Erwin Schrödinger International Institute
for Mathematics and Physics

ESI

universität wien

ANNUAL REPORT 2023

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.

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 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.

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.

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 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 2023

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Preface

Message of the Director

I am delighted to present the Annual Report for 2023 of the Erwin Schrdinger Institute for Mathematics and Physics. After several years of disruptions caused by the COVID-19 pandemic, 2023 has seen a return to near pre-pandemic normalcy at the Institute. Throughout the year, the ESI hosted four thematic programmes and eleven workshops, along with numerous other scientific activities, attracting approximately 800 scientists from around the world. The majority of these activities were conducted onsite, with only a few participants joining online. This underscores the importance of personal interactions in fostering meaningful scientific discussions.

One of the highlights of 2023 was the ESI@30 Symposium, celebrating the Institute's 30th anniversary. Since its founding in 1993, the ESI has served as an international hub for mathematics and physics, facilitating scientific discussions and advancing scholarly research in these fields. At the symposium, we were honored to welcome Sebastian Schütze, Rector of the University of Vienna, as well as many colleagues who have contributed to the ESI's development over the years. Distinguished speakers, including Nobel Laureate Anton Zeilinger, covered a wide range of current topics in mathematics and physics, reflecting the broad scientific scope of the ESI. The symposium also provided a valuable opportunity to reflect on the Institute's mission, review past achievements, and envision the future of the ESI.

To commemorate the 30th anniversary, we created a video of the Institute, which can be viewed on the ESI YouTube Channel (https://www.youtube.com/watch?v=zIgFvKfz79o). The channel now features over 1,300 videos of talks given at the Institute, watched by viewers worldwide, including those from less privileged regions where travel to the ESI is challenging. These videos are complemented by our social media activities on platforms such as X/Twitter, Blue Sky, and Instagram. Follow us on these platforms to stay updated on ESI's activities!

The composition of the Scientific Advisory Board (SAB) of the ESI changed at the end of 2022. After two terms, Mirjam Cvetič (University of Pennsylvania, Philadelphia) retired from the Board. We are deeply grateful for her valuable advice and support over the years, especially her leadership as Chair from 2019 to 2022. Mariana Graña (CEA Paris-Saclay) joined the Board on January 1, 2023, as a new member. With the help of the SAB and the scientific community, the ESI continues to do what it does best: to bring people together and provide an excellent environment for scientific discussion, as well as the quiet and peace required for intense intellectual work in mathematics and physics.

Christoph Dellago
Director of the ESI

August 2024

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; In 2023, no SRF visited the ESI.

(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 2023

The list of research areas in mathematics and physics covered by the scientific activities of the Erwin Schrödinger Institute in 2023 shows a wide variety.

Thematic Programmes

In 2023, the following thematic programmes took place at the ESI:

- *The Dynamics of Planetary-scale Fluid Flows*
  April 11 – June 2, 2023
  Organizers: Adrian Constantin (U of Vienna), David Dritschel (U of St Andrews), Nathan Paldor (The Hebrew U of Jerusalem)

- *Spectral Theory and Mathematical Relativity*
  June 5 – July 28, 2023
  Organizers: Piotr T. Chruściel (U of Vienna), Peter Hintz (ETH Zurich), Alexander Strohmaier (U of Leeds), Steven Morris Zelditch† (Northwestern U Evanston)

- *Quantum Field Theory at the Frontiers of the Strong Interaction*
  July 31 – September 1, 2023
  Organizers: André H. Hoang (U of Vienna), Simon Plätzer (U of Graz), Massimiliano Procura (U of Vienna), Malin Sjödahl (Lund U), Iain Stewart (MIT)

- *Geometry beyond Riemann: Curvature and Rigidity*
  September 11 – November 3, 2023
  Organizers: Ivan Izmestiev (TU of Vienna), Athanase Papadopoulos (Institut de Recherche Mathématique Avancée), Marc Troyanov (EPFL, Lausanne), Sumio Yamada (Gakushuin U)

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

Workshops

In addition to these thematic programmes, nine workshops, the Symposium ESI@30 at the occasion of the 30th anniversery of the ESI including the ESI Medal Award Ceremony 2023 and the IMO-Training took place at the ESI in 2023, complemented by visits of some individual scholars who collaborated with scientists of the University of Vienna and the local community. Here is a list of these activities:

- *Workshop: Blackbody Radiation Induced Effects and Phenomena*
  February 13 – 17, 2023
  Organizers: Philipp Haslinger (TU of Vienna), Francesco Intravaia (Humboldt U), Arkadiusz Kosior (U of Innsbruck), Dennis Rätzel (Center for Applied Space Technology and Microgravitation, U of Bremen)

- *Workshop: Between Regularity and Defects: Variational and Geometrical Methods in Materials Science*
  February 20 – 24, 2023
  Organizers: Stefano Almi (U Federico II of Napoli), Anastasia Molchanova (U of Vienna)

- *Workshop: Non-regular Spacetime Geometry*
  March 13 – 24, 2023
  Organizers: Piotr T. Chruściel (U of Vienna), Melanie Graf (U of Hamburg), Michael

Kunzinger (U of Vienna), Ettore Minguzzi (U of Florence), Roland Steinbauer (U of Vienna)

– *Workshop: Non-commutative Geometry meets Topological Recursion*
April 24 – 28, 2023
Organizers: Gaëtan Borot (Humboldt U), Elba Garcia Failde (Sorbonne U), Harald Grosse (U of Vienna), Masoud Khalkhali (Western U, Ontario), Hannah Markwig (U of Tübingen), Raimar Wulkenhaar (U of Münster)

– *International Mathematical Olympiad Training 2023*
June 26 – 30 and October 26 – 31, 2023
Organizer: Theresia Eisenkölbl (U of Vienna)

– *Workshop: Geometric and Asymptotic Group Theory with Applications 2023 - Groups and Dynamics*
July 17 – July 21, 2023
Organizers: Christopher Cashen (U of Vienna), Javier de la Nuez González (Korea Institute for Advanced Study), Alexandra Edletzberger (U of Vienna), Yash Lodha (U of Hawaii)

– *Workshop: Large-N Matrix Models and Emergent Geometry*
September 4 – 8, 2023
Organizers: Sumit Ranjan Das (U of Kentucky), Masanori Hanada (Queen Mary U of London), Sean Hartnoll (U of Cambridge), Antal Jevicki (Brown U), Joanna Karczmarek (U of British Columbia Vancouver), Harold Steinacker (U of Vienna)

– *Symposium: ESI@30 & ESI Medal Award Ceremony 2023*
November 9 – 10, 2023
Organizers: Christoph Dellago (U of Vienna, ESI Director), Stefan Fredenhagen (U of Vienna), Ilaria Perugia (U of Vienna), Adrian Constantin (U of Vienna), Michael Eichmair (U of Vienna), Bernadett Weinzierl (U of Vienna), Jakob Yngvason (U of Vienna)

– *Workshop: Analysis and Geometry in Several Comples Variables*
November 20 – 24, 2023
Organizers: Peter Ebenfelt (U of California, San Diego), Purvi Gupta (Indian Institute of Science, Bengalore), Bernhard Lamel (U of Vienna), Nordine Mir (Texas A&M U at Qatar)

– *Workshop: Mathematical Relativity: Past, Present, Future*
December 4 – 7, 2023
Organizers: Piotr T. Chruściel (U of Vienna), Pedro del Real Lavergne (U of Vienna), Michael Eichmair (U of Vienna), Gerhard Huisken (U of Tübingen), Jim Isenberg (U of Oregon)

– *Workshop: New perspective on Shape and Topology Optimization*
December 11 – 15, 2023
Organizers: Elisa Davoli (TU of Vienna), Idriss Mazari-Fouquer (CEREMADE U Paris Dauphine), Kevin Sturm (TU of Vienna)

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 2023.

- Agnese Callegari (U of Gothenburg), Roberto Cerbino (U of Vienna), Norma Caridad Palmero Cruz (U of Guanajuato), Giuseppe Pesce (U of Gothenburg), Giovanni Volpe (U of Gothenburg), *Non-equilibrium hydrodynamic Casimir-like forces in colloidal suspensions*, March 1 – August 31, 2023
- Henk Bruin (U of Vienna), Charles Fougeron (IRIF, Paris), Davide Ravotti (U of Vienna), Dalia Terhesiu (U of Leiden), *Limit Theorems for Parabolic Dynamical Systems*, April 13 – 21 and June 5 – 16, 2023
- Harald Grosse (U of Vienna), Naoyuki Kanomata (Tokyo U of Science), Akifumi Sako (Tokyo U of Science), Raimar Wulkenhaar (U Münster), *Integrability*, April 13 – August 31, 2023
- Christopher Cashen (U of Vienna), Pallavi Dani (Louisiana State U, Baton Rouge), Kevin Schreve (Louisiana State U, Baton Rouge), Emily Stark (Wesleyan U), *Rigidity in Coxeter Groups*, July 4 – August 4, 2023
- Jianrong Li (U of Vienna), Arkady Berenstein (U of Oregon), Jacob Greenstein (U of California, Riverside), *Tropical Mirror Symmetry, Langlands Duality, and Symmetries in Mathematics and Physics*, June 12 - September 1, 2023

Junior Research Fellows

In the year 2023 the following Junior Research Fellows visited the ESI to work on their research projects:

- Carlos Pérez Sánchez (U Heidelberg), *Random finite gauge matrix geometries: numerical and analytic aspects*, March 1 – September 12, 2023.
- Sergio Gómez (U of Pavia), *Structure-preserving methods for nonlinear PDEs*, March 13 – September 13, 2023.
- Cesare Tresca (U dell'Aquila), *Dark matteR dEtection viA novel Materials (DREAM)*, March 1 – April 30, 2023.
- Şeyma Karadereli (Bogazii U), *Real algebraic overtwisted contact structures on 3-spheres with negative invariants*, February 1 – June 12, 2023.
- Yang Yang (Mathematical Research Institute of Oberwolfach), *Landau–Ginzburg models and the string-net construction of CFT correlators*, February 1 – May 19, 2023.
- Fiona Torzewska (U of East Anglia), *From motion groupoids to defect TQFT*, April 1 – September 30, 2023.
- Kaushlendra Kumar (U of Hannover), *IKKT model & Gravity*, March 5 – June 15, 2023.

- Abhiram M. Kidambi (MPI MiS Leipzig), *Novel mathematical structures in 3d quantum gravity*, September 14 – December 14, 2023 & April 1 – 30, 2024.
- Onirbam Islam (U of Potsdam), *Feynman Greens Operators on a Black Hole Spacetime*, June 24 – July 15, 2023.

Other activities

On March 8, 2023 an Erwin Schrödinger Lecture by Georg Kaser (U of Innsbruck) on the very timely topic "Our changing climate system" was held.

Furthermore, several individual talks by invited scientists like Elliott H. Lieb (Princton U) were hosted.

Oleg Korotchenkov (Kiev U), an Ukrainian Research Fellow visited the ESI for another months in 2023 in addition to his stay in 2022, though the special Fellowship programme for Ukrainian scientist had been terminated by the end of 2022.

The ESI offered also space for the following external activities:

- *ViRAPID Retreat* on March 27, 2023
- The *Kharkiv-Vienna International Science School* for Ukrainian high-school students from Kharkiv, Ukraine, all finalists of the All-Ukrainian Science Olympiads, September 25 – 29, 2023
- *Vienna Soft Matter Day* organized by Andreas Zöttl, Faculty of Physics, December 1, 2023

As already in the years before, the ESI hosted also in 2023 the MCMP Seminars of the Master Class Mathematical Physics, a joint activity of the Faculties of Mathematics and Physics, organized by David M. Fajman and Roland Donninger.

- *Maximilian Ofner*, Faculty of Mathematics, U of Vienna on "Dynamics of relativistic fluids in cosmology", March 6, 2023
- *Iryna Karpenko*, Faculty of Mathematics, U of Vienna on "Riemann-Hilbert problems and integrable nonlinear partial differential equations", October 9, 2023
- *Nils Carqueville*, Faculty of Physics, U of Vienna on "A first taste of Topological Quantum Field Theory", November 13, 2023
- *Jörg Weber*, Faculty of Mathematics, U of Vienna on "Travelling water waves", December 11, 2023

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

- *DocSchools Meet Arts: Science and Art a desirable symbiosis?*, interdisciplinary panel discussion on January 19, 2023
- *DocSchools Meet ChatGPT in Research and Higher Education*, panel discussion on November 28, 2023

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. On January 1, 2023, Bernadett Weinzierl (Physics) was newly appointed to the Kollegium replacing André H. Hoang, who completed his third term in the Kollegium. The Institute is very grateful to him for many years of valuable contributions and support. Hence, in the period January 1 - December 31, 2023, the Kollegium consisted of A. Constantin (Mathematics), C. Dellago (Physics), M. Eichmair (Mathematics), S. Fredenhagen (Physics), I. Perugia (Mathematics) and B. Weinzierl (Physics). 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 2023, the SAB consisted of: Douglas N. Arnold (U Minnesota), Alberto Bressan (Penn State U), Sandra Di Rocco (KTH, Stockholm) [chair], Domenico Giulini (U Hannover), Mariana Graña (CEA Paris Saclay), Gerhard Huisken (U Tübingen), Julia Kempe (NYU), and Francesco Sciortino (U of Rome).

The composition of the SAB of the ESI changed by the end of the year 2022. After two terms of office Mirjam Cvetič (U of Pennsylvania, Philadelphia) has retired from the Board. The Institute is very grateful to her for many years of valuable advice and support, especially for her work as chair of the Board in the years 2019 - 2022. Mariana Graña (CEA Paris Saclay) joined the Board on January 1, 2023, as a new member.

Administration

Since May 2023 Sophie Kurzmann returned for part-time to the administrative team beneath her work as video editor and ESI YouTube channel manager. Blanka Molnár left the ESI administration team at the end of September 2023 since she moved back to her home-country Hungary. We would like to thank her for her valuable work for the ESI during the last two years. Especially for establishing the ESI on the social media platform x/twitter. The open position at the administration could be filled with Roxelane Schön in December 2023. The administration team continued its work with customary efficiency for our visitors, research fellows and board.

Christoph Dellago August 2024

ESI Director

The ESI in 2023: 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, Bernadett Weinzierl

Administration: Sophie Kurzmann (from May 2023 on), Maria Marouschek, Blanka Molnár (till October 2023), Roxelane Schön (from December 2023 on), Beatrix Wolf (Head)

Computing and networking support: Marion Praschl, Thomas Leitner

Video recording and publishing: Sophie Kurzmann

International Scientific Advisory Board in 2023:

Douglas N. Arnold (U Minnesota)	Domenico Giulini (U Hannover)
Alberto Bressan (Penn State U)	Mariana Graña (CEA Paris Saclay)
Sandra Di Rocco (KTH, Stockholm) [chair]	Gerhard Huisken (U Tübingen)
Julia Kempe (NYU)	Francesco Sciortino (U of Rome)

Budget and visitors: In 2023 the support of ESI received from the University of Vienna amounted to **€ 790 000**. Additionally the ESI obtained a total of € 60 745 in third party funds from external sources for the support of the various activities.

The total amount spent in 2023 on scientific activities was € 546 178, € 485 973 from the ESI budget plus the external third party funds of € 60 745, while the expenditures for administration (mainly salaries) and infrastructure (mainly rent) amounted to € 515 377.

The total number of scientists visiting the Erwin Schrödinger Institute in 2023 was 753, see pages 107 – 123. Gender ratio: male: 570 (75,7 %), female: 126 (16,7 %), non-binary: 5 (0,7 %), prefer not to disclose or unspecified 52 (6,9 %). Moreover, 71 registered people participated online in various activities of the ESI.

ESI research documentation: Starting from January 2013, the ESI research output is tracked using the published articles and the arXiv database. The ESI website provides web links to these arXiv preprints and to the local ESI preprints collected until December 2013. It also contains the bibliographical data of the already published articles. Moreover, publications which appeared in 2023 but are related to past ESI activities, starting from 2011, have been tracked as well in order to provide a long-term evidence of the ESI research outcome success.

The total number of preprints and publications contributed to the ESI research documentation database in 2023 is 75 [related to the activities in 2023: 68, related to the activities in previous years: 7], see pages 101 – 105 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 293 videos were recorded in 2023 amounting

to more than 225 hours of video material. These videos have been accessed 83.113 times in 2023 alone, which is a 30% increase to last year. Currently, the number of views is growing quickly indicating the strong interest for recorded ESI lectures in the community.

Scientific Reports

Main Research Programmes

The Dynamics of Planetary-scale Fluid Flows

Organizers: Adrian Constantin (U of Vienna), David Dritschel (U of St Andrews), Nathan Paldor (HU of Jerusalem)

Dates: April 11 – June 2, 2023

Budget: ESI € 32 261

€ 5 000 from the Wittgenstein-prize award of A. Constantin were used to cover the travel expenses of some visitors.

Report on the thematic programme

Several themes were discussed during the programme, chosen among currently very active research areas of physical oceanography and atmospheric science. Also, some challenging problems with good perspectives of steadily advancing the state-of-the-art were identified (for example, regarding the stability of planetary-scale flows) and some research collaborations were initiated. A very gratifying aspect was the successful interdisciplinary communication (between people with backgrounds in mathematics, physics or engineering) that took place. This way interplays between theory and observation were highlighted, a very important aspect since in many geophysical problems of current interest analytical and computational aspects are often intertwined and mutually reinforce each other. We believe that the programme succeeded in presenting the state-of-the-art of the interdisciplinary field of planetary-scale fluid flows in the ocean and in the atmosphere.

Activities

The programme workshop took place in the period May 22 – 24 and featured 17 talks by experts, covering theoretical topics as well as studies of field data and numerical simulations. Colloquim talks were scheduled in the other weeks of the programme (typically on Wednesdays) and two minicourses (each consisting of 4 lectures aimed at graduate students) were organised, with lectures by Prof. N. Paldor “Waves and wind-driven flows in the ocean”) and Prof. D. Dritschel (“Balance, jets and coherent structures in geophysical fluid dynamics”).

Specific information on the thematic programme

Several PhD-students (G. Dritschel from Leeds, J. McCarney from Cork, L. Roberti from Vienna) participated in the minicourses, listened to several colloquim talks and discussed with

some of the visiting researchers. Roberti started even a promising research collaboration with R. I. Ivanov from the Dublin Technical University. Also, a number of young and promising researchers established or enhanced contacts with experts from abroad (for example, K. Marynets from the Delft Institute of Technology was able to continue to work on a joint research project started with C. I. Martin from the University of Vienna on the occasion of an ESI programme in geophysics that took place in 2018).

Outcomes and achievements

Several scientific collaborations were started during this programme. Useful contacts were established between people with expertise in theoretical aspects of geophysical flows and visiting experts with access to reliable field data. For example, mathematicians from the University of Vienna participated in several detailed discussions with M. Spall and gained a lot of insight on the dynamics of arctic ocean flows from accurate recent field data gathered at the Woods Hole Oceanographic Institution. Also, several ongoing research collaborations were started (e.g. one on planetary dynamics involving A. Constantin, D. Dritschel and P. Germain, another involving the modelling of hurricanes A. Constantin and R. S. Johnson, and an analysis of surface drifter trajectories using dynamical systems methods by N. Paldor, A. Mariano and J. LaCasce). The open discussions that took place during the workshop prompted the co-organizers to plan for a follow-up workshop, that would facilitate further fruitful interactions between some of the participants.

List of talks

Zhiwu Lin (GATECH, Atlanta)	The stability of Kelvin-Stuart cat's eye flows
Michael A. Spall (WHOI, Woods Hole)	Mechanisms of offshore solid and liquid freshwater flux from the East Greenland Current
Michael A. Spall (WHOI, Woods Hole)	Wind-forced seasonal exchange between marginal seas and the open ocean
Francisco Javier Beron-Vera (U Miami)	Nonlinear dynamics insights into "golden tides" in the Caribbean Sea
Nathan Paldor (HU of Jerusalem)	Waves and wind-driven flows in the ocean, Lecture I
Nathan Paldor (HU of Jerusalem)	Waves and wind-driven flows in the ocean, Lecture II
Nathan Paldor (HU of Jerusalem)	Waves and wind-driven flows in the ocean, Lecture III
Arthur Mariano (U Miami)	Some Comments on Ocean Modeling
Arthur Mariano (U Miami)	Ocean Diffusivity
Nathan Paldor (HU of Jerusalem)	Waves and wind-driven flows in the ocean
David Dritschel (U of St Andrews)	Balance, jets and coherent structures in geophysical fluid dynamics, Lecture I
David Dritschel (U of St Andrews)	Balance, jets and coherent structures in geophysical fluid dynamics, Lecture II
David Dritschel (U of St Andrews)	Balance, jets and coherent structures in geophysical fluid dynamics, Lecture III
Robin S. Johnson (U Newcastle upon Tyne)	The mathematical fluid dynamics of atmospheric and oceanic flows
David Dritschel (U of St Andrews)	Balance, jets and coherent structures in geophysical fluid dynamics, Lecture IV
William Dewar (Florida State U, Tallahassee)	North Atlantic Spectra Viewed Through an Ensemble
Vladimir Zeitlin (ENS Paris)	Small is beautiful: understanding dynamics of tropical atmosphere with moist-convective rotating shallow water models

Xavier Carton (U Brest)	The dynamics of oceanic vortices
Nathan Paldor (HU of Jerusalem)	Wind-driven transport at the ocean surface: Beyond the f-plane
Richard Scott (U of St Andrews)	The limits of beta plane turbulence
Edward Johnson (U College London)	Dipolar geophysical vortices
Vered Rom-Kedar (Weizmann Institute, Rehovot)	Modeling density driven flows in the presence of chaotic advection.
David Dritschel (U of St Andrews, UK)	Wavy jets and potential vorticity staircases
Marcel Oliver (KU Eichstätt)	Quasi-convergence of optimal balance by nudging
Robin S. Johnson (U Newcastle upon Tyne)	Nonlinear atmospheric waves with application to the morning glory
Jean-Pierre Croisille (U Lorraine)	Finite difference schemes for several partial differential equations for the atmosphere and the ocean
Joe LaCasce (U Oslo)	Vortices over bathymetry
Ofer Shamir (CIMS, New York)	The Matsuno-Gill model on the sphere
Matania Ben-Artzi (HU of Jerusalem)	Nonlinear Hyperbolic Conservation Laws on Manifolds
Pierre Germain (CIMS, New York)	Stratospheric planetary flows from the perspective of the Euler Equation on a rotating sphere
Yair De-Leon (HU of Jerusalem)	Waves on the β-planes in the presence of a mean zonal flow: Beyond the Doppler shift
Hao Zhu (Nanjing University)	Dynamics near a shear flow with Coriolis force
Miklós Vincze (ELTE Budapest)	Modeling planetary-scale fluid flows in the laboratory

Publications and preprints contributed

I. Yacoby, H. Gildor, N. Paldor, *The effects of curvature and ß on zonally invariant f-plane dynamics*, Physics of Fluids 36, 046601 (2024).

Invited scientists

Matania Ben-Artzi, Francisco Javier Beron-Vera, Xavier Carton, Adrian Constantin, Jean-Pierre Croisille, Yair De-Leon, William Dewar, David Dritschel, Pierre Germain, Delia Ionescu-Kruse, Rossen I. Ivanov, Edward Johnson, Robin S. Johnson, Joe LaCasce, Zhiwu Lin, Tony Lyons, Arthur Mariano, Calin Martin, Kateryna Marynets, Jordan McCarney, Marcel Oliver, Nathan Paldor, Ronald Quirchmayr, Vered Rom-Kedar, Richard Scott, Ofer Shamir, Michael A. Spall, Raphael Stuhlmeier, Miklós Vincze, Vladimir Zeitlin, Hao Zhu.

Spectral Theory and Mathematical Relativity

Organizers: Peter Hintz (ETH-Zürich), Piotr Chruściel (U of Vienna), Alexander Strohmaier (Leed-Hannover U), Steve Zelditch† (Northwestern)

Dates: June 3 – July 30, 2023

Budget: ESI € 68 480

Report on the programme

Introduction

Since the discovery of quantum theory we know that spectral theory of linear operators in Hilbert spaces is fundamental in our description of nature. Apart from its significance in the formulation of quantum mechanics, spectral theory has also been very influential in other areas of pure and applied mathematics. The programme was broadly about novel applications of spectral methods in general relativity. More concretely, we focused on the following areas.

- Spectral Theory of Stationary Spacetimes
- Stability questions in General Relativity
- Mathematics of quantum field theory and Hawking radiation

The focus was on strengthening the links between spectral geometry, wave propagation in general relativity, and quantum field theory on curved spacetimes.

Activities

The programme consisted of an introductory workshop and a research conference, as well as regular daily activities (talks, discussions, time for collaborations).

The *introductory workshop* took place between June 19 and 23, 2023. It featured four series of 3 – 4 lectures each. The main aim was to introduce graduate students and postdocs, but also more senior participants, to current research areas. The main speakers were:

Dietrich Häfner	Dirac fields on Kerr spacetime and Hawking radiation
Birgit Schoerkhuber	Singularity formation, stability and spectral analysis
Alexander Strohmaier	Spectral theory of stationary spacetimes
Maciej Zworski	Microlocal methods for operators with analytic coefficients

The *main conference* took place between July 7 and 11, 2023. It was a research conference of the highest international caliber, featuring both senior people working on the topics of the programme as well as more junior researchers who have already made significant contributions to their respective fields; the institutions of the speakers include the University the Cambridge, MIT, Université Paris–Saclay, Stanford University, Chicago University, and Princeton University, among others. The talks were scheduled in such a way so that individual morning and afternoon sessions would be thematically aligned while keeping the topics covered on each day as diverse as possible. The speakers and talks were as follows.

Christian Bär (U of Potsdam)	Survey on index theory on Lorentzian manifolds
Dean Baskin (TAMU, College Station)	The Feynman propagator for the wave equation with an inverse square potential
Tanya Christiansen (U of Missouri, Columbia)	Resolvent at low energy in two dimensions
Stefan Czimek (U of Leipzig)	Obstruction-free gluing for the Einstein equations
Claudio Dappiaggi (U of Pavia)	Fundamental solutions and Hadamard states for a scalar field with arbitrary boundary conditions on an asymptotically AdS spacetime
Semyon Dyatlov (MIT, Cambridge)	Microlocal analysis of internal waves in 2D aquaria
Michael Eichmair (U of Vienna)	On the canonical geometric structure of initial data for the Einstein equations
Colin Guillarmou (U Paris-Saclay)	Virasoro semi-groups and conformal blocks

Stefan Hollands (U of Leipzig)	Semi-classical analysis of strong cosmic censorship
Christoph Kehle (ETH Zürich)	A small divisors instability at the Kerr–AdS Cauchy horizon
Jonathan Luk (Stanford U)	Late time tail of waves on dynamic asymptotically flat spacetimes of odd space dimensions
Jeremy Marzuola (U of North Carolina, Chapel Hill)	Spectral minimal partitions, nodal deficiency and the Dirichlet-to-Neumann map
Georgios Moschidis (EPFL, Lausanne)	Weak turbulence on Schwarzschild–AdS spacetime
Kasia Rejzner (U of York)	New proposal for renormalisation group equations on curved spacetimes
Rita Teixeira da Costa (U Cambridge)	The Teukolsky equation on Kerr in the full subextremal range
András Vasy (Stanford U)	The Feynman propagator and self-adjointness
Robert Wald (U of Chicago)	Quantum Field Theory in Curved Spacetime
Claude Warnick (U Cambridge)	Quasinormal modes of (near) extremal black holes
Michał Wrochna (Cergy Paris U)	Low-energy obstructions to quantizing linearized gravity
Jared Wunsch (Northwestern U Evanston)	Wave propagation on rotating cosmic string backgrounds
Zoe Wyatt (KCL, London)	Global stability of spacetimes with supersymmetric compactifications

In the weeks outside of these events, participants of the programme contributed individual talks:

Håkan Andréasson (Chalmers U of Technology, Gothenburg)	The weak cosmic censorship conjecture and the Hoop conjecture in the case of the axially symmetric Einstein–Vlasov system
Clotilde Fermanian Kammerer (UPEC)	Semi-classical approximation for time-dependent systems
Jonathan Glöckle (U Regensburg)	Initial data rigidity via Dirac–Witten operators
Ethan Sussman (MIT, Cambridge)	Massive waves gravitationally bound to static bodies
Amir Vig (U of Michigan, Ann Arbor)	Cancellations in the wave trace
Maciej Maliborski (U of Vienna)	Instability of scalar fields in a reflective cavity
Allen Fang (Princeton U)	Nonlinear stability of Kerr–de Sitter
Oliver Petersen (KTH Stockholm)	Wave equations in Kerr–de Sitter spacetimes: the full subextremal range
Onirban Islam (U of Potsdam)	Feynman propagators on curved spacetime
Gautam Satishchandran (Princeton U)	Infrared finite scattering theory in QFT and Quantum Gravity
Alden Waters (U Leeds)	The relative trace formula in electromagnetic scattering
Florian Johne (Columbia U, New York)	Intermediate curvature and a generalization of Geroch's conjecture
Pascal Millet (U Grenoble Alpes)	Leading-order term expansion for the Teukolsky equation on subextremal Kerr black holes
Lionel Mason (U Oxford)	Gravity from holomorphic discs and celestrial $\mathrm{Lw}1+\infty$ symmetries
Simone Murro (U Genova)	Hadamard states for Maxwell fields via complete gauge fixing
Andrea Nützi (ETH Zürich)	Maurer–Cartan perturbation theory and scattering amplitudes in general relativity
Shi-Zhuo Looi (CalTech)	Asymptotics of non-linear and linear waves on asymptotically flat spacetimes
Zhongkai Tao (UC, Berkeley)	Solution operators for the Einstein constraint equation
Dietrich Häfner (U Grenoble Alpes)	On the linear stability of Kerr black holes

Moritz Doll (U Melbourne)	Microlocal analysis of the Klein–Gordon equation with spatial potentials
Rudrajit Banerjee (Okinawa IST)	Wick rotating the heat kernel

As usual for the ESI a lot of discussions and collaborations took place informally between the lectures and workshop activities. The ESI provided a fantastic environment for this to happen.

Specific information on the programme

Of the total of 99 invited scientists who accepted the invitation, there were 23 postdocs, 22 PhD students, and 17 female participants. The participants ranged from junior colleagues to the most senior figures in the relevant fields.

Scientific content

The eigenvalues of the Laplace operator on a compact Riemannian manifold are the fundamental frequencies of the manifold and have been subject of intense investigation in the past (e.g. Weyl's law). Spectral theory on Riemannian manifolds corresponds to the analysis of waves on ultrastatic spacetimes which rarely occur in general relativity. For such spacetimes, one instead considers the spectrum of the generator of time translations on the space of solutions of the wave equation. For spacetimes with compact Cauchy surfaces without boundary, a Weyl law and trace formula were proved by Strohmaier–Zelditch. Strohmaier's lecture series introduced these results and the required background from hyperbolic partial differential equations (PDE) theory and microlocal analysis. Trace formulae also featured prominently in talks by Vig on cancellations in the wave trace and by Waters on the Casimir effect, and were the subject of discussions of Marzuola, Strohmaier, Waters, and Warnick.

The behavior of waves (gravitational, electromagnetic, scalar, linear and nonlinear, ...) depends sensitively on the geometric and dynamical structure of the spacetime on which they propagate. For linear waves on stationary spacetimes, this can be neatly captured by passing to the Fourier transform in time which converts the wave operator into a family of operators depending on a frequency parameter – for ultrastatic spacetimes, the spectral family of the Laplace operator of the spatial manifold. Spectral theory thus plays an essential role in determining the asymptotic behavior of waves. Quasinormal modes are the complex frequencies which describe the late-time asymptotics of solutions of wave equations on *cosmological spacetimes*, as first shown in works of Bony, Häfner, Dyatlov, and Vasy. Lindblad Petersen presented his joint work with Vasy extending such results to the full subextremal range of Kerr–de Sitter black hole spacetimes. The absence of non-decaying quasinormal modes is a key requirement for nonlinear stability results in general relativity, as demonstrated by Hintz–Vasy, and this aspect features prominently also in Fang's new proof of the stability of Kerr–de Sitter black holes which he presented in this programme. Warnick presented his work on the asymptotic behavior of quasinormal modes on near-extremal black hole spacetimes. Next, on *asymptotically flat* spacetimes, quasinormal modes play a lesser role – unless they correspond to oscillatory or exponentially growing solutions, as in Sussman's talk –, and it is instead the regularity of the resolvent at low energies which dominates the late time behavior (which now features merely inverse polynomial decay). Millet presented his work on sharp asymptotics for solutions of the Teukolsky equation for all values of the spin on all subextremal Kerr spacetimes via a precise analysis of the resolvent at low energies, and Christiansen discussed her novel results on the low energy behavior of resolvents in 2 spatial dimensions. Looi's results on asymptotics of (non)linear waves on asymptotically flat spacetimes likewise rely on a de-

tailed understanding of the low energy resolvent; and similarly Häfner's talk on his joint work with Hintz and Vasy on the linear stability of slowly rotating Kerr black holes emphasized the crucial role of the delicate structure of the resolvent, which in this setting features a second order pole at zero. On *asymptotically anti–de Sitter* spacetimes finally, where Gannot, Holzegel, and Smulevici had established (sharp) inverse logarithmic decay, quasinormal modes close to the real axis (signifying very weak decay) were used in a spectacular fashion by Kehle in the work on strong cosmic censorship in the interior of AdS black holes, which he presented at the research conference. Such quasinormal modes are also of crucial importance in the work by Moschidis and Kehle on weak turbulence for a quasilinear wave equation on Schwarzschild–AdS spacetimes. The high frequency asymptotics of the spectral family depends delicately on the behavior of null-geodesics which are trapped in a bounded region of spacetime (suitably interpreted); following seminal work by Wunsch–Zworski and Dyatlov, Hintz and Millet started a collaboration aimed at proving a maximally general microlocal propagation result at normally hyperbolic trapping. Wunsch discussed the solution theory for wave equations on rotating cosmic string backgrounds, in which the null-geodesic flow may disrespect causality.

A different perspective on the analysis of waves on curved spacetimes is provided by energy estimates and approximate conservation laws. Wyatt proved the global stability of Kaluza–Klein spacetime with Huneau and Stingo, Teixeira da Costa presented her work with Shlapentokh-Rothman on the Teukolsky equation on subextremal Kerr spacetimes (complementing Millet's work), and Luk together with Oh proved the surprising result that the decay rate of linear waves undergoes a sudden change when a stationary spacetime is perturbed in a non-stationary fashion. These results are either nonlinear stability results (including also Fang's aforementioned work), or at least closely related to such. The construction of initial data for the Einstein field equations was addressed by Czimek who, with Rodnianski, introduced a method to overcome, in nonlinear theory, obstructions (cokernels) in the linear theory; Tao's talk on joint work with Mao addressed gluing constructions in the asymptotically flat setting, and Eichmair presented results on the geometric structure of initial data sets.

The third major topic of the conference was quantum field theory (QFT) on curved spacetimes. Two point functions in perturbative QFT are (typically) required to satisfy the 'Hadamard condition' and a positivity condition. Closely related to such Hadamard states is the Feynman propagator for wave operators on curved spacetimes, which propagates 'positive' frequencies in forward time and 'negative' frequencies in backward time. Rejzner discussed a new and highly flexible proposal for renormalisation group equations on curved spacetimes. Dappiaggi reported on these topics on asymptotically AdS spacetimes via a generalization of Vasy's results on the propagation of singularities at the conformal boundary; and Murro and Wrochna discussed low energy (positivity) issues and their partial resolution in Maxwell theory and linearized gravity. Feynman propagators were discussed from the perspective of asymptotic analysis – allowing for a natural specification of 'positive' and 'negative' – by Baskin and Vasy. How Hadamard states can be used to deduce physical properties of quantum fields near the inner horizon of black hole spacetimes was addressed by Hollands and Klein in their talks and ongoing projects.

Outcomes and achievements

The programme provided ample opportunity for starting, continuing, or finish collaborative projects. We believe that the interactions of researchers working in different areas of mathematics – ranging from index theory, spectral theory, and microlocal analysis to nonlinear hyperbolic PDE and differential geometry – and also of the sizeable group of mathematical and

theoretical physicists which this programme facilitated will have a lasting impact on the areas that this programme was concerned with. At the time of writing, the organizers are aware of the following collaborations and progress achieved during and following the programme.

- Håkan Andréasson continued his work on a project on stationary solutions for the axisymmetric Einstein–Vlasov system with Ellery Ames. He also initiated a discussion about a potential project on cosmological spacetimes with David Fajman.
- Christian Bär continued work on Lorentzian index theory with Alexander Strohmaier.
- Dean Baskin advanced his collaboration with Moritz Doll on a project about the Klein–Gordon equation.
- Daine Danielson continued work with Gautam Satishchandran and Bob Wald elucidating certain entanglement, decoherence, and superselection phenomena in scattering processes of interacting quantum field theories and quantum gravity and benefitted from insightful discussions with Stefan Hollands and Peter Hintz on related questions.
- Semyon Dyatlov discussed with Peter Hintz regarding applications of b-calculus to understanding forced internal waves in 2-dimensional aquaria in the presence of corners.
- Clotilde Fermanian Kammerer produced a preprint on quantization on groups (see below).
- Jonathan Glöckle worked out an example showing that dec initial data sets do not necessarily extend to dec spacetimes (see preprint below).
- Onirban Islam started a collaboration with Roland Donninger on scalar wave equationon black hole spacetimes and continued collaboration with AlexanderStrohmaier on spectral analysis on stationary spacetimes.
- Christoph Kehle continued his collaboration with Georgios Moschidis on "turbulent instabilities on AdS black holes" and with Ryan Unger on "critical phenomena associated with extremal black holes", resulting in a preprint (see below).
- Christiane Klein continued a collaboration with P. Hintz on quantum effects on Cauchy-horizons, and continued collaboration with S. Hollands, M. Casals and M. Soltani on quantum effects in Kerr-de Sitter, resulting in two preprints (see below).
- Oliver Lindblad Petersen continued working with Dietrich Häfner, Peter Hintz and András Vasy on wave equations in spacetimes modelling a rotating black hole in an expanding universe.
- Shi-Zhuo Looi began a collaboration on asymptotics for solutions of Schrödinger equations with Ethan Sussman.
- Jose Luis Jaramillo made progress on an ongoing research project on black hole inequalities with Juan A. Valiente-Kroon.
- Jeremy Marzuola was able to work on a project with Alex Strohmaier and Alden Waters related to the Polya conjecture resulting in a newly conjectured use of an interior trace formula representation, and on a project with Dean Baskin related to nonlinear wave/Dirac equations with singular potentials.
- Pascal Millet began a collaboration with Peter Hintz on normally hyperbolic trapping estimates for operators acting on vector bundles.

- Simone Murro finalized a project on Hadamard states for Maxwell theory (see below), and he also discussed with Claudio Dappiaggi about microlocal properties of Hadamard states and Feynman propagators for gauge theories.
- Andrzej Rostworowski continued his work with Maciej Maliborski on gravitational collapse in asymptotically flat and asymptotically AdS spacetimes.
- Birgit Schörkhuber had intensive discussions with Mathias Ostermann and David Wallauch on singularity formation in nonlinear wave equation.
- Amir Vig began work with Alexander Strohmaier on asymptotic expansions of the Casimir energy density.
- Claude Warnick continued work on projects with Jonathan Luk on AdS stability, and with Filip Ficek on numerical approaches to near extremal black holes; discussed starting a project with Dietrich Häfner on quasinormal modes for extremal and asymptotically flat black holes; additionally had many useful discussions, including with Jose Luis Jaramillo on spectral instabilities of black holes, with Stefan Hollands on nonlinear interactions between quasinormal modes and with Alex Strohmaier on trace formulae in the Lorentzian setting.
- Alden Waters completed a preprint with Y.-L. Fang on dispersive estimates for Maxwell's equations (see below). She also worked with her postdoc Ronald Quirchmayr on the generalization of dispersive estimates for conservative PDE to the exterior of the torus; and began a collaboration with Jeremy Marzuola and Alexander Strohmaier on counting functions for bounded domains using relative trace formulae.
- Michał Wrochna progressed on collaborative work with Dean Baskin and Jared Wunsch on second quantization for fermions in the presence of Coulomb singularities, and discussed with Vincent Moncrief and other participants various aspects of quantization of linearized gravity including the role of constraint equations and infrared problems.
- Jared Wunsch made progress on a project with Dean Baskin and Michal Wrochna on QFT for the Dirac-Coulomb Hamiltonian. He worked with Shi-Zhuo Looi on an ongoing project on decay of nonlinear waves in asymptotically Minkowski spacetimes.
- Raphaela Wutte continued work with Piotr Chruściel on a project about mass in $(2+1)$-dimensional general relativity.
- Maciej Zworski continued discussions with A. Strohmaier about applications of microlocal methods in the real analytic category in quantum field theory, specifically, to regularity issues of push forwards of propagators, following his recent work with E. Witten.

Publications and preprints contributed

E. Ames, H. Andréasson, *Stationary solutions of the axially symmetric Einstein-Vlasov system: present status and open problems*, arXiv:2310.00776[gr-qc].

L. Benedetto, C. Fermanian Kammerer, V. Fischer, *Quantization on groups and Gårding inequality*, https://hal.science/hal-04171881.

Y.-L. Fang, A. Waters, *Dispersive Estimates for Maxwell's Equations in the Exterior of a Sphere*, arXiv:2308.00536[math.AP].

A. E. Fischer, V. Moncrief, *Hamiltonian Reduction of Einstein's Equations*, Elsevier Press, Encyclopedia of Mathematical Physics.

J. Glöckle, *Initial data sets with dominant energy condition admitting no smooth dec spacetime extension*, arXiv:2308.00643[gr-qc].

P. Hintz, *Asymptotically de Sitter metrics from scattering data in all dimensions*, https://doi.org/10.1098/rsta.2023.0037.

C. Kehle, R. Unger, *Extremal black hole formation as a critical phenomenon*, arXiv:2402.10190[gr-qc].

C. Klein, P. Hintz, *Universality of the quantum energy flux at the inner horizon of asymptotically de Sitter black holes*, https://doi.org/10.1088/1361-6382/ad2cee

C. Klein, M. Soltani, M. Casals, S. Hollands, *Infinite quantum twisting at the Cauchy horizon of rotating black holes*, arXiv:2402.14171[gr-qc].

J. Kudler-Flam, S. Leutheusser, G. Satishchandran, *Generalized Black Hole Entropy is Von Neumann Entropy*, arXiv:2309.15897[hep-th].

S. Murro, G. Schmid, *The Quantization of Maxwell Theory in the Cauchy Radiation Gauge: Hodge Decomposition and Hadamard States*, arXiv:2401.08403[math.AP].

A. Waters, Y. Long Fang, *Dispersive Estimates for Maxwell's Equations in the Exterior of Sphere*, arXiv:2308.00536[math.AP].

Invited scientists

Peter C. Aichelburg, Selim Amar, Håkan Andréasson, Rudrajit Banerjee, Christian Bär, Dean Baskin, Robert Beig, Anxo Biasi, Andras Bonk, Tanya Christiansen, Piotr T. Chruściel, Wan Cong, Stefan Czimek, Daine Danielson, Claudio Dappiaggi, Pedro del Real Lavergne, Moritz Doll, Roland Donninger, Semyon Dyatlov, Michael Eichmair, David Fajman, Allen Juntao Fang, Clotilde Fermanian Kammerer, Filip Ficek, Stefano Galanda, Jonathan Glöckle, Juan Manuel González Brantes, Finnian Gray, Colin Guillarmou, Dietrich Häfner, Peter Hintz, Stefan Hollands, Gemma Hood, Albert Huber, Onirban Islam, Oana Ivanovici, Jose-Luis Jaramillo, Florian Johne, Istvan Kadar, Christopher Kauffman, Christoph Kehle, Christiane Klein, Michael Kunzinger, Rubens Longhi, Shi-Zhuo Looi, Jonathan Luk, Maciej Maliborski, Jeremy Louis Marzuola, Lionel Mason, Peter Michor, Pascal Millet, Vincent Moncrief, Gabriele Mondello, Katrina Morgan, Georgios Moschidis, Simone Murro, Andrea Nützi, Marius A. Oancea, Maximilian Ofner, Leonid Parnovski, Oliver Petersen, Ronald Quirchmayr, Kasia Rejzner, Paola Rioseco, Andrzej Rostworowski, Ashkan Sadat Kyaee, Gautam Satishchandran, Gabriel Schmid, Birgit Schoerkhuber, Walter Simon, Roland Steinbauer, Alexander Strohmaier, Thomas Stucker, Ethan Sussman, Zhongkai Tao, Greg Taujanskas, Rita Teixeira da Costa, Ryan Unger, Liam Urban, András Vasy, Amir Vig, Magnus von Terzi, Robert Wald, David Wallauch-Hajdin, Claude Warnick, Alden Waters, Micha Wrochna, Jared Wunsch, Raphaela Wutte, Zoe Wyatt, Ruben Zeitoun, Xuwen Zhu, Maciej Zworski.

Quantum Field Theory at the Frontiers of the Strong Interaction

Organizers: André H. Hoang (U of Vienna), Simon Plätzer (U of Graz & U of Vienna), Massimiliano Procura (U of Vienna), Malin Sjödahl (Lund U), Iain W. Stewart (MIT)

Dates: July 31 - September 1, 2023

Budget: ESI € 46 600
Faculty for Physics, U of Vienna € 1 686

Report on the programme

Activities and Organization

One major aspect of current theoretical work within particle physics is to increase the precision and accuracy of predictions for state-of-the-art collider physics experiments such as the Large-Hadron-Collider (LHC) from the Standard Model, which incorporates the state-of-the-art knowledge on the strong, weak and electromagnetic forces in the context of Abelian and Non-Abelian gauge theories. These predictions aim at the determination of observables such as cross sections in particle collisions or the life-times of elementary or bound-state particles at the fully inclusive or differential level. The ESI workshop *Quantum Field Theory at the Frontiers of the Strong Interaction* focused on a number of key theoretical development areas which are critical to improve the precision for or to gain access to kinematic regions in differential cross section and decay rate predictions where common so-called fixed-order perturbation theory in powers of the gauge couplings is insufficient. These developments aim at incorporating in addition the summation of large higher-order corrections and corrections from beyond perturbation theory, so-called non-perturbative corrections. Approaches to address and control these important effects in a systematic manner in accordance to quantum field theory requires the developments of sophisticated expansion methods supplemented by symmetry arguments and entail proofs for factorization theorems as well the application of renormalization group methods. Many of these developments have been incorporated into simulations programs, called Monte-Carlo event generators (MCs), which are used in all state-of-the-art experimental analyses. In this context the understanding of strong interactions are most critical due to the large size of the color SU(3) gauge coupling. Nevertheless, due to the increasing precision of the LHC experimental analyses also the smaller electroweak effects are becoming more and more important.

The theme of the programme was therefore well received by the particle physics phenomenology community, and many world experts in the areas of quantum chromodynamics and electroweak physics, effective field theories, such as Soft-Collinear-Effective Theory (SCET) and Heavy-Quark-Effective Theory (HQET), resummation methods, factorization proofs and fixed-order perturbation theory were present to discuss their recent ideas and developments and to collaborate among each other using the amenities of the ESI venue. The workshop successfully created a common framework where established senior researchers, postdocs and students from five key directions in precision collider physics came together. These key directions of the five week long programme, which we also referred to as“research pockets”, are described in more detail below.

During each week, 4 key talks from leading scientists on particularly interesting and timely topics within the research pockets where organized by invitations on Tuesday and Thursday mornings starting at 10:00 AM. On average each morning presentation session lasted around 2.5 hours. The speakers were encouraged to provide easily accessible blackboard presentations, which served as a seed for intense discussions on the research pocket topic of the week. Furthermore, on Wednesday morning at 10:30 AM participants had the opportunity to give a presentation on an interesting additional topic of high interest after consulting the organizers. A Mattermost Channel was provided for all programme participants to allow the easy exchange of literature references and discussion material to all participants on issues there were discussed. The financial support provided by the ESI was distributed among the (external) participants following the guideline of providing about 50% coverage of business days for permanently employed physicists (professors, staff, faculty), about 75% coverage of business

days for postdoctoral researchers, and full coverage for PhD students. The organizational setup of the programme has been highly appreciated by all participants and contributed a lot to a real working and productive atmosphere, in contrast to the fast-paced environment of a conferences or workshops focusing primarily on full-day presentations.

To support students and early career researchers we offered the senior participants to nominate "Junior Collaborators" which could be PhD or master students or early postdocs. These nominations aimed at either supporting existing collaborations or at the initiation of new collaborations between senior and early career participants and were highly appreciated. Eight PhD and master students and one postdoc participated at the programme through these nominations. Further, each Wednesday afternoon a poster session, for hand-written posters on the blackboards, was organized among the participating PhD students, where the best poster was awarded a price of 50 Euros generously donated by Prof. Stewart.

The feedback of the participants concerning the organization and the research-friendly format of the programme was overwhelmingly positive, and all participants expressed the desire to have another workshop at the Erwin Schrödinger Institute in Vienna in the near future. The participants were also very positive about the ESI working environment and in particular to the warm and welcoming support provided by the ESI secretaries.

At the time of writing of this report 17 preprints and articles [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17] have been published from programme participants which either acknowledge partial support of the Erwin Schrödinger Institute or were actually prepared and written during the ESI program "Quantum Field Theory of the Frontiers of the Strong Interaction".

Specific Information on the Programme

Finite-Mass and Electroweak Effects in Gauge Theories

The first week focused on resummed precision calculations for observables where mass effects from quarks and weak massive gauge bosons are important, and where strongly interacting processes are initiated by electroweak massive gauge boson exchange. An important application of resummations of electroweak higher-order corrections in the context of the weak annihilation of very heavy Dark Matter particles in the early universe was discussed by M. Beneke (TU Munich). He showed that due to the large Dark Matter particle mass, different types of resummations are mandatory which are related to separable dynamical processes [19]. V. Mateu (U Salamanca) provided an explanation for a long-standing discrepancy between two different schemes of QCD perturbation theory for the hadronic decay rate of the τ lepton [18]. The two schemes, contour-improved (CI) and fixed-order (FO), each yield very precise but mutually inconsistent predictions. He showed that CI yields a non-uniform asymptotic expansion which makes it incompatible with the operator product expansion. This insight will allow for more accurate determinations of the strong coupling α_s. A novel type of LHC observables is based on the tracks of charge particles in the detector. These track-based observables do not require an extrapolation (based on MCs) towards all particles (i.e. including neutral ones), but also yield a novel theoretical treatment. W. Waalewijn (U of Amsterdam) presented the status of this interesting novel approach [20] and its peculiarities, and how it could be employed to improve MC simulations. Finally, S. Marzani (U of Genova) discussed the status of the treatment of massive quarks in jet observables in the context of classic QCD factorization [13], which uses a alternative formulation than effective theories such as SCET or HQET. The presentation provided a very instructive insight in the differences of the two approaches that triggered a number of discussions.

Singularity Structure of Quantum Field Theory Beyond the Leading Power

The second week of the programme targeted the study of quantum field theory (QFT) and collider physics beyond leading power in soft and collinear limits. The physical description at leading power has been well understood for decades, with concepts such as splitting functions and showers for collinear radiation, and eikonalization with Wilson line operators for soft radiation. The physics at leading power leads to factorization theorems which describe distinct physical parts of a collision process by independent field theory objects which are tied together by integrals over certain momenta. This enables high precision predictions for collider physics observables. Beyond leading power the physics becomes more complicated and there are many open questions, which were the target for this week of the programme. These have been investigated with effective field theory methods in SCET, as well as by other field theory techniques. One novel aspect of factorization beyond leading power is the appearance of endpoint singularites, which are divergences in the momentum integrals that seek to obtain well defined predictions by tying together subleading versions of factorized quantum field theory functions. The talks by Ze Long Liu (CERN) and by Robert Szafron (BNL) reported on the development of new methods for handling such singularities, based on a refactorization procedure that reorganizes terms in the subleading power predictions. A further complication at subleading power is that the renormalization procedure for the QFT objects becomes more complicated, with both multiplicative and additive renormalization and a more complicated pattern of mixing between different QFT objects. Johannes Michel (MIT) discussed how these divergences can be handled for transverse momentum dependent factorization in the Drell-Yan and Semi-Inclusive DIS processes. Subleading power factorization is also useful for the prediction of higher order perturbative corrections which are enhanced by large logarithms, as discussed in the talk by Leonardo Vernazza (INFN, Turin) [1]. Members of all the leading groups that have been spearheading advances in the field of subleading power gauge theories were present at the programme, and many discussions took place which helped to advance this field.

Factorization Violation and the Space of Universal Functions

Week three was devoted to the question when factorization theorems, which determine theoretical predictions in terms of universal building blocks, do hold for the complex processes observed at the LHC. Violation of factorization signals that certain structures in the theory predictions, say for jet processes, contribute to the final results even though simpler analyses of Drell-Yan processes indicate that they should cancel, provided that the measurements are sufficiently inclusive. Breakdown of factorization triggers rich phenomenological consequences and typically points at contributions from double parton scattering or the presence of super-leading logarithmic contributions, both of which show intricate colour correlations, which were also subject to week 4. In this week, Markus Diehl (DESY) was reporting on the (colour) evolution of double-parton distribution functions [16], which are crucial for an accurate description of double parton scattering, and Thomas Becher (Bern) was addressing how super-leading logarithms can be resummed provided one identifies the right basis and building blocks for their colour structure [21].

Many of the aspects of factorization violating processes are deeply connected to fundamental questions about the properties of the S Matrix, and in particular its analyticity and (generalized) unitarity. Hofie Hannesdottir (Princeton) was giving an overview of recent developments of S Matrix Theory [22]. The QCD dynamics which trigger the appearance of factorization breaking terms typically originate from the so-called Glauber momentum region, and are of utmost importance to the discussion of scattering partons with small momentum fractions, where their densities inside the colliding hadrons grow significantly. The topic, which naturally lead to a dedicated discussion in week 4, was addressed by Aditya Pathak (DESY), who reported on the

analysis of small-x scattering from an effective field theory point of view [23]. The densities of partons at small momentum fractions are expected to saturate at a certain energy scale, and Varun Vaidya (U of South Dakota) reported on the connection of small-x evolution, effective field theories, and factorization breaking.

Simulation of the all order structure of scattering amplitudes

During Week 4, the thematic programme delved deeply into the intricate world of scattering amplitudes in quantum chromodynamics (QCD), exploring diverse strategies to enhance the accuracy of both analytic calculations and simulations. An obvious such direction is to go to higher order in perturbation theory. The challenges associated with computing collider observables up to the third non-trivial order in QCD perturbation theory was addressed by Thomas Gehrmann, with a focus on recent progress on multi-loop integrals, subtraction methods and applications to simple observables [24]. The complementary strategy of capturing only the most important contributions, but doing so to all orders by employing resummation techniques, was also explored in a talk by Gherardo Vita, going up to the precision of N4LL [25]. In this direction, the formulation in terms of Soft Collinear Effective Theory (SCET) is particularly interesting and connections were made. Generally, amplitude-level evolution equations are needed to handle resummation, a topic that was also discussed. This necessitates detailed knowledge of invariant tensor structures for describing the color structure, an area where significant progress was made [26].

In the context of resummation, Glauber gluons, associated with imaginary parts of the scattering amplitudes, play an important role, in particular for non-global observables and no-emission probabilities. Generally, Glauber gluons will destroy coherence as discussed by Jeffery Forshaw [27]. Alternatively, towers of logarithms associated with Regge cuts can be explored. The non-planar origin of Regge cuts, which manifests itself in the color structure, helps to disentangle between the Regge pole and Regge cut and hence determine the Regge pole parameters to three loops, a topic discussed by Einan Gardi [28]. The question of how to organize universal and process dependent parts of the scattering at higher orders has been addressed by the alternative organization in Ref. [2].

Multi-Variable Techniques for All Order Resummations in QFT

During Week 5, the programme focused on recent advances in the evaluation of both classic and novel observables measured either on the full hadronic final state or only part of it. Two presentations dealt with precision calculations involving jets and transverse momentum dependent parton distributions, which encode information on the three-dimensional structure of hadrons. The talk by I. Scimemi (U Complutense, Madrid) focused on the study of next-to-leading power corrections for precision transverse momentum measurements in $e^+e^- \to 2$ jets [29]. The seminar by H.X. Zhu (Peking U) illustrated novel techniques based on the classical conformal symmetry of the QCD Lagrangian to resum a class of power corrections in the back-to-back region of the energy-energy correlator distribution in e^+e^- annihilations [30]. The session with the presentation by P. Monni (CERN) based on [31] was devoted to the discussion of modern techniques aimed at establishing a connection between systematically improvable QCD resummations and Monte Carlo parton showers, with the ultimate goal of developing event generators with next-to-next-to-leading logarithmic accuracy. The discussion allowed for a direct exchange of ideas and comparison of different approaches. Applications to jet substructure studies were reviewed. The talk by I. Rothstein (Carnegie Mellon U) was devoted to the presentation and discussion of a novel method to derive rapidity anomalous dimensions from the phase of the S-matrix for a certain class of observables. This study, which led to a very recent publication [32], opens up novel possibilities to achieve resummation of rapidity logarithms without the need of cumbersome regulators, and further broadened the range of topics

discussed at the workshop.

List of presentations

Martin Beneke (TU Munich)	Electroweak resummation in dark matter physics
Vicent Mateu (U Salamanca)	Mathematical Aspects of Perturbative Hadronic Tau Decays
Wouter Waalewijn (U Amsterdam)	Precise predictions for track-based observables
Simone Marzani (U Genova)	A consistent resummation of mass and soft logarithms in processes with heavy flavours
Ze Long Liu (CERN, Geneva)	Factorization, resummation and endpoint divergences at subleading power
Johannes Michel (MIT, Cambridge)	Subleading-Power Soft Subtleties in SIDIS
Leonardo Vernazza (INFN, Turin)	Factorization and resummation at next-to-leading power
Robert Szafron (BNL, Upton)	Next-to-leading power factorization for collider observables
Markus Diehl (DESY Hamburg)	Double parton scattering: basics and recent developments
Thomas Becher (U Bern)	Factorization of Non-Global LHC Observables and Resummation of Super-Leading Logarithms
Hofie Hannesdottir (IAS, Princeton)	Analytic properties of the S-matrix
Aditya Pathak (DESY Hamburg)	Small-x factorization from effective field theory
Varun Vaidya (U of South Dakota)	Factorization violation and saturation physics
German Rodrigo (CSIC, Madrid)	Causality and singularities of multiloop scattering amplitudes from the loop-tree duality
Jeffrey Forshaw (U Manchester)	Some aspects concerning Coulomb (Glauber) gluons
Einan Gardi (U Edinburgh)	Regge pole and Regge cuts in full colour
Thomas Gehrmann (U Zürich)	Towards N3LO calculations of collider observables
Gherardo Vita (CERN, Geneva)	Resummation of Collider Observables at N4LL Accuracy
Ira Rothstein (Carnegie Mellon U, Pittsburgh)	S Matrix asymptotic from S Matrix Phases
HuaXing Zhu (Peking U)	Sudakov Resummation for EEC from Local Operator Product Expansion
Ignazio Scimemi (U Complutense de Madrid)	Higher power expansion and jets for tmd
Pier Monni (CERN, Geneva)	Generating functionals for collinear fragmentation amp; resummation of groomed angularities and fractional moments of EEC

Publications and preprints contributed

G. Bell, Philipp Böer, T. Feldmann, D. Horstmann, V. Shtabovenko, *Soft-overlap contribution to $B_c \to \eta_c$ form factors: diagrammatic resummation of double logarithms*, arXiv:2309.08410[hep-ph].

S. Caletti, A. Ghira, S. Marzani, *On heavy-flavour jets with Soft Drop*, arXiv:2312.11623[hep-ph].

W. Chen, M. Luo, T. Yang, H. X. Zhu, *Soft Theorem to Three Loops in QCD and N=4 Super Yang-Mills Theory*, arXiv:2309.03832[hep-ph].

B. Dehnadi, A. H. Hoang, O. L. Jin, V. Mateu, *Top Quark Mass Calibration for Monte Carlo Event Generators - An Update*, arXiv:2309.00547[hep-ph].

M. Diehl, F. Fabry, P. Ploessl *Evolution of colour correlated double parton distributions: a quantitative study*, arXiv:2310.16432[hep-ph].

A. Ghira, S. Marzani, G. Ridolfi, *A consistent resummation of mass and soft logarithms in processes with heavy flavours*, arXiv:2309.06139[hep-ph].

Invited scientists

Samuel Alipour-Fard, Thomas Becher, Guido Bell, Martin Beneke, Miguel Benitez-Rathgeb, Philipp Böer, Diogo Boito, Radja Boughezal, Alejandro Bris, Alessandro Broggio, Robin Brüser, Yang-Ting Chien, Marston Copeland, Tyler Corbett, Simon Dampfhofer, Mrinal Dasgupta, Bahman Dehnadi, Markus Diehl, Gerhard Ecker, Anna Ferdinand, Jeffrey Forshaw, Anjie Gao, Einan Gardi, Jonathan Gaunt, Thomas Gehrmann, Aude Gehrmann-De Ridder, Andrea Ghira, Marco Guzzi, Hofie Hannesdottir, André H. Hoang, Reed Hodges, Max Jaarsma, Matthias Jamin, Sebastian Jaskiewicz, Elizabeth Jenkins, Daekyoung Kang, Stefan Keppeler, Sergio Leal Gomez, Daniel Lechner, Kyle Lee, Zoltán Ligeti, Ze Long Liu, Maximilian Löschner, Michael Luke, Axel Maas, Peter Majcen, Aneesh Manohar, Simone Marzani, Vicent Mateu, Thomas Mehen, Dmitri Melikhov, Johannes Michel, Sven-Olaf Moch, Pier Monni, Helmut Neufeld, Aditya Pathak, Frank Petriello, Simon Plätzer, Massimiliano Procura, Rudi Rahn, Sanjay Raman, Anton Rebhan, Christoph Regner, German Rodrigo, Ira Rothstein, Ines Ruffa, Nicolas Schalch, Matthew Schwartz, Ignazio Scimemi, Malin Sjödahl, Maximilian Stahlhofen, Iain Stewart, Julian Strohm, Zhiquan Sun, Robert Szafron, Fernando Torre Gonzalez, Varun Vaidya, Leonardo Vernazza, Gherardo Vita, Rebecca von Kuk, Wouter Waalewijn, HuaXing Zhu.

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[3] A. Bris,V. Mateu, *Secondary massive quarks with the Mellin-Barnes expansion*, arXiv:2402.09536[hep-ph].

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[9] J. Zhu, Y. Song, J. Gao, D. Kang, T. Maji, *Angularity in Higgs boson decays via $H \to gg$ at NNLL$'$ accuracy* arXiv:2311.07282[hep-ph].

[10] I. Belov, A. Berezhnoy, D. Melikhov, *Charming-loop contribution to $Bs \to \gamma\gamma$ decay* arXiv:2309.00358[hep-ph].

[11] A. E. Faraggi, M. Guzzi, A. McEntaggart, *String Derived Z' Model at an Upgraded Superconducting Super Collider*, arXiv:2309.15707[hep-ph].

[12] A. Ablat, M. Guzzi, K. Xie, S. Dulat, T. J. Hou, I. Sitiwaldi, C. P. Yuan, *Exploring the impact of high-precision top-quark pair production data on the structure of the proton at the LHC*, arXiv:2307.11153[hep-ph].

[13] A. Ghira, S. Marzani, G. Ridolfi, *A consistent resummation of mass and soft logarithms in processes with heavy flavours*, arXiv:2309.06139[hep-ph].

[14] S. Caletti, A. Ghira, S. Marzani, *On heavy-flavour jets with Soft Drop*, arXiv:2312.11623[hep-ph].

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[16] M. Diehl, F. Fabry, P. Ploessl, *Evolution of colour correlated double parton distributions: a quantitative study*, arXiv:2310.16432[hep-ph].

[17] W. Chen, M. x. Luo, T. Z. Yang, H. X. Zhu, *Soft theorem to three loops in QCD and $\mathcal{N} = 4$ super Yang-Mills theory*, arXiv:2309.03832[hep-ph].

[18] N. G. Gracia, A. H. Hoang, V. Mateu, *Mathematical aspects of the asymptotic expansion in contour improved perturbation theory for hadronic tau decays*, arXiv:2305.10288[hep-ph].

[19] M. Beneke, S. Lederer, C. Peset, *Electroweak resummation of neutralino dark-matter annihilation into high-energy photons*, arXiv:2211.14341[hep-ph].

[20] K. Lee, I. Moult, F. Ringer, W. J. Waalewijn, *A formalism for extracting track functions from jet measurements*, arXiv:2308.00028[hep-ph].

[21] T. Becher, M. Neubert, D. Y. Shao, M. Stillger, *Factorization of non-global LHC observables and resummation of super-leading logarithms*, arXiv:2307.06359[hep-ph].

[22] S. Caron-Huot, M. Giroux, H. S. Hannesdottir, S. Mizera, *What can be measured asymptotically?*, arXiv:2308.02125[hep-ph].

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[24] T. Gehrmann, P. Jakubk, C. C. Mella, N. Syrrakos, L. Tancredi, *Planar three-loop QCD helicity amplitudes for V +jet production at hadron colliders*, arXiv:2307.15405[hep-ph].

[25] C. Duhr, B. Mistlberger, G. Vita, *Four-Loop Rapidity Anomalous Dimension and Event Shapes to Fourth Logarithmic Order*, arXiv:2205.02242[hep-ph].

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Geometry beyond Riemann: Curvature and Rigidity

Organizers: Ivan Izmestiev (TU of Vienna), Athanase Papadopoulos (IRMA, Strasbourg), Marc Troyanov (EPFL, Lausanne), Sumio Yamada (Gakushuin U, Tokyo)

Dates: September 11 – November 3, 2023

Budget: ESI € 45 831
TU Vienna € 7 214

Report on the Thematic Programme

A two-months-long activity was carried out, around recent developments on generalized curvature, rigidity, and convexity and their applications to various domains of geometry and physics. The project involved specialists from different fields and in the end it allowed many fruitful exchanges of ideas. It included the participation of several postdocs and PhD students. In order to make the access to the new ideas and research problems easier for the young participants, we organized one week-long thematic school, in addition to a-week-long conference for the specialists from the different fields. The programme benefited from the strong thematic intersection with the interests of the Viennese mathematical and physical community.

Activities

1. School with six mini-courses over September 18 – 22, 2023
2. Conference over October 16 – 20, 2023

Specific information on the Thematic Programme

The **School** consisted of six mini-course given by

- Peter Aichelburg and Piotr Chrusciel (U of Vienna): Elements of general relativity
- Andreas Bernig (U of Frankfurt): Curvature tensors and measures of singular spaces
- Mohammad Ghomi (Georgia Institute of Technology): Geometric inequalities in spaces of nonpositive curvature
- Feng Luo (Rutgers U): Discrete conformal geometry of polyhedral surfaces
- Vladimir Matveev (U Jena): Nijenhuis geometry
- Andrea Seppi (U Grenoble): Anti-de Sitter geometry and applications to hyperbolic surfaces.

A wide range of topics were presented, but always with sufficient expositions for non-experts, which benefited not only the young researchers, but also the established scientists with different expertise. For example, Peter Aichelburg gave a series of talks from physical viewpoints regarding the Einstein equation, yet, his style was always mathematically robust, which made the talks very informative for the mathematicians present.

The **Conference** was well attended throughout the week, with many questions asked, and with much discussion during and after the talks. The topics of the talks were quite wide ranging, reflective of the diverse background of the organizing committee, and the diversity played a key role in encouraging many lively discussions among the participants, many of whom attended

the majority of the lectures throughout the week of the **Conference**. Such chemistry was truly unexpected, and the organizers were pleasantly surprised by the overall quality of engagements by the participants. Much of the credit is due to the speakers who delivered materials carefully organized and clearly presented to the (mostly) non-specialists.

Outcomes and achievements

Riemannian geometry is a fundamental component of modern mathematics, with important applications in physics, in particular in general relativity, where the spacetime is a Lorentzian manifold satisfying the Einstein field equations, making the relation between curvature and gravity.

In fact, relativity led to a natural extension of the notion of Riemannian metric, and variations and generalizations of the notions and techniques of Riemannian geometry have been developed over time to include more general spaces. In this thematic programme, we emphasized precisely this extension of the various notions of Riemannian geometry, including the applications to physics. Our two-month project included a part where we plan to introduce the basic geometric concepts and another part, in which the applications to physics are explained. The team of organizers consisted of mathematicians whose backgrounds covers the classical metric and Finsler geometry as well as the applications to physics, and the width of our technical expertise was indeed instrumental in realizing many active discussions before, after and during the lectures.

List of talks

Andreas Bernig (Goethe U Frankfurt)	Curvature tensors and measures of singular spaces I - IV
Andrea Seppi (U Grenoble Alpes)	Anti-de Sitter geometry and applications to hyperbolic surfaces I - IV
Peter C. Aichelburg (U of Vienna) & Piotr T. Chruściel (U of Vienna)	Elements of general relativity I - VI
Mohammad Ghomi (GATECH, Atlanta)	Geometric inequalities in space of nonpositive curvature I - IV
Vladimir Matveev (U Jena)	Nijenhuis geometry I - IV
Feng Luo (Rutgers U)	Discrete conformal geometry of polyhedral surfaces I - IV
Francesco Bonsante (U Pavia)	Projective rigidity of circle packings
Roman Prosanov (U of Vienna)	On hyperbolic 3-manifolds with polyhedral boundary
Jean-Marc Schlenker (U of Luxembourg)	Understanding convex hyperbolic manifolds from their boundary
Andrea Seppi (U Grenoble Alpes)	On the (non-)uniqueness of minimal surfaces in hyperbolic three-space
Alexander Lytchak (KIT, Karlsruhe)	Conformal planes of bounded area
Dmitry Faifman (Tel Aviv U)	The Funk metric in and around convex geometry
Ken'ichi Ohshika (Gakushuin U, Tokyo)	The bounded image theorem, the original argument and a new proof
Yurii Neretin (U of Vienna)	"Rational" maps of Bruhat–Tits buildings.
Sergiu Moroianu (IMAR)	Gauss-Bonnet formulae on noncompact manifolds
Mohammad Ivaki (TU Vienna)	Firey's worn stones are round.
Gérard Besson (U de Grenoble)	Bishop-Gromov's Inequality: a central tool in Geometry.

Anders Karlsson (UNIGE, Geneve)	A fixed point theorem for isometries of metric spaces
Hiroyasu Izeki (Keio U)	Harmonic maps and random walks on countable groups
Tatiana Nagnibeda (U Genève)	On spectra of Laplacians on infinite graphs
Ayato Mitsuishi (U Fukuoka)	Quantitative Lipschitz homotopy convergence of Alexandrov spaces.
Irina Markina (U of Bergen)	A unified approach to extremal curves on Stiefel manifolds
Michael Kunzinger (U of Vienna)	Lorentzian length spaces
Christian Müller (TU of Vienna)	Tensegrities and Koenigs nets
Francois Fillastre (U Montpellier)	Flat surfaces, cellulations of hyperbolic surfaces and convex polyhedra
Ingrid Irmer (SUSTech, Shenzhen)	Schmutz-Thurston duality
Daniel Massart (U de Montpellier)	Algebraic intersection on surfaces.
Joan Porti (UA de Barcelona)	A local approach to Anosov groups
Nicolas Tholozan (ENS Paris)	Globally hyperbolic anti-de Sitter manifolds and compact Clifford-Klein forms

Publications and preprints contributed

A. Bernig, J. Kotrbat, T. Wannerer, *Hard Lefschetz theorem and Hodge-Riemann relations for convex valuations*, arXiv:2312.12294[math.DG].

P. T. Chrusciel, R. Wutte, *Gluing-at-infinity of two-dimensional asymptotically locally hyperbolic manifolds*, arXiv:2401.04048[gr-qc].

F. Fillastre, R. Prosanov, *Polyhedral surfaces in flat (2+1)-spacetimes and balanced cellulations on hyperbolic surfaces*, arXiv:2312.14266[math.MG].

T. Goliski, A. Tumpach, *Integrable system on partial isometries: a finite dimensional picture*, arXiv:2311.07412[nlin.SI].

Y. Huang, K. Ohshika, A. Papadopoulos, *The infinitesimal and global Thurston geometry of Teichmüller space*, arXiv:2111.13381[math.GT].

Y. Huang, K. Ohshika, A. Papadopoulos, *The earthquake metric on Teichmüller space*, preprint, 2024.

A. Papadopoulos, Galilei and Huygens, *Music and science*, to appear in the volume Vincenzo Galilei: The Renaissance dialogue between music and science, ed. Ferdinando Abbri and Natacha Fabbri, Brepols, 2024.

Invited scientists

Antoine Ablondi, Norbert A'Campo, Annette A'Campo-Neuen, Peter C. Aichelburg, Alisher Aikyn, Mohammad Alattar, Tobias Beran, Andreas Bernig, Silvan Bernklau, Gérard Besson, Alexey Bolsinov, Francesco Bonsante, Samuel Bronstein, Javier Casado, Christopher Cashen, Nicola Cavallucci, Charalampos Charitos, Piotr T. Chruściel, Manuel Cuerno, Farid Diaf, Abraham Dorsaz, Dmitry Faifman, Francois Fillastre, Valerie Freund, Christoph Fritz, Mohammad Ghomi, Tomasz Goliski, Franois Guéritaud, Sachiko Hamano, Joseph Hoisington, Yingxiang Hu, Yi Huang, Ingrid Irmer, Mohammad Ivaki, Hiroyasu Izeki, Ivan Izmestiev, Anders Karlsson, Michael Kunzinger, Wai Yeung Lam, René Langen, Jihye Lee, Feng Luo, Alexander Lytchak, Irina Markina, Daniel Massart, Leo Mathis, Vladimir Matveev, Thomas Mieling, Ayato Mitsuishi, Hideki Miyachi, Sergiu Moroianu, Thiziri Moulla, Christian Müller, Tatiana Nagnibeda, Stylianos Negrepontis, Yurii Neretin, Argam Ohanyan, Ken'ichi Ohshika, Athanase Papadopoulos, Alan Pinoy, Denis Polly, Joan Porti, Roman Prosanov, Manuel Quaschner,

Matteo Raffaelli, Nicholas Rungi, Jaime Santos Rodrguez, Jean-Marc Schlenker, Andrea Seppi, Rym Smai, Alexey Sossinsky, Roland Steinbauer, Darya Sukhorebska, Gudrun Szewieczek, Susumu Tanabe, Nicolas Tholozan, Enrico Trebeschi, Marc Troyanov, Alice Barbara Tumpach, Raphaela Wutte, Sumio Yamada.

Workshops organized independently of the main programmes

Blackbody Radiation Induced Effects and Phenomena

Organizers: Philipp Haslinger (TU of Vienna), Francesco Intravaia (HU Berlin), Arkadiusz Kosior (U of Innsbruck), Dennis Rätzel (ZARM, Bremen)

Dates: February 13 – 17, 2023

Budget: ESI € 12 652
Quantum Frontiers € 8 399

Report on the Workshop

The workshop "Blackbody radiation induced effects and phenomena" aimed to lay the ground for a synergetic interplay of different perspectives on blackbody radiation by bringing together prominent senior/junior experimentalists and theoreticians, whose research is concerned with this topic. The target was to discuss and address the questions and challenges it poses to fundamental investigations as well as to present and future (quantum) technologies.

Activities

Thirty talks were distributed over four days following five main scientific directions:

- Atoms in thermal fields close to surfaces
- Thermal fields and matter-wave interferometry
- Atoms in thermal fields close to surfaces
- Thermal radiation in space
- New experiments with broadband radiation

With the aim of pushing the interaction even further we had long coffee-breaks, a poster session on Tuesday and discussion time followed by a social activity after the talks on Monday, Wednesday and Thursday. In particular, the conference dinner on Wednesday was combined with an excursion of all interested participants to Herrnbaumgarten, where we visited the Nonseum and had a tour through the vine cellar labyrinth before the actual dinner at Heuriger Umschaid. The bus trip to Herrnbaumgarten and back took about one hour which encouraged longer conversations among participants that were seated together. During the tours and the dinner, the participants discussed their work and met each other on more personal level, which we hope will lead to lasting connections.

Regarding the documentation of the workshop, many speakers gave their permission for recording their presentation so that most of the material is available online on the ESI page dedicated to the workshop. Furthermore, the event was documented by a professional filmmaker including interviews with some of the speakers and the organizers. The documentation will result in a short video (approx. 5 minutes) that will be finished towards the second half of 2023. A link to the video will be provided on the event website by the ESI.
https://www.esi.ac.at/events/e474/

Specific information on the workshop

The event was quite heterogeneous, with many participants at different stages in the career path. More than one quarter of the ($\sim$ 50) participants were PhD student which actively participated in the scientific program with talks and posters. Next to the opportunity to present their work and to receive feedback, the workshop gave them the possibility to interact with prominent scientist in their field of expertise, all within a quite relaxed and friendly atmosphere.

List of participating PhD students and their contributions

- Thomas Agrenius (U Innsbruck) - Poster
- Bettina Beverungen (HU Berlin) - Talk
- Cameron Bunney (U Nottingham) - Talk
- Jack Homans (U Southampton) - none
- Clemens Jakubec (U of Vienna) - Participation
- Janning Meinert (U Heidelberg) - Participation
- Augustin Muster (U of Fribourg) - Poster
- Jaka Perovek (ZARM, Bremen) - Poster
- Govindarajan Prakash (ZARM, Bremen) - Poster
- Jakob Rieser (U of Vienna) - Poster
- Martin Steinel (PTB, Braunschweig) - Poster

Quite a number of post-doctoral scientists actively participated (often giving a presentation) to the activity of the workshop. As for the PhD students, the event provided a broad overview of the state of the art of many areas of science related to their field of research as well as a simple and direct access to exchange to renewed scientists working in those areas. The interactions and the overview can result to be relevant for the post-doctoral scientists' future career paths.

List of participating post-doctoral scientists and their contributions

- Victoria Esteso Carrizo (LENS, Firenze) - Talk
- Omar Jess Franca Santiago (U Kassel) - Talk
- Anne Hutter (U Copenhagen) - Talk
- Yaakov Fein (U of Vienna) - Poster
- Marta Maria Marchese (U Siegen) - Talk
- Daniel Reiche (HU Berlin) - Talk
- René Sedmik (TU of Vienna) - Talk
- Victoria Xu (MIT, Cambridge) - Talk
- Christian Vogt (ZARM, Bremen) - Poster
- Uros Delic (U of Vienna) - Poster
- Peter Asenbaum (U of Vienna) - none
- Ivor Kresic (TU of Vienna) - Talk

Outcomes and achievements

The workshop is part of a continuation of a Research in Teams (RIT) project Blackbody radiation induced inertial effects and collective phenomena - Theoretical basis and experimental feasibility by Philipp Haslinger (TU of Vienna), Francesco Intravaia (HU Berlin), Matthias Sonnleitner (at the time U of Innsbruck), Dennis Rätzel (ZARM, Bremen) at the ESI that started in February 2019.

List of talks

Jean-Jacques Greffet (IOGS, U Paris-Saclay)	Thermal metasurfaces
Carsten Henkel (U Potsdam)	Casimir-Polder interaction at finite temperature
Bettina Beverungen (HU Berlin)	Numerical evaluation of the Casimir-Polder interaction at finite temperature
Sol Carretero Palacios (U Autonoma de Madrid)	Modelling and design of photonic structures for quantum trapping
Victoria Esteso Carrizo (LENS, Firenze)	Casimir-Lifshitz force in multilayer systems: optical interference effect and pre-melting of ice
René Sedmik (TU of Vienna)	Out of equilibrium thermal Casimir effect and how to measure it
Daniel Reiche (HU Berlin)	Nonequilibrium atom-field interactions at finite temperature
Omar Jess Franca Santiago (U Kassel)	Quantum friction near nonreciprocal media and chiral media
Robin Kaiser (U Cte d'Azur, Nice)	Collective cold-atom interactions and astrophysical perspectives
Luis Froufe-Pérez (U of Fribourg)	Interactions induced by fluctuating electromagnetic fields
Arno Rauschenbeutel (HU Berlin)	Thermalization via Heat Radiation of an Individual Object Thinner than the Thermal Wavelength
Philipp Schneeweiss (HU Berlin)	Feedback-cooling the fundamental torsional mechanical mode of a tapered optical fiber to 30 mK
Ivor Kresic (TU of Vienna)	Exploring quantum coherence, cooling and self-ordering with optical frequency combss
Stephen Barnett (U Glasgow)	Unusual representations of blackbody radiation
Stefan Rotter (TU of Vienna)	Blackbody radiation and the Weyl law in disordered media
Tomasz Wasak (NCU, Torun)	Non-equilibrium Fermi polarons in driven-dissipative systems
Christian Lisdat (PTB, Braunschweig)	Optical Clocks: An Introduction
Helmut Ritsch (U Innsbruck)	Broad Band Radiation Gradient Forces in Space
Cameron Bunney (U Nottingham)	Detecting the Unruh Effect in Thermal Analogue Systems
Marcus Huber (TU of Vienna)	Blackbody radiation in quantum thermodynamics
Marta Maria Marchese (U of Siegen)	Large baseline optical imaging assisted by single photons and linear quantum optics
Ekkehard Peik (PTB, Braunschweig)	Effects of Blackbody Radiation in Atomic Clocks
Tanja Mehlstäubler (PTB, Braunschweig)	Blackbody Radiation Shifts in an Optical In+/Yb+ Ion Clock

Anne Hutter (U Copenhagen)	The physical processes governing structure formation in our Universe
Ruth Durrer (UNIGE, Geneve)	The Cosmic Microwave Background
Mathieu Remazeilles (CSIC, Madrid)	Probing the early universe with spectral distortions of the cosmic microwave background blackbody radiation
Dennis Schlippert (Leibniz U)	SUnderstanding the environment surrounding a very long baseline atom interferometer
Franck Pereira Dos Santos (SYRTE, Paris)	Short range force sensing with a trapped atom interferometer
Victoria Xu (MIT, Cambridge)	Probing exotic potentials with lattice atom interferometry
Naceur Gaaloul (Leibniz U)	Quantum State Engineering for precision measurements

Invited scientists

Thomas Agrenius, Stephen Barnett, Bettina Beverungen, Cameron Bunney, Sol Carretero Palacios, Uros Delic, Ruth Durrer, Victoria Esteso Carrizo, Yaakov Fein, Omar Jess Franca Santiago, Luis Froufe-Pérez, Naceur Gaaloul, Jean-Jacques Greffet, Philipp Haslinger, Carsten Henkel, Jack Homans, Anne Hutter, Francesco Intravaia, Clemens Jakubec, Robin Kaiser, Nikolai Kiesel, Arkadiusz Kosior, Ivor Kresic, Claus Lämmerzahl, Christian Lisdat, Marta Maria Marchese, Tanja Mehlstäubler, Janning Meinert, Augustin Muster, Stefan Nimmrichter, Ekkehard Peik, Franck Pereira Dos Santos, Govindarajan Prakash, Ernst M. Rasel, Dennis Rätzel, Arno Rauschenbeutel, Daniel Reiche, Mathieu Remazeilles, Jakob Rieser, Helmut Ritsch, Stefan Rotter, Frank Scheffold, Dennis Schlippert, Philipp Schneeweiss, René Sedmik, Martin Steinel, Christian Vogt, Tomasz Wasak, Victoria Xu.

Between Regularity and Defects: Variational and Geometrical Methods in Materials Science

Organizers: Stefano Almi (U Napoli), Anastasia Molchanova (U of Vienna)

Dates: February 20–24, 2023

Budget: ESI € 13 120
Other financial support:
Austrian Science Fund through the project ESP-61, € 238 (PI Dr. Stefano Almi),
REWIRE grant (Marie Skłodowska-Curie Actions COFUND), € 2 786
(PI Dr. Anastasia Molchanova).

Report on the Workshop

Website of the workshop: https://www.esi.ac.at/events/e462/.

Background: Predicting how different materials behave when undergoing external stresses is a fundamental issue in Materials Science attracting the attention of the mathematical, physical, and engineering communities. The applicative implications of such a basic question are paramount in numerous industrial sectors, ranging from health care to civil engineering and renewable energies. In all these areas, we are interested in the material elastic response and

the development of defects, which could lead to failure. A deep understanding of the above phenomena is crucial and comes with a number of challenging questions regarding the mathematical modeling and analysis in Continuum Mechanics.

Aim: The main goal of the workshop was to bring together experts with shared interests at the interface between Geometrical Analysis, Calculus of Variations, Partial Differential Equations, and applications to Materials Science, and therefore to promote discussions of different viewpoints on interconnected issues and problems in Materials Science. Furthermore, the most recent results on the mathematical modeling and analysis in nonlinear elasticity, fracture mechanics, dislocations and plasticity have been presented.

Activities

The detailed schedule of the workshop may be found at
https://www.esi.ac.at/events/e462/.

The workshop included 28 seminars of 40 minutes each, all in presence, organized in 8 sessions. Two sessions (one in the morning and one in the afternoon) were on Monday, Tuesday, and Thursday, and only the morning session was planned on Wednesday and Friday. The afternoon sessions always contained 4 seminars, while the Monday morning session contained 3 seminars plus a 40-minute registration slot, the Tuesday, Thursday, and Friday morning sessions contained 4 talks, and finally, the Wednesday morning session had 5 seminars. Each session included a 30-minute coffee break. A 1h 50 minutes break was allowed for lunch on Monday, Tuesday, and Thursday.

Wednesday afternoon was left free for scientific discussions between the workshop participants at the ESI. On Wednesday evening, from 6.30 pm, most participants took part in the conference dinner organized at the *Heuriger Schübel-Auer, Kahlenberger Straße 22, 1190 Vienna*. The dinner was funded by the REWIRE project. A group picture was taken on Monday after the morning session. Please refer to https://www.mat.univie.ac.at/~molchanova/files/ESI2023.JPG for the group photo.

Specific information on the workshop

Besides the 2 organizers, the workshop had 63 participants. Among them PhD students and Postdocs from Vienna and external institutions. Most of the external PhDs and Postdocs have been offered the standard per diem from ESI for accommodation and living expenses.

Participants among PhDs: Andrea Chiesa, Giacomo Bertazzoni, Francesco Bozzola, Katharina Brazda, Jakob Deutsch, Anna Doležalová, Rossella Giorgio, Leon Happ, Susanna Heikkilä, Tim Heilmann, Anna Kubin, Dario Reggiani, Samuele Riccò, Manuel Seitz, Andrea Torricelli, Riccardo Voso.

Participants among Postdocs: Marco Bresciani, Maicol Caponi, Lorenza D'Elia, Myrto Galanopoulou, Chiara Gavioli, Wojciech Gorny, Aleksis Koski, Andrea Kubin, Luca Lombardini, Valerio Pagliari, Chiara Rigoni, Filippo Riva, Fabian Rupp, Viktor Shcherbakov, Giacomo Enrico Sodini, Emanuele Tasso, Andreas Vikelis.

Participants with permanent positions: Jean-Francois Babadjian (Paris-Saclay U), Marco Barchiesi (U Trieste), Barbora Benešövá (Charles U Prague), Daniel Campbell (Charles U Prague), Marco Cicalese (TU Munich), Elisa Davoli (TU of Vienna), Manuel Friedrich (FAU Erlangen-Nürnberg), Stanislav Hencl (Charles U Prague), Flaviana Iurlano (CNRS), Pekka Koskela (JYU), Carolin Kreisbeck (KU Eichstätt), Stefan Krömer (Czech Academy of

Sciences), Martin Kružík (Czech Academy of Sciences), Carlos Mora Corral (U Autonoma de Madrid), Marco Morandotti (Politecnico di Torino), Jani Onninen (Syracuse U), Pekka Pankka (U Helsinki), Marcello Ponsiglione (U Roma 1), Aldo Pratelli (U Pisa), Stephen Preston (Brooklyn College), Emanuela Radici (U L'Aquila), Tomáš Roskovec (U of South Bohemia), Lucia Scardia (Heriot-Watt U), Sebastian Schwarzacher (Uppsala U), Francesco Solombrino (U Napoli), Filip Soudský (TU of Liberec), Ulisse Stefanelli (U of Vienna), Alice Barbara Tumpach (Lille U, WPI Vienna); Barbara Zwicknagl (HU Berlin).

Outcomes and achievements

Here is a list of the collaborations that started or continued during the workshop:

- S. Almi, M. Morandotti, and F. Solombrino continued their work on "Mean-field optimal control problems";
- S. Almi, M. Caponi, M. Friedrich, and F. Solombrino continued their work on "Rigidity on Sobolev spaces with variable exponent";
- E. Davoli, C. Kreisbeck, and S. Riccó started a new collaboration on "Laminates & phase transitions";
- E. Davoli and C. Kreisbeck started collaborating on the topic "Optimal design of auxetic materials";
- E. Davoli, J. Deutsch, and M. Friedrich started to work on the topic "Non-isothermal phase transitions";
- E. Davoli and F. Solombrino started a new collaboration on "Nonlocal theories in BV/BD";
- S. Hencl, D. Campbell, A. Pratelli, and E. Radici continued their work on "Homeomorphic approximation in $W^{2,1}$";
- S. Krömer and A. Molchanova started a new collaboration on "Self-contact of thin elastic structures";
- A. Molchanova, T. Roskovec and F. Soudsky initiated a collaboration on "Rademacher theorem in fractional Sobolev spaces".

List of talks

Pekka Koskela (JYU, Jyväskylä)	Homeomorphic Sobolev extensions of parametrizations of Jordan curves
Carolin Kreisbeck (KU Eichstätt)	Variational analysis of auxetic metamaterials of checkerboard type
Sebastian Schwarzacher (Uppsala U)	Variational methods for hyperbolic evolutions and fluid-structure interactions
Marco Morandotti (Politecnico, Torino)	Semi-discrete modeling of systems of disclinations and dislocations
Tomá Roskovec (U of South Bohemia)	Modern trends in Gagliardo-Nirenberg inequality
Filip Soudsk (TU of Liberec)	An elementary proof of classical result of calculus of variations
Manuel Friedrich (FAU Erlangen-Nürnberg)	Finite crystallization via stratification
Francesco Solombrino (U Napoli)	Integral representation and Γ-convergence for free-discontinuity problems with $p(\cdot)$-growth
Lucia Scardia (Heriot-Watt U, Edinburgh)	Minimisers of anisotropic Coulomb energies in 3d

Aldo Pratelli (U Pisa)	Existence and non-existence of optimal sets for non-local energies
Stanislav Hencl (Charles U, Prague)	Weak limit of homeomorphisms in $W^{1,n-1}$: invertibility and lower semicontinuity of energy
Anna Dolealová (Charles U, Prague)	Weak limit of homeomorphisms in $W^{1,n-1}$ and (INV) condition: 2
Viktor Shcherbakov (U Kassel)	Fully discrete approximation schemes for rate-independent crack propagation
Stefan Krömer (Czech Academy of Sciences, Prague)	Thin film asymptotics in a model related to single -crystal plasticity
Barbora Beneová (Charles U, Prague)	Non-interpenetration in thin-film models
Jani Onninen (Syracuse U)	Quasiregular values
Aleksis Koski (U Helsinki)	Sobolev Homeomorphic Extensions
Pekka Pankka (U Helsinki)	De Rham algebras of closed quasiregularly elliptic manifolds are Euclidean
Barbara Zwicknagl (HU Berlin)	Pattern formation in helimagnets
Carlos Mora Corral (U Autonoma de Madrid)	Regularity, cavitation and harmonic dipoles in Nonlinear Elasticity
Marco Barchiesi (U Trieste)	Minimization problems for the axisymmetric neo-Hookean energy
Daniel Campbell (Charles U, Prague)	Injectivity in second-gradient Nonlinear Elasticity
Emanuela Radici (U L'Aquila)	Characterisation of area-strict limits of planar BV homeomorphisms
Flaviana Iurlano (CNRS, Paris)	Existence of solutions for the 2d Signorini-Coulomb problem with arbitrarily large friction coefficient
Marcello Ponsiglione (U Roma 1)	Two slope functions minimizing fractional seminorms and applications to misfit dislocations
Jean-Francois Babadjian (Paris-Saclay U)	Characteristic flow and partial uniqueness for a non strictly convex problem with linear growth in the calculus of variations
Marco Cicalese (TU Munich)	From crystals to Wulff shapes
Martin Kruk (Czech Academy of Sciences, Prague)	Minimal Energy for Geometrically Nonlinear

Publications and preprints contributed

S. Almi, M. Morandotti, and F. Solombrino, *Optimal control problems in transport dynamics with additive noise*, 2303.04877[math.OC].

S. Almi, E. Tasso, *Generalized bounded deformation in non-Euclidean settings*, 2304.11372[math.AP].

S. Almi, M. Caponi, M. Friedrich, and F. Solombrino, *Geometric rigidity on Sobolev spaces with variable exponents and applications*, 2305.00740[math.AP].

S. Almi, A. Molchanova, and S. Krömer, *A new example for the Lavrentiev phenomenon in Nonlinear Elasticity*. 2309.08288[math.AP].

M. Bresciani, M. Friedrich and C. Mora-Corral, *Variational models with Eulerian-Lagrangian formulation allowing for material failure*. 2402.12870[math.AP].

Invited scientists

Stefano Almi, Jean-Francois Babadjian, Marco Barchiesi, Barbora Beneová, Giacomo Bertazzoni, Francesco Bozzola, Katharina Brazda, Marco Bresciani, Daniel Campbell, Maicol Caponi, Andrea

Chiesa, Debajyoti Choudhuri, Marco Cicalese, Elisa Davoli, Lorenza D'Elia, Jakob Deutsch, Anna Dolealová, Manuel Friedrich, Myrto Galanopoulou, Chiara Gavioli, Rossella Giorgio, Wojciech Gorny, Leon Happ, Susanna Heikkilä, Tim Heilmann, Stanislav Hencl, Flaviana Iurlano, Pekka Koskela, Aleksis Koski, Carolin Kreisbeck, Stefan Krömer, Martin Kruk, Andrea Kubin, Anna Kubin, Luca Lombardini, Anastasia Molchanova, Carlos Mora Corral, Marco Morandotti, Jani Onninen, Valerio Pagliari, Pekka Pankka, Marcello Ponsiglione, Aldo Pratelli, Stephen Preston, Emanuela Radici, Dario Reggiani, Samuele Ricc, Chiara Rigoni, Filippo Riva, Tomá Roskovec, Fabian Rupp, Lucia Scardia, Sebastian Schwarzacher, Manuel Seitz, Viktor Shcherbakov, Giacomo Enrico Sodini, Francesco Solombrino, Filip Soudsk, Ulisse Stefanelli, Emanuele Tasso, Andrea Torricelli, Alice Barbara Tumpach, Andreas Vikelis, Riccardo Voso, Barbara Zwicknagl.

Non-regular Spacetime Geometry

Organizers: Piotr Chruściel (U of Vienna), Melanie Graf (U Tübingen), Michael Kunzinger (U of Vienna), Ettore Minguzzi (U Florence), Roland Steinbauer (U of Vienna)

Dates: March 13 – 24, 2023

Budget: ESI € 20 000

Report on the workshop

Scientific Aims

In recent years, regularity issues have increasingly come into the focus of researchers in Mathematical General Relativity and in Lorentzian geometry as they have turned out to be crucial in solving some of the most persistent open questions in the field. Traditionally most studies have assumed, explicitly or implicitly, smoothness of the spacetime metric. However, new insights are needed when the metric is not and, consequently, it appears reasonable to call such geometries non-regular spacetimes.

In Riemannian signature geometers have long studied non-regular manifolds using a variety of methods, such as comparison geometry, metric geometry and others. Many of these techniques have yet to be exported to the Lorentzian setting since, of course, a number of difficulties have to be addressed. At the moment the field is very dynamic as new methods and approaches are being developed and merged together with older techniques and accounts.

This workshop aimed at gathering researchers at the forefront of the field to discuss and advance recent related results in areas such as causality theory, cone and Lorentz-Finsler structures, Alexandrov geometry, length spaces, metric geometry, -extendibility of spacetimes, transport theory and curvature-dimension conditions, as well as non-commutative geometry.

A precursor to this workshop took place in Florence in June 2017, which turned out to be very fruitful in providing a strong impetus for creating a more structured approach to the study of low-regularity General Relativity and Lorentzian geometry. Our mid- to long-term goal is to establish a series of biennial workshops, held in varying venues, dedicated to this goal.

Activities

The first week of the workshop was organized as a conference, so as to inform participants about the current status of research in the various directions outlined above. Week 2 was then

almost exclusively reserved for discussions among varying groups of researchers and for initiating scientific collaborations.

Outcomes and achievements

The workshop was very successful in initiating or intensifying collaborations between various researchers and research groups. It is especially remarkable that several collaborations between established researchers on the one hand and early carrier scientists on the other have been started during week 2 of the workshop. As examples we mention the work of Melanie Graf, Argam Ohanyan and Eric Woolgar on almost splitting results, the large scale collaboration of Tobias Beran, Mathias Braun, Matteo Calisti, Nicola Gigli, Robert McCann, Argam Ohanyan, Felix Rott, and Clemens Sämann on Sobolev calculus of time functions and synthetic d'Alembertian comparison. John Harvey has started to work with Tobias Beran, Michael Kunzinger, Lewis Napper, Felix Rott and Clemens Sämann on various topics in Lorentzian metric geometry. Matthias Braun and Shin-ichi Ohta started a collaboration on timelike lower Ricci curvature bounds on Finsler spacetimes. Marc Mars, Miguel Manzano, Argam Ohanyan and Roland Steinbauer have intensified their collaboration on the topic of matching of spacetimes. Marc Mars, Carl Rossdeutscher, Walter Simon and Roland Steinbauer have started a collaboration on MOTS in asymptotically de Sitter spacetimes. Jiri Podolsky, Clemens Sämman and Roland Steinbauer have begun to work on impulsive gravitational wave geometries seen as Lorentzian length spaces.

List of talks

Robert McCann (U Toronto)	A nonsmooth approach to Einsteins theory of gravity
Andrea Mondino (U Oxford)	Timelike Ricci bounds and Einstein's theory of gravity in a non smooth setting
Fabio Cavalletti (SISSA, Trieste)	Synthetic time-like Ricci curvature lower bounds: the isoperimetric inequality
Olaf Müller (HU Berlin)	Lorentzian functors and closures of relevant subsets of Lorentzian Gromov-Hausdorff space
Felix Rott (U of Vienna)	Alexandrov's Patchwork and the Bonnet Myers theorem for Lorentzian length spaces
Mathias Braun (U Toronto)	Gromov's reconstruction theorem and measured Gromov-Hausdorff convergence in Lorentzian geometry
Clemens Sämann (U Oxford)	A Lorentzian analog for Hausdorff dimension and measure
Miguel Sanchez (U Granada)	Some issues on the regularity of spacetimes related to Finsler Geometry
Shin-ichi Ohta (U Osaka)	Geometry of weighted Finsler spacetimes
Miguel ángel Javaloyes Victoria (U Murcia)	Finsler spacetimes: regularity and physical interpretations
Eleni Kontou (U Amsterdam)	Generalizations of classical relativity theorems
Marc Mars (USAL)	Abstract null geometry, the constraint tensor and applications
Miguel Manzano (U Salamanca)	Null shells: abstract formulation of the junction conditions and particularization to cut-and-paste
Moritz Reintjes (City U of Hong Kong)	On the regularity implied by the assumptions of geometry
Charlie Beil (U of Graz)	Spacetime geometry of spin, polarization, and wavefunction collapse
Nicola Gigli (SISSA, Trieste)	Differentiating in a non-differentiable environment

Chiara Rigoni (U of Vienna)	Tamed spaces - Dirichlet spaces with distribution-valued Ricci bounds
Didier Solis Gamboa (UADY)	The space of causal diamonds as a Lorentzian pre-length space
Lorenzo Mazzieri (University of Trento)	Some Mass Concepts in General Relativity
Brian Allen (CUNY)	Properties of the null distance on a spacetime
Leonardo Garca-Heveling (Radboud U)	Global hyperbolicity through the eyes of the null distance
Tobias Beran (U of Vienna)	Constructing distance realizers via midpoints in Lorenzian mid-length space
Sumati Surya (RRI, Bangalore)	Causal Set Kinematics: Reconstructing Spacetime Geometry from Random Posets
Patrick Bernard (U Paris-Dauphine)	Uniform temporal functions
Tomasz Miller (Jagiellonian University)	Causal evolution of measures and continuity equation
Pierre Martinetti (UNIGE	INFN)
Felix Finster (U Regensburg)	Quasi-Local Mass, Positive Scalar Curvature and a Positive Mass Theorem for Causal Variational Principles
Eric Ling (U of Copenhagen)	Remarks on the cosmological constant appearing as an initial condition for Milne-like spacetimes
Jose M M Senovilla (UPV/EHU)	Beyond black holes: uniqueness properties of ultra-massive spacetimes
Naceur Gaaloul (Leibniz U)	Quantum State Engineering for precision measurements

Publications and Preprints contributed

B. Allen, *Null Distance and Gromov-Hausdorff Convergence of Warped Product Spacetimes*, arXiv:2306.03165[gr-qc].

T. Beran, M. Braun, M. Calisti, N. Gigli, R. McCann, A. Ohanyan, F. Rott, C. Sämann, *Sobolev calculus of time functions and synthetic d'Alembertian comparison*.

T. Beran, F. Rott, *Characterizing intrinsic Lorentzian length spaces via τ-midpoints.* arXiv:2309.12962[math.MG].

T. Beran, J. Harvey, L. Napper, F. Rott, *A Toponogov globalisation result for Lorentzian length spaces.* arXiv:2309.12733[math.DG].

T. Beran, M. Kunzinger, F. Rott, *On curvature bounds in Lorentzian length spaces.* arXiv:2309.12062[math.DG].

T. Beran, L. Napper, F. Rott, *Alexandrov's Patchwork and the Bonnet-Myers Theorem for Lorentzian length spaces.* arXiv:2302.11615[math.DG].

M. Braun, S. Ohta, *Optimal transport and timelike lower Ricci curvature bounds on Finsler spacetimes.* arXiv:2305.04389[math.DG].

S. Burgos, J. L. Flores, J. Herrera, *The c-completion of Lorentzian metric spaces*, arXiv:2305.02004[gr-qc].

St. G. Harris, *Convergence at Past Timelike Infinity in the Causal Boundary*, *Classical and Quantum Gravity*.

M. Kunzinger, A. Ohanyan, B. Schinnerl, R. Steinbauer, *Conjugate points along timelike geodesics in Lorentzian length spaces*.

E. Ling, A. Ohanyan, *Cosmological spacetimes without CMC Cauchy surfaces*.

F. Rott, *Gluing of Lorentzian length spaces and the causal ladder.* arXiv:2209.06894[math.DG].

C. Sämann, B. Schinnerl, R. Steinbauer, R. Švarc, *Cut-and-paste for impulsive gravitational waves with Λ: The mathematical analysis.* arXiv:2312.01980[gr-qc].

A. Daniel Santhosh, S. Surya, *Gromov-Hausdorff type distance between 2d orders using the Null Distance Function.*

Invited scientists

Brian Allen, Charlie Beil, Tobias Beran, Patrick Bernard, Mathias Braun, Matteo Calisti, Peter Cameron, Fabio Cavalletti, Piotr T. Chruściel, David Fajman, Albert Fathi, Christopher Fewster, Filip Ficek, Felix Finster, Jose Luis Flores, Leonardo Garca-Heveling, Nicola Gigli, Melanie Graf, James D. E. Grant, Finnian Gray, Stacey Harris, John Harvey, Jonatan Herrera, Albert Huber, Miguel ángel Javaloyes Victoria, Eleni Kontou, Klaus Kröncke, Michael Kunzinger, Eric Ling, Miguel Manzano, Marc Mars, Pierre Martinetti, Lorenzo Mazzieri, Robert McCann, Benjamin Meco, Tomasz Miller, Ettore Minguzzi, Carla Mladek, Andrea Mondino, Valter Moretti, Olaf Müller, Argam Ohanyan, Shin-ichi Ohta, Jiri Podolsky, Moritz Reintjes, Chiara Rigoni, Carl Rossdeutscher, Felix Rott, Anna Sakovich, Clemens Sämann, Miguel Sanchez, Jan Sbierski, Jose M M Senovilla, Walter Simon, Didier Solis Gamboa, Roland Steinbauer, Stefan Suhr, Sumati Surya, Georgios Tsimperis, James A. Vickers, Daniele Volpe, Eric Woolgar.

Non-commutative Geometry meets Topological Recursion

Organizers: Gatan Borot (HU Berlin), Elba Garcia Failde (Sorbonne U, Paris), Harald Grosse (U of Vienna), Masoud Khalkhali (Western U, London Ontario), Hannah Markwig (U Tübingen; was unable to attend), Raimar Wulkenhaar (U Münster)

Dates: April 24 – 28, 2023

Budget: ESI € 13 882

Report on the Workshop

A meeting with the topic "Non-commutative geometry meets topological recursion" was originally planned at BIRS Hangzhou in Fall 2020 but cancelled due to the pandemic. To keep the momentum, a first workshop in Münster was organized in August 2021, which was very successful. In June 2022 there was a Fields Institute Workshop on Noncommutative Geometry, Free Probability Theory and Random Matrix Theory at Western University, London Ontario. As described below, this workshop brought together several mathematical communities. The ground for interactions between them has been laid during the first workshop in Münster, which featured 4 introductory mini-courses. The one-week ESI-workshop we describe now has built on this and kept the same format which has been successful, namely 4 advanced mini-courses and a number of research talks.

Workshop objectives

Non-commutative geometry is an arsenal of tools to study non-commutative operator algebras from a topological or geometric viewpoint. Universal methods permit to treat ordinary Riemannian manifolds, spaces of non-integral dimensions (e.g. fractals and boundaries of trees) as well as spaces of leaves of a foliation and quantum groups on the same footing, using spectral

triples. A finite set of points can be equipped into an interesting differential geometry where the spectral triple is represented by matrices, and studying random geometries then relates to random matrix models. Free probability and more generally non-commutative probability provide tools to study coupled systems of random matrices in the large size limit. Topological recursion is a universal structure invented by Chekhov, Eynard and Orantin, providing a recursive procedure to compute all-order asymptotic expansions (for large size) in certain matrix models. Once formulated abstractly in terms of the geometry of spectral curves, it has found an increasing number of applications beyond matrix models: in enumerative geometry, mirror symmetry, low-dimensional quantum field theories, and more recently deformation quantization and hyperbolic geometry. Tropical geometry is an array of techniques to reduce problems of enumerative geometry to combinatorics. Some promising bridges between these four topics have been discovered in the last 5 years. This workshop therefore aimed at developing further these interactions and encourage the transfer of knowledge to address problems in all four areas thanks to this broader perspective.

The workshop incorporated the following developments:

- The array of results by Eynard and his school establishing the computation of the $N \to \infty$ formal all-order expansions of observables in a large class of multi-matrix multi-trace matrix models of size N by the topological recursion and its generalizations.
- In the past 5 years the theory of higher order freeness of Collins, Mingo, Speicher, Śniady has significantly advanced in two different directions: first, it has been related to topological recursion in the work of Borot and Garcia-Failde using combinatorial techniques originating from 2d quantum gravity, which has led in their work with Charbonnier, Shadrin and Leid to provide a long sought-for analytic approach to higher order free cumulants; second, Collins, Gurau and Lionni have developed an appropriate theory of freeness for tensors.
- The exact solution of certain renormalized quantum field theory models on non-commutative spectral triples by Grosse, Wulkenhaar and collaborators via Dyson Schwinger equations. These consist of a non-linear problem solved by complex analysis and a recursive system governed by blobbed topological recursion of Borot and Shadrin.
- The application of bootstrap techniques and blobbed topological recursion to models of random spectral triples (Dirac ensembles) by Azarfar, Khalkhali and collaborators.

Topological recursion can produce generating series for many important enumerations, such as the Catalan numbers or intersection indices in $\mathcal{M}_{g,n}$. The recursive equation can be phrased combinatorially, as a sum over degenerations of a Riemann surface. The ultimate combinatorial framework to study such degenerations is tropical geometry, which has been applied with some success in curve counting problems, some of them also addressed by the topological recursion. Point of contacts between tropical geometry and topological recursion have subsequently appeared, notably in Hurwitz theory (i.e. the enumeration of branched covers of $\mathbb{P}^1$).

The recent developments in each of these directions offered the possibility of new applications of the underlying tools, which brings a better understanding in the other fields. This will hopefully lead, for instance, to more powerful tools of computations in non-commutative probability, and new relations to geometry. A unique feature of the Workshop was that it embraced at the same time probabilistic/asymptotic, algebraic/geometric, and combinatorially aspects of the problems under study, for the benefit of all communities. For this reason, the scope of the workshop was in fact unified by the mathematical models under consideration.

Activities

The Workshop consisted of four mini-courses (with three hours each) given by

Renzo Cavalieri (Colorado): *Tropical contributions to enumerative geometry of target dimension one*

A number of problems from enumerative geometry connected to moduli spaces of curves and maps from curve to curve can be treated and solved by tropical geometry. An example are the Hurwitz numbers, which connect the geometry of algebraic curves to combinatorics of the symmetric group. Tropical Hurwitz numbers are the combinatorial analogues of classical Hurwitz numbers. In the lectures a further interpretation of tropical Hurwitz numbers was presented. It allows to compute the intersection numbers of the double ramification cycle of the moduli space of curves (called in this case the branch polynomial).

Benoît Collins (Kyoto): *Around the joint behaviour of independent random tensor matrices*

Free probability describes the joint behavior of independent random matrices, if the distributions are invariant under unitary conjugation. These talks described situations where the matrices have a tensor structure and the symmetries are given by tensors of groups. Two cases have been treated: The case where the invariants are tensors of local unitaries and the case where the symmetries are the image of the unitary group under an irreducible representation. The first case generalizes the Weingarten calculus and the Harish-Chandra–Itzykson–Zuber integral formalism.

Alexander Hock (Oxford): *x-y-symplectic transformation in Topological Recursion and applications*

The first lecture gave a general introduction to topological recursion, which associates to a spectral curve (Σ, x, y, B) a family $\omega_{g,n}$ of multi-differentials and related meromorphic functions $W_{g,n}(z_1,..,z_n) = \frac{\omega_{g,n}(z_1,\ldots,z_n)}{dx(z_1)\cdots dx(z_n)}$. Important examples and connections to other mathematical fields were outlined. The other two lectures were devoted to formulae and deep relations between the $\omega_{g,n}$ and a dual family $\omega^{\vee}_{g,n}$ built from the swapped spectral curve (Σ, y, x, B). The formulae are expressed in terms of bipartite graphs whose edges and vertices have special weights. The first cases $\omega_{1,1}$ and $\omega_{0,3}$ were treated explicitly. For special cases such as $y(z) = z$ these formulae permit an efficient solution of the $\omega_{g,n}$ which avoids the usual recursion formula. In the last part, Hock considered the Laplace transform of the $W_{g,n}(z_1,..,z_n)$ and showed that it permits an even simpler picture.

Rei Inoue (Chiba): *Symmetries of discrete and ultradiscrete integrable systems*

She gave three lively interesting and clear talks: Starting from two integrable systems, the KdV equation and the Toda lattice, Lax pairs and conserved quantities were discussed. Both have solutions given by the Riemann Theta function defined over a hyper elliptic curve. In the second talk the discretized versions of both systems was discussed. It leads to the discrete KdV and the discrete Toda lattice. Lax pairs exist, spectral curves are obtained. A further tropical limit means restricting the values of the functions to discrete points and leads to the so-called ultra discrete KdV and ultra discrete Toda system and the Box-Ball System (BBS), which is an interesting cellular automata.

In addition we had eight research talks by:

Omid Amini (Ecole Polytechnique): *Higher rank Voronoi tilings and metric degenerations of tori*

After mentioning tilings and Voronoi decompositions metric degenerations of real and complex tori was discussed: Limits of Laplacian, behaviour of solutions of the Poisson equation, limits of the canonical measure, asymptotic of Green functions and asymptotics, if one approaches the boundary of the moduli space, were discussed.

Valentin Bonzom (Paris 13): *Enumeration of maps via integrability*

Although there are a number of methods to enumerate maps and to obtain iterative formulae for them, an efficient and interesting method has been presented in this talk. It relies on the use of an infinite hierarchy of integrable PDEs, the KdV hierarchy, for example. One is able to derive recurrence formulae for triangulations by size and genus. For example, the KP hierarchy can be derived from the Tuttes equation.

Ariane Carrance (Ecole Polytechnique): *Exploring boundary conditions of bicolored maps: universal behaviors and new structures*

Maps with bi-colored faces can be understood as 2-matrix models. If one intends to color the boundaries, the choice of boundary conditions at different boundaries (monochromatic, alternating,...) matters. The study of these different boundary conditions yields similar asymptotic behaviour and an unforeseen underlying structure.

Maria Immaculada Gálvez Carrillo (UPC, Barcelona): *On B_∞-algebra structures*

Algebraic structures encoding higher multi-braces, as they occur in iterated loop spaces, were discussed. Especially the appearance of a canonical B_∞-algebra structure on any algebra with an independent differential graded algebra structure, was discussed. A special case of a commutative analogue is the Koscul L_∞ brace hierarchy, which is of importance in the BRST approach of closed string theory.

Luca Lionni (Heidelberg): *Progress in the combinatorial understanding of higher-order free cumulants*

Higher order free moments and cumulants describe the fluctuations of unitarily invariant random matrices in the limit of infinite size. They have been introduced in 2006. A combinatorially derived functional relation for the second order contribution was given too. Recently functional relations for higher orders have been obtained using Fock space techniques. A combinatially derivation is still missing. Steps in that direction were given in this talk.

Margerida Melo (Roma): *Tropicalization of the universal Jacobian: logarithmic and non-archimedian view points*

Moduli spaces of tropical objects can often be obtained by tropicalization of suitable compactification of algebro-geometric objects. An overview of the construction of the universal compactified Jacobians together with their tropical counterparts was given in this talk.

Sergey Shadrin (Amsterdam): *Functional relations for higher order free cumulants and moments*

An overview of the proof of formulae which give functional relations between generating series of cumulants and moments on higher order free probability was given. In an impressive talk the universal role of these relations for matrix models and topological recursion was emphasized.

Teun van Nuland (UNSW Sydney): *One-loop renormalizability of the spectral action using cyclic cocycles*

After a long development Chamseddine and Connes reproduced the Standard model of particle physics by applying the spectral action principle. It is expressed as a Trace functional of a smeared Dirac operator, where a potential is added. In this talk an expansion in terms of the potential leading to an interesting cyclic structure was given. It leads to ribbon graphs and the one loop renormalizability of the spectral action is obtained.

Common to almost all contributions were (beside non-commutative geometry and spectral triples) topological recursion (and blobbed topological recursion), free probability, tropical geometry and integrability.

Specific information on the workshop

We had two GONG TALK Seminars of short 10 minutes presentations by young researchers:

- Adam Afandi (U Münster):
  Tautological Intersection Numbers and Ehrhart Theory
- Thomas Buc-d'Alche (UMPA ENS Lyon):
  Topological expansion of unitary integrals and maps
- Adrian Celestino Rodriguez (TU Graz):
  Cumulants in Non-commutative Probability and Hopf Algebras
- Séverin Charbonnier (U Genève):
  Topological Recursion, ciliated maps and non commutative geometry
- L Glaser (U of Vienna):
  Pictures of deformed spheres
- Marvin Anas Hahn (Trinity College, Dublin):
  Combinatorics of pruned Hurwitz numbers
- Katharina Harengel (U Münster):
  The Combinatorial Structure of Correlation Functions in the Quartic Kontsevich Model
- Roberta Anna Iseppi (U Göttingen):
  The BV formalism for finite spectral triple: from classical to quantum
- Finn Bjarne Kohl (U Münster):
  The quartic Kontsevich model and the moduli space of curves
- Carlos Pérez Sánchez (U Heidelberg):
  (More on) gauge networks in noncommutative geometry
- Davide Scazzuso (HU Berlin):
  Strings and recursion
- Yannic Vargas (TU Graz):
  Hopf algebras, species and non-commutative probability

Outcomes and achievements

Borot, Charbonnier, Garcia-Failde and Shadrin expanded their paper with Leid on functional relations for higher-order free cumulants.
See the recent version 2 at https://arxiv.org/abs/2112.12184.

Borot and Wulkenhaar completed their work on the Kontsevich matrix model with arbitrary potential in which they showed that the partition function is a BKP tau function with respect to polynomial deformations of the potential.
See https://arXiv.org/abs/2306.01501.

We enjoyed our stay at the ESI Workshop and like to thank the secretaries for the friendly atmosphere and perfect organization.

Gatan Borot, Elba Garcia Failde, Harald Grosse, Masoud Khalkhali and Raimar Wulkenhaar.

List of talks

Alexander Hock (U Oxford)	*x-y* symplectic transformation in topological recursion, Lecture 1 - 3
Renzo Cavalieri (CSU, Fort Collins)	Tropical contributions to enumerative geometry of target dimension one., Lecture 1 -3
Margarida Melo (U Roma Tre)	Tropicalization of the universal Jacobian: logarithmic and non-archimedian view points.
Adam Afandi (U Münster)	Tautological Intersection Numbers and Ehrhart Theory
Thomas Buc-d'Alche (UMPA ENS Lyon)	Topological expansion of unitary integrals and maps
Adrian Celestino Rodriguez (TU Graz)	Cumulants in Non-commutative Probability and Hopf Algebras
Séverin Charbonnier (U Genve)	Topological Recursion, ciliated maps and non commutative geometry
L Glaser (U of Vienna)	Pictures of deformed spheres
Marvin Anas Hahn (Trinity College, Dublin)	Combinatorics of pruned Hurwitz numbers
Katharina Harengel (U Münster)	The Combinatorial Structure of Correlation Functions in the Quartic Kontsevich Model
Roberta Anna Iseppi (Georg-August-U, Gttingen)	The BV formalism for finite spectral triple: from classical to quantum
Finn Bjarne Kohl (U Münster)	The quartic Kontsevich model and the moduli space of curves
Carlos Pérez Sánchez (U Heidelberg)	(More on) gauge networks in noncommutative geometry
Davide Scazzuso (HU Berlin)	Strings and recursion
Yannic Vargas (TU Graz)	Hopf algebras, species and non-commutative probability
Omid Amini (École Polytechnique, Palaiseau)	Higher rank Voronoi tilings and metric degenerations of tori
Benoit Collins (Kyoto U)	Around the joint behaviour of independent random tensor matrices., Lecture 1 - 3
Rei Inoue (U Chiba)	Symmetries of discrete and ultradiscrete integrable systems, Lecture 1 - 3
Valentin Bonzom (U Paris-Nord)	Enumeration of maps via integrability
Sergey Shadrin (U of Amsterdam)	Functional relations for higher order free cumulants and moments

Teun van Nuland (UNSW Sydney)	One-loop renormalizability of the spectral action using cyclic cocycles
Luca Lionni (U Heidelberg)	Progress in the combinatorial understanding of higher-order free cumulants
Ariane Carrance (École Polytechnique, Palaiseau)	Exploring boundary conditions of bicolored maps: universal behaviors and new structures
Maria Immaculada Gálvez Carrillo (UPC, Barcelona)	On B-algebra structures

Publications and preprints contributed

A. Alexandrov, B. Bychkov, P. Dunin-Barkowski, M. Kazarian, S. Shadrin, *KP integrability through the x – y swap relation*, arXiv:2309.12176[math-ph].

G. Borot, S. Charbonnier, E. Garcia-Failde, F. Leid, S. Shadrin, *Functional relations for higher-order free cumulants*, arXiv:2112.12184[math.OA].

G. Borot, R. Wulkenhaar, *A short note on BKP for the Kontsevich matrix model with arbitrary potential* arXiv:2306.01501[math-ph].

Invited scientists

Adam Afandi, Omid Amini, John Barrett, Valentin Bonzom, Gatan Borot, Thomas Buc-d'Alche, Boris Bychkov, Ariane Carrance, Renzo Cavalieri, Adrian Celestino Rodriguez, Séverin Charbonnier, Nitin Chidambaram, Alessandro Chiodo, Benoit Collins, Kurusch Ebrahimi-Fard, Maria Immaculada Gálvez Carrillo, Elba Garcia Failde, David Garca Zelada, L Glaser, Harald Grosse, Marvin Anas Hahn, Katharina Harengel, Alexander Hock, Rei Inoue, Roberta Anna Iseppi, Masoud Khalkhali, Finn Bjarne Kohl, Thomas Krajewski, Felix Leid, Luca Lionni, Margarida Melo, James Mingo, Carlos Pérez Sánchez, Akifumi Sako, Davide Scazzuso, Jörg Schürmann, Sergey Shadrin, Roland Speicher, Teun van Nuland, Yannic Vargas, Raimar Wulkenhaar.

IMO Training 2023

Organizers: Theresia Eisenkölbl (U of Vienna)

Dates: June 26 – June 30, 2023 and October 26 – October 31, 2023

Budget: ESI € 10 392
Federal Ministry of Education, Science and Research € 280 travel cost

Report on the training

The goal of the event was to prepare the Austrian team for IMO (International Mathematical Olympiad) and MEMO (Middle European Mathematical Olympiad). The more general aim is to enable the best high school students to become proficient at many mathematical subjects and problem-solving early on and prepare them for a mathematics career.

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 in-

teractive problem solving, participation in the problem solving seminar of the department of mathematics and a competition set by the students for each other.

Specific information on the workshop

Due to the nature of the event, the young participants had the chance to increase their mathematical knowledge significantly. The presenters included a prae-doc and a post-doc.

Outcomes and achievements

We are happy to report that the participants obtained a silver medal, a bronze medal and four honorable mentions at the International Mathematical Olympiad in Japan (July 2-13) and four bronze medals and two honorouble mentions at the Middle European Mathematical Olympiad in Slovakia (August 21-27).

List of talks

June 2023

Theresia Eisenkölbl	Combinatorics, Algebra
Moritz Hiebler	Number Theory
Ivan Izmestiev	Geometry
Morteza Saghafian	Combinatorics

October 2023

Theresia Eisenkölbl	Satz von Monge, Inversion
Theresia Eisenkölbl/Moritz Hiebler	Geometrische Konfigurationen
Moritz Hiebler	Zahlentheorie
Daniel Holmes	Polynome und Irreduzibilität
Ivan Izmestiev	Satz von Helly
Morteza Saghafian	Asymptotic Sorting

Participants

June 2023
Benjamin Aster, Martin Bierbaumer, Theresia Eisenkölbl, Valentin Glatz, Paul Hametner, Fabian Heinricher, Raphael Heuchl, Moritz Hiebler, Ivan Izmestiev, Dominik Pultar, Morteza Saghafian, Jan Schiller, Jan Strehn, Georg Weisbier.

October 2023
Benjamin Aster, Gerfried Berkenhoff, Martin Bierbaumer, Cassandra Bot, Theresia Eisenkölbl, Valentin Glatz, Paul Hametner, Fabian Heinricher, Raphael Heuchl, Moritz Hiebler, Daniel Holmes, Ivan Izmestiev, Anastasya Pazniak, Dominik Pultar, Johannes Rosenkranz, Morteza Saghafian, Jan Schiller, William Shi, Jan Strehn, Georg Weisbier.

Geometric and Asymptotic Group Theory with Applications 2023 - Groups and Dynamics

Organizers: Christopher Cashen (U of Vienna), Javier de la Nuez González (KIAS, Seoul), Alexandra Edletzberger (U of Vienna), Yash Lodha (U of Hawaii, Honolulu)

Dates: July 17 – 21, 2023

Budget: ESI € 15 736
NSF conference proposal DMS-2311110 (GAGTA 2023), PI Kim Ruane, Tufts U $ 16 000
Samsung Science and Technology Foundation (SSTF-BA1301-51), PI Sang-Hyun Kim, KIAS € 13 140
Austrian Science Fund (FWF): P 34214-N, PI Christopher Cashen, U of Vienna € 1 953

Report on the Workshop

This workshop served as the 16th installment of the conference series on Geometric and Asymptotic Group Theory with Applications (GAGTA). The conference meets each summer and generally alternates between Europe and the New York City area, although meetings have also taken place in Korea, Israel, and Australia.

Topics include geometric and combinatorial theory of groups, asymptotic and probabilistic methods as well as the algorithmic and computational aspects of groups, and applications. This years conference emphasized topics in Groups and Dynamics, including random walks, groups of dynamical origin, and the thermodynamic formalism.

One of the goals of the workshop was to encourage interaction between different groups of Mathematicians with overlapping interests. For instance, we had experts on random walks and statistical mechanics and experts on asymptotic boundaries of groups and metric spaces with a common interest in Poisson boundaries of random walks. We had experts in ergodic theory and the thermodynamic formalism and experts in growth of groups and amenability who apply such techniques.

In keeping with the GAGTA mission, we also had several talks on applications, some of which also made connections with other areas represented at the workshop. Delaram Kahrobaei gave a talk about post-quantum secure hash functions based on earlier work on expander graphs by workshop participant Goulnara Arzhantseva. Physicist Alexander Stottmeister gave a talk on the use of Thompson's groups in the renormalization problem for many-body quantum physics, and there were several experts in Thompson's groups present in the audience.

An additional goal was to foster the involvement of early career researchers. Out of the 60 participants, 15 were postdocs and 15 were PhD students. In addition to the invited speakers, all participants were offered a chance to make a presentation, either in the form of a Quick Talks Session (10 minute presentations by postdocs) or a Poster Session for PhD students. We also had a Problem Session for people to propose open research problems.

Activities

Planning of the scientific aspects of the workshop was undertaken by a scientific committee consisting of Christopher Cashen (U of Vienna), Ilya Kapovich (CUNY), Sang-hyun Kim (KIAS), Ian Leary (Southampton), Yash Lodha (Hawaii), Andrés Navas (Santiago de Chile), Kim Ruane (Tufts), and Tianyi Zheng (UCSD).

The daily schedule consisted of Plenary sessions in the mornings: 11 talks of 50 minutes as well as the Quick Talks, Poster Session, and Problem Session. In the afternoons we split into two parallel sessions for 40 minute talks.

In addition to the 60 in-person participants, we had roughly 60 registered online participants. All of the talks were streamed on Zoom, and recordings were added to the ESI Youtube channel. Only the Boltzman hall was equipped for streaming. For the parallel session in the Schroedinger hall we used equipment borrowed from the Faculty of Mathematics. The borrowed wireless microphone developed a fault, which caused a disruption for the online audience the first afternoon, but was subsequently corrected. The ESI provided equipment worked well.

We had breaks each morning and afternoon and no scheduled activity on Wednesday afternoon to leave time for discussion and collaboration. We also had a conference dinner at Heuriger Wagner on Thursday night that was attended by 52 of the participants.

Specific information on the workshop

We made it a priority to include early career researchers, and 50% of the in-person participants were postdocs or PhD students:

Postdocs

Matt Cordes (ETH Zurich)	invited talk
Arman Darbinyan (Vienna)	invited talk
James Hyde (Copenhagen)	invited talk
Javier de la Nuez - Gonzalez (KIAS)	invited talk, organizer
Harry Petyt (Oxford)	invited talk
Donggyun Seo (Seoul)	invited talk
Cagri Sert (Zurich)	invited talk
Alex Stottmeister (Hannover)	invited talk
Tomasz Szarek (BCAM)	invited talk
Henry Bradford (Cambridge)	quick talk
Kevin Li (Regensburg)	quick talk
Hanna Oppelmayer (Innsbruck)	quick talk
Davide Spriano (Oxford)	quick talk
Merlin Incerti-Medici (Vienna)	
Markus Steenbock (Vienna)	

PhD students

Alexandra Edletzberger (Vienna)	poster, organizer
Francesco Fournier-Facio (ETH Zurich)	invited talk
Jacob Garcia (UC Riverside)	poster
Leon Pernak (Saarland)	poster
Eduardo Silva (ENS Paris)	poster
Elliott Vest (UC Riverside)	poster
Corentin Bodart (Genveva)	
Darien Farnham (Virginia)	
Pawel Fedorynski (Hawaii)	
Sydney Fields (Hawaii)	
Ana Isakovi (Cambridge)	
Rob Merrell (Oklahoma)	
Francesco Milizia (Pisa)	
Anna Ribelles Pérez (Munich)	
Rta liakait (Warwick)	

This was primarily an in-person event. We did also stream the talks on Zoom and record them, and are hopeful that the recordings will be a valuable resource. The online audience were able to ask questions during the talks in the Zoom chat. However, they were not able to interact directly with the speakers or in-person audience, nor did we supply any between-talk online activities to make this a truly hybrid conference.

Outcomes and achievements

We were very successful in achieving a 50/50 mixture of junior and senior researchers, and in achieving a broad geographic spread (17 participants from North America, 3 from Israel, 3 from East Asia.)

The recordings of the talks are preserved on the ESI Youtube channel, and will be a valuable resource for the community. The list of problems suggested in the Problem Session was transcribed and posted to the arXiv.

Three of the plenary talks announced important achievements that had not yet appeared as preprints at the time of the conference:

Richard Sharp	"A non-symmetric Kesten criterion for random walks on groups"
Collin Bleak	"Embeddings into Finitely Presented Simple Groups"
Kasra Rafi	"The quasi-redirecting boundary"

List of talks

Pierre Mathieu (U Aix-Marseille)	Boundaries of random walks on (hyperbolic) groups
Delaram Kahrobaei (CUNY, New York)	Post-quantum Blockchains using hash functions using higher dimensional special linear groups over finite fields as platforms
Tomasz Z. Szarek (BCAM, Bilbao)	Pointwise ergodic theorems on nilpotent groups
Donggyun Seo (Seoul National U)	RAAGs generated by Dehn twists with uniform intersection number
Arman Darbinyan (U of Vienna)	Orderable groups and their computability properties
Harry Petyt (U Oxford)	Obstructions to coarse cubulation
Michele Triestino (UB)	Actions on the circle with at most N fixed points
Matt Cordes (ETH Zürich)	Coxeter groups with (locally)-connected Morse boundary
Volodymyr Nekrashevych (TAMU, College Station)	Topological and conformal dimensions of self-similar groups
Tom Hutchcroft (CalTech)	Uniqueness and non-uniqueness for percolation on groups
Henry Bradford (U Cambridge)	Equations with constants in some hyperbolic and linear groups
Davide Spriano (U Oxford)	Hyperbolicity of uniquely geodesic group
Hanna Oppelmayer (U of Innsbruck)	Amenable IRAs
Kevin Li (U Regensburg)	Complexity of groups via open covers
James Hyde (U of Copenhagen)	Finitely Presented Simple Groups of Homeomorphisms of the Reals
Ariel Yadin (Ben-Gurion U, Beer-Sheva)	Metric-functional boundary of Cayley graphs
Franceso Fournier-Facio (ETH Zürich)	Ulam stability of Thompson groups
Adam Dor-On (Haifa U.)	Ratio-limit boundaries for random walks on relatively hyperbolic groups.

Javier de la Nuez González (KIAS, Seoul)	Minimality of the compact-open topology on diffeomorphism and homeomorphism groups
Ecaterina Sava-Huss (U of Innsbruck)	Abelian sandpile Markov chains
Richard Sharp (U Warwick)	A non-symmetric Kesten criterion for random walks on groups
Alexander Stottmeister (ITP Hannover)	Operator Algebras, the Renormalization Group, and Jones Actions of Thompsons Groups
Collin Bleak (U of St Andrews)	Embeddings into Finitely Presented Simple Groups
Clara Löh (U Regensburg)	Vanishing of logarithmic torsion homology growth via dynamics
Nicolás Matte Bon (Institute Camille Jordan, U Lyon)	Liouville property for self-similar groups via conformal dimension
Rémi Coulon (UB)	Equations in periodic groups
Joseph Maher (CUNY, New York)	Singularity of measures for Cannon-Thurston maps
Samuel Tapie (U Lorraine)	Entropy at infinity in negative curvature and applications
Talia Fernós (UNCG)	An invitation to the lifting decomposition
Pim van der Hoorn (TU Eindhoven)	Convergence of Ollivier-Ricci curvature in random geometric graphs on Riemannian manifolds
Kasra Rafi (U Toronto)	The quasi-redirecting boundary.
Cagri Sert (U Zürich)	Counting limit theorems for representations of Gromov-hyperbolic groups
Yulan Qing (Fudan)	Boundary of Groups
Thomas Koberda (U Virginia)	First order theory of homeomorphism groups of compact manifolds
Ilya Gekhtman (Technion Haifa)	Stationary random subgroups and injectivity radius of hyperbolic manifolds

Publications and preprints contributed

H. Bradford, Ch. H. Cashen, F. Fournier-Facio, N. Matte Bon, H. Petyt, *GAGTA 2023 Problem Session*, arXiv:2310.04207[math.GR].

Invited scientists

Invited scientists who participated on site
Collin Bleak, Corentin Bodart, Henry Bradford, Christopher Cashen, Matt Cordes, Rémi Coulon, Arman Darbinyan, Javier de la Nuez González, Adam Dor-On, Alexandra Edletzberger, Darien Farnham, Pawel Fedorynski, Talia Fernós, Sydney Fields, Franceso Fournier-Facio, Jacob Garcia, Ilya Gekhtman, Wolfgang Herfort, Tom Hutchcroft, James Hyde, Merlin Incerti-Medici, Ana Isakovi, Delaram Kahrobaei, Ilya Kapovich, Olga Kharlampovich, Thomas Koberda, Ian Leary, Kevin Li, Yash Lodha, Clara Löh, Joseph Maher, Pierre Mathieu, Nicolás Matte Bon, Rob Merrell, Francesco Milizia, Volodymyr Nekrashevych, Hanna Oppelmayer, Leon Pernak, Harry Petyt, Yulan Qing, Kasra Rafi, Anna Ribelles Pérez, Ecaterina Sava-Huss, Donggyun Seo, Cagri Sert, Richard Sharp, Eduardo Silva, Rta liakait, Davide Spriano, Markus Steenbock, Alexander Stottmeister, Tomasz Z. Szarek, Samuel Tapie, Michele Triestino, Pim van der Hoorn, Elliott Vest, Pascal Weil, Ariel Yadin, Tianyi Zheng.

Invited scientists who participated online
Goulnara Arzhantseva, Jennifer Beck, Mark Bell, Alex Bishop, Mark Brittenham, Zixiang Chow, Laura Ciobanu, Jonas Deré, Mikhail Ershov, Wu Fan, Nate Fisher, Anthony Genevois, Jiyoung Han, Yo Hasegawa, Susan Hermiller, Wonyong Jang, Sarasi Jayasekara, Arie Juhasz, Annette Karrer, Jaeyoung Kim, Corentin Le Bars, Francois Ledrappier, Gilbert Levitt, Seonhee Lim, Yuan Liu, Antonio Lopez

Neumann, Joel Louwsma, Olga Lukina, Igor Lysenok, Keivan Mallahi Karai, Richard Mandel, Alexis Marchand, Biswajit Nag, Josiah Oh, Sangrok Oh, Shane ORourke, Sven Raum, Eduard Schesler, Zlil Sela, Asif Shaikh, Vladimir Shpilrain, Lin Shu, Ignat Soroko, Yves Stalder, Vera Tonic, Petra Lynn Vanderhei.

Large-N Matrix Models and Emergent Geometry

Organizers:

Sumit Ranjan Das (U Kentucky), Masanori Hanada (QMU London), Sean Hartnoll (U Cambridge) Antal Jevicki (Brown U, Providence), Joanna Karczmarek (UBC Vancouver), Harold Steinacker (U of Vienna)

Dates:

September 4 – 8, 2023

Budget: ESI € 13 476
€ 1 802 from personal FWF project P32086 (PI Harold Steinacker) for some travel support

Report on the Workshop

This workshop was centered around recent developments in the context of large-N matrix models, as an approach towards emergent geometry. This topic is grounded on long-term efforts to underestand large-N quantum field theories and matrix models, which play an important role in string theory and the holographic correspondence. The aim was to gather researchers working on different aspects of this topic, to assess the new developments and conceptual perspectives that have led to renewed progress and interest in these models.

One important area of recent progress has been numerical methods, including Lattice Monte Carlo simulations in the Euclidean case and other approaches such as Langevin methods in the Lorentzian case. Besides this computational work, several mechanisms of emergent holographic geometry have recently been pursued. One central theme are various notions of entanglement, which is a key ingredient in understanding the emergence of smooth internal spaces in the holographic AdS/CFT correspondence. In gauge theories per se, notions of entanglement provide insight into the phase structure, as well as into the properties of states arising in condensed matter systems.

Progress on emergent geometry has also been made in pure matrix models, most notably the IKKT matrix model. This is based on the concept of quantized symplectic spaces, often denoted as fuzzy geometry, which is appropriate in the weak coupling regime. This regime is complementary to the holographic point of view, and allows a perturbative analysis of the matrix models on non-trivial backgrounds corresponding to quantum geometries.

The aim of this workshop was to provide an opportunity to discuss the recent progress and interplay between these different models and approaches.

Activities

The workshop was thematically structured around review talks in the morning, followed by talks on related topics and with ample discussion time during long coffee breaks, both in the

morning and the afternoon. The afternoon talks typically covered topics from a somewhat wider context.

One talk (de Mello Koch) had to be moved online due to short-term travel issues. All other talks were given in presence. The slides are available from the website of the meeting, and recordings of most of them can be found on the Youtube channel of ESI.

The specific talks and contributions can be summarized as follows:

- Moday, September 4:

  focus on entanglement & related aspects of holography

  review talk by Frenkel (entanglement & matrix QM), followed by talks by Berenstein (combinatorial tools at large N), Mandal & Das (large N & holography), and related contributions by Yoon and Ramgoolam

- Tuesday, September 5:

  focus on new technical approaches such as bootstrap and algebraic methods to describe emergent large-N structures and the relation with string or M theory

  review talk by Lin (bootstrap), followed by Hanada (numerics & phase transition in the D0 brane model), Tsuchiya (renormalization group aspects of tensor networks), O'Connor (algebraic aspects of large matrices), Jevicki (holography in bi-local models), and Tropper (scattering & symmetries in the BFSS model)

- Wednesday, September 6:

  further aspects of holography: tilings & holography (Erdmenger), master fields in multi-matrix models (Rodrigues) and a contribution on spherically symmetric quantum spaces (Kovacik)

  followed by a free afternoon & conference dinner

- Thursday, September 7:

  this day was dedicated to the IKKT model: Nishimura (definition & implementation of the Lorentzian model), Anagostopoulos (numerical results), Asano (relation with string theory), Steinacker (semi-classical solutions & gravity), and contributions by Tran (higher spin theories) and Battista (cosmological aspects)

- Friday, September 8:

  a conceptual talk on fine-tuning, naturalness & phase transitions by Kawai was followed by 3 talks on an appropach to coosmology using the BFSS model (Brandenberger, Brahma, Laliberte) & a contribution by Liu on entaglement & lowest Landau level

  On friday afternoon, an informal discussion session comprising all topics of the workshop was held, which turned out to work very well. This was very useful to clarify many of the issues arising in the talks, and to link the different strands.

The conference dinner was held at the Heurigen "Feuerwehr-Wagner". This was greatly appreciated, and essentially all participants attended.

Specific information on the workshop

Although most of their participants were either senior scientists/professors or postdocs, there were also two talks by PhD students (A. Tropper, S. Laliberte), and a beginning PhD student (A.

Manta) was able to participate. Some talks were also attended by scientists from the University of Vienna and the TU Vienna.

The overall number of participants was 36 participants.

Outcomes and achievements

This workshop has led to numerous new initiatives and ideas for collaborations, including

- A new collaboration was initiated between Jun Nishimura, Harold Steinacker and other participants.
- The talk by Adam Tropper sparked a new preprint by Harold Steinacker and Tung Tran (listed below).
- A new collaboration was started between Sumit Das and Sinong Liu about MERA in time dependent backgrounds and isometric time evolution.
- Robert Brandenberger together with some of the present organizers and participants of this workshop submitted an application for a related follow-up meeting at the Banff International Research Station (Canada).

List of talks

Alexander Frenkel (Stanford U)	Entanglement in Matrix Quantum Mechanics
David Berenstein (UC, Santa Barbara)	Strings, Young diagrams and all that.
Gautam Mandal (TIFR Mumbai)	A fresh look at the large N limit of matrix models and holography
Sumit Ranjan Das (U Kentucky)	Entanglement of Internal Degrees of Freedom and Holography
Junggi Yoon (APCTP)	Gravitational edge mode for AdS2
Sanjaye Ramgoolam (QMU London)	Classical identification of emergent geometries in AdS spacetimes and quantum algorithms for algebras in dual CFTs.
Henry Lin (Stanford U)	Review of the large N matrix bootstrap
Masanori Hanada (QMU London)	Recent numerical results on D0-brane matrix model
Asato Tsuchiya (Shizuoka U)	Renormalization group and quantum error correction
Denjoe O'Connor (DIAS, Dublin)	Trace Relations and Matrix Models
Adam Tropper (Harvard U, Cambridge)	New Symmetries in Old Matrix Models
Antal Jevicki (Brown U, Providence)	Symmetries and Hilbert Space at Large N
Robert de Mello Koch (Huzhou U)	Microscopic Entanglement Wedges from Bilocal Holography
Joao Rodrigues (U of Witwatersrand)	Large N Master Field Optimization for Multi-Matrix Systems
Johanna Erdmenger (U Würzburg)	Discrete Holography
Samuel Kovacik (Comenius U, Bratislava	The Fuzzy Onion
Jun Nishimura (KEK, Tsukuba)	Lorentzian IKKT matrix model with the mass term as a nonperturbative formulation of superstring theory
Konstantinos Anagnostopoulos (National and Technical U of Athens)	Recent progress in the numerical studies of the Lorentzian IKKT model
Yuhma Asano (U of Tsukuba)	Perturbative superstring theory and the IKKT matrix model

Harold Steinacker (U of Vienna)	3+1-dimensional gravity as a quantum effect in the IKKT model
Tung Tran (U Mons)	(Quasi-)chiral higher-spin theories from twistor space
Battista Emmanuele (U of Vienna)	The propagation of fermions on curved backgrounds of matrix models
Hikaru Kawai (National Taiwan University)	Quantum Phase Transition and Naturalness in Generalized Effective Action
Robert Brandenberger (McGill U)	Emergent Metric Space-Time and Early Universe Cosmology from the BFSS Matrix Model
Suddhasattwa Brahma (U Edinburgh)	Emergent Matrix Cosmology
Samuel Laliberte (McGill U)	A Wilsonian effective action for (1+3+6)-dimensional emergent universes in the IKKT model
Sinong Liu (U Warsaw)	Entanglement entropy and phase space density: from lowest Landau levels to 1/2 BPS states

Publications and preprints contributed

E. Battista and H. C. Steinacker, *One-loop effective action of the IKKT model for cosmological backgrounds*, arXiv:2310.11126[hep-th].

A. Hock, *Laplace transform of the x – y symplectic transformation formula in Topological Recursion*, arXiv:2304.03032[math-ph].

H. C. Steinacker, Tung Tran, *Soft limit of cubic higher-spin interactions in the IKKT model*, arXiv:2311.14163[hep-th].

Invited scientists

Konstantinos Anagnostopoulos, Yuhma Asano, David Berenstein, Suddhasattwa Brahma, Robert Brandenberger, Maja Buric, Sumit Ranjan Das, Battista Emmanuele, Johanna Erdmenger, Veselin Filev, Alexander Frenkel, Masanori Hanada, Antal Jevicki, Joanna Karczmarek, Hikaru Kawai, Samuel Kovacik, Samuel Laliberte, Henry Lin, Sinong Liu, Gautam Mandal, Jun Nishimura, Denjoe O'Connor, Sanjaye Ramgoolam, Joao Rodrigues, Ronak Soni, Harold Steinacker, Juraj Tekel, Tung Tran, Adam Tropper, Asato Tsuchiya, Gabriel Wong, Junggi Yoon.

Symposium: ESI@30 – The first 30 years of the ESI

Organizer: Christoph Dellago, ESI Director (U of Vienna), Stefan Fredenhagen (U of Vienna), Ilaria Perugia (U of Vienna), Adrian Constantin (U of Vienna), Michael Eichmair (U of Vienna), Bernadett Weinzierl (U of Vienna), Jakob Yngvason (U of Vienna)

Dates: November 9 – 10, 2023

In 2023, we celebrated the 30th anniversary of the ESI with a symposium titled *ESI@30 – the first 30 years of the Erwin Schrödinger Institute*. This milestone event, where we had the honor of welcoming Rector Sebastian Schütze and Nobel Laureate Anton Zeilinger, was a wonderful opportunity to reflect on the Institute's significant contributions to mathematics and physics over the past three decades and celebrate its ongoing commitment to advancing scholarly research and fostering international collaboration. The ESI@30 Symposium was a festive two-day event that started on Thursday, November 9, at 14:00, and concluded on Friday, November

10, at 14:00. It was packed with outstanding scientific talks, lively discussions, and plenty of opportunities for networking and reconnecting with colleagues and friends.

A Look Back: ESI's Journey

Founded in 1993, the Erwin Schrödinger International Institute for Mathematics and Physics (ESI) in Vienna was born from the vision of pioneering scientists like Walther Thirring, Heider Narnhofer, and Peter Michor. The idea for the Institute emerged in the wake of the 1989 events in Eastern Europe, which led to the fall of the Iron Curtain. This period presented a unique opportunity to foster international collaboration in science, particularly to support colleagues in Eastern Europe facing challenging job conditions. With the backing of Austrian Federal Minister for Science and Research Erhard Busek, the ESI was established to provide a platform for high-level research in mathematical physics. The Institute began its journey in a building on Pasteurgasse, a location notable for being the residence of Erwin Schrödinger from 1956 to 1961, before moving to its current home on Boltzmanngasse in the Priesterseminar 1996.

Over the years, ESI has evolved from its initial focus on mathematical physics to a broader scope, now encompassing all areas of mathematics and physics, including theoretical, computational and experimental aspects. The ESI faced a significant funding crisis in 2010, when the Austrian Federal Ministry of Science and Research decided to cease direct funding. The continuation of the ESI was made possible by the University of Vienna, which stepped in to support the institute and since 2011 the ESI is part of the University of Vienna. This transition marked a new era of growth and diversification for the ESI. The institute introduced various programms such as the Senior Research Fellowship, Junior Research Fellowship, and Research in Teams initiatives, which have played a crucial role in fostering a dynamic and collaborative research environment. Today, the ESI continues to uphold its founding principles of promoting innovative research, encouraging international collaboration, and supporting the exchange of ideas across scientific disciplines.

ESI Medal 2023 Award Ceremony

One of the highlights of the symposium was the Award Ceremony for the ESI Medal 2023, held on November 9. This prestigious medal, established in 2020, honors outstanding achievements in mathematics and physics. This year, it was awarded to Professor Isabelle Gallagher from the École Normale Supérieure in Paris. Professor Gallagher was honored for her numerous innovative and highly significant contributions to the mathematical theory of fluid dynamics. With rigorous mathematical analysis she has greatly advanced our understanding of the relationships between microscopic and macroscopic models of fluid. In particular, her work explains how the Boltzmann equation, which gives a statistical description of the dynamics of dilute gases, emerges from an atomic-level model of the gas as a vast collection of interacting particles moving and colliding according to Newton's laws. The Laudatio for Prof. Gallagher was given by Pierre Germain from Imperial College London, which was followed by a beautiful Award Lecture of the awardee, in which she gave a overview of her fascinating work.

ESI in numbers 1993-2023

Since its establishment in 1993, ESI has been a vibrant hub for international research in mathematics and physics, hosting countless scientific programms on a wide array of topics. Over the years, the ESI has hosted 138 Thematic Programms, 178 Workshops, and 27 Graduate Schools. It has supported 69 Senior Research Fellows, 209 Junior Research Fellows, and facilitated 51 Research-in-Team initiatives. These efforts have led to almost 10,000 talks and numerous scholarly publications, significantly contributing to advancements in mathematics and physics. The programms of the ESI attract nearly 1,000 visitors annually from around the world, creating a dynamic and collaborative research environment.

ESI the Movie

On the occasion of its 30th anniversary, the ESI produced a promotion video that showcases its diverse activities. The video is available on the Youtube-Channel of the Institute:

https://www.youtube.com/watch?v=zIgFvKfz79o

Looking Ahead

As the ESI looks to the future, it remains committed to its core values of fostering interactions between mathematics and physics, promoting international collaboration, and upholding scientific excellence. The ESI@30 Symposium was a joyous celebration of three decades of excellence and innovation in mathematics and physics. As the ESI continues to evolve, it remains a beacon of scholarly research and a hub for the international scientific community.

Talks of the Symposium ESI@30

Christoph Dellago (U of Vienna)	Introduction
Wolfgang Reiter (U of Vienna)	ESI The Foundational Period: Personal Reminiscences
Anton Zeilinger (U of Vienna)	Quantum Entanglement Beyond two Particles and in Higher Dimensions
Pierre Germain (Imperial College London)	Laudatio
Isabelle Gallagher (ENS Paris)	Award Lecture
Gitta Kutyniok (LMU Munich)	Reliable AI: Successes, Challenges, and Limitations
Ulrike Lohmann (ETH Zurich)	Clouds - their Formation and Importance for Present and Future Climate
Christopher Jarzynski (U of Maryland)	Quantum Super Impulses
Irene Fonseca (Carnegie Mellon U, Pittsburgh)	From Phase Separation in Heterogeneous Media to Learning Training Schemes for Image Denoising

Invited scientists

Douglas Arnold, Radu Ioan Bot, Alberto Bressan, Adrian Constantin, Apostolos Damialis, Christoph Dellago, Sandra Di Rocco, Michael Eichmair, Heinz W. Engl, Irene Fonseca, Stefan Fredenhagen, Isabelle Gallagher, Pierre Germain, Domenico Giulini, Norbert Hegyvári, Nigel Hitchin, Gerhard Huisken, Christopher Jarzynski, Julia Kempe, Gitta Kutyniok, Ulrike Lohmann, Ilaria Perugia, Wolfgang Reiter, Klaus Schmidt, Sebastian Schütze, Joachim Schwermer, Francesco Sciortino, Bernadett Weinzierl, Jakob Yngvason, Anton Zeilinger.

Analysis and Geometry in Several Complex Variables

Organizers: Peter Ebenfelt (UC San Diego), Purvi Gupta (IIS Bengalore), Bernhard Lamel (Texas A&M U at Qatar & U of Vienna), Nordine Mir (Texas A&M U at Qatar)

Dates: November 20 – 24, 2023

Budget: ESI € 11 920
€ 3 000 (Social Event, and some participant travel funded by external funds)

Report on the Workshop

The goal of the workshop was to advance the rich and profitable interactions between SCV, algebraic and analytic Geometry, partial differential equations and dynamics. Complex analysis in one variable has played an important and unifying role in mathematics. Over the last couple of centuries, its influence in other fields of pure and applied mathematics has led to a better understanding of and deep results in number theory, geometry, analysis, and algebra alike. In the XXth century, complex analysis in several variables was developed as a distinct branch of mathematics starting with the pioneering works of mathematicians such as Poincaré, Cartan, Hartogs, Levi, Oka, to name a few, who discovered new phenomena starkly in contrast with the one dimensional theory. A crucial role in these developments is played by the analysis of the Cauchy–Riemann equations in complex Euclidean spaces or in complex manifolds. Most of the advances of the last century were possible through the understanding of the inhomogeneous Cauchy–Riemann equations from a partial differential equations perspective, an approach often referred to as the $\bar{\partial}$ method. Moreover, not only did complex analysis profit from these developments, but the new methods have also found applications in other areas of mathematics. The development of the theory of $\bar{\partial}$ and $\Box = \bar{\partial}\bar{\partial}^* + \bar{\partial}^*\bar{\partial}$ has served as a model in the development of PDE theory and this theory has also had a profound impact in algebraic and complex geometry. Several Complex Variables (SCV) is a subject full of rich and deep interactions with a variety of different mathematical fields, including Partial Differential Equations, Algebraic and Complex Analytic Geometry, Cauchy–Riemann geometry, and Dynamics. Our workshop focused on these interactions in the specific context of Cauchy-Riemann geometry, Biholomorphically invariant metrics, and classical analysis of several complex variables, in particular the theory of the $\bar{\partial}$-Neumann problem.

Activities

We opted for a light schedule with 20 talks overall in order to give participants the chance to use the ESI facilities to discuss and to initiate and pursue joint projects. Every day, one could see research in pairs and larger groups happening at the fabulous blackboards, and many participants took advantage of the opportunities provided for interaction.

On the first day of the workshop, we closed the day with a wine&cheese social gathering, which gave us to opportunity to introduce the junior workshop participants to the more senior researchers (in particular, a number or prae-PhDs and prae-docs were participating, and they networked within the community and explored possible PhD/postdoc opportunities. In terms of social activities, we also invited the participants to a classical Heurigenabend, which was a great success.

Specific information on the workshop

A number of master students from the U of Vienna participated actively (in particular G. Schneider, F. Xerakia, and C. Neumayer). The following praedocs participated: Anand Chavan (Jagiellonian U), Soumya Ganguly (U of California San Diego), Nai-Yu Hu (U of Vienna), Vinicius Novelli (U de Sao Paulo), Dariusz Piekarz (Jagiellonian U). Also, the following postdocs participated: Antonio Victor da Silva Jr (Texas A&M U at Qatar), Luke Edholm (U of Vienna), Stefan Fürdös (U of Vienna), Tobias Harz (U Wuppertal), Valentin Kunz (U of Bologna), Thomas Pawlaschyk (U Wuppertal), Jonathan Shelah (U v Ljubljani), Nick Treuer (U of California San Diego), and Weixia Zhu (U of Vienna). That means of the registered participants roughly 1/3 were junior colleagues.

A major component of the workshop was to give enough time for the junior participants to talk about their work with the senior participants. Judging from the workshop experience, this was succesfully accomplished.

Outcomes and achievements

We successfully gathered some of the leading figures in the analysis of several complex variables and CR geometry, and many idease have been communicated and discussed during the workshop. We are trying to group the talks in several groups for the purpose of this report:

CR geometry/mappings: Ilya Kossovskiy presented his work on detecting sphericity of strictly pseudoconvex hypersurfaces in low regularity, which yielded interesting discussions on unexpected regularity of a priori non-regular geometric invariants. Dmitri Zaitsev gave an overview of his ongoing project developing an alternate approach to Caitlin's regularity theory, in which he emphasizes the CR geometry of a weakly pseudoconvex hypersurface. In a similar vein, talks by Sean Curry and Howard Jacobowitz explored the state of the art of the (local) CR embedding problem for strictly pseudoconvex hypersurface type structures. John D'Angelo presented current work on rational sphere maps, in particular the gap property and how one can find maps realizing known gaps. Shif Berhanu talked about recent results on the Rado property for continuous CR functions.

Invariant metrics, curvature and other geometric aspects of complex spaces: Ming Xiao discussed in his talk current results concerning the conjectures of Cheng and Yau, which relate the Kähler-Einstein property of the Bergman metric of a domain with it being homogeneous. Nikolay Sherbina presented his proof that strictly pseudoconvex rigid model domains are Kobayashi hyperbolic. Franc Forstnerič talked about a recent work which relates Oka properties and metric positivity of complex manifolds: for a semipositive hermitian line bundle on a compact complex manifold, it is shown that its unit disc bundle is Oka, while its complement is Kobayashi hyperbolic. Laurent Stolovitch gave an overview over current work on Grauert's "formal principle" for embeddings of complex tori under diophantine conditions (replacing known curvature conditions). Rasul Shafikov discussed generalizations of rational convexity to Stein and projective manifolds with applications characterizing convexity of some compact sets. Severine Biard talked about a localization formula for the first Chern class in terms of residues of a given connections, with applications to holomorphic foliations of codimension 1. Jean Ruppenthal presented results and examples to illustrate the failure of the L^2-Stokes theorem for the $\bar{\partial}$-operator on Hermitian complex spaces, and made a case for considering W^1-theory instead of L^2-theory for the $\bar{\partial}$-operator on singular spaces.

Classical analysis of several complex variables: Emil Straube opened the meeting with a new result on a classical question, namely, whether Diederich-Fornæss index 1 implies global reg-

ularity in the $\bar{\partial}$-Neumann problem; the result presented shows that this is the case for domains with comparable Levi-eigenvalues. In related but different directions, Nick Treuer presented his work related to regularity in the $\bar{\partial}$-Neumann problem by an application of the Levi core recently introduced by Dall'Ara and Mongodi, and Dall'Ara talked about recent work on the relation of spectral gap estimates and subellipticity in the $\bar{\partial}$-Neumann problem. Andrew Raich's talk discussed his current work trying to understand why many of the sufficient conditions which imply regularity in the $\bar{\partial}$-Neumann problem are not invariant under changes of the metric, a question which has been of renewed interest in the last years. Anne-Katrin Gallagher reported on her current work on the Poincaré inequality. Takeo Ohsawa presented his work on weighted Bergman spaces of weakly pseudoconvex domains. Loredana Lanzani presented a new transform method for solving certain mixed boundary value problems such as Laplace's equation and the complex Helmholtz equation on bounded convex planar domains.

Synthetic Judgment: The workshop clearly showed that the interaction between (boundary) geometry and the analysis of several complex variables remains a fertile field for mathematical research with interesting new outcomes and questions as well as progress on classical problems alike. We hope that the interactions sparked by the exchanges in our workshop will yield more breakthroughs and collaborations across the field.

Specific Collaborations: We have polled the workshop participants on this point, but got limited feedback, so the following might be incomplete. Laurent Stolovitch and Sean Curry started discussions revolving around Fefferman's ambient metric, which are ongoing. Bernhard Lamel and Laurent Stolovitch continued their collaboration on the holomorphic classification for real-analytic nonminimal hypersurfaces in two-dimensional complex space. Takeo Ohsawa and Friedrich Haslinger continued collaborative efforts also including Joe Kamimoto. Franc Forstneric and Laurent Stolovitch initiated discussions about singular embeddings. Purvi Gupta and Rasul Shafikov continued their collaboration on the minimal embedding dimension of polynomially convex embeddings. Sean Curry started to discuss common projects with Gian Maria Dall'Ara. Howard Jacobowitz, Siqi Fu, and Weixia Zhu continued their collaboration on the spectral gap for three-dimensional CR manifolds.

List of talks

Emil Straube (TAMU, College Station)	Diederich-Fornss index, D'Angelo forms, and global regularity in the $\bar{\partial}$-Neumann problem
Severine Biard (U Polytechnique, Haute-de-France)	A Residue formula and applications to stable sets of foliations
Anne-Katrin Gallagher (GTI, Redmond)	On the Poincare inequality on open sets in R^n
Andrew Raich (U of Arkansas, Fayetteville)	The d-bar problem on Z(q) domains
Rasul Shafikov (U of Western Ontario)	Rational convexity on Stein and projective manifolds
Shiferaw Berhanu (U of Maryland)	The Rado property for CR functions.
Ilya Kossovskiy (Masaryk U, Brno)	Sphericity and analyticity of a strictly pseudoconvex hypersurface in low regularity
Ming Xiao (UC, San Diego)	Kähler-Einstein Bergman metrics on pseudoconvex domains
Jean Ruppenthal (Bergische U Wuppertal)	The L2-Stokes Theorem on Complex Varieties and Dolbeault Cohomology
Takeo Ohsawa (Nagoya U)	Weighted Bergman spaces on locally pseudoconvex domains
John (Nick) Treuer (UC, San Diego)	Modifications of the Levi core
Dmitri Zaitsev (Trinity College, Dublin)	Catlin's global regularity - a new proof and generalizations.

John P. D'Angelo (U Illinois)	Rational sphere maps: symmetries, gaps, and optimization.
Loredana Lanzani (U of Bologna)	A numerical method for the solution of BVPs for $\bar{\partial}$ on convex planar domains
Sean Curry (Oklahoma State U, Stillwater)	The local CR embedding problem
Howard Jacobowitz (Rutgers U)	CR Geometry and Analysis
Nikolay Shcherbina (Bergische U Wuppertal)	On Kobayashi and Bergman hyperbolicity of strictly pseudoconvex rigid domains
Laurent Stolovitch (U Cte d'Azur, Nice)	On neighborhoods of embedded complex tori
Gian Maria Dall'Ara (INDAM and SNS, Pisa)	Spectral gap estimates for $\bar{\partial}$-Laplacians and subellipticity in the $\bar{\partial}$-Neumann problem
Franc Forstneric (U Ljubljana)	Oka tubes in holomorphic line bundles

Publications and preprints contributed

F. Forstneric, Y. Kusakabe, *Oka tubes in holomorphic line bundles*, arXiv:2310.14871[math.CV].

Invited scientists

Shiferaw Berhanu, Severine Biard, Anand Chavan, Sean Curry, Gian Maria Dall'Ara, John P. D'Angelo, Antonio Victor Da Silva Jr, Makhlouf Derridj, Peter Ebenfelt, Luke Edholm, Franc Forstneric, Stefan Fürdös, Anne-Katrin Gallagher, Soumya Ganguly, Purvi Gupta, Tobias Harz, Friedrich Haslinger, Nai-Yu Hu, Howard Jacobowitz, David Kalaj, Ilya Kossovskiy, Valentin Kunz, Bernhard Lamel, Loredana Lanzani, Nordine Mir, Christina Neumayer, Vinicius Novelli, Takeo Ohsawa, Thomas Pawlaschyk, Dariusz Piekarz, Andrew Raich, Jean Ruppenthal, Rasul Shafikov, Nikolay Shcherbina, Jonathan Shelah, Laurent Stolovitch, Emil Straube, John (Nick) Treuer, Fani Xerakia, Ming Xiao, Dmitri Zaitsev, Weixia Zhu.

Mathematical Relativity: Past, Present, Future

Organizers: Piotr T. Chruściel (U of Vienna), Michael Eichmair (U of Vienna), Gerhard Huisken (U of Tübingen), Jim Isenberg (U of Oregon, Eugene)

Dates: December 4 – 7, 2023

Budget: ESI € 10 316
Four participants from the United States, namely
Nishanth Gudapati (Clark U),
Sven Hirsch (Institute for Advanced Studies, Princeton),
Andrea Nützi (Stanford U), and
Andrade E Silva (U of Maryland)
were funded by a grant of the National Science Foundation.

Report on the Workshop

The 100th birthday of Yvonne Choquet-Bruhat, whose 1952 paper on the Cauchy problem for the Einstein equations opened up the field of mathematical general relativity, provided an excellent occasion to organize a high-level workshop on mathematical general relativity at the Erwin Schrödinger International Institute for Mathematics and Physics. Our goal was to bring

together advanced doctoral students, promising young researchers, and leading experts in the field to discuss the spectacular recent developments in the area, to share and discuss techniques that have proven particularly successful, to assess new areas of contact, and to support existing and promote new collaborations.

There have been spectacular developments in mathematical general relativity in the last few years: the long awaited proof of stability of Kerr, at least for small angular momenta; the discovery of two new gluing methods; and several proofs of positivity of energy with new methods or under new conditions. The authors of these major breakthroughs in mathematical general relativity presented their work during our meeting.

Activities

The meeting consisted of three and a half days of talks, with one afternoon free for individual interactions. The opening included, among others, a pre-recorded video message from the daughter and the son of Yvonne Choquet-Bruhat, whose state of health did not allow participation, and a pre-recorded video message from Emanuele Berti, president of the General Relativity and Gravitation Society. Due to the expected high number of participants, all lectures were streamed to a second lecture hall. All lectures were also streamed live on zoom. The talk by Richard Schoen was streamed as part of the "Joint Mathematical Relativity Seminar", a monthly online colloquium co-organized by a group of researchers from the Netherlands, Germany, Greece, Portugal, and Sweden.

Specific information on the workshop

Young researchers:

Raphaela Wutte (postdoc in Tempe, Arizona), continued collaboration with Piotr Chruściel, preprint arXiv:2401.04048[gr-qc].
Andrea Nützi (postdoc in Stanford) joined a collaboration with Piotr Chruściel and Albachiara Cogo (PhD student in Tübingen); work in progress.
Thomas Körber (postdoc in Vienna) and Sven Hirsch (postdoc in Princeton) gave lectures in the meeting; this is likely to be significant to their future careers.
Luca Benatti (postdoc in Pisa)
Jordan Marajh (postdoc at Queen Mary U of London)
Tong Tong Hu (postdoc at Queen Mary U of London)
Benjamin Meco (PhD student at Uppsala U)
Francesca Oronzio (postdoc at KTH Royal Institute of Technology)
Robert Samsun (postdoc at Queen Mary U of London)
Markus Wolff (postdoc at KTH Royal Institute of Technology)
several PhD students (Fritz, Lindstroem, Mieling, Oeffner, Steininger, Urban) and postdocs (Cong, Ficek, Gray, Körber, Oancea) from Vienna.

Outcomes and achievements

One of us (PC) made substantial progress in two research projects thanks to discussions with participants of the programme (two preprints in preparation).
Andrea Nützi (postdoc in Stanford), whose participation in the workshop was funded by an NSF grant, joined an ongoing collaboration of Piotr Chruściel and Albachiara Cogo (PhD student from Tübingen) on hyperboloidal general relativistic constraint equations.

List of talks

Jan Sbierski (U Edinburgh)	The C^0-*inextendibility* of a class of FLRW spacetimes
Gustav Holzegel (U Münster)	Stability Problems for Black Holes
Rita Teixeira da Costa (U Cambridge)	Homogenization of the Einstein equations under symmetry
Thomas Körber (U of Vienna)	Schoen's conjecture for limits of isoperimetric surfaces
Jean-Pierre Bourguignon (IHES, Paris)	Modified Lagrangians for General Relativity
Lan-Hsuan Huang (U Conn)	Existence of Einstein metrics with prescribed boundary data
Stefan Czimek (U Leipzig)	The Null Gluing Problem in General Relativity: Past, Present, and Future
Lorenzo Mazzieri (U of Trento)	On the classification problem for static metrics with positive cosmological constant
Sven Hirsch (IAS, Princeton)	Which manifolds are positively curved?
Jose Martin-Garcia (Wolfram Research)	xAct Tensor Computation: A Thousand Projects
Melanie Graf (U Hamburg	Initial data sets that do not satisfy the ReggeTeitelboim conditions
Zoe Wyatt (U Cambridge)	Global stability of Kaluza-Klein spacetimes
Hans Ringström (KTH Stockholm)	A quiescent regime for big bang formation
Peter Hintz (ETH Zurich)	Gluing black holes along timelike geodesics
Sergiu Klainerman (Princeton U)	Mathematical GR seventy two years after Yvonne's foundational Acta paper
Jérémie Szeftel (Sorbonne U, Paris)	The nonlinear stability of Kerr for small angular momentum
Sakovich (Uppsala U)	A definition of the mass aspect function for weakly regular asymptotically hyperbolic manifolds
Richard Schoen (Stanford U)	How minimal hypersurface and MOTS singularities affect relativity theorems

Publications and preprints contributed

P. T. Chruściel, R. Wutte, *Gluing-at-infinity of two-dimensional asymptotically locally hyperbolic manifolds*, arXiv:2401.04048 [gr-qc].

Invited scientists

Peter C. Aichelburg, Rodrigo Andrade e Silva, Håkan Andréasson, Robert Beig, Luca Benatti, Stefano Borghini, Jean-Pierre Bourguignon, Volker Branding, Annegret Burtscher, Demetrios Christodoulou, Piotr T. Chruściel, Albachiara Cogo, Stefan Czimek, Mattias Dahl, Erwann Delay, Pedro del Real Lavergne, Roland Donninger, Michael Eichmair, David Fajman, Filip Ficek, Arthur Fischer, Grigorios Fournodavlos, Christoph Fritz, Gregory Galloway, Marco Galoppo, Melanie Graf, Finnian Gray, Nishanth Gudapati, Peter Hintz, Sven Hirsch, Gustav Holzegel, Tong Tong Hu, Lan-Hsuan Huang, Gerhard Huisken, Jim Isenberg, Sergiu Klainerman, Thomas Körber, Maximilian Kraft, Klaus Kröncke, Michael Kunzinger, Jerzy Lewandowski, Adam Lindström, Maciej Maliborski, Jordan Marajh, Jose Martin-Garcia, Lorenzo Mazzieri, Benjamin Meco, Andrea Nützi, Marius A. Oancea, Maximilian Ofner, Francesca Oronzio, Roger Penrose, István Rácz, Hans Ringström, Paola Rioseco, Carl Rossdeutscher, Helmut Rumpf, P.K. Sahoo, Anna Sakovich, Robert Sansom, Jan Sbierski, Richard Schoen, Walter Simon, Jacques Smulevici, Roland Steinbauer, Florian Steininger, Jérémie Szeftel, Rita Teixeira da Costa, Paul Tod, Liam Urban, Juan A. Valiente Kroon, Li Weijia, Markus Wolff, Raphaela Wutte, Zoe Wyatt, Sumio Yamada, Rudolf Zeidler.

New perspective on Shape and Topology Optimization

Organizers: Elisa Davoli (TU of Vienna), Idriss Mazari-Fouquer (CEREMADE, Paris), Kevin Sturm (TU of Vienna)
Dates: December 11 – 15, 2023

Budget: ESI € 9 817

In the end some speakers cancelled their trips at the very last minute due to COVID 19, so that the whole ESI budget was not necessary. In particular, a total of € 1 703 was not used.

Report on the Workshop

Over the last years, shape optimization and its interactions with material sciences have seen a trove of new approaches and questions being developed. The goal of this workshop was to bring together young and experienced scientists in order to foster new collaborations in these topics and to further pre-existing collaborations. The workshop revolved around three main themes:

1. **Theoretical aspects in spectral and shape optimization:** These talks covered various aspects of shape and topology optimisation (Talenti inequalities, spectral optimisation, adversarial shape optimization...).
2. **Calculus of variations and material sciences:** These talks were more focused on innovative approaches to material sciences and their newly found applications, ranging from the theoretical (including new contributions on plasticity systems) to the more applied (*e.g.* the control of nanomaterials).
3. **Numerical aspects for robust shape and topology optimization:** These talks were focused on the numerical approximation and simulation of optimal shapes and topologies, with a wide range of applications (from rotor optimization to the design of general methods for topology optimization).

Most talks of the workshop were recorded and uploaded on the Youtube channel of the Institute. We believe this workshop was timely, and helped bring together scientists working on related, albeit usually separated fields.

Activities

The week was centered around the aforementioned talks, and we purposefully planned for a schedule of around 5 talks a day in order to allow for scientific exchanges in the facilities provided by the Institute.

Specific information on the workshop

The following praedocs and postdocs (identified by the Dr. title) at the time of the workshop joined the conference: Phillip Baumann (TU of Vienna), Giacomo Bertazzoni (U Modena), Dr. Elise Bonhomme (U Paris Sud, Orsay), Dr. Stefano Buccheri (U of Vienna), Alessio Cesarano (RICAM, Linz), Théodore Cherrière (RICAM, Linz), Andrea Chiesa (U Vienna), Dr. Lorenza

D'Elia (TU of Vienna), Jakob Deutsch (TU of Vienna), Matteo Fornoni (U Pavia), Dr. Chiara Gavioli (TU of Vienna), Rossella Giorgio (TU of Vienna), Leon Happ (TU of Vienna), Dr. Shokhrukh Kholmatov (U of Vienna), Anna Kubin (TU of Vienna), Dr. Anastasia Molchanova (U of Vienna), Dr. Katerina Nik (U of Vienna), Dr. Raphael Prunier (Ceremade, Paris), Dario Reggiani (Sc. Norm. Mer.), Samuele Riccó (TU of Vienna), Dr. Chiara Rigoni (U of Vienna), Dr. Fabian Rupp (U of Vienna), Manuel Seitz (U of Vienna), Dr. Emanuele Tasso (TU of Vienna), Farzad Tatar (U Parma), Maximilian Urmann (U Regensburg), Riccardo Voso (U of Vienna), Huidong Yang (U of Vienna).

The contribution of young researchers to the workshop was essential. In fact, some of the aforementioned young colleagues held talks (Dr. Elise Bonhomme and Dr. Raphael Prunier). All the young colleagues had the chance to listen to very high quality presentations and interact with the other speakers, thus benefiting a lot from the scientific exchanges originating from the workshop.

Outcomes and achievements

List of talks

Cristina Trombetti (U Napoli)	On the Rearrangement of a function and its applications
Giuseppe Buttazzo (U Pisa)	Antagonistic cost functionals in shape optimization
Elvise Berchio (Politecnico, Torino)	Some optimization problems in mathematical models for suspension bridges
Raphael Fernandes (U Leicester)	Level set shape optimisation on aggregated polytopic meshes
Antoine Laurain (U Duisburg-Essen)	Sensitivity analysis and tailored design of minimization diagrams
Annika Bach (TU Eindhoven)	Emergence of topological singularities in the antiferromagnetic XY-model on the triangular lattice
Giuseppe Tomassetti (U Roma Tre)	Shape programming of a magnetic elastica
Elvira Zappale (U Roma 1)	Optimal design problems and applications to thin structures
Peter Gangl (RICAM, Linz)	Numerical approximation of topological derivatives and some applications
Marc Dambrine (University of Pau)	Towards robustness in shape optimization
Ilaria Lucardesi (U Pisa)	On Blaschke-Santaló diagrams in shape optimization
Flaviana Iurlano (U Genova)	Approximation of functions with possibly infinite jump set
Charles Dapogny (U Grenoble Alpes)	Optimization of the shape of regions supporting the boundary conditions of a physical problem
Davide Buoso (UEP, Amedeo Avogadro)	Inequalities and asymptotics for polyharmonic eigenvalues
Samuel Amstutz (Avignon U)	Anisotropic perimeter approximation for topology optimization
Caterina Zeppieri (WWU Münster)	Homogenisation of nonlinear Dirichlet problems in randomly perforated domains
Stefano Almi (U Napoli)	Phase-field Topology Optimization and applications to plasticity and microstructures
Elise Bonhomme (U Paris Sud, Orsay)	Can quasi-static evolutions of perfect plasticity be derived from brittle damage evolutions?

Kathrin Welker (TU Bergakademie Freiberg)	Optimization of piecewise-smooth shapes
Raphael Prunier (CEREMADE, Paris)	Stability in shape optimization with regularity theory
Rémi Robin (MINES ParisTech)	Some optimisation problems for magnetic confinement in stellarator
Nicolas Van Goethem (U Lisboa)	Some fracture evolution problems by topological sensitivity analysis

Invited scientists

Stefano Almi, Samuel Amstutz, Annika Bach, Phillip Baumann, Elvise Berchio, Giacomo Bertazzoni, Elise Bonhomme, Stefano Buccheri, Davide Buoso, Giuseppe Buttazzo, Alessio Cesarano, Théodore Cherrière, Andrea Chiesa, Marc Dambrine, Charles Dapogny, Elisa Davoli, Lorenza D'Elia, Jakob Deutsch, Raphael Fernandes, Matteo Fornoni, Peter Gangl, Harald Garcke, Chiara Gavioli, Rossella Giorgio, Leon Happ, Flaviana Iurlano, Shokhrukh Kholmatov, Anna Kubin, Antoine Laurain, Randy Llerena, Luca Lombardini, Ilaria Lucardesi, Idriss Mazari-Fouquer, Anastasia Molchanova, Katerina Nik, Antonio André Novotny, Raphael Prunier, Mara Luisa Rapn, Dario Reggiani, Samuele Ricc, Chiara Rigoni, Rémi Robin, Fabian Rupp, Manuel Seitz, Ulisse Stefanelli, Kevin Sturm, Emanuele Tasso, Farzad Tatar, Giuseppe Tomassetti, Cristina Trombetti, Maximilian Urmann, Nicolas Van Goethem, Kathrin Welker, Huidong Yang, Elvira Zappale, Caterina Zeppieri.

Research in Teams

Research in Teams Project 1: Non-equilibrium hydrodynamic Casimir-like forces in colloidal suspensions

Collaborators: Agnese Callegari (U of Gothenburg), Roberto Cerbino (U of Vienna), Norma Caridad Palmero Cruz (U of Guanajuato), Giuseppe Pesce (U of Gothenburg), Giovanni Volpe (U of Gothenburg)

Dates: March 1 - August 31, 2023

Budget: ESI € 14 400
U of Gothenburg (travel expenses of Dr. Giuseppe Pesce) € 1 500

Report on the project

The phenomenon of Casimir forces, where closely-placed conducting plates in a vacuum experience an attractive force due to quantum electromagnetic fluctuations, has been a subject of investigation for many decades. This study delves into an analogous phenomenon manifesting in fluids out of equilibrium, aiming to provide empirical evidence for the presence of non-equilibrium hydrodynamic Casimir-like forces in colloidal suspensions during diffusion. Performed by an international team of experts, this research bridges theoretical predictions with experimental validation. As out-of-equilibrium fluids exhibit intriguing hydrodynamic fluctuations, confining these fluctuations theoretically produces Casimir-like forces. The challenge lies in experimentally verifying this occurrence, given the complications of accurately measuring forces under non-equilibrium conditions. Therefore, this project presents an ambitious endeavor: to design, implement, and interpret optical measurements of these forces between colloidal particles immersed in a complex time-dependent medium, thus potentially providing the first experimental evidence of non-equilibrium Casimir-like forces. Through a blend of careful experimental design, advanced instrumentation, and theoretical insight, the team aims to unveil the mysteries of these forces and their implications in the wider scientific community.

Scientific Background

The Casimir effect originates from the restricted fluctuations of the vacuum electromagnetic field between two conducting plates placed closely in a vacuum. Typically, Casimir forces manifest as an attractive force between these plates. Though this phenomenon was initially associated with quantum electrodynamics, it was later realized that analogous forces could arise in other systems, especially in condensed matter physics, given the right conditions.

Fluids approaching their critical point have been a particular focus in this regard. In such systems, thermal fluctuations become pronounced, leading to variations in density and refractive index at microscopic scales. When these fluctuations are confined between surfaces, such as plates or particles, they can give rise to forces akin to the Casimir effect, known as critical Casimir forces [1]. These forces can influence the behavior of colloids in critical mixtures, affecting their aggregation, dispersion, and overall stability [2].

More recently, the scientific community has turned its attention to out-of-equilibrium fluids. These fluids, when disturbed from their equilibrium state, exhibit hydrodynamic fluctuations [3,4], a phenomenon where the amplitude and correlation range of fluctuations can, in some instances, surpass those observed in systems close to their critical point. Theoretical predictions

suggest that, when these fluctuations are confined, especially in narrow spaces, they should induce remarkably large Casimir-like forces [5]. However, the challenge has always been to empirically verify these theoretical assertions due to the inherent complexities in measuring forces under non-equilibrium conditions.

This rich scientific background sets the stage for the current project. By attempting to harness, measure, and understand these elusive forces in colloidal suspensions, the research seeks to expand our comprehension of how fluctuating fields, confined or otherwise, influence the macroscopic behavior of systems, especially in non-equilibrium states. This exploration not only enhances our fundamental understanding of physics but could also pave the way for innovative applications across various scientific domains.

Project aims and scope

This project's primary aim has been to experimentally measure Casimir-like forces in a complex time-varying medium out of thermodynamic equilibrium. Building on theoretical predictions [5-7] and preliminary results [8], we have designed, implemented, and interpreted precise optical measurements of these forces between two large probe colloidal particles submerged in the complex medium. By tracing these particles, the project has been focused on providing the first experimental evidence and accurate measurement of non-equilibrium Casimir-like forces. This initiative not only stands to expand our fundamental understanding of physics in non-equilibrium states but also promises potential innovative applications in soft matter, active matter, and self-assembly (also potentially in microgravity conditions).

Outcomes and achievements

The team dedicated to studying non-equilibrium hydrodynamic Casimir-like forces in colloidal suspensions has made significant progress. The theoretical groundwork laid out at the project's onset has transitioned into the experimental phase, thanks to the coordinated efforts of the international team.

The practical realization of the project took place under the local supervision of Roberto Cerbino in his laboratory at the University of Vienna with inputs from Giovanni Volpe. Norma Caridad Palmero Cruz, the PhD student from the University of Guanajuato, took the lead in the hands-on execution of the experiments, with help and supervision from Giuseppe Pesce. Her involvement in the laboratory was instrumental in turning the theoretical models and hypotheses into actionable experimental procedures.

Throughout this rigorous experimental phase, Agnese Callegari provided theoretical guidance and supervision. Her expertise ensured that the experiments remained aligned with the theoretical expectations, offering insights into potential adjustments and refinements that might be necessary. The symbiotic relationship between the theoretical and practical aspects of the project ensured a holistic approach to the research, combining the strengths of both conceptual understanding and empirical validation.

As the experiments are still ongoing, the team is diving deep into the interpretation phase, working diligently to analyze the results (see, for example, Fig. 1) and draw meaningful conclusions. The outcomes of these experiments will be pivotal in understanding and validating the existence of non-equilibrium Casimir-like forces in colloidal suspensions. As the research progresses in the following months, the collaborative spirit of the team, which combines the expertise of theory, simulation, and experimental practice, promises to bring fresh insights into this emergent area of study.

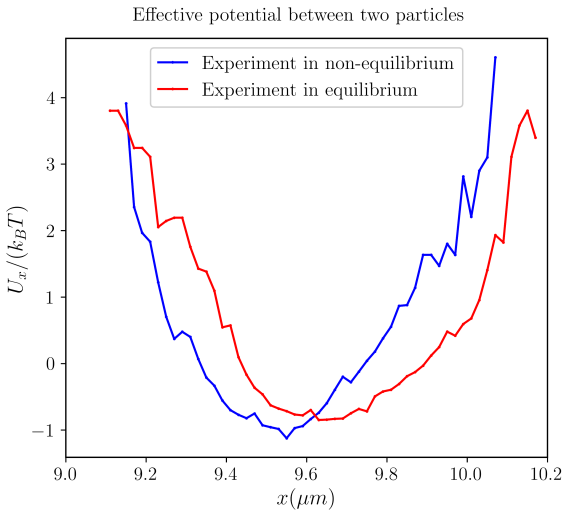

Figure 1: **Experimental total potential.** Comparison of the effective potential between two particles when in equilibrium (red line) and out of equilibrium (blue line). The minimum of the out-of-equilibrium effective potential is located at a closest interparticle distance than the one of the equilibrium potential, a signature that attractive non-equilibrium interaction is at play.

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Research in Teams Project 2: Limit Theorems for Parabolic Dynamical Systems

Collaborators: Henk Bruin (U of Vienna), Charles Fougeron (IRIF, Paris), Davide Ravotti (U of Vienna), Dalia Terhesiu (U Leiden)

Dates: April 10 - 21, 2023 and June 5 - 16, 2023

Budget: ESI € 3 920

Scientific Background

Whereas the statistical properties of (non-uniformly) hyperbolic flows are understood to an astounding degree, much less is known when the system lacks hyperbolicity. Yet such systems are wide-spread, and include polygonal billiards, wind-tree models (where the billiard table is the plane with rectangular scatterers at each point in $\mathbb{Z}^2$), horocycle flows on negatively curved surfaces and also flows on flat surfaces with rest-points.

Specific results of interest include recent papers on ergodicity resp. diffusion coefficients of the wind-tree flows by Bromberg & Ulcigrai [1] and Delecroix et al. [2] respectively. Also the paper by Avila et al. [3] on rational ergodicity of $\mathbb{Z}$-extensions over circle maps became central to our research.

A central tool that we used in our research is renormalization, in the form of an automorphism ψ of the phase space that commutes with the translation flow according to $\phi^{\lambda t} \circ \psi = \psi \circ \phi^t$, where λ is an eigenvalue of ψ. This allows one to convert statistical properties of the hyperbolic automorphism into properties of the translation flow.

Project aims and scope

The existence of such "commuting" automorphism is somewhat specific, and depends on the phase space (of the $\mathbb{Z}^d$-extension of the dynamical system at hand). Specifically, we need Dehn twists of the fundamental domain to commute properly with deck transformation of the extension. When this holds, then any hyperbolic composition of the Dehn twist gives a suitable automorphism, but specifies a specific translation flow. One class of such systems are specific translation flows on so-called staircases ($\mathbb{Z}$-extensions of rectangular translation surfaces), also used in [3]. $\mathbb{Z}^d$-extensions ($d \geq 2$) where this works are not in the literature, but we constructed some examples analogous (but not the same as) the classical wind-tree model.

The aim is to understand now the ergodic properties of the translation flows. Specifically:

- Rational ergodicity with rates. This is a strengthened form of ergodicity, where rates at which ergodic averages converge are indicated. Note that according to [1], the wind-tree model is recurrent but typically non-ergodic.
- Diffusion rates. Taking ξ to be the $\mathbb{Z}^d$-component of the $\mathbb{Z}^d$-extension, this is a measure at which $\xi \circ \phi^t(z) - \xi(z)$ grows; it usually is polynomial in time, and the exponent is the diffusion coefficient.
- Rational weak mixing. This is the equivalent of rational ergodicity, but for weak mixing (i.e., convergence of averages of correlation coefficients, but equivalent to the absence of non-trivial eigenvalues of the Koopman operator). No results are present in the literature, and this aim may remain a long-term aim, but at least we determined instance among

our examples where at least the translation flow on the compact translation surface is a suspension over a weakly mixing intervale exchange transformation.

Outcomes and achievements

The class of $\mathbb{Z}$-extensions of translation surfaces we studied in particular are so-called staircases. Their fundamental domain is a rectangle with side lengths $s \in \mathbb{N}$ and 1 (say $[0,s] \times [0,1]$ in $\mathbb{R}^2$) and orientation preserving identifications $\{0\} \times [0,1] \sim \{s\} \times [0,1]$, $[0,1] \times \{0\} \sim [s-1,s] \times \{1\}$, $[0,1] \times \{1\} \sim [s-1,s] \times \{0\}$, $[1,s-1] \times \{0\} \sim [1,s-1] \times \{1\}$. Using the cocycle $\kappa = +1$ when crossing $[s-1,s] \times \{1\}$ upwards and $\kappa = -1$ when crossing $[0,1] \times \{1\}$ upwards we get a non-compact translation surface which is called the $(s,1)$-staircase.

The $(s,1)$-rectangle allows horizontal and vertical Dehn twists D_h and D_v that commute with the deck transformation of the $\mathbb{Z}$-extension generated by the cocycle κ. Therefore every hyperbolic composition A of D_hs and D_vs gives a good automorphism, for the translation flow ϕ^t in the unstable direction of A.

Using the action of A on the elements of 1st homology, one can prove recurrence and also ergodicity of ϕ^t - this goes along fairly standard arguments using essential values, see [4].

Rational ergodicity is a more quantitative statement than just ergodicity and we proved it under general assumptions:

(H1) Let St_0 be some compact manifold. We assume that there exists an automorphism $\psi : St \to St$, $St = St_0 \times Z$ that commutes with φ_t, that is $\psi \circ \varphi^t = \varphi^{\lambda t} \circ \psi$ for some $\lambda \in (0,1)$.

(H2) Throughout, let ξ be the $\mathbb{Z}$ component of ψ. We assume that the automorphism ψ is a $\mathbb{Z}$ cover of a linear automorphism $\psi_0 : St_0 \to St_0$ defined via

$$\psi(x,\ell) = (\psi_0(x), \ell + F(x)), x \in St_0, \ell \in \mathbb{Z},$$

where $F(x) = \xi(\psi(x)) - \xi(x) : St_0 \to \mathbb{Z}$.

The invariant measure for both the finite and the infinite measure preserving automorphism, ψ_0 and ψ is the Lebesgue measure m.

Theorem 1 *Let G be a function supported in St_0 with $\int_{St_0} G\,dm > 0$. Given $\lambda \in (0,1)$ as in (H1), set $\log_* T = \lfloor \log_{\lambda^{-1}} T \rfloor$. Then*

$$\int_0^T G \circ \varphi_t \, dt = \frac{T}{2\pi\sqrt{\log_* T}} + \textit{higher order terms}.$$

The precise for of these higher order terms still need to be fine-tuned.

Diffusion coefficients of the flow ϕ^t can in principle be computed using the eigenvalue of the matrix describing the action of the automorphism ψ_A on homology; we are still trying to get a general statement here, rather than computing singular examples.

For rational weak mixing, the techniques are still in its infancy. However, we have the following results on the translation flow on the compact $(s,1)$-rectangle, which clearly is a suspension flow over an interval exchange transformation (IET):

Theorem 2 *For $s = 2,3$, this IET has a continuous eigenvalue. For $s \geq 4$, the IET is weak mixing.*

Regarding $\mathbb{Z}^d$-extensions for $d \geq 2$, it is not easy to find shapes (compact domains) where the Dehn twists commute with the deck transformations (which form the group $\mathbb{Z}^d$ rather than just $\mathbb{Z}$). For the classical wind-tree model (with square at lattice points as obstacles) the fact that the horizon is infinite in the coordinate directions is an obstruction to the Dehn twists being both continuous and commuting with the deck transformations. However, when the obstacles obstruct infinite corridors, such as in Figure , then bona fide automorphisms appear to be present.

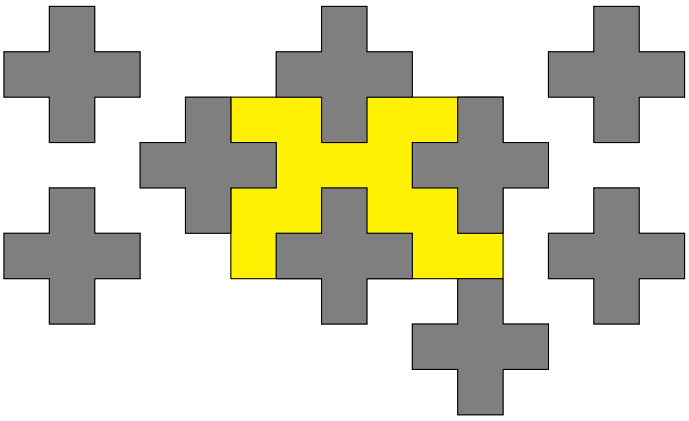

Figure 2: Wind-tree model with plus-shapes (and finite horizon in coordinate directions). A fundamental domain in yellow.

Publications and preprints contributed

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Research in Teams Project 3: Integrability

Collaborators: Harald Grosse (U of Vienna), Naoyuki Kanomata (Tokyo U of Science), Akifumi Sako (Tokyo U of Science), Raimar Wulkenhaar (U Münster)

Dates: April 13 – August 31, 2023

Budget: ESI € 9 760
Periods of stay: Akifumi Sako (AS) stayed April 13 – August 30, 2023
Raimar Wulkenhaar (RW) stayed April 19 –28, May 15 –24 and June 28 – July 12
Naoyuki Kanomata, student of (AS), stayed May 17 – June 16 (paid by Japan).

Report on the project

Scientific Background

In order to improve quantum field theory methods and to take into account quantum gravity effects, it was suggested to deform or quantize space-time, too. The obtained models suffer from infrared/ultraviolet mixing. For a scalar field theory, two of us (HG+RW) found a way out by adding a confining potential. The resulting model turned out to be a matrix model similar to the Kontsevich model [Kon92], but with the cubic potential replaced by a quartic interaction term. While the commutative scalar (Higgs) field model suffers from the triviality problem, we have been able to show, by a number of steps, that the non-commutative 4-dimensional model is non-trivial [GHW20]. A key step was a closed non-linear integral equation for the planar 2-point function, discovered during an ESI Senior Research Fellowship in 2009.

Later (HG+AS+RW) understood that the methods developed for the quartic model can be applied to the Kontsevich model as well, for any covariance [GSW17, GSW18]. Renormalizability holds in dimensions less or equal to 6. Exact formulae were obtained for genus zero and any number of marked points. Later (HG+RW) together with A. Hock extended the results to any genus and connected the formulae to topological recursion [EO07].

In 2018, (RW) with E. Panzer [PW20] were able to solve the non-linear integral equation from 2009 for the important special case where the noncommutative geometry is the 2D Moyal space. With the insight gained from cubic model, (HG+RW) achieved with A. Hock in [GHW19] the exact solution of the planar 2-point function of the model on any noncommutative geometry (of spectral dimension < 6). They also proved that this quartic model on 4D Moyal space does not suffer from the triviality problem [GHW20]!

Next, (RW) with J. Schürmann connected the solution with structures in complex algebraic geometry. Then, (RW) with J. Branahl and A. Hock understood in [BHW22] that certain derivatives of the partially summed 2-point function give rise to meromorphic differentials $\omega_{g,n}$ affiliated with the moduli space of Riemann surfaces to genus g and with n marked points. They established Dyson-Schwinger equations between the these differentials and two families of auxiliary functions and succeeded to solve the lowest genus and number of points cases. These $\omega_{g,n}$ satisfy the abstract loop equations for a spectral curve. It is then natural to conjecture that all higher differentials obey blobbed topological recursion [BS17]. In the meantime (RW) with A. Hock proved this conjecture via extended loop equations. The loop equations are completely known for $g = 0$ and $g = 1$ and uniquely provide $\omega_{0,n}$ and $\omega_{1,n}$. For a recent review see [BGHW22].

Project aims and scope

The RIT project was devoted to the widely open question whether the exact solvability of the quartic matrix model is related to integrability. Integrability means that the $\omega_{g,0}$, with corrections for $g = 0$ and $g = 1$, provide a τ-function for a Hirota equation. For standard topological

recursion, this is automatic. But not for the blobbed case to which the quartic matrix model belongs.

Outcomes and achievements

Soon after Akifumi Sako and Raimar Wulkenhaar settled in Vienna, a workshop on "Noncommutativity Geometry meets Topological Recursion" (from April 24 to April 28) gave an interesting overview on these subjects, which have overlap to our problem of integrability in special systems. Central to the workshop were 4 minicourses of 3 hours of lecture each. There were 8 further research talks and 2 gong talk sessions. The key topics were noncommutative geometry, free probability, topological recursion and tropical geometry.

During the workshop, Raimar Wulkenhaar interacted with Gatan Borot and completed their proof that the Kontsevich matrix model with arbitrary potential is a BKP tau function with respect to polynomial deformations of the potential [BW23].

After the workshop, according to our different backgrounds, we first exchanged our knowledge on

- Dyson–Schwinger techniques and Ward–Takahashi identities for integrable models (AS)
- Maya diagrams and details of the Harish-Chandra–Itzykson–Zuber integrals(AS)
- topological recursion and its blobbed generalization (RW)
- quantization of chiral one dimensional Fermions, Bose-Fermion correspondence and the relation to the KdV and KP hierarchies (HG)
- Bogoliubov transformations (HG)

Soon after our interactions it became clear that our main interests concern two main questions:

1. Is it possible to derive new identities for the quartic matrix model?
2. Borot–Shadrin give in [BS17] a graphical representation for $\omega_{g,n}$ satisfying blobbed topological recursion, which is generated by a differential operator acting on products of KdV τ-functions. Can this be used to associate an integrable structure to blobbed topological recursion?

Concerning the first question, we found interesting answers:

(HG+AS) studied first a matrix model with a quartic interaction term and a kinetic part with a positive definite Hermitian matrix, similar to the Kontsevich model. We were able to show [GS23] that the partition function solves the zero-energy Schrödinger equation of an N-particle system with harmonic oscillator interaction. For the derivation, we followed the method used by Itzykson and Zuber in their study of the Kontsevich integrals. This signals the integrability structure and will have further consequences.

Next, we turned our attention to the same model but for real symmetric matrices. The external matrix E entering the kinetic part is assumed to have no degenerate eigenvalues. This time the partition function of this model is a zero-energy solution of a Schrödinger type equation with Calogero-Moser Hamiltonian [GKSW23] . A family of differential equations satisfied by the partition function is also obtained from the Virasoro algebra.

For one month, Naoyuki Kanomata joined our discussions (very actively): He gave an interesting talk on "The finite cubic-quartic matrix model" on June 7.

Work on the second question was started especially by (RW), but preparation of grant proposals in Germany prevented so far the completion. The idea is the following: Borot and Shadrin assign in [BS17] a partition function to any family of meromorphic differentials, which satisfy abstract loop equations. After introducing local coordinates and developing into Laurant series one obtains a partition function depending on families of time variables, for which it is possible to prove that it has a representation in terms of deformed KdV τ-functions, and which obey Hirota's bilinear identity. We were not able to reproduce all formulae in [BS17]; either due to lack of understanding on our side, or typos. In order to analyze the discrepancy, (RW) developed a graphical method which allows to control the tricky algorithm. Work will resume in 2024.

Summarizing, we can say that we obtained interesting new identities obeyed by the partition function of the quartic Hermitian matrix model as well as for the analogous model with real symmetric matrices. Consequences will be worked out. Work on the Borot–Shadrin approach will also continue.

Acknowledgement: We enjoyed our stay at ESI very much and we are grateful to the Institute for support and for the perfect organization and hospitality.

Akifumi Sako, Raimar Wulkenhaar and Harald Grosse

Publications and preprints contributed

H. Grosse, A. Sako, *Integrability of Φ^4 Matrix Model as N-body Harmonic Oscillator System*, arXiv:2308.11523[math-ph].

H. Grosse, N. Kanomata, A. Sako, R. Wulkenhaar, *Real symmetric Φ^4-matrix model as Calogero-Moser model*, arXiv:2311.10974[hep-th].

N. Kanomata, A. Sako, *Exact Solutions v.s. Perturbative Calculations of Finite Φ^3-Φ^4 Hybrid-Matrix-Model*, arXiv:2304.10364[hep-th].

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Research in Teams Project 4: Rigidity in Coxeter Groups

Collaborators: Christopher Cashen (U of Vienna), Pallavi Dani (Louisiana State U, Baton Rouge), Kevin Schreve (Louisiana State U, Baton Rouge), Emily Stark (Wesleyan U)

Dates: July 4 - August 4, 2023

Budget: ESI € 6 960

Report on the project

Scientific Background

Coxeter groups are abstract reflection groups. This class of groups makes many appearances in Geometry, Topology, and Combinatorics, as well as in Algebra. While there are some combinatorial results that apply to all Coxeter groups, such as Tits's solution to the Word Problem, the class as a whole is incredibly diverse, and many results are only known for special subclasses.

We were interested in rigidity phenomena. There are a variety of these, but the general flavor is that if G is a group of interest, and G acts on some object X, then G is a finite index subgroup of the automorphism group of X. A specific case of interest for us was work of Mahan Mj [1] saying that if G is a hyperbolic Poincaré duality group, or, more specifically, a hyperbolic manifold group, and H is a codimension one filling subgroup, then G is of finite index in the group $\mathrm{PPQI}(G,H)$ of quasi-isometries of G that coarsely preserve the G-translates of H. The proof involves studying the induced action on the ideal boundary of G, which in the n–manifold case is the $(n-1)$-sphere. Ingredients include a version of the Hilbert-Smith conjecture and Yang's theorem on the dimension of the quotient of a homology manifold by an action of the p-adic integers $\mathbb{Z}_p$.

This theorem already applies to Coxeter groups that are hyperbolic manifold groups. It is not known how much that condition can be relaxed. In particular, the question is open for pseudo-manifold (PM-type) Coxeter groups. For these Coxeter groups the natural geometric model is a cell complex that is manifold-like except at the vertices, where the link is a manifold, but not a sphere. In the 3-dimensional case this implies that the ideal boundary is not the 2-sphere, but the Pontryagin sphere, which is a compact, "infinite genus" surface.

Project aims and scope

The question that we worked on the most was:

Question 3 *Do the p-adic integers act faithfully on the Pontryagin sphere?*

We came to this problem through hyperbolic PM-type Coxeter groups, but it is broader than that, and is tantalizingly positioned between the 2-sphere case, where the p-adics cannot act, and the Menger curve case where they do.

Outcomes and achievements

We were able to provide a solution to Question 3 after adding strong metric assumptions on both the space and the action. In this theorem, $\mathrm{QI}(G)$ denotes the self quasi-isometry group of G. Note that any self quasi-isometry of G induces a self homeomorphism of $\partial_\infty(G)$.

Theorem 4 *There exist hyperbolic groups whose boundaries are homeomorphic to the Pontryagin sphere Σ_∞, and where the image of $QI(G)$ in* $\mathrm{Homeo}(\partial G)$ *does not contain $\mathbb{Z}_p$.*

There are two main ideas in the proof. The first involves finding "optimal enough" visual metrics on ∂G, i.e. metrics on ∂G with small enough Hausdorff dimension. Note that this is bounded below by the topological dimension (which is 2 in this case), but a priori could be much larger. In fact, we constructed a sequence of right-angled Coxeter groups where the minimal Hausdorff dimension arising from a visual metric goes to infinity.

Finding these visual metrics combines many deep but previously known results. Using work of Davis and Charney–Davis, we construct a locally CAT(-1) manifold and a totally geodesic subcomplex whose fundamental group has Pontryagin sphere boundary. Work of Ontaneda implies that these manifolds can be given negatively curved Riemannian metrics with arbitrarily pinched curvature, so the Hausdorffff dimension of the S^3-boundary with the corresponding visual metric can be made arbitrarily close to 3. The fundamental group of the subcomplex corresponding is quasiconvex in the ambient one, so we get the same bound on Hausdorff dimension.

Now that we have our optimal enough metrics, our proof follows the above theorem of Mj. The main idea is to use a classical result of Yang that taking the quotient of a faithful $\mathbb{Z}_p$-action must raise topological dimension by at least two. On the other hand, when the $\mathbb{Z}_p$-action is coming from $\mathrm{QI}(G)$, the Hausdorff dimension decreases under taking quotients. Since the Hausdorff dimension of ∂G is less than 4 and is bounded below by the topological dimension, this is a contradiction.

Yang's dimension raising result (as well as some other necessary classical results) were formulated only for p-adic actions on manifolds, and we have to further verify that the result holds for actions on the Pontryagin sphere. Though this isn't a manifold, it does have Čech homology $\cong \mathbb{Z}$ in the top dimension (i.e. there is a *fundamental class*) and it turns out that this is all the proofs require.

We expect that similar methods can be used to find examples which are right-angled Coxeter groups. Przytycki and Swiatkowski [4] showed that any flag triangulation of S^3 has a refinement which is flag no-square (so the resulting right-angled Coxeter group is hyperbolic). So it would suffice to show that Ontaneda's smoothing construction works on the corresponding Davis manifolds.

Theorem 4 is a restricted answer to Question 3, but we developed an approach towards the general question as well. Pardon showed [2] that the Hilbert-Smith conjecture holds in dimension 3 (dimensions 1 and 2 are classical and due to Montgomery-Zippin). Pardon [3] further showed how his proof gives an alternative proof of the 2-dimensional case. The basic idea is to construct (from a faithful action of $\mathbb{Z}_p$ on some surface Σ) a continuous homomorphism from $\mathbb{Z}_p$ to some braid group B_n (which essentially encodes how $\mathbb{Z}_p$ moves the orbit of a point). Since the braid group is torsion-free this homomorphism has to be trivial. On the other hand, Pardon shows the image surjects onto the symmetric group S_n under the canonical quotient $B_n \to S_n$, which yields a contradiction. It is very tempting to modify Pardon's proof for the Pontryagin sphere Σ_∞. Since Σ_∞ is the inverse limit of surfaces, we attempted to show that a faithful $\mathbb{Z}_p$-action on Σ_∞ will induce a homomorphism to a mapping class group of some punctured surface in the inverse limit. Our strategy was to use the fact that given any surface Σ, there are embedded arcs α_i so that any mapping class group element is determined by where it sends the α_i. We will continue to pursue this approach.

A side project involved Cashen and Dani and Alexandra Edletzberger (U Vienna). We considered the large-scale of geometry of 2–dimensional right-angled Coxeter groups via its action on its maximal product subgroups. We make a 'product region graph' of these for the Coxeter group to act on. The expectation is that these product regions are the non-hyperbolic regions, but their relative arrangements should be hyperbolic. This is analogous to the curve graph for mapping class groups, and the extension graph for right-angled Artin groups. Both are hyperbolic graphs encoding the non-hyperbolic parts of those groups, and in the Artin case the graph is, in fact, quasi-isometric to a tree. We showed:

Theorem 5 *The product region graph of a right-angled Coxeter group need not be a quasi-tree.*

The method suggests a more precise result that we continue to work towards:

Conjecture 6 *Every stable subgroup of a right-angled Coxeter group quasi-isometrically embeds via the orbit map into its graph of product regions.*

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Research in Teams Project 5: Tropical Mirror Symmetry, Langlands Duality, and Symmetries in Mathematics and Physics

Collaborators: Jianrong Li (U of Vienna), Arkady Berenstein (U of Oregon), Jacob Greenstein (UC, Riverside)

Dates: June 12 - September 1, 2023

Budget: ESI € 10 560

Report on the project

Scientific Background

Representation theory of quantum groups is an importan research field in mathematics and it has a lot of applications to other areas of mathematics and physics. For several years we have been working on representation theory of quantum groups. In particular, in [BG11], the first two applicants introduced a quantum analogue of the classical folding of a simply-laced Lie algebra $\mathfrak{g}$ to the non-simply-laced algebra $\mathfrak{g}^\sigma$ along a Dynkin diagram automorphism σ of $\mathfrak{g}$. In [BG17, BG17b], the first two applicants introduced and studied new canonical bases for all quantum groups along with their symmetries which refine celebrated Lusztig's braid group actions on representation categories $\mathcal{O}_q$ of these quantum groups. In [BGL19], the applicants jointly introduced and studied the actions of various groups generated by involutions on all $\mathcal{O}_q$'s which generalize Kashiwara and others' symmetries on the corresponding crystal bases.

Project aims and scope

One of our present projects aims to geometrize these actions using unipotent crystals for the Langlands dual of the Lie group of $\mathfrak{g}$. These would result in constructing the "tropical mirror" of representations of the quantum group $U_q(\mathfrak{g})$. Our second project is to construct new braid group actions and their generalizations on various categories by introducing and solving a generalization of the quantum Yang-Baxter equation as well as its classical counterparts. This was motivated by non-standard braidings on representations of $U_q(\mathfrak{g})$ obtained previously in our study of quantum folding.

Outcomes and achievements

During the stay at ESI, we successfully proved an important result that the projection of a parabolic element is still parabolic in the parabolic subgroup. Moreover, we found natural generalization of parabolic elements which we called multi-parabolic elements. We studied homomorphisms between Hecke monoids, Coxeter groups, and braid monoids. We defined homomorphisms of braid monoids of Hecke type and Coxeter type. We classified certain families of homomorphisms of braid monoids of Hecke type or Coxeter type. We proved that the projection of a parabolic element is parabolic. These results will be applied to study geometric cactus groups.

We also studied a type of edge coloring problem on undirected graphs and directed graphs. We introduce a transitive analogue for acyclic directed graphs, and generalize both notions to Coxeter systems, matroids and commutative algebras. We show that for any finite matroid (or oriented matroid), the maximal number of colors is equal to the matroid rank. The number of Gallai (or transitive) colorings of the matroid that use at most k colors is a polynomial in k. For any acyclic oriented matroid, represented over the real numbers, the number of transitive colorings using at most 2 colors is equal to the number of chambers in the dual hyperplane arrangement. We count Gallai and transitive colorings of the root system of type A using the maximal number of colors, and show that, when equipped with a natural descent set map, the resulting quasi-symmetric function is symmetric and Schur-positive.

Publications and preprints contributed

R. M. Adin, A. Berenstein, J. Greenstein, J.-R. Li, A. Marmor, Y. Roichman, *Transitive and Gallai colorings*, https://arxiv.org/abs/2309.11203arXiv:2309.11203[math.CO].

A. Berenstein, J. Greenstein, J.-R. Li, *Hecke monoids and their homomorphisms*, in preparation.

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[BG11] A. Berenstein and J. Greenstein, *Quantum folding*, Int. Math. Res. Not. IMRN 2011, no. 21, 4821–4883.

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[BGL19] A. Berenstein, J. Greenstein, and J.-R. Li, *On cacti and crystals*, In: M. Gorelik, V. Hinich, A. Melnikov (eds) Representations and Nilpotent Orbits of Lie Algebraic Systems, Progress in Mathematics, vol. 330 (2019), Birkhäuser, Cham.

Erwin Schrödinger Lectures 2023

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.

Georg Kaser: Our changing climate system

Speaker: Georg Kaser (U of Innsbruck)

Georg Kaser is a glaciologist and climatologist at the Department of Atmospheric and Cryospheric Sciences of the University of Innsbruck, Austria. His research interests include mass and energy balances on glaciers, fluctuations of climate and glaciers, glaciology, climatology and hydrology in tropical mountain regions, fresh water availability and demand and global glacier mass change and drivers. Georg Kaser has served as lead author for the IPCC climate report and currently he is vice president of the Austrian Science Fund FWF.

Date: March 8, 2023

Abstract: Climate change is ongoing. Both insidious changes such as sea level rise or vector migration and the increase of extreme events in their frequency as well as their intensity are evident. Extensive detrimental impacts and related costs will occur in the targeted +1.5C World and even more so if we get to +2C above pre-industrial levels. It is all but sure that we will be able to meet this Paris agreement at all. Global greenhouse gas emissions are higher than ever and they increase further. There are first indications of the onsets of several irreversible subsystem changes that may both individually or in cascades cause positive feedbacks leaving us without any further chance to counteract. There is still a small window open for action, yet it requires an immediate and deep transition of the global society.

Junior Research Fellows Programme

Carlos Pérez Sánchez: Random finite gauge matrix geometries: numerical and analytic aspects

Carlos Pérez Sánchez (U of Heidelberg)[1]: March 1 – September 12, 2023

Report

Physical motivation.
The search for a theory of *quantum gravity* has been a driving force in mathematical physics, which in some cases impacts also 'pure' mathematics. Among the diverse proposals for emerging spacetime in quantum gravity it is not rare to find discrete structures. These approximate or regularize the ill-defined path-integral in the continuum theory—e.g. matrix models, tensor models, causal dynamical triangulations—and/or they are a consequence of a minimal length in space(time) in quantum regimes. The framework we chose to generate space(time), called spin networks (spin foams), is not an exception. Spin networks are graphs decorated with representation-theoretical data; spin foams are the traces that spin networks leave as they evolve in time, in some sense. Roughly speaking, our project aims at an extension of the ordinary representation theory used in spin networks to the representation theory of spectral triples.

To explain la raison d'łtre of such extension we briefly introduce noncommutative geometry (NCG), to which spectral triples belong. Let us first recall what differential geometry (the geometric predecessor of noncommutative geometry) is. Differential geometry studies 'smooth shapes', i.e. spaces that are continuous (not torn apart) and without 'wrinkles'. This property allows to define the notion of tangent space and thus of curvature, which turns out to be essential in classical physics, as the latter quantity governs Einstein's General Relativity, the classical theory of gravitation. Also Maxwell's electromagnetism, and a generalisation of it, called *gauge theory*, are modeled with differential geometric tools. Although it is not common, it is possible to describe differential geometry through algebras satisfying commutativity: $a \cdot b = b \cdot a$, where a and b are observables (i.e. quantities to measure, like real functions a, b on the space in question). In this sense 'commutative geometry' is ordinary differential geometry. Connes' *Noncommutative Geometry* is an extension of the tools of differential geometry for which the commutativity law does not necessarily hold, but for which geometric notions, expressed in the language of (noncommutative) algebra, still make sense.

Along these lines, *spectral triples* constitute the noncommutative generalisation of spin manifold (a core-concept in differential geometry), which, as proven in the 90's and beginning of this century, sheds light upon the mathematical structure of high energy physics. Spectral triples accommodate mathematical objects that *classically* model gravitational fields, gauge fields, Higgs fields and fermions under the same geometric roof. Based on previous work of Marcolli-van Suijlekom, it makes sense to suppose that combining spectral triples with spin networks would create a framework to treat quantum gravity coupled to matter gauge fields. At ESI, I further developed gauge networks, and with Dr. Glaser (U of Vienna) and Dr. Steinhaus (U Jena), worked on a proposal to get spin foams coupled to gauge fields from noncommutative geometric data.

[1] The actual stay was 1st to 24th March; 29th March to 2nd April; 17th April to 23rd May; 30th May to 7th June; 20th - 24rd June, 2023, Aug. 29, 2023 – Sept. 12, 2023

Mathematical implementation of the project.
A quiver is a directed multigraph like

$Q =$  . Although it is usual to allow self-loops (here the dashed edge), in our theory it will be convenient to forbid them. Given a quiver Q, a natural task in quiver representation theory is to classify, up to isomorphism, the representations of Q into vector spaces (i.e. to classify functors from Q to the category VECT of vector spaces, modulo natural transformations). Having the motivation above in mind, we replace VECT by ST, the category whose objects are finite-dimensional spectral triples; it is not highly technical to describe morphisms here, but it requires a long detour.

The space $X_0(Q)$ of ST-representations of a quiver Q has been provided in [MvS]. There, Marcolli and van Suijlekom computed also the gauge group $G_0(Q)$ (automorphisms of the spectral triples attached at the vertices of Q). They characterised $X_0(Q)/G_0(Q)$ (which turns out to be a homogeneous space) and provided the notion of *gauge network* as data associated to a orthonormal basis (via Peter-Weyl theorem) of the space

$$L^2[X_0(Q)/G_0(Q)] = [L^2(X_0(Q))]^{G_0(Q)}$$

of square integrable gauge-invariant functions on $X_0(Q)$ (cf. [Ba] for the relation to spin networks). The subindex 0 above means that the operator D associated to each vertex of Q is zero. To obtain the complete matter sector from these representation data, we should allow $D \neq 0$ too, which is a case not treated in [MvS]. My research stay at ESI was fundamental to achieve the first examples, lemmata and conjectures that are essential to answer the following questions:

- Q1: How do the data in $X_0(Q)$ behave when one adds a Dirac operator? Denote by $X(Q)$ the resulting space.
- Q2: Which is the new symmetry group $G(Q)$ (after allowing $D \neq 0$) and how does this group act on $X(Q)$?
- Q3: Understand the quotient $X(Q)/G(Q)$ and construct a basis for $L^2[X(Q)]^{G(Q)}$ (via Peter-Weyl theorem too).
- Q4: Using Q3, define 'gauge networks with non-trivial Dirac operators'. Find the right concept of spectral action and compute it.
- Q5: Relate Q4 to the Yang-Mills–Higgs theory. Is the latter a continuum limit of that in Q4? Extend this theory to 'spacetime', i.e. extend it from generalisations of spin networks to generalisations of spin foams.

Non-research, yet ESI-related activities:
During my stay at ESI

- I attended on a regular basis the Mathematical Colloquium, Faculty of Mathematics, and the Mathematical Physics or Joint Theory Seminar (with TU of Vienna).
- Participated in the ESI-Workshop Non-commutative Geometry meets Topological Recursion from April 24 to April 28, 2023, delivering a minitalk (but also as auxiliar, operating the video recorder for all talks, cf. ESI YouTube channel).
- I attended Large-N Matrix Models and Emergent Geometry (no registration).

Publications and preprints contributed

Carlos I. Pérez-Sánchez, *The Spectral Action on quivers*, arXiv:2401.03705[math.RT].

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[MvS] Matilde Marcolli and Walter D. van Suijlekom. Gauge networks in noncommutative geometry, *J. Geom. Phys.*, 75:71–91, 2014.

Sergio Gómez: Structure-preserving methods for nonlinear PDEs

Sergio Gómez (U of Pavia): March 13 – September 13, 2023

Report

The aim of this project, in collaboration with Prof. Perugia (U of Vienna) and Prof. Jüngel (TU Vienna), was the design of a high-order structure-preserving Local Discontinuous Galerkin (LDG) method for the discretization of nonlinear cross-diffusion systems of the form:

$$\partial_t \rho - \nabla \circ (A(\rho)\nabla\rho) = f(\rho) \quad \text{in } \Omega \times (0,T), \tag{1a}$$

$$(A(\rho)\nabla\rho)\vec{n}_\Omega = 0 \quad \text{on } \partial\Omega \times (0,T), \tag{1b}$$

$$\rho(\cdot,0) = \rho_0 \quad \text{in } \Omega. \tag{1c}$$

Here, the unknown $\rho := (\rho_1, \dots, \rho_N)$ for some number of species $N \in \mathbb{N}$, $A : \mathbb{R}^N \to \mathbb{R}^{N\times N}$ is the diffusion matrix, $f : \mathbb{R}^N \to \mathbb{R}^N$ describes the nonlinear interaction between the N species, and $\rho_0 \in [L^\infty(\Omega)]^N$ is a given initial datum.

The main difficulty in the design of methods for the discretization of problem (1) is that the diffusion matrix A may be neither symmetric nor positive semidefinite, which prevents the use of standard techniques for the analysis of such problems, even at the continuous level. However, the framework introduced in [Jüngel, 2015] uses a transformation of variables based on the entropy density function to obtain an equivalent problem with the following properties:

- the diffusion matrix is positive semidefinite
- suitable gradient estimates are available
- the positivity/boundedness of the solution is guaranteed even if a maximum principle is not available

More precisely, assuming the existence of a convex function $s \in \mathcal{C}^2(\mathcal{D};[0,\infty)) \cap \mathcal{C}^0(\overline{\mathcal{D}};[0,\infty))$ for a bounded domain $\mathcal{D} \subset (0,\infty)^N$, with $s' : \mathcal{D} \to \mathbb{R}^N$ invertible and inverse $u := (s')^{-1} \in \mathcal{C}^1(\mathbb{R}^N;\mathcal{D})$, and the existence of a constant $\gamma > 0$ such that

$$z^T(s''(\rho)A(\rho))z \geq \gamma|z|^2 \qquad \forall z \in \mathbb{R}^N,\ \rho \in \mathcal{D},$$

the equivalent problem is obtained by introducing the entropy variable $w := s'(\rho)$. In particular, the following essential chain rule is obtained:

$$\nabla w = \nabla s'(\rho) = s''(\rho)\nabla\rho. \tag{2}$$

During my stay at ESI, we designed a high-order LDG method with the following desirable properties:

- the numerical solution naturally preserves the positivity/boundedness of the exact solution
- nonlinearities do not appear within differential operators, thus substantially reducing the computational cost of the method
- a discrete chain rule, analogous to (2), is weakly imposed, which allows us to show a discrete entropy stability estimate

The proposed method is based on the following suitable decomposition: we introduce the auxiliary variables w, ζ, σ, and q defined by

$$\rho := u(w), \tag{3a}$$
$$\zeta := -\nabla w, \tag{3b}$$
$$A(\rho)^T s''(\rho)\sigma := -A(\rho)^T s''(\rho)\nabla\rho = A(\rho)^T \zeta, \tag{3c}$$
$$q := A(\rho)\sigma, \tag{3d}$$

and rewrite problem (1) as

$$\begin{aligned} \partial_t \rho + \nabla \circ q &= f(\rho) && \text{in } \Omega \times (0,T), \\ q \circ \vec{n}_\Omega &= \mathbf{0} && \text{on } \partial\Omega \times (0,T), \\ \rho(\cdot,\mathbf{0}) &= \rho_0 && \text{in } \Omega. \end{aligned}$$

In particular, definition (3c) is a reformulation of the chain rule (2) in terms of the auxiliary variables.

Moreover, during my stay, I have finished writing my PhD thesis and collaborated with Prof. Perugia, L. Mascotto (U Milano-Bicocca), A. Moiola (U Pavia), and P. Stocker (U Göttingen), on the following side projects:

- In [Gómez, Mascotto, Perugia, 2024], we presented an hp spacetime virtual element method for the discretization of the heat equation for general prismatic meshes. We also discussed strategies to handle efficiently the spacetime mesh structure.
- In [Gómez, Moiola, Perugia, Stocker, 2023], we studied the approximation properties and the construction of bases of polynomial Trefftz spaces for the $(d+1)$-dimensional linear time-dependent Schrödinger equation. Such spaces are spanned by local polynomial solutions to the considered PDE, and we proved that their dimension is equal to that of the space of polynomials of degree $2p$ in only d variables.

References

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S. Gómez. *Nonconforming space–time methods for evolution PDEs*. PhD thesis, University of Pavia, 2023.

Publications and preprints contributed

S. Gómez, A. Jüngel, and I. Perugia. *Structure-preserving Local Discontinuous Galerkin method for cross-diffusion systems: a time stepping approach*, in preparation, 2023.

S. Gómez, A. Moiola, I. Perugia, P. Stocker, *On polynomial Trefftz spaces for the linear time-dependent Schrödinger equation*, arXiv:2306.09571[math.NA].

S. Gómez, L. Mascotto, I. Perugia, *Design and performance of a space-time virtual element method for the heat equation on prismatic meshes*, arXiv:2306.09191[math.NA].

Cesare Tresca: Dark matteR dEtection viA novel Materials (DREAM)

Cesare Tresca (Consiglio Nazionale delle Ricerche - SuPerconducting and other INnovative materials and devices institute, Italy): March – April 30, 2023

Report

During my stay at the Erwin Schrödinger Institute I worked in the group of Prof. Cesare Franchini at University of Vienna. Alongside engaging in general scientific discussions and participating in group seminars, I collaborated actively with Dr. Michele Reticcioli, a postdoctoral researcher, as well as Luigi Ranalli and Andrea Angeletti, both PhD students in the group.

The primary objective of this research fellowship was to develop a method for calculating the dielectric constant of materials as a function of energy and momentum to assess the detection rate of Dark Matter (DM). Various approaches have been proposed to compute the DM detection rate, beginning with a first-principles description of the wavefunctions of the crystal target [1]. By assuming a spin-independent DM-electron interaction Hamiltonian, we could derive the DM scattering rate directly from the experimentally-measured energy loss function, which is the inverse of the material-specific dielectric constant [1]. This quantity can be predicted and computed using Density Functional Theory-based numerical methods.

During the visiting period, our main research focus was on implementing dielectric constant calculations within the Vienna Ab initio Simulation Package (VASP), avoiding computationally demanding methods like Bethe-Salpeter equations. We made significant progress in computational implementation, achieving the desired results for a reference sample system (Silicon). Unfortunately, further tests on different systems (semiconductors, semimetals, metals and superconductors) were halted due to the conclusion of the visiting period.

In parallel, we also investigated new hydrogen-based superconducting materials using innovative techniques. Employing machine learning-based molecular dynamics, we predicted the formation of molecular hydrogen in the N-doped LuH3 hydride, initially reported as a room temperature superconductor (now retracted). Subsequently, we analyzed the electronic, dynamical, and superconducting properties of this compound, our results have been formalised in the article titled 'Evidence of Molecular Hydrogen in the N-doped LuH3 System: a Possible Path to Superconductivity?'[2].

In summary, the visiting period was very fruitful for both parties involved, not only in advancing the calculation of the dielectric constant and thus the detection rate for DM but also for new and ongoing collaborations on other research topics that have already yielded their first fruits (see submitted paper [2]) and are still continuing.

References

[1] Y. Hochberg et al., Phys. Rev. Lett. 127, 151802 (2021).

[2] C. Tresca, P. M. Forcella, A. Angeletti, L. Ranalli, C. Franchini, M. Reticcioli, G. Profeta, *Evidence of Molecular Hydrogen in the N-doped LuH_3 System: a Possible Path to Superconductivity?*, arXiv:2308.03619[cond-mat.supr-con].

Publications and preprints contributed

C. Tresca, P. M. Forcella, A. Angeletti, L. Ranalli, C. Franchini, M. Reticcioli, G. Profeta, *Evidence of Molecular Hydrogen in the N-doped LuH_3 System: a Possible Path to Superconductivity?*, arXiv:2308.03619[cond-mat.supr-con].

Şeyma Karadereli: Real algebraic overtwisted contact structures on 3-spheres with negative invariants

Şeyma Karadereli (Bogazici U): February 1 – June 12, 2023

Report

A Milnor fillable 3-manifold is defined as a closed, oriented, contact 3-manifold that has a contact isomorphism to the contact link manifold of a complex analytic surface with an isolated singularity. It is known that such manifolds admit a unique Milnor fillable contact structure up to contactomorphism. As the contact structures on the 3-manifolds are of two types, called tight and overtwisted, it is known that the Milnor fillable contact structure of a Milnor fillable manifold is tight [CNPP06]. As we restrict ourselves to the 3-spheres, there is a unique tight contact structure and countably infinitely many overtwisted contact structures which are distinguished by the half integer valued d_3 invariant. It has been previously established that all overtwisted structures in the 3-spheres are real algebraic by computing the Hopf invariant of a family of real algebraic multilinks [Ina14]. However, the constructed open book decompositions that support the contact structures have pages with varying genus.

In our previous work [K22], by considering Seifert/graph multilinks, we have shown that every overtwisted contact structure on 3-spheres with positive d_3 invariant is real algebraic and the associated open books are planar (except 13 of them). As it is known that any overtwisted contact structure is supported by a planar open book [Etn04], the goal of this project was to investigate whether there are real algebraic planar overtwisted contact structures on 3-spheres with negative d_3 invariant. As a result, we have obtained a positive response to this question.

Furthermore, in [K22] while constructing wider families of graph multilinks, we used the splicing operation, which is a topological operation preserving the algebraicity of the multilinks under some conditions. Another question considered in this project was to find an algebraic paste operation of 4-manifolds which corresponds to the splicing operation on the boundary of the 4-manifold. However, we have not observed promising results in this direction.

During my stay at ESI, for the latter question, I focused on the existing operations on contact structures, such as Murasugi sum, fiber connected sum and binding sum, to find relations with the splicing operation and benefitted from the valuable discussions with Vera Vertesi. I have also spent time on understanding the effect of the splicing on abstract open books and 4-manifolds. Unlike the case where we considered the planar open books whose bindings are links, the splicing of multilinks might behave unexpectedly on the splicing tori of abstract open books in general.

Later on, for the former direction, I focused on the paper [NR90], where the authors explain an easier method to compute the enhanced Milnor number of links in S^3 and show that the enhanced Milnor number can take negative values. The enhanced Milnor number of the binding of the open book is related to d_3 invariant of the supported contact structure. Therefore, thanks to the aforementioned results in [NR90] and [Ina14], by conjugating one of the variables of the real algebraic functions that we constructed in our previous article [K22], we obtained infinitely many planar overtwisted contact structures in S^3 with negative d_3 invariants. Besides, the recent work of B. Bode [Bod22] gives a large family of fibered links which are real algebraic. With the help of this result, we considered another family of fibered links which are the binding of planar open book decompositions. As a result, we have also obtained the missing values of the d_3 invariant by constructing new real algebraic links via splicing of these new families of fibered links.

During my stay, I also had the chance to participate in the Winter School in Singularities and Low Dimensional Topology, The Singular Workshop and The Low-dimensional Workshop (Alfréd Rényi Institute of Mathematics, Budapest) co-organized by Vera Vertesi and had an opportunity to give a lightning talk about my research. Lastly, I have also worked on referee revisions of the preprint [K22].

References

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Yang Yang: LandauGinzburg models and the string-net construction of CFT correlators

Yang Yang (Oberwolfach Research Institute for Mathematics, Germany): February 1 – May 19, 2023

Report

The long-term goal of this program is to apply the string-net construction of CFT correlators developed in my PhD thesis [7] to the pivotal bicategory $\mathcal{LG}$ of the (topological B-twists of) Landau-Ginzburg models and their associated defects, and study the conjectured LG/CFT-correspondence from this perspective.

The Landau-Ginzburg models are closely related to the other class of topological field theories, namely the Rozansky-Witten models (they are topological twists of 3-dimensional supersymmetric sigma models with holomorphic sympectic target manifolds): the most prominent common feature is that they both involve *matrix factorizations* as their central algebraic structures. During my stay at ESI, Nils Carqueville and I decided to first work on a project related to the latter class of field theories due to its relative simplicity, in order to gain familiarity with certain algebraic structures arising from matrix factorizations, which is essential to our long-term goal.

In [1], it was rigorously shown that when restricted to affine Rozansky-Witten models (i.e. those whose targets are of the form $T^*\mathbb{C}^n$) and truncated at dimension 2, the tricategory $\mathcal{RW}$ proposed by Kapustin and Rozansky in [4] via path integral analysis give rise to a symmetric monoidal bicategory $\mathrm{Ho}_2(\mathcal{RW}^{\mathrm{aff}})$ where every object is fully dualizable and admits an essentially unique trivialization of its Serre automorphism. Therefore, according to the cobordism hypothesis (in fact a theorem in dimension 2), every object $(x_1,\cdots,x_n)\in \mathrm{Ho}_2(\mathcal{RW}^{\mathrm{aff}})$ produces a fully extended oriented topological field theory $Z_n\colon \mathrm{Bord}^{\mathrm{or}}_{2,1,0}\to \mathrm{Ho}_2(\mathcal{RW}^{\mathrm{aff}})$, which is explicitly constructed in [1].

We would like to lift the closed sector of each 2d TFT Z_n to an *ansular functor*, i.e. a consistent system of handlebody group representations, valued in the symmetric monoidal bicategory $\mathcal{S}=\mathrm{End}_{\mathcal{RW}^{\mathrm{aff}}}(\emptyset)$, as a first step towards lifting the 2-truncated TFTs to full-fledged 3d TFTs. Based on the results from [5, 6], such an ansular functor is fully determinded by its genus 0 data, i.e. a *cyclic algebra* over the framed little disks operad fE_2. Such a cyclic fE_2-algebra can in turn be presented via generators and relations as a categorified commutative Frobenius algebra in $\mathcal{S}$ and has structures akin to those of a *ribbon Grothendieck-Verdier category*: it has a weakly associative and unital multiplication $\mu\colon A_n\otimes A_n\to A_n$ on its underlying object $A_n=Z_n(\mathbb{S}^1)\in\mathcal{S}$, a non-degenerate pairing $\kappa\colon A_n\otimes A_n\to\mathbb{I}$, a braiding $\mu\Rightarrow\mu^{\mathrm{op}}$, and a twist $\theta\colon 1_{A_n}\Rightarrow 1_{A_n}$, such that they fulfill the coherence conditions listed in [5]. Although the evaluation of the 2-truncated TFT Z_n on a pair of pants and a cylinder with two in-going boundary circles provides representatives of the matrix factorizations that would define the 1-morphisms μ and κ, it is a non-trivial task to find the suitable 2-morphisms β and θ satisfying the desired coherent diagrams. We are continuing the quest for these 2-morphisms after my stay.

I have been benefited greatly from my interaction with Nils and his research group during my stay, which includes Alex, Ekin, Fiona, Giovanni, Konrad, and Lóránt. I also enjoyed giving the 1-hour introductory talk on my PhD thesis.

During my stay at the ESI, I continued the collaboration with Jürgen Fuchs (Karlstads Universitet) and Christoph Schweigert (Universität Hamburg) which led to a preprint [2]. In addition, together with Simon Wood (Cardiff University), the four of us completed the invited contribution [3] to the 2nd edition of the *Encyclopedia of Mathematical Physics*.

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Publications and preprints contributed

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

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Fiona Torzewska: From motion groupoids to defect TQFT

Fiona Torzewska (U of East Anglia): April 1 – September 30, 2023

Report

During my PhD a significant proportion of my work was dedicated to developing the theory of motion groupoids. These are groupoids which are potentially useful for modelling particle motion in certain condensed matter systems known as topological phases. Mathematically, given a manifold M, the motion groupoid has as objects all subsets of M, and as morphisms equivalence classes of paths in an appropriate space of self homeomorphisms of M. Looking at the group of morphisms from a finite set of points to itself in 2-dimensional space recovers the braid groups, see [TFM] for more.

Nils Carqueville and his collaborators have made significant recent progress developing the theory of defect topological quantum field theory (TQFT). Mathematically these theories are formalised by functors $\mathbb{Z}^{\text{def}}\colon \text{Bord}_n^{\text{def}}(\mathbb{D}) \to \text{Vect}_{\mathbb{C}}$ where $\text{Bord}_n^{\text{def}}(\mathbb{D})$ is the category of n-dimensional stratified bordisms, with strata labelled by elements of some input set $\mathbb{D}$, see [Car],[CMS] for more. Defects in field theories describe a variety of different physical phenomena including particle trajectories, phase transitions and domain walls.

One may expect that, since motion groupoids and defect TQFT both have applications to modelling particle trajectories, there is a direct mathematical relationship between the two. Investigating this relationship was the aim of my research visit to Vienna. We made progress via two key different approaches to this question.

(i) **Maps into** $\text{Bord}_n^{\text{def}}$**:** We made some useful progress in discussing how to directly construct a map which takes as input motions, and produces morphisms in $\text{Bord}_n^{\text{def}}$. To turn this into a functor will, in general, require choosing some way to assign each defect a labelling. Even before considering labellings there are several choices. One can map a motion to the bordism defined by the same manifold/ submanifold pair, although this will necessarily lose some information that was present on the motion groupoid side. For example, a 2π rotation of the circle with a marked point represents a non trivial motion in the motion groupoid, but a trivial morphism in $\text{Bord}_n^{\text{def}}$. An alternative approach is

to look for different choices of maps which are injective on motions. An example of a promising choice is to consider a 'thickening' of a motion, so a 2π rotation of the circle is sent to a bordism from $S^1 \times [0,1]$ to itself.

(ii) **Local invariants of** Mot_M**:** An alternative approach is to use defect TQFT to directly obtain representations of motion subgroupoids which are well understood. For example, in the case of the loop braid groupoid, which consists of motions of unknotted, unlinked loops in 3-dimensional space, we have a presentation [Dam]. This means that we can make sensible guesses as to how to use defect TQFTs to assign linear maps to motions, and only need to check that the appropriate relations are satisfied, bypassing the need to construct a functorial mapping. Further in this direction, topological phases are of interest for topological quantum computation, and in this setting it is of interest to look for *local* representations of certain motion subgroupoids, see [DRW] for details. These are representations that can be formulated as strict monoidal functors. We made some progress looking for ways to manipulate a given defect TQFT to obtain local representations of the braid groupoid.

Overall my visit to Vienna was very productive. I was able to learn a huge amount by being part of a group that was closely related to my research interests and attending regular research seminars on topics related to TQFT, as well as being part of the wider mathematical physics group. I also gave talks, both at the University of Vienna, and in the algebra seminar at Masaryk University in Brno. I took part in many research discussions with both Nils Carqueville, and Vincentas Mulevičius who was visiting Vienna for some of my visit. I hope that Vincentas and I will write a paper on our progress in the next year. Aside from any papers we may produce I expect the visit to be hugely beneficial to my future career due to the networking and learning opportunities that were available. In particular I was able to attend the conference 'Higher structures in functorial field theory' at the University of Regensburg, which has led to the initiation of a research project with Catherine Meusburger who is based at the Friedrich Alexander University in Erlangen.

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Kaushlendra Kumar: IKKT model & Gravity

Kaushlendra Kumar (Queen Mary U of London): March 5 – June 15, 2023

Report

The emergent geometry. The IKKT matrix model is given by the following action (with bosonic T, fermionic Ψ and $so(1,9)$ Clifford Γ_A matrices),

$$S[T,\Psi] = \mathrm{Tr}\left([T^A,T^B][T_A,T_B] + \bar{\Psi}\Gamma_A[T^A,\Psi]\right), \tag{4}$$

that admits gauge invariance, a global $SO(1,9)$ symmetry as well as maximal supersymmetry. The solution of the bosonic part of this classical action yields 10 Hermitian matrix configurations $T^A \in \mathrm{End}(\mathcal{H})$ with $A = 0,\ldots,9$. Of special interest are backgrounds $\bar{T}^a$ with $a = 0,\ldots,3$ producing $(3{+}1)$-dimensional embedding branes $\mathcal{M}^{1,3} \hookrightarrow \mathbb{R}^{1,9}$. The backbone of such a semi-classical ($n\to\infty$) analysis is the equivalence between the algebra of functions $t^a \in C^\infty(\mathcal{M})$ and a quantum algebra $T^a \in \mathrm{End}(\mathcal{H}_n)$, denoted by $t^a \sim T^a$, such that $[\cdot,\cdot] \sim i\{\cdot,\cdot\}$. This Poisson bracket comes from a symplectic structure $\theta^{\mu\nu} = \{x^\mu, x^\nu\}$ for the spacetime coordinates $x^\mu \in \mathcal{M}^{1,3}$. A special class of solutions are $T^a = R^{-1}\mathcal{M}^{a4}$; $a = 0,\ldots,3$ ($\mathcal{M}^{a4}$ are $\mathfrak{so}(2,4)$ generators) that leads to an emergent manifold, viewed as S^2-bundle $\mathbb{C}P^{1,2}$ over the spacetime $\mathcal{M}^{1,3}$. Another useful solution is the Kaluza-Klein (KK) embedding, $T^a \sim x^a : \mathcal{M}^{1,3} \hookrightarrow \mathbb{R}^{1,3}$ and $T^i \sim z^i : \mathcal{K} \hookrightarrow \mathbb{R}^6$ with $i = 4,\ldots,6$, for some compact manifold $\mathcal{K}$. The fluctuations around these backgrounds, $T^A = \bar{T}^A + \mathcal{A}^A$, can be expanded in terms of S^2-harmonics and KK-modes respectively. Moreover, these fluctuations determine an effective metric $G^{\mu\nu}$ obtained from the kinetic term of the action (4). It turns out that this metric is conformally related to an auxiliary metric $\gamma^{\mu\nu} = \eta^{ab}E^\mu_a E^\nu_b$ constructed from the frames $E^\mu_a = \{\bar{T}_a, x^\mu\}$; this yields an extra Dilaton field ρ, also related to the frame. Furthermore, E^μ_a obeys a divergence constraint (arising from the Jacobi identity) which breaks the local Lorentz invariance. As a consequence, this emergent theory has more physical content than in usual GR and is interpreted as a torsion tensor, $T^a = \mathrm{d}E^a = (1/2)T_{\mu\nu}{}^a \mathrm{d}x^\mu \wedge \mathrm{d}x^\nu$, constructed from the frame field $E^a = E^a_\mu \mathrm{d}x^\mu$.

Previous 1loop result. The following 1loop expression with $\mathcal{M}_{AB}$ being $\mathfrak{so}(1,9)$ generators in vector (V) and spinor (ψ) representations,

$$\Gamma_{1\mathrm{loop}} \sim \mathrm{Tr}\left(\log(\Box + \mathcal{M}^{(V)}_{AB}[\Theta^{AB},\cdot]) - \frac{1}{2}\log(\Box + \mathcal{M}^{(\psi)}_{AB}[\Theta^{AB},\cdot]) - 2\log(\Box)\right), \tag{5}$$

arises from a 'partition function' around the free action $S_0[T] = \mathrm{Tr}([T^A,T^B][T_A,T_B])$. The first three terms in the log expansion vanishes due to supersymmetry and it, furthermore, splits into three parts with individual/mixed contributions coming from $\mathcal{M}$ and $\mathcal{K}$. The result was computed in [S22-S23] for the above-mentioned backgrounds using the so called *string modes*; the $\mathcal{M}$ contribution turns out to be negligible in the long wavelength regime while the $\mathcal{K}$-(vacuum energy) and mixed-part yields,

$$\begin{aligned}
\Gamma^{\mathcal{K}}_{1\mathrm{loop}} &\equiv S_{\mathrm{vac}} = \int_{\mathcal{M}} \Omega\rho^{-2}\left(C_1 m^4_{\mathcal{K}} + C_2\frac{1}{R^4} + C_3\frac{1}{R^8 m^4_{\mathcal{K}}}\right), \\
\Gamma^{\mathcal{M}-\mathcal{K}}_{1\mathrm{loop}} &= \int_{\mathcal{M}} \mathrm{d}^4x \frac{\sqrt{|G|}}{16\pi G_N}\left(\mathcal{R} + \frac{1}{2}T\cdot T - 2\rho^{-2}\partial\rho\cdot\partial\rho + 2\rho^{-1}G_N^{-1}\partial\rho\cdot\partial G_N\right).
\end{aligned} \tag{6}$$

Here C_i are some large constants and the Newton's constant $G_N = \frac{\pi^3\rho^2}{2c^2_{\mathcal{K}}m^2_{\mathcal{K}}}$ is made from parameters on the compact manifold: a constant $c_{\mathcal{K}}$ and the KK mass $m_{\mathcal{K}}$.

Outcome. During this fellowship I worked with Harold Steinacker to understand the equation of motion arising from an effective action consisting of the free (Yang–Mills), matter and 1loop actions,

$$S_{\text{eff}} \sim -\int \Omega \left(\{T^a, T^b\}\{T_a, T_b\} + m_{\mathcal{K}}^4 F_{\mathcal{K}}^2 \right) + \int \mathrm{d}^4x \sqrt{|G_{\mu\nu}|}\, \mathcal{L}_{\text{matter}} + \Gamma_{1\text{loop}}, \tag{7}$$

where Ω is the symplectic volume form and the extra term proportional to $m_{\mathcal{K}}^4$ comes from transversal $\mathcal{K}$ direction with some discrete $F_{\mathcal{K}}$. We computed the variations, by first considering $G^{\mu\nu}$, $m_{\mathcal{K}}$ and ρ as independent dynamical quantities to get (a) a mass-constraint that can in principle be solved for $m_{\mathcal{K}}$ and (b) fix it to then express the result in term of frame variation using the following results,

$$\delta\sigma = -\frac{1}{2} E^{a\sigma}\delta E_{a\sigma}, \quad \delta G^{\mu\nu} = 2\rho^{-2} E_a^{\mu}\delta E^{a\nu} + G^{\mu\nu}E^{a\sigma}\delta E_{a\sigma}\,. \tag{8}$$

A key challenge was to handle the Yang–Mills-term, which we did by using $\Box_G T_a = \{C_{a\mu}, x^\mu\}$, for some "anharmonicity" tensor $C_{\mu\nu} = C_{a\mu}E^a_\nu$, to obtain (torsion-free) *modified Einstein equations* (dilaton field is re-parametrized as $\sigma = \log(\rho)$)

$$\begin{aligned} \mathcal{R}_{\mu\lambda} - \frac{1}{2}G_{\mu\lambda}\mathcal{R} = 8\pi G_N \Big[T^{(m)}_{\mu\lambda} - \frac{1}{\rho^4}G_{\mu\lambda}\big(2\rho^2 F_{\mathcal{K}}^2 m_{\mathcal{K}}^4 - C_1 m_{\mathcal{K}}^4 + \frac{C_2}{R^4} + \frac{3C_3}{R^8 m_{\mathcal{K}}^4}\big) + 4(C_{\mu\lambda} - \frac{1}{2}G_{\mu\lambda}C) \Big] \\ + 2\big(\partial_\mu\sigma\partial_\lambda\sigma - \partial_\mu\partial_\lambda\sigma + G_{\mu\lambda}(\Box_G\sigma - \frac{3}{2}\partial\sigma\cdot\partial\sigma)\big)\,. \end{aligned} \tag{9}$$

Our analysis shows that this emergent gravity theory is close to general relativity (up to a modifications due to extra fields) at shorter scales, but deviates significantly from GR on cosmic scales. During this stay I also made contacts with other visitors (especially useful were contacts with John Barrett, whom I met again in Berlin last September, and Sumati Surya; these may develop into future collaborations) and my previous work at ESI seminar on May 4, 2023 that was titled "Exact gauge fields from anti-de Sitter space". At the time of writing this report, I am working at the Queen Mary University of London as a DFG Walter-Benjamin research fellow.

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Publications and preprints contributed

K. Kumar, H.C. Steinacker, *Modified Einstein equations from the 1-loop effective action of the IKKT model*, arXiv:2312.01317 [hep-th].

Abhiram M. Kidambi: Novel mathematical structures in 3d quantum gravity

Abhiram M. Kidambi (MPI MiS, Leizpig): September 14 – December 14, 2023 and April 1 – April 30, 2024

Report

Scientific achievements: The key aim of the fellowship was to address and apply novel number theoretic and lattice theoretic concepts to the study of low dimensional quantum gravity, particularly for the case of the AdS_3/CFT_2 correspondence. This correspondence conjectures a duality of a large set of observables between gravity on a $d-$dimensional AdS spacetime and a $d-1$ dimensional conformal field theory. The statement of this duality lacks mathematical rigor and the aim of the proposal was to attempt to formulate and calculate in a mathematical rigorous manner a particular proposed aspect of the duality viz. ensemble averages.
Ensemble averages of CFT have been discussed in the context of wormholes in gravity. However, in the context of this research stay, I considered ensemble averages of arbitrary conformal field theories whose moduli spaces are well defined orthogonal varieties (the so called *Narain* moduli spaces, which are isomorphic to the space of lattices of the same rank as the orthogonal varieties quotient out by discrete and rotational symmetries of lattice vectors).
Conformal field theories (which in this context are lattice valued vertex operator algebras) can be defined using the theory of binary quadratic forms and theta functions on lattices. To construct the ensemble average, one needs to take additional care of many additional contributions (such as theta functions on smaller congruence subgroups, additional cusps, additional multiplicative characters etc.) and therefore prove the Siegel Weil theorem for a large class of spaces of conformal field theories. Part of this research was carried out in 2021 by M. Ashwinkumar, M. Dodelson, A. Kidambi, J. Leedom and M. Yamazaki.
In the preprint listed below, we extended the proof of the theorem and ensemble averages to the case of orbifolded conformal field theories and made progress towards a topological interpretation of the average partition function, which is given by a non-holomorphic Eisenstein series.

In addition to work on the above projects, I was also able to form three novel collaborations on various projects related to computational number theory and applications to physics, particularly string theory and scattering amplitudes. These projects are promising but are not at a stage where I can report on their progress yet.

This progress has been possible due to the facilities and support of the ESI and I am extremely grateful to them, the staff, the directors and the scientific visitors for making my stay there productive and fruitful.

Courses Taught
Automorphic forms and L-functions (Erwin Schrödinger Institute for Mathematics and Physics, U of Vienna, April 2024)

Invited Talks

- U Cambridge: $g = 2$ *Hyperelliptic curves and Siegel Modular Functions*, October 2023
- U Cambridge: *Introduction to the Birch and Swinnerton-Dyer Conjecture*, October 2023
- TU of Vienna: *Applications of non-holomorphic Eisenstein series in* 3*d gravity*, April 2024
- U of Vienna: *Hodge theoretic characterizations of rational CFTs*, April 2024

Publications and preprints contributed

M. Ashwinkumar, A. Kidambi, J. Leedom, M. Yamazaki, *Generalized Narain Theories Decoded: Discussions on Eisenstein series, Characteristics, Orbifolds, Discriminants and Ensembles in any Dimen-*

sion, arXiv:2311.00699[hep-th].

Onirbam Islam: Feynman Greens Operators on a Black Hole Spacetime

Onirbam Islam (U of Potsdam): June 24 – July 15, 2023

Report

Green operators for a wave operator are one of the central objects to understand classical and quantum aspects of wave equations. Due to the hyperbolic nature of wave operators, the existence of their Green operators is highly non-trivial. It is a classic result due to Duistermaat and Hörmander [1] (see also [2]) that a wave operator on a globally hyperbolic spacetime admits four independent Green operators: retarded, advanced, Feynman, and anti-Feynman. There are several methods to construct these operators. Amongst those, Donninger et al. [3] have developed a spectral theoretic method to obtain the Schwartz kernels of the retarded and advanced Green operators on the exterior region of a Schwarzschild black hole. On the other hand, with Strohmaier, I propounded the Duistermaat-Hörmander (anti-)Feynman parametrix construction to a vector bundle (over a globally hyperbolic spacetime) setting [2]. The aim of this research fellowship was to initiate a systematic investigation of (anti-)Feynman Green kernels on spacetimes with a bifurcate Killing horizon by making a bridge between the spectral theoretical ideas and the microlocal methods.

During my stay at the Erwin Schrödinger International Institute for Mathematics and Physics (ESI), I have participated in the thematic programme ”Spectral Theory and Mathematical Relativity” where I have a talk on Feynman Propagators on a Curved Spacetime. Furthermore, I have had in-person meetings with Professor A. Vasy (Stanford U) and Professor R. Donninger (U of Vienna) regarding the analysis of wave equation around the Schwartzschild event horizon.

At present, I am in collaboration with Donninger to construct (anti-)Feynman kernel on the Kruskal-Szekeres-Schwartzschild spacetime. In order to incorporate the effects of Schwartzschild horizon, it requires to extend the aforementioned results by Donninger et al. [3] and by Islam and Strohmaier [2]. Since (anti-)Feynman Green operators are intimately connected with quantum states, we also preparing an expository note to provide a common ground for the partial differential equation community and quantum field theorists. Unfortunately, a herniated disk problem was diagnosed shortly after my visit at ESI. Therefore, our progress could not be as expected. However, we are expecting to have a pre-print at the end of this year.

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[2] O. Islam, A. Strohmaier *On microlocalisation and the construction of Feynman Propagators for normally hyperbolic operators*, arXiv:2012.09767[math.AP].

[3] R. Donninger, W. Schlag, A. Soffer, *A proof of Price's Law on Schwarzschild black hole manifolds for all angular momenta*, arXiv:0908.4292[gr-qc] and R. Donninger, W. Schlag, A. Soffer, *On pointwise decay of linear waves on a Schwarzschild black hole background*, arXiv:0911.3179[math.AP].

ESI Special Research Fellowship for Ukrainian Scientists

Oleg Korotchenkov: Time-domain impedance and thermal analysis of carrier recombination in ZnO thin films and hybrid nanostructures

Oleg Korotchenkov (Kiev U): April 29 – June 1, 2023

Report

During my stay at the Erwin Schrödinger International Institute extended to 2023 the project was focused on the influence of Au plasmonics on the thermoacoustic response of integrated thiol-linked CdSe quantum dot-Au nanotrench hybrid structures. The thermoacoustic measurement technique uses a modulated light beam illuminating the sample placed into the air-filled cell and measures the temperature oscillation in the sample resulting from the light absorption. The intermittent heat generates an acoustic signal in the cell that is detected by a microphone. An enhanced acoustic signal is observed due to plasmonic absorption by the Au grating layers. The Au grating layer absorbs the energy of a modulated light near the plasmon resonance producing a thermal expansion of Au due to periodic temperature rise as the created plasmons lose their energy, which in turn generates acoustic waves. The dipole plasmon resonance shifts predictably toward the red after assembly with thiol-linked CdSe quantum dots. The thermoacoustic signal is even more enhanced in two well-defined spectral bands peaking at about 400 and 490 nm due to CdSe quantum dots placed into gold nanotrenches. The results can be extended in various fields employing light-to-heat conversion processes in hybrid metal-semiconductor nanomaterials, nanoplasmonic systems and periodic grating structures.

Another aspect of the project refers to studying the thermal conductivity of polymer/multilayered graphene/TiO_2 nanocomposites. An analytical model based on the effective medium approximation with a reasonable number of input parameters was used to simplify the thermal conductivity simulations by including a phenomenological thermal boundary resistance. The sensitivity of the modeled thermal conductivity to geometrical and material parameters of filling particles and host polymer matrix, filler's mass concentration, self-assembling degree, and Kapitza thermal boundary resistances at emerging interfaces was numerically evaluated. A fair agreement of the calculated and measured room-temperature thermal conductivity was obtained.

The Erwin Schrödinger International Institute has offered a high quality setting for the best conduct of these studies. The ESI team charming management is greatly appreciated.

Publications and preprints contributed

A. Nadtochiy, O. K. Suwal, D.-S. Kim, O. Korotchenkov, *Revealing CdSe quantum dots plasmonics confined in Au nanotrenches by thermoacoustic spectroscopy*, ACS Applied Optical Materials, 1, 1272–1280 (2023).

A. B. Nadtochiy, A. M. Gorb, B. M. Gorelov, O. I. Polovina, O. Korotchenkov, V. Schlosser, *Model approach to thermal conductivity in hybrid graphene-polymer nanocomposites*, Molecules, 28 (2023).

Seminars and colloquia outside main programmes and workshops

419 seminar and colloquia talks have taken place at the ESI in 2023 including the following individual talks.

2023 03 07, Sara Bonella (CECAM, EPF Lausanne): “Welcome to the MaZe, a new approach for simulating adiabatic systems”
2023 03 07, Ignacio Pagonabarraga (U of Barcelona): “Phase transitions and self assembly in active matter”
2023 03 08, Georg Kaser (U of Innsbruck): “Our changing climate system”
2023 03 16, Elliott H. Lieb (Princeton U): “Study of a simple equation that describes the ground-state energy of a Bose gas at low and high density and in dimensions one, two and three”
2023 05 04, Kaushlendra Kumar (U of Hannover): “Exact gauge elds from anti-de Sitter space”
2023 06 07, Naoyuki Kanomata (Tokyo U of Science): “The finite cubic-quartic matrix model”
2023 11 07, Nigel Hitchin (U of Oxford): “ALE metrics and nodal curves”

ESI Research Documentation

ESI research in 2023: publications and arXiv preprints

THEMATIC PROGRAMMES

The Dynamics of Planetary-scale Fluid Flows (PDC)

I. Yacoby, H. Gildor, N. Paldor, *The effects of curvature and ß on zonally invariant f-plane dynamics*, Physics of Fluids 36, 046601 (2024).

Spectral Theory and Mathematical Relativity (CSZ)

E. Ames, H. Andréasson, *Stationary solutions of the axially symmetric Einstein-Vlasov system: present status and open problems*, arXiv:2310.00776[gr-qc].

L. Benedetto, C. Fermanian Kammerer, V. Fischer, *Quantization on groups and Gårding inequality*, https://hal.science/hal-04171881.

Y.-L. Fang, A. Waters, *Dispersive Estimates for Maxwell's Equations in the Exterior of a Sphere*, arXiv:2308.00536[math.AP].

A. E. Fischer, V. Moncrief, *Hamiltonian Reduction of Einstein's Equations*, Elsevier Press, Encyclopedia of Mathematical Physics.

J. Glöckle, *Initial data sets with dominant energy condition admitting no smooth dec spacetime extension*, arXiv:2308.00643[gr-qc].

P. Hintz, *Asymptotically de Sitter metrics from scattering data in all dimensions*, https://doi.org/10.1098/rsta.2023.0037.

C. Kehle, R. Unger, *Extremal black hole formation as a critical phenomenon*, arXiv:2402.10190[gr-qc].

C. Klein, P. Hintz, *Universality of the quantum energy flux at the inner horizon of asymptotically de Sitter black holes*, https://doi.org/10.1088/1361-6382/ad2cee

C. Klein, M. Soltani, M. Casals, S. Hollands, *Infinite quantum twisting at the Cauchy horizon of rotating black holes*, arXiv:2402.14171[gr-qc].

J. Kudler-Flam, S. Leutheusser, G. Satishchandran, *Generalized Black Hole Entropy is Von Neumann Entropy*, arXiv:2309.15897[hep-th].

S. Murro, G. Schmid, *The Quantization of Maxwell Theory in the Cauchy Radiation Gauge: Hodge Decomposition and Hadamard States*, arXiv:2401.08403[math.AP].

A. Waters, Y. Long Fang, *Dispersive Estimates for Maxwell's Equations in the Exterior of Sphere*, arXiv:2308.00536[math.AP].

Quantum Field Theory at the Frontiers of the Strong Interaction (SPH)

G. Bell, Philipp Böer, T. Feldmann, D. Horstmann, V. Shtabovenko, *Soft-overlap contribution to $B_c \to \eta_c$ form factors: diagrammatic resummation of double logarithms*, arXiv:2309.08410[hep-ph].

S. Caletti, A. Ghira, S. Marzani, *On heavy-flavour jets with Soft Drop*, arXiv:2312.11623[hep-ph].

W. Chen, M. Luo, T. Yang, H. X. Zhu, *Soft Theorem to Three Loops in QCD and N=4 Super Yang-Mills Theory*, arXiv:2309.03832[hep-ph].

B. Dehnadi, A. H. Hoang, O. L. Jin, V. Mateu, *Top Quark Mass Calibration for Monte Carlo Event Generators - An Update*, arXiv:2309.00547[hep-ph].

M. Diehl, F. Fabry, P. Ploessl *Evolution of colour correlated double parton distributions: a quantitative study*, arXiv:2310.16432[hep-ph].

A. Ghira, S. Marzani, G. Ridolfi, *A consistent resummation of mass and soft logarithms in processes with heavy flavours*, arXiv:2309.06139[hep-ph].

Geometry beyond Riemann: Curvature and Rigidity (IPT)

A. Bernig, J. Kotrbat, T. Wannerer, *Hard Lefschetz theorem and Hodge-Riemann relations for convex valuations*, arXiv:2312.12294[math.DG].

P. T. Chruściel, R. Wutte, *Gluing-at-infinity of two-dimensional asymptotically locally hyperbolic manifolds*, arXiv:2401.04048[gr-qc].

F. Fillastre, R. Prosanov, *Polyhedral surfaces in flat (2+1)-spacetimes and balanced cellulations on hyperbolic surfaces*, arXiv:2312.14266[math.MG].

T. Goliski, A. Tumpach, *Integrable system on partial isometries: a finite dimensional picture*, arXiv:2311.07412[nlin.SI].

T. Goliski, A. Tumpach, *Geometry of integrable systems related to the restricted Grassmannian*, arXiv:2407.21605[nlin.SI].

Y. Huang, K. Ohshika, A. Papadopoulos, *The infinitesimal and global Thurston geometry of Teichmüller space*, arXiv:2111.13381[math.GT].

Y. Huang, K. Ohshika, A. Papadopoulos, *The earthquake metric on Teichmüller space*, preprint, 2024.

A. Papadopoulos, Galilei and Huygens, *Music and science*, to appear in the volume Vincenzo Galilei: The Renaissance dialogue between music and science, ed. Ferdinando Abbri and Natacha Fabbri, Brepols, 2024.

WORKSHOPS

Between Regularity and Defects: Variational and Geometrical Methods in Materials Science (MA)

St. Almi, M. Morandotti, F. Solombrino, *Optimal control problems in transport dynamics with additive noise*, arXiv:2303.04877[math.OC].

S. Almi, E. Tasso, *Generalized bounded deformation in non-Euclidean settings*, arXiv:2304.11372[math.AP].

S. Almi, M. Caponi, M. Friedrich, and F. Solombrino, *Geometric rigidity on Sobolev spaces with variable exponents and applications*, arXiv:2305.00740[math.AP].

S. Almi, A. Molchanova, and S. Krömer, *A new example for the Lavrentiev phenomenon in Nonlinear Elasticity*. arXiv:2309.08288[math.AP].

M. Bresciani, M. Friedrich and C. Mora-Corral, *Variational models with Eulerian-Lagrangian formulation allowing for material failure*. arXiv:2402.12870[math.AP].

Non-regular Spacetime Geometry (CKM)

B. Allen, *Null Distance and Gromov-Hausdorff Convergence of Warped Product Spacetimes*, arXiv:arXiv:2306.03165[gr-qc].

T. Beran, M. Braun, M. Calisti, N. Gigli, R. McCann, A. Ohanyan, F. Rott, C. Sämann, *Sobolev calculus of time functions and synthetic d'Alembertian comparison*,

T. Beran, F. Rott, *Characterizing intrinsic Lorentzian length spaces via τ-midpoints.* arXiv:2309.12962[math.MG].

T. Beran, J. Harvey, L. Napper, F. Rott, *A Toponogov globalisation result for Lorentzian length spaces.* arXiv:2309.12733[math.DG].

T. Beran, M. Kunzinger, F. Rott, *On curvature bounds in Lorentzian length spaces.* arXiv:2309.12062[math.DG].

T. Beran, L. Napper, F. Rott, *Alexandrov's Patchwork and the Bonnet-Myers Theorem for Lorentzian length spaces.* arXiv:2302.11615[math.DG].

M. Braun, S. Ohta, *Optimal transport and timelike lower Ricci curvature bounds on Finsler spacetimes.* arXiv:2305.04389[math.DG].

S. Burgos, J. L. Flores, J. Herrera, *The c-completion of Lorentzian metric spaces*, arXiv:2305.02004[gr-qc].

St. G. Harris, *Convergence at Past Timelike Infinity in the Causal Boundary*, *Classical and Quantum Gravity*

M. Kunzinger, A. Ohanyan, B. Schinnerl, R. Steinbauer, *Conjugate points along timelike geodesics in Lorentzian length spaces*,

E. Ling, A. Ohanyan, *Cosmological spacetimes without CMC Cauchy surfaces*,

F. Rott, *Gluing of Lorentzian length spaces and the causal ladder.* arXiv:2209.06894[math.DG].

C. Sämann, B. Schinnerl, R. Steinbauer, R. Švarc, *Cut-and-paste for impulsive gravitational waves with Λ: The mathematical analysis.* arXiv:2312.01980[gr-qc].

A. Daniel Santhosh, S. Surya, *Gromov-Hausdorff type distance between 2d orders using the Null Distance Function.*

Non-commutative Geometry meets Topological Recursion (BGW)

A. Alexandrov, B. Bychkov, P. Dunin-Barkowski, M. Kazarian, S. Shadrin, *KP integrability through the $x - y$ swap relation*, arXiv:2309.12176[math-ph].

G. Borot, S. Charbonnier, E. Garcia-Failde, F. Leid, S. Shadrin, *Functional relations for higher-order free cumulants*, arXiv:2112.12184[math.OA].

G. Borot, R. Wulkenhaar, *A short note on BKP for the Kontsevich matrix model with arbitrary potential* arXiv:2306.01501[math-ph].

Quantum Field Theory at the Frontiers of the Strong Interaction (CLE)

H. Bradford, Ch. H. Cashen, F. Fournier-Facio, N. Matte Bon, H. Petyt, *GAGTA 2023 Problem Session*, arXiv:2310.04207[math.GR].

Large-N Matrix Models and Emergent Geometry (HKS)

E. Battista and H. C. Steinacker, *One-loop effective action of the IKKT model for cosmological backgrounds*, arXiv:2310.11126[hep-th].

A. Hock, *Laplace transform of the x – y symplectic transformation formula in Topological Recursion*, arXiv:2304.03032[math-ph].

H. C. Steinacker, Tung Tran, *Soft limit of cubic higher-spin interactions in the IKKT model*, arXiv:2311.14163[hep-th].

Analysis and Geometry in Several Comples Variables (GLM)

F. Forstneric, Y. Kusakabe, *Oka tubes in holomorphic line bundles*, arXiv:2310.14871[math.CV].

Mathematical Relativity: Past, Present, Future (EHC)

P. T. Chruściel, R. Wutte, *Gluing-at-infinity of two-dimensional asymptotically locally hyperbolic manifolds*, arXiv:2401.04048[gr-qc].

RESEARCH IN TEAMS (RIT)

H. Bruin, Ch. Fougeron, D. Ravotti, D. Terhesiu, *On asymptotic expansions of ergodic integrals for $\mathbb{Z}^d$-extensions of translation flows*, arXiv:2402.02266[math.DS].

H. Grosse, A. Sako, *Integrability of Φ^4 Matrix Model as N-body Harmonic Oscillator System*, arXiv:2308.11523[math-ph].

H. Grosse, N. Kanomata, A. Sako, R. Wulkenhaar, *Real symmetric Φ^4-matrix model as Calogero-Moser model*, arXiv:2311.10974[hep-th].

N. Kanomata, A. Sako, *Exact Solutions v.s. Perturbative Calculations of Finite Φ^3-Φ^4 Hybrid-Matrix-Model*, arXiv:2304.10364[hep-th].

R. M. Adin, A. Berenstein, J. Greenstein, J.-R. Li, A. Marmor, Y. Roichman, *Transitive and Gallai colorings*, https://arxiv.org/abs/2309.11203arXiv:2309.11203[math.CO].

A. Berenstein, J. Greenstein, J.-R. Li, *Hecke monoids and their homomorphisms*, in preparation.

JUNIOR RESEARCH FELLOWS PROGRAMME (JRF)

M. Ashwinkumar, A. Kidambi, J. M. Leedom, M. Yamazaki, *Generalized Narain Theories Decoded: Discussions on Eisenstein series, Characteristics, Orbifolds, Discriminants and Ensembles in any Dimension*, arXiv:2311.00699[hep-th].

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

J. Fuchs, Ch. Schweigert, S. Wood, Y. Yang, *Algebraic structures in two-dimensional conformal field theory*, arXiv:2305.02773[math.QA].

S. Gómez, A. Jüngel, and I. Perugia. *Structure-preserving Local Discontinuous Galerkin method for cross-diffusion systems: a time stepping approach*, in preparation, 2023.

S. Gómez, A. Moiola, I. Perugia, P. Stocker, *On polynomial Trefftz spaces for the linear time-dependent Schrödinger equation*, arXiv:2306.09571[math.NA].

S. Gómez, L. Mascotto, I. Perugia, *Design and performance of a space-time virtual element method for the heat equation on prismatic meshes*, arXiv:2306.09191[math.NA].

K. Kumar, H. Steinacker, *Modified Einstein equations from the 1-loop effective action of the IKKT model*, arXiv:2312.01317[hep-th].

Carlos I. Pérez-Sánchez, *The Spectral Action on quivers*, arXiv:2401.03705[math.RT].

C. Tresca, P. M. Forcella, A. Angeletti, L. Ranalli, C. Franchini, M. Reticcioli, G. Profeta, *Evidence of Molecular Hydrogen in the N-doped LuH_3 System: a Possible Path to Superconductivity?*, arXiv:2308.03619[cond-mat.supr-con].

ESI research in previous years: additional publications and arXiv preprints

The following papers and publications complement the ESI preprints already taken into account in the previous years.

SLE11 = Qualitative and numerical aspects of water waves and other interface problems, 2011
LCW19 = Quantum Simulation - from Theory to Application, 2019
MKS21 = Memory Effects in Dynamical Processes: Theory and Computational Implementation, 2021
URF22 = Special Research Fellow Programme, 2022
BGL22 = Spectral Theory of Differential Operators in QT, 2022
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).

T. Kano, *Tunamis on a deep open sea and on a gentle sloping beach*, unpublished preprint, (SLE11).

A. Michelangeli, *On creating new essential spectrum by self-adjoint extension of gapped operators*, arXiv:2304.02579 [math.SP], (BGL22).

N. Mohseni, C. Navarrete-Benlloch, T. Byrnes, F. Marquardt, *Deep recurrent networks predicting the gap evolution in adiabatic quantum computing*, arXiv:2109.08492[quant-ph], (LCW19).

A. Nadtochiy, O. K. Suwal, D.-S. Kim, O. Korotchenkov, *Revealing CdSe quantum dots plasmonics confined in Au nanotrenches by thermoacoustic spectroscopy*, in: ACS Applied Optical Materials 1, 12721280 (2023), (URF22).

A. B. Nadtochiy, A. M. Gorb, B. M. Gorelov, O. I. Polovina, O. Korotchenkov, V. Schlosser, *Model approach to thermal conductivity in hybrid graphene-polymer nanocomposites*, in: Molecules 28, 7343 (2023), (URF22).

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 2023

753 scientists have visited the ESI in 2023.

The gender distribution is as follows:
male: 570
female: 126
prefer not to disclose: 14
non-binary: 5
unspecified: 38

Affiliation by country:
AUS, Australia: 2
AUT, Austria: 227
BEL, Belgium: 3
BRA, Brazil: 3
BGR, Bulgaria: 1
CAN, Canada: 13
CHL, Chile: 3
CHN, China: 11
HRV, Croatia: 1
CZE, Czech Republic: 10
DNK, Denmark: 3
FIN, Finland: 4
FRA, France: 70
DEU, Germany: 108
GRC, Greece: 4
HKG, Hong Kong: 1
HUN, Hungary: 3
IND, India: 7
IRL, Ireland: 7
ISR, Israel: 10
ITA, Italy: 57
JPN, Japan: 19
KOR, Korea (Republic of): 7
LUX, Luxembourg: 2
MEX, Mexico: 2
MNE, Montenegro: 1
NLD, Netherlands: 13
NZL, New Zealand: 1
NIU, Niue: 5

NOR, Norway: 4
POL, Poland: 8
PRT, Portugal: 1
QAT, Qatar: 2
ROU, Romania: 2
SAU, Saudi Arabia: 1
SRB, Serbia: 1
SVK, Slovakia: 2
SVN, Slovenia: 2
ZAF, South Africa: 1
ESP, Spain: 23
SWE, Sweden: 19
CHE, Switzerland: 33
TWN, Taiwan: 1
TUR, Turkey: 2
UKR, Ukraine: 2
GBR, United Kingdom of Great Britain and Northern Ireland: 71
USA, United States of America: 128

The following codes indicate the association of visitors with specific ESI activities:
BGW23 = Non-commutative Geometry meets Topological Recursion
CKM23 = Non-regular Spacetime Geometry
CLE23 = Geometric and Asymptotic Group Theory with Applications 2023 - Groups and Dynamics
CSZ23 = Spectral Theory and Mathematical Relativity
DMS23 = New perspective on Shape and Topology Optimization
EHC23 = Mathematical Relativity: Past, Present, Future
ESI@3023 = ESI@30
GLM23 = Analysis and Geometry in Several Complex Variables
HKS23 = Large-N Matrix Models and Emergent Geometry
IMO23 = IMO Training 2023
JRF23 = Junior Research Fellow
IPT23 = Geometry beyond Riemann: Curvature and Rigidity
IS23 = Individual Visiting Scientist
MA23 = Between Regularity and Defects: Variational and Geometrical Methods in Materials Science
PDC23 = The Dynamics of Planetary-scale Fluid Flows
RHI23 = Blackbody Radiation Induced Effects and Phenomena
RIT23 = Research in Teams Fellow
SPH23 = Quantum Field Theory at the Frontiers of the Strong Interaction
URF23 = Ukranian Research Fellow

Ablondi Antoine, ENS de Lyon; 2023-09-11 - 2023-11-06, IPT23
A'Campo Norbert, U of Basel; 2023-10-16 - 2023-10-24, IPT23
A'Campo-Neuen Annette, U of Basel; 2023-10-18 - 2023-10-24, IPT23
Afandi Adam, U Münster; 2023-04-24 - 2023-04-28, BGW23
Agrenius Thomas, U of Innsbruck; 2023-02-12 - 2023-02-17, RHI23
Aichelburg Peter C., U of Vienna; 2023-06-12 - 2023-07-27, CSZ23; 2023-09-18 - 2023-09-22, IPT23;

2023-12-04 - 2023-12-07, EHC23
Aikyn Alisher, KAUST, Thuwal; 2023-10-15 - 2023-10-21, IPT23
Alattar Mohammad, Durham U; 2023-09-17 - 2023-09-23, IPT23
Alipour-Fard Samuel, MIT, Cambridge; 2023-08-20 - 2023-09-01, SPH23
Allen Brian, CUNY; 2023-03-12 - 2023-03-19, CKM23
Almi Stefano, U Napoli; 2023-02-19 - 2023-02-25, MA23; 2023-12-10 - 2023-12-15, DMS23
Amar Selim, Stanford U; 2023-06-17 - 2023-07-14, CSZ23
Amini Omid, école Polytechnique, Palaiseau; 2023-04-23 - 2023-04-28, BGW23
Amstutz Samuel, Avignon U; 2023-12-10 - 2023-12-16, DMS23
Anagnostopoulos Konstantinos, National and Technical U of Athens; 2023-09-04 - 2023-09-08, HKS23
Andrade e Silva Rodrigo, U of Maryland; 2023-12-03 - 2023-12-09, EHC23
Andréasson Håkan, Chalmers U of Technology, Gothenburg; 2023-06-11 - 2023-06-21, CSZ23
Arnold Douglas, U of Minnesota; 2023-11-08 - 2023-11-12, ESI@3023
Asano Yuhma, U of Tsukuba; 2023-09-03 - 2023-09-09, HKS23
Aster Benjamin, AKADGYM Salzburg; 2023-06-25 - 2023-06-30, 2023-10-27 - 2023-10-31, IMO23
Babadjian Jean-Francois, Paris-Saclay U; 2023-02-20 - 2023-02-24, MA23
Bach Annika, TU Eindhoven; 2023-12-10 - 2023-12-14, DMS23
Banerjee Rudrajit, Okinawa IST; 2023-07-16 - 2023-07-23, CSZ23
Bär Christian, U of Potsdam; 2023-07-09 - 2023-07-22, CSZ23
Barchiesi Marco, U Trieste; 2023-02-20 - 2023-02-25, MA23
Barnett Stephen, U of Glasgow; 2023-02-12 - 2023-02-17, RHI23
Barrett John, U of Nottingham; 2023-04-20 - 2023-05-04, BGW23
Baskin Dean, TAMU, College Station; 2023-07-09 - 2023-07-21, CSZ23
Baumann Phillip, TU of Vienna; 2023-12-11 - 2023-12-15, DMS23
Becher Thomas, U Bern; 2023-08-14 - 2023-08-25, SPH23
Beig Robert, U of Vienna; 2023-12-04 - 2023-12-07, EHC23
Beil Charlie, U of Graz; 2023-03-12 - 2023-03-18, CKM23
Bell Guido, U of Siegen; 2023-08-27 - 2023-09-01, SPH23
Ben-Artzi Matania, HU of Jerusalem; 2023-05-05 - 2023-05-26, PDC23
Benatti Luca, U Pisa; 2023-12-03 - 2023-12-07, EHC23
Beneke Martin, TU Munich; 2023-07-30 - 2023-08-09, SPH23
Beneová Barbora, Charles U, Prague; 2023-02-19 - 2023-02-24, MA23
Benitez-Rathgeb Miguel, USAL; 2023-07-31 - 2023-08-20, SPH23
Beran Tobias, U of Vienna; 2023-03-13 - 2023-03-24, CKM23; 2023-09-18 - 2023-09-29, IPT23
Berchio Elvise, Politecnico, Torino; 2023-12-10 - 2023-12-13, DMS23
Berenstein Arkadiy, U of Oregon, Eugene; 2023-06-12 - 2023-07-03, 2023-07-03 - 2023-10-01, RIT23
Berenstein David, UC, Santa Barbara; 2023-09-03 - 2023-09-08, HKS23
Berhanu Shiferaw, U of Maryland; 2023-11-19 - 2023-11-25, GLM23
Berkenhoff Gerfried, HTBLA Salzburg; 2023-10-27 - 2023-10-31, IMO23
Bernard Patrick, U Paris-Dauphine; 2023-03-11 - 2023-03-20, CKM23
Bernig Andreas, Goethe U Frankfurt; 2023-09-09 - 2023-10-01, IPT23
Bernklau Silvan, U of Jena; 2023-09-17 - 2023-09-22, IPT23
Beron-Vera Francisco Javier, U Miami; 2023-04-26 - 2023-05-03, PDC23
Bertazzoni Giacomo, U Modena; 2023-02-19 - 2023-02-24, MA23; 2023-12-10 - 2023-12-15, DMS23
Besson Gérard, U de Grenoble; 2023-10-15 - 2023-10-21, IPT23
Beverungen Bettina, HU Berlin; 2023-02-12 - 2023-02-17, RHI23
Biard Severine, UPHF; 2023-11-19 - 2023-11-24, GLM23
Biasi Anxo, ENS Paris; 2023-06-21 - 2023-06-23, CSZ23
Bierbaumer Martin, HTL3R, Vienna; 2023-06-26 - 2023-06-30, 2023-10-27 - 2023-10-28, IMO23

Bleak Collin, U of St Andrews; 2023-07-15 - 2023-07-20, CLE23
Bodart Corentin, UNIGE, Geneve; 2023-07-16 - 2023-07-22, CLE23
Böer Philipp, U Mainz; 2023-08-27 - 2023-09-01, SPH23
Boito Diogo, USP; 2023-07-22 - 2023-08-06, SPH23
Bolsinov Alexey, Loughborough U; 2023-09-10 - 2023-09-17, IPT23
Bonella Sara, EPFL, Lausanne; 2023-03-04 - 2023-03-08, L012023
Bonhomme Elise, U Paris Sud, Orsay; 2023-12-10 - 2023-12-15, DMS23
Bonk Andras, U of Vienna; 2023-06-19 - 2023-07-28, CSZ23
Bonsante Francesco, U Pavia; 2023-10-15 - 2023-10-20, IPT23
Bonzom Valentin, U Paris-Nord; 2023-04-23 - 2023-04-28, BGW23
Borghini Stefano, U Trient; 2023-12-03 - 2023-12-07, EHC23
Borot Gatan, HU Berlin; 2023-04-25 - 2023-04-28, BGW23
Bot Radu Ioan, U of Vienna; 2023-11-09 - 2023-11-10, ESI@3023
Bo Cassandra, BRG1; 2023-10-27 - 2023-10-31, IMO23
Boughezal Radja, Argonne National Laboratory; 2023-08-06 - 2023-08-19, SPH23
Bozzola Francesco, U of Parma; 2023-02-19 - 2023-02-25, MA23
Bradford Henry, U of Cambridge; 2023-07-16 - 2023-07-23, CLE23
Brahma Suddhasattwa, U of Edinburgh; 2023-09-03 - 2023-09-09, HKS23
Brandenberger Robert, McGill U; 2023-09-06 - 2023-09-10, HKS23
Branding Volker, U of Vienna; 2023-12-04 - 2023-12-07, EHC23
Braun Mathias, U Toronto; 2023-03-12 - 2023-03-25, CKM23
Brazda Katharina, U of Vienna; 2023-02-20 - 2023-02-24, MA23
Bresciani Marco, FAU Erlangen-Nürnberg; 2022-02-20 - 2022-02-24, MA23
Bressan Alberto, Penn State U; 2023-11-09 - 2023-11-11, ESI@3023
Bris Alejandro, U Autonoma de Madrid; 2023-07-30 - 2023-08-05, SPH23
Broggio Alessandro, U of Vienna; 2023-08-07 - 2023-09-01, SPH23
Bronstein Samuel, ENS Paris; 2023-09-13 - 2023-09-22, 2023-10-15 - 2023-10-21, IPT23
Bruin Henk, U of Vienna; 2023-04-11 - 2023-04-21, 2023-06-05 - 2023-06-16, RIT0223
Brüser Robin, ALU Freiburg; 2023-07-30 - 2023-08-11, SPH23
Buccheri Stefano, U of Vienna; 2023-12-11 - 2023-12-15, DMS23
Buc-d'Alche Thomas, UMPA ENS Lyon; 2023-04-23 - 2023-04-28, BGW23
Bunney Cameron, U of Nottingham; 2023-02-12 - 2023-02-17, RHI23
Buoso Davide, UEP, Amedeo Avogadro; 2023-12-10 - 2023-12-15, DMS23
Burde Dietrich, U of Vienna; 2023-03-24 - 2023-03-31, IS23
Buric Maja, Belgrade U; 2023-09-03 - 2023-09-09, HKS23
Buttazzo Giuseppe, U Pisa; 2023-12-10 - 2023-12-15, DMS23
Bychkov Boris, Haifa U.; 2023-04-23 - 2023-04-28, BGW23
Calisti Matteo, U of Vienna; 2023-03-13 - 2023-03-24, CKM23
Callegari Agnese, U Gothenburg; 2023-03-05 - 2023-03-25, 2023-05-20 - 2023-05-27, 2023-07-28 - 2023-08-31, RIT0123
Cameron Peter, U of Edinburgh; 2023-03-12 - 2023-03-24, CKM23
Campbell Daniel, Charles U, Prague; 2023-02-19 - 2023-02-25, MA23
Caponi Maicol, U Napoli; 2023-02-19 - 2023-02-24, MA23
Carrance Ariane, école Polytechnique, Palaiseau; 2023-04-23 - 2023-04-29, BGW23
Carretero Palacios Sol, U Autonoma de Madrid; 2023-02-12 - 2023-02-16, RHI23
Carton Xavier, U Brest; 2023-05-21 - 2023-05-25, PDC23
Casado Javier, U Autonoma de Madrid; 2023-09-17 - 2023-09-22, IPT23
Cashen Christopher, U of Vienna; 2023-07-06 - 2023-08-04, RIT23; 2023-07-17 - 2023-07-21, CLE23; 2023-09-18 - 2023-09-22, IPT23

Cavalieri Renzo, CSU, Fort Collins; 2023-04-23 - 2023-04-26, BGW23
Cavalletti Fabio, SISSA, Trieste; 2023-03-12 - 2023-03-17, CKM23
Cavallucci Nicola, EPFL, Lausanne; 2023-09-17 - 2023-09-22, IPT23
Celestino Rodriguez Adrian, TU Graz; 2023-04-23 - 2023-04-28, BGW23
Cerbino Roberto, U of Vienna; 2023-03-05 - 2023-08-06, 2023-08-24 - 2023-08-31, RIT23
Cesarano Alessio, RICAM, Linz; 2023-12-13 - 2023-12-13, DMS23
Charbonnier Séverin, U Genève; 2023-04-24 - 2023-04-27, BGW23
Charitos Charalampos, Agricultural U of Athens; 2023-09-17 - 2023-09-30, IPT23
Chavan Anand, Jagiellonian U, Krakow; 2023-11-19 - 2023-11-25, GLM23
Cherrière Théodore, RICAM, Linz; 2023-12-13 - 2023-12-13, DMS23
Chidambaram Nitin, U of Edinburgh; 2023-04-23 - 2023-04-28, BGW23
Chien Yang-Ting, Georgia State U; 2023-08-21 - 2023-08-26, SPH23
Chiesa Andrea, U of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Chiodo Alessandro, Sorbonne U, Paris; 2023-04-23 - 2023-04-29, BGW23
Choudhuri Debajyoti, NIT Rourkela; 2023-02-20 - 2023-02-24, MA23
Christiansen Tanya, U of Missouri, Columbia; 2023-07-09 - 2023-07-15, CSZ23
Chruściel Piotr T., U of Vienna; 2023-06-05 - 2023-07-05, CSZ23; 2023-03-13 - 2023-03-24, CKM23; 2023-12-04 - 2023-12-07, EHC23; 2023-09-11 - 2023-11-03, IPT23
Cicalese Marco, TU Munich; 2023-02-19 - 2023-02-24, MA23
Cogo Albachiara, U Tübingen; 2023-12-03 - 2023-12-08, EHC23
Collins Benoit, Kyoto U; 2023-04-25 - 2023-04-28, BGW23
Cong Wan, U of Vienna; 2023-06-19 - 2023-07-27, CSZ23
Constantin Adrian, U of Vienna; 2023-04-11 - 2023-06-02, PDC23; 2023-11-09 - 2023-11-09, ESI@3023
Copeland Marston, Duke U; 2023-08-20 - 2023-09-01, SPH23
Corbett Tyler, U of Vienna; 2023-07-31 - 2023-09-01, SPH23
Cordes Matt, ETH Zurich; 2023-07-16 - 2023-07-22, CLE23
Coulon Rémi, UB; 2023-07-16 - 2023-07-22, CLE23
Croisille Jean-Pierre, U Lorraine; 2023-05-07 - 2023-05-27, PDC23
Cuerno Manuel, U Autonoma de Madrid; 2023-09-17 - 2023-09-22, IPT23
Curry Sean, OSU; 2023-11-19 - 2023-11-25, GLM23
Czimek Stefan, U Leipzig; 2023-07-09 - 2023-07-15, CSZ23; 2023-12-03 - 2023-12-08, EHC23
Dahl Mattias, KTH Stockholm; 2023-12-02 - 2023-12-10, EHC23
Dall'Ara Gian Maria, INDAM and SNS (Pisa); 2023-11-19 - 2023-11-24, GLM23
Dambrine Marc, U of Pau; 2023-12-10 - 2023-12-14, DMS23
Damialis Apostolos, EMS Berlin; 2023-11-08 - 2023-11-10, ESI@3023
Dampfhofer Simon, U of Graz; 2023-08-21 - 2023-08-25, SPH23
D'Angelo John P., U Illinois; 2023-11-18 - 2023-11-25, GLM23
Dani Pallavi, LSU; 2023-07-04 - 2023-08-04, RIT23
Dani Shrikrishna Gopalrao, U of Mubmai; 2023-07-04 - 2023-08-03, IS23
Danielson Daine, U of Chicago; 2023-06-03 - 2023-07-22, CSZ23
Dapogny Charles, U Grenoble Alpes; 2023-12-10 - 2023-12-15, DMS23
Dappiaggi Claudio, U Pavia; 2023-07-02 - 2023-07-14, CSZ23
Darbinyan Arman, U of Vienna; 2023-07-17 - 2023-07-22, CLE23
Das Sumit Ranjan, U Kentucky; 2023-09-03 - 2023-09-08, HKS23
Dasgupta Mrinal, U Manchester; 2023-08-20 - 2023-08-25, SPH23
Da Silva Jr Antonio Victor, Texas A&M U at Qatar; 2023-11-19 - 2023-11-25, GLM23
Davoli Elisa, TU of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Dehnadi Bahman, DESY Hamburg; 2023-07-30 - 2023-08-21, SPH23
Dekimpe Karel, KU Leuven; 2023-03-23 - 2023-03-31, IS23

de la Nuez González Javier, KIAS, Seoul; 2023-07-16 - 2023-07-22, CLE23
Delay Erwann, Avignon U; 2023-12-03 - 2023-12-08, EHC23
De-Leon Yair, HU of Jerusalem; 2023-05-21 - 2023-05-25, PDC23
D'Elia Lorenza, TU of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Delic Uros, U of Vienna; 2023-02-13 - 2023-02-17, RHI23
Dellago Christoph, U of Vienna; 2023-11-09 - 2023-11-11, ESI@3023
Derridj Makhlouf, U de Rouen; 2023-11-18 - 2023-11-25, GLM23
Deutsch Jakob, TU Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Dewar William, Florida State U, Tallahassee; 2023-05-14 - 2023-05-27, PDC23
Diaf Farid, U Grenoble Alpes; 2023-09-17 - 2023-09-23, IPT23
Diehl Markus, DESY Hamburg; 2023-08-12 - 2023-08-26, SPH23
Di Rocco Sandra, KTH Stockholm; 2023-11-10 - 2023-11-12, ESI@3023
Dolealová Anna, Charles U, Prague; 2023-02-19 - 2023-02-24, MA23
Doll Moritz, U Melbourne; 2023-06-19 - 2023-06-23, 2023-07-03 - 2023-07-27, CSZ23
Donninger Roland, U of Vienna; 2023-06-05 - 2023-07-11, CSZ23; 2023-12-04 - 2023-12-07, EHC23
Dor-On Adam, Haifa U.; 2023-07-16 - 2023-07-22, CLE23
Dorsaz Abraham, EPFL, Lausanne; 2023-09-17 - 2023-09-22, IPT23
Dritschel David, U of St Andrews; 2023-05-14 - 2023-06-04, PDC23
Durrer Ruth, UNIGE, Geneve; 2023-02-15 - 2023-02-18, RHI23
Dyatlov Semyon, MIT, Cambridge; 2023-07-09 - 2023-07-15, CSZ23
Ebenfelt Peter, UC San Diego; 2023-11-20 - 2023-11-25, GLM23
Ebrahimi-Fard Kurusch, NTNU, Trondheim; 2023-04-23 - 2023-04-28, BGW23
Ecker Gerhard, U of Vienna; 2023-07-31 - 2023-09-01, SPH23
Edholm Luke, U of Vienna; 2023-11-20 - 2023-11-24, GLM23
Edletzberger Alexandra, U of Vienna; 2023-07-17 - 2023-07-21, CLE23
Eichmair Michael, U of Vienna; 2023-07-14 - 2023-07-14, CSZ23; 2023-11-09 - 2023-11-10, ESI@3023; 2023-12-04 - 2023-12-07, EHC23
Eisenkölbl Theresia, U of Vienna; 2023-10-27 - 2023-10-31, 2023-06-26 - 2023-06-30, IMO23
Emmanuele Battista, U of Vienna; 2023-09-04 - 2023-09-08, HKS23
Engl Heinz W., U of Vienna; 2023-11-09 - 2023-11-10, ESI@3023
Erdmenger Johanna, U Würzburg; 2023-09-04 - 2023-09-09, HKS23
Esteso Carrizo Victoria, LENS, Firenze; 2023-02-12 - 2023-02-17, RHI23
Faifman Dmitry, Tel Aviv U; 2023-10-15 - 2023-10-21, IPT23
Fajman David, U of Vienna; 2023-06-05 - 2023-07-28, CSZ23; 2023-03-13 - 2023-03-24, CKM23; 2023-12-04 - 2023-12-07, EHC23
Fang Allen Juntao, Princeton U; 2023-06-18 - 2023-07-15, CSZ23
Farnham Darien, U Virginia; 2023-07-14 - 2023-07-24, CLE23
Fathi Albert, GATECH, Atlanta; 2023-03-19 - 2023-03-25, CKM23
Fedorynski Pawel, U of Hawaii, Honolulu; 2023-07-16 - 2023-07-22, CLE23
Fein Yaakov, U of Vienna; 2023-02-13 - 2023-02-17, RHI23
Ferdinand Anna, MIT, Cambridge; 2023-08-06 - 2023-08-19, SPH23
Fermanian Kammerer Clotilde, UPEC; 2023-06-04 - 2023-06-17, CSZ23
Fernandes Raphael, U Leicester; 2023-12-09 - 2023-12-16, DMS23
Fernós Talia, UNCG; 2023-07-15 - 2023-07-21, CLE23
Fewster Christopher, U of York; 2023-03-15 - 2023-03-18, CKM23
Ficek Filip, U of Vienna; 2023-03-13 - 2023-03-24, CKM23; 2023-06-05 - 2023-07-28, CSZ23; 2023-12-04 - 2023-12-07, EHC23
Fields Sydney, U of Hawaii, Honolulu; 2023-07-15 - 2023-07-23, CLE23
Filev Veselin, BAS, Sofia; 2023-09-03 - 2023-09-09, HKS23

Fillastre Francois, U Montpellier; 2023-09-10 - 2023-11-04, IPT23
Finster Felix, U Regensburg; 2023-03-12 - 2023-03-18, CKM23
Fischer Arthur, UC Santa Cruz; 2023-12-01 - 2023-12-12, EHC23
Flores Jose Luis, U Malaga; 2023-03-12 - 2023-03-19, CKM23
Fonseca Irene, Carnegie Mellon U, Pittsburgh; 2023-11-08 - 2023-11-11, ESI@3023
Forshaw Jeffrey, U Manchester; 2023-08-14 - 2023-08-25, SPH23
Forstneric Franc, U Ljubljana; 2023-11-19 - 2023-11-25, GLM23
Fougeron Charles, CNRS, Paris; 2023-04-09 - 2023-04-22, 2023-06-05 - 2023-06-17, RIT23
Fournier-Facio Franceso, ETH Zurich; 2023-07-17 - 2023-07-22, CLE23
Fournodavlos Grigorios, U of Crete; 2023-12-03 - 2023-12-07, EHC23
Franca Santiago Omar Jess, U Kassel; 2023-02-12 - 2023-02-17, RHI23
Fredenhagen Stefan, U of Vienna; 2023-11-09 - 2023-11-11, ESI@3023
Frenkel Alexander, Stanford U; 2023-09-03 - 2023-09-09, HKS23
Freund Valerie, U Leipzig; 2023-09-17 - 2023-09-23, IPT23
Friedrich Manuel, FAU Erlangen-Nürnberg; 2023-02-19 - 2023-02-25, MA23
Fritz Christoph, UBO; 2023-09-18 - 2023-09-22, IPT23; 2023-12-04 - 2023-12-07, EHC23
Froufe-Pérez Luis, U of Fribourg; 2023-02-13 - 2023-02-16, RHI23
Fürdös Stefan, U of Vienna; 2023-11-20 - 2023-11-24, GLM23
Gaaloul Naceur, Leibniz U; 2023-02-13 - 2023-02-18, RHI23
Galanda Stefano, U Genova; 2023-06-19 - 2023-06-23, CSZ23
Galanopoulou Myrto, Heriot-Watt U, Edinburgh; 2023-02-19 - 2023-02-24, MA23
Gallagher Anne-Katrin, GTI; 2023-11-16 - 2023-11-24, GLM23
Gallagher Isabelle, ENS Paris; 2023-11-07 - 2023-11-11, ESI@3023
Gálvez Carrillo Maria Immaculada, UPC, Barcelona; 2023-04-23 - 2023-05-01, BGW23
Gangl Peter, RICAM, Linz; 2023-12-11 - 2023-12-15, DMS23
Ganguly Soumya, UC San Diego; 2023-11-19 - 2023-11-25, GLM23
Gao Anjie, MIT, Cambridge; 2023-08-06 - 2023-08-20, SPH23
Garcia Jacob, UC Riverside; 2023-07-16 - 2023-07-23, CLE23
Garcia Failde Elba, Sorbonne U, Paris; 2023-04-21 - 2023-04-28, BGW23
Garca-Heveling Leonardo, Radboud U; 2023-03-13 - 2023-03-24, CKM23
Garca Zelada David, Sorbonne U, Paris; 2023-04-23 - 2023-04-29, BGW23
Gardi Einan, U of Edinburgh; 2023-08-12 - 2023-08-26, SPH23
Gaunt Jonathan, U Manchester; 2023-08-06 - 2023-08-19, SPH23
Gavioli Chiara, TU of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Gehrmann Thomas, U Zurich; 2023-08-20 - 2023-08-26, SPH23
Gehrmann-De Ridder Aude, ETH Zurich; 2023-08-21 - 2023-08-25, SPH23
Gekhtman Ilya, Technion Haifa; 2023-07-16 - 2023-07-22, CLE23
Germain Pierre, Imperial College London; 2023-04-12 - 2023-05-30, PDC23; 2023-11-09 - 2023-11-11, ESI@3023
Ghira Andrea, UNIGE & INFN; 2023-07-30 - 2023-08-03, SPH23
Ghomi Mohammad, GATECH, Atlanta; 2023-09-17 - 2023-09-23, IPT23
Gigli Nicola, SISSA, Trieste; 2023-03-12 - 2023-03-17, CKM23
Giorgio Rossella, TU of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Giulini Domenico, Leibniz U; 2023-11-08 - 2023-11-12, ESI@3023
Glaser L, U of Vienna; 2023-04-24 - 2023-04-28, BGW23
Glatz Valentin, BG/BRG Graz; 2023-10-27 - 2023-10-31, 2023-06-25 - 2023-06-30, IMO23
Glöckle Jonathan, U Regensburg; 2023-06-04 - 2023-07-01, CSZ23
Goliski Tomasz, U of Biaystok; 2023-09-05 - 2023-09-22, IPT23
Gómez Macas Sergio Alejandro, U Pavia; 2023-03-13 - 2023-09-13, JRF23

González Brantes Juan Manuel, Pontificial Catholic U of Chile; 2023-07-05 - 2023-07-10, CSZ23
Gorny Wojciech, U of Vienna; 2023-02-20 - 2023-02-24, MA23
Graf Melanie, U Hamburg; 2023-03-13 - 2023-03-24, CKM23; 2023-12-04 - 2023-12-07, EHC23
Grant James D. E., U Surrey; 2023-03-13 - 2023-03-24, CKM23
Gray Finnian, U of Vienna; 2023-03-13 - 2023-03-20, CKM23; 2023-06-19 - 2023-07-21, CSZ23; 2023-12-04 - 2023-12-07, EHC23
Greenstein Jacob, UC Riverside; 2023-06-15 - 2023-08-04, RIT23
Greffet Jean-Jacques, IOGS, U Paris-Saclay; 2023-02-12 - 2023-02-19, RHI23
Grosse Harald, U of Vienna; 2023-04-24 - 2023-04-28, BGW23; 2023-04-13 - 2023-07-31, RIT23; 2023-09-05 - 2023-09-08, HKS23
Gudapati Nishanth, Clark U, Worcester; 2023-12-03 - 2023-12-10, EHC23
Guéritaud Franois, U Strasbourg; 2023-09-18 - 2023-11-06, IPT23
Guillarmou Colin, U Paris-Saclay; 2023-07-09 - 2023-07-21, CSZ23
Gupta Purvi, IIS Bengalore; 2023-11-19 - 2023-11-26, GLM23
Guzzi Marco, KSU; 2023-07-31 - 2023-08-05, SPH23
Häfner Dietrich, U Grenoble Alpes; 2023-06-18 - 2023-07-28, CSZ23
Hahn Marvin Anas, Trinity College, Dublin; 2023-04-24 - 2023-04-28, BGW23
Hamano Sachiko, Kyoto Sangyo U; 2023-09-11 - 2023-09-18, IPT23
Hametner Paul, HS Linz; 2023-06-25 - 2023-06-30, IMO23
Hanada Masanori, QMU London; 2023-09-03 - 2023-09-08, HKS23
Hannesdottir Hofie, IAS, Princeton; 2023-08-13 - 2023-08-18, SPH23
Happ Leon, TU Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Harengel Katharina, U Münster; 2023-04-23 - 2023-04-29, BGW23
Harris Stacey, Saint Louis U; 2023-03-12 - 2023-03-24, CKM23
Harvey John, Cardiff U; 2023-03-21 - 2023-03-25, CKM23
Harz Tobias, BUW; 2023-11-19 - 2023-11-25, GLM23
Haslinger Friedrich, U of Vienna; 2023-11-20 - 2023-11-24, GLM23
Haslinger Philipp, TU of Vienna; 2023-02-13 - 2023-02-16, RHI23
Hegyvári Norbert, MTA RENYI; 2023-11-09 - 2023-11-10, ESI@3023
Heikkilä Susanna, U Helsinki; 2023-02-19 - 2023-02-25, MA23
Heilmann Tim, TU Munich; 2023-02-19 - 2023-02-25, MA23
Heinricher Fabian, BG/BRG Lienz; 2023-06-25 - 2023-06-30, 2023-10-27 - 2024-01-31, IMO23
Hencl Stanislav, Charles U, Prague; 2022-02-19 - 2022-02-24, MA23
Henkel Carsten, U of Potsdam; 2023-02-12 - 2023-02-17, RHI23
Herfort Wolfgang, TU of Vienna; 2023-07-18 - 2023-07-18, CLE23
Herrera Jonatan, U of Cordoba; 2023-03-13 - 2023-03-17, CKM23
Heuchl Raphael, BG Oberschützen; 2023-06-25 - 2023-06-30, 2023-10-27 - 2023-10-31, IMO23
Hiebler Moritz, AAU, Klagenfurt; 2023-10-27 - 2023-10-31, 2023-06-25 - 2023-06-30, IMO23
Hintz Peter, ETH Zurich; 2023-06-25 - 2023-07-13, CSZ23; 2023-12-06 - 2023-12-08, EHC23
Hirsch Sven, IAS, Princeton; 2023-12-03 - 2023-12-08, EHC23
Hitchin Nigel, U Oxford; 2023-11-07 - 2023-11-10, ESI@3023
Hoang André H., U of Vienna; 2023-07-31 - 2023-09-01, SPH23
Hock Alexander, U Oxford; 2023-04-23 - 2023-04-28, BGW23
Hodges Reed, Duke U; 2023-08-14 - 2023-08-26, SPH23
Hoisington Joseph, MPIM, Bonn; 2023-09-15 - 2023-09-24, IPT23
Hollands Stefan, U Leipzig; 2023-07-14 - 2023-07-28, CSZ23
Holmes Daniel, ISTA, Klosterneuburg; 2023-10-27 - 2023-10-27, IMO23
Holzegel Gustav, U Münster; 2023-12-03 - 2023-12-07, EHC23
Homans Jack, U Southampton; 2023-02-12 - 2023-02-17, RHI23

Hood Gemma, Imperial College London; 2023-07-09 - 2023-07-17, CSZ23
Hu Nai-Yu, U of Vienna; 2023-11-19 - 2023-11-24, GLM23
Hu Tong Tong, QMU London; 2023-12-03 - 2023-12-07, EHC23
Hu Yingxiang, TU of Vienna; 2023-09-11 - 2023-11-03, IPT23
Huang Lan-Hsuan, U Conn; 2023-12-03 - 2023-12-09, EHC23
Huang Yi, YMCS; 2023-09-11 - 2023-09-18, IPT23
Huber Albert, UAS; 2023-03-13 - 2023-03-17, CKM23; 2023-07-10 - 2023-07-14, CSZ23
Huisken Gerhard, U Tübingen; 2023-12-03 - 2023-12-07, EHC23; 2023-11-09 - 2023-11-12, ESI@3023
Hutchcroft Tom, CalTech; 2023-07-16 - 2023-07-23, CLE23
Hutter Anne, U of Copenhagen; 2023-02-12 - 2023-02-17, RHI23
Hyde James, U of Copenhagen; 2023-07-16 - 2023-07-21, CLE23
Incerti-Medici Merlin, U of Vienna; 2023-07-17 - 2023-07-21, CLE23
Inoue Rei, U Chiba; 2023-04-23 - 2023-04-29, BGW23
Intravaia Francesco, HU Berlin; 2023-02-12 - 2023-02-17, RHI23
Ionescu-Kruse Delia, IMAR, Bucharest; 2023-05-09 - 2023-05-19, PDC23
Irmer Ingrid, SUSTech, Shenzhen; 2023-10-15 - 2023-10-21, IPT23
Isakovi Ana, U of Cambridge; 2023-07-17 - 2023-07-21, CLE23
Iseppi Roberta Anna, Georg-August-U, Göttingen; 2023-04-22 - 2023-04-30, BGW23
Islam Onirban, U of Potsdam; 2023-06-24 - 2023-07-15, CSZ23 + JRF23
Iurlano Flaviana, CNRS, Paris; 2023-02-21 - 2023-02-24, MA23
Ivaki Mohammad, TU of Vienna; 2023-09-11 - 2023-11-03, IPT23
Ivanov Rossen I., TU Dublin; 2023-05-11 - 2023-05-26, PDC23
Ivanovici Oana, Sorbonne U, Paris; 2023-06-18 - 2023-06-23, CSZ23
Izeki Hiroyasu, Keio U; 2023-10-15 - 2023-10-21, IPT23
Izmestiev Ivan, TU Vienna; 2023-09-11 - 2023-11-04, IPT23; 2023-10-26 - 2023-10-31, 2023-06-26 - 2023-06-29, IMO23
Jaarsma Max, U of Amsterdam; 2023-08-06 - 2023-08-11, SPH23
Jacobowitz Howard, Rutgers U; 2023-11-16 - 2023-11-27, GLM23
Jakubec Clemens, U of Vienna; 2023-02-13 - 2023-02-17, RHI23
Jamin Matthias, U Heidelberg; 2023-07-30 - 2023-08-12, SPH23
Jaramillo Jose-Luis, UB; 2023-06-26 - 2023-06-30, CSZ23
Jarzynski Christopher, U of Maryland; 2023-11-08 - 2023-11-10, ESI@3023
Jaskiewicz Sebastian, Durham U; 2023-07-31 - 2023-08-11, SPH23
Javaloyes Victoria Miguel ángel, U Murcia; 2023-03-11 - 2023-03-18, CKM23
Jenkins Elizabeth, UC San Diego; 2023-08-13 - 2023-08-24, SPH23
Jevicki Antal, Brown U, Providence; 2023-09-04 - 2023-09-08, HKS23
Johne Florian, Columbia U, New York; 2023-07-04 - 2023-07-04, CSZ23
Johnson Edward, U College London; 2023-05-21 - 2023-05-31, PDC23
Johnson Robin S., U Newcastle upon Tyne; 2023-04-19 - 2023-05-25, PDC23
Kadar Istvan, U of Cambridge; 2023-07-10 - 2023-07-15, CSZ23
Kahrobaei Delaram, CUNY, New York; 2023-07-16 - 2023-07-18, CLE23
Kaiser Robin, U Cte d'Azur, Nice; 2023-02-13 - 2023-02-16, RHI23
Kang Daekyoung, Fudan; 2023-07-30 - 2023-08-12, SPH23
Kanomata Naoyuki, Tokyo U of Science; 2023-05-18 - 2023-06-16, RIT23
Kapovich Ilya, CUNY, New York; 2023-07-16 - 2023-07-22, CLE23
Karadereli Şeyma, Bogazici U; 2023-02-01 - 2023-06-12, JRF23
Karczmarek Joanna, UBC; 2023-09-02 - 2023-09-09, HKS23
Karlsson Anders, UNIGE, Geneve; 2023-10-16 - 2023-10-18, IPT23
Kaser Georg, U of Innsbruck; 2023-03-07 - 2023-03-09, ESL0123

Kauffman Christopher, U Münster; 2023-07-19 - 2023-07-29, CSZ23
Kawai Hikaru, National Taiwan U; 2023-09-02 - 2023-09-08, HKS23
Kehle Christoph, ETH Zurich; 2023-07-05 - 2023-07-15, CSZ23
Kempe Julia, CIMS, New York; 2023-11-08 - 2023-11-11, ESI@3023
Keppeler Stefan, U Tübingen; 2023-08-21 - 2023-09-01, SPH23
Khalkhali Masoud, Western U, Ontario; 2023-04-23 - 2023-05-02, BGW23
Kharlampovich Olga, CUNY, New York; 2023-07-16 - 2023-07-22, CLE23
Kholmatov Shokhrukh, U of Vienna; 2023-12-11 - 2023-12-15, DMS23
Kiesel Nikolai, U of Vienna; 2023-02-13 - 2023-02-17, RHI23
Klainerman Sergiu, Princeton U; 2023-12-05 - 2023-12-07, EHC23
Klein Christiane, U Leipzig; 2023-06-19 - 2023-07-14, CSZ23
Koberda Thomas, U Virginia; 2023-07-17 - 2023-07-23, CLE23
Kohl Finn Bjarne, U Münster; 2023-04-23 - 2023-04-30, BGW23
Kontou Eleni, U of Amsterdam; 2023-03-12 - 2023-03-22, CKM23
Körber Thomas, U of Vienna; 2023-12-04 - 2023-12-07, EHC23
Korotchenkov Oleg, Kiev U; 2022-07-06 - 2022-08-06, 2022-12-10 - 2023-01-21, 2023-04-29 - 2023-06-01, URF22
Kosior Arkadiusz, U of Innsbruck; 2022-02-12 - 2022-02-17, RHI23
Koskela Pekka, JYU, Jyväskylä; 2023-02-19 - 2023-02-22, MA23
Koski Aleksis, U Helsinki; 2023-02-19 - 2023-02-24, MA23
Kossovskiy Ilya, Masaryk U, Brno; 2023-11-20 - 2023-11-24, GLM23
Kovacik Samuel, Comenius U, Bratislava; 2023-09-03 - 2023-09-08, HKS23
Krajewski Thomas, U Aix-Marseille; 2023-04-24 - 2023-04-28, BGW23
Kreisbeck Carolin, KU Eichstätt; 2023-02-19 - 2023-02-24, MA23
Kresic Ivor, TU Vienna; 2023-02-13 - 2023-02-17, RHI23
Krömer Stefan, Czech Academy of Sciences, Prague; 2023-02-19 - 2023-02-24, MA23
Kröncke Klaus, KTH Stockholm; 2023-03-13 - 2023-03-17, CKM23; 2023-12-03 - 2023-12-09, EHC23
Kruk Martin, Czech Academy of Sciences, Prague; 2023-02-19 - 2023-02-24, MA23
Kubin Andrea, TU München; 2023-02-19 - 2023-02-24, MA23
Kubin Anna, TU of Vienna; 2022-02-19 - 2022-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Kumar Kaushlendra, QMU London; 2023-03-05 - 2023-06-15, JRF23
Kunz Valentin, U Bologna; 2023-11-19 - 2023-11-25, GLM23
Kunzinger Michael, U of Vienna; 2023-03-13 - 2023-03-24, CKM23; 2023-06-05 - 2023-07-28, CSZ23; 2023-09-18 - 2023-11-03, IPT23; 2023-12-04 - 2023-12-07, EHC23
LaCasce Joe, U Oslo; 2023-05-21 - 2023-05-26, PDC23
Laliberte Samuel, McGill U; 2023-09-03 - 2023-09-09, HKS23
Lam Wai Yeung, U of Luxembourg; 2023-10-15 - 2023-10-20, IPT23
Lamel Bernhard, U of Vienna; 2023-11-20 - 2023-11-24, GLM23
Lämmerzahl Claus, ZARM, Bremen; 2023-02-12 - 2023-02-16, RHI23
Langen René, U of Bergen; 2023-09-17 - 2023-09-22, IPT23
Lanzani Loredana, U of Bologna & Syracuse U; 2023-11-18 - 2023-11-24, GLM23
Laurain Antoine, U Duisburg-Essen; 2023-12-10 - 2023-12-13, DMS23
Leal Gomez Sergio, U of Vienna; 2023-08-24 - 2023-09-01, SPH23
Leary Ian, U Southampton; 2023-07-16 - 2023-07-23, CLE23
Lechner Daniel, U of Vienna; 2023-07-31 - 2023-08-04, SPH23
Lee Jihye, UC, Santa Barbara; 2023-09-15 - 2023-09-23, IPT23
Lee Kyle, MIT, Cambridge; 2023-08-05 - 2023-08-18, SPH23
Leid Felix, U of Saarland; 2023-04-23 - 2023-04-28, BGW23
Li Jianrong, U of Vienna; 2023-06-12 - 2023-09-01, RIT23

Li Kevin, U Regensburg; 2023-07-16 - 2023-07-23, CLE23
Lieb Elliott, Princeton U; 2023-03-12 - 2023-03-18, IS23
Ligeti Zoltán, LBL, Berkeley; 2023-08-26 - 2023-09-02, SPH23
Lin Henry, Stanford U; 2023-09-04 - 2023-09-09, HKS23
Lin Zhiwu, GATECH, Atlanta; 2023-04-06 - 2023-04-24, PDC23
Lindström Adam, U of Vienna; 2023-12-04 - 2023-12-07, EHC23
Ling Eric, U of Copenhagen; 2023-03-12 - 2023-03-24, CKM23
Lionni Luca, U Heidelberg; 2023-04-23 - 2023-04-30, BGW23
Lisdat Christian, PTB, Braunschweig; 2023-02-13 - 2023-02-17, RHI23
Liu Sinong, U Warsaw; 2023-09-04 - 2023-09-10, HKS23
Liu Ze Long, CERN, Geneva; 2023-08-06 - 2023-08-11, SPH23
Lodha Yash, U of Hawaii, Honolulu; 2023-07-16 - 2023-07-28, CLE23
Löh Clara, U Regensburg; 2023-07-19 - 2023-07-21, CLE23
Lohmann Ulrike, ETH Zurich; 2023-11-09 - 2023-11-10, ESI@3023
Lombardini Luca, TU Vienna; 2023-02-20 - 2023-02-24, MA23
Longhi Rubens, U of Potsdam; 2023-07-09 - 2023-07-14, CSZ23
Looi Shi-Zhuo, CalTech; 2023-07-07 - 2023-07-23, CSZ23
Löschner Maximilian, DESY Hamburg; 2023-07-31 - 2023-08-11, SPH23
Lucardesi Ilaria, U Pisa; 2023-12-10 - 2023-12-15, DMS23
Luk Jonathan, Stanford U; 2023-07-10 - 2023-07-15, CSZ23
Luke Michael, U Toronto; 2023-08-13 - 2023-08-24, SPH23
Luo Feng, Rutgers U; 2023-09-17 - 2023-09-23, IPT23
Lyons Tony, SETU; 2023-05-15 - 2023-05-25, PDC23
Lytchak Alexander, KIT, Karlsruhe; 2023-10-09 - 2023-10-19, IPT23
Maas Axel, U of Graz; 2023-08-21 - 2023-08-25, SPH23
Maher Joseph, CUNY, New York; 2023-07-16 - 2023-07-22, CLE23
Majcen Peter, U Padua; 2023-08-20 - 2023-09-02, SPH23
Maliborski Maciej, U of Vienna; 2023-06-05 - 2023-07-28, CSZ23; 2023-12-04 - 2023-12-07, EHC23
Mandal Gautam, TIFR Mumbai; 2023-09-04 - 2023-09-09, HKS23
Manohar Aneesh, UC San Diego; 2023-08-13 - 2023-08-24, SPH23
Manta Alessandro, U of Vienna; 2023-09-03 - 2023-09-08, HKS23
Manzano Miguel, U Salamanca; 2023-03-12 - 2023-03-25, CKM23
Marajh Jordan, QMU London; 2023-12-03 - 2023-12-07, EHC23
Marchese Marta Maria, U of Siegen; 2023-02-12 - 2023-02-17, RHI23
Mariano Arthur, U Miami; 2023-05-08 - 2023-05-17, PDC23
Markina Irina, U of Bergen; 2023-09-17 - 2023-09-22, 2023-10-15 - 2023-10-21, IPT23
Mars Marc, USAL; 2023-03-12 - 2023-03-25, CKM23
Martin Calin, U of Vienna; 2023-04-11 - 2023-06-02, PDC23
Martinetti Pierre, UNIGE & INFN; 2023-03-13 - 2023-03-17, CKM23
Martin-Garcia Jose, Wolfram Research; 2023-12-01 - 2023-12-11, EHC23
Marynets Kateryna, TU Delft; 2023-05-07 - 2023-05-27, PDC23
Marzani Simone, U Genova; 2023-07-30 - 2023-08-05, SPH23
Marzuola Jeremy Louis, U of North Carolina, Chapel Hill; 2023-07-09 - 2023-07-22, CSZ23
Mason Lionel, U Oxford; 2023-07-04 - 2023-07-11, CSZ23
Massart Daniel, U de Montpellier; 2023-10-15 - 2023-10-20, IPT23
Mateu Vicent, U Salamanca; 2023-07-25 - 2023-08-05, SPH23
Mathieu Pierre, U Aix-Marseille; 2023-07-15 - 2023-07-22, CLE23
Mathis Leo, Goethe U Frankfurt; 2023-09-17 - 2023-09-23, IPT23
Matte Bon Nicolás, Institute Camille Jordan, U Lyon; 2023-07-16 - 2023-07-21, CLE23

Matveev Vladimir, U of Jena; 2023-09-10 - 2023-09-22, IPT23
Mazari-Fouquer Idriss, CEREMADE, Paris; 2023-12-10 - 2023-12-15, DMS23
Mazzieri Lorenzo, U of Trento; 2023-03-13 - 2023-03-17, CKM23; 2023-12-03 - 2023-12-08, EHC23
McCann Robert, U Toronto; 2023-03-12 - 2023-03-22, CKM23
McCarney Jordan, UC Cork; 2023-05-22 - 2023-05-27, PDC23
Meco Benjamin, Uppsala U; 2023-03-13 - 2023-03-17, CKM23; 2023-12-03 - 2023-12-08, EHC23
Mehen Thomas, Duke; 2023-08-16 - 2023-08-30, SPH23
Mehlstäubler Tanja, PTB, Braunschweig; 2023-02-13 - 2023-02-17, RHI23
Meinert Janning, U Heidelberg; 2023-02-12 - 2023-02-18, RHI23
Melikhov Dmitri, U of Vienna; 2023-07-31 - 2023-08-18, SPH23
Melo Margarida, U Roma Tre; 2023-04-23 - 2023-04-26, BGW23
Merrell Rob, Oklahoma; 2023-07-16 - 2023-07-22, CLE23
Michel Johannes, MIT, Cambridge; 2023-07-30 - 2023-08-12, SPH23
Michor Peter, U of Vienna; 2023-06-12 - 2023-07-13, CSZ23
Mieling Thomas, U of Vienna; 2023-09-19 - 2023-11-03, IPT23
Milizia Francesco, SNS Pisa; 2023-07-17 - 2023-07-22, CLE23
Miller Tomasz, Jagiellonian U; 2023-03-12 - 2023-03-17, CKM23
Millet Pascal, U Grenoble Alpes; 2023-06-18 - 2023-07-15, CSZ23
Mingo James, Queen's U; 2023-04-23 - 2023-04-29, BGW23
Minguzzi Ettore, U Florence; 2023-03-12 - 2023-03-24, CKM23
Mir Nordine, Texas A&M U at Qatar; 2023-11-19 - 2023-11-25, GLM23
Mitsuishi Ayato, U Fukuoka; 2023-10-15 - 2023-10-21, IPT23
Miyachi Hideki, Kanazawa U; 2023-10-08 - 2023-10-14, IPT23
Mladek Carla, U of Vienna; 2023-03-13 - 2023-03-24, CKM23
Moch Sven-Olaf, U Hamburg; 2023-08-06 - 2023-08-18, SPH23
Molchanova Anastasia, U of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Moncrief Vincent, Yale U, New Haven; 2023-06-29 - 2023-08-29, CSZ23
Mondello Gabriele, U Roma 1, Sapienza; 2023-07-09 - 2023-08-16, CSZ23
Mondino Andrea, U Oxford; 2023-03-12 - 2023-03-20, CKM23
Monni Pier, CERN, Geneva; 2023-08-21 - 2023-09-01, SPH23
Mora Corral Carlos, U Autonoma de Madrid; 2022-02-19 - 2022-02-24, MA23
Morandotti Marco, Politecnico, Torino; 2023-02-19 - 2023-02-24, MA23
Moretti Valter, U of Trento; 2023-03-14 - 2023-03-18, CKM23
Morgan Katrina, Northwestern U Evanston; 2023-06-18 - 2023-06-24, CSZ23
Moroianu Sergiu, IMAR; 2023-10-15 - 2023-10-21, IPT23
Moschidis Georgios, EPFL, Lausanne; 2023-07-09 - 2023-07-13, CSZ23
Moulla Thiziri, U Montpellier; 2023-09-17 - 2023-09-22, IPT23
Müller Christian, TU of Vienna; 2023-10-16 - 2023-10-20, IPT23
Müller Olaf, HU Berlin; 2023-03-12 - 2023-03-21, CKM23
Murro Simone, U Genova; 2023-07-02 - 2023-07-14, CSZ23
Muster Augustin, U of Fribourg; 2023-02-12 - 2023-02-17, RHI23
Nagnibeda Tatiana, U Genève; 2023-10-15 - 2023-10-20, IPT23
Negrepontis Stylianos, National and Technical U of Athens; 2023-10-23 - 2023-10-28, IPT23
Nekrashevych Volodymyr, TAMU, College Station; 2023-07-15 - 2023-07-22, CLE23
Neretin Yurii, U of Vienna; 2023-10-16 - 2023-10-20, IPT23
Neufeld Helmut, U of Vienna; 2023-07-31 - 2023-08-14, SPH23
Neumayer Christina, U of Vienna; 2023-11-20 - 2023-11-24, GLM23
Nimmrichter Stefan, U of Siegen; 2023-02-12 - 2023-02-17, RHI23

Nishimura Jun, KEK, Tsukuba; 2023-09-02 - 2023-09-09, HKS23
Novelli Vinicius, U San Paolo; 2023-11-20 - 2023-11-24, GLM23
Nützi Andrea, ETH Zurich; 2023-06-18 - 2023-06-24, 2023-07-06 - 2023-07-10, CSZ23
Nützi Andrea, Stanford U; 2023-12-02 - 2023-12-08, EHC23
Oancea Marius A., U of Vienna; 2023-06-05 - 2023-07-28, CSZ23; 2023-12-04 - 2023-12-07, EHC23
O'Connor Denjoe, DIAS, Dublin; 2023-09-03 - 2023-09-08, HKS23
Ofner Maximilian, U of Vienna; 2023-06-05 - 2023-07-28, CSZ23; 2023-12-04 - 2023-12-07, EHC23
Ohanyan Argam, U of Vienna; 2023-03-11 - 2023-03-26, CKM23; 2023-09-16 - 2023-09-26, IPT23
Ohsawa Takeo, Nagoya U; 2023-11-20 - 2023-11-25, GLM23
Ohshika Ken'ichi, Gakushuin U, Tokyo; 2023-09-24 - 2023-10-21, IPT23
Ohta Shin-ichi, U Osaka; 2023-03-12 - 2023-03-17, CKM23
Oliver Marcel, KU Eichstätt; 2023-05-03 - 2023-05-12, 2023-05-22 - 2023-06-03, PDC23
Onninen Jani, Syracuse U; 2023-02-19 - 2023-02-24, MA23
Oppelmayer Hanna, U of Innsbruck; 2023-07-16 - 2023-07-20, CLE23
Oronzio Francesca, KTH; 2023-12-03 - 2023-12-08, EHC23
Pagliari Valerio, TU Vienna; 2023-02-20 - 2023-02-24, MA23
Pagonabarraga Ignacio, U of Barcelona; 2023-03-05 - 2023-03-08, L022023
Paldor Nathan, HU of Jerusalem; 2023-05-08 - 2023-05-25, PDC23
Palmero Cruz Norma Caridad, Guanajuato U; 2023-03-01 - 2023-08-31, RIT23
Pankka Pekka, U Helsinki; 2023-02-19 - 2023-02-25, MA23
Papadopoulos Athanase, IRMA, Strasbourg; 2023-09-10 - 2023-11-03, IPT23
Parnovski Leonid, U College London; 2023-07-18 - 2023-07-28, CSZ23
Pathak Aditya, DESY Hamburg; 2023-08-05 - 2023-08-20, SPH23
Pawlaschyk Thomas, BUW; 2023-11-19 - 2023-11-25, GLM23
Pazniak Anastasya, AMS; 2023-10-26 - 2023-10-30, IMO23
Peik Ekkehard, PTB, Braunschweig; 2023-02-12 - 2023-02-17, RHI23
Pereira Dos Santos Franck, SYRTE, Paris; 2022-02-13 - 2022-02-16, RHI23
Pérez Sánchez Carlos, U Heidelberg; 2023-04-24 - 2023-04-28, BGW23; 2023-03-01 - 2023-03-24, 2023-03-29 - 2023-05-31, 2023-05-31 - 2023-06-07, 2023-06-20 - 2023-06-24, 2023-08-29 - 2023-09-12, JRF23
Pernak Leon, U of Saarland; 2023-07-16 - 2023-07-21, CLE23
Perugia Ilaria, U of Vienna; 2023-11-09 - 2023-11-11, ESI@3023
Petersen Oliver, KTH Stockholm; 2023-06-25 - 2023-06-30, CSZ23
Petriello Frank, Northwestern U Evanston; 2023-08-06 - 2023-08-19, SPH23
Petyt Harry, U Oxford; 2023-07-15 - 2023-07-23, CLE23
Piekarz Dariusz, Jagiellonian U, Krakow; 2023-11-19 - 2023-11-25, GLM23
Pinoy Alan, KTH Stockholm; 2023-09-17 - 2023-09-23, IPT23
Plätzer Simon, U of Graz; 2023-07-31 - 2023-09-01, SPH23
Podolsky Jiri, U Prague; 2023-03-13 - 2023-03-24, CKM23
Polly Denis, TU of Vienna; 2023-09-18 - 2023-10-22, IPT23
Ponsiglione Marcello, U Roma 1; 2023-02-20 - 2023-02-24, MA23
Porti Joan, UA de Barcelona; 2023-10-17 - 2023-10-21, IPT23
Prakash Govindarajan, ZARM, Bremen; 2023-02-12 - 2023-02-19, RHI23
Pratelli Aldo, U Pisa; 2023-02-20 - 2023-02-24, MA23
Preston Stephen, Brooklyn College; 2023-02-20 - 2023-02-24, MA23
Procura Massimiliano, U of Vienna; 2023-07-31 - 2023-09-01, SPH23
Prosanov Roman, U of Vienna; 2023-09-11 - 2023-11-03, IPT23
Prunier Raphael, CEREMADE, Paris; 2023-12-10 - 2023-12-15, DMS23
Pultar Dominik, BRG Wien 6; 2023-06-26 - 2023-06-30, 2023-10-27 - 2023-10-31, IMO23

Qing Yulan, Fudan; 2023-07-16 - 2023-07-22, CLE23
Quaschner Manuel, U of Jena; 2023-09-17 - 2023-09-22, IPT23
Quirchmayr Ronald, U Groningen; 2023-05-21 - 2023-05-27, PDC23; 2023-06-06 - 2023-06-23, CSZ23
Rácz István, WIGNER RCP, Budapest; 2023-12-03 - 2023-12-07, EHC23
Radici Emanuela, U L'Aquila; 2023-02-19 - 2023-02-24, MA23
Raffaelli Matteo, TU of Vienna; 2023-09-18 - 2023-09-22, IPT23
Rafi Kasra, U Toronto; 2023-07-16 - 2023-07-22, CLE23
Rahn Rudi, U of Manchester; 2023-08-06 - 2023-08-18, SPH23
Raich Andrew, UA; 2023-11-19 - 2023-11-25, GLM23
Raman Sanjay, MIT, Cambridge; 2023-08-07 - 2023-08-16, SPH23
Ramgoolam Sanjaye, QMU London; 2023-09-03 - 2023-09-09, HKS23
Rasel Ernst M., Leibniz U; 2023-02-13 - 2023-02-17, RHI23
Rätzel Dennis, ZARM, Bremen; 2023-02-12 - 2023-02-17, RHI23
Rauschenbeutel Arno, HU Berlin; 2023-02-13 - 2023-02-17, RHI23
Ravotti Davide, U of Vienna; 2023-04-11 - 2023-04-21, 2023-06-05 - 2023-06-16, RIT23
Rebhan Anton, TU Vienna; 2023-07-31 - 2023-09-01, SPH23
Reggiani Dario, Scuola Normale Meridionale; 2023-02-19 - 2023-02-24, MA23; 2023-12-10 - 2023-12-15, DMS23
Regner Christoph, U of Vienna; 2023-08-14 - 2023-09-01, SPH23
Reiche Daniel, HU Berlin; 2023-02-13 - 2023-02-17, RHI23
Reintjes Moritz, City U of Hong Kong; 2023-03-11 - 2023-03-17, CKM23
Reiter Wolfgang, U of Vienna; 2023-11-09 - 2023-11-10, ESI@3023
Rejzner Kasia, U of York; 2023-07-10 - 2023-07-28, CSZ23
Remazeilles Mathieu, CSIC, Madrid; 2023-02-12 - 2023-02-17, RHI23
Ribelles Pérez Anna, LMU Munich; 2023-07-16 - 2023-07-22, CLE23
Ricc Samuele, TU of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Rieser Jakob, U of Vienna; 2023-02-13 - 2023-02-16, RHI23
Rigoni Chiara, U of Vienna; 2023-03-13 - 2023-03-24, CKM23; 2023-02-20 - 2023-02-24, MA23
Ringström Hans, KTH Stockholm; 2023-12-03 - 2023-12-08, EHC23
Rioseco Paola, U de Chile, Santiago; 2023-06-22 - 2023-07-13, CSZ23; 2023-12-06 - 2023-12-07, EHC23
Ritsch Helmut, U of Innsbruck; 2023-02-13 - 2023-02-17, RHI23
Riva Filippo, U Pavia; 2023-02-19 - 2023-02-24, MA23
Robin Rémi, MINES ParisTech; 2023-12-10 - 2023-12-15, DMS23
Rodrigo German, CSIC, Madrid; 2023-08-15 - 2023-08-23, SPH23
Rodrigues Joao, U of Witwatersrand; 2023-09-02 - 2023-09-08, HKS23
Rom-Kedar Vered, Weizmann Institute, Rehovot; 2023-05-22 - 2023-05-28, PDC23
Rosenkranz Johannes, BORG Linz; 2023-10-26 - 2023-10-31, IMO23
Roskovec Tomá, U of South Bohemia; 2023-02-19 - 2023-02-24, MA23
Rossdeutscher Carl, U of Vienna; 2023-03-13 - 2023-03-24, CKM23
Rostworowski Andrzej, Jagiellonian U, Krakow; 2023-06-19 - 2023-06-30, CSZ23
Rothstein Ira, Carnegie Mellon U, Pittsburgh; 2023-08-24 - 2023-08-31, SPH23
Rott Felix, U of Vienna; 2023-03-13 - 2023-03-24, CKM23
Rotter Stefan, TU of Vienna; 2023-02-13 - 2023-02-15, RHI23
Ruffa Ines, U of Vienna; 2023-07-31 - 2023-08-27, SPH23
Rungi Nicholas, SISSA, Trieste; 2023-09-17 - 2023-09-23, IPT23
Rupp Fabian, U of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Ruppenthal Jean, BUW; 2023-11-20 - 2023-11-25, GLM23
Sadat Kyaee Ashkan, Sorbonne U, Paris; 2023-06-19 - 2023-06-24, CSZ23

Saghafian Morteza, ISTA, Klosterneuburg; 2023-06-30 - 2023-06-30, IMO23
Sahoo P.K., Birla Institute of Technology and Science, Pilani; 2023-12-03 - 2023-12-07, EHC23
Sako Akifumi, Tokyo U of Science; 2023-04-13 - 2023-08-31, RIT23; 2023-04-24 - 2023-04-28, BGW23
Sakovich Anna, Uppsala U; 2023-03-12 - 2023-03-17, CKM23; 2023-12-04 - 2023-12-07, EHC23
Sämann Clemens, U Oxford; 2023-03-12 - 2023-03-25, CKM23
Sanchez Miguel, U Granada; 2023-03-12 - 2023-03-18, CKM23
Sansom Robert, QMU London; 2023-10-03 - 2023-10-07, EHC23
Santos Rodrguez Jaime, U Autonoma de Madrid; 2023-09-17 - 2023-09-23, IPT23
Satishchandran Gautam, Princeton U; 2023-06-05 - 2023-07-23, CSZ23
Sava-Huss Ecaterina, U of Innsbruck; 2023-07-16 - 2023-07-21, CLE23
Sbierski Jan, U of Edinburgh; 2023-03-12 - 2023-03-22, CKM23; 2023-12-03 - 2023-12-08, EHC23
Scardia Lucia, Heriot-Watt U, Edinburgh; 2023-02-19 - 2023-02-24, MA23
Scazzuso Davide, HU Berlin; 2023-04-23 - 2023-04-29, BGW23
Schalch Nicolas, U Bern; 2023-08-14 - 2023-08-25, SPH23
Scheffold Frank, U of Fribourg; 2023-02-12 - 2023-02-15, RHI23
Schiller Jan, HTLWY; 2023-10-26 - 2023-10-31, 2023-06-25 - 2023-06-30, IMO23
Schlenker Jean-Marc, U of Luxembourg; 2023-10-15 - 2023-10-19, IPT23
Schlippert Dennis, Leibniz U; 2023-02-12 - 2023-02-17, RHI23
Schmid Gabriel, U Genova; 2023-06-18 - 2023-06-24, CSZ23
Schmidt Klaus, U of Vienna; 2023-11-09 - 2023-11-10, ESI@3023
Schneeweiss Philipp, HU Berlin; 2023-02-12 - 2023-02-17, RHI23
Schoen Richard, Stanford U; 2023-12-03 - 2023-12-08, EHC23
Schörkhuber Birgit, U of Innsbruck; 2023-06-18 - 2023-06-20, CSZ23
Schreve Kevin, LSU; 2023-07-06 - 2023-08-02, RIT23
Schürmann Jörg, U Münster; 2023-04-23 - 2023-04-29, BGW23
Schütze Sebastian, U of Vienna; 2023-11-09 - 2023-11-09, ESI@3023
Schwartz Matthew, Harvard U, Cambridge; 2023-08-12 - 2023-08-19, SPH23
Schwarzacher Sebastian, Uppsala U; 2023-02-20 - 2023-02-24, MA23
Schwermer Joachim, U of Vienna; 2023-11-08 - 2023-11-11, ESI@3023
Scimemi Ignazio, U Complutense de Madrid; 2023-08-27 - 2023-09-01, SPH23
Sciortino Francesco, U Roma 1; 2023-11-10 - 2023-11-12, ESI@3023
Scott Richard, U of St Andrews; 2023-05-13 - 2023-05-27, PDC23
Sedmik René, TU of Vienna; 2023-02-13 - 2023-02-17, RHI23
Seitz Manuel, U of Vienna; 2023-02-20 - 2023-02-24, MA23; 2023-12-11 - 2023-12-15, DMS23
Senovilla Jose M M, UPV/EHU; 2023-03-16 - 2023-03-19, CKM23
Seo Donggyun, Seoul National U; 2023-07-14 - 2023-07-21, CLE23
Seppi Andrea, U Grenoble Alpes; 2023-09-17 - 2023-09-21, 2023-10-15 - 2023-10-18, IPT23
Sert Cagri, U Zurich; 2023-07-16 - 2023-07-22, CLE23
Shadrin Sergey, U of Amsterdam; 2023-04-23 - 2023-04-28, BGW23
Shafikov Rasul, UWO; 2023-11-19 - 2023-11-26, GLM23
Shamir Ofer, CIMS, New York; 2023-05-21 - 2023-05-27, PDC23
Sharp Richard, U Warwick; 2023-07-16 - 2023-07-22, CLE23
Shcherbakov Viktor, U Kassel; 2023-02-19 - 2023-02-24, MA23
Shcherbina Nikolay, BUW; 2023-11-19 - 2023-11-25, GLM23
Shelah Jonathan, U Ljubljana; 2023-11-19 - 2023-11-24, GLM23
Shi William, BRG4, Vienna; 2023-10-27 - 2023-10-31, IMO23
Silva Eduardo, ENS Paris; 2023-07-15 - 2023-07-22, CLE23
Simon Walter, U of Vienna; 2023-06-05 - 2023-07-28, CSZ23; 2023-03-13 - 2023-03-17, CKM23; 2023-12-04 - 2023-12-07, EHC23

Sjödahl Malin, Lund U; 2023-07-29 - 2023-09-02, SPH23
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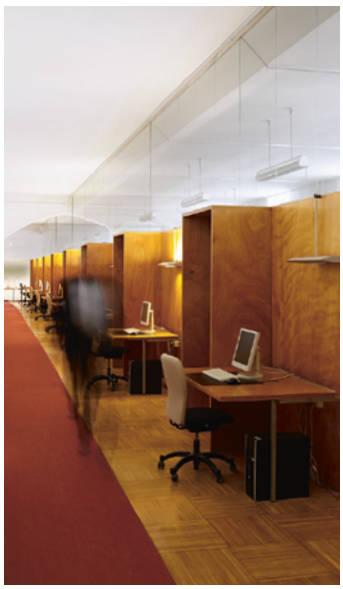


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