fellner (U of Graz)	Oscillatory behaviour of a bi-monomeric, nonlinear Becker-Döring type model for prion dynamics

Kyoto-Vienna biomath workshop, December 1 – 2, 2022

Sungrim Seirin-Lee (Kyoto U)	From Geometry to Patterns
Sara Merino-Aceituno (U of Vienna)	Emergence in collective dynamics using kinetic theory
Shotaro Otsuka (Med U Vienna)	Visualising inter-organelle communication by light and electron microscopy
Antoine Diez (Kyoto U)	Swarmalators without force reciprocity
Ansgar Jüngel (TU Vienna)	A coupled stochastic differential reaction-diffusion system for angiogenesis
Hiroshi Ishii (Kyoto U)	Dynamics of localized patterns in reaction-diffusion equations with nonlocal effect
Steffen Plunder (U Vienna)	Agent-based modelling of epithelial-to-mesenchymal transitions and the initation of cell migration.
Christian Schmeiser (U of Vienna)	Mathematical modeling of actin driven motility

Publications and preprints contributed

No publications or preprints have been contributed. But we expect that some of the collaborations established or continued during the event will give rise to publications.

Invited scientists

Gaurav Athreya, Olga Babadei, Tiwari Barkha, Cedrik Barutel, Laura Bocanegra, Farid Bozorgnia, Maria Bruna, Chloé Bucheron, Vincent Calvez, Antoine Diez, Alba Diz-Muñoz, Marie Doumic, Raluca Eftimie, Charles Elbar, Klemens Fellner, Amalio Fernandez-Pacheco, Francis Filbet, Basile Fornara, Amic Frouvelle, Guillaume Garnier, Rohit Krishnan Harish, Sophie Hecht, Hiroshi Ishii, Ansgar Jüngel, Anna Kicheva, Kasumi Kishi, Richard Kollár, Katarzyna Kuzmicz-Kowalska, Doron Levy, Salvo Danilo Lombardo, Chitaranjan Mahapatra, Sascha Martens, James Mason, Annamaria Massimini, Sara Merino-Aceituno, Maya Mincheva, Thomas Minchington, Purnedu Mishra, Carmela Moschella, Patrick Müller, Claudia Mussnig-Wytrzens, Toru Ohira, Sascha Ollertz, Shotaro Otsuka, Rubén Pérez-Carrasco, Diane Peurichard, Diana Pinheiro, Steffen Plunder, Jitka Polechova, Simone Portaro, Luigi Preziosi, Human Rezaei, Alex Richardson, Maria Romanova-Michaelides, Stefanie Rus, Timothy Saunders, Christian Schmeiser, Sungrim Seirin-Lee, Daria Siekhaus, Jakub Skrzeczkowski, Katharina Sonnen, Samuel Stephan, Zuzanna Szymanska, Elly Tanaka, Eric Theveneau, Amandine Véber, Boyi Wang, Kees Weijer, Raphael Winter, Tobias Wöhrer, Katarina Wolf, Wei-Feng Xue, Havva Yoldas, Alexandra Zampataki, Madeleine Zillner.

Workshops organized independently of the main programmes

Workshop and School: Optimal Point Configurations on Manifolds

Organizers: 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)

Dates: January 10 – 21, 2022

Budget: ESI € 8 000

Report on the Graduate School and Workshop

The Graduate School and Workshop on "Optimal Point Configurations on Manifolds" was part of an informal roughly biannual series of workshops and conferences on subjects related to finding well-distributed point sets on manifolds. Several quality measures for such point sets have been introduced and studied:

- *discrepancy* as a measure to compare an empirical distribution of points $x_1,\ldots,x_N$ with the limiting measure μ (also known as Kolmogorov-Smirnov statistics)

$$\sup_C \left| \frac{1}{N}\sum_{n=1}^{N} \mathbb{1}_C(x_n) - \mu(C) \right|,$$

  where the supremum is extended over a suitable family of test sets C. The study of lower bounds for this quantity has been initiated by Schmidt in the 1970s (see [1,6]) and obtained new interest by recent progress (see [2]).
- the *energy*

$$\sum_{i\neq j} g(\|x_i - x_j\|)$$

  of a point set has the physical interpretation of the cumulative pairwise energy of a particle system under a repulsive potential g depending only on the distance. Examples for such are of course the well studied energies of physical systems (Coulomb interaction), but go far beyond that with Riesz potentials or worst case errors of numerical integration that can be expressed in a similar form. The exact determination of the minimal energy for N points is a difficult unsolved problem. For a general reference on energy problems we refer to [3].
- the *packing density* of an infinite point configuration X (assuming that $\forall x,y \in X : x \neq y \Rightarrow \|x-y\| \geq 1$) in euclidean space is given by

$$\liminf_{R\to\infty} \frac{\lambda_d\left(\bigcup_{x\in X\cap B(0,R)} B(x,1)\right)}{\lambda_d(B(0,R))}.$$

  Here recent progress has been made by the determination of the best packing configurations in dimensions 8 (see [7]) and 24 (see [4]). Very recently, a further major step has been made by the same group of authors in proving the universal optimality of the E_8

and the Leech lattice in these dimensions [5]. Universal optimality refers to the fact that these lattices minimise the p-energy

$$\sum_{\substack{\mathbf{x}\in\Lambda \\ \mathbf{x}\neq\mathbf{0}}} p(\|\mathbf{x}\|)$$

for all completely monotonic functions $p : \mathbb{R}^+ \to \mathbb{R}$ and all infinite configurations Λ of asymptotic density 1.

The title of the program refers to the quest of finding optimal configurations with respect to one of these quality measures.

Activities

The school part of the programme intended to introduce participants to newest results and techniques in the context of

- Minimal energy, packing, and covering
- Statistical mechanics of particle systems

in two lecture series given by Dmitriy Bilyk (University of Minnesota) and Thomas Leblé (Université de Paris). These lecture series were especially aimed at PhD-students and young PostDocs.

The workshop part of the program was held in a hybrid format, up to nine participants were present at the ESI, the others participated online. In total 20 talks were given. The discussions were transmitted via the online system of the ESI.

Unfortunately, only the small group of participants present in Vienna could profit from the inspiring atmosphere at the ESI. Nevertheless, they took the opportunity of discussions.

The programme had been originally scheduled for June 2020 and had been deferred twice due to the restrictions implemented to prevent Covid 19.

Specific information on the school and workshop

The first week was dedicated to a winter school with two lecture series. Dmitriy Bilyk is a specialist in the application of harmonic analysis to questions of uniform distribution and packing. He presented many classical and new results in that context in compilation especially designed for an audience of PhD-students and yound PostDocs, including a number of stimulating open problems. Thomas Leblé comes from a background of mathematical physics and gave an introduction to statistical mechanics with a lot of physical intuition also aimed for the specific audience. The connection of the general subject to statistical physics is rather new, and thus it can be expected that this provides new insights and interactions.

The workshop in the second week was organised with talks on one general subject per day:

- Minimal energy point configurations
- Linear programming
- Lattices and tilings
- Packing
- Applications to numerical integration

Outcomes and achievements

The main achievement of the programme was that it allowed for personal scientific interaction after two years of deprivation. The participants especially appreciated the opportunity to interact personally and to have intensive scientific discussions. Specific outcomes like preprints can only expected some time after the programme.

List of talks

Thomas Leble (U de Paris)	Statistical mechanics of particle systems, I , II, III, IV, V
Dmitriy Bylik (U of Minnesota)	Minimal energy, packing, and covering, I, II, III, IV, V
Sergiy Borodachov (Towson U)	Min-Max Polarization for Certain Classes of Sharp Configurations on the Sphere
Peter Dragnev (Purdue U Fort Wayne)	Riesz energy problems with external fields and related theory
Ryan Matzke (TU Graz)	Energy Minimization on Projective Spaces via Determinantal Point Processes
Alexey Glazyrin (U of Texas Rio Grande Valley)	Optimal point configurations and measures for multivariate geometric potentials
Nando Leijenhorst (TU Delft)	A specialized SDP solver for sums-of-squares problems in discrete geometry
Lenny Fukshansky (Claremont McKenna College)	Geometric constructions for sparse integer signal recovery
Nathaniel Tenpas (Vanderbilt U, Nashville)	Some Optimal Periodic Point Configurations
Andrew Salmon (MIT, Cambridge)	Three point bounds for sphere packing
Laurent Bétermin (UCB Lyon)	Theta functions and optimal lattices for a grid cells model
Nihar Gargava (EPFL Lausanne)	Lattice packings through division algebras
Mircea Petrache (Pontificial Catholic U of Chile)	Almost-sure recovery of quasi-periodic structures from their random perturbation
Chuanming Zong (Tianjin U)	Characterization of the Three-Dimensional Multiple Tiles
Carlos Beltran (U of Cantabria)	A Fast Algorithm for Designing Grassmannian Constellations
Werner Krauth (ENS Paris)	Hard-disk packings, fast Markov chains, and the two phase transitions of two-dimensional particle systems
Oleksandr Vlasiuk (Vanderbilt U, Nashville)	Optimal polarization and covering on sets of low smoothness
Ji Hoon Chun (TU Berlin)	Finite sphere packings in low and high dimensions
Mario Ullrich (JKU, Linz)	Function values are almost optimal for L_2-approximation
Johann Brauchart (TU Graz)	Spherical Fibonacci Points: Weyl sums, ...
Mathias Sonnleitner (JKU, Linz)	A characterization of optimal points for integration on manifolds
David Krieg (JKU, Linz)	Lower bounds for quadrature and recovery in L2

Publications and preprints contributed

J. Luong, K. Tran, *Zeros of a table of polynomials satisfying a four-term contiguous relation*, arXiv:2008.08707 [math.CV].

List of participants

Laurent Bétermin, Kerrin Bielser, Dimitriy Bilyk, Bence Borda, Sergiy Borodachov, Markus Faulhuber, Damir Ferizović, Nihar Gargava, Peter Grabner, David Krieg, Oleg Musin, Mathias Sonnleitner, Robert Tichy, Mario Ullrich.

Invited scientists who participated online

Michael Baake, Eiichi Bannai, Rémi Bardenet, Eva Bayer-Fluckiger, Carlos Beltran, Sergey Berezin, Peter Boyvalenkov, Johann Brauchart, Raphael Butez, Ji Hoon Chun, Henry Cohn, Renaud Coulangeon, Valentin Dannenberg, Matthew de Courcy-Ireland, David de Laat, Victor de la Torre, Willem de Muinck Keizer, Maria Dostert, Peter Dragnev, Daniel El-Baz, Maria de Ujue Etayo Rodriguez, Fernando Mário de Oliveira Filho, Lenny Fukshansky, Alexey Garber, Bianca Maria Gariboldi, Alexey Glazyrin, Felipe Gonçalves, Mateja Gosenca, Peter Grabner, Karlheinz Gröchenig, Anupam Gumber, Antti Haimi, Douglas Hardin, Martin Henk, Ryan Koenig, Werner Krauth, David Krieg, Arno Kuijlaars, Woden Kusner, Frieder Ladisch, Thomas Leble, Chin-Yen Lee, Nando Leijenhorst, Norman Levenberg, Fatima Lizarte, Pedro López, Felipe Marceca, Jordi Marzo, Michelle Mastrianni, Ryan Matzke, Paolo Minelli, Philippe Moustrou, Gabriele Nebe, Joaquim Ortega, Mircea Petrache, Danylo Radchenko, Hannes Richter, Sinai Robins, Jose Luis Romero, Juan Pablo Rossetti, Edward Saff, Andrew Salmon, Etienne Sandier, Sebastian Schmutzhard-Hoefler, Robert Schüler, Achill Schürmann, Vlad Serban, Irina Shafkulovska, Lucas Slot, Michael Speckbacher, Andreas Spomer, Tetiana Stepaniuk, Maya Stoyanova, Nathaniel Tenpas, Florian Theil, Kai Toyosawa, Khang Tran, Frank Vallentin, Oleksandr Vlasiuk, Minh Quan Vu, Chen Xuemei, Wei-Hsuan Yu, Ofer Zeitouni, Steven Morris Zelditch, Chuanming Zong.

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[2] D. Bilyk, M. T. Lacey, and A. Vagharshakyan, *On the small ball inequality in all dimensions*, J. Funct. Anal. 254 (2008), no. 9, 2470–2502.

[3] S. V. Borodachov, D. P. Hardin, and E. B. Saff, *Discrete energy on rectifiable sets*, Springer Monographs in Mathematics, Springer, New York, [2019] ©2019.

[4] H. Cohn, A. Kumar, S. D. Miller, D. Radchenko, and M. Viazovska, *The sphere packing problem in dimension 24*, Ann. of Math. (2) 185 (2017), no. 3, 1017–1033.

[5] ———, *Universal optimality of the* E_8 *and Leech lattices and interpolation formulas*, Ann. of Math. (2 (2022), to appear, available at arXiv:1902.05438.

[6] W. M. Schmidt, *Irregularities of distribution. VII*, Acta Arith. 21 (1972), 45–50.

[7] M. S. Viazovska, *The sphere packing problem in dimension 8*, Ann. of Math. (2) 185 (2017), no. 3, 991–1015.

Online-Workshop: Free Boundary Problems and Related Evolution Equations

Organizers: Giovanni Bellettini (U of Siena), Shokhrukh Kholmatov (U of Vienna), Paolo Piovano (Politecnico di Milano)

Dates: February 21 – 25, 2022

Budget: ESI € 109

Report on the Workshop

The workshop aimed at providing an international platform to present and discuss the state of the art and the most recent developments in the field. Prominent scientists in the areas of calculus of variations, partial differential equations, geometric flows, and continuum mechanics were brought together with interested participants to promote the exchange of ideas and enhance collaborations. Special emphasis was placed on shape optimization, minimal surfaces, phase-field analysis, fracture, delamination, phase transition, mean curvature flow and quasistatic evolutions in elastic media.

Activities

The event was initially assumed to be held in a hybrid mode using the Zoom platform. Unfortunately, because of the high Covid numbers in Austria and in Europe, a number of invited speakers decided not to come to Vienna, and therefore, we took a difficult decision passing to a completely online form, also for the sake of the safety of participants. There were 26 talks splitted in five afternoons (in Central European Time) from Monday to Friday, comprising speakers from Europe, USA and Japan. Detailed program as well as abstracts of talks can be found in the website of the workshop at

`https://www.univie.ac.at/workshop_free_boundary_problems/`

Specific information on the school

More than 100 young researchers (postdocs and PhD students) all around the world from variuos fields of research have registered and participated in the program and have benefited from the talks of experts.

Among young participants:

- *PhD students:* Roberta Marziani, Luciano Sciaraffia, Sven Hirsch, Georgios Domazakis, Lorenzo Liverani, Randy Llerena, Francesco Bozzola, Jona Lelmi, Alexander Menovschikov, Anna Chiara Zagati, Andreas Vikelis, Serena Della Corte, Luigi De Masi, Alice Marveggio, Nicola Picenni, Mattia Freguglia, Lorenza D'Elia, Fumihiko Onoue, Mickael Nahon, Katharina Brazda, Marco Bresciani, Andrea Chiesa, Almuratov Firdavs, Enzo Maria Merlino, Ken Shirakawa
- *PostDocs:* Mattia Fogagnolo, Anastasia Molchanova, Marius Müller, Francesco Sapio, Maicol Caponi, Francesca Bianchi, Filippo Riva, Valerio Pagliari, Michal Lasica, Chiara Gavioli, Emanuele Tasso, Maximilian Moser
- *Established:* Sebastian Hensel, Stefano Almi, Elisa Davoli, Julian Fischer, Nadia Ansini, Martin Jesenko, Keisuke Takasao, Karel Svadlenka, Hirotoshi Kuroda

Outcomes and achievements

Since the meeting was online, ESI kindly allowed us to use the gather.town and Zoom breakout-rooms. In the breaks speakers used these facilities to answer more (informal) questions about their talks or to coordinate with their collaborators. It seems that these discussions were helpful, however, it is possibly too early to see the outcomes of the meeting.

List of talks

The talks were recorded and have been already posted in the ESI YouTube Channel. Below we list the talks in the order that they have been presented during the workshop.

Yoshikazu Giga (U of Tokyo)	On a singular limit of a single-well Modica-Mortola functional and its applications
Anna Dall'Acqua (U Ulm)	An obstacle problem for the p-elastic energy
Piotr Rybka (U Warsaw)	Dynamic boundary conditions as a limit of a boundary layer problem
Maria Giovanna Mora (U Pavia)	Explicit minimizers for a class of nonlocal interaction energies
Maurizio Paolini (Cath. U Brescia)	About soap films spanning a nonregular tetrahedron
Nicola Fusco (U Napoli)	The isoperimetric inequality outside a convex set: the case of equality
Massimiliano Morini (U Parma)	The asymptotics of the area preserving mean curvature flow in two dimensions
Dorin Bucur (U Savoie)	Rigidity results for measurable sets
Gian Paolo Leonardi (U Trento)	The prescribed mean curvature measure equation
Stefan Krömer (Czech Acad. Sc.)	Relaxation of functionals with linear growth: interaction of measures and free discontinuities
Harald Garcke (U Regensburg)	On the interaction of mean curvature flow and diffusion on evolving hypersurfaces
Alessandra Pluda (U Pisa)	Resolution of singularities of the network flow
Tim Laux (U Bonn)	A new varifold solution concept for mean curvature flow: convergence of the Allen–Cahn equation and weak-strong uniqueness
Riccardo Scala (U Siena)	A non-parametric Plateau problem with partial free boundary
Matteo Novaga (U Pisa)	Isoperimetric clusters
Vittorino Pata (Politecnico di Milano)	Viscoelasticity with time-dependent memory kernels
Patrick Dondl (U Freiburg)	A proof of Taylor scaling for curvature-driven dislocation motion through random arrays of obstacles
Maurizio Grasselli (Politecnico di Milano)	Cahn-Hilliard-Hele-Shaw systems with singular potential
Martin Kružík (Czech Acad. Sc.)	Equilibrium for multiphase solids with Eulerian interfaces
Igor Velčić (U Zagreb)	High-contrast random composites: homogenisation framework and new spectral phenomena
Anja Schlömerkemper (U Würzburg)	Extensions of the Cahn-Hilliard equation to a temperature-dependent setting
Adriana Garroni (U Rome La Sapienza)	Derivation of surface tension of grain boundaries in polycrystals
Marcello Ponsiglione (U Rome La Sapienza)	Stability results for nonlocal geometric evolutions
Gilles Francfort (U New York)	Fracture with healing as a template for cavitation
Jean-François Babadjian (U Paris-Saclay)	On the convergence of critical points of the Ambrosio-Tortorelli functional
Irene Fonseca (U Carnegie Mellon)	Phase separation in heterogeneous media

Invited scientists

Stefano Almi, Firdavs Almuratov, Nadia Ansini, Jean-Francois Babadjian, Giovanni Bellettini, Konstantinos Bessas, Francesca Bianchi, Tania Biswas, Farid Bozorgnia, Francesco Bozzola, Katharina Brazda, Marco Bresciani, Dorin Bucur, Maicol Caponi, Simone Carano, Nikolai Chemetov, Andrea Chiesa, Sergio Conti, Anna Dall'Acqua, Elisa Davoli, Thaícia De Almeida, Daniele De Gennaro, Lorenza D'Elia, Serena Della Corte, Antonia Diana, Alberto x Dominguez Corella, Patrick Dondl, Tokuhiro Eto, Nikita Evseev, Rifaldy Fajar, Julian Fischer, Mattia Fogagnolo, Irene Fonseca, Gilles Francfort, Mattia Freguglia, Harald Garcke, Carlo Gasparetto, Chiara Gavioli, Yoshikazu Giga, Wojciech Gorny, Maurizio Grasselli, Nico Groh, Sebastian Hensel, Jonas Ingmanns, Martin Jesenko, Nicolai Jork, Shokhrukh Kholmatov, Milan Kroemer, Martin Kružík, Anna Kubin, Hirotoshi Kuroda, Leonie Langer, Michal Lasica, Tim Laux, Gian Paolo Leonardi, Lorenzo Liverani, Randy Llerena, Alice Marveggio, Roberta Marziani, Enzo Maria Merlino, Claudiu Mindrila, Masashi Mizuno, Anastasia Molchanova, Maria Giovanna Mora, Massimiliano Morini, Maximilian Moser, Marius Müller, Mickael Nahon, Katerina Nik, Matteo Novaga, Jun Okamoto, Fumihiko Onoue, Valerio Pagliari, Nicola Picenni, Paolo Piovano, Adriano Pisante, Alessandra Pluda, Marcello Ponsiglione, Julius Fergy Rabago, Dario Reggiani, Filippo Riva, José Francisco Rodrigues, Marlene Sophie Rose, Piotr Rybka, Abdelmouksit Sagueni, Francesco Sapio, Riccardo Scala, Manuel Schlierf, Anja Schlömerkemper, Luciano Sciaraffia, Ken Shirakawa, Ulisse Stefanelli, Karel Svadlenka, Keisuke Takasao, Emanuele Tasso, Igor Velčić, Andreas Vikelis, Anna Chiara Zagati.

Adaptivity, High Dimensionality and Randomness

Organizers: Carsten Carstensen (HU Berlin), Albert Cohen (Sorbonne U, Paris), Michael Feischl (TU Vienna), Christoph Schwab (ETH Zurich)

Dates: April 4 – 8, 2022

Budget: ESI € 7 162

Report on the Workshop

The overall goal of this workshop was to initiate new and groundbreaking research in algorithm design and mathematical analysis in scientific computing. The focus was directed at the numerical approximation of partial differential equations, when randomness is involved either in the input data of the modeling equations or in the approximation algorithms themselves.

Rather than a tight focus on a highly specialized, clearly delineated research field, the workshop aimed at cross-fertilization of several recently emerged research directions in applied and computational mathematics around the numerical solution of PDEs. This comprised, in particular, mathematically justified paradigms for the design of adaptive algorithms, the recently strongly advanced understanding of randomized and number-theoretic algorithms such as Monte-Carlo, quasi-Monte Carlo and Markov Chain MC, sparse and high dimensional approximation, tensor-formatted computations, deep neural network approximation and machine learning algorithms, to name a few developments most related to the proposed workshop theme.

Activities

The workshop was held in a hybrid format with around seven talks each day. For each talk we allocated 50 minute time slots. We had two coffee breaks every day as well as a lunch break. On Wednesday, we organized a conference dinner at Heuriger Wolf.

Due to the pandemic, many of the invited guests chose to participate via Zoom so that around half of the participants were presents in person. This was sufficient to spark lively discussions among the in-person participants in the breaks and to create an inspiring workshop atmosphere. However, all participants agreed that a fully offline workshop would be preferable but not realistic at the time.

The hybrid organization of the talks was flawless. This is in large parts due to the perfect technical support provided by the ESI, which even dedicated a full time technical assistant to manage the equipment and the switching between offline and online talks. This also resulted in numerous high-quality recordings of the talks.

We briefly summarize the scientific program:

- Monday: On the first day, we accommodated some overview lectures by the experts in the fields. This, e.g., includes Michael Griebel (U Bonn) who gave the opening talk or Aretha Teckentrup (U Edinburgh) who introduced Gaussian process regression.
- Tuesday: This day was focused on machine learning and started with a talk by Wolfgang Dahmen (U of South Carolina, formerly U Aachen) on Physics informed neural networks. Even overseas contributors overcame the time difference and we enjoyed a talk on Gaussian process learning by Houman Owhadi (Caltech).
- Wednesday: In order to stimulate the intended cross-fertilization of themes, we switched focus and continued with adaptive finite element talks. Rob Stevenson (U Amsterdam) gave a presentation on adaptivity and least squares for parabolic problems and Ricardo Nochetto (U of Maryland) presented a new work on adaptive Virtual Element Methods.
- Thursday: The entire day was dedicated to uncertainty quantification in stochastic PDEs. We heard new results on rare event estimation by Elisabeth Ullmann (TU Munich) and multi-level adaptivity by Catherine Powell (U Manchester)
- Friday: The final day started with two talks on tractability of high-dimensional integration (Friedrich Pillichshammer and Peter Kritzer (JKU Linz)) and concluded with a lecture on density estimation in high dimensions by Fabio Nobile (EPFL Lausanne).

Specific information on the workshop

We are proud that we were able to attract some of the most distinguished researchers in the fields of uncertainty quantification, machine learning, and adaptivity. Many of them play a leading role in the recent development of their respective fields. All of them gave high-quality lectures which can be viewed on the ESI website.

Furthermore, we also attracted young but already highly successful researchers, e.g., Barbara Verfürth (U Bonn, formerly KIT Karlsruhe), Vladimir Kazeev (U of Vienna), Michele Ruggeri (U Strathclyde), Arbaz Khan (IIT Roorkee), Tabea Tscherpel (U of Bielefeld), Markus Faustmann (TU Wien), Cosmas Heiss (TU Berlin), Jakob Zech (U Heidelberg), Aretha Teckentrup (U Edinburgh).

On top of that, several local PhD students and post-docs attended the lectures, e.g., Marko Zank (U of Vienna), Leila Taghizadeh (TU Munich), Andrea Scaglioni (TU Wien), Marcello Longo (ETH Zürich).

Outcomes and achievements

The main outcome and goal of the workshop was to connect experts from the fields of adaptivity, randomness, and high-dimensionality. This was definitively achieved as evidenced by the diverse scientific program and the lively discussions in the coffee breaks.

List of talks

Michael Griebel (INS, Bonn)	Sparse Tensor Product Approximation for a Class of Generalized Method of Moments Estimators
Ivan Oseledets (SKOLTECH Moscow)	Approximation of high-dimensional probability distributions
Chris Oates (U Newcastle upon Tyne)	Optimal Thinning of MCMC Output
Olga Mula Hernandez (Dauphine U, Paris)	Sparse, Adaptive Interpolation of Measures with Wasserstein Barycenters. Application to Model Order Reduction.
Aretha Teckentrup (U Edinburgh)	Convergence and Robustness of Gaussian Process Regression
Jakob Zech (U Heidelberg)	UQ for PDEs with Gaussian random field inputs
Wolfgang Dahmen (U of South Carolina, Columbia)	Some Thoughts on PINN - Prediction Capability
Giovanni Migliorati (Sorbonne U, Paris)	Adaptive approximation by weighted least-squares methods
Cosmas Heiss (TU Berlin)	Approximating Parametric PDEs: Defeating the Curse of Dimensionality Using Multilevel CNNs
Bruno Després (Sorbonne U, Paris)	A non probabilistic proof of the efficiency of the Latin hypercube method
Reinhold Schneider (TU Berlin)	Numerical solution of Hamilton Jacobi Bellmann (HJB) equations from a Mean Field Game Perspective
Houman Owhadi (Caltech, Pasadena)	Solving/learning nonlinear PDEs and completing computational graphs with GPs
Clayton Webster (U of Texas, Austin)	Sparse polynomial approximation of high-dimensional functions from random samples
Rob Stevenson (U Amsterdam)	First order least squares methods for parabolic and instationary Stokes equations
Tabea Tscherpel (U of Bielefeld)	Interpolation operators on negative Sobolev spaces
Markus Faustmann (TU Wien)	Adaptive FEM for fractional diffusion
Martin Eigel (WIAS, Berlin)	An empirical adaptive Galerkin method for parametric PDEs
Christian Kreuzer (TU Dortmund)	On the threshold condition for Dörfler marking
Ricardo Nochetto (U of Maryland)	Adaptive Virtual Element Methods
Arbaz Khan (IIT Roorkee)	Mixed finite element approximation for poroelasticity
Catherine Powell (U Manchester)	Multilevel Adaptive Stochastic Galerkin Approximation Using Hierarchical Error Estimation
Michele Ruggeri (U Strathclyde, Glasgow)	Convergence and rate optimality of adaptive multilevel stochastic Galerkin FEM
Barbara Verfürth (KIT, Karlsruhe)	Offline-online strategy for multiscale problems with random defects

Markus Bachmayr (U Mainz)	Optimality of adaptive stochastic Galerkin methods for affine-parametric elliptic PDEs
Alex Bespalov (U of Birmingham)	A posteriori error estimation and adaptivity for stochastic collocation FEM
Elisabeth Ullmann (TU Munich)	Rare event estimation with PDE-based models
Vladimir Kazeev (U Vienna)	Stable multilevel low-rank representation for elliptic PDEs: approximation and preconditioning
Friedrich Pillichshammer (JKU, Linz)	Tractability of approximation in the weighted Korobov space in the worst-case setting
Peter Kritzer (RICAM)	Digit-by-digit constructions of good lattice rules
Fabio Nobile (EPFL Lausanne)	Density estimation in RKHS with application to Korobov spaces in high dimensions

Invited scientists

Markus Bachmayr, Alex Bespalov, Carsten Carstensen, Albert Cohen, Bruno Després, Martin Eigel, Markus Faustmann, Michael Feischl, Lars Grasedyck, Michael Griebel, Philipp Grohs, Cosmas Heiss, Vladimir Kazeev, Peter Kritzer, Marcello Longo, Fabio Nobile, Anthony Nouy, Ilaria Perugia, Daniel Peterseim, Philipp Petersen, Friedrich Pillichshammer, Davide Pradovera, Dirk Praetorius, Michele Ruggeri, Andrea Scaglioni, Christoph Schwab, Rob Stevenson, Leila Taghizadeh, Tabea Tscherpel, Elisabeth Ullmann, Marco Zank, Jakob Zech.

Minimal Representations and Theta Correspondencen

Organizers: Wee Teck Gan (National U of Singapore), Marcela Hanzer (U Zagreb), Alberto Minguez (U of Vienna), Goran Muic (U Zagreb), Martin Weissman (UC Santa Cruz)

Dates: April 11 – 15, 2022

Budget: ESI € 12 720
NSF $ 20 000

Report on the Workshop

This workshop is devoted the subject of theta correspondences and minimal representations. Minimal representations of real or p-adic Lie groups are analogs of the classical Weil representations of metaplectic groups. The theta correspondence studies the branching laws when minimal representations are restricted to a pair of mutually commuting subgroups. This transcendental version of classical invariant theory was initiated by Roger Howe some 45 years ago in the setting of classical groups. Since the 1990's there has been a systematic extension of this theory to the setting of exceptional groups. There has been significant progress in this subject in the past few years with several foundational problems resolved and has also found applications in the theory of automorphic forms and arithmetic geometry. The purpose of the workshop is to provide a platform for the announcement and discussion of new results, as well as to explore new avenues of research in view of these recent progresses. In additional, the workshop is held in honor of Gordan Savin's 60th birthday. Savin has done pioneering work in the theory of minimal representations and the theta correspondence, both in the classical and exceptional settings.

Because of strict travel restrictions in many East Asian countries due to the pandemic, the workshop was held in hybrid mode with the platform zoom. There were about 40 on site participants and about 40 online participants. Likewise, about slightly more than half the talks were on-site while the rest were online.

Activities

There were 22 talks in total with each talk 45 minutes long. For each day, there are essentially 3 talks in the morning and two in the afternoon, with each session specifically on-site or online. Online talks were conducted via zoom, which worked sufficiently well. Between the talks, there were coffee breaks during which there were active discussions among on-site participants.

Since this was the first in-person workshop for many on-site participants, there was a strong sense of enthusiasm and joyful atmosphere among the on-site participants. For many participants it was indeed the first time in two years too meet face-to-face. However, the set up was such that it was not really possible for on-site and online participants to interact with each other.

There was also a conference dinner held on Wednesday. A hike was planned for Friday afternoon, but the weather was not cooperative and the plan was changed to a closing dinner at a restaurant in Prater. Through these social events, new networks and friendships were being formed.

Specific information on the workshop

The following is a list of young researchers (recent PhDs, postdocs and PhD students):

- Justin Trias (speaker)
- Wan-Yu Tsai (speaker, female)
- Sonja Zunar (speaker, female)
- Melissa Emory (speaker, female)
- Emile Okada (speaker, PhD student)
- Rahul Dalal (speaker)
- Adel Betina (participant)
- Barbara Bošnjak (participant, female)
- Giancarlo Castellano (participant)
- Cheng Chen (online participant)
- Rui Chen (online participant)
- Peiyi Cui (participant, female)
- Johannes Droschl (participant)
- Johannes Girsch (participant, PhD student)
- Guanjie Huang (online participant)
- Ruben La (participant, PhD student)
- Nhat Hoang Le (online participant, PhD student)
- Yusheng Lei (online participant)
- Zhaolin Li (online participant, PhD student)

- Hengfei Lu (participant)
- Yi Luo (online participant, PhD student)
- Lucas Mason Brown (online participant)
- Finn McGlade (participant, PhD student)
- Xinchen Miao (online participant, PhD student)
- Sam Mundy (participant)
- Markus Reibnegger (participant)
- Sheng-Chi Shih (participant)
- Alexander Stadler (participant, PhD student)
- Ruishen Zhao (participant, PhD student)

As one can see, there were many young researchers who participated in the workshop and 6 of them (including 3 females) also gave talks. The workshop allowed the speakers to showcase their results in front of many experts and the on-site participants to discuss mathematics with experts of the field. The decision to hold the workshop in a hybrid form, instead of insisting on a purely on-site format, allowed some of these young participants to benefit while remaining in their home institutions.

Outcomes and achievements

After the ESI workshop, 4 of the participants (Wee Teck Gan, Nadya Gurevich, Aaron Pollack and Gordan Savin) remained at ESI for an extra week under the support of the Research in Teams programme. The title of their project is "Modular Forms and Thea Correspondence for Exceptional Groups". Thus this Research in Teams project built upon the momentum of the ESI workshop and allowed these 4 participants to collaborate on projects arising from the workshop. More precisely,

- one of the projects arising from discussion during the workshop is the construction of a family of nontempered Arthur packets for G_2 using a sequence of classical and exceptional theta correspondences involving $Spin_8$. This should allow one to give a concrete construction of the level 1 modular form on G_2 of lowest possible weight, whose existence was discussed in R. Dalal's talk. This project was initiated in conversations of W.T. Gan with Sam Mundy during the workshop.
- Another project pursued in the Research in Teams project is the explicit description of a Fourier transform operator on the Schrodinger model of the minimal representation of E_7. This was inspired by the talks of T. Kobayashi and J. Frahm during the conference.
- Yet another progress that was made during the workshop was the local Langlands correspondence project of W.T. Gan and G. Savin. Here, discussion with G. Chenevier (who was a participant) led to the proof of a key lemma. This would not have happened if these 3 individuals were not together at the same place and time.

Undoubtedly, there will be other such progress that resulted from the interactions among the participants and that we are not aware of. One idea suggested to two of the organizers by the talk of M. Tadic is that it will be timely to consider proposing an ESI programme/workshop on the problem of unitary dual of real and p-adic groups. Hopefully, that will come to pass!

List of talks

Dipendra Prasad (IIT Bombay)	Homological methods in theta correspondence
Anne-Marie Aubert (CNRS, Paris)	Theta correspondence and wave front set
Justin Trias (Imperial College, London)	Towards a theta correspondence in families for type II dual pairs
Jeffrey Adams (U of Maryland)	Equivalent definitions of Arthur packets for real classical groups
Baiying Liu (Purdue U)	Recent progress on certain problems related to local Arthur packets of classical groups
Toshiyuki Kobayashi (U Tokyo)	Schrödinger model of minimal representations and branching problems
Jing-Song Huang (HKUST)	Model orbits and unipotent representations
Wan-Yu Tsai (CYCU)	Some genuine small representations of a covering group and their wavefront sets
Sonja Zunar (U Zagreb)	On topological aspects of smooth automorphic forms
Jan Frahm (U Aarhus)	Conformally invariant differential operators on Heisenberg groups and minimal representations
Melissa Emory (U Toronto)	On Restrictions of Representations
Emile Okada (U Oxford)	On the construction of some unipotent local Arthur packets
David Soudry (Tel Aviv U)	New types of Siegel-Weil formulas
Dihua Jiang (U of Minnesota)	Wavefront Sets, Local Descents and Spectrum
Kei Yuen Chan (Fudan)	Quotient branching law for p-adic general linear groups and affine Hecke algebra of type A
Jiajun Ma (Xiamen U)	Generic Hecke algebra and theta correspondence over finite fields
Hung Yean Loke (U of Singapore)	A Cauchy - Harish-Chandra integral for a dual pair over a p-adic field
Rahul Dalal(Johns Hopkins U, Baltimore)	Counting Level-1, Quaternionic Automorphic Representations on G_2
Aaron Pollack (UC San Diego)	Modular forms of half-integral weight on G_2
Nadya Gurevich (Ben-Gurion)	Gelfand-Graev representation for covering groups and applications
Marko Tadic (U Zagreb)	An approach to the unitarizability problem in the case of classical p-adic groups
Pavle Pandzic (U Zagreb)	Dirac index and associated cycles of Harish-Chandra modules

Publications and preprints contributed

B. Mesland, M. H. Sengun, *Equal rank local theta correspondence as a strong Morita equivalence*, arXiv:2207.13484 [math.RT].

W.T. Gan, B.H. Gross and D. Prasad, *Twisted GGP problems and conjectures*, arXiv:2204.10108 [math.RT].

Invited scientists

Anne-Marie Aubert, Adel Betina, Barbara Bošnjak, Adam Brown, Giancarlo Castellano, Gaëtan Chenevier, Peiyi Cui, Rahul Dalal, Johannes Droschl, Melissa Emory, Jan Frahm, Wee Teck Gan, Johannes Girsch, Harald Grobner, Nadya Gurevich, Marcela Hanzer, Guy Henniart, Ed Karasiewicz, Ruben La, Thomas Lanard, Hengfei Lu, Joachim Mahnkopf, Finn McGlade, Alberto Minguez, Sam Mundy, Emile Okada, Pavle Pandzic, Aaron Pollack, Dipendra Prasad, Markus Reibnegger, Gordan Savin, Haluk Sengun, Alexander Stadler, Marko Tadic, Shuichiro Takeda, Justin Trias, Hongjie Yu, Ruishen Zhao, Sonja Zunar.

Invited scientists who participated online

Jeffrey Adams, Hiraku Atobe, Valentin Buciumas, Kei Yuen Chan, Cheng Chen, Rui Chen, Dan Ciubotaru, Masaaki Furusawa, Fan Gao, Guanjie Huang, Jing-Song Huang, Atsushi Ichino, Dihua Jiang, Eyal Kaplan, Axel Kleinschmidt, Toshi Kobayashi, Nhat Hoang Le, Yusheng Lei, Zhaolin Li, Baiying Liu, Hung Yean Loke, Yongzhi Luan, Yi Luo, Jiajun Ma, Lucas Mason Brown, Xinchen Miao, Kazuki Morimoto, Gil Moss, Goran Muic, Shu-Yen Pan, Anna Puskas, Sheng-Chi Shih, David Soudry, Miyu Suzuki, Dani Szpruch, Wan-Yu Tsai, Chenyan Wu, Guodong Xi, Lei Zhang, Chengbo Zhu.

International Mathematical Olympiad and MEMO Training 2022

Organizers: Michael Eichmair (U of Vienna), Theresia Eisenkölbl (U of Vienna)

Dates: June 27 – July 1, 2022
October 26 – 31, 2022

Budget: ESI € 8 823
Federal Ministry of Education, Science and Research € 1 427 for subsistance and travel costs in July 2022.
Federal Ministry of Education, Science and Research € 598 for subsistance and travel costs in October 2022.
Bäckerei Ströck: Daily bread and pastries

Report on the training

The goal of the event was to prepare for IMO (International Mathematical Olympiad), MEMO (Middle European Mathematical Olympiad) and the CPS-match (Czech-Polish-Slovak-Austrian competition) and foster interaction between the mathematics team and the physics team that met at the same time at the ESI. This opportunity was very fruitful because many of the students had spent a lot of time during the pandemic without the possibility to personally interact with other students similarly interested in mathematics and physics.

Activities

The event included talks on all the main topics of international mathematics competitions for high school students (algebra, combinatorics, geometry, number theory), discussion and interactive problem solving, a competition set by the students for each other and an excursion of all teams together.

Specific information on the workshop

Due to the nature of the event, the young participants had the chance to increase their mathematical knowledge significantly. Many of the talks were given by excellent university students at the beginning of their mathematical career.

Outcomes and achievements

We are happy to report that the participants obtained a 4th place and four honorable mentions at the CPS-match at the IST Austria (July 1-4), a bronze medal and four honorable mentions at the International Mathematical Olympiad in Norway (July 9-15) and three bronze medals and an honorouble mention as well as 5th place in the team competition at the Middle European Mathematical Olympiad in Switzerland (August 25-31).

List of talks

June/July 2022

Thiemo Dsubanko	Functional Equations
Theresia Eisenkölbl	Number Theory
Josef Greilhuber	Geometry
Moritz Hiebler	Algebra
Ivan Izmestiev	Geometry
Veronika Schreitter	Combinatorics

October 2022

Theresia Eisenkölbl	Projective Geometry, Pell Equation, Continued Fractions
Moritz Hiebler	Spiral Similarities, Cyclotomic Polynomials
Daniel Holmes	Generating Functions
Lorenz Hübel	Supporting Line, RCF
Ivan Izmestiev	Complex Numbers and Geometry, Solutions of Polynomial Equations
Veronika Schreitter	Selected Problems from Combinatorics

Participants

June/July 2022

Martin Bierbaumer, David Buchmaier Bofill, Thiemo Dsubanko, Theresia Eisenkölbl, Josef Greilhuber, Paul Hametner, Raphael Heuchl, Moritz Hiebler, Ivan Izmestiev, Jakob Kapelari, Doris Obermaier, Felix Pernegger, Dominik Pultar, Veronika Schreitter, Jan Strehn, Raphael Vanham, Georg Weisbier,

October 2022

Nina Bemetz, David Buchmaier Bofill, Theresia Eisenkölbl, Paul Hametner, Raphael Heuchl, Moritz Hiebler, Daniel Holmes, Lorenz Hübel, Ivan Izmestiev, Jakob Kapelari, Elias Klein, Ha An Nguyen, Anastasya Pazniak, Felix Pernegger, Dominik Pultar, Jan Schiller, Veronika Schreitter, Jan Strehn, Raphael Vanham, Georg Weisbier.

IPhO and EuPhO Training 2022

Organizers: Marianne Korner (U of Vienna), Stefan Lorbek (BRG Mürzzuschlag)

Dates: June 26 – July 1, 2022

Budget: ESI € 3 175
Federal Ministry of Education, Science and Research, Republic of Austria € 2 200

Report on the training

From June 26, 2022 to July 1, 2022, the ten most interested and skilled high school students aged 16 to 19 from all over Austria met to further improve their skills in solving physics tasks and in order to succeed at the IPhO-2022 (International Physics Olympiad). This training is the final step in a consecutive multi-stage process of trainings and competitions in order to select the most suitable candidates for the IPhO.

Activities

Due to the pandemic, the trainings of the last two years were either cancelled or held online which did not sufficiently improve the skills of the participants. Therefore, it was very important to bring the students together in a place where they can get into closer contact by discussing physics problems face to face. Thanks to the support of ESI including hotel and rooms expenses (which exceeded the basic founding of the BMBWF) it was possible that the candidates for this year's IPhO and the potential candidates for the next year's IPhO could participate in the training. If we support the younger ones with this high-quality training their chances for a top placing in the following year will increase.

Another important point is that these gifted students crave for a protected environment where they can socialize and where their non-cognitive needs for friendship and sharing are met which is not always possible in their own schools. Therefore, the organizers of this training week have managed to hold the training for the IMO (International Mathematics Olympiad) parallel with the IPhO training at the ESI. It allowed IPhO students and IMO students to spend their breaks and a half-day excursion together on Thursday afternoon. This promoted social contact and was highly appreciated by the students concerning the academic programme there were a variety of activities.

Specific information on the workshop

On Sunday, June 26, Elias Hohl, a former IPhO participant and gold medalist, worked with the students on IPhO-specific problems and shared his experiences during such a long and demanding competition. In order to prepare students best, training was provided on task-specific problems as well as strategies for maximizing performance and managing the resulting stress.

On Monday, June 27, Lucas Hörl, another former IPhO participant and silver medalist, worked with the students on mathematical methods (e.g. differential approaches) and applied the techniques to concrete problems.

Tuesday, June 28, was conducted by one of the IPhO leaders, Marianne Korner, and was dedicated to accuracy in completing tasks and focused on proper documentation of reasoning. In the afternoon the aforementioned excursion of IPhO and IMO students took place. The two groups decided to spend time together in a more non-academic way and therefore visited the Prater to recover together from the demanding work of the previous days. It was great to see how the students from both groups harmonized with each other when communicating and enjoyed going on different rides together.

On Wednesday, June 29, a special guest, Prof. Fredenhagen from the University of Vienna, Faculty of Physics, guided the training. The course dealt with differential equations and the coupled harmonic oscillator.

Thursday, June 30, was conducted by another IPhO leader, Stefan Lorbek. His topic included several difficult problems from previous IPhOs in electromagnetism and electricity. Students were first encouraged to solve the problems themselves and then to discuss their approaches. They were given various hints to help them reach the solution more easily and/or quickly, and were shown details of the physics behind the tasks.

The last half day, Friday, July 1, focused on confidence-building tasks, strategies to maximize scores and stress management during the competition. After lunch, the training ended, and the students headed back home.

Outcomes and achievements

From an instructor's point of view and after a few weeks have passed, we all, including students and instructors, really enjoyed the stay and the working atmosphere at the ESI. Most importantly, it promoted the students' knowledge of physics, which led to remarkable results at the 52nd edition of the IPhO with three Honourable Mentions. In addition, students enjoyed being amongst their peers after two years of pandemic isolation which lead to the forging of many new friendships between students. We are grateful for this opportunity!

List of talks

Theresia Eisenkölbl (U Vienna)	Number Theory I, II
Josef Greilhuber (U Vienna)	Geometry I, II, III, IV
Moritz Hiebler (AAU Klagenfurt)	Algebra I, II
Veronika Schreitter (U Vienna)	Combinatorics I, II
Ivan Izmestiev (TU Vienna)	Geometry I, II

Participants

Simon Marcher, Maximilian Auer, Haolei Zhang, Lukas Gabriel, Benjamin Tonner, Elias Koschier, Taylan Algan, Anja Piecuch, Vinzent Willis, Pascal Lun.

Set-Theory

Organizers: Jörg Brendle (Kobe U), Vera Fischer (U Vienna), Sy David Friedman (U Vienna)
Dates: July 4 – 8, 2022

Budget: ESI € 9 444

Report on the Workshop

The workshop gathered specialists working in three areas of set theory - infinitary combinatorics and forcing, descriptive set theory and large cardinals.

Infinitary combinatorics and forcing originate in problems of combinatorics, real analysis, general topology and algebra. The very first infinitary combinatorial question one can ask about the real line is the well-known continuum problem: What is its size? Another example is the Suslin problem: Up to isomorphism, is the real line the unique dense-in-itself, complete, linear order without endpoints which has the countable chain condition? Similarly, one can ask: Does the existence of a non-measurable set of reals of a given size imply the existence of a non-meager set of reals of the given size? These questions, when viewed in the appropriate context, can be reduced to purely combinatorial problems. Forcing yields insight into questions that cannot be answered using classical methods, allowing one to establish the relative consistency of statements with, or even their independence from, the usual axioms of mathematics. For example, the answers to the above questions are independent from these axioms. In recent years, many new forcing techniques have appeared, e.g., iterations along coherent systems and different methods of non-linear iterations. Forcing has a rich interplay with both descriptive set theory and large cardinals. One very active area of research residing in the interplay of forcing and descriptive set theory is the study of definability properties of sets of reals having appropriate combinatorial properties, especially in models with large continuum. Another quickly developing area is the study of generalized Baire spaces, which depends upon the interplay between forcing and large cardinals.

Descriptive Set Theory is the study of definable subsets of the real numbers. One central theme concerns Borel reducibility, which simultaneously provides a definable refinement of the usual notion of cardinality and a means of gauging obstacles of definability inherent in mathematical classification problems, and has deep connections with other fields such as ergodic theory and operator algebras. Another important theme concerns Borel analogues of problems in combinatorics, a topic of interest in ergodic theory, as well. Yet another theme concerns connections between topological dynamics and Ramsey theory, which grew out of the Pestov-Kechris-Todorcevic characterisation of extreme amenability of automorphism groups of Fräïıssé structures in terms of structural Ramsey properties of their skeletons.

Large Cardinals is a rich and dynamic area of set theory, with deep connections to a wide range of problems in definability and combinatorial set theory, as well as to the choice of new axioms for set theory. Recent work is concerned with singular cardinal problems, reflection principles and the study of ideals. Also important is the development of new "forcing axioms", whose consistency is verified using large cardinals. An especially challenging area is inner model theory, which seeks to find "canonical" models in which large cardinal properties are realised; this area has a long tradition and continues to be very active. Large cardinal theory is also intimately connected with forms of the axiom of determinacy. The combination of large cardinal theory with forcing has produced a powerful set of techniques with a wide range of applications across set theory.

Highlights from the programme

We had 28 invited lectures (6 of those held online), 65 participants, 40 of which international guests from 16 different countries. The programme included lectures by

1. David Aspero, who was awarded **the Hausdorff Medal of the European Set Theory Society** just a few months later, in September 2022. His talk included an outline, of the work (joint with Ralf Schindler), for which he was awarded the medal.

2. Ben De Bondt (Université Paris Diderot) presented recent advances in the actively developing area of forcing with side conditions, which form part of his doctoral thesis and are joint work with his doctoral thesis adviser Boban Velickovic.

3. Natasha Dobrinen (University of Notre Dame) gave her talk at the **International Congress of Mathematicians** about "Ramsey theory on homogenous structures " in front of live audience in the *Boltzmann Lecture Hall.*

4. Sandra Müller (Technical University of Vienna) spoke about "Preserving universally Baire sets and Sealing". Sandra Müller is a recipient of the **FWF START Prize 2022**,

which she was awarded just a few weeks prior to the workshop. Sandra Müller is also a recipient of **the Medal of the Austrian Mathematical Society 2022**.

5. Itay Neeman (UCLA) spoke about “Restrictions of OCAT with large continuum”. Itay Neeman is a recipient of **the Hausdorff Medal of the European set Theory Society**, which he was awarded during the European Set Theory Conference in 2019 at the University of Vienna.

6. Zoltan Vidnyanszky (California Institute of Technology) spoke about “Large Borel chromatic numbers of bounded degree acyclic graphs”. Dr. Vidnyanszky is a recipient of the prestigious **Momentum grant of the Hungarian Academy of Sciences**.

In addition to the invited lectures, the workshop featured a poster session and a number of discussion sessions.

Activities

We had 28 invited lectures, 6 of which online via Zoom. In addition to the invited lectures, the workshop featured a poster session and a number of discussion sessions. The Zoom equipment worked exceptionally well, we had also great technical support. There were 15 lectures by senior scientists; 7 lectures by postdocs and tenure-track faculty; 3 lectures by doctoral students; 6 posters by postdoctoral fellows.

Specific collaborations that participants had begun or continued at the Institute

Below is a short list of some of the collaborations which begun or continued during the workshop. The actual list of such interactions is much longer, as in fact most of the workshop participants had active scientific discussions with other participants.

1. Omer Ben-Neria (Hebrew University of Jerusalem) and Diana Carolina Montoya (University of Vienna) discussed properties of the maximal independent families in the context of higher Baire spaces. Their work resulted in an article, listed below.

2. Serhii Bardyla, Jonathan Cancino, Vera Fischer and Corey Switzer discussed indestructibility properties of maximal ideal independent families. Moreover, they saw an interesting interplay between such combinatorial objects and general topology, which resulted in a joint publicaiton, listed below.

3. Alan Dow (UNC Charlotte) spoke about “Pseudo-intersections and a variant of matrix forcing”. This lead to a number of discussions with David Chodounsky, Vera Fischer, Marlene Koelbing, Wolfgang Wohofsky. This discussions, are related to some of the work appearing in “Games on base matrices” listed below.

4. Marlene Koelbing (University of Vienna) spoke about “Fresh Functions Spectra”, joint work with Vera Fischer and Wolfgang Wohofsky, which was recently accepted at the Annals of Pure and Applied Logic and is listed below. Interesting discussions with David Chodounsky, Martin Goldstern, Mohammad Golshani, and Peter Holy contributed towards the final outcomes of the paper.

5. Jelle Mathis Kuiper (University of Kiel) spoke about “Mycielski ideals and uniform Sacks trees”. This is joint work with Otmar Spinas, his doctoral thesis adviser.

6. Sandra Müller had numerous discussions with Lena Wallner, who subsequently decided to write her Master thesis under the supervision of Dr. Müller.

7. David Schrittesser and Asger Törnquist, collaborated on ongoing work regarding definable maximal cofinitary groups. Part of the results will appear in a joint paper with Severin Mejak, who successfully completed his doctoral degree at University of Copenhagen in March 2023. The work is also closely connected to an ongoing project of Vera Fischer and David Schrittesser.

8. David Chodounsky, Vera Fischer, Jan Grebik, Jaroslav Supina, Otmar Spinas and Corey Switzer had discussions related to the indestructiblity of maximal independent families. Both, Dr. Supina and Dr. Spinas had had prior experience with Miller partition forcing. The discussions were also closely related to joint work of Fischer and Supina on the consistency of $\mathfrak{i} < \mathfrak{a}_T$. During a visit to University of Kiel of Vera Fischer, not long prior to the workshop in April of 2022, hosted by Otmar Spinas, (re-)emerged some interesting ideas regarding the existence of more general preservation properties for selective independent families, which were recently published in the Annals of Pure and Applied Logic (also listed below).

9. Alexander Wendlinger had various discussions with workshop participants on the topic of his master thesis, *Independence and its spectrum*, which he successfully defended in March 2023 at the University of Vienna.

List of talks

Heike Mildenberger (ALU Freiburg)	A Simple $P_{\aleph_1}$-Point and a Simple $P_{\aleph_2}$-Point
Jonathan Cancino-Manriquez (Czech Academy of Sciences, Prague)	No Hausdorff ultrafilters with large continuum
Jindřich Zapletal (U of Florida, Gainesville)	Algebra and the Axiom of Choice
Sean Cox (Virginia Commonwealth U)	Homological algebra, elementary submodels, and stationary logic
Alexander Kechris (Caltech, Pasadena)	The compact action realization problem
Mirna Dzamonja (CNRS, Paris)	Reasonable uncountable structures
Ben De Bondt (Université de Paris)	On a playfully defined family of countable elementary submodels of H_θ
Lorenz Halbeisen (ETH Zurich)	Four Cardinals and Their Relations in ZF
François Le Maître (U Paris-Diderot)	Global aspects of transitive actions of free groups and Baumslag Solitar groups
Omer Ben Neria (HU Jerusalem)	Diamond, Compactness, and product approximations
Osvaldo Guzman (UNAM, Morelia)	More on the P-ideal Dichotomy and cardinal invariants of the continuum
Michael Hrusak (UNAM, Mexico City)	Tukey order on F_σ ideals
Sandra Müller (TU Vienna)	Preserving universally Baire sets and Sealing
Otmar Spinas (Christian-Albrechts-U, Kiel)	Mycielski ideals and uniform Sacks trees
David Aspero (U of East Anglia, Norwich)	On forcibility of Σ_2 sentences over $L(V_\delta)$
Mohammad Golshani (IPM, Tehran)	Universal graphs at uncountable regular cardinals
Marlene Koelbing (U Vienna)	Fresh function spectra
Alan Dow (UNC Charlotte)	Pseudo-intersections and a variant of matrix forcing
Grigor Sargsyan (Polish Academy of Science, Warsaw)	There are no long sequences of definable sets of reals
Natasha Dobrinen (University of Denver)	Ultrafilters and topological Ramsey spaces

James Cummings (Carnegie Mellon U, Pittsburgh)	Pathological measures
Anton Bernshteyn (GATECH, Atlanta)	Constructing equivariant maps to free (and almost free) subshifts
Itay Neeman (UCLA)	Restrictions of OCA_T with large continuum
Šárka Stejskalová Ph.D. (Charles U, Prague)	Indestructibility of some compactness principles over models of PFA
Jelle Mathis Kuiper (Christian-Albrechts-U, Kiel)	Mycielski Ideals and Uniform Sacks Trees
David Schrittesser (U Toronto)	Maximal discrete sets
Zoltán Vidnyánszky (CalTech)	Large Borel chromatic numbers of bounded degree acyclic graphs
Natasha Dobrinen (University of Denver)	Ramsey theory of homogeneous structures ICM Talks
William Chan (Carnegie Mellon U, Pittsburgh)	A Survey of Cardinalities under Determinacy
Asger Törnquist (U of Copenhagen)	Regularity properties and mad families in higher dimensions

Publications and preprints contributed

L. Halbeisen, R. Plati, S. Schuhmacher, S. Shelah, *Vive la Différence!*, arXiv:2109.11315v1 [math. LO].

B. De Bondt, B. Velickovic, *Increasing the second uniform indiscernible by strongly ssp forcing*, arXiv:2212.13797 [math.LO].

J. A. Cruz-Chapital, V. Fischer, O. Guzman, J. Supina, *Partition forcing and maximal independent families*, Journal of Symbolic Logic, doi:10.1017/jsl.2002.68, 2022.

S. Bardyla, J. Cancino, V. Fisher, C. Switzer, *Filters, ideal independence and ideal Mrowka spaces*, arXiv:2304.04651 [math.LO].

V. Fischer, M. Koelbing, W. Wohofsky, *Games on base matrices*, arXiv:2203.02581 [math.LO].

V. Fischer, M. Koelbing, W. Wohofsky, *Fresh function spectra*, Annals of Pure and Applied Logic, 2023, Volume 174, Issue 9.

V. Fischer, C. Switzer, *Cohen preservation and independence*, arXiv:2208.09854 [math.LO].

J. M. Kuiper, O. Spinas, *Mycielski Ideals and Uniform Trees*, Christian-Alberecht-U zu Kiel.

S. Mejak, D. Schrittesser, *Maximal independence and singulars*, arXiv:2212.05318 [math.GR].

D. C. Montoya, *Mycielski Ideals and Uniform Trees*, U Vienna.

Invited scientists

David Aspero, Ömer Faruk Bag, Serhii Bardyla, Omer Ben-Neria, Anton Bernshteyn, Jörg Brendle, Jonathan Cancino-Manriquez, Miguel Antonio Cardona-Montoya, William Chan, David Chodounsky, Sean Cox, James Cummings, Ben De Bondt, Natasha Dobrinen, Roman Doerner, Alan Dow, Mirna Dzamonja, Monroe Eskew, Vera Fischer, Matthew Foreman, Sy David Friedman, Takehiko Gappo, MichałGodziszewski, Martin Goldstern, Mohammad Golshani, Jan Grebik, Osvaldo Guzman, Lorenz Halbeisen, Stefan Hoffelner, Peter Holy, Radek Honzik, Michael Hrusak, Marlene Koelbing, Alexander Kechris, Alexander Kechris, Jakob Kellner, Danish Khan, Jelle Mathis Kuiper, Boriša Kuzeljević, François Le Maître, Severin Mejak, Diego Mejia, Heike Mildenberger, Benjamin Miller, Julia Millhouse, Rahman Mohammadpour, Miguel Antonio Cardona Montoya, Diana Carolina Montoya, Miguel

Moreno, Sandra Müller, Itay Neeman, Omer Ben Neria, Riccardo Plati, Grigor Sargsyan, Lukas Schembecker, David Schrittesser, Damian Sobota, Otmar Spinas, Šárka Stejskalová, Jaroslav Šupina, Corey Switzer, Asger Törnquist, Boban Velickovic, Zoltán Vidnyánszky, Lena Wallner, Thilo Weinert, Alexander Wendlinger, Wolfgang Wohofsky, Jindřich Zapletal, Lyubomyr Zdomskyy.

ESI-DCAFM-TACO-VDSP Summer School on ”Machine Learning for Materials Hard and Soft”

Organizers: Christoph Dellago (U of Vienna), Ulrike Diebold (TU Vienna), Leticia Gonzalez Herrero (U of Vienna), Jani Kotakoski (U of Vienna)

Dates: July 11 – 22, 2022

Budget: The Summer School was organized and supported jointly by the Erwin Schrödinger International Institute for Mathematics and Physics (ESI), the Vienna Doctoral School in Physics (VDSP), the Doctoral College Advanced Functional Materials (DCAFM) and the Special Research Area Taming Complex Oxides (TACO). The two latter organizations are funded by the Austrian Science Fund FWF. The financial contributions to the school are as follows:

ESI € 12 817
VDSP € 4 290
DCAFM € 20 000
TACO € 2 000

Report on the school

Machine learning (ML) is currently transforming all areas of science, particularly in the study of materials. ML methods are not only used to represent potential energies for atomistic simulations of materials, but also to create low-dimensional models of complex processes through coarse-graining. Moreover, enhanced sampling methods based on ML push the boundaries of the system one can model on current computers. On a macroscopic level, ML approaches can be utilized to predict the relationship between structure and properties, leading to the design of new materials. ML methods are also important in many other fields of science and technology, and their significance in driving innovation, economic growth, and competitiveness is reflected in their inclusion in the European Parliament and Council of the European Union’s first-ever pan-European digital programme.

The main objective of the ”Summer School Machine Learning for Materials Hard and Soft” was to provide an overview of machine learning techniques and their use in studying both hard and soft materials. This event was backed by the Doctoral College AFM, the Special Research Area TACO, and the Vienna Doctoral School Physics, and was primarily aimed at doctoral students and postdocs. The aim was to supplement conventional science curricula, which primarily focus on physics-based modeling and have not yet fully embraced the recent shift towards data-driven approaches.

Overall, the summer school provided a unique and valuable learning experience for the participants and helped to strengthen the community of researchers and students working in the field of machine learning for materials science. The organizers received positive feedback from the participants, who appreciated the high-quality content and the opportunity to interact with leading experts in the field.

Activities

The Summer School ran from July 11-22, 2022 at the ESI, and included 9 full days of lectures and tutorials as well as one day of seminar style presentations about case studies of machine learning given by leading scientists.

The morning sessions at the Summer School featured presentations from international guest lecturers who covered a range of subjects, from the mathematical basis of machine learning to materials design, in three hour-long introductory lectures. These lectures offered a comprehensive overview of the latest advancements in the field. During the afternoon sessions, the participants of the Summer School gained hands-on experience through interactive tutorials lasting three hours. In these tutorials, the participants put into practice the computational techniques introduced in the morning lectures by working in small teams under the guidance of the invited speakers and additional tutors.

The first two days of the Summer School were dedicated to the foundational concepts and mathematical principles of machine learning, as well as the most crucial computational tools, through lectures and hands-on tutorials. This foundation was then followed by an introduction to image analysis, which is particularly relevant for the automated analysis of microscopy images. The curriculum also covered machine learning for electronic structure calculations, the use of ML potentials for atomistic simulations (such as artificial neural networks and Gaussian process regression), dimensionality reduction and coarse-graining techniques, statistical sampling, and the prediction of material properties.

On Friday of the first week, the participants of the Summer School were treated to a selection of case studies presented by international speakers, showcasing the use of machine learning methods in a variety of scientific applications. The same day also featured presentations from representatives of companies (MLR, Image Biopsy Lab, Verbund, and Fehrmann) who discussed the challenges and opportunities of using machine learning in industry. During a lunch provided in the ESI common room, the participants had the chance to interact with the people from the companies.

A wine and cheese reception on the first day, a shared social dinner at a traditional Viennese restaurant, and daily lunch and coffee breaks provided the participants of the Summer School with ample opportunities to engage in further conversations and foster interactions among all attendees.

Specific information on the school

The local and international scientific communities have expressed strong interest in the Summer School, which received an overwhelming number of applications. Out of 180 applicants, the organizing committee selected 64 participants based on their knowledge and experience, as well as their research interests. About half of the participants were from the Vienna area, while the other half came from various countries across Europe and beyond.

Outcomes and achievements

The attendees of the Summer School are now equipped with a comprehensive understanding of machine learning concepts and techniques and possess the skills to apply these cutting-edge methods to tackle real-world research problems.

Lecturers, Tutors and Seminar Speakers

Introductory Lectures

Philipp Grohs (U of Vienna)	Mathematical Introduction
Thomas Pock (TU Graz)	Image Analysis
James Spencer (DeepMind)	Introduction to Electronic Structure Methods
David Pfau (DeepMind)	Deep Learning and Ab-initio Electronic Structure
Philipp Marquetand (U Vienna)	Machine Learned Potentials
Peter Wirnsberger (DeepMind)	Statistical Sampling
Luigi Bonati (IIT Genova)	Free energies and enhanced sampling
Taylor D. Sparks (U of Utah)	Materials properties prediction

Tutors

Pavol Harar (U of Vienna)
Michael Scherbela (U Vienna)
Halvard Sutterud (Imperial College)
Lukas Kyvala (U of Vienna)
Alexander Gorfer (U of Vienna)
Alessandro Coretti (U of Vienna)
Sebastian Falkner (U of Vienna)
Enrico Trizio (IIT Genova)
Sterling Baird (U of Utah)

Research Seminars

Bingqing Cheng (IST Austria)	Predicting material properties with the help of machine learning
Andrew Ferguson (U of Chicago)	Machine learning-enabled enhanced sampling and ultra-fast molecular simulators
Marjolein Dijkstra (Utrecht U)	Machine learning and Inverse design of soft materials
Milica Todorovic (U Turku)	Computational materials engineering with active learning
Reinhard Maurer (U Warwick)	Deep learning surrogates of electronic structure for quantum dynamics and molecular design
Roberto Covino (FIAS, Frankfurt)	Investigating mechanisms of biomolecular self-organization by integrating physics-based simulations and AI

AI Cases Studies from Industry

Marine Pigneur (MLR GmbH)
Christopher Lepenik (Image Biopsy Lab)
Christian Leitold (Verbund)
Bhuiyan S.M. Ebna-Hai (Fehrmann)

List of particpants

Raihan Ahammed, Qais Ali, Andrea Angeletti, Brigitta Bachmair, Sterling Baird, Joselyn Benalcazar, Maria Bilichenko, Viktor Birschitzky, Luigi Bonati, Anna Braghetto, Lukas Brandfellner, Matteo Brizioli, Florian Buchner, Lorenzo Celiberti, Bingqing Cheng, Marco Corrias, Christoph Dellago, Ulrike Diebold, Marjolein Dijkstra, Enrico Drigo, Sebastian Falkner, Andrew Ferguson, Lucía Fernández-Sedano, Alexander Genest, Willem Gispen, Leticia Gonzalez Herrero, Alexander Gorfer, Philipp Grohs, Pavol Harar, Santiago Helbig, Alexander Michael Imre, Priyanka Iyer, Nikolaos Kalafatakis, Manpreet Kaur, Eva Kogler, Denys Kononenko, Jani Kotakoski, Péter Kovács, Lukas Kyvala, Enrico Lattuada, Luca Leoni, Christiane Losert-Valiente Kroon, Cesare Malosso, Philipp Marquetand, Dario Massa, Reinhard Maurer, Fahimeh Najafi, Lappawat Ngamwongwan, Apinya Ngoipala, Sucharita Niyogi, Ivan Novikau, Shanil Panara, David Pfau, Pedro Pires Ferreira, Michael Pittenauer, Thomas Pock, Sebastian Poscher, Jon Eunan Quinlivan Dominguez, Luigi Ranalli, Madlen Maria Reiner, Salvatore Romano, Thantip Roongcharoen, Fiona Sander, Michael Scherbela, Jihong Shi, Panukorn Sombut, Taylor D. Sparks, Daniel Speckhard, Zoran Sukurma, Halvard Sutterud, Alberto Tampieri, Parinya Tangpakonsab, Maximilian Xaver Tiefenbacher, Milica Todorovic, Enrico Trizio, Nico Unglert, Martin Unzog, Andés Felipe Usuga, Ryan van Mastrigt, Dóra Vörös, Jakub Vrabel, Ralf Wanzenböck, Jan Weinreich, Peter Wirnsberger, Qichen Xu.

Symposium: ESI Medal Award Ceremony 2022

Organizer: Christoph Dellago, ESI Director (U Vienna)

Dates: November 4, 2022

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 current and previous ESI Thematic Programmes, current and former ESI Senior Research Fellows, former members of the Scientific Advisory Board (SAB) 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 2022

The winner of the the *Medal of the Erwin Schrödinger Institute for Mathematics and Physics* for the year 2022 is Martin Hairer, Professor of Pure Mathematics at the Department of Mathematics of Imperial College London.

Professor Hairer has been honored for his groundbreaking work on stochastic partial differential equations (SPDEs). Physicists and mathematicians use SPDEs to describe physical systems which evolve in an environment permeated by randomness. However, for the modeling of some fundamental physical phenomena such as random interface growth, the mathematical tools developed over the past several centuries are insufficient to make sense of these singular, nonlinear, noise-driven equations, much less to solve them. In a remarkable breakthrough, Hairer's theory of regularity structures overcomes this barrier. It provides a powerful and coherent toolbox, which has already enabled the solution of several important SPDEs by him and his coauthors and which opens a pathway to new discoveries.

Award Ceremony

The award ceremony took place on November 4, 2022 at the ESI Boltzmann Lecture Hall.

Schedule of the Ceremony

Christoph Dellago, ESI Director (U of Vienna)	Welcome
Hendrik Weber (U Münster	Convergence of the Ising-Kac model to Φ^4 in three dimensions
Felix Otto (MPI MiS Leipzig)	Thoughts on Regularity Structures
Jan Mass (ISTA, Klosterneuburg),	Laudatio
Christoph Dellago, ESI Director (U of Vienna)	Award of the ESI Medal
Martin Hairer (Imperial College, London)	Award Lecture
Christoph Dellago, ESI Director (U of Vienna)	Closing

Spectral Theory of Differential Operators in Quantum Theory

Organizers: Jussi Behrndt (TU Graz), Fritz Gesztesy (Baylor U, Waco), Ari Laptev (Imperial College, London), Christiane Tretter (U Bern)
Dates: November 7 – 11, 2022

Budget: ESI € 15 592

Report on the Workshop

Spectral theory of differential operators is an exciting area at the interface of differential equations, mathematical physics, and functional analysis, with applications in many branches of mathematics, including mathematical and theoretical physics, and applied mathematics. More specifically, this workshop focused on recent advances in the spectral and scattering theory of self-adjoint and non-self-adjoint Schrödinger and Dirac-type operators, and, more generally, in the theory of elliptic differential operators.

Special emphasis was given to underlying analytic operator-valued functions, such as the Dirichlet-to-Neumann map and its many ramifications.

Concrete applications to resonances in quantum theory, quantum graphs and more general network problems, photonic crystals and quasicrystals, were discussed.

The workshop attracted speakers from eleven countries and four continents.

Activities

The focus of the workshop was on direct and inverse spectral problems for self-adjoint and non-self-adjoint Schrödinger and Dirac-type operators, mathematical scattering theory, and the multitude of interplays between spectral theory, complex analysis, and functional analysis. One of the principal aims was to bring together leading experts from different, but closely related, fields in this broad area, to stimulate exchange and discussions between them, and to highlight the most recent developments and applications.

Spectral theory of differential operators is a highly topical area in modern mathematical analysis; its importance can not be overestimated due to its manifold applications and connections to quantum theory and its modern developments such as quantum information technologies.

Regarding the overall structure of the workshop, we thus focused on the following topics:

- Nonreal eigenvalues of Schrödinger operators with complex potentials
- Dirichlet-to-Neumann maps for Schrödinger operators on Lipschitz domains
- Strongly singular perturbations of Schrödinger and Dirac operators
- Spectral and scattering theory for Schrödinger operators on unbounded domains and manifolds
- Quantum graphs and differential operators on network structures and quasi one-dimensional systems

Specific information on the workshop

The list of speakers, including that of 45 minute speakers, exhibited diversity and presented a mixture of young and seasoned researchers. Regarding young investigators we mention, for instance, S. Bögli, F. Ferraresso, D. Frymark, M. Holzmann, N. Nicolussi, J. Rohleder, P. Schlosser, C. Stelzer, and G. Stenzel.

The workshop ran Monday through Friday and the first lecture on each morning (9a.m.) as well as the first lecture each afternoon (2p.m.), were planned for the duration of 45 minutes, all remaining lectures were of 30 minute length.

In addition, we had a short lecture by A. Damialis surveying the EMS publishing program and one by C. Tretter on publishing in the Birkhäuser publications IEOT and in the OTAA book series.

We also mention the Workshop Dinner on Thursday, November 10th, in the relaxing atmosphere of the Heurigen Schübel-Auer, that nicely complemented an otherwise rather intense week of scientific exchange.

The inspiring atmosphere at ESI fostered lively discussions among the workshop participants not only after the talks, but also during the coffee breaks. We thank ESI very much for giving us the chance to hold this workshop and for ESI's generous hospitality during the entire workshop.

List of talks

Pavel Exner (Czech Academy of Sciences, Prague)	Spectral properties of soft quantum waveguides
Jonathan Rohleder (U Stockholm)	A new approach to the hot spots conjecture
Gerald Teschl (U of Vienna)	Relative oscillation theory and essential spectra of Sturm-Liouville operators
Sabine Bögli (Durham U)	Improved Lieb-Thirring type inequalities for non-selfadjoint Schroedinger operators
Francesco Ferraresso (Cardiff U)	Spectral approximation for Maxwell's equations in conductive media
Noema Nicolussi (U of Potsdam)	Laplacians on Infinite Graphs
Alexander Strohmaier (U Leeds)	The Casimir energy as a trace
Vladimir Derkach (Vasyl'Stus Donetsk National U	Similarity problem for indefinite Sturm-Liouville operator
Matthias Keller (U of Potsdam)	From Hardy to Rellich inequalities and Agmon estimates on graphs

Robert Seiringer (ISTA, Klosterneuburg)	Absence of excited eigenvalues for Fröhlich type polaron models at weak coupling
Aleksey Kostenko (U of Vienna)	Inverse spectral theory for strings and the conservative Camassa-Holm flow
Alexander Sakhnovich (U Vienna)	On the class of canonical systems corresponding to matrix string equations: fundamental solutions, asymptotics of Weyl functions and inverse problems
Dorina Mitrea (Baylor U, Waco)	Higher dimensional scattering theory and integral representation formulas
Olaf Post (U of Trier)	Some recent developments in generalised norm resolvent convergence
Georg Stenzel (TU Graz)	Schrödinger operators with oblique transmission conditions in R2
Marcus Waurick (TU Freiberg)	Laminated Metamaterials
Tom ter Elst (U of Auckland)	The Dirichlet-to-Neumann operator on $C^{1+\kappa}$-domains
Markus Holzmann (TU Graz)	Geometrically induced discrete eigenvalues of Dirac operators with Lorentz scalar δ-shell potentials supported on a broken line
Christian Stelzer (TU Graz)	Approximation of Dirac operators with δ-shell potentials supported on a straight line
Marius Mitrea (Baylor U, Waco)	Cauchy Operators and Calderon Decompositions in Uniformly Rectifiable Domains
Seppo Hassi (U of Vaasa)	Representing maps for semibounded forms and their applications
Andrea Posilicano (U of Insubria)	On the self-adjoint realizations of H+A*+A
Claudio Cacciapuoti (U of Insubria)	Three-body Hamiltonians with zero range interactions
Tomio Umeda (U of Hyogo)	Continuum limits for discrete Dirac operators on 2D square lattices
Alessandro Michelangeli (U Bonn)	Spectral problems for quantum particle systems with zero-range interactions
Peter Schlosser (TU Graz)	Schrödinger operators with delta-potentials on unbounded Lipschitz surfaces
Christiane Tretter (U Bern)	Publishing in IEOT and OTAA
Apostolos Damialis (EMS)	Publishing at the EMS
Constanze Liaw (U Delaware)	Finite-rank perturbations and applications
Pavel Kurasov (U Stockholm)	Dissipative graphs
Konstantin Pankrashkin (U Oldenburg)	Curvature contribution to the essential spectrum of Dirac operators with critical shell interactions
Dale Frymark (TU Graz)	The Spectrum of Self-Adjoint Extensions associated with Exceptional Laguerre Differential Expressions
Bernard Helffer (U de Nantes)	Computing nodal deficiency with a refined spectral flow (after G. Berkolaiko, G. Cox, B. Helffer, and M. Persson Sundqvist)

Publications and preprints contributed

J. Behrndt, F. Gesztesy, P. Schmitz, and C. Trunk, *Lower bounds for self-adjoint Sturm–Liouville operators*, arXiv:2212.09837 [math.SP].

B. Benhellal, K. Pankrashkin, *Curvature contribution to the essential spectrum of Dirac operators with critical shell interactions*, arXiv:2211.10264 [math.SP].

V. Franceschi, K. Naderi, K. Pankrashkin, *Embedded trace operator for infinite metric trees*, arXiv:2303.04527 [math-ph].

K. M. Schmidt and T. Umeda, *Continuum limits for discrete Dirac operators on 2D square lattices*, arXiv:2109.04052 [math-ph].

M. Waurick, *Homogenisation of Laminated Metamaterials and the Inner Spectrum*, arXiv:2210.04650 [math.AP].

Invited scientists

Jussi Behrndt, Sabine Bögli, Claudio Cacciapuoti, Apostolos Damialis, Vladimir Derkach, Henk de Snoo, Pavel Exner, Francesco Ferraresso, Dale Frymark, Fritz Gesztesy, Harald Grosse, Seppo Hassi, Bernard Helffer, Thomas Hoffmann-Ostenhof, Markus Holzmann, Iryna Karpenko, Matthias Keller, Aleksey Kostenko, Pavel Kurasov, Constanze Liaw, Alessandro Michelangeli, Johanna Michor, Dorina Mitrea, Marius Mitrea, Noema Nicolussi Konstantin Pankrashkin, Andrea Posilicano, Olaf Post, Jonathan Rohleder, Alexander Sakhnovich, Peter Schlosser, Robert Seiringer, Iveta Semorádová, Petr Siegl, Christian Stelzer, Georg Stenzel, Alexander Strohmaier, Tom ter Elst, Gerald Teschl, Christiane Tretter, Carsten Trunk, Tomio Umeda, Marcus Waurick.

Research in Teams

Research in Teams Project 1: Three-Dimensional Minimal Massive Supergravity

Collaborators: Nihat Sadik Deger (Bogazici University) and Jan Rosseel (University of Vienna)
Dates: January 31 – February 28, 2022 and May 22 – June 5, 2022

Budget: ESI € 3 360

Report on the project

Scientific Background

Three-dimensional (3D) gravity theories have attracted a lot of attention during the last four decades since they provide useful laboratories for investigating some difficult problems of higher dimensional General Relativity in a technically easier set-up. This research area was motivated further after the proposal of the famous AdS/CFT duality [4], according to which a gravity theory in a D-dimensional Anti-de Sitter (AdS) spacetime is equivalent to a (D-1)-dimensional Conformal Field Theory (CFT) that lives on its boundary. This makes 3D gravities special since 2-dimensional CFTs are much better understood.

The pure 3D Einstein gravity is locally trivial since in 3D the Riemann curvature tensor can be expressed in terms of the Ricci tensor, and hence Einstein's field equations imply the vanishing of the spacetime curvature. To have a non-trivial local dynamics one may consider adding higher derivative terms, however, generically this results in ghost modes. One notable exception is the Topologically Massive Gravity (TMG) [5], where the gravitational Chern-Simons term is added to the Einstein-Hilbert action, which gives rise to a single massive propagating graviton mode. If a negative cosmological constant is also present, then this model has an AdS vacuum and admits the BTZ black hole [6] as an exact solution which makes the theory even more interesting. However, TMG is ghost free only when the sign of the Einstein-Hilbert term is opposite to the standard one which yields negative mass BTZ black holes. From the AdS/CFT correspondence this implies that the dual boundary CFT has a negative central charge and hence it is non-unitary. This problem is usually referred to as the "bulk-boundary clash" and continues to exist in ghost-free extensions of TMG with higher curvature terms constructed in [7, 8]. Remarkably, another recently discovered deformation of TMG, called Minimal Massive Gravity (MMG) [9], avoids this conflict in a certain region of its parameter space thanks to an additional mass parameter it contains. This theory is 'minimal' in the sense that it has only one massive spin-2 mode in the bulk like TMG.

Since MMG has physically well-defined bulk and boundary descriptions, it is a potentially useful toy model for examining properties of quantum gravity [10]. However, it also has a rather peculiar property: Its field equation, which contains an extra curvature squared term compared to TMG, does not come from the variation of a local action of the metric alone. Consequently, the Bianchi identity on its own does not guarantee the consistency of this equation. Nevertheless, this equation still makes sense on-shell since its divergence vanishes if one uses the field equation again. This novel mechanism is called the "third way consistency", see [11, 12] for review. Further such 3D gravity models were constructed in [13, 14]. Although these models do not have second order actions with the metric field alone, they can be derived from first order actions that contain auxiliary Lorentz valued 1-forms in addition to the usual dreibein and spin-connection. There also exist third way consistent gauge theories. The first example was found in [15] which is a 3D Yang-Mills theory. Interacting p-form theories with this property in general dimensions were constructed in [16].

Project aims and scope

The aim of our project is to construct the $N = 1$ supersymmetric extension of the MMG model [9] and study its properties. It is clearly desirable to do this, since supersymmetry is expected to improve its ultraviolet behaviour. Once achieved, this will be the first example of a supersymmetric third way consistent gravity theory. Until very recently it was not known whether supersymmetry and third way consistency were compatible, but in [17] we showed that in the gauge theory case this is possible by explicitly constructing the $N = 1$ supersymmetric version of the massive Yang-Mills theory of [15].

Outcomes and achievements

Together with our collaborators Marc Geiller and Henning Samtleben at ENS de Lyon, we achieved the main goal of our project, namely the construction of the $N = 1$ supersymmetric extension of MMG and presented our results briefly as a letter in [1]. Our construction is based on a new first order bosonic action that can reproduce all known third way consistent 3D massive gravities [9, 13, 14] and their higher curvature extensions with particular choices. In the case of MMG [9] it is especially simple and is given by the sum of the standard and exotic [18] first order actions of 3D Einstein gravity. We then made an ansatz for the fermionic action with two gravitino fields sharing one local supersymmetry and showed that the full action remains invariant under the supersymmetry transformations that we proposed. We also proved that our fermionic equations can be integrated out to a single gravitino field equation which reduces to that of the superymmetric TMG [19] in the appropriate limit. We then analyzed the (A)dS vacua of our model and found that whenever it admits an AdS vacuum a supersymmetric extension exists. Perhaps the most surprising result of our analysis is the observed clash between supersymmetry and bulk/boundary unitarity. It is precisely the AdS vacua in which supersymmetry is spontaneously broken which reconcile positive central charges with a positive energy bulk graviton.

After completing [1] we started working on [2] which will contain all the technical details and further investigation of properties of our model.

During this collaboration at ESI one of us also finished a paper [3] on a Yang-Mills analogue [15] of the MMG [9]. It is observed in [16] that the Yang-Mills model of [15] is actually dual to a principal chiral sigma model. In [3] this correspondence is made more concrete using the on-shell duality between vector and scalar fields in 3D [20] and it is found that the dual formulation of [15] is a gauged sigma model with two Chern-Simons gauge fields. Then, results of [21] are used to construct the coupling of [15] with $N = 1$ supergravity. After decoupling gravity, the model reduces to the supersymmetric system that we found earlier in [17]. The dual formulation also shows that this construction cannot be extended to $N > 1$ case, since for a sigma model higher supersymmetry requires further constraints on the scalar target space that cannot be satisfied.

Publications and preprints contributed

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Research in Teams Project 2: Modular Forms and Theta Correspondence for Exceptional Groups

Collaborators: Wee Teck Gan (NU of Singapore), Nadya Gurevich (Ben-Gurion U of the Negev), Aaron Pollack (UC, San Diego), Gordan Savin (U of Utah, Saltlake City)

Dates: April 16 - 22, 2022

Budget: ESI € 2 240

Report on the project

This one-week RIT project follows on the heels of the ESI workshop "Minimal Representations and Theta Correspondence", in which the four team members participated. Building upon the momentum of the workshop, team members discussed and formulated new research projects concerning modular forms and theta correspondences on exceptional groups, taking into account recent progresses that were showcased in the workshop, as well as brainstormed on possible approaches. The intensive one-week discussion and collaboration was very effective and productive, resulting in several new projects and potential solutions, more than what we could reasonably complete in a one-week window. In the following, we give a more detailed discussion of the outcome of this RIT project.

Scientific Background

This RIT project is devoted to the construction and classification of automorphic forms on exceptional groups. The analogous problem for classical groups have seen great progress in the past decade. For the classification problem, one can mention the work of J. Arthur on the endoscopic classification of square-integrable automorphic forms [1], in terms of their Hecke eigenvalues and couched in the language of A-packets. Arthur's work, via the trace formula, does not provide explicit construction of these automorphic forms. On the other hand, the classical theta correspondence, which studies the spectrum of the Weil representation, has provided many useful constructions of these automorphic forms, allowing one to understand their Fourier coefficients and other automorphic periods, as well as other arithmetic applications. This is possible only because of the advances in the internal theory of classical theta correspondences in the past eight years, to which some of the team members have made contributions.

Not surprisingly, the situation for exceptional groups has lagged behind that of classical groups. There has been some construction of A-packets for the smallest exceptional group G_2 [2, 3] using exceptional theta correspondences from more than 15 years ago, by two of the team members (Gan and Gurevich) of this RIT project. As for the theory of Fourier coefficients of modular forms on exceptional groups, there was a theory developed by Gan, Gross and Savin some twenty years ago [4]. In the past four years, however, the situation has significantly improved because of the work of the members of this RIT project:

- Pollack developed a theory of Fourier coefficients for all quaternionic exceptional groups [9], going far beyond the original theory of Gan-Gross-Savin and obtaining a much more definitive form of the theory;
- Gurevich, through her work with Kazhdan [7, 8], has developed a better understanding of minimal representations, which play the pivotal role in exceptional theta correspondences;
- Gan and Savin have realised how one can show the analog of the Howe duality theorem for exceptional theta correspondences [5].

In view of these, it is timely for the four team members to get together to consolidate these recent advances and to join forces to seek new advances.

Project aims and scope

The main goals of the RIT project are:

(a) Give a systematic treatment of the Howe duality conjecture for exceptional dual pairs, making systematic use of the exceptional algebraic structures underlying exceptional groups, so that one can give a uniform treatment of the Howe duality conjecture, as well as developing a version of similitude theta correspondences in the exceptional setting;

(b) obtaining a better understanding of minimal representations of type E groups by extending the results of Gurevich-Kazhdan [7] on "Fourier transform on the cone" to the setting of exceptional groups;

(c) Showing algebraicity of quaternionic modular forms on G_2;

(d) Using the exceptional theta correspondence to construct examples of quaternionic modular forms, especially cusp forms, for groups like G_2, $Spin(8)$ and F_4 and compute their Fourier coefficients;

(e) using exceptional theta correspondences to construct interesting families of A-packets for exceptional groups;

(f) Use the exceptional theta correspondence to show the LLC for G_2;

(g) Developing new Rankin-Selberg integrals involving modular forms on exceptional groups.

Outcomes and achievements

One-week of intensive work has produced the following exciting outcomes, for each of the goals mentioned above:

(a) Gan and Savin, together with Bakić, have developed a theory of similitude theta correspondences. They have also developed some uniform strategy for establishing Howe duality correspondences. A preprint is currently being written up.

(b) Gan, Gurevich and Savin have developed a strategy to explicate the "Fourier transform on the cone" which will complete the description of the minimal representation of E_7. This involves finding an equivariant identification of the Schrödinger model and the Heisenberg model of the minimal representation. The details still need to be carried out, but looks very promising, and it is expected that with Gurevich's previous experience, it should not take long to sort out the details.

(c) Pollack developed a strategy for showing algebraicity of quaternionic modular forms on G_2 by using theta lifting from the anisotropic F_4. For this, one needs to show that all quaternionic modular forms of G_2 come from the anisotropic F_4 via theta lifting. Showing this would require showing a certain Siegel-Weil formula for the $D_4 \times D_4$ dual pair in E_8. This seems to be a viable approach.

(d) In the course of the week, team members realised that one can construct the quaternionic cusp form on G_2 of level 1 and weight 6 (which is the lowest weight one epxects to see level 1 cusp forms). Starting with Ramanujan's Δ-function, this involves using the following series of theta liftings:

$$PGL_2^3 \longrightarrow PGSO_8 \longrightarrow PGSp_6 \longrightarrow G_2,$$

starting with the triple $\Delta \times \Delta \times \Delta$ on PGL_2^3. Here the first arrow is the similitude exceptional theta lifting given by the dual pair $PGL_2^3 \times PGSO_8$ in E_7. The second is a classical similitude theta lift. The third is an exceptional theta lifting for $G_2 \times PGSp_6$ in E_7.

Team members also realised that one has an analogue of the above construction by working with the group $E_{7,3}$ which has a Hermitian symmetric domain. Then the groups G_2 and $PGSO_8$ above are anisotropic. In this setting, one would get the lowest weight algebraic modular form on compact G_2 as well as the lowest weight holomorphic level 1 Siegel modular form F on $PGSp_6$, and in particular a full determination of their Hecke eigenvalues in terms of those of Δ. Because of these arithmetic applications and the fact that the archimedean theta correspondences for compact dual pairs are known, team members agree to work on this case first before the split case above. A follow-up here is to use this construction to compute the Fourier coefficients of Siegel modular form F.

(e) By pursuing the approach in (d) further, team members realised that one can construct the remaining family of nontempered A-packets of G_2 (the so-called long root A-packets), at least under some nonvanishing of central L-value condition, thus completing the work of Gan-Gurevich [2] from 15 years ago.

On this theme of construction, another advance made by team members during the week is a systematic examination of the nontempered A-parameters of F_4 and the systematic usage of exceptional theta correspondences to construct these A-packets. This led to a better understanding of the Heisenberg Fourier coefficients of F_4, as well as establishing the initial steps of this programme. This is expected to become a project for Savin's postdoc at Utah.

(f) It has been a long term project of Gan and Savin to establish the local Langlands correspondence for G_2 using exceptional theta correspondences. During the week, several difficulties in this approach were resolved (some with the help of participants form the ESI workshop a week earlier). The last difficulties had been resolved during the week and a preprint has been prepared [6].

(g) Almost out of the blue, team members began discussing possible Rankin-Selberg integrals for the quadruple tensor product L-function for GL_2 and the triple product L-function for GL_3. Promising candidates were discovered. On unfolding the Rankin-

Selberg integrals, it was discovered that the open orbit gives rise to the invariant quadrilinear form on GL_2 and the invariant trilinear form on GL_3, respectively. An even more interesting feature is that, unlike most other Rankin-Selberg integrals, the contribution of the non-open orbits do not all vanish due to cuspidality. Indeed, the next largest orbit gives an interesting contribution involving the integrals of the Whittaker models of the cusp forms involved. This integral looked manifestly computable and it is hoped that it will give rise to the desired L-function. Team members will be pursuing this computation in the coming months, and hope to develop new ideas to take care of the contribution of the open orbit in due course.

This last item (g) indicates that research can develop in unexpected fruitful directions when a team of experts are put together at the right place at the right time.

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Research in Teams Project 3: A study of nonlinear nonlocal asymptotic shallow-water models, with an emphasis on wave breaking and stability of peaked waves

Collaborators: Anna Geyer (Delft U of Technology), Guilong Gui (Northwest U, Xian), Yue Liu (U of Texas at Arlington), Dmitry Pelinovsky (McMaster U, Hamilton)

Dates: May 9 – June 11, 2022

Budget: ESI € 5 440

Report on the project

Scientific Background

The theory of water waves relies on studies of the Euler equations of fluid mechanics closed with some boundary conditions. Due to the complexity and the difficulties arising in the theoretical and numerical studies, simpler model equations have been proposed as approximations to the Euler equations in some specific physical regimes. The motivation in this research project was to investigate such asymptotic models for water waves, seeking a better understanding of wave breaking phenomena and stability of solitary waves. These questions have attracted the attention of mathematicians for more than a century.

More specifically, the project is concerned with the analysis of nonlinear wave propagation in several model equations arising in fluid mechanics which have higher-order nonlocal nonlinearity compared to the local quadratic nonlinearity of the KdV equation, but still capture some of the interesting properties of the Euler equation and retain some integrable features. Due to the nonlocal nonlinearity, their dynamical features are different from those of the KdV equation in at least two ways: they allow wave breaking of strong solutions and, at the same, time they permit peaked waves which can be stable enough to persist in the time evolution of weak solutions.

Project aims and scope

The stability theory of solitary wave solutions for nonlinear wave equations has attracted significant attention of not only mathematicians but also physicists. It is known that solitary waves play the role of elements in a nonlinear basis, with respect to which it is natural to view a strong solution in the limit of large time. An important type of solution is the peaked solitary wave (or peakon in the theory of integrable systems), which is a solitary wave with discontinuous first derivative at its crest. It is also worth noting that peakons replicate waves of largest amplitude that are common for irrotational water waves [11]. Since peakon solutions are only piecewise differentiable, they are only defined in the space of weak solutions to the nonlinear wave equations. To understand the asymptotic decomposition of weak solutions in the large time limit, stability of peakons has to be addressed [2, 8]; in particular, the behaviour of solutions with initial data in the neighbourhood of peakons [10]. In the case of the integrable Camassa-Holm equation, the inverse scattering method has been used to study stability of peakons and resolution of a weak solution into a sequence of peakons [1, 7].

The aim of the project was to develop new mathematical studies of stability of peaked waves and other smooth solitary waves and periodic waves, which do not rely on integrability and conserved quantities of the underlying equations. These techniques can help shed new light on the modelling, characterisation, and prediction of waves of large amplitudes. There is great potential for further research in this field, which may have important implications for oceanographic applications.

In particular, we have analysed the stability of nonlinear waves in several models with wave breaking and peaked waves: *the Degasperis-Procesi (DP) equation* [3], the modified Camassa–Holm (mCH) equation [6], and *the Camassa-Holm-KP* (CH-KP) equation [5]. The first two models are one-dimensional and the last model is two-dimensional with weakly transverse effect for the horizontal velocity component.

Outcomes and achievements

Due to COVID restrictions in China, one member of our team (G. Gui) was unable to visit ESI and to participate in our collaborative work. The other three members of the team were actively involved in collaboration according to the project aims and scopes above.

The most important outcomes of our work are as follows.

[1] The stability of smooth periodic waves for the Degasperis–Procesi (DP) equation.

We have derived the energy stability criterion for smooth periodic waves. Compared to the Camassa-Holm (CH) equation [4], the number of negative eigenvalues of an associated Hessian operator changes in the existence region of smooth periodic waves. As a result, using properties of the period function with respect to two parameters, a smooth existence curve for the family of smooth periodic waves of a fixed period is established. The energy stability criterion is then derived on parts of this existence curve which correspond to either one or two negative eigenvalues of the Hessian operator. We have also shown numerically that the energy stability condition is satisfied on both parts of the curve.

[2] The transverse linear stability of line solitary waves to the CH-KP model.

A continuous curve of eigenvalues of the linearised operator is found in a neighbourhood of the eigenvalue $\lambda = 0$, the curve being parameterised by the transverse wave number. The curve is located in the left-half of the complex plane, therefore, the time evolution of the corresponding eigenmodes is described by a one dimensional damped wave equation in the transverse variable. By adopting the argument in [9], we are able to show the linear stability of the transversely modulating line solitary waves in the CH-KP equation.

We have also inspected the question of stability of peaked solitary waves in the mCH equation but ran into difficulties related to the lack of local well-posedness results in the spaces where the peaked waves are properly defined. It is unlikely that we will be able to complete this project in the near future but it will serve as a guidance for future work.

In addition to the above activities, two members of our research team (Anna Geyer and Dmitry Pelinovsky) have been collaborating on writing a research monograph on stability of solitary waves for AMS.

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Research in Teams Project 4: Infinite Dimensional Riemannian Geometry

Collaborators: Martin Bauer (Florida State U), Philipp Harms (NTU Singapore), Peter W. Michor (U Vienna)

Dates: May 23 - July 1, 2022

Budget: ESI € 3 360

Report on the project

The research team met for several weeks at the Erwin-Schrödinger institute in Vienna in the summer of 2022. During this time they continued previous collaborations on Riemannian geometry with a focus on a broad class of infinite-dimensional manifolds, called half-Lie groups. The following report summarizes the results of these investigations, which will be published in an article called *Regularity and completeness of half-Lie groups*.

Scientific Background

Riemannian geometry has established itself as a successful framework for handling the nonlinear and infinite-dimensional aspects involved in geometric data analysis and fluid dynamics. Intuitively, the Riemannian metric quantifies infinitesimal deformations of shapes and infinitesimal displacements of fluids, respectively. These interpretations go back to d'Arcy Thompson and Vladimir Arnold and naturally involve manifolds with infinite dimension.

Infinite-dimensional Riemannian geometry comes with many surprises: For instance, the geodesic distance of a Riemannian metric may vanish, as shown by Eliashberg–Polterovich and Michor–Mumford. This is in stark contrast to the finite-dimensional situation, where the geodesic distance is always a true distance and even induces the original manifold topology. Another important example is the theorem of Hopf–Rinow, which fails in infinite dimensions, as shown by Atkin. These issues are of fundamental importance for the above-mentioned applications, and careful analysis of the respective geometries is needed to rule out the unexpected misbehaviors.

Project aims and scope

Several recent results suggest that differential-geometric results, which have been developed for specific infinite-dimensional manifolds of e.g. diffeomorphism groups or spaces of immersions, can be obtained in a unified way on more general spaces. For example, the perturbative results for Laplace operators of our previous ESI-Research in Team lead to local well-posedness of the geodesic equation not only on spaces of Riemannian metrics but also on many other manifolds of mappings. As a further example, several completeness and regularity results for diffeomorphism groups can be obtained by generic arguments in more general settings, which is the main target of this research-in-teams project.

Outcomes and achievements

The following description of our outcomes and achievements is to a large extent extracted from our preprint called *Regularity and completeness of half-Lie groups*.

We consider a special class of infinite-dimensional manifolds, namely, half-Lie groups. These are topological groups and smooth manifolds such that all right translations are smooth, but left translations are only continuous. Thus, by definition, the group structure and differentiable structure of a half-Lie group are only partially compatible. This explains on the one hand the better regularity and completeness properties enjoyed by half-Lie groups compared to general infinite-dimensional manifolds, and on the other hand the occurrence of well-known degeneracies in infinite-dimensional group and representation theory. Our main contributions are as follows:

- Differentiable elements in half-Lie groups: We study differentiable elements in a given half-Lie group, i.e., those elements such that left translation is k times continuously differentiable. We then show that these differentiable elements form again half-Lie groups and that the inverse limit $k \to \infty$ of these half-Lie groups is a Fréchet Lie group. This generalizes previous results of Marquis and Neeb, who studied related questions for semidirect products, which are special cases of half-Lie groups.
- Regularity of half-Lie groups: We also discuss smooth regularity of half-Lie groups, i.e., the question if one can integrate smooth curves in the tangent space at the identity to

smooth curves in the group by inverting the right-logarithmic derivative. While we are unable to show that every Banach half-Lie group is regular, we show that the half-Lie groups of k times continuously differentiable elements, as described above, are regular for any $k \geq 1$.

- Extension theory for half-Lie groups: Next we show that the extension theory of Lie groups largely carries over to half-Lie groups. We can describe all extensions satisfying some conditions by extension data and we are able to describe the subgroups of k times continuously differentiable elements in an extension as another extension.
- Completeness on half-Lie groups: Many half-Lie groups carry smooth right-invariant strong Riemannian metrics. Under an additional technical assumption, we show that all completeness statements of the theorem of Hopf-Rinow hold, i.e., they are geodesically and metrically complete, and there exists a minimizing geodesic between any two points. Previously, only geodesic completeness was known, thanks to a result of Ratiu and Gay-Balmaz.

Publications and preprints contributed

M. Bauer, P. Harms, P. Michor, *Regularity and completeness of half-Lie groups*, arXiv:2302.01631[math.DG].

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 12 - June 8, 2022; September 2 - 10, 2022; December 9 - 22, 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 [MS]), and we denote by $\mathfrak{m} \mapsto Z(\mathfrak{m})$ this parametrisation. In [KM2] 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 semisimple LLC ([V]): 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 [KM1] and [KM2]). 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 [KM2] 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 [A], [Mok]).

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

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

Naive Conjecture 0.1 *Let* $\pi_1, \pi_2 \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(G)$ *and* $\theta : \mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(G) \to \mathrm{Irr}_{\overline{\mathbb{Q}_\ell}}(G')$ *denote the Howe correspondence for the dual pair* (G, 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-dimensio-nal 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* $\pi_1, \pi_2 \in \mathrm{Irr}_{\overline{\mathbb{Q}_\ell},\mathrm{int}}(G)$ *(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 proved 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 (GL_n, GL_1)). Generalisations of this work are under consideration by Mínguez's current PhD student. Also Matringe benefited from his stays at the ESI to think of related issues on representations of $(GL_n$ as well as modular representations of reductive groups, leading to the publications [M] and [MT] with Mínguez' former PhD student J. Trias, both of which acknowledge the Erwin Schrödinger Institute.

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). During the last stays at ESI, they first focused on the third step, aiming at adapting the classical argument of Piatetski-Shapiro to our ℓ-adic setting. However they could finally circumvent this difficulty by using strong results on the global Langlands correspondence, to prove the local transfer for modular representations of quasi-split classical groups. The paper containing the results above is now submitted and available online, see [MS1] in the reference list. The modular strong mutiplicity one property is still of interest, and they hope to come back to it with Matringe later.

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.

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Publications and preprints contributed

N. Matringe, *Local distinction, quadratic base change and automorphic induction for* $(\mathrm{GL}_n$, J. Théor. Nombres Bordeaux 34 (2022), no. 3, 903-916.

N. Matringe, J. Trias, *Whittaker functionals and contragredient in characteristic not p*, to appear in Math. Res. Let. arXiv:2209.15353 [math.RT].

A. Mínguez, V. Sécherre, *Local transfer for quasi-split classical groups and congruences mod ℓ*, arXiv:2302.04532 [math.RT]

Research in Teams Project 6: Chaos, Butterflies, and Entanglement in Flat Space

Collaborators: Arjun Bagchi (IIT Kanpur), Stefan Fredenhagen (U of Vienna), Daniel Grumiller (TU Vienna), Antti Haimi (Acoustics Research Institute, Vienna), Günther Koliander (Acoustics Research Institute, Vienna), José Luis Romero (U of Vienna)

Dates: June 12 – July 23, 2022

Budget: ESI € 3 280

Report on the project

The project was initially proposed in 2020 and was designed to address aspects of the Holographic Principle outside the realm of the Anti de Sitter/ Conformal Field Theory (AdS/CFT) correspondence and specifically to understand holographic entanglement in flat spacetimes. However, with the onset of the COVID-19 pandemic, the project was deferred by two years. In the intervening period, the main outlined problem was solved and a paper published on this, as we will describe below. So in the actual period of the collaboration in Vienna in 2022, several other problems were addressed and some completed. These will be detailed below.

Scientific Background

The holographic principle [1] states that a quantum theory of gravity in a certain spacetime can be understood completely in terms of a non-gravitational quantum field theory living on the boundary of the spacetime. The concrete exemplification of this rather amazing conjecture came in the form of the AdS/CFT correspondence [2] where the holographic dual of type IIB superstring theory in $AdS_5 \times S^5$ was proposed to be $\mathcal{N} = 4$ Supersymmetric Yang-Mills theory living on the four dimensional flat boundary of AdS_5. Although the holographic principle is supposed to hold for generic spacetimes, its formulation beyond AdS spacetimes has remained a substantial challenge.

In particular, for the more familiar and physically relevant asymptotically flat spacetimes, a concrete holographic correspondence has been lacking. There have been efforts to remedy this of late and the two avenues in which research has been carried out have been called the Celestial and the Carrollian approaches. While the Celestial approach [3, 4] posits that the dual of 4 dimensional asymptotically flat space is a 2d CFT living on the celestial sphere, the Carrollian approach [5] suggests that the dual is a co-dimension one Carrollian CFT, living on the null boundary of Minkowski spacetime. A Carrollian CFT can be understood as a limit of a relativistic CFT where the speed of light has been taken to zero and the lightcone collapsed to a line.

Project aims and scope

Our original project aimed to investigate Carrollian holography with applications to entanglement and chaos. Subsequent investigations during the period spent in Vienna in 2022 focussed on aspects of holography in flatspace involving Carrollian CFTs with additional symmetry, studies of Carrollian Boundary CFTs, and also a rather unique and innovative approach to understanding black hole microstates using null strings that exhibit Carrollian worldsheet symmetry.

Outcomes and achievements

Below we outline the collaborative work done in the project.

- *Non-Lorentzian Chaos and Cosmological Holography*: In this project, we studied chaos in non-Lorentzian field theories, specifically Galilean and Carrollian conformal field theories in two dimensions. In a large central charge limit, we found that the Lyapunov exponent saturates the bound on chaos, conjectured originally for relativistic field theories. We recovered the same Lyapunov exponent holographically by a shock-wave calculation in three-dimensional flat space cosmologies, providing further evidence for flat space holography.

  This resulted in the publication [I]. This was the original goal of the project envisioned in 2020. This project was a collaboration between Arjun Bagchi, Daniel Grumiller and other scientists.

- *Carrollian Boundary CFTs*: In this project, we have begun the investigation of boundary conformal field theories which live on null manifolds and thus inherit a Carrollian structure. The aim is to understand holographic applications to asymptotically flat spacetimes and also to the theory of open tensionless strings.

  The project in progress [II] and is a collaboration between Arjun Bagchi, Daniel Grumiller and Stefan Fredenhagen initiated during our stay at the ESI.

- *Horizon Strings as 3d Blackhole Microstates*: We construct microstates of 3d black holes in the Hilbert space of tensionless null strings with non-zero winding along the direction transversal to the horizon. Their combinatorics is compatible with the Bekenstein–Hawking entropy and its semiclassical logarithmic corrections.

  The project was a result of collaboration between Arjun Bagchi, Daniel Grumiller and M.M. Sheikh-Jabbari initiated during our stay at the ESI. The project resulted in the publication [III].

- *BMS Field Theories with U(1) Symmetry*: In this project, we investigate quantum field theories in two dimensions (2d) with an underlying Bondi-van der Burgh-Metzner-Sachs (BMS) symmetry augmented by U(1) currents. These field theories are expected to holographically capture features of charged versions of cosmological solutions in asymptotically flat 3d spacetimes called Flat Space Cosmologies (FSCs). We conduct a study of the modular properties of these field theories. The characters for the highest weight representations of the symmetry algebra are constructed, and the partition function of the theory is obtained from them. We derive the density of (primary) states and find the entropy and asymptotic values of the structure constants exploiting the modular properties of the partition function and the torus one-point function. The expression for the asymptotic structure constants shows shifts in the weights and one of the central terms and an extra phase compared to the earlier results in the literature for BMS invariant theories without U(1) currents present. We reproduce our field results for the structure constants by a bulk computation involving a scalar probe in the background of a charged FSC.

  The project was a result of collaboration between Arjun Bagchi (AB), the members of his group in India and Dr. Max Riegler, a postdoctoral fellow at the University of Vienna initiated during AB's stay at the ESI. The project resulted in the publication [IV].

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Publications and preprints contributed

I. A. Bagchi, S. Chakrabortty, D. Grumiller, B. Radhakrishnan, M. Riegler and A. Sinha, *"Non-Lorentzian chaos and cosmological holography,"* Phys. Rev. D 104, no.10, L101901 (2021) [arXiv:2106.07649 [hep-th]].

II. A. Bagchi, D. Grumiller, and S. Fredenhagen, *In progress*.

III. A. Bagchi, D. Grumiller, and M.M. Sheikh-Jabbari, *"Horizon Strings as 3d Blackhole Microstates,"* [arXiv:2210.10794 [hep-th]].

IV. A. Bagchi, R. Chatterjee, R. Kaushik, S. Pal, M. Riegler and D. Sarkar, *"BMS Field Theories with* $\mathfrak{u}(1)$ *Symmetry,"* [arXiv:2209.06832 [hep-th]].

Research in Teams Project 7: Variational Approaches to Modelling Geophysical Waves and Flows

Collaborators: Delia Ionescu-Kruse (Simon Stoilow Institute, Bucharest), Rossen I. Ivanov (TU Dublin)

Dates: July 1 - 31, 2022

Budget: ESI € 4 800

Report on the project

Scientific Background

The classical mathematical water wave problem involves the Euler equations in a free boundary domain, the fluid incompressibility equation and the appropriate boundary conditions. The high complexity of the full Euler equations, even without taking into account the Earth's rotation and the influence of stratification, led mathematicians and physicists to derive simpler sets of equations convenient to describe the fluid motion in some specific physical regimes. Small-amplitude, long-wavelength (or shallow water) waves are approximated by weakly nonlinear long waves models such as the Korteweg-de Vries (KdV) and Boussinesq equations. A series of nonlinear evolution equations (e.g., Green-Naghdi (GN), Camassa-Holm (CH), Degasperis-Procesi (DP), two-component Camassa-Holm (CH2), etc.), which constitute more accurate approximations of Euler's equations than the classical KdV equation, have been studied intensively during the last decades. The derivation of simpler sets of equations that model flow phenomena is done in such a way that the resulting so-called approximate equations are easier to handle than the full equations but still keep some of their important structural features such as a variational or Hamiltonian structure. The Hamiltonian approach to free surface water waves dynamics has been put forward for the first time by Zakharov in 1968. His work for irrotational waves in deep water was extended in 2007-2008 to rotational flows of constant vorticity of finite depth [5.15]. The two-dimensional two-layer irrotational gravity water flows with a free surface have been shown [7] to possess a Hamiltonian formulation too; for the rotational counterpart (with constant vorticity in each layer) the Hamiltonian approach was developed in [4] for periodic water flows. In [12] it is shown that accounting for Coriolis effects in the equatorial f-plane approximation, for stratified two dimensional periodic water flows with piecewise constant vorticity, does not hinder the Hamiltonian description of the governing equations. For the propagation of irrotational surface waves over variable bottoms, see [1, 2]. The inclusion of stratification and rotation in the fluid body introduces even more complexity in the equations. The recent research on these effects has been extremely active and important results have been obtained, some of them with the input of the authors of this proposal. Nevertheless many difficult theoretical challenges still remain, especially in the area of exact analytical results. The project therefore aims to make contributions in these active research directions. Selected recent works of the authors are listed in References.

Project aims and scope

The focus is on the derivation and the investigation of different model equations as approximations to the full water wave problem taking into account the vorticity, the Coriolis effect and the stratification. The starting point of the analysis are the nonlinear governing equations for a two-dimensional, one-layer, incompressible, inviscid, rotational flow with arbitrary non-zero vorticity, over a flat bed and with a free surface. Then, the influence of the Coriolis force at the level of f-plane approximation plays a role in the governing equations. In modelling internal waves, the stratification has to be considered, too.

Outcomes and achievements

The currents and Coriolis forces are contributing additional rotational effects to the fluid flow. We have decided to look at a more general problem and to provide a general description of a two-dimensional fundamental model with arbitrary non-zero vorticity field, in a domain with a flat bed and a free surface. This is a challenging task, since there is a complicated interaction between the rotational motion in the bulk of the fluid and the surface motion. In the mathematical formulation of the nonlinear system of equations very important role is played by the Dirichlet-Neumann operator (DNO) and the Green function of the Laplacian operator in the bulk of the fluid (which depends on the surface as well). We provide explicit expressions for both the Dirichlet-Neumann operator and the Green's function for Laplace's equation in the free boundary domain.

As an illustration of the general setting, the small-amplitude long wave scaling regime is analysed, and the corresponding expression for the Dirichlet-Neumann operator is obtained and compared with the Craig-Sulem expression [6] as a power series expansion in terms of the free surface variables. Also, the field of a point-vortex and its interaction with the surface is studied as an example.

The stratification such as configuration with several layers of different densities is a subject for further studies.

Among other advantages, the proposed formulation could be useful for numerical simulations.

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Publications and preprints contributed

D. Ionescu-Kruse and R. Ivanov, *Nonlinear two-dimensional water waves with arbitrary vorticity*, in preparation.

Research in Teams Project 8: Noncommutative Cluster Structures and their Symmetries

Collaborators: Arkady Berenstein (U of Oregon), Vladimir Retakh (Rutgers U)

Dates: July 1 - August 31, 2022

Budget: ESI € 4 800

Report on the project

Scientific Background

The theory of cluster algebras became one of the main tools in representation theory, Teichmüller theory, total positivity, integrable systems, and other fields over last 20 years. For several years we were working on finding pure noncommutative analogues of these results and constructions. In particular, in [1] we found noncommutative analogues of double Bruhat cells and there related them to "noncommutative positivity", in [2] we studied *noncommutative envelopes* of Lie algebras including semi-simple and Kac-Moody Lie algebras, in [4] we started our work on noncommutative Laurent phenomenon as a prelude to our approach to a noncommutative version of cluster algebras. This work was continued in [4], where we discussed the Laurent phenomenon related to noncommutative triangulations of surfaces. This paper also led us to new *noncommutative surface invariants*. Our further studies of the Laurent phenomenon led us to a noncommutative generalisation of Catalan and ballot numbers, and binomial coefficients (see [5]). The listed results serve us a gateway to a pure noncommutative theory of cluster algebras.

Project aims and scope

Our main goal was to further study noncommutative clusters and their symmetries, especially their tagged versions which are known in commutative situation for any punctured surface ([6]), but were lacking in the noncommutative setting. This should give a better understanding of local systems on various punctured surfaces and the corresponding (commutative and noncommutative) character varieties.

Outcomes and achievements

We have constructed a large set of noncommutative tagged clusters $\mathbb{T}_\Delta \subset \mathcal{A}_\Sigma$ for all *tagged* triangulations Δ on any marked surface Σ with punctures and showed that noncommutative mutations identify with chosen collections of isomorphisms $f_{\Delta,\Delta'} : \mathbb{T}_\Delta \to \mathbb{T}_{\Delta'}$.

The first example when we must invert all cluster variables is the noncommutative polygon $\mathcal{A}_n = \mathcal{A}_{\Sigma_n}$, where Σ_n is the disk with n marked boundary points and no punctures. If we take a triangle with vertices $\{1,3,5\}$, then the corresponding triangle relation $x_{13}x_{53}^{-1}x_{51} = x_{15}x_{35}^{-1}x_{31}$ cannot be rewritten without inverting at least one of x_{ij}'s. This algebra has exactly the Catalan number C_{n-2} noncommutative clusters which are not yet tagged.

The first class of algebras for which we must use tagged triangulations is $\mathcal{A}_{n,1} = \mathcal{A}_{\Sigma_{n,1}}$, where $\Sigma_{n,1}$ is the disk with n marked boundary point and a single puncture. Then, the number of all (commutative or noncommutative) clusters is $\frac{3n-2}{n}\binom{2n-2}{n-1} = \binom{2n-2}{n} + \binom{2n-1}{n}$, out of which $\binom{2n-1}{n}$ can be viewed as ordinary triangulations and the $\binom{2n-2}{n}$ remaining ones inevitably include tagged clusters (that is, the number of unavoidably tagged clusters is approximately $\frac{1}{3}$ of all clusters).

For instance, $\mathcal{A}_{2,1}$ is generated by $\{x_{12}^{\pm}, x_{21}^{\pm}, x_{10}, x_{01}, y_{10}, y_{01}, x_{20}, x_{02}, y_{20}, y_{02}\}$, subject to the relations

$$x_{i0}y_{0i} = y_{i0}x_{0i}, i \in \{1,2\}, x_{21}^{+}y_{01}^{-1}x_{10}^{-1}x_{12}^{-} = x_{21}^{-}x_{01}^{-1}y_{10}^{-1}x_{12}^{+}, x_{12}^{+}y_{02}^{-1}x_{20}^{-1}x_{21}^{-} = x_{12}^{-}x_{02}^{-1}y_{20}^{-1}x_{21}^{+},$$

$$x_{21}^{\pm}x_{01}^{-1}x_{02} = x_{20}x_{10}^{-1}x_{12}^{\pm}, x_{21}^{\pm}y_{01}^{-1}x_{02} = x_{20}y_{10}^{-1}x_{12}^{\pm}$$

and

$$y_{10} = (x_{12}^{+} + x_{12}^{-})x_{02}^{-1}, y_{20} = (x_{21}^{+} + x_{21}^{-})x_{01}^{-1}, y_{01} = x_{20}^{-1}(x_{21}^{+} + x_{21}^{-}), y_{02} = x_{10}^{-1}(x_{12}^{+} + x_{12}^{-}) .$$

This algebra has exactly four noncommutative clusters (each of them also has frozen variables $x_{12}^{\pm}, x_{21}^{\pm}$):

$$\{x_{10}, x_{01}, x_{20}, x_{02}\}, \{x_{10}, x_{01}, y_{10}, y_{01}\}, \{y_{20}, y_{02}, x_{20}, x_{02}\}, \{y_{10}, y_{01}, y_{20}, y_{02}\} ,$$

one of which cannot be reduced to the ordinary triangulation similarly to the commutative or quantum case.

It turns out that $\mathcal{A} = \mathcal{A}_\Sigma$ has an interesting group Γ_Σ (we refer to it as *cluster automorphism group*) of birational automorphisms acting on each of the cluster groups $\mathbb{T}_\Delta$ in a way similar to the mapping class group action on a fundamental group of a surface.

In fact, any triangulation Δ of Σ corresponds to a specific generating set of Γ_Σ, and these generators are determined by neighbouring triangulations Δ' of Δ via a pair of natural isomorphisms $f^{\pm} : \mathbb{T}_\Delta \to \mathbb{T}_{\Delta'}$ corresponding to the terms in the right hand side of the "exchange relation" so that their discrepancy $T := (f^-)^{-1} \circ f^+$ is an automorphism of $\mathbb{T}_\Delta$ which scales the diagonal of a common quadrilateral by a noncommutative cross-ratio.

We find a (yet conjectural) presentation of this group Γ_Σ for various surfaces Σ and, in particular, prove that Γ_{Σ_n} is isomorphic to the braid group Br_{n-2}. Curiously, we obtain many new presentations of Br_{n-2} by choosing various triangulations of Σ_n.

Theorem Let Δ be triangulation of Σ_n, $n \geq 4$. Then:
(a) Γ_{Σ_n} is generated by $T_{ij} = T_{ji}^{-1}$ for all diagonals $(ij) \in \Delta$ subject to

$$\begin{cases} T_{ij}T_{k\ell}T_{ij} = T_{k\ell}T_{ij}T_{k\ell} & \text{if } (ij) \text{ and } (k\ell) \text{ are adjacent and form a triangle in } \Delta \\ T_{ij}T_{k\ell} = T_{k\ell}T_{ij} & \text{otherwise} \end{cases}$$

(b) Γ_{Σ_n} is isomorphic to the braid group Br_{n-2}.

For instance, if Δ is a triangulation of a hexagon with triangles diagonals (135), (123), (345) and (156), the braid group Br_4 is generated by T_{13}, T_{35}, T_{51} subject to

$$T_{13}T_{35}T_{13} = T_{35}T_{13}T_{35},\ T_{13}T_{51}T_{13} = T_{51}T_{13}T_{51},\ T_{35}T_{51}T_{35} = T_{51}T_{35}T_{51}$$

which, in particular, implies that Br_4 has an outer automorphism of order 3.

The group Γ_Σ is closely related to both cluster modular group and mapping class group. The analogous group is well-defined in rank 2 noncommutative cluster structure $\mathcal{A}_{r_1,r_2}$ in [3] and, not surprisingly anymore, it is an Artin braid group in two generators if $r_1 r_2 \leq 3$ and free group in two generators otherwise.

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Research in Teams Project 9: Two-Layer Periodic Water Waves

Collaborators: Jinfeng Chu (Shanghai Normal U, China), Calin Martin (U of Vienna), Kateryna Marynets (TU Delft)

Dates: October 1–31, 2022

Budget: ESI € 2 400

Report on the Project

This project was devoted to the derivation and (the subsequent analysis) of an exact solution to the governing equations of geophysical fluid dynamics. The latter equations are written in spherical coordinates and incorporate a discontinuous fluid stratification that varies with depth and latitude. An important aspect of our analysis refers to the incorporation of a general body force vector which is thought to be a key mechanism for the dynamical balance of the Antarctic Circumpolar Current (ACC) to which our analysis refers.

Our work was organized in a hybrid setting since Jifeng Chu could not be physically present at ESI due to the COVID-19 and travel restrictions. We had regular discussions about the progress on the project by Zoom online and by email. We continue to work on the project after the official end of the research stay in Vienna. Currently we are finalizing a draft of the paper and expect to submit it in the first quarter of 2023.

Scientific Background

Undoubtedly, the ACC is one of the most significant currents in the Earth's oceans and is very important in studying the global ocean circulation and climate because the ACC is linked to Atlantic, Indian, and Pacific oceans. Besides, the ACC is the only current that completely encircles the polar axis, flowing eastward through the southern regions of the Atlantic, Indian and Pacific oceans along 23.000 km, and extends in places over 2000 km in width, cf. [1-3]. Its massiveness is also reflected by the huge volumes of water it transports estimated to be between 165 million and 182 million cubic meters of water every second, which represents more than 100 times the flow of all the rivers on Earth.

Among many factors that shape the complex behaviour of ACC is the presence of stratification which accommodates observed sharp changes in water density (due to variations in temperature and salinity, cf. [4-8]), known as fronts or jets; the two main fronts of the ACC are the

Subantarctic Front to the north and the Polar Front further south. Very often (discontinuous) stratification (like the type we have analysed in this project) gives rise to internal waves [5, 9-14], however, allowing for stratification complicates the analysis of an already very demanding analytical problem. We would like to point out that — due to the complexity of the governing equations — exact and/or explicit solutions in fluid mechanics constitute a special, but, otherwise, quite rare event. However, once the exact solutions are available, they provide new avenues of investigation of physically realistic flows, by means of asymptotic, or multiple scale methods. See [6, 12-20] for more recent results on the ACC.

Project aims and scope

The scope of the project was to address the topic of stratified geophysical water flows exhibiting vertical structure, internal waves (arising as a result of the discontinuous stratification) and a preferred propagation direction. In particular, we aim to derive the exact and partially explicit solutions to the problem under consideration and to prove some related properties for such two-layer water waves.

Outcomes and achievements

During our work in the framework of the Research in Teams project we considered a mathematical model of a stratified jet flow of the ACC. More precisely, following an approach devised in [6] for homogeneous flows and extended in [11,12] to the case with discontinuous density, we used spherical coordinates (in a rotating frame) to derive a new exact and partially explicit solution to the governing equations of geophysical fluid dynamics for an inviscid and incompressible azimuthal flow with a discontinuous density distribution and subjected to forcing terms. The latter are of paramount importance for the modeling of realistic flows – that is, flows that are observed in some averaged sense in the ocean. The discontinuous density triggers the appearance of an interface which plays the role of an internal wave. While the velocity and the pressure are determined explicitly, we used functional analytical techniques which render (in a unique way) the surface and interface defining functions in an implicit way as soon as a small enough pressure is applied on the free surface. In this setting we were also able to show that the interface has also nice regularity properties.

Currently we work on setting out relations between the monotonicity of the surface pressure and the monotonicity of the surface distortion that concur with the physical expectations.

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Publications and preprints contributed

J. Chu, C.I. Martin, K. Marynets, *Exact solutions and internal waves for the Antarctic Circumpolar Current in spherical coordinates with density depending on depth and latitude*, in progress.

Senior Research Fellows Programme

To stimulate the interaction with the local scientific community the ESI offers regular lecture courses on an advanced graduate level 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 Lecture Courses:

Lecture Courses, Winter Term 2021/22:

Martin Kružík (Czech Academy of Sciences, Prague):
Lower Semicontinuity of Integral Functionals and Applications
Lecture Course (250136 VU): January 10 to 19, 2022
Start: Monday: 09:00 - 12:00
Further dates: Wednesday, January 12, Friday, January 14, Monday, January 17, 2022, 9:00 - 11:00, Wednesday, January 19, 2022, 9:00 - 11:00

Lecture Courses, Summer Term 2022:

Sergei A. Egorov (Virginia U):
Classical Density Functional Theory with applications to colloid/polymer systems in the bulk and under confinement
Lecture Course (260060 VO): May 11 – June 22, 2022
Wednesday 9:45 – 11:15

Lecture Courses, Winter Term 2022/23:

John Barrett (U of Nottingham):
Introduction to Non-commutative Geometry
Lecture Course (260024 VU): October 3 – 24, 2022
Every Monday and Wednesday 14:00 – 15:30

Visitors associated with Senior Research Fellowships:

Thomas Laird (U of Nottingham), September 1 – 18, 2022

Martin Kružík: Lower semicontinuity of integral functionals and applications

Prof. Martin Kružík (Czech Academy of Sciences, Prague): January 9 – February 25, 2022

Course

Integral functionals of the form $I(y) = \int_\Omega W(x,y(x),\nabla y(x))\mathrm{d}x$ where $y : \Omega \subset \mathbb{R}^n \to \mathbb{R}^m$ play an important role in variational methods applied to mathematical continuum mechanics and continuum physics, in general. Hyperelasticity, magnetism, magnetoelasticity, or electroelasticity can serve as genuine examples. The modern development has started by a seminal work by J.B. Morrey Jr. who identified a condition on $W(x,y,\cdot)$ making I lower semicontinuous in the weak* topology of $W^{1,\infty}(\Omega;\mathbb{R}^m)$ which is now called (Morrey's) *quasiconvexity*. In 1965, N.G. Meyers significantly extended weak lower semicontinuity results for integral functionals depending on maps and their gradients available at that time to allow for integrands unbounded from below. While calculus of variations provides us with a rich toolkit of powerful approaches allowing to show lower semicontinuity of I in appropriate topology, many problems have been unsolved for decades if proper physics is taken into account. We traced the development on this topic from that time on. Particular attention was paid to signed integrands and to applications arising in continuum mechanics of solids. In this case, W stands for the elastic energy density of the body including work of external forces. We review existing results for polyconvex, simple as well as nonsimple materials, i.e., when W above depends also on $\nabla^2 y$, and related statements about sequential weak continuity of minors. These are non-coercive and belong precisely to the class of integrands studied by Meyers in his work. In spite of terrific progress in the mathematical theory, many questions, which only appear when we apply purely analytical results to mechanics, have remained unanswered. One such question is lower semicontinuity along sequences of orientation-preserving maps, in other words mappings satisfying $\det \nabla y > 0$ almost everywhere in Ω. We also discussed this particular problem and mention recent partial results on this topic. We mentioned various instances where lower semicontinuity is of major importance. This includes semidiscretization in time of evolutionary problems, relaxation (i.e. finding the largest lower semicontinuous envelope of I) and dimension reduction. Besides, we emphasized some recent progress in lower semicontinuity of functionals along sequences satisfying differential and algebraic constraints which have applications in continuum mechanics of solids to ensure injectivity and orientation-preservation of elastic deformations.

Research

I worked mainly with the group of Prof. Ulisse Stefanelli (U of Vienna) and with the group of Prof. Elisa Davoli (TU Vienna). Besides that, I have also finished some preprints with other collaborators. The preprint *Badal-Friedrich-Kružík* considers a quasistatic nonlinear model in thermoviscoelasticity at a finite-strain setting in the Kelvin-Voigt rheology where both the elastic and viscous stress tensors comply with the principle of frame indifference under rotations. The force balance is formulated in the reference configuration by resorting to the concept of nonsimple materials whereas the heat transfer equation is governed by the Fourier law in the deformed configurations. Weak solutions are obtained by means of a staggered in-time discretization where the deformation and the temperature are updated alternatingly. Afterward, we focus on the case of deformations near the identity and small temperatures, and we show by a rigorous linearization procedure that weak solutions of the nonlinear system converge in a suitable sense to solutions of a system in linearized thermoviscoelasticity. The same property holds for time-discrete approximations and we provide a corresponding commutativity result.

The preprint *Brazda-Kružík-Stefanelli* is devoted to gradient flow of the Canham-Helfrich functionals. We prove the existence of solutions in Wasserstein spaces of varifolds, as well as upper and lower diameter bounds. In the more regular setting of multiply covered $C^{1,1}$ surfaces, we provide a Li-Yau-type estimate for the Canham-Helfrich energy and prove the conservation of multiplicity along the evolution.

The paper *Dondl-Jesenko-Kružík-Valdman* deals with local minimizers in nonlinear viscoelasticity. Many computational experiments are performed.

The preprint *Drozdenko et al.* formulates a large-strain model of single-slip crystal elastoplasticity in the framework of energetic solutions. Numerical performance of the model is compared with lab experiments on the compression of a stack of note papers.

Lecture Notes

Lecture notes *Weak Lower Semicontinuity of Integral Functionals and Applications* by B. Benešová and M. Kružík are in preparation.

Publications and preprints contributed

R. Badal, M. Friedrich, M. Kružík, *Nonlinear and linearized models in thermoviscoelasticity*, arXiv:2203.02375[math.AP].

K. Brazda, M. Kružík, U. Stefanelli, *Generalized minimizing movements for the varifold Canham-Helfrich flow*, arXiv:2207.03426[math.AP].

P. Dondl, M. Jesenko, M. Kružík, J. Valdman, *Linearization and computation for large-strain visco-elasticity*, Math. Engrg. **5** (2022), 1–15, DOI:10.3934/mine.2023030.

D. Drozdenko, M. Knapek, M. Kružík, K. Máthis, K. Švadlenka, J. Valdman, *Elastoplastic deformations of layered structures*, arXiv:2207.01986[math.AP].

Sergei A. Egorov: Classical Density Functional Theory with applications to colloid/polymer systems in the bulk and under confinement

Prof. Sergei A. Egorov (Virginia U): May 1 – July 31, 2022

Course

The course provided a general overview of the use of classical Density Functional Theory in theoretical Soft Matter Research, e.g. studies of structural and dynamical properties of colloids, polymers, and liquid crystals. The course was well attended (about 20 students in total) with very active class participation and numerous insightful questions. The following topics were covered:

Week 1: Fundamentals of Classical Density Functional Theory.

Week 2: Simple Applications: Hard Spheres, Fundamental Measure Theory, Asakura-Oosawa model of Colloid-Polymer Mixtures.

Week 3: Beyond Hard Spheres: Classical Density Functional Theory of Polymeric Molecules at a Monomer-resolved Level.

Week 4: Beyond Hard Spheres: Classical Density Functional Theory of Liquid Crystals, Isotropic-Nematic Transition.

Week 5: Dynamics: Langevin, Fokker-Planck, and Smoluchowski Equations

Week 6: Dynamics: Time-Dependent Density Functional Theory and Mode-Coupling Theory.

Week 7: Advanced Topics: Crystallization and Freezing.

Research

During my stay at the ESI I have worked on the following research projects:

1) Colloidal gelation induced by ring polymers: Density Functional Theory study.

2) Phase behaviour of binary mixtures of poly-n-catenates and linear polymers.

3) Cluster Crystals formed by soft dimers.

Publications and preprints contributed

S. A. Egorov, R. Stano, and C. N. Likos, *Bulk phase behaviour of binary mixtures of poly[n]catenates and linear polymers: a Density Functional Theory Study*, manuscript in preparation.

E. Moghimi, I. Chubak, M. Kaliva, P. Kiany, S. A. Egorov, D. Vlassopulos, and C. N. Likos *Bulk phase behaviour of poly[n]catenates and linear polymers: a Density Functional Theory study*, manuscript in preparation.

John Barrett: Introduction to Non-commutative Geometry

Prof. John Barrett (U of Nottingham): September 1 – October 31, 2022

Course

The course described the spectral triple approach to non-commutative geometry and its use in high-energy physics. It described the mathematical formalism of spectral triples, some simple examples, and their use in the description of the standard model of particle physics. The second part of the course outlined an approach to quantum gravity based on integration over the data of a spectral triple. The seven sessions were:

[1] Introduction. Fuzzy spaces with symmetry.

[2] Commutative analogues. Dirac operator.

[3] Real structures. Real spectral triples

[4] Standard model charges. Standard Model masses

[5] The fuzzy sphere. The fuzzy torus.

[6] Fluctuations. Matrix spectral triples.

[7] Quantum gravity and matter. Random spectral triples.

The lectures were delivered in person at the Schrödinger Lecture Hall.

Research

During the stay at ESI I carried out research into non-commutative geometry models for physics, in collaboration with L. Glaser (U of Vienna) and T. Laird (U of Nottingham). The chosen technique for non-commutative geometry is a mathematical framework called a spectral triple. It was also very useful to discuss the research programme with local researchers and visitors to ESI.

- A collaboration to include fermion fields in the integral over spectral triple data was initiated. There was a discussion of the fermion formalism and of fermion observables that might be suitable for either analytic or numerical investigations. We looked into adapting existing code for numerical simulations.

- A project to investigate deformations of spectral triples for the fuzzy sphere that break the rotational symmetry was carried out. For a class of examples we were able to compute the spectrum of the Dirac operator analytically. We also made progress characterising the corresponding classical geometry. There were useful discussions with H. Steinacker (U of Vienna) in which we discovered our results are related to some previous work of his.
- There was progress on a project to define spectral triples for coadjoint orbits.

Lecture Notes

The lecture notes are available in draft form at https://johnwbarrett.wordpress.com/ The complete notes will be posted to arXiv and considered for publication.

Publications and preprints contributed

The research projects are not yet complete. Publications that will acknowledge ESI support are expected to be

- Fermionic fields in random spectral triples
- Spectral triples for deformed fuzzy spheres
- Spectral triples for fuzzy coadjoint orbits

Erwin Schrödinger Lectures 2022

The Erwin Schrödinger Lectures are directed towards a general audience of mathematicians and physicists. In particular it is an intention of theses lectures to inform non-specialists and graduate students about recent developments and results in some area of mathematics or physics.

Philip Walther: Photonic quantum computing – a bright future for many applications

Speaker: Philip Walther (University of Vienna)

Philip Walther is a professor at the Faculty of Physics of the University of Vienna. His research interests include photonic quantum computation and quantum simulation, quantum-enhanced cybersecurity, the development of scalable quantum photonic technology, and experimental investigation of the interface between quantum physics and gravity. Prof. Walther is the speaker of the SFB BeyondC and he heads the Christian Doppler Laboratory for Photonic Quantum Computing. In 2021 he received the prestigious Friedrich Wilhelm Bessel Award of the Alexander von Humboldt Stiftung.

Date: December 12, 2022

Abstract: The precise quantum control of single photons, together with the intrinsic advantage of being mobile make optical quantum system ideally suited for quantum information applications that require communication or the delegation of tasks. Prominent examples include quantum cryptography as well as quantum clouds and quantum computer networks.

Here I present the current architectures for scalable photonic quantum computers and special purpose applications that exploit advantages of photonic quantum system. This is shown by examples for various quantum computations such as quantum machine learning and in particular reinforcement learning, in addition to secure quantum and classical computing tasks that require quantum networks. As outlook I will discuss technological challenges for the scale up of photonic quantum computers and remarkable opportunities for special-purpose applications such as neuromorphic circuits.

Junior Research Fellows Programme

Stephan Eckstein: Numerics of Adapted Transport and Applications to Mathematical Finance

Stephan Eckstein (U Hamburg): November 29 – January 31, 2022

Report

During my stay at the Erwin Schrödinger Institute of the University of Vienna, I participated in the activities of the group around Prof. Mathias Beiglböck and Prof. Julio Backhoff from the Faculty of Mathematics. Aside from general scientific discussions and participation in their group seminar, I actively collaborated with Daniel Bartl (who is a postdoc in the group) and Gudmund Pammer (a former PhD student from the group who was visiting during the same period).

The main topic of research was adapted optimal transport, which is a variant of the optimal transport problem for distributions of a time series. Theoretical aspects of adapted optimal transport, like generated topologies or geodesic properties, have been studied in various recent works. Among others, it was shown that the adapted Wasserstein distance yields stability estimates in mathematical finance or allows one to take model ensembles of different martingale models. To actually use those properties in practice though, one requires numerical solution methods for adapted optimal transport, which have so far received little attention.

During my stay in Vienna, we developed computational methods for the adapted optimal transport problem based on discretization and regularization. We showed that the errors arising from both discretization and regularization be controlled. Further, applying entropic regularization leads to an efficient algorithm, which is an adapted version of Sinkhorn's algorithm. We analyzed the numerical tractability of this variant of Sinkhorn's algorithm and showed its exponential convergence. Along the way we observed some novel theoretical properties, like strong equivalence of the adapted and non-adapted total variation distance. The main part of the results together with Gudmund Pammer are published in the paper "Computational methods for adapted optimal transport".

Aside from the collaborations, the scientific discussions with members of the group gave me a lot of insights about various topics, like adapted topologies, shadow martingales and statistical estimation, which I am sure will continue to influence my research in the future. In turn, I shared some tools regarding numerical methods in mathematical finance with the group. Overall, my impression is that this was a highly beneficial and productive stay for both parties involved.

References

S. Eckstein, G. Pammer, *Computational methods for adapted optimal transport*, arXiv:2203.05005[math.PR], forthcoming in Annals of Applied Probability.

Publications and preprints contributed

S. Eckstein, G. Pammer, *Computational methods for adapted optimal transport*, arXiv:2203.05005[math.PR], forthcoming in Annals of Applied Probability.

Hamed Barzegar: Mathematical Analysis of Dark Matter

Hamed Barzegar (U Vienna): October 1 – November 30, 2021 and January 1 - March 1, 2022

Report

The goal of this research fellowship was to obtain a more rigorous understanding of one of the problems related to Dark matter (DM) as a solution to the Einstein–Vlasov–Klein–Gordon (EVKG) system in a static spherically symmetric spacetime.

DM is one of the mysteries of the standard model of cosmology, i.e., ΛCDM model, which assumes the existence of the cold dark matter (CDM). Despite many theoretical efforts to understand the nature of DM, its existence has not yet been confirmed. On the other hand, there are only few works that address this problem mathematically rigorously.

There were two mathematical reasons for this project which make the problem more interesting. First, we wanted to analyse the Cauchy problem for the EVKG system where our proposed model could play a role as an attractor of dynamical evolution and also to show the existence of a solution to the EVKG system in a static spherically symmetric spacetime. Second, we wanted to provide the first mathematical result for the EVKG system in a static spherically symmetric spacetime. It should be noted that the future stability of an even larger class of such models in cosmological spacetimes is provided by Ringström [1].

The EKG system forms a system of ODEs in the present setting. Therefore, the goal was to adapt the shooting method used in [2] to cover the Vlasov equation since the latter is a PDE and needs more careful analysis. For the distribution function appearing in the Vlasov equation we made the so-called Polytropic Ansatz which is well motivated by astrophysics in the present context. The corresponding problem for the EV system is studied intensively both analytically and numerically [3, 4, 5, 6]. On the other hand, besides the work by Bizoń and Wasserman there are some numerical results for the EKG system [7, 8, 9].

The DM problem in the present context is usually modelled by the the Schrödinger–Poisson system (or Vlasov–Poisson system for large scales) and not by the EVKG system. Moreover, although the spacetime is static the scalar field is not. This results in dynamics of the DM and the result would defer from that for the SP system in a static spherically symmetric spacetime [10, 11, 12].

This fellowship was thought to be a first step for attracting another grant from, e.g., the Austrian Academy of Sciences which unfortunately did not work out. Nevertheless, we worked on the basics of the problem and gained a better insight into its difficulties. The results of this fellowship may be useful in the future in case I want to continue to work on the same project. I changed my field of study slightly and now I am working on other problems and therefore have not made any publication based on this fellowship. Nevertheless, I enjoyed the support and hospitality of the Erwin Schrödinger Institute which I sincerely acknowledge. Moreover, I attended the Online-Workshop: "Mathematical Perspectives of Gravitation beyond the Vacuum Regime" at the institute which was organized, among others, by Prof. David Fajman with whom I worked during my fellowship.

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Lorenzo Del Re: Dimensional Crossover of Layered Strongly Correlated Ultra-cold Fermi Gases

Lorenzo Del Re (Georgetown U): June 6 – June 20, 2022

Report

As it has been already stated in the previous report, the original idea of the project was to investigate how properties of strongly correlated fermionic systems change as a function of a parameter that allows to continuously interpolate from a three dimensional to a two dimensional system: e.g. the difference between the in plane hopping $t_{||}$ from the inter-planes hopping $t_{\perp}$ in the three-dimensional Hubbard model. The study of such an anisotropic system has been partially undertaken in Ref. [1], where the authors addressed the problem via static mean-field theory, and our initial idea consists in including quantum fluctuations using the Dynamical Vertex Approximation (DΓA) [3], that falls into the category of the diagrammatic expansions [2] of Dynamical Mean Field Theory (DMFT) [4].

However, in order to provide with a satisfactory description of the dimensional crossover one should let the system to spontaneously break symmetries such as the SU(2) spin symmetry in the repulsive case and the U(1) symmetry of pseudo-spins in the attractive case [5]. In fact, we expect that such a dimensional crossover would induce a phase transition fixing the temperature and varying $t_{\perp} - t_{||}$. This consideration has led us to the successful extension of the DΓA method to the case of broken symmetry phases [6], as previously reported.

In my last period in the institute I was therefore able to lay the foundations for the theoretical investigation of the dimensional crossover in the strongly correlated regime on the basis of the results previously obtained and thanks to the discussions with Prof. A. Toschi and his research group.

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Alexander Evetts: The cogrowth of finitely generated groups

Alexander Evetts (Heriot-Watt U, Edinburgh): May 2 – May 26, 2022

Report

Let G be a group with finite generating set S. The *word length* of an element $g \in G$ is the length of a shortest word in S^* that represents g. We write

$$|g|_S = \min\{|w| : w \in S^*,\ w =_G g\}.$$

The *growth function* of G (with respect to S) is then the function that counts the number of elements of length n, or, equivalently, the number of elements on the sphere of radius n in the Cayley graph. We write

$$\sigma_{G,S}(n) = \#\{g \in G : |g|_S = n\}.$$

More generally, let $U \subset G$ be any subset. Then, the *relative growth function* of U in G counts only the elements of U. We write

$$\sigma_{U \subset G,S}(n) = \#\{g \in U \colon |g|_S = n\}.$$

Let $G = \langle S \mid R \rangle$ be a group presentation with $|S| < \infty$, so $G = F/N_R$ where F denotes the free group generated by S and N_R is the normal closure in F of the relators R. The *cogrowth function* of G with respect to S is defined to be the *relative growth function* in F of the normal subgroup N_R, $\gamma(n) = \sigma_{N_R \subset F,S}(n)$. The *cogrowth exponent* γ is the associated growth rate, that is

$$\gamma = \limsup_{n \to \infty} \sqrt[n]{\gamma(n)}.$$

It is a fact that either $\gamma = 1$ (if and only if N_R is trivial) or $\sqrt{2r-1} < \gamma \leq 2r-1$, where $r = |S|$. Furthermore, $\gamma = 2r-1$ if and only if G is *amenable* [4]. This criterion for amenability has been used, for example, to show the existence of a non-amenable group with no non-abelian free subgroups [6].

Consider the simple random walk on the Cayley graph of G, and denote the probability of an n-step transition from g to h by $p^{(n)}(g,h)$. The *spectral radius* of this random walk is the number

$$\mu = \limsup_{n \to \infty} \sqrt[n]{p^{(n)}(g,h)}.$$

Results of Grigorchuk [4] relate cogrowth and random walks and imply that γ is a rational number if and only if μ is a rational number. Therefore we can think of these as two phrasings of the same question. Calculation of this number for general groups is a hard problem. For example, it is not known for hyperbolic groups in general. In the particular case of fundamental groups of closed orientable surfaces (or surface groups for short) the best results are estimates of the spectral radius, for example [1].

With Professor Arzhantseva, we discussed potential avenues for improving these existing estimates, and for small cancellation groups more generally. Champetier [2] provides asymptotic calculations of the cogrowth of certain small cancellation groups by estimating the number of distinct van Kampen diagrams with boundaries of length n. We aim to understand this argument and refine it for the surface group case. Small cancellation theory is new to me and I also discussed some of the standard notion with Professor Christopher Cashen.

It is worth noting that there is a language-theoretic problem associated to cogrowth. The *word problem* of a finitely generated group is the language of words in S^* which represent the identity. An alternative definition of cogrowth is as the growth function of the word problem. The problem of identifying the formal language properties of this language has a long history (see [5]), including the famous Theorem of Muller and Schupp which asserts that the word problem of a group is a *context-free language* if and only if the group is virtually free. In this case, the language is in fact *unambiguously* context-free, which implies that the associated generating function is algebraic. We tentatively conjecture that the converse also holds, namely that the growth series of the word problem (and equivalently the *cogrowth series*) is algebraic if and only the group in question is virtually free.

During my visit I also gave a talk in the Mathematics Department seminar series ‘Geometry and Analysis on Groups’ entitled ‘Equations, rational sets and formal languages’, discussing some of my recent work, including the paper [3] that was completed during my previous visit to ESI in the autumn of 2020.

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Judith Alcock-Zeilinger: Multiplet bases for resummation — understanding structures of color evolution

Judith Alcock-Zeilinger (Independent Researcher): July 11 – November 10, 2022

Report

In the perturbative limit, the cross section of QCD scattering processes factorizes into hard and soft operators, $\mathbf{A}_n$ and $\mathbf{S}_n$ (respectively), where n is the number of hard partons and the explicit dependence of both $\mathbf{A}_n$ and $\mathbf{S}_n$ on the resolution scale E (which, in the simplest cases, describes the energy of the emitted gluons) has been suppressed. More intuitively, $\mathbf{S}_n$ describes the hadronization of the n hard partons into hadrons, and $\mathbf{A}_n$ encapsulates the emission of (non-collinear) soft gluons off the hard partons [1,2].

The long term aim of this project is to better understand the physical structure of such QCD cross sections involving many external legs. The path chosen in this project towards achieving this goal is to take the viewpoint of color evolution and $\mathsf{SU}(N_c)$ symmetry, and thus use the associated mathematical machinery to our advantage.

The first paper (see section "Publications and preprints contributed"), a collaboration with Dr. Malin Sjödahl (Lund University) and Dr. Stefan Keppeler (Universität Tübingen), is a continuation of a research-in-teams project which took place at ESI from September 13 to September 24, 2021. In this paper, we provided closed form expressions of all Wigner-$6j$ symbols involving two quark lines on opposite sides, up to a minus sign. As it is argued in previous work [3], these $6j$ symbols are part of a small set of $6j$ symbols that are sufficient to fully decompose color structure into group invariants.

This paper was also the basis of two seminars entitled "Loops, birdtracks and $6j$s – exploring QCD color structure" given a the University of Vienna (October 28, 2022) and the Karl-Franzens-Universität Graz (November 11, 2022), respectively.

The second paper (in preparation) focuses on the soft anomalous dimension matrix $\Gamma_n(E)$: As mentioned earlier, the hard function $\mathbf{A}_n(E)$ depends on the energy E of the emitted gluons, and its energy evolution governed by renormalization group equations, where the soft anomalous dimension matrix $\Gamma_n(E)$ acts as the Hamiltonian of the evolution. Recent work [1] has shed light on the two-loop calculation of the anomalous dimension matrix in the color flow basis, in particular establishing important results regarding the kinematics of the associated processes. In this second paper resulting from our collaboration, we will supplement the results of Plätzer and Ruffa with calculations in color space, and also lay the groundwork for extending these results to an arbitrary number of loops.

The third, and last, paper (in preparation) that will result from this collaboration is a continuation of the first one. Here, we aim to complement the $6j$ symbols with two quark lines with $6j$s containing gluon lines, in order to obtain a full set of group invariants necessary to decompose the color structures of interest to the current context. This work promises to furnish a full color decomposition in terms of $\mathsf{SU}(N_c)$ group invariants of the QCD scattering processes of interest here.

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Publications and preprints contributed

So far, one paper has been published as a result of this collaboration. Another paper is in preparation, and a third paper will likely be completed in the present year.

J. Alcock-Zeilinger, S. Keppeler, S. Plätzer, M. Sjodahl, *Wigner 6j symbols for SU(N): Symbols with at least two quark-lines*, arXiv:2209.15013[hep-ph].

Aliaksandr Hancharuk: Higher Gauge Theories

Aliaksandr Hancharuk (U Lyon): July 31 – August 30, 2022

Report

During the stay at ESI my main focus was on working on a joint project with Prof. Strobl and Prof. Laurent-Gengoux that concerns a construction of Koszul-Tate resolutions. In other words, for $\mathcal{O}$ being a unital commutative ring and $\mathcal{I} \subset \mathcal{O}$ a proper ideal, our aim was to study particular resolutions of a $\mathcal{O}$-module $\mathcal{O}/\mathcal{I}$ that admit a structure of a symmetric $\mathcal{O}$-algebra. One of our results is a construction of an *arborescent Koszul-Tate resolution* that circumvents the limitations of the classical algorithm [Tate57], namely we obtain a desired resolution in a finite number of homological calculations, which is in a drastic contrast with [Tate57]. During my stay at the institute we did a progress in studying the transfered structures of the arborescent Koszul-Tate resolutions of $\mathcal{O}/\mathcal{I}$ to any projective resolutions of $\mathcal{O}/\mathcal{I}$. In particular, we learned of examples of pairs $(\mathcal{O},\mathcal{I})$ which do not admit a DGA structure on minimal projective resolutions of $\mathcal{O}/\mathcal{I}$ [Kat19]. The results of Katthan, as well as other examples can be systematically obtained through the homotopy trasfer of symmetric algebra structure of the arborescent Koszul-Tate resolution. The other work that was partially done during the ESI stay was comparing the construction of [CK12] to ours. In [CK12] the authors present a particular algebra resolution by means of a cobar construction of a certain A_∞ coalgebra of ”dots and brackets”. We expect that an arborescent Koszul-Tate resolution can be viewed as a quotient costruction of [CK12] at least for a class of examples. The ongoing work was discussed with Dr. Salnikov, Prof. Kotov, Prof. Strobl and Prof. Sharygin, whose ideas helped to improve the overall understanding. The summary of our work in progress I presented in a talk at ESI. I am grateful to the organizers of the workshop ”Higher Structures and Field Theory” for that opportunity.

During the fellowship together with Prof. Strobl we finalized the details of a joint preprint *BFV extensions for mechanical systems with Lie-2 symmetry*, which is now published. I benefited as well from the discussions of this work with Prof. Grigoriev and Prof. Skvortsov.

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Publications and preprints contributed

A.Hancharuk, T. Strobl, *BFV extensions for mechanical systems with Lie-2 symmetry*, arXiv:2104.12257[hep-th], Phys. Rev. D 107, 025014.

Sudipta Dutta: Holography of Asymptotically flat spacetimes

Sudipta Dutta (IIT Kanpur): September 1 – December 31, 2022

Report

The principal purpose of my research visit to the ESI was to investigate the aspects of holographic dualities for asymptotically flat spacetimes. One of the long-standing candidates for holographic duals for flat spacetimes are Carrollian conformal field theories that lives on the null boundary of flat spacetimes [1-3]. Carroll symmetry arises in the intrinsic geometry of generic null surfaces replacing the usual Poincare algebra. The degrees of freedom attached to null hypersurfaces are thus Carrollian in nature. As the null hypersurfaces are omnipresesent in thoeries of gravity, the studies of these Carrollian field theories are interesting for its own right. Apart from its inevitable role in flat holography, these Carrolian symmetries have also found universal applications in diverse situations ranging from black hole horizons to condensed matter systems with vanishing Fermi velocities [4-6]. During my stay in Vienna I have focussed on investigating features of these Carrollian versions of conformal field theories which resulted to the following publications:

1 **Carroll fermions in 2d**
In this work, we concentrate on fermions living on two dimensional (2d) null manifolds and explore the Carroll invariant structure of the associated field theories in a systematic manner. The free massless versions of these fermions are shown to exhibit 2d Conformal Carroll or equivalently the 3d Bondi-Metzner-Sachs (BMS) algebra as their symmetry.

Due to the degenerate nature of the manifold, we show the presence of two distinct classes of Clifford Algebras. We also find that in two dimensions there are two distinct fermion actions. We study discrete and continuous symmetries of both theories, and quantize them using highest weight representation of the vacuum. We also discuss how the symmetries of 2d free fermion CFTs can be continually deformed by infinite boosts or degenerate linear transformations on coordinates, leading to the corresponding BMS invariant theory at singular points.

2 **Stress tensor of 3d Carrollian CFT**

In this work, we have discussed kinematical features of conformal Carroll field theories in three dimensions (3d). Conformal extension of Carroll algebra is infinite dimensional even in 3d unlike its relativistic counterpart, and hence 3d Carroll CFTs share similarities with 2d CFT. We provide a construction for the conserved charges for Carrollian CFTs and an expression for stress tensor OPEs consistent with the algebra of charges. We discuss a free field model where these symmetries are realised and explicitly compute the OPEs verifying our construction. In addition we comment on the possibility of extending the conformal symmetries to diffeomorphisms of spatial slice for these Carrollian theories.

Apart from the abovementioned projects, during my stay at the ESI, I have also started working on aspects of null branes and associated worldvolume theory. This project is being carried out in collaboration with Prof. Daniel Grumiller. Carroll symmetries have also appear in the context of null strings or branes in general [7]. As the tension of a brane is dialled down to zero, it induces a Carrollian limit on the worldvolume theory. Recently this construction of quantised null worldsheet has been found to be relevant in the context of black holes. In [8] it has been proposed that the spectrum of a null string wrapping the horizon of a BTZ black hole has the right microstates that gives rise to the precise entropy formula, along with the first logarithmic correction. This result bring together the near horizon symmetry consideration and the stringy origin of non-extremal black hole microstates. It would be really interesting to test this idea for more realistic four dimensional black holes where the horizon is a 3d null hypersurface. In this ongoing project we intend to use the techniques of 3d Carrollian CFT in the context of null branes and investigate its possible connection with black hole microstates in higher dimensions.

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Acknowledgement

I would like thank Prof. Daniel Grumiller for being my mentor during my visit at the ESI. I also thank the secretaries of both the ESI and TU Wien for helping me out with various non academic aspects.

Publications and preprints contributed

A. Banerjee, S. Dutta, S. Mondal, *Carroll fermions in two dimensions*, arXiv:2212.11002[hep-th].

S. Dutta *Stress tensors of 3d Carroll CFTs* arXiv:2212.11002 [hep-th].

Barbara Bošnjak: The unitarizability problem through Arthur packets

Barbara Bošnjak (U Zagreb): April 4 – July 3, 2022 and September 1 – October 1, 2022

Report

The project I worked on during my stay at the Erwin Schrödinger Institute fits into a web of far-reaching conjectures of *the Langlands program*. Conjectures of the Langlands program specify how some of the fundamental objects of arithmetics can be characterized by harmonic analysis on algebraic groups. An important part of the Langlands program is *the local-global principle*, which connects two aspects of the programme. Namely, the global objects of interest, called *automorphic representations*, decompose as a restricted product of irreducible representations of a local type.

Problems within this project belong to the local representation theory. Let us denote by G a reductive algebraic group defined over a local non-archimedean field F. The fundamental question of the local representation theory is the classification of the unitary dual $\hat{G}$. This problem was solved in the case of a general linear group by M. Tadić in [4], whereas it remains open for groups $Sp_{2n}(F)$ and $SO_{2n+1}(F)$, shortly denoted by G_n. The basic building blocks of the unitary dual of a general linear group are *the essentially Speh representations*. A conjecture, which predicts the building blocks of the unitary dual of the group G_n, says that they should be irreducible subquotients of the following parabolically induced representation

$$\pi_1 \times \pi_2 \times \ldots \times \pi_k \rtimes \pi_A. \tag{1}$$

Here π_i, for $i = 1,2,\ldots,k$, denote essentially Speh representations and π_A denotes a representation of Arthur type. One can see a representation of Arthur type as an analogue of a Speh representation, since both are local factors of square-integrable automorphic representations. C. Mœglin established their explicit representation-theoretic construction (see e.g. [3]) and H. Atobe continued the study in paper [1].

The aim of the pursued project is to understand the reducibility and irreducible subquotients of the induced representation (1). Namely, even though the representation (1) is induced by irreducible representations, it is generally not irreducible. My work on this topic as ESI's Junior Research Fellow can be divided into two parts.

I have finished writing two papers, which are both accepted for publication. The first one consists of a part of the results from my PhD thesis, while the other is a new collaboration with my PhD advisor prof. Ivan Matić. Both papers deal with the representation of the form (1) in special cases. Namely, we take π_A to be a supercuspidal representation, which is an important class of representations of Arthur type. Moreover, we consider only one essentially Speh representation on the general linear part of the induction and denote the representation (1) with $\pi \rtimes \sigma_c$.

In the joint paper with Prof. Matić, we determined when the induced representation $\pi \rtimes \sigma_c$ contains a discrete series subquotient. We also identified all discrete series subquotients. Besides being interesting by itself, the existence of such subquotients usually presents one of the crucial steps towards the description of all irreducible composition factors of representation $\pi \rtimes \sigma_c$. In the other paper, I completed the description of all irreducible subquotients of the representation $\pi \rtimes \sigma_c$, when π is defined with two segments in terms of the Langlands classification.

The main topic of my research stay was to prove the following claim:

$$\text{The induced representation } \pi_1 \times \ldots \times \pi_k \rtimes \pi_A \text{ is irreducible if and only if}$$
$$\text{the representations } \begin{cases} \pi_i \times \pi_j \\ \pi_i \times \widetilde{\pi}_j \\ \pi_i \rtimes \pi_A \end{cases} \text{ are irreducible for all } i, j \in \{1, 2, \ldots, k\}.$$

This is still a work in progress with Prof. Alberto Mínguez at the Faculty for Mathematics, University of Vienna. Using the machinery of the extended multi-segments developed by H. Atobe, we were able to prove the claim in case π_i, for $i = 1, 2, \ldots, k$, are Speh representations. For the general case of essentially Speh representations, we use the results of H. Atobe from paper [2]. There he gives a description of irreducible subrepresentations and the irreducibility criterion in the case of one essentially Speh representation.

During my research stay, I also participated in the conference *"Minimal Representations and Theta Correspondence"*, at The Erwin Schrödinger International Institute for Mathematics and Physics (ESI), Vienna, Austria, 11 - 15 April 2022.

Publications and preprints contributed

B. Bošnjak, *Composition series and unitary subquotients of representations induced from essentially Speh and cuspidal representations*, accepted for publication in *Journal of Lie Theory*, p.38 (2022)

B. Bošnjak, I. Matić, *Discrete series and the essentially Speh representations*, accepted for publication in *Journal of Algebra*, p.21 (2022)

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Vincentas Mulevicius: Defects in Douglas-Reutter 4-dimensional TQFT

Mulevicius (U Hamburg): October 1 – December 21, 2022

Report

The concept of a defect in a field theory is used to describe a variety of phenomena: phase transitions, domain walls, boundary conditions, etc. This project aimed at exploring defects in topological quantum field theories (TQFTs). Mathematically, such theories admitting defects can be formalised as symmetric monoidal functors $Z^{\text{def}}\colon \text{Bord}_n^{\text{def}}(\mathbb{D}) \longrightarrow \text{Vect}_{\mathbb{C}}$, where $\text{Bord}_n^{\text{def}}(\mathbb{D})$ is the category of n-dimensional stratified bordisms, with strata carrying labels from a predetermined set $\mathbb{D}$ (see [CRS1] for details). An illustrative example is that of 1-dimensional defect TQFTs in which bulk theories (1-strata) are labelled by finite dimensional vector spaces and point defects (0-strata) by linear maps.

Naturally, as the dimension n of the bordisms (i.e. spacetime manifolds) increases, the examples of TQFTs and their counterparts with defects become more difficult to come by. Most of the previously studied examples are 2- and 3-dimensional, e.g. 2- and 3-dim. state-sum models [DKR, Meus], 2-dim. Landau–Ginzburg models [CM], 3-dim. Reshetikhin–Turaev models [CRS2, KMRS]. A promising entry into the study of 4-dimensional TQFTs is constituted by the introduction of state-sum type invariants of 4-manifolds due to Christopher Douglas and David Reutter in [DR]. The intent of this project was to initiate a programme to turn these invariants into a fully-fledged 4-dimensional state-sum TQFT admitting defects. In that regard, together with Nils Carqueville and Lukas Müller, we have made a decent progress which can be summarised as follows:

1. We have defined the trivial 4-dimensional defect TQFT, i.e. a TQFT that only has vacuum bulk theory, but can have non-trivial defects of higher codimension. The definition is based on the observation that state-sum models in particular can be generalised to manifolds with singular regions - a defect network in vacuum can then be interpreted as such a singular manifold and evaluated with the lower (in this case 3-) dimensional state-sum defect TQFT. We have also extracted the general idea behind this construction, which potentially can be applied to higher dimensions and work for TQFTs beyond the state-sum construction.

2. We have proved that the Douglas–Reutter invariants extend to a 4-dimensional TQFT $\text{Bord}_4 \longrightarrow \text{Vect}_{\mathbb{C}}$ (at this point without defects). This was achieved by showing that one can obtain them as a so-called *generalised orbifold* [CRS1] of the aforementioned trivial defect TQFT. Generalised orbifold of a defect TQFTs Z^{def} is a construction providing one with a new (ordinary) TQFT, which roughly works by filling a given bordism with a network of defects - a foam - end then evaluating it with Z^{def}. This yields a well defined TQFT provided that the evaluation does not depend on the foam, which can be achieved if the labels are taken from a specific subset $\mathcal{A} \subseteq \mathbb{D}$ called an *orbifold datum*. The algebraic input for the Douglas–Reutter invariants - a spherical fusion 2-category - happens to yield an instance of such an orbifold datum for the defect TQFT in . This is analogous to the situation in dimension 3, where the state-sum models - TQFTs of Turaev–Viro–Barrett–Westbury type - are generalised orbifolds of the trivial 2-dimensional TQFT, with the orbifold datum obtained from the corresponding algebraic input - spherical fusion (1-)category [CRS3].

3. In dimension 3, the state spaces assigned to a surface Σ by the state-sum TQFTs are known to be isomorphic to the so-called string-net spaces. These are defined as the linear span of all string diagrams labelled by objects and morphisms of the input spherical fusion (1-)category, embedded into Σ, modulo the composition relations. We have shown that a similar statement holds for the Douglas–Reutter TQFTs as well: the state spaces assigned to a 3-manifold M are spans of surface diagrams whose components are labelled by the objects, 1- and 2- morphisms of the input spherical fusion 2-category, modulo compositions of 1- and 2-morphisms.

4. TQFTs obtained from the generalised orbifold construction have canonical domain walls defined by terminating the foam at them. Having achieved objective opened us the possibility to apply this observation to the Douglas–Reutter type theories, thereby obtaining the first instances of defects in them. In particular, we looked at the example where the spherical fusion 2-category is $B\mathcal{C}$ - the delooping of a modular fusion category $\mathcal{C}$. The bulk theory in this case is the invertible TQFT of Crane–Yetter type, while the 3-dimensional boundary theory is known to be the Reshetikhin–Turaev type theory. Our approach puts this known fact into a general framework and allows further generalisations, for example we expect the Reshetikhin–Turaev *defect* TQFT [CRS2] to be obtained as a boundary theory of the one obtained from the idempotent completion of $B\mathcal{C}$.

Overall, I found my research stay very well organised and enjoyable. I am particularly thankful to the ESI administration for the hospitality and the opportunity to participate in the numerous scientific events held locally and to Emmanuele Battista, Nils Carqueville, Stefan Fredenhagen, Ruth Fröler, L Glaser, Harold Steinacker and Lóránt Szegedy for discussions and involvement in the activities of the Mathematical Physics' group.

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ESI Special Research Fellowship for Ukrainian Scientists

Vira Niestierkina: Influence of defects on radiative relaxation of halide and oxide scintillators

Vira Niestierkina (National Academy of Sciences of Ukraine, Kharkiv): April 1 – July 31, 2022

Report

Previous long-term studies [1] showed that the presence of structural defects in crystals invariably leads to a change in the optical characteristics of materials. Research was aimed at obtaining an ideal crystal for use as an effective detector of ionising radiation. The requirements for the properties of crystals vary significantly depending on the application and are not always completely satisfied. In this work, it is shown that the presence of certain point defects in the crystal structure can be useful for purposefully changing the optical properties of a material.

The current project is a deeper study of the role of structural defects (intrinsic and impurity) on the luminescent and scintillation properties of crystals. Introduction of additional ions into host leads to crystal lattice changes and defects appearance. The presence of these defects may reduce or increase the efficiency of energy transfer to luminescence centres and make worse or improve scintillation properties of crystals. The aim of the research work was to determine the specifics of the influence of crystal structure defects on the processes of energy conversion in some halide (BaF_2 and NaI) and oxide ($Y_3Al_5O_{12}$) dielectric compounds.

Representatives of three different compounds were chosen as research objects: fluoride (BaF_2), oxide ($Y_3Al_5O_{12}$) and iodide (NaI). Fluorides and garnets were grown by the Czochralski method. Sodium iodide was obtained by the Bridgman-Stockbarger method in a quartz ampoule.

BaF_2 is a widely known superfast scintillator [2]. It exhibits core-valence (CV) emission with decay time less than 1 ns and luminescence of self-trapped excitons (STE) with decay time $\sim$ 700 ns. Unfortunately, because of low CV intensity, it is difficult to obtain a scintillator with a large quantum yield. It was found that the introduction of Lu^{3+} ions in BaF_2 scintillators allows suppressing the slow STE luminescence, while the efficiency of ultrafast CV transitions does not change. This decrease in the STE emission output of Lu^{3+} doped crystals is due to the change in the number of free charge carriers, which can create exciton by successive capture on the impurity. The introduction of a triple valence impurity leads to the appearance of interstitial fluoride ions in order to compensate for the excess charge. In the future, the most important role in the processes of energy exchange and accumulation is played by interstitial fluorine ions, fluorine vacancies, impurity centers and their aggregates.

Along with defects associated with the presence of activator ions, there are also defects of stoichiometry deviations. The influence of such defects on the optical properties was studied using the yttrium-aluminum garnet (YAG) crystals ($Y_3Al_5O_{12}$), which are also promising scintillation materials [3]. The high temperature of melting (1940^oC) leads to the appearance of crystal lattice defects: anion and cation vacancies, their aggregates, antisite defects, as well as electron and hole color centers. Samples of crystals were obtained that were grown under different conditions and had different stoichiometric composition and content of defects. It is shown that the presence of internal and external structure defects, even in small amount, leads to the appearance of additional energy dissipation channels in YAG, which significantly changes the optical and scintillation properties of garnets. The possibility of obtaining high light yield for pure $Y_3Al_5O_{12}$ crystals is shown. Controlling the purity of raw materials, growth conditions and subsequent heat treatment can reduce the concentration of structural defects associated with stoichiometry deviation.

Scintillators based on iodide matrices are traditionally considered the most promising. Parameters that require improvement are the energy resolution and also the decay time for some applications. The issue is also the possibility of reaching the theoretical limit of light output. The long-term studies of NaI and NaI:Tl [4] scintillation crystals showed that their properties are determined by their high hygroscopicity and the associated presence of oxygen and oxygen-containing impurities. Ca^{2+} ions have a high affinity for oxygen ions. Ca^{2+} ions can reduce the concentration of oxygen-containing impurities in NaI and NaI:Tl. It is also shown that co-doping of NaI crystals with Tl^{+} and Ca^{2+} improves the energy resolution up to 6%

The practical significance of the work is in the fact that the research results show the possibility of a directed change in the properties of alkaline and alkaline-earth halides and oxides by controlling their defect structure. This approach is the basis for similar researching for a wider range of dielectric systems.

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Ivan Kyrchei: Quaternion algebras and their application in the study of quaternion generalized inverse matrices

Ivan Kyrchei (National Academy of Sciences of Ukraine, Lviv): April 12 – June 12, 2022

Report

A generalized inverse of a matrix is a matrix that can serve as an inverse in some sense for a wider class of matrices than invertible matrices. Let $\mathbb{H}^{m\times n}$ present the set of all $m \times n$ matrices over the quaternion skew field

$\mathbb{H}=\{h_0+h_1\mathbf{i}+h_2\mathbf{j}+h_3\mathbf{k}\mid \mathbf{i}^2=\mathbf{j}^2=\mathbf{k}^2=\mathbf{ijk}=-1, h_0,h_1,h_2,h_3\in\mathbb{R}\}$.

Due to noncommutativity in the quaternion skew field, for arbitrary $\mathbf{A}\in\mathbb{H}^{m\times n}$, it has meaning to define its right and left column spaces, $\mathcal{C}_r(\mathbf{A})$ and $\mathcal{R}_l(\mathbf{A})$, and its right and left null spaces, $\mathcal{N}_r(\mathbf{A})$ and $\mathcal{N}_l(\mathbf{A})$. Generalized inverses are extended to quaternion matrices considering their features. *The Moore-Penrose (MP-)inverse* of $\mathbf{A}\in\mathbb{H}^{n\times m}$ is the unique solution $\mathbf{A}^{\dagger}:=\mathbf{X}$ that satisfies Penrose's equations:

(1) $\mathbf{A}=\mathbf{AXA}$, (2) $\mathbf{X}=\mathbf{XAX}$, (3) $\mathbf{AX}=(\mathbf{AX})^*$, (4) $\mathbf{XA}=(\mathbf{XA})^*$.

Outer inverses satisfy only Eq. (2). The *Drazin (D-)inverse* of $\mathbf{A}\in\mathbb{H}^{n\times n}$ is the unique $\mathbf{A}^D:=\mathbf{X}$ determined by Eq. (2) and the following $\mathbf{A}^k=\mathbf{XA}^{k+1}$, $\mathbf{XA}=\mathbf{AX}$, where $k=\operatorname{Ind}(\mathbf{A})=\min\{k\in\mathbb{N}\cup\{0\}\mid \operatorname{rank}(\mathbf{A}^k)=\operatorname{rank}(\mathbf{A}^{k+1})\}$. If $\operatorname{Ind}(\mathbf{A})\leq 1$, then $\mathbf{A}^D$ reduces to the *the group inverse* $\mathbf{A}^{\#}$. The core-EP inverse was presented over quaternion skew field [1] similarly as in [2] but with features of quaternionic vector spaces. The *core-EP (CEP)-inverse* $\mathbf{A}^{\circledcirc}:=\mathbf{X}$ of $\mathbf{A}\in\mathbb{H}^{n\times n}$ is the unique matrix satisfied Eq.(2) and $\mathcal{C}_r(\mathbf{X})=\mathcal{C}_r(\mathbf{A}^D)=\mathcal{R}_l(\mathbf{X})$. Combinations of the MP-inverse, the D-inverse, the CEP-inverse, and others induce new generalized inverses that have their special characterizations, representations, and applications as tools in solving matrix equations. In particular, the representations of DMP-, MPD-, CMP-, MPCEP-, and CEPMP-inverses are, respectively, as follows, $\mathbf{A}^{D,\dagger}=\mathbf{A}^D\mathbf{A}\mathbf{A}^{\dagger}$, $\mathbf{A}^{\dagger,D}=\mathbf{A}^{\dagger}\mathbf{A}\mathbf{A}^D$, $\mathbf{A}^{c,\dagger}=\mathbf{A}^{\dagger}\mathbf{A}\mathbf{A}^D\mathbf{A}\mathbf{A}^{\dagger}$, $\mathbf{A}^{\dagger,\circledcirc}=\mathbf{A}^{\dagger}\mathbf{A}\mathbf{A}^{\circledcirc}$, and $\mathbf{A}_{\circledcirc,\dagger}=\mathbf{A}_{\circledcirc}\mathbf{A}\mathbf{A}^{\dagger}$. One of direct methods of constructions of generalized inverse matrices are their determinantal ($\mathfrak{D}$-)representations. In the case of quaternion matrices, the problem of defining a determinant with noncommutative entries arises. This problem is solved by the theory of column and row noncommutative determinants recently developed by the author in [3]. For arbitrary quaternion matrix $\mathbf{A}=(a_{ij})\in\mathbb{H}^{n\times n}$, there exist an exact technique to generate n row $\mathfrak{R}$-determinants, $\operatorname{rdet}_i\mathbf{A}$, and n column $\mathfrak{C}$-determinants, $\operatorname{cdet}_i\mathbf{A}$ for all $i=1,\dots,n$, by stating a certain order of factors in each term of determinants. All quaternionic $\mathfrak{R}$- and $\mathfrak{C}$-determinants are different, in general. But for a Hermitian matrix, they match each other and are a extension of Moore's determinant defined only for Hermitian matrices [4]. Using $\mathfrak{R}$- and $\mathfrak{C}$-determinants, $\mathfrak{D}$-representations of various generalized inverses were obtained. For example [5], for $\mathbf{A}\in\mathbb{H}_s^{n\times n}$ with $\operatorname{Ind}(\mathbf{A})=k$ and $\operatorname{rank}(\mathbf{A}^k)=s_1$ its MPCEP-inverse $\mathbf{A}^{\dagger,\circledcirc}=\left(a_{ij}^{\dagger,\circledcirc}\right)$ can be componentwise represented as

$$a_{ij}^{\dagger,\circledcirc}=\frac{\sum\limits_{\alpha\in I_{s_1,n}\{j\}}\operatorname{rdet}_j\left(\left(\mathbf{A}^{k+1}\left(\mathbf{A}^{k+1}\right)^*\right)_{j.}\left(\mathbf{v}_{i.}^{(1)}\right)\right)_{\alpha}^{\alpha}}{\sum\limits_{\beta\in J_{s,n}}\left|\mathbf{A}^*\mathbf{A}\right|_{\beta}^{\beta}\sum\limits_{\alpha\in I_{s_1,n}}\left|\mathbf{A}^{k+1}\left(\mathbf{A}^{k+1}\right)^*\right|_{\alpha}^{\alpha}}=\frac{\sum\limits_{\beta\in J_{s,n}\{i\}}\operatorname{cdet}_i\left(\left(\mathbf{A}^*\mathbf{A}\right)_{.i}\left(\mathbf{u}_{.j}^{(1)}\right)\right)_{\beta}^{\beta}}{\sum\limits_{\beta\in J_{s,n}}\left|\mathbf{A}^*\mathbf{A}\right|_{\beta}^{\beta}\sum\limits_{\alpha\in I_{s_1,n}}\left|\mathbf{A}^{k+1}\left(\mathbf{A}^{k+1}\right)^*\right|_{\alpha}^{\alpha}},$$

where

$$\mathbf{v}_{i.}^{(1)}=\left[\sum_{\beta\in J_{s,n}\{i\}}\operatorname{cdet}_i\left(\left(\mathbf{A}^*\mathbf{A}\right)_{.i}\left(\widetilde{\mathbf{a}}_{.l}\right)\right)_{\beta}^{\beta}\right]\in\mathbb{H}^{1\times n},\ l=1,\dots,n,$$

$$\mathbf{u}_{.j}^{(1)}=\left[\sum_{\alpha\in I_{s_1,n}\{j\}}\operatorname{rdet}_j\left(\left(\mathbf{A}^{k+1}\left(\mathbf{A}^{k+1}\right)^*\right)_{j.}\left(\widetilde{\mathbf{a}}_{f.}\right)\right)_{\alpha}^{\alpha}\right]\in\mathbb{H}^{n\times 1},\ f=1,\dots,n,$$

and $\widetilde{\mathbf{a}}_{.l}$ and $\widetilde{\mathbf{a}}_{f.}$ are the lth column and the fth row of $\widetilde{\mathbf{A}}=\mathbf{A}^*\mathbf{A}^{k+1}(\mathbf{A}^{k+1})^*$.

According to the denotations, $\mathbf{A}_{.j}(\mathbf{a}_{.i})$ ($\mathbf{A}_{i.}(\mathbf{a}_{j.})$) mean matrices formed by replacing jth column (resp. ith row) of $\mathbf{A}$ by its ith column $\mathbf{a}_{.i}$ (resp. by its jth row $\mathbf{a}_{j.}$), and $(\mathbf{A})_{\alpha}^{\alpha}$ $\left((\mathbf{A})_{\beta}^{\beta}\right)$ – principal submatrices of $\mathbf{A}$ with rows indexed by $\alpha:=\{\alpha_1,\dots,\alpha_k\}\in I_{k,m}\subseteq\{1,\dots,m\}$ (resp. with columns by $\beta:=\{\beta_1,\dots,\beta_k\}\in J_{k,n}\subseteq\{1,\dots,n\}$). Obtained $\mathfrak{D}$-representations of generalizes inverses allow to give Cramer-type solution of quaternion matrix equations with related constrains of solution spaces and Sylvester-type matrix equations. Proposed approach retains its novelty in the case of complex matrices.

Many thanks to ESI (U of Vienna) for support and the given opportunity to work under a peaceful sky in Vienna.

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Volodimir Simulik: New approach to relativistic quantum mechanics and field theory of arbitrary spin

Volodimir Simulik (National Academy of Sciences of Ukraine, Kiev): April 20 – June 20, 2022

Report

Relativistic wave equation of motion without redundant components for the particle having spin 3/2 has been considered [1, 2]. In order to show the newness a comparison with the known equations for the spin $s = 3/2$ field is given. Therefore, the brief review of the relativistic wave equations for the particle with spin $s = 3/2$ is suggested. In our equation the wave function for the particle-antiparticle doublet contains only 8 components. The consideration is carried out both at the level of relativistic quantum mechanics and at the level of local field theory [3]. The extended Foldy–Wouthuysen transformation, which gives the operator link between these two levels is suggested.

In order to simplify the formalism for the particle with spin $s = 3/2$ of [1–3] the development of new mathematical methods was carried out. The proposed mathematical objects allow generalisation of our results, obtained earlier in [3] for the standard Dirac equation, for equations of higher spin and, especially, for equations, describing particles with spin 3/2. The 256-dimensional representations of the Clifford algebras $C\ell^{\mathbb{R}}(0,8)$ and $C\ell^{\mathbb{R}}(1,7)$ in terms of 8×8 Dirac γ matrices are introduced. The corresponding gamma matrix representations of 45-dimensional SO(10) and SO(1,9) algebras, which contain standard and additional spin operators, are introduced as well. The SO(10), SO(1,9) and the corresponding $C\ell^{\mathbb{R}}(0,8), C\ell^{\mathbb{R}}(1,7)$ representations are determined as algebras over the field of real numbers in the space of 8-component spinors. Relationships between the suggested representations of the SO(m,n) and Clifford algebras are investigated. The role of matrix representations of such algebras in the quantum field theory is briefly considered. Comparison with the correspondent algebras in the space of standard 4-component Dirac spinors is demonstrated. The maximal 84-dimensional pure matrix algebra of invariance of the 8-component Dirac equation in the Foldy–Wouthuysen representation is found. The corresponding symmetry of the Dirac equation in ordinary representation is found as well. The manuscript containing these results is under consideration [4] in Advances in Applied Clifford Algebras.

Staying in ESI I published two papers and collaborated online and offline with few known scientists. Our goal is to submit for ESI the project to ESI Programme "'Research in Teams"'. I had also few scientific workshops and discussions with Dr. Harold C. Steinacker on the alternative theories of gravity and spin 2 fields (Department of Physics, University of Vienna).

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V.M. Simulik, I.I. Vyikon. On the choice of relativistic wave equation for the particle having spin s = 3/2, J. Phys. Comm. 2022, Vol. 6, is. 7, p. 075008(1–7).

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V.M. Simulik, I.I. Vyikon. On the Representations of Clifford and SO(1,9) Algebras for 8-Component Dirac Equation, Adv. Appl. Clifford Algebras (2023) 33:53, ©The Author(s), under exclusive licence to Springer Nature Switzerland AG 2023, https://doi.org/10.1007/s00006-023-01295-7.

Anna Kosogor: The spin-wave contribution to the specific heat of Heusler alloys

Anna Kosogor (National Academy of Sciences of Ukraine, Kiev): May 23 – July 23 and August 8 – October 8, 2022

Report

The aim of the project was the elaboration of theoretical approach for the quantitative description of specific heat capacity for the magnetic solids, exhibiting magnetic and magnetostructural phase transitions. Indeed, the accurate estimation of heat capacity is needed for the description of magnetocaloric effect (MCE), which is promising alternative to the traditional cooling technology based on the vapor compression [1]. Magnetic refrigeration can play a key role in global efforts to improve the energy efficiency of temperature control. The giant magnetocaloric effect is linked to magnetic and magnetostructural phase transitions in solids. However, accurately measuring the MCE value can be difficult due to hysteresis phenomena and the limitations of applicability of thermodynamic Maxwell relations for first-order phase transitions. Estimating the MCE from heat capacity data is considered to be more reliable [1].

During the project fulfillment the theoretical approach for the quantitative description of anomaly of specific heat capacity during the field- and temperature-induced ferromagnetic to antiferromagnetic phase transitions was elaborated. To this end the phenomenological Landau-type theory of phase transitions was used. The theory starts from the consideration of magnetic part of Gibbs free energy density of antiferromagnetic solid with two equivalent magnetic sublattices [2]. The minimization of this energy allows the computation of magnetic-filed-induced entropy change and specific heat capacity from the basic thermodynamic equations. This approach allows the computation of the magnetocaloric effect without use of magnetic Maxwell relations.

The magnetic and magnetostructural phase transitions usually are accompanied by the peaks of specific heat capacity, which strongly depend on temperature and magnetic field [3]. It has been shown that disregard of this dependence leads to the noticeable overestimation of adiabatic temperature change. Moreover, it is shown that simplified equation, which is often used for the estimation of MCE, gives improper results if the dependence of specific heat capacity on magnetic field and temperature is ignored.

The developed approach was applied for the description of isostructural antiferromagnetic-ferro-magnetic phase transition in Fe-Rh alloy, which is one of the most promising materials for magnetic refrigeration [4] and also is attractive for use in heat-assisted magnetic recording. It has been shown that application of magnetic field decreases the temperature of antiferromagnetic-ferromagnetic phase transition in Fe-Rh with the rate of 8.75 K/T, which is very close to the experimentally observed value of 8.5 K/T [5]. The specific heat capacity allows rigorous estimation of adiabatic temperature change during magnetic phase transition in Fe-Rh. For considered Fe49Rh51 alloy the computed adiabatic temperature change, induced by application of magnetic field of 2 T, is equal to 6.5 K. This value is significantly different from value of 10 K, which is obtained without accounting temperature dependence of specific heat, inherent to Fe-Rh alloys in the vicinity of magnetic phase transition. The reasonable agreement between theoretical results and available experimental data is demonstrated. It can be concluded, therefore, that the magnetic component of specific heat capacity must be considered for the accurate computation of magnetic-field-induced temperature change. Ignoring this component will lead to an incorrect evaluation of MCE.

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Publications and preprints contributed

The article *Calculation of magnetocaloric effect with regard for dependence of heat capacity on magnetic field* by A. Kosogor, V.A. Lvov was submitted to the Scientific Reports journal.

A. Kosogor, V. A. Lvov, R. Y. Umetsu, X. Xu, R. Kainuma, *Strong influence of magnetic order on the low-temperature specific heat of Heusler alloys*, Books of Abstracts of 12th International Conference on Nanomaterials: Applications & Properties 2022 (Krakow, Poland, 11-19 September, 2022), p. 07nmm-23.

Valeri Lozovski: The self-consistent description of plasmon-assisted Brillouin Light Scattering (BLS) spectroscopy

Valeri Lozovski (Taras Shevchenko National University Kiev): June 6 - August 6, 2022

Report

Optical studies of magnetic systems are non-destructive, provides high sensitivity and thus, are perspectives. The methods based on the scanning optical microscopy can provide the high space resolution. An important feature of magnetic-optical studies is that they do not require magnetic probes and thus do not affect the magnetic structure of the studied systems. The most important is that optical studies can be carried out in external magnetic fields. Brillouin light scattering (BLS) is well established a very powerful tool to investigate the magnetization dynamics in different ferromagnetic nanostructures. To enhance the Brillouin scattering of light intensity and obtain acceptable resolution we propose to use the elements of technique of apertureless scanning near-field optical microscopy (a-SNOM) and local-field enhancing effect in nano-plasmonic systems. Using the apertureless probe scanning along the surface with nanoplasmonic structure, one can achieve a high resolution when the reflected field being measured. Thus, development of the theoretical approach to describe Brillouin scattering of light intensity was the main aim of the staying in ESI in 2022. The general approach to calculate the characteristics of BLS from the probing Gauss-like beam was developed. The approach was based on the method used in Ref.[1], where the theory of far- and nearfield second-harmonic scanning optical microscopy of molecular quasione-dimensional aggregates, such as molecular nanoneedles, was modeled in the frame of the effective susceptibility concept formulated beyond the near-field approximation. Using the approach, as a first step for the studies, we calculate the polarization state of BLS light caused by magnon-photon interaction. The experimental setup using in Ref.[2] is shown in Fig.1.

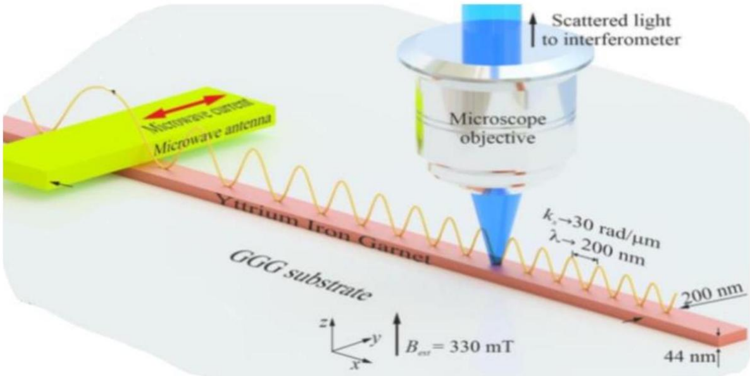

Figure 1: Experimental setup for calculations [2] (with the author's permission)

We consider the two-interface model consisting of a dielectric substrate at which the thin (~ 40 nm) magnetic film is situated. Due to back-scattering of BLS light, the nonzero pulse of scattered light directed along OX axis forms the anisotropy of the system. The photon-magnon scattering leads to BLS at frequency $\bar{\omega} = \omega - \Omega$, where ω is the frequency of incident light, Ω is the frequency of magnon. The wave vector of magnon equals to $k_m = \eta k_0$, which corresponds to wavelength $\lambda_m = 200$ nm. k_0 is the wave vector of the light corresponding to the light wavelength $\lambda_0 = 457$ nm. We consider the forward volume spin waves (FVSWs) case, in which the magnetization has been dragged to out-of-plane. In this case, the z-component of dynamic magnetization is zero ($m_z = 0$) and the relationship between x-and y-component is $m_x = im_y$ assuming circular precession, that means that inducing the electrical dipole momentum directed along OZ axis $-P_z$. This oscillating dipole momentum is the reason of the BLS signal. The dipole momentum induces the electrical field at the detector

$$E_i(R_d) = -\bar{\omega}^2 \mu_0 \int_{V_p} d\mathbf{R}' G_{iz}(\mathbf{R}, \mathbf{R}') P_z, \quad i = x, y,$$

where $G_{iz}(\mathbf{R}, \mathbf{R}')$ is a photon propagator describing the light propagation in the environment, and x component of electric field inside the film E_x. This field in turn, induces the dipole momentum $P_x = \varepsilon_0 \chi_{xx} E_x$ inside the film (χ_{xx} is the effective susceptibility of thin film). The dipole P_x induces the addition part of scattered field directed along OX

$$E_x(R_d) = -\bar{\omega}^2 \mu_0 \int_{V_p} d\mathbf{R}' G_{xx}(\mathbf{R}, \mathbf{R}') P_x.$$

Thus, the x - and y - components of the field of BLS signal at the detector are

$$E_x(R_d) = -\bar{\omega}^2 \mu_0 \int_{V_p} d\mathbf{R}' G_{xz}(\mathbf{R}, \mathbf{R}') P_z + \bar{\omega}^2 \mu_0 \int_{V_p} d\mathbf{R}' G_{xx}(\mathbf{R}, \mathbf{R}') \bar{\omega}^2 \mu_0 \varepsilon_0 \chi^f_{xx} \int_{V_{\text{int}}} d\mathbf{R}'' G^{NF}_{xz}(\mathbf{R}', \mathbf{R}'') P_z,$$

$$E_y(R_d) = -\bar{\omega}^2 \mu_0 \int_{V_p} d\mathbf{R}' G_{yz}(\mathbf{R}, \mathbf{R}') P_z.$$

The analysis of correlations between these components gives us the characteristic of polarization of scattered light. Particularly, we estimate the characteristics of ellipse of polarization of BLS for the system considered in [2]. The results of the estimations are given in Tabl.1 where one can see the dependence of parameters of ellipse of polarization of BLS (see, Fig.2) on the wave vector of magnon (parameter η) interacting with the photon. Finally, proposed simple model answers the basic questions of experimental results: why in the case of FVSW the BLS signal is observed at the 'fundamental' frequency and why the observed signal is elliptically polarized.

Table 1

η	E'_x/E_y	E''_x/E_y	Ψ	φ	b/a
2.00	0.72	0.16	36.5^0	36.2^0	0.11
2.15	0.74	0.12	36.9^0	36.8^0	0.08
2.30	0.76	0.10	37.6^0	37.5^0	0.07

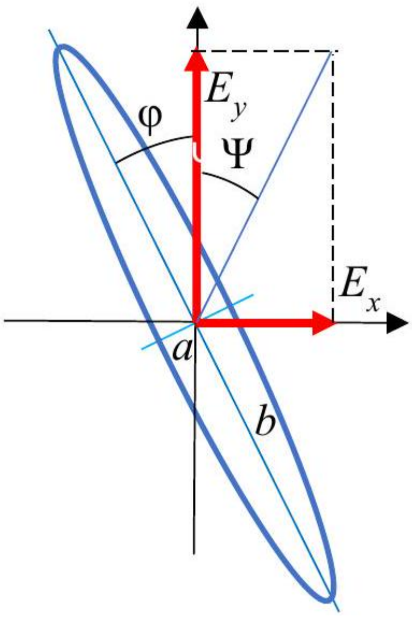

Figure 2: Ellipse of polarization of BLS

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Yurii Sitenko: Quantum effects in the background of a topological defect

Yurii Sitenko (National Academy of Sciences of Ukraine, Kiev): June 30 – August 31, 2022

Report

Scientific background

Topological phenomena are of great interest and importance because of their universal nature connected with general properties of space-time, as well as of their numerous practical applications. Since the discovery of Aharonov and Bohm in 1959, it has become clear that topology has to do with the fundamental principles of quantum theory. A field-theoretical analogue of the quantum-mechanical Aharonov-Bohm effect has been discovered in 1990: vacuum polarization in quantum field theory is shown to depend on geometry and topology of the base space, see [1].

Project aims and scope

At present much attention is paid to the study of nonperturbative effects in quantum systems, arising as a consequence of interaction of quantized fields with various configurations of classical fields. Especial interest is to the investigation of the influence of configurations with nontrivial topology (kinks, vortices, monopoles, or, in general, topological defects) on the properties of quantum systems. There is a need, in this regard, to take account of the finite size of a topological defect and to set up a boundary condition on its edge. Our idea consists in the employment of the most general boundary conditions ensuring the impenetrability of quantized fields into the interior of a topological defect; in mathematical parlance, this means the condition of self-adjointness for the appropriate quantum-mechanical operator of energy. We set the task of discovering effects which are induced by a topological defect in general case in the ground state of quantum matter system. Further analysis and the requirement of physical plausibility of obtained results may restrict the ambiguity in the choice of boundary conditions. In this case, there is an opportunity of the unambiguous determination of effects which are induced by a topological defect in quantum matter, see [2,3]. In the planned research a topological defect in the form of the Abrikosov-Nielsen-Olesen vortex is considered. Such defects are known in cosmology and astrophysics under the name of cosmic strings, they emerge in the aftermath of phase transitions with spontaneous gauge symmetry breaking during evolution of the early Universe. The vortex-type defects are widely discussed in the context of condensed matter physics as well, in particular, they can be viewed as disclinations in graphene-like structures, see [4].

Outcome and results

The relativistic spin-0 matter field is quantized in the background of a straight cosmic string with nonvanishing transverse size. The most general boundary condition ensuring the impenetrability of the matter field into the interior of the cosmic string is shown to be the Robin condition with a boundary parameter varying arbitrarily from point to point of the boundary. The role of the bound states in the spectrum of solutions to the Fock-Klein-Gordon equation is elucidated. We derive, in the general case, an analytic expression for the total magnetic flux which is induced in the vacuum in the cosmic string background. The further numerical analysis and requirement of physical plausibility are shown to restrict an ambiguity which is due to the boundary condition. The dependence of the induced vacuum magnetic flux on the string flux and tension, as well as on the transverse size of the string, is analysed.

Lecture "Self-adjointness and bounded systems in quantum theory" was given on the 3rd of August 2022 (https://www.youtube.com/watch?v=QB_kD- -KFB4).

Perspectives of scientific collaboration with Prof. Christoph Dellago and Prof. Emeritus Harald Grosse from U Vienna were initiated during my stay at ESI.

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Yurii Zhuchok: Endomorphism semigroups and free Loday's structures

Yurii Zhuchok (Luhansk Taras Shevchenko National University): July 11 – November 10, 2022

Report

One of the classic tools for studying the structure and classification of algebraic systems are derivative structures. The most common derivative structures of algebraic systems traditionally include automorphism groups, endomorphism semigroups, congruence lattices and subalgebra lattices. This project was aimed at solving such a fundamental problem as the classification of endomorphism semigroups of algebraic systems up to an isomorphism, as well as to study the properties of such free Loday's structures as dimonoids and trioids [1, 2]. A special attention was devoted to the investigation of relatively free monogenic algebras in the given varieties.

We have constructed a new model of the free commutative monogenic trioid. The obtained model for the free commutative trioid of rank 1 looks more convenient and simpler than the original construction of [3] since all its operations reduce to the ordinary addition and multiplication of non-negative integers. Using the new trioid construction, all endomorphisms of the free commutative monogenic trioid were described and it was proved that the endomorphism semigroup of the free commutative monogenic trioid can be represented as an adjoint semigroup of some natural commutative semiring defined on the trioid. We have shown that the endomorphism monoids of the free commutative monogenic trioids are commutative. In contrast, the endomorphism monoids of the free monogenic ring and the free monogenic trioid [4] are not commutative.

During my stay, we also began to study endomorphisms of free monogenic g-dimonoids to construct a semigroup which is isomorphic to the endomorphism semigroup of the free monogenic g-dimonoid. It should be noted that the construction of the free g-dimonoid of an arbitrary rank first appeared in [5].

Finally, I would like to thank to the whole team of the Erwin Schrödinger International Institute for Mathematics and Physics at the University of Vienna for the organization of a Special Research Fellowship to help Ukrainian scientists.

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Publications and preprints contributed

Yu.V. Zhuchok, *New models for the free commutative monogenic trioid and its endomorphism monoid*, Semigroup Forum 105 (2022), 575–581. https://doi.org/10.1007/s00233-022-10313-2.

Yu.V. Zhuchok, M.Yu. Zmiienko, *On endomorphisms of free g-dimonoids of rank 1*, Abstracts of the International Algebraic Conference *"At the End of the Year" 2022*, Kyiv, Ukraine, December 27–28, p. 64.

Yuliia V. Zhuchok: Free trioids

Yuliia V. Zhuchok (Luhansk Taras Shevchenko National University): August 15 – December 15, 2022

Report

Scientific Background

During the study of planar trees J.-L. Loday and M.O. Ronco [1] introduced a type of algebras, called trialgebras, which are vector spaces endowed with three binary associative operations satisfying eight axioms. See, e.g., [2–4] for more information about trialgebras. A trialgebra is just a linear analog of a trioid [1] and therefore all results obtained for trioids can be applied to trialgebras. A free trioid of rank 1 was given in [1]. Later, A. Zhuchok, the author as well as others obtained the important results on the structure of free objects in the varieties of trialgebras and trioids, namely, they gave explicit structure theorems for the free trioid [5, 6], the free commutative trioid [7], the free n-nilpotent trioid [8], the free left (right) n-trinilpotent trioid

[9], the free rectangular trioid [10], the free abelian trioid [11]. These results develop the variety theory of algebraic structures and some of them can be applied to constructing relatively free trialgebras (see also the survey [12]). Trioids have close relationships with *n*-tuple semigroups. Recall that an *n*-tuple semigroup is an algebra defined on a set with *n* binary associative operations. This notion play a prominent role in the theory of *n*-tuple algebras of associative type.

Outcomes and achievements

One of the central activities of the programme actually concerned the description of the structure of free trioids, some congruences on them and the properties of underlying semigroups of free trioids. At the same time, our attention was aimed to studying the class of *n*-tuple semigroups. We constructed a free *k*-nilpotent *n*-tuple semigroup and characterized the least *k*-nilpotent congruence on a free *n*-tuple semigroup. The obtained results can be applied to trialgebra theory and the theory of *n*-tuple algebras of associative type. During the stay, we also attended scientific seminars, studied literature on semigroup theory and acquainted with Austria algebraic schools.

Acknowledgements

I would like to thank the Erwin Schrödinger International Institute for Mathematics and Physics, University of Vienna, for the organization of a Special Research Fellowship and for the support given.

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Publications and preprints contributed

A.V. Zhuchok, Yul.V. Zhuchok, *Free k-nilpotent n-tuple semigroups*, submitted to the journal.

Anatolii V. Zhuchok: Relatively free trioids and generalized dimonoids

Anatolii V. Zhuchok (Luhansk Taras Shevchenko National University): August 15 – December 15, 2022.

Report

Scientific Background

When Loday and Ronco studied ternary planar trees [1], they introduced a type of algebras, called trioids, which are sets equipped with three binary associative operations satisfying additional eight axioms relating these operations. The theory of trioids (see, e.g., [2–5]) has wide applications in trialgebra theory. Trialgebras were introduced by Loday and Ronco about twenty years ago [1], and during the last years they are of doubtless scientific interest (see, e.g., [1, 6]). Originally, trioids and trialgebras arose in algebraic topology. They have close relationships with Hopf algebras, Leibniz 3-algebras and Rota-Baxter operators. One of the main motivations for the study of trioids is the fact that all results obtained for trioids can be applied to trialgebras. Another reason for our interest in trioids is their connection with the notions of a dimonoid [7, 8], a generalized dimonoid [9, 10], a dialgebra [7], and a semigroup. If two concrete operations of a trioid (trialgebra) coincide, we obtain the notion of a dimonoid (dialgebra). Dimonoids and dialgebras were introduced by Loday [7] while studying periodicity phenomena in algebraic K-theory. They have applications in the theory of Leibniz algebras. A generalized dimonoid [11, 12] is a nonempty set equipped with two binary operations satisfying some four axioms of a dimonoid. For short, generalized dimonoids are called g-dimonoids. Thus, all results obtained for g-dimonoids can be applied to dimonoid theory. This gives us one of the main motivations for studying g-dimonoids. If all operations of a trioid (g-dimonoid) coincide, we obtain the notion of a semigroup. An n-tuple semigroup is an algebra defined on a set with n binary associative operations. This notion play a prominent role in the theory of n-tuple algebras of associative type and is associated with trioids. The class of all trioids (g-dimonoids, n-tuple semigroups) forms a variety. Relatively free systems play a crucial role in studying varieties. Dealing with such problems, it is important to know the structure of free objects in the variety. The variety theory of trioids (g-dimonoids, n-tuple semigroups) is not so well developed. Partially it is due our lack of knowledge on relatively free trioids (g-dimonoids, n-tuple semigroups). Their structure is far from being trivial and needs special consideration. This motivates us to study explicit constructions of free objects in the varieties of trioids, g-dimonoids and n-tuple semigroups.

Outcomes and achievements

During the stay, the research activity has been concentrated mainly in the theory of free systems in the varieties of Loday-type algebras. We studied some relatively free trioids and relatively free generalized dimonoids as well as characterized a series of the least congruences on the constructed free algebras. The latter problem is equivalent to the world problem for relatively free algebras. Further, we developed the variety theory of n-tuple semigroups, namely, we constructed a free k-nilpotent n-tuple semigroup and characterized the least k-nilpotent congruence on a free n-tuple semigroup. At the same time, we investigated certain congruences on free trioids. More precisely, we characterized the least n-nilpotent $d^{\perp}_{\dashv}$-congruence, the least n-nilpotent $d^{\perp}_{\vdash}$-congruence and the least n-nilpotent semigroup congruence on the free trioid. The latter results develop and complement the description of one-generated free trioids obtained by Loday and Ronco.

Acknowledgements

I would like to thank to the Erwin Schrödinger International Institute for Mathematics and Physics, University of Vienna, for the organization of a Special Research Fellowship and for the support given.

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Publications and preprints contributed

A.V. Zhuchok, *The least n-nilpotent dimonoid congruences on the free trioid*, Abstracts of the International Algebraic Conference "At the End of the Year" 2022, Kyiv, Ukraine, December 27–28, p. 63.

A.V. Zhuchok, Yul. V. Zhuchok, *Free k-nilpotent n-tuple semigroups*, submitted to the journal.

Oleg Korotchenkov: Time-domain impedance analysis of carrier recombination in ZnO thin films grown on Si

Oleg Korotchenkov (Kiev University): July 6 – August 6, 2022 and December 10 2022 – January 21, 2023.

Report

During my stay at the Erwin Schrödinger International Institute the project was focused on the approximation of the surface photovoltage (SPV) transients in ZnO/Si nanostructures by employing the time-domain impedance analysis. In order to gain an understanding of the interfacial electronic properties and the band bending at the substrate/layer interface, the metal-insulator (oxide)-semiconductor capacitance and conductance upon varying gate voltage and frequency can generally be measured [1]. Analysis of the frequency-dependent capacitance and conductance uses an equivalent circuit, which can take into account effects of interface states. It is also possible to employ the impedance spectroscopy technique capturing an electrical response of the structure to the ac signal in a broad frequency range [2]. Surface roughness, leakage capacitance and nonuniform charge distribution in semiconductor-insulator systems result in the nonideal capacitor behavior [1]. In order to address this behavior, the equivalent circuit can be supplemented with additional distributed impedance elements, e.g. the constant phase elements (CPEs) [2], which are defined in the frequency domain and analytically derived from the specific carrier transfer processes [3]. However, it is quite difficult to realize the direct time-domain access to the behavior of the CPEs [3,4]. Several approximations have been reported, such as multiple RC circuit [5], high-order integer transfer function [6], Grünwald-Letnikov fractional derivative [7]. Laplace transform technique has also been employed and compared with the multiple RC circuit results [8]. However, the literature on the selection of a most feasible approach is still an obscure. This work is focused on searching of the simplest equivalent electrical circuit, including resistance (R), capacitance (C), and inductance (L) elements, that reproduces the measured SPV transients rather well. It can thus be said that the presented *RCL* circuit method is designed to emulate the CPE matched conditions due to the presence of L. Experimental SPV transients were taken in ZnO nm-sized films, which were deposited onto Si(100) substrates by the magnetron sputtering. We find excellent agreement between the SPV transients modeled with the *RCL* circuit method and experimentally observed transient curves.

The second important point of the project was to investigate the influence of Au plasmonics on time-varying photocurrent generation in integrated thiol-linked CdSe quantum dot/Au nanogap structures. Metallic nanogaps have been advantageous in offering interesting quantum plasmonics opportunities [9]. It has been observed that a metal nanogap can highly confine an electric field of the incident long-wavelength light between the gap of two metal surfaces (referred to as the field enhancement) [10]. A metal/insulator/metal nanogap offers effective mode volumes well below the diffraction limit in the gap material, even if there is a significant loss of energy inside the metal [11]. A self-assembly lithography method was used to manufacture CdSe QDs-gold nanogap structure with periodic dimensions [12]. The plasmonic absorption is sensed utilizing thermoacoustic (TA) detection technique. The laser diode is modulated to generate the TA excitation that oscillates the air-filled cell. When light absorption increases, an enhanced acoustic signal is captured. The observed enhancement in the TA response is related to plasmonic absorption by the Au layers, and the response is even more enhanced by about 20% due to CdSe QDs. In our QD-nanogap material, the surface plasmon resonance (SPR) wavelength is approximately 500 nm. The usage of SPR aims to enhance photocurrents in CdSe quantum dots. Due to energy transfer from the dot to closely spaced Au surface through thiol links, a smooth transmission channel of electrons is established that forms a detectable photocurrent, which can be tuned by a bias voltage. The approach presented here can be extended in various fields employing molecular control of the charge excitation and transfer processes with interfaces in hybrid metal semiconductor nanomaterials.

The high-level support programme provided by the ESI was really unfailing in finalising the above research. The ESI team help and grateful management are greatly appreciated.

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Publications and preprints contributed

A. Nadtochiy, O.K. Suwal, D.-S. Kim, and O. Korotchenkov, *Photocurrent and photoacoustic detection of plasmonic behavior of CdSe quantum dots grown in Au nanogaps*, ArXiv:2210.02542[cond-mat.mes-hall].

A. Nadtochiy, A. Podolian, O. Korotchenkov, *Time-domain impedance method for transient photovoltage analysis*, ArXiv:2210.07928[[cond-mat.mtrl-sci].

Seminars and colloquia outside main programmes and workshops

560 seminar and colloquia talks have taken place at the ESI in 2022 including the following individual talks.

2022 08 03, Yurii Sitenko (National Academy of Sciences Ukraine, Kiev): “Self-adjointness and bounded systems in quantum theory”
2022 10 27, Vadim Kaimanovich (U of Ottawa): “Singularity of stationary measures”
2022 12 12, Philip Walther (U of Vienna): “Photonic quantum computing – a bright future for many applications”

ESI Research Documentation

ESI research in 2022: publications and arXiv preprints

THEMATIC PROGRAMMES

Mathematical Perspectives of Gravitation beyond the Vacuum Regime (FAO)

S. Günther, G. Rein, C. Straub, *A Birman-Schwinger Principle in General Relativity: Linearly Stable Shells of Collisionless Matter Surrounding a Black Hole*, arXiv:2204.10620 [math-AP].

M. Kunze, *A Birman-Schwinger principle in galactic dynamics*, arXiv:103087 [math-ph].

Computational Uncertainty Quantification: Mathematical Foundations, Methodology & Data (HSW)

T. Cui, S. Dolgov, R. Scheichl, *Deep importance sampling using tensor-trains with application to a priori and a posteriori rare event estimation*, arXiv:2209.01941 [stat.ML].

D. Elfverson, R. Scheichl, S. Weissmann, F.A. DiazDelaO, *Adaptive multilevel subset simulation with selective refinement for rare event probabilities*, arXiv:2208.05392 [math.NA].

L. Herrmann and Ch. Schwab, J. Zech, *Neural and gpc operator surrogates: construction and expression rate bounds*, Report number 2022-27, Seminar for Applied Mathematics, ETH Zürich.

P.B. Rohrbach, H. Kobayashi, R. Scheichl, N.B. Wilding, R.L. Jack, *Multilevel simulation of hard-sphere mixtures*, arXiv:2206.00974 [cond-mat.stat-mech].

Higher Structures and Field Theory (AFZ)

A. Hancharuk, T. Strobl, *BFV extensions for mechanical systems with Lie-2 symmetry*, arXiv:2104.12257 [hep-th].

N. Ikeda, T. Strobl, *BV and BFV for the H-twisted Poisson sigma model*, arXiv: 1912.13511 [hep-th].

B. Janssens, L. Ryvkin, C. Vizman, *The L_∞-algebra of a symplectic manifold*, arXiv:2012.03836 [math.SG].

H. Nahari, T. Strobl, *Singular Riemannian foliations and I-Poisson manifolds*, arXiv: 2210.17306 [math.DG].

Tensor Networks: Mathematical Structures and Novel Algorithms (VPS)

S. Bollmann, A. Osterkorn, E. J. König, S.R. Manmana, *Lifshitz transition in the phase diagram of two-leg t-J ladder systems at low filling*, arXiv:2211.13065 [cond-mat.str-el].

P. Brighi, M. Ljubotina, M. Serbyn, *Hilbert space fragmentation and slow dynamics in particle-conserving East model* arXiv:2210.15607 [quant-ph].

M. V. Damme, J.-Y. Desaules, Z. Papić, J. C. Halimeh, *The Anatomy of Dynamical Quantum Phase Transitions*, arXiv:2210.02453 [quant-ph].

J. Fuchs, C. Schweigert, Y. Yang, *String-net models for pivotal bicategories*, arXiv:2302.01468 [math.QA].

M. Ljubotina, J.-Y. Desaules, M. Serbyn, Z. Papić, *The Anatomy of Dynamical Quantum Phase Transitions*, arXiv:2210.01146 [cond-mat.stat-mech].

M. Ljubotina, J.-Y. Desaules, M. Serbyn, Zl. Papić, *Superdiffusive Energy Transport in Kinetically Constrained Models*, arXiv:2210.01146 [cond-mat.stat-mech].

A. Lucia, A. Young, *A Nonvanishing Spectral Gap for AKLT Models on Generalized Decorated Graphs*, arXiv:2212.11872 [math-ph].

B. Nachtergaele, R. Sims, A. Young *Stability of the bulk gap for frustration-free topologically ordered quantum lattice systems*, arXiv:2102.07209 [math-ph].

Y. Zhang, A. Hulsch, H.-C .Zhang, W. Tang, L. Wang, H.-H. Tu, *Universal scaling of Klein bottle entropy near conformal critical points*, arXiv:2211.09745 [cond-mat.str-el].

Large Deviations, Extremes and Anomalous Transport in Non-equilibrium Systems (DPS)

A. Das, M. Barma, *Fluctuation dominated phase ordering in coarse-grained depth models: Domain wall structures, extreme values and coarsening*, arXiv:2212.07471 [cond-mat.stat-mech].

WORKSHOPS

Optimal Point Configurations on Manifolds (GBC)

J. Luong, K. Tran, *Zeros of a table of polynomials satisfying a four-term contiguous relation*, Zeitschrift für Analysis und ihre Anwendungen. arXiv:2008.08707 [math.CV].
see also https://doi.org/10.1016/j.euromechflu.2020.07.001.

Minimal Representations and Theta Correspondence (WMH)

W.T. Gan, B.H. Gross and D. Prasad, *Twisted GGP problems and conjectures*, arXiv:2204.10108 [math.RT].

B. Mesland, M. H. Sengun, *Equal rank local theta correspondence as a strong Morita equivalence*, arXiv:2207.13484 [math.RT].

Set-Theory (FMF)

S. Bardyla, J. Cancino, V. Fisher, C. Switzer, *Filters, ideal independence and ideal Mrowka spaces*, arXiv:2304.04651 [math.LO].

J. A. Cruz-Chapital, V. Fischer, O. Guzman, J. Supina, *Partition forcing and maximal independent families*, Journal of Symbolic Logic, doi:10.1017/jsl.2002.68, 2022.

B. De Bondt, B. Velickovic, *Increasing the second uniform indiscernible by strongly ssp forcing*, arXiv:2212.13797 [math.LO].

V. Fischer, M. Koelbing, W. Wohofsky, *Games on base matrices*, arXiv:2203.02581 [math.LO].

V. Fischer, M. Koelbing, W. Wohofsky, *Fresh function spectra*, Annals of Pure and Applied Logic, 2023, Volume 174, Issue 9.

V. Fischer, C. Switzer, *Cohen preservation and independence*, arXiv:2208.09854 [math.LO].

L. Halbeisen, R. Plati, S. Schuhmacher, S. Shelah, *Vive la Différence!*, arXiv:2109.11315v1 [math.LO].

J. M. Kuiper, O. Spinas, *Mycielski Ideals and Uniform Trees*, Christian-Alberecht-U zu Kiel.

S. Mejak, D. Schrittesser, *Maximal independence and singulars*, arXiv:2212.05318 [math.GR].

D. C. Montoya, *Mycielski Ideals and Uniform Trees*, U Vienna, Faculty of Mathematics.

Spectral Theory of Differential Operators in Quantum Theory (BGL)

J. Behrndt, F. Gesztesy, P. Schmitz, and C. Trunk, *Lower bounds for self-adjoint Sturm–Liouville operators*, arXiv:2212.09837 [math.SP].

B. Benhellal, K. Pankrashkin, *Curvature contribution to the essential spectrum of Dirac operators with critical shell interactions*, arXiv:2211.10264 [math.SP].

V. Franceschi, K. Naderi, K. Pankrashkin, *Embedded trace operator for infinite metric trees*, arXiv:2303.04527 [math-ph].

K. M. Schmidt and T. Umeda, *Continuum limits for discrete Dirac operators on 2D square lattices*, arXiv:2109.04052 [math-ph].

M. Waurick, *Homogenisation of Laminated Metamaterials and the Inner Spectrum*, arXiv:2210.04650 [math.AP].

RESEARCH IN TEAMS (RIT)

A. Bagchi, S. Chakrabortty, D. Grumiller, B. Radhakrishnan, M. Riegler, A. Sinha, *Non-Lorentzian chaos and cosmological holography*, Phys. Rev. D 104, no.10, L101901 (2021) arXiv:2106.07649[hep-th].

A. Bagchi, D. Grumiller, M.M. Sheikh-Jabbari, *Horizon Strings as 3d Blackhole Microstates*, arXiv:2210.10794[hep-th].

A. Bagchi, R. Chatterjee, R. Kaushik, S. Pal, M. Riegler, D. Sarkar, *BMS Field Theories with* $\mathfrak{u}(1)$ *Symmetry*, arXiv:2209.06832[hep-th].

M. Bauer, P. Harms, P. Michor, *Regularity and completeness of half-Lie groups*, arXiv:2302.01631[math.DG].

J. Chu, C.I. Martin, K. Marynets, *Exact solutions and internal waves for the Antarctic Circumpolar Current in spherical coordinates with density depending on depth and latitude*, manuscript in preparation.

N.S. Deger, M. Geiller, J. Rosseel and H. Samtleben, *Minimal Massive Supergravity*, arXiv:2206.00675[hep-th].

N.S. Deger, M. Geiller, J. Rosseel and H. Samtleben, *Properties of Minimal Massive Supergravity*, manuscript in preparation.

N.S. Deger and H. Samtleben, *A note on the third way consistent deformation of Yang-Mills theory*, arXiv:2205.15578[hep-th].

W.T. Gan, G. Savin, *The local Langlands conjecture for* G_2, arXiv:2209.07346[math.NT].

A. Geyer, D. Pelinovsky, *Stability of smooth periodic traveling waves in the Degasperis–Procesi equation*, arXiv:2210.03063[math.AP].

A. Geyer, Y. Liu, D. Pelinovsky, *On the stability of smooth solitary travelling waves in the CH-KP equation*, manuscript in preparation.

D. Ionescu-Kruse and R. Ivanov, *Nonlinear two-dimensional water waves with arbitrary vorticity*, manuscript in preparation.

N. Matringe, *Local distinction, quadratic base change and automorphic induction for* (GL_n, J. Théor. Nombres Bordeaux 34 (2022), no. 3, 903-916.

N. Matringe, J. Trias, *Whittaker functionals and contragredient in characteristic not p*, to appear in Math. Res. Let., arXiv:2209.15353 [math.RT].

A. Mínguez, V. Sécherre, *Local transfer for quasi-split classical groups and congruences mod* ℓ, arXiv:2302.04532 [math.RT].

A. Pollack, *Exceptional theta functions*, arXiv:2211.05280[math.NT].

SENIOR RESEARCH FELLOWS PROGRAMME (SRF)

R. Badal, M. Friedrich, M. Kružík, *Nonlinear and linearized models in thermoviscoelasticity*, https://doi.org/10.48550/arXiv.2203.02375.

K. Brazda, M. Kružík, U. Stefanelli, *Generalized minimizing movements for the varifold Canham-Helfrich flow*, https://doi.org/10.48550/arXiv.2207.03426.

P. Dondl, M. Jesenko, M. Kružík, J. Valdman, *Linearization and computation for large-strain visco-elasticity*, arXiv:2110.13728[math.NA].

D. Drozdenko, M. Knapek, M. Kružík, K. Máthis, K. Švadlenka, J. Valdman, *Elastoplastic deformations of layered structures*, https://doi.org/10.48550/arXiv.2207.01986.

S. A. Egorov, R. Stano, and C. N. Likos, *Bulk phase behaviour of binary mixtures of poly[n]catenates and linear polymers: a Density Functional Theory Study*, manuscript in preparation.

E. Moghimi, I. Chubak, M. Kaliva, P. Kiany, S. A. Egorov, D. Vlassopulos, and C. N. Likos *Bulk phase behaviour of poly[n]catenates and linear polymers: a Density Functional Theory study*, manuscript in preparation.

JUNIOR RESEARCH FELLOWS PROGRAMME (JRF)

J. Alcock-Zeilinger, S. Keppeler, S. Plätzer, M. Sjodahl, *Wigner 6j symbols for SU(N): Symbols with at least two quark-lines*, arXiv:2209.15013[hep-ph].

A. Banerjee, S. Dutta, S. Mondal, *Carroll fermions in two dimensions*, arXiv:2212.11002[hep-th].

B. Bošnjak, *Composition series and unitary subquotients of representations induced from essentially Speh and cuspidal representations*, accepted for publication in *Journal of Lie Theory*, p.38 (2022).

B. Bošnjak, I. Matić *Discrete series and the essentially Speh representations*, accepted for publication in *Journal of Algebra*, p.21 (2022).

S. Dutta *Stress tensors of 3d Carroll CFTs* arXiv:2212.11002 [hep-th].

S. Eckstein, G. Pammer, *Computational methods for adapted optimal transport*, arXiv:2203.05005[math.PR].

A. Hancharuk, T. Strobl, *BFV extensions for mechanical systems with Lie-2 symmetry*, arXiv:2104.12257[hep-th].

UKRAINIAN RESEARCH FELLOWS PROGRAMME (URF)

A. Kosogor, V. A. Lvov, R. Y. Umetsu, X. Xu, R. Kainuma, *Strong influence of magnetic order on the low-temperature specific heat of Heusler alloys*, Books of Abstracts of 12th International Conference on

Nanomaterials: Applications & Properties 2022 (Krakow, Poland, 11-19 September, 2022), p. 07nmm-23.

I. Kyrchei, *Quaternion MPCEP, CEPMP, and MPCEPMP Generalized Inverses*, In: M. I. Andriychuk (Ed.): Matrix Theory - Classics and Advances , London: IntechOpen,s intechopen:103087. https://doi.org/10.52305/MJVE4994.

I.I. Kyrchei, D. Mosić, P.S. Stanimirović, *Quaternion two-sided matrix equations with specific constraints*. Coming soon in: M.S. Moslehian (Ed.), Matrix and Operator Equations and Applications, Springer.

I. Kyrchei, D. Mosić, P.S. Stanimirović, *W-MPD–N-DMP-solutions of constrained quaternion matrix equations*, In: Special Matrices 11(1) https://doi.org/10.1515/spma-2022-0183.

A. Nadtochiy, Om Krishna Suwal, Dai-Sik Kim, O. Korotchenkov *Plasmonic behavior of CdSe quantum dots thiol-linked in Au nanogaps*.

A. Nadtochiy, O.K. Suwal, D.-S. Kim, and O. Korotchenkov, *Photocurrent and photoacoustic detection of plasmonic behavior of CdSe quantum dots grown in Au nanogaps*, arXiv:2210.02542[cond-mat.mes-hall].

A. Nadtochiy, A. Podolian, O. Korotchenkov, *Time-domain impedance method for transient photovoltage analysis*, arXiv:2210.07928[cond-mat.mtrl-sci].

A. Rehman, I.I. Kyrchei , *Solving and algorithm to system of quaternion Sylvester-type matrix equations with * -Hermicity*, In: Advances in Applied Clifford Algebras 32: 49, 2022. https://doi.org/10.1007/s00006-022-01222-2.

A. Rehman, I.I. Kyrchei , I. Ali Khan, M. Nasir, I. Ali, *Closed-form formula for a classical system of matrix equations*, In: Arab Journal of Basic and Applied Sciences 29(1), 257-267, 2022. https://doi.org/10.1080/25765299.2022.2113497.

V.M. Simulik, I.I. Vyikon, *On the choice of relativistic wave equation for the particle having spin s = 3/2*, J. Phys. Comm. 2022, Vol. 6, is. 7, p. 075008(1–7).

V. Simulik, I. Vyikon, *On the "old" and "new" relativistic wave equations for the particle having spin s=3/2*, arXiv:2204.05167v2 [hep-th] 23 May 2022.

V.M. Simulik, I.I. Vyikon, *Representations of Clifford and SO(1,9) algebras in the space of 8-component spinors.* Advanc. Appl. Cliff. Alg. 2022 (under consideration for publication).

V.M. Simulik, *On the 256-dimensional Clifford Algebra, gamma matrix representations of the Lie algebras SO(1,9), SO(10) and their applications to the physics of elementary particles*, Proceedings of the Jubilee Conference"30 Years for the Institute of Electron Physics of Ukrainian National Academy of Sciences", 21–23 September 2022, Uzhgorod, Ukraine, p. 192–195 (in Ukrainian).

Y.A. Sitenko, V. M. Gorkavenko, M. S. Tsarenkova, *Magnetic flux in the vacuum of quantum bosonic matter in the cosmic string background*, In: Phys. Rev. D 106 (10), 105010 (2022). arXiv:2208.06398[hep-th].

I.I. Vyikon, V.M. Simulik, *Spin 3/2 in relativistic equations of motions*, Proceedings of the Jubilee Conference "30 Years for the Institute of Electron Physics of Ukrainian National Academy of Sciences", 21–23 September 2022, Uzhgorod, Ukraine, p. 138-139 (in Ukrainian).

A.V. Zhuchok, *The least n-nilpotent dimonoid congruences on the free trioid*, Abstracts of the International Algebraic Conference "At the End of the Year" 2022, Kyiv, Ukraine, December 27–28, p. 63.

A.V. Zhuchok, Y. V. Zhuchok, *Free k-nilpotent n-tuple semigroups, Communications in Algebra*, https://doi.org/10.1080/00927872.2023.2195000.

Y.V. Zhuchok, *New models for the free commutative monogenic trioid and its endomorphism monoid*, Semigroup Forum 105 (2022), 575–581. https://doi.org/10.1007/s00233-022-10313-2.

Yu.V. Zhuchok, M.Yu. Zmiienko, *On endomorphisms of free g-dimonoids of rank 1*, Abstracts of the International Algebraic Conference *"At the End of the Year" 2022*, Kyiv, Ukraine, December 27–28, p. 64.

Y. V. Zhuchok, *New models for the free commutative monogenic trioid and its endomorphism monoid*, In: Semigroup Forum 105, 575-581. https://doi.org/10.1007/s00233-022-10313-2.

ESI research in previous years: additional publications and arXiv preprints

The following papers and publications complement the papers and publications already taken into account in the previous years.

MKS21 = Memory Effects in Dynamical Processes: Theory and Computational Implementation, 2021
JRF = Junior Research Fellows

L. F. Elizondo-Aguilera, T. Rizzo, T. Voigtmann, *From Subaging to Hyperaging in Structural Glasses*, In: Physical Review Letters 129, 238003 (2022), (MKS21).

P. Rioseco and O. Sarbach, *Phase space mixing of a Vlasov gas in the exterior of a Kerr black hole*, arXiv:2302.12849, (JRF 2021).

List of all visitors in 2022

A total of 815 scientist visited the ESI in 2022.

The gender distribution is as follows:
male: 602
female: 157
prefer not to disclose: 9
non-binary: 2
unspecified: 45

Affiliation by country:

ARG, Argentina: 1
AUS, Australia: 4
AUT, Austria: 227
BEL, Belgium: 14
BRA, Brazil: 2
BGR, Bulgaria: 2
CAN, Canada: 7
CHL, Chile: 2
HRV, Croatia: 10
CZE, Czech Republic: 11
DNK, Denmark: 6
FIN, Finland: 2
FRA, France: 67
DEU, Germany: 124
HUN, Hungary: 1
IND, India: 11
IRN, Iran (Islamic Republic of): 1
IRL, Ireland: 3
ISR, Israel: 15
ITA, Italy: 28
JPN, Japan: 13
KOR, Korea (Republic of): 5
LUX, Luxembourg: 1
MEX, Mexico: 2
NLD, Netherlands: 25
NZL, New Zealand: 1
NIU, Niue: 1
NOR, Norway: 4

POL, Poland: 13
PRT, Portugal: 2
ROU, Romania: 3
RUS, Russian Federation: 4
SAU, Saudi Arabia: 1
SGP, Singapore: 3
SVK, Slovakia: 3
SVN, Slovenia: 1
ESP, Spain: 12
SWE, Sweden: 10
CHE, Switzerland: 32
TUR, Turkey: 1
UKR, Ukraine: 11
ARE, United Arab Emirates: 1
GBR, United Kingdom of Great Britain and Northern Ireland: 63
USA, United States of America: 65

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

AFZ22 = Higher Structures and Field Theory
BGL22 = Spectral Theory of Differential Operators in Quantum Theory
DPS22 = Large Deviations, Extremes and Anomalous Transport in Non-equilibrium Systems
EM22 = ESI Medal Award Ceremony 2022
FAO22 = Mathematical Perspectives of Gravitation beyond the Vacuum Regime
FMF22 = Set-Theory
GBC22 = Optimal Point Configurations on Manifolds
GDK22 = ESI-DCAFM-TACO-VDSP Summer School on ”Machine Learning for Materials Hard and Soft”
HSW22 = Computational Uncertainty Quantification: Mathematical Foundations, Methodology & Data
IMO22 = IMO and MEMO Training 2022
IPhO22 = IPhO and EuPhO Training 2022
IS22 = Individual Visiting Scientists 2022
JRF = Junior Research Fellow KMS22 = Mathematical Methods for the Study of Self-organization in the Biological Sciences
RIT = Research in Teams Fellow SAB2022 = Scientific Advisory Board Meeting 2022
SFC22 = Adaptivity, High Dimensionality and Randomness
SRF = Senior Research Fellow URF0122 = Vira Niestierkina (National Academy of Sciences of Ukraine, Kharkiv): Influence of defects on radiative relaxation of halide and oxide scintillators
VPS22 = Tensor Networks: Mathematical Structures and Novel Algorithms
VPS22S = School on Tensor Networks based approaches to Quantum Many-Body Systems
WMH22 = Minimal Representations and Theta Correspondence

Ahammed Raihan, Institute of Nano Science and Technology, Mohali; 2022-07-10 - 2022-07-22, GDK22
Alcock-Zeilinger Judith, U Tübingen; 2022-07-11 - 2022-11-10, JRF0322
Alekseev Anton, U Genève; 2022-08-22 - 2022-08-26, AFZ22

Algan Taylan, BGRG Schwechat; 2022-06-30 - 2022-07-01, IPhO22
Ali Qais, Danube U, Krems; 2022-07-11 - 2022-07-22, GDK22
Amir Ariel, Harvard U, Cambridge; 2022-09-28 - 2022-10-02, DPS22
Andréasson Håkan, Chalmers U of Technology, Gothenburg; 2022-03-06 - 2022-03-12, 2022-02-06 - 2022-02-18, FAO22
Angeletti Andrea, U of Vienna; 2021-07-11 - 2021-07-22, GDK22
Anselme Martin Baptiste, U Paris-Saclay; 2022-09-04 - 2022-09-10, VPS22S
Appert-Rolland Cecile, U Paris-Saclay; 2022-10-08 - 2022-10-13, DPS22
Arias Espinoza Juan Diego, U Amsterdam; 2022-09-09 - 2022-09-17, 2022-10-03 - 2022-10-11, VPS22
Arildsen Mark, UC, Santa Barbara; 2022-10-02 - 2022-10-21, VPS22
Arnold Anton, TU Vienna; 2022-06-13 - 2022-06-17, HSW22
Aspero David, U of East Anglia, Norwich; 2022-07-04 - 2022-07-08, FMF22
Athreya Gaurav, Max Planck Institute for Evolutionary Biology; 2022-11-13 - 2022-11-21, KMS22
Aubert Anne-Marie, CNRS, Paris; 2022-04-10 - 2022-04-16, WMH22
Aucar Boidi Nair Sophia, Instituto Balseiro, San Carlos de Bariloche; 2022-09-05 - 2022-09-09, VPS22S
Auer Maximilian, BRG4, Vienna; 2022-06-26 - 2022-07-01, IPhO22
Babadei Olga, U of Vienna; 2022-11-14 - 2022-11-24, KMS22
Bach Francis, INRIA, Rocquencourt; 2022-05-30 - 2022-06-01, HSW22
Bachmair Brigitta, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Bachmayr Markus, U Mainz; 2022-05-10 - 2022-05-14, HSW22
Bachmayr Markus, U Mainz; 2022-04-03 - 2022-04-09, SFC22
Bae Gichan, Seoul National U; 2022-06-11 - 2022-06-18, HSW22
Bagchi Arjun, IITK, Kanpur; 2022-06-12 - 2022-07-23, RIT0420
Baird Sterling, U of Utah, Saltlake City; 2022-07-11 - 2022-07-23, GDK22
Banuls Mari Carmen, MPI Quantum Optics, Garching; 2022-09-26 - 2022-10-07, VPS22
Bao Jiahui, Okinawa IST; 2022-09-04 - 2022-09-12, VPS22S
Bardyla Serhii, U of Vienna; 2022-07-04 - 2022-07-08, FMF22
Barkai Eli, Bar Ilan U; 2022-09-25 - 2022-10-03, DPS22
Barkha Tiwari, Norwegian U of Life Sciences; 2022-11-28 - 2022-12-04, KMS22
Barma Mustansir, TIFR Hyderabad; 2022-09-17 - 2022-10-02, DPS22
Barrett John, U of Nottingham; 2022-09-01 - 2022-10-31, SRF0322
Barron Andrew, Yale U, New Haven; 2022-05-29 - 2022-06-03, HSW22
Barutel Cedrik, U Toulouse; 2022-11-14 - 2022-11-21, KMS22
Barzegar Hamed, U of Vienna; 2022-02-01 - 2022-03-01, FAO22
Bashkirov Denis, Academy of Sciences, Prague; 2022-08-18 - 2022-08-24, AFZ22
Basile Thomas, U Mons; 2022-08-14 - 2022-08-20, AFZ22
Basu Urna, SNBNCBS, Kolkata; 2022-09-18 - 2022-10-01, DPS22
Bauer Martin, Florida State U, Tallahassee; 2022-06-09 - 2022-06-29, RIT0222
Baumgarten Niklas, KIT, Karlsruhe; 2022-05-01 - 2022-05-09, HSW22
Bechinger Clemens, U of Konstanz; 2022-09-25 - 2022-09-28, DPS22
Behrndt Jussi, TU Graz; 2022-11-07 - 2022-11-11, BGL22
Beig Robert, U of Vienna; 2022-02-07 - 2022-02-12, FAO22
Benalcazar Joselyn, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Benichou Olivier, Sorbonne U, Paris; 2022-09-25 - 2022-09-30, DPS22
Berenstein Arkadiy, U of Oregon, Eugene; 2022-07-01 - 2022-08-31, RIT0620
Berezutskii Aleksandr, U of Sherbrooke; 2022-09-04 - 2022-09-10, VPS22S
Bertaglia Giulia, U of Ferrara; 2022-06-14 - 2022-06-16, HSW22
Bespalov Alex, U. of Birmingham; 2022-04-03 - 2022-04-09, SFC22
Bespalov Alex, U. of Birmingham; 2022-05-08 - 2022-05-14, HSW22

Bétermin Laurent, UCB Lyon; 2022-01-16 - 2022-01-21, GBC22
Betina Adel, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Bierbaumer Martin, HTL3R, Vienna; 2022-06-28 - 2022-07-01, IMO22
Bilichenko Maria, U Zürich; 2022-07-10 - 2022-07-22, GDK22
Bilyk Dimitriy, U of Minnesota; 2022-01-10 - 2022-01-22, GBC22
Birschitzky Viktor, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Blanik David, U of Vienna; 2022-08-29 - 2022-10-21, VPS22+VPS22S
Blohmann Christian, MPIM, Bonn; 2022-07-31 - 2022-08-08, AFZ22
Bocanegra Laura, ISTA, Klosterneuburg; 2022-11-16 - 2022-11-22, KMS22
Bocini Saverio, U Paris-Saclay; 2022-09-04 - 2022-09-10, VPS22S
Bögli Sabine, Durham U; 2022-11-06 - 2022-11-12, BGL22
Bojowald Martin, Penn State; 2022-08-15 - 2022-08-21, AFZ22
Bölcskei Helmut, ETH Zürich; 2022-05-30 - 2022-06-03, HSW22
Bonati Luigi, IIT, Genova; 2022-07-19 - 2022-07-22, GDK22
Boneberg Mario, U Tübingen; 2022-09-04 - 2022-09-10, VPS22S
Bonechi Francesco, INFN, Firenze; 2022-08-21 - 2022-08-27, AFZ22
Bonizzoni Francesca, U Augsburg; 2022-06-12 - 2022-06-17, HSW22
Borda Bence, TU Graz; 2022-01-18 - 2022-01-21, GBC22
Borodachov Sergiy, Towson U; 2022-01-10 - 2022-01-21, GBC22
Bošnjak Barbara, U Zagreb; 2022-04-04 - 2022-07-03, 2022-09-01 - 2022-10-01, JRF0222+WMH22
Bozorgnia Farid, IST Lisboa; 2022-11-21 - 2022-12-03, 2022-11-12 - 2022-11-21, KMS22
Braghetto Anna, U Padua; 2022-07-10 - 2022-07-22, GDK22
Brandfellner Lukas, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Bressan Alberto, Penn State; 2022-11-04 - 2022-11-06, SAB2022
Brighi Pietro, ISTA, Klosterneuburg; 2022-09-19 - 2022-10-14, VPS22
Brizioli Matteo, U Milan; 2022-07-10 - 2022-07-22, GDK22
Brown Adam, ISTA, Klosterneuburg; 2022-04-11 - 2022-04-15, WMH22
Bruna Maria, U Cambridge; 2022-11-20 - 2022-11-25, KMS22
Bucheron Chloé, U of Vienna; 2022-11-14 - 2022-12-09, KMS22
Buchmaier Bofill David, BG/BRG Baden; 2022-06-27 - 2022-07-01, IMO22
Buchner Florian, TU Vienna; 2022-07-11 - 2022-07-22, GDK22
Bugden Mark, Max Planck Institute, Konstanz; 2022-08-07 - 2022-08-13, AFZ22
Bultinck Nick, U Oxford; 2022-10-03 - 2022-10-14, VPS22
Butin Frédéric, Institution Saint Marie, Paris; 2022-08-07 - 2022-08-11, AFZ22
Cacciapuoti Claudio, U of Insubria, Como; 2022-11-06 - 2022-11-11, BGL22
Calliari Gabriele, U of Innsbruck; 2022-09-04 - 2022-09-10, VPS22S
Calvez Vincent, UCB Lyon; 2022-11-20 - 2022-11-25, KMS22
Cancino-Manriquez Jonathan, Czech Academy of Sciences, Prague; 2022-07-03 - 2022-07-08, FMF22
Capel Cuevas Angela, U Tübingen; 2022-10-02 - 2022-10-05, 2022-10-11 - 2022-10-21, VPS22
Carchedi David, George Mason U, Fairfax; 2022-08-07 - 2022-08-12, AFZ22
Cardona-Montoya Miguel Antonio, U of Kosice; 2022-07-05 - 2022-07-08, FMF22
Carqueville Nils, U of Vienna; 2022-08-16 - 2022-08-30, AFZ22
Carstensen Carsten, HU Berlin; 2022-04-03 - 2022-04-08, SFC22
Castellano Giancarlo, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Cataldi Giovanni, U Padua; 2022-09-04 - 2022-09-10, VPS22S
Celiberti Lorenzo, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Chakraborty Tapash, U of Manitoba; 2022-11-12 - 2022-11-19, IS22
Chan William, Carnegie Mellon U, Pittsburgh; 2022-07-02 - 2022-07-09, FMF22
Chatzistavrakidis Athanasios, RBI, Zagreb; 2022-08-07 - 2022-08-20, AFZ22

Chen Peng, U of Texas, Austin; 2022-05-15 - 2022-05-28, HSW22
Chenevier Gaëtan, CNRS, Paris; 2022-04-10 - 2022-04-16, WMH22
Cheng Bingqing, ISTA, Klosterneuburg; 2022-07-15 - 2022-07-15, GDK22
Chepiga Natalia, TU Delft; 2022-09-11 - 2022-10-01, VPS22
Chernov Alexey, U of Oldenburg; 2022-05-15 - 2022-05-20, HSW22
Chetrite Raphael, CNRS Nice; 2022-10-09 - 2022-10-14, DPS22
Chinot Geoffrey, ETH Zürich; 2022-05-29 - 2022-06-03, HSW22
Chodounsky David, Czech Academy of Sciences, Prague; 2022-07-03 - 2022-07-09, FMF22
Christen Andrés, CIMAT, Guanajuato; 2022-05-12 - 2022-05-26, HSW22
Ciliberto Sergio, CNRS, Paris; 2022-09-24 - 2022-09-30, DPS22
Cirac J. Ignacio, MPI Quantum Optics, Garching; 2022-09-05 - 2022-09-06, 2022-09-12 - 2022-09-13, VPS22
Cocchiarella Denise, MPIQ, Munich; 2022-09-04 - 2022-09-09, VPS22S
Cohen Albert, Sorbonne U, Paris; 2022-04-06 - 2022-04-09, SFC22
Cohen Albert, Sorbonne U, Paris; 2022-05-08 - 2022-05-12, HSW22
Corboz Philippe, U Amsterdam; 2022-09-12 - 2022-09-16, VPS22
Corrias Marco, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Cosserat Oscar, U of La Rochelle; 2022-08-21 - 2022-08-26, AFZ22
Crossley Joe, U of St Andrews; 2022-09-04 - 2022-09-09, VPS22S
Cueca Miquel, U Göttingen; 2022-08-14 - 2022-08-20, AFZ22
Cui Peiyi, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Cui Tiangang, Monash U, Melbourne; 2022-05-28 - 2022-06-16, HSW22
Cvetic Mirjam, UPenn, Philadelphia; 2022-11-04 - 2022-11-06, SAB2022
Cvetkovic Nada, TU Eindhoven; 2022-05-15 - 2022-05-20, HSW22
Czarnik Piotr, Jagiellonian U, Krakow; 2022-09-12 - 2022-09-16, VPS22
Dalal Rahul, Johns Hopkins U, Baltimore; 2022-04-10 - 2022-04-16, WMH22
Dalipi Rea, U Genève; 2022-07-31 - 2022-08-05, AFZ22
Damialis Apostolos, EMS Berlin; 2022-11-08 - 2022-11-11, BGL22
Dapo Edvin, U of Vienna; 2022-02-16 - 2022-03-11, FAO22
Dashti Masoumeh, U Sussex; 2022-05-13 - 2022-05-21, HSW22
Davydov Alexei, Ohio State U, Columbus; 2022-08-08 - 2022-08-16, AFZ22
de Amorim Erik, U Cologne; 2022-02-06 - 2022-02-18, FAO22
De Bondt Ben, U Paris Jussieu; 2022-07-02 - 2022-07-08, FMF22
De Bruyne Benjamin, Paris-Saclay U; 2022-09-26 - 2022-09-29, DPS22
Defenu Nicolo, ETH Zurich; 2022-10-03 - 2022-10-14, DPS22
Deger Nihat Sadik, Boğaziçi University; 2022-01-31 - 2022-02-28, 2022-05-22 - 2022-06-05, RIT0322
del Hoyo Matias L, UFF Rio de Janeiro; 2022-07-31 - 2022-08-05, AFZ22
Dellago Christoph, U of Vienna; 2022-09-19 - 2022-10-14, DPS22
Dellago Christoph, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Del Re Lorenzo, Georgetown U; JRF0319-22
Derkach Vladimir, Vasyl'Stus Donetsk National U; 2022-11-06 - 2022-11-10, BGL22
de Snoo Henk, U Groningen; 2022-11-06 - 2022-11-12, BGL22
Després Bruno, Sorbonne U, Paris; 2022-04-04 - 2022-04-08, SFC22
Devos Lukas, Ghent U; 2022-09-12 - 2022-09-16, VPS22
Dhar Abhishek, TIFR, Bangalore; 2022-09-18 - 2022-10-01, DPS22
Diebold Ulrike, TU Vienna; 2022-07-11 - 2022-07-15, GDK22
Diez Antoine, Kyoto U; 2022-11-20 - 2022-12-04, KMS22
Dijkstra Marjolein, Utrecht U; 2022-07-13 - 2022-07-15, GDK22
Dimarco Giacomo, U of Ferrara; 2022-06-12 - 2022-06-16, HSW22

Di Rocco Sandra, KTH Stockholm; 2022-11-04 - 2022-11-06, SAB2022
Diz-Muñoz Alba, EMBL, Heidelberg; 2022-11-23 - 2022-11-25, KMS22
Dneprov Ivan; 2022-08-07 - 2022-08-20, AFZ22
Dobrinen Natasha, U of Denver; 2022-07-03 - 2022-07-10, FMF22
Doerner Roman, U of Vienna; 2022-07-04 - 2022-07-08, FMF22
Dolbeault Matthieu, Sorbonne U, Paris; 2022-05-09 - 2022-05-13, HSW22
Doumic Marie, Sorbonne U, Paris; 2022-11-21 - 2022-11-25, KMS22
Dow Alan, UNC Charlotte; 2022-07-03 - 2022-07-08, FMF22
Drigo Enrico, SISSA, Trieste; 2022-07-10 - 2022-07-22, GDK22
Droschl Johannes, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Dubail Jerôme, U Lorraine; 2022-08-29 - 2022-09-09, VPS22
Dunham Jack, University College London; 2022-09-05 - 2022-09-09, VPS22S
Dutta Sudipta, IITK, Kanpur; 2022-09-01 - 2022-12-31, JRF0422
Dzamonja Mirna, CNRS, Paris; 2022-07-04 - 2022-07-08, FMF22
Dziubyna Anna Maria, Jagiellonian U, Krakow; 2022-09-03 - 2022-09-11, VPS22S
Eftimie Raluca, U Franche-Comte, Besancon; 2022-11-23 - 2022-11-25, KMS22
Egorov A. Sergei, Virginia U; 2022-05-01 - 2022-07-31, SRF22
Ehrlacher Virginie, ENPC, Paris; 2022-05-08 - 2022-05-13, HSW22
Eigel Martin, WIAS, Berlin; 2022-04-03 - 2022-04-10, SFC22
Eisenkölbl Theresia, U of Vienna; 2022-06-27 - 2022-07-01, IMO22
Eisert Jens, FU Berlin; 2022-10-06 - 2022-10-08, VPS22
Eisler Viktor, TU Graz; 2022-10-09 - 2022-10-14, 2022-10-02 - 2022-10-06, VPS22
Elbar Charles, Sorbonne U, Paris; 2022-11-13 - 2022-11-18, KMS22
Emory Melissa, U Toronto; 2022-04-10 - 2022-04-16, WMH22
Engquist Bjorn, U of Texas, Austin; 2022-06-14 - 2022-06-17, HSW22
Ernst Oliver, TU Chemnitz; 2022-05-08 - 2022-05-15, HSW22
Evans Martin, U Edinburgh; 2022-09-19 - 2022-10-15, DPS22
Evertz Hans-Gerd, TU Graz; 2022-09-05 - 2022-09-09, 2022-09-12 - 2022-09-17, VPS22
Evetts Alexander, U of Manchester; 2022-05-02 - 2022-05-26, JRF0120-22
Exner Pavel, Czech Academy of Sciences, Prague; 2022-11-06 - 2022-11-11, BGL22
Fajman David, U of Vienna; 2022-02-07 - 2022-03-11, FAO22
Falkner Sebastian, U of Vienna; 2022-07-10 - 2022-07-22, GDK22
Faulhuber Markus, U of Vienna; 2022-01-20 - 2022-01-21, GBC22
Faustmann Markus, TU Vienna; 2022-04-04 - 2022-04-08, SFC22
Feischl Michael, TU Vienna; 2022-04-04 - 2022-04-08, SFC22
Feischl Michael, TU Vienna; 2022-05-02 - 2022-05-06, HSW22
Fellner Klemens, U of Graz; 2022-11-21 - 2022-11-25, KMS22
Fendley Paul, U Oxford; 2022-10-02 - 2022-10-06, VPS22
Feng Xiaobing, U of Tennessee, Knoxville; 2022-06-12 - 2022-06-18, HSW22
Ferguson Andrew, U of Chicago; 2022-07-14 - 2022-07-16, GDK22
Ferizović Damir, KU Leuven; 2022-01-09 - 2022-01-22, GBC22
Fernandez-Pacheco Amalio, U Zaragoza; 2022-11-21 - 2022-11-28, KMS22
Fernández-Sedano Lucía, Complutense University of Madrid; 2022-07-10 - 2022-07-22, GDK22
Ferraresso Francesco, Cardiff U; 2022-11-06 - 2022-11-11, BGL22
Fertl Sebastian, U of Vienna; 2022-08-17 - 2022-08-17, AFZ22
Filbet Francis, U Paul Sabatier, Toulouse; 2022-11-13 - 2022-11-20, KMS22
Fischer Vera, U of Vienna; 2022-07-04 - 2022-07-08, FMF22
Floreani Simone, TU Delft; 2022-09-26 - 2022-09-27, DPS22
Florido Llinàs Marta, MPI Quantum Optics, Garching; 2022-09-04 - 2022-09-10, VPS22S

Fornara Basile, INRAe, Jouy en Josas; 2022-11-21 - 2022-11-25, KMS22
Frabetti Alessandra, U Lyon; 2022-08-15 - 2022-08-26, AFZ22
Frahm Jan, U Aarhus; 2022-04-10 - 2022-04-14, WMH22
François Jordan, U Mons; 2022-08-13 - 2022-08-25, AFZ22
Franco-Rubio Adrián, MPI Quantum Optics, Garching; 2022-10-02 - 2022-10-09, VPS22
Francuz Anna, U of Vienna; 2022-08-29 - 2022-10-21, VPS22
Fredenhagen Stefan, U of Vienna; 2022-06-13 - 2022-07-22, RIT0420
Fredenhagen Stefan, U of Vienna; 2022-08-23 - 2022-08-26, AFZ22
Frenkler Joachim, U Bayreuth; 2022-03-08 - 2022-03-09, FAO22
Frouvelle Amic, CEREMADE, Paris; 2022-11-14 - 2022-11-22, KMS22
Frymark Dale, TU Graz; 2022-11-06 - 2022-11-11, BGL22
Fuchs Jürgen, U Karlstad; 2022-09-19 - 2022-10-10, VPS22
Fuchs Jürgen, U Karlstad; 2022-08-10 - 2022-08-20, AFZ22
Fuksa Jonas, FU Berlin; 2022-09-04 - 2022-09-10, VPS22S
Gabriel Lukas, AMS; 2022-06-27 - 2022-07-01, IPhO22
Gadge Karun, U Göttingen; 2022-09-04 - 2022-09-11, VPS22S
Gambassi Andrea, SISSA, Trieste; 2022-09-26 - 2022-10-02, DPS22
Gan Wee Teck, U of Singapore; 2022-04-10 - 2022-04-17, WMH22
Gan Wee Teck, U of Singapore; 2022-04-17 - 2022-04-24, RIT0422
Ganahl Martin, SandboxAQ, Palo Alto; 2022-09-06 - 2022-09-16, VPS22
Gappo Takehiko, Rutgers U; 2022-07-03 - 2022-07-08, FMF22
Gargava Nihar, EPFL, Lausanne; 2022-01-09 - 2022-01-22, GBC22
Garnier Guillaume, INRIA, Rocquencourt; 2022-11-13 - 2022-11-19, KMS22
Garnier Josselin, Ecole Polytechnique, Palaiseau; 2022-06-12 - 2022-06-16, HSW22
Garrahan Juan, U of Nottingham; 2022-09-27 - 2022-10-14, VPS22+DPS22
Garre Rubio José, U of Vienna; 2022-09-05 - 2022-10-07, VPS22
Gasull Albert, MPI Quantum Optics, Garching; 2022-10-03 - 2022-10-07, VPS22
Genest Alexander, TU Vienna; 2022-07-11 - 2022-07-22, GDK22
Gesztesy Fritz, Baylor U, Waco; 2022-11-06 - 2022-11-17, BGL22
Geyer Anna, TU Delft; 2022-05-21 - 2022-06-06, RIT0121
Girsch Johannes, Imperial College, London; 2022-04-10 - 2022-04-16, WMH22
Gispen Willem, Utrecht U; 2022-07-10 - 2022-07-23, GDK22
Giulini Domenico, Leibniz U; 2022-11-04 - 2022-11-06, SAB2022
Gleis Andreas, LMU Munich; 2022-09-05 - 2022-09-16, VPS22+VPS22S
Goldstern Martin, TU Vienna; 2022-07-04 - 2022-07-08, FMF22
Golshani Mohammad, IPM, Tehran; 2021-07-03 - 2021-07-09, FMF22
Gomes Susana, U Warwick; 2022-05-15 - 2022-05-20, HSW22
Gonzalez Herrero Leticia, U of Vienna; 2022-07-12 - 2022-07-22, GDK22
Gorfer Alexander, U of Vienna; 2022-07-12 - 2022-07-22, GDK22
Grabner Peter, TU Graz; 2022-01-10 - 2022-01-21, GBC22
Gradenigo Giacomo, Gran Sasso Science Institute, L'Aquila; 2022-10-10 - 2022-10-15, DPS22
Graham Ivan, U Bath; 2022-06-11 - 2022-06-18, HSW22
GrandPre Trevor, Princeton U; 2022-09-20 - 2022-09-30, DPS22
Granek Omer, Technion Haifa; 2022-09-18 - 2022-09-30, DPS22
Grasedyck Lars, RWTH Aachen; 2022-04-03 - 2022-04-08, SFC22
Grebik Jan, U Warwick; 2022-07-04 - 2022-07-07, FMF22
Green Andrew, University College London; 2022-08-28 - 2022-09-09, 2022-09-11 - 2022-09-17, VPS22+VPS22S
Greilhuber Josef, U of Vienna; 2022-06-27 - 2022-07-01, IMO22
Gribonval Remi, Inria Lyon; 2022-05-29 - 2022-06-03, HSW22

Griebel Michael, INS, Bonn; 2022-04-01 - 2022-04-08, SFC22
Grigoriev Maxim; 2022-08-08 - 2022-08-21, AFZ22
Griniari Elena, Springer Heidelberg; 2022-06-13 - 2022-06-15, HSW22
Grobner Harald, U of Vienna; 2022-04-10 - 2022-04-16, WMH22
Grohs Philipp, U of Vienna; 2022-05-30 - 2022-06-03, HSW22
Grohs Philipp, U of Vienna; 2022-04-05 - 2022-04-08, SFC22
Grohs Philipp, U of Vienna; 2022-07-11 - 2022-07-12, GDK22
Grosse Harald, U of Vienna; 2022-11-07 - 2022-11-11, BGL22
Grumiller Daniel, TU Vienna; 2022-06-12 - 2022-07-15, RIT0420
Gunn David Kenworthy, U of Innsbruck; 2022-10-02 - 2022-10-07, VPS22
Günther Sebastian, U Bayreuth; 2022-02-13 - 2022-02-18, FAO22
Gurevich Nadya, Ben-Gurion U, Beer-Sheva; 2022-04-09 - 2022-04-18, WMH22
Gurevich Nadya, Ben-Gurion U, Beer-Sheva ; 2022-04-18 - 2022-04-25, RIT0422
Ha Seung-Yeal, Seoul National U; 2022-06-11 - 2022-06-18, HSW22
Haegeman Jutho, Ghent U; 2022-09-11 - 2022-09-16, 2022-10-02 - 2022-10-07, VPS22
Hairer Martin, Imperial College, London; 2022-11-03 - 2022-11-05, EM22
Haji-Ali Abdul-Lateef, Heriot-Watt U, Edinburgh; 2022-05-01 - 2022-05-06, HSW22
Halbeisen Lorenz, ETH Zurich; 2022-07-04 - 2022-07-08, FMF22
Hametner Paul, HS Linz; 2022-06-27 - 2022-07-01, IMO22
Hancharuk Aliaksandr, U Lyon; 2022-07-31 - 2022-08-30, JRF0520+AFZ22
Hanzer Marcela, U Zagreb; 2022-04-10 - 2022-04-16, WMH22
Harar Pavol, U of Vienna; 2022-07-11 - 2022-07-12, GDK22
Harbrecht Helmut, U of Basel; 2022-05-08 - 2022-05-13, HSW22
Harish Rohit Krishnan, ISTA, Klosterneuburg; 2022-11-15 - 2022-11-25, KMS22
Harms Philipp, NTU Singapore; 2022-05-18 - 2022-06-29, RIT0222
Harris Rosemary, QMU London; 2022-09-18 - 2022-09-24, DPS22
Hartmann Alexander, U Oldenburg; 2022-09-23 - 2022-10-08, DPS22
Hasik Juraj, U Amsterdam; 2022-08-28 - 2022-09-16, VPS22+VPS22S
Hassi Seppo, U of Vaasa; 2022-11-06 - 2022-11-11, BGL22
Hastermann Gottfried, U of Potsdam; 2022-05-15 - 2022-05-21, HSW22
Hauschild Johannes, TU München; 2022-08-29 - 2022-09-17, VPS22
He Yanchen, ETH Zurich; 2022-06-20 - 2022-06-26, HSW22
Hecht Sophie, Sorbonne U, Paris; 2022-11-21 - 2022-11-25, KMS22
Heidrich-Meisner Fabian, U Göttingen; 2022-09-18 - 2022-09-23, VPS22
Heiss Cosmas, TU Berlin; 2022-04-03 - 2022-04-07, SFC22
Heitzinger Clemens, TU Vienna; 2022-06-14 - 2022-06-17, HSW22
Helbig Santiago, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Helffer Bernard, U of Nantes; 2022-11-07 - 2022-11-11, BGL22
Heller Michal P., Ghent U; 2022-10-18 - 2022-10-22, VPS22
Henniart Guy, U Paris Sud; 2022-04-10 - 2022-04-15, WMH22
Herrmann Lukas, RICAM, Linz; 2022-05-05 - 2022-05-05, HSW22
Heuchl Raphael, BG Oberschützen; 2022-06-25 - 2022-07-01, IMO22
Hiebler Moritz, AAU, Klagenfurt; 2022-06-27 - 2022-07-01, IMO22
Hiptmair Ralf, ETH Zürich; 2022-06-13 - 2022-06-15, 2022-05-22 - 2022-06-03, HSW22
Hoel Håkon, U Oslo; 2022-04-30 - 2022-05-06, HSW22
Hoffmann-Ostenhof Thomas, U of Vienna; 2022-11-07 - 2022-11-11, BGL22
Hohm Olaf, HU Berlin; 2022-08-22 - 2022-08-25, AFZ22
Holtzman Roi, Weizmann Institute, Rehovot; 2022-09-18 - 2022-10-03, 2022-10-03 - 2022-10-17, DPS22

Holy Peter, –; 2022-07-04 - 2022-07-08, FMF22
Holzmann Markus, TU Graz; 2022-11-07 - 2022-11-11, BGL22
Honzik Radek, Charles U, Prague; 2022-07-04 - 2022-07-09, FMF22
Hörl Lucas, TU Vienna; 2022-06-27 - 2022-06-30, IPhO22
Huisken Gerhard, U Tübingen; 2022-11-03 - 2022-11-06, SAB2022
Hull Chris, Imperial College, London; 2022-08-02 - 2022-08-09, 2022-08-12 - 2022-08-17, AFZ22
Hwang Gyuyoung, Seoul National U; 2022-06-12 - 2022-06-18, HSW22
Ibarrondo Rubén, U Basque Country; 2022-09-04 - 2022-09-10, VPS22S
Ikeda Noriaki, Ritsumeikan U, Kusatsu; 2022-07-30 - 2022-08-27, AFZ22
Ilieva Nevena, IICT, Sofia; 2022-08-24 - 2022-09-04, AFZ22
Imre Alexander Michael, TU Vienna; 2022-07-11 - 2022-07-22, GDK22
Ionescu-Kruse Delia, IMAR, Bucharest; 2022-07-01 - 2022-07-31, RIT0520-22
Iseppi Roberta Anna, Georg-August-U, Göttingen; 2022-08-07 - 2022-08-21, AFZ22
Ishii Hiroshi, Kyoto U; 2022-11-20 - 2022-12-04, KMS22
Ivanov Rossen I., TU Dublin; 2022-07-01 - 2022-07-31, RIT0520-22
Iyer Priyanka, FZ Jülich; 2022-07-09 - 2022-07-23, GDK22
Jabiri Fatima-Ezzahra, University College London; 2022-02-28 - 2022-03-06, FAO22
Jack Robert, U Cambridge; 2022-09-25 - 2022-10-02, DPS22
Jackson Thomas, UC Davis; 2022-09-04 - 2022-09-10, VPS22S
Janssens Bas, TU Delft; 2022-08-21 - 2022-08-25, AFZ22
Jayakumar Vaishnavi, U Cologne; 2022-09-04 - 2022-09-09, VPS22S
Jerez-Hanckes Carlos, U Adolfo Ibanez, Santiago de Chile; 2022-06-05 - 2022-06-18, HSW22
Jonke Larisa, RBI Zagreb; 2022-08-07 - 2022-08-20, AFZ22
Jüngel Ansgar, TU Vienna; 2022-12-01 - 2022-12-02, KMS22
Jurco Branislav, Charles U, Prague; 2022-08-08 - 2022-08-12, AFZ22
Kafri Yariv, Technion Haifa; 2022-09-28 - 2022-10-02, DPS22
Kaimanovich Vadim, U of Ottawa; 2022-10-27 - 2022-10-31, L022022
Kalafatakis Nikolaos, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Kaltenbacher Barbara, AAU, Klagenfurt; 2022-05-17 - 2022-05-20, HSW22
Kapelari Jakob, Akademisches Gymnasium Innsbruck; 2022-06-27 - 2022-07-01, IMO22
Karasiewicz Ed, U of Utah, Saltlake City; 2022-04-09 - 2022-04-16, WMH22
Karle Volker, ISTA, Klosterneuburg; 2022-09-04 - 2022-09-09, VPS22S
Karlsson Philip, CUT, Gothenburg; 2022-02-06 - 2022-02-12, FAO22
Karner Clemens, U of Vienna; 2022-05-31 - 2022-05-31, HSW22
Karpenko Iryna, U of Vienna; 2022-11-07 - 2022-11-11, BGL22
Kasim Yusuf, U Ljubljana; 2022-09-04 - 2022-09-11, VPS22S
Kastoryano Michael, ITU Copenhagen; 2022-10-02 - 2022-10-06, VPS22
Kaur Manpreet, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Kawashima Naoki, U Tokyo; 2022-09-11 - 2022-10-07, VPS22
Kazashi Yoshihito, U Heidelberg; 2022-05-08 - 2022-05-13, HSW22
Kazeev Vladimir, U of Vienna; 2022-04-04 - 2022-04-08, SFC22
Kazeev Vladimir, U of Vienna; 2022-05-04 - 2022-06-24, HSW22
Kazeev Vladimir, U of Vienna; 2022-09-13 - 2022-10-21, VPS22
Kazes Inbar, Technion Haifa; 2022-09-04 - 2022-09-10, VPS22S
Keller Matthias, U of Potsdam; 2022-11-07 - 2022-11-11, BGL22
Kelman Ariel, HU of Jerusalem; 2022-09-05 - 2022-09-09, VPS22S
Kempe Julia, CIMS, New York; 2022-11-04 - 2022-11-07, SAB2022
Kicheva Anna, ISTA, Klosterneuburg; 2022-11-14 - 2022-12-09, KMS22
Kirchner Kristin, TU Delft; 2022-05-04 - 2022-05-20, HSW22

Kirchner Nico, TU Munich; 2022-09-04 - 2022-09-10, VPS22S
Kishi Kasumi, ISTA, Klosterneuburg; 2022-11-14 - 2022-12-09, KMS22
Koelbing Marlene, U of Vienna; 2022-07-04 - 2022-07-08, FMF22
Kogler Eva, TU Graz; 2022-07-11 - 2022-07-22, GDK22
Kollár Richard, Comenius U, Bratislava; 2022-11-14 - 2022-11-25, KMS22
Kononenko Denys, IFW Dresden; 2022-07-11 - 2022-07-22, GDK22
Korner Marianne, U of Vienna; 2022-06-27 - 2022-07-01, IPhO22
Korotchenkov Oleg, Kiev U; 2022-07-06 - 2022-08-06, 2022-12-10 - 2023-01-21, URF0722
Koschier Elias, ERG Donaustadt; 2022-06-25 - 2022-07-01, IPhO22
Kosogor Anna, NAS, Kiev; 2022-05-23 - 2022-10-08, URF0222
Kostenko Aleksey, U of Vienna; 2022-11-07 - 2022-11-11, BGL22
Kotakoski Jani, U of Vienna; 2022-07-11 - 2022-07-13, 2022-07-18 - 2022-07-20, GDK22
Kotov Alexei, U Hradec Králové; 2022-08-01 - 2022-09-11, AFZ22
Kourtis Stefanos, U of Sherbrooke; 2022-08-31 - 2022-09-15, VPS22
Kovács Péter, TU Vienna; 2022-07-14 - 2022-07-22, GDK22
Koval Karina, U Heidelberg; 2022-06-12 - 2022-06-18, HSW22
Krapivsky Paul, U of Boston; 2022-09-25 - 2022-10-02, DPS22
Krieg David, JKU, Linz; 2022-01-16 - 2022-01-21, GBC22
Kritzer Peter, RICAM, Linz; 2022-05-03 - 2022-05-05, HSW22
Kritzer Peter, RICAM, Linz; 2022-04-06 - 2022-04-08, SFC22
Kružík Martin, Czech Academy of Sciences, Prague; 2022-01-09 - 2022-02-25, SRF0222
Kuiper Jelle Mathis, Christian-Albrechts-U, Kiel; 2022-07-03 - 2022-07-09, FMF22
Kull Ilya, U of Vienna; 2022-09-13 - 2022-10-21, VPS22
Kundu Anupam, TIFR, Bangalore; 2022-09-18 - 2022-10-01, DPS22
Kunze Markus, U Cologne; 2022-02-06 - 2022-03-11, FAO22
Kurasov Pavel, U Stockholm; 2022-11-06 - 2022-11-11, BGL22
Kurchan Jorge, ENS Paris; 2022-09-25 - 2022-10-01, DPS22
Kurinczuk Robert, U of Sheffield; 2022-05-27 - 2022-05-31, 2022-09-06 - 2022-09-10, RIT0320-22
Kuzmicz-Kowalska Katarzyna, ISTA, Klosterneuburg; 2022-11-14 - 2022-11-25, KMS22
Kyrchei Ivan, NAS Ukraine, Lviv; 2022-04-12 - 2022-06-12, URF0422
Kyvala Lukas, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
La Ruben, U Oxford; 2022-04-10 - 2022-04-17, WMH22
Lacroix-À-Chez-Toine Bertrand, KCL, London; 2022-09-18 - 2022-10-01, DPS22
Laird Thomas, U of Nottingham; 2022-09-01 - 2022-09-18, SRF0322
Lanard Thomas, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Langer Sophie, TU Darmstadt; 2022-05-29 - 2022-06-03, HSW22
La Rivière Bowy, TU Delft; 2022-09-04 - 2022-09-10, VPS22S
Lattuada Enrico, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Lau Liam L.H., Rutgers U; 2022-09-03 - 2022-09-12, VPS22S
Läuchli Andreas, PSI, Villigen; 2022-09-11 - 2022-09-16, VPS22
Lazaroiu Iuliu-Calin, IFIN-HH, Bucharest; 2022-08-01 - 2022-08-22, AFZ22
Lecomte Vivien, U Grenoble Alpes; 2022-09-21 - 2022-09-29, DPS22
Le Doussal Pierre, ENS Paris; 2022-09-19 - 2022-09-30, DPS22
Legeza Örs, WIGNER RCP, Budapest; 2022-09-12 - 2022-09-16, 2022-10-03 - 2022-10-05, VPS22
Le Maître François, U Paris-Diderot; 2022-07-03 - 2022-07-09, FMF22
Leoni Luca, U Bologna; 2022-07-14 - 2022-07-22, GDK22
Lepri Stefano, ISC, Florence; 2022-09-26 - 2022-10-05, DPS22
Levy Doron, U of Maryland; 2022-11-20 - 2022-11-27, KMS22
Li Jheng-Wei, LMU Munich; 2022-09-05 - 2022-09-16, VPS22+VPS22S

Li Jimin, U Bonn; 2022-10-05 - 2022-10-07, 2022-09-26 - 2022-09-29, DPS22+VPS22
Li Qin, U of Wisconsin-Madison; 2022-05-15 - 2022-05-19, HSW22
Li Yahui, TU Munich; 2022-09-04 - 2022-09-10, VPS22S
Liaw Constanze, U Delaware; 2022-11-06 - 2022-11-12, BGL22
Lie Han Cheng, U of Potsdam; 2022-05-14 - 2022-05-21, HSW22
Limmer David, UC, Berkeley; 2022-09-22 - 2022-10-01, DPS22
Lin Shenghsuan, TU Munich; 2022-09-12 - 2022-09-16, VPS22
Liu Yue, U of Texas, Arlington; 2022-05-13 - 2022-06-10, RIT0121
Ljubotina Marko, ISTA, Klosterneuburg; 2022-09-06 - 2022-10-21, VPS22
Loeffler Matthias, ETH Zürich; 2022-05-29 - 2022-06-02, HSW22
Lombardo Salvo Danilo, U of Vienna; 2022-11-14 - 2022-12-09, KMS22
Longo Marcello, ETH Zürich; 2022-04-03 - 2022-04-08, SFC22
Longo Marcello, ETH Zürich; 2022-05-08 - 2022-05-13, HSW22
Lootens Laurens, Ghent U; 2022-10-02 - 2022-10-06, VPS22
López Manzanares Esperanza, UAM-CSIC, Madrid; 2022-09-11 - 2022-09-21, VPS22
Lorbek Stefan, BRG Mürzzuschlag; 2022-06-30 - 2022-06-30, IPhO22
Losert-Valiente Kroon Christiane, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Loulidi Faedi, U Paul Sabatier, Toulouse; 2022-10-02 - 2022-10-14, VPS22
Lozovski Valeri, Taras Shevchenko U Kiev; 2022-06-06 - 2022-10-06, URF0622
Lu Hengfei, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Lucia Angelo, U Complutense de Madrid; 2022-10-02 - 2022-10-21, VPS22
Ludwig Andreas, UC, Santa Barbara; 2022-10-02 - 2022-10-08, VPS22
Lun Pascal, BRG Wörgl; 2022-06-27 - 2022-07-01, IPhO22
Maas Jan, ISTA, Klosterneuburg; 2022-11-04 - 2022-11-04, EM22
Madrigal Cianci Juan Pablo, EPFL, Lausanne; 2022-05-01 - 2022-05-08, HSW22
Maes Christian, KU Leuven; 2022-09-18 - 2022-10-01, DPS22
Mahapatra Chitaranjan, CNRS/Paris Saclay; 2022-11-13 - 2022-11-20, KMS22
Mahnkopf Joachim, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Majcen Peter, U Padua; 2022-09-04 - 2022-09-10, VPS22S
Majumdar Satya, U Paris Sud, Orsay; 2022-09-18 - 2022-10-01, DPS22
Malosso Cesare, SISSA, Trieste; 2022-07-10 - 2022-07-22, GDK22
Manaparambil Anand, Adam Mickiewicz U Poznan; 2022-09-04 - 2022-09-10, VPS22S
Manmana Salvatore, U Göttingen; 2022-09-13 - 2022-09-17, 2022-08-28 - 2022-09-08, VPS22
Marcati Carlo, U Pavia; 2022-06-17 - 2022-06-24, HSW22
Marcher Simon, HTBLA Kaindorf; 2022-06-27 - 2022-07-01, IPhO22
Marquetand Philipp, U of Vienna; 2022-07-18 - 2022-07-22, GDK22
Martens Sascha, U of Vienna; 2022-11-15 - 2022-11-15, KMS22
Martin Calin, U of Vienna; 2022-09-30 - 2022-10-31, RIT0522
Martyn John, MIT, Cambridge; 2022-09-02 - 2022-09-10, VPS22S
Marynets Kateryna, TU Delft; 2022-09-30 - 2022-10-31, RIT0522
Mason James, U Cambridge; 2022-11-20 - 2022-11-25, KMS22
Massa Dario, NCBJ, Warsaw; 2022-07-10 - 2022-07-22, GDK22
Massimini Annamaria, TU Vienna; 2022-11-14 - 2022-11-18, KMS22
Matringe Nadir, U Paris; 2022-05-27 - 2022-06-08, 2022-09-02 - 2022-09-10, RIT0320-22
Matthies Hermann, TU Braunschweig; 2022-05-03 - 2022-05-12, HSW22
Maurer Reinhard, U Warwick; 2022-07-14 - 2022-07-16, GDK22
Mazur Jakub, Jagiellonian U, Krakow; 2022-09-04 - 2022-09-10, VPS22S
McCulloch Ian, U of Queensland, Brisbane; 2022-08-30 - 2022-09-30, VPS22+VPS22S
McGlade Finn, UC San Diego; 2022-04-10 - 2022-04-16, WMH22

Meerson Baruch, HU of Jerusalem; 2022-09-19 - 2022-10-13, DPS22
Mejak Severin, U of Copenhagen; 2022-07-04 - 2022-07-15, FMF22
Mejia Diego, SU; 2022-07-03 - 2022-07-09, FMF22
Mekonnen Manuel, U of Vienna; 2022-08-29 - 2022-10-21, VPS22
Merino-Aceituno Sara, U of Vienna; 2022-11-14 - 2022-12-09, KMS22
Michel Simon, U Zürich; 2022-06-12 - 2022-06-17, HSW22
Michelangeli Alessandro, U Bonn; 2022-11-06 - 2022-11-12, BGL22
Michor Johanna, U of Vienna; 2022-11-07 - 2022-11-11, BGL22
Michor Peter, U of Vienna; 2022-05-23 - 2022-07-01, RIT0222
Mila Frédéric, EPFL, Lausanne; 2022-10-16 - 2022-10-21, VPS22
Mildenberger Heike, ALU Freiburg; 2022-07-03 - 2022-07-09, FMF22
Millhouse Julia, U of Vienna; 2022-07-04 - 2022-07-04, FMF22
Mincheva Maya, Northern Illinois U; 2022-11-19 - 2022-11-26, KMS22
Minchington Thomas, ISTA, Klosterneuburg; 2022-11-21 - 2022-11-25, KMS22
Minguez Alberto, U of Vienna; 2022-04-10 - 2022-04-16, WMH22
Minguez Alberto, U of Vienna; 2022-05-27 - 2022-06-08, 2022-12-09 - 2022-12-22, RIT0320-22
Mishra Purnedu, Norwegian U of Life Sciences, As; 2022-11-28 - 2022-12-04, KMS22
Miti Antonio, MPIM, Bonn; 2022-08-21 - 2022-08-26, AFZ22
Mitrea Dorina, Baylor U, Waco; 2022-11-06 - 2022-11-13, BGL22
Mitrea Marius, Baylor U, Waco; 2022-11-06 - 2022-11-13, BGL22
Mohammadpour Rahman, TU Vienna; 2022-07-04 - 2022-07-08, FMF22
Möller Gunnar, U of Kent; 2022-09-03 - 2022-09-16, VPS22
Møller Frederik, TU Vienna; 2022-09-15 - 2022-09-16, VPS22
Molnár András, U of Vienna; 2022-08-29 - 2022-10-21, VPS22
Mong Roger, U Pittsburgh; 2022-09-11 - 2022-09-13, 2022-09-13 - 2022-10-07, VPS22
Montaña Lopez Jordi Arnau, MPI Quantum Optics, Garching; 2022-09-04 - 2022-09-10, VPS22S
Montangero Simone, U Padova; 2022-09-13 - 2022-09-16, VPS22
Montoya Diana Carolina, U of Vienna; 2022-07-05 - 2022-07-08, FMF22
Moreno Miguel, U of Vienna; 2022-07-04 - 2022-07-08, FMF22
Mori Francesco, U Paris-Saclay; 2022-09-19 - 2022-09-24, DPS22
Moschella Carmela, U of Vienna; 2022-11-14 - 2022-12-09, KMS22
Mukamel David, Weizmann Institute, Rehovot; 2022-09-18 - 2022-10-12, DPS22
Mulevicius Vincentas, MPIM, Bonn; 2022-11-02 - 2022-12-21, 2022-10-01 - 2022-11-02, JRF0122
Müller Patrick, U of Konstanz; 2022-11-21 - 2022-11-25, KMS22
Müller Sandra, TU Vienna; 2022-07-04 - 2022-07-08, FMF22
Mundy Sam, Princeton U; 2022-04-11 - 2022-04-17, WMH22
Mussnig-Wytrzens Claudia, U of Vienna; 2022-11-21 - 2022-12-02, KMS22
Nachtergaele Bruno, UC Davis; 2022-09-04 - 2022-09-09, 2022-10-02 - 2022-10-15, VPS22+VPS22S
Nahari Hadi, U Lyon; 2022-08-01 - 2022-08-26, AFZ22
Nahum Adam, ENS Paris; 2022-10-04 - 2022-10-07, VPS22
Najafi Fahimeh, U Oslo; 2022-07-13 - 2022-07-24, GDK22
Nárožný Jiří, Charles U, Prague; 2022-08-15 - 2022-08-26, AFZ22
Naumann Jan, FU Berlin; 2022-09-04 - 2022-09-10, VPS22S
Neria Omer Ben, HU of Jerusalem; 2022-07-03 - 2022-07-08, FMF22
Ngamwongwan Lappawat, Utrecht U; 2022-07-10 - 2022-07-24, GDK22
Ngoipala Apinya, U Limerick; 2022-07-10 - 2022-07-24, GDK22
Nguyen Hai Mi, Columbia University, New York; 2022-09-03 - 2022-09-09, VPS22S
Nickl Richard, U Cambridge; 2022-05-29 - 2022-06-05, HSW22
Nicolussi Noema, U of Potsdam; 2022-11-07 - 2022-11-11, BGL22

Nielsen Anne, U Arhus; 2022-10-02 - 2022-10-08, VPS22
Niestierkina Vira, NAS Ukraine, Kharkiv; 2022-04-01 - 2022-07-31, URF0122
Niestijl Milan, TU Delft; 2022-08-22 - 2022-08-27, AFZ22
Nikshych Dmitri, U of New Hampshire; 2022-08-07 - 2022-08-19, AFZ22
Niu Sen, U Paul Sabatier, Toulouse; 2022-09-11 - 2022-09-17, VPS22
Niyogi Sucharita, Vellore Institute of Technology; 2022-07-10 - 2022-07-24, GDK22
Noack Reinhard, Philipps U, Marburg; 2022-09-05 - 2022-09-17, VPS22
Nobile Fabio, EPFL, Lausanne; 2022-05-01 - 2022-05-20, 2022-05-29 - 2022-06-18, HSW22
Nobile Fabio, EPFL, Lausanne; 2022-04-03 - 2022-04-08, SFC22
Noh Jae Dong, U of Seoul; 2022-09-23 - 2022-09-30, DPS22
Nolan Brien, Dublin City U; 2022-02-13 - 2022-02-19, FAO22
Nouy Anthony, CN, Nantes; 2022-04-04 - 2022-04-08, SFC22
Novikau Ivan, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Obermaier Doris, BRG1 Vienna; 2022-06-27 - 2022-07-01, IMO22
Ofner Maximilian, U of Vienna; 2022-01-31 - 2022-03-11, FAO22
Ogata Yoshiko, U Tokyo; 2022-09-25 - 2022-10-08, VPS22
Ohira Toru, Nagoya U; 2022-11-21 - 2022-11-25, KMS22
Okada Emile, U Oxford; 2022-04-10 - 2022-04-16, WMH22
Ollertz Sascha, U Würzburg; 2022-11-13 - 2022-11-19, KMS22
Opschoor Joost, ETH Zürich; 2022-05-29 - 2022-06-03, HSW22
Osborne Tobias, ITP Hannover; 2022-10-03 - 2022-10-07, VPS22
Oseledets Ivan; 2022-09-11 - 2022-09-17, VPS22
Oshikawa Masaki, ISSP, U of Tokyo; 2022-09-26 - 2022-10-11, VPS22
Ostermann Matthias, U of Vienna; 2022-02-07 - 2022-02-10, FAO22
Otsuka Shotaro, Med U Vienna; 2022-12-01 - 2022-12-01, KMS22
Otto Felix, MPI MiS Leipzig; 2022-11-03 - 2022-11-05, EM22
Palaparthy Krishna Chaitanya, TU Dresden; 2022-09-04 - 2022-09-09, VPS22S
Panara Shanil, Imperial College, London; 2022-07-10 - 2022-07-22, GDK22
Pandzic Pavle, U Zagreb; 2022-04-10 - 2022-04-16, WMH22
Pankrashkin Konstantin, U Oldenburg; 2022-11-06 - 2022-11-12, BGL22
Papic Zlatko, U Leeds; 2022-08-29 - 2022-09-17, VPS22
Park Hyunggyu, KIAS, Seoul; 2022-09-23 - 2022-10-09, DPS22
Pawlik Konrad, Jagiellonian U, Krakow; 2022-09-04 - 2022-09-10, VPS22S
Peherstorfer Benjamin, CIMS, New York; 2022-05-03 - 2022-05-06, HSW22
Pelinovsky Dmitry, McMaster U, Hamilton; 2022-05-17 - 2022-06-10, RIT0121
Pérez-Carrasco Rubén, Imperial College, London; 2022-11-11 - 2022-11-17, KMS22
Pérez-García David, U Complutense de Madrid; 2022-10-03 - 2022-10-07, VPS22
Perez Romero Arturo, Georg-August-U, Göttingen; 2022-09-04 - 2022-09-10, VPS22S
Pernegger Felix, BG/BRG Ried im Innkreis; 2022-06-27 - 2022-07-01, IMO22
Perugia Ilaria, U of Vienna; 2022-04-04 - 2022-04-08, SFC22
Perugia Ilaria, U of Vienna; 2022-06-13 - 2022-06-17, HSW22
Peterseim Daniel, U Augsburg; 2022-03-31 - 2022-04-08, SFC22
Petersen Philipp, U of Vienna; 2022-05-03 - 2022-06-24, HSW22
Petersen Philipp, U of Vienna; 2022-04-04 - 2022-04-08, SFC22
Petrova Elena, ISTA, Klosterneuburg; 2022-09-05 - 2022-09-09, VPS22S
Peurichard Diane, INRIA Paris; 2022-11-21 - 2022-11-25, KMS22
Pfau David, DeepMind, London; 2022-07-13 - 2022-07-15, GDK22
Piecuch Anja, WRG/ORG Wels; 2022-06-26 - 2022-07-01, IPhO22
Pillichshammer Friedrich, JKU, Linz; 2022-04-04 - 2022-04-08, SFC22

Pinheiro Diana, Vienna Biocenter; 2022-11-14 - 2022-11-18, KMS22
Pinto Allison, HU Berlin; 2022-08-22 - 2022-08-26, AFZ22
Pires Ferreira Pedro, USP; 2022-07-10 - 2022-07-22, GDK22
Pittenauer Michael, TU Vienna; 2022-07-11 - 2022-07-22, GDK22
Plati Riccardo, ETH Zürich; 2022-07-04 - 2022-07-08, FMF22
Plunder Steffen, U of Vienna; 2022-12-01 - 2022-12-02, KMS22
Pock Thomas, TU Graz; 2022-07-12 - 2022-07-13, GDK22
Poilblanc Didier, U Paul Sabatier, Toulouse; 2022-09-13 - 2022-09-17, VPS22
Polechova Jitka, U of Vienna; 2022-11-14 - 2022-11-26, KMS22
Pollack Aaron, UC San Diego; 2022-04-10 - 2022-04-16, WMH22
Pollack Aaron, UC San Diego; 2022-04-16 - 2022-04-23, RIT0422
Pollmann Frank, TU Munich; 2022-09-04 - 2022-09-16, VPS22+VPS22S
Portaro Simone, KAUST, Thuwal; 2022-11-13 - 2022-11-19, KMS22
Posch Harald, U of Vienna; 2022-09-19 - 2022-10-14, DPS22
Poscher Sebastian, None; 2022-07-15 - 2022-07-15, GDK22
Posilicano Andrea, U of Insubria, Como; 2022-11-06 - 2022-11-12, BGL22
Post Olaf, U of Trier; 2022-11-06 - 2022-11-13, BGL22
Powell Catherine, U Manchester; 2022-05-07 - 2022-05-14, HSW22
Pradhan Sunny, U Bologna; 2022-09-04 - 2022-09-09, VPS22S
Pradovera Davide, U of Vienna; 2022-05-02 - 2022-06-24, HSW22
Pradovera Davide, U of Vienna; 2022-04-04 - 2022-04-08, SFC22
Praetorius Dirk, TU Vienna; 2022-05-10 - 2022-05-11, HSW22
Praetorius Dirk, TU Vienna; 2022-04-04 - 2022-04-08, SFC22
Prasad Dipendra, IIT Bombay; 2022-04-10 - 2022-04-17, WMH22
Preziosi Luigi, Politecnico, Torino; 2022-11-13 - 2022-11-19, KMS22
Pultar Dominik, BRG Wien 6; 2022-06-25 - 2022-07-01, IMO22
Quinlivan Dominguez Jon Eunan, U Barcelona; 2022-07-10 - 2022-07-22, GDK22
Ragone Michael, UC Davis; 2022-09-03 - 2022-09-10, VPS22S
Raikos Andreas, University College London; 2022-09-04 - 2022-09-10, VPS22S
Rampp Michael Alexander, PKS-MPG; 2022-09-04 - 2022-09-09, VPS22S
Ranalli Luigi, U of Vienna; 2022-07-10 - 2022-07-22, GDK22
Ravanpak Zohreh, IMPAN, Warsaw; 2022-08-16 - 2022-08-26, AFZ22
Raz Oren, Weizmann Institute, Rehovot; 2022-09-23 - 2022-09-29, DPS22
Reibnegger Markus, U of Vienna; 2022-04-11 - 2022-04-15, WMH22
Reich Sebastian, U of Potsdam; 2022-05-15 - 2022-05-21, HSW22
Reiner Madlen Maria, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Repellin Cécile, LBMMC, Grenoble; 2022-10-09 - 2022-10-14, VPS22
Reutter David, U Hamburg; 2022-08-14 - 2022-08-19, AFZ22
Reuveni Shlomi, Tel Aviv U; 2022-09-26 - 2022-10-10, DPS22
Rezaei Human, INRAe, Jouy en Josas; 2022-11-20 - 2022-11-25, KMS22
Richardson Alex, U Edinburgh; 2022-11-13 - 2022-11-18, KMS22
Rieger Christian, Philipps U, Marburg; 2022-05-08 - 2022-05-13, HSW22
Rigobello Marco, U Padua; 2022-09-04 - 2022-09-10, VPS22S
Rioseco Paola, U de Chile, Santiago; 2022-01-01 - 2022-03-13, FAO22
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Rohrbach Paul, U Cambridge; 2022-05-01 - 2022-05-07, HSW22

Romano Salvatore, U of Vienna; 2022-07-11 - 2022-07-22, GDK22
Romanova-Michaelides Maria, U Genève; 2022-11-15 - 2022-11-18, KMS22
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Trias Justin, Imperial College, London; 2022-04-07 - 2022-04-16, WMH22
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Tu Hong-Hao, TU Dresden; 2022-09-25 - 2022-10-08, VPS22
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Umeda Tomio, U of Hyogo; 2022-11-04 - 2022-11-12, BGL22
Unglert Nico, TU Vienna; 2022-07-11 - 2022-07-22, GDK22
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Urban Liam, U of Vienna; 2022-02-07 - 2022-02-18, FAO22
Uschmajew André, MPI MiS Leipzig; 2022-05-08 - 2022-05-11, HSW22
Usuga Andrés Felipe, U Autonoma Barcelona; 2022-07-11 - 2022-07-22, GDK22
Valach Fridrich, Imperial College, London; 2022-08-21 - 2022-08-26, AFZ22
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Vanderstraeten Laurens, Ghent U; 2022-09-12 - 2022-09-16, VPS22
Vanham Raphael, Akademisches Gymnasium Innsbruck; 2022-06-27 - 2022-07-01, IMO22
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Vidnyánszky Zoltán, CalTech Pasadena; 2022-07-04 - 2022-07-09, FMF22
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Wang Sven, MIT, Cambridge; 2022-05-29 - 2022-06-05, HSW22
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Publisher: Christoph Dellago, Director, The Erwin Schrödinger International Institute for Mathematics and Physics, University of Vienna, Boltzmanngasse 9, 1090 Vienna / Austria. **Editorial Office:** Christoph Dellago, Beatrix Wolf. **Cover-Design:** steinkellner.com **Photos:** Österreichische Zentralbibliothek für Physik, Philipp Steinkellner. **Printing:** Berger, Horn.