Erwin Schrödinger International Institute
for Mathematics and Physics

ANNUAL REPORT 2019

THE INSTITUTE PURSUES ITS MISSION THROUGH A VARIETY OF PROGRAMMES

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

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

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

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

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

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

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

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

ESI Annual Report 2019

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Preface

Note: *At the time of writing, the world is still in the midst of the coronavirus pandemic, which has also strongly affected activities at the ESI. Following measures put in place by the Austrian Government to contain the spread of the virus, the Institute has been completely closed from mid-March to the end of July and many activities, including several thematic programmes and workshops have been cancelled or postponed. All staff worked remotely and were very busy reorganizing the ESI program. While some activities have been moved online, most organizers have preferred to reschedule their programme or workshop to a later point in time so that participants can interact in person and enjoy the particular atmosphere at the ESI. Now, at the beginning of August 2020, we are slowly and carefully reopening the ESI at a reduced level, maintaining strict measures to ensure the safety of ESI visitors and staff. The ESI will continue to monitor the course of the pandemic closely and adjust the measures accordingly, following the guidelines of public health authorities and of the University of Vienna. It is currently unclear how the pandemic will evolve in the coming months, but I am confident that thanks to the dedicated work of its staff the ESI will emerge from this challenging period as strong as ever and we all hope that normal operations will be resumed soon. A full account of the effect of the coronavirus pandemic on the ESI in 2020 will be given in the next annual report.*

Christoph Dellago
Director of the ESI
August 2020

The Institute and its Mission

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

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

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

The Institute currently pursues its mission in several ways:

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

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

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

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

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

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

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

Scientific Activities in 2019

The list of research areas in mathematics and physics covered by the scientific activities of the Erwin Schrödinger Institute in 2019 shows a wide variety. The following thematic programmes took place:

- *Modern Maximal Monotone Operator Theory: From Nonsmooth Optimization to Differential Inclusions*
  January 28 – March 8, 2019
  (org.: Heinz Bauschke (U of British Columbia, Kelowna), Radu Ioan Bot (U Vienna), Helene Frankowska (CNRS, Paris), Michael Hintermüller (WIAS, Berlin), Russell Luke (U Göttingen))

- *Higher Spins and Holography*
  March 11 – April 5, 2019
  (org.: Andrea Campoleoni (U Mons), Stefan Fredenhagen (U Vienna), Matthias Gaberdiel (ETH Zürich), Daniel Grumiller (TU Vienna), Mikhail Vasiliev (Lebedov Physical Institute, Moscow))

- *Optimal Transport*
  April 14 – June 14, 2019
  (org.: Mathias Beiglböck (U Vienna), Alessio Figalli (ETH Zürich), Jan Maas (ISTA, Klosterneuburg), Robert McCann (U Toronto), Justin Solomon (MIT, Cambridge))

– *Astrophysical Origins: Pathways from Star Formation to Habitable Planets*
June 17 – August 2, 2019
(org.: Ramon Brasser (ELSI, Tokyo), Manuel Güdel (U Vienna), Theresa Lüftinger (U Vienna), Stephen Mojzsis (U of Colorado, Boulder))

– *Quantum Simulation - from Theory to Application*
September 2 – October 31, 2019
(org.: Tommaso Calarco (FZ Jülich), Wolfgang Lechner (U Innsbruck), Jörg Schmiedmayer (TU Vienna), Philip Walther (U Vienna))

A detailed account of these thematic programmes is given in subsequent sections of this report.

In addition to thematic programmes, several workshops and conferences took place at the ESI in 2019, complemented by visits of individual scholars who collaborated with scientists of the University of Vienna and the local community. Here is a list of these activities:

– *Categorification in Quantum Topology and beyond*
January 7 – 18, 2019
(org.: Nils Carqueville (U Vienna), Anton Mellit (U Vienna), Paul Wedrich (ANU, Canberra))

– *Graduate School: YRSIW2019 A modern Primer for 2D CFT*
February 11 – 15, 2019
(org.: Andrea Campoleoni (U Mons), Stefan Fredenhagen (U Vienna), Elli Pomoni (DESY Hamburg), Alessandro Sfondrini (ETH Zurich))

– *Operator related Function Theory*
April 8 – 12, 2019
(org.: Alexandru Aleman (U Lund), Karlheinz Gröchenig (U Vienna), Kristian Seip (NTNU, Trondheim))

– *Parton Showers, Event Generators and Resummation Workshop*
June 11 – 14, 2019
(org.: Simon Plätzer (U Vienna))

– *Numeration and Substitution*
July 8 – 12, 2019
(org.: Henk Bruin (U Vienna), Clemens Heuberger (AAU, Klagenfurt), Daniel Krenn (AAU, Klagenfurt), Jörg Thuswaldner (Montanuniversität Leoben))

– *STRONG-DM 2019, Searches, Theories, Results, Opportunities, and New Ideas for sub-GeV Dark Matter*
August 5 – 16, 2019
(org.: Brian Batell (U Pittsburgh), Nicolás Bernal (U Antonio Narino, Bogota), Xiaoyong Chu (HEPHY Vienna), Hey-Sung Lee (KIAS, Seoul), Josef Pradler (HEPHY Vienna), Tomer Volansky (Tel Aviv U))

– *MAIA 2019: Multivariate Approximation and Interpolation with Applications*
August 26 – 30, 2019
(org.: Maria Charina (U Vienna), Philipp Grohs (U Vienna), Karlheinz Gröchenig (U Vienna), Johannes Wallner (TU Graz))

- *Modeling of Crystalline Interfaces and Thin Film Structures: A Joint Mathematics-Physics Symposium*
  November 11 – 15, 2019
  (org.: Ulrike Diebold (TU Vienna), Irene Fonseca (Carnegie Mellon U, Pittsburgh), Paolo Piovano (U Vienna))

- *ESI Symposium: What is Life?*
  November 18, 2019
  (org.: Wolfgang Reiter (U Vienna), Klaus Schmidt (U Vienna), Jakob Yngvason (U Vienna))

- *New Trends in the Variational Modeling and Simulation of Liquid Crystals*
  December 2 – 6, 2019
  (org.: Giovanni Di Fratta (TU Vienna), Michele Ruggeri (TU Vienna), Valeriy V. Slastikov (U Bristol), Arghir Dani Zarnescu (BCAM, Bilbao))

- *Polarons in the 21st Century*
  December 9 – 13, 2019
  (org.: Jozef Devreese (U Antwerpen), Cesare Franchini (U Vienna), Georg Kresse (U Vienna), Jacques Tempere (U Antwerpen))

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

In the summer term Andreas Buchleitner (U of Freiburg) gave a course on *Quantum Theory II* and Antoine Van Proeyen (KU Leuven) a course on *Supergravity*.

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 two research teams worked at the ESI in 2019:

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

- Harald Grosse (U Vienna), Raimar Wulkenhaar (U of Münster), *Nonperturbative Construction of Quantum Field Theory Models*, April 28 – May 3, June 13 – 18, July 28 – August 2, 2019.

- Robin Ming Chen (U of Pittsburgh), Samuel Walsh (U of Missouri), Miles H. Wheeler (U Vienna), *Global Bifurcation Techniques for Traveling Waves on Non-Compact Domains*, May 20 – June 20, 2019.

- David Henry (U College Cork), Gabriele Villari (U of Florence), *Underlying Flow Induced by Internal Water Waves*, June 1 – July 31, 2019.

- Martin Bauer (Florida State U), Philipp Harms (U Freiburg), Peter W. Michor (U Vienna), *Geodesic Equations on Mapping Spaces*, June 17 – July 31, 2019.

- Nihat Sadik Deger (Bogazici U, Bebek), Jan Rosseel (U Vienna), *Asymptotically AdS and Flat Spacetimes in 3-Dimensional Supergravities*, August 11 – September 15, 2019.

The report of the Research in Teams project of Philipp Haslinger, Francesco Intravaia, Dennis Rätzel, and Matthias Sonnleitner will be part of the Annual Report 2021 since their project was awarded for a period of two months tenable in 2019, 2020 and 2021.

In the year 2019 the following Junior Research Fellows visited the ESI to work on their research project:

– Mattia Ornaghi, *Dg enhancements via A ∞-categories*, October 15, 2018 – February 15, 2019.

– Jarrod Lewis Williams, *Exact and Approximate Killing Symmetries in General Relativity: Dain Invariants on Black Hole Spacetimes and Integrability of KID Equations*, November 1, 2018 – February 28, 2019.

– Zahra Ahmadian Dehaghani, *Nonequilibrium Dynamics of Knotted Polymers in Elongational Flow*, January 1 – April 30, 2019.

– Arindam Biswas, *Expander Graphs and Non-linear Spectral Gap*, January 1 – April 30, 2019.

– Pulastya Parekh, *Scattering Tensionless Strings, and its Effect on Spacetime*, February 1 – May 31, 2019.

– Sergio Hörtner, *Hidden Symmetries of Gravity in Cosmological Scenarios and Applications to Holography*, March 1 – June 30, 2019.

– Edward Mortimer, *The Effect of Hydrogen Contamination on the Formation Rates of Stone-Wales Defects in Graphene*, June 7 – July 7, 2019.

– Lorenzo Del Re, *Dimensional Crossover of Layered Strongly Correlated Ultracold Fermi Gases*, December 1, 2019– January 31, 2020.

The report of Lorenzo Del Re will be part of the annual report 2020.

In 2019, we started the ESI-Colloquia, lectures given by individual visitors outside of workshops and thematic programmes. The first ESI-Colloquium was given by Ilse Fischer from the Faculty of Mathematics of the University of Vienna.

In 2019 the Erwin Schrödinger Institute hosted also two events of the Vienna Doctoral School:

– *Science Meets: Space* on January 24, 2019 was the third joint meeting of the VDS Mathematics and VDS Physics.

– *VDS Meets Sports* on November 8, 2019 was organized by the VDS of Mathematics.

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 President (Rektor) of the University after consultations with the Deans of the Faculties of Physics and Mathematics. There was no change in the composition of the Kollegium of the ESI in 2018. Hence, in the period January 1 - December 31, 2019, the Kollegium consisted of A. Constantin (Mathematics), C. Dellago (Physics), M. Eichmair (Mathematics), S. Fredenhagen (Physics), A. Hoang (Physics), I. Perugia (Mathematics). All members of the Kollegium act as professors at the University.

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), who became deputy director on January 1, 2020, and Ilaria Perugia (Deputy Director). At this point we want to thank André H. Hoang for acting as Deputy Director from January 2017 to December 2019.

Scientific Advisory Board

The scientific activities of the ESI are supervised by the Scientific Advisory Board (SAB), composed of leading scientists. The SAB also reflects the international ties which are essential for the ESI. In 2019, the SAB consisted of: Alberto Bressan (Penn State U), Mirjam Cvetic (U of Pennsylvania, Philadelphia) [chair], Domenico Giulini (U Hannover), Gerhard Huisken (U Tübingen), Christian Lubich (U Tübingen), Stefano Ruffo (SISSA, Trieste), Catharina Stroppel (U Bonn), and Martin Zirnbauer (U Cologne).

The composition of the SAB of the ESI changed by the end of the year 2019. After two terms of office Christian Lubich and Catharina Stroppel have retired from the Board. The Institute is very grateful to them for many years of valuable advice and support. Douglas N. Arnold (U Minnesota) and Sandra Di Rocco (KTH, Stockholm) joined the Board on January 1, 2020, as new members.

Administration

The composition of the administrative staff of the ESI also changed in 2019. Renate Zechner left the administration. We would like to thank her for her work for the ESI. For her position we could win Isabella Janger who was already a team member several years ago. Also Sophie Kurzmann came back to the Institute to take over the new agenda of processing the videos of the talks we are regularly recording since the summer of 2019 and to maintain the ESI YouTube channel. Also since then, Theresa Kalchhauser is supporting the ESI administration on two days a week, which is a great help for the administration team to continue its work with customary efficiency for our visitors, research fellows and board.

Christoph Dellago August 4, 2020
ESI Director

The ESI in 2019: facts and figures

Management and Administration:

Director: Christoph Dellago

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

Administration: Isabella Janger, Theresa Kalchhauser, Maria Marouschek, Beatrix Wolf (Head)

Computing and networking support: Sascha Biberhofer, Thomas Leitner

Video recording and publishing: Sophie Kurzmann

International Scientific Advisory Board in 2019:

Alberto Bressan (Penn State U)
Miriam Cvetic (U Pennsylvania, Philadelphia) [chair]
Domenico Giulini (U Hannover)
Gerhard Huisken (U Tübingen)
Christian Lubich (U Tübingen)
Stefano Ruffo (SISSA, Trieste)
Catharina Stroppel (U Bonn)
Martin Zirnbauer (U Cologne)

Budget and visitors: In 2019 the support of ESI received from the University of Vienna amounted to **€ 790 000**. In addtion the ESI received an extra budget of EUR 120 000 to increase the visibility of the Institute, e.g. for the installation of a permanent video recording system. Additionally the ESI obtained a total of € 96 893 in third party funds from external sources for the support of the various activities.

The total amount spent in 2019 on scientific activities was € 572 732 while the expenditures for administration (mainly salaries) and infrastructure (mainly rent) amounted to € 468 473.

The total number of scientists visiting the Erwin Schrödinger Institute in 2019 was 1 116, see pages 124 – 148. This was the first time that the number of visitors exceeded the mark of 1 000. Gender ratio: male: 904 (81 %), female: 178 (16 %), non-binary: 34 (3 %).

The handling of large numbers of visitors is greatly facilitated by the new online registration system, which was introduced at the ESI in 2019.

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 2019 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 2019 is 172 [related to the activities in 2019: 141, related to the activities in previous years: 31], see pages 114 – 123 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 129 videos were recorded in 2019 amounting to more than 100 hours of video material. These videos have been accessed more than 15 000 times in 2019 alone. Currently, the number of views is growing quickly indicating the strong interest for recorded ESI lectures in the community.

Scientific Reports

Main Research Programmes

Modern Maximal Monotone Operator Theory: From Nonsmooth Optimization to Differential Inclusions

Organizers: Heinz H. Bauschke (U of British Columbia), Radu I. Boţ (U Vienna), Hélene Frankowska (U Paris 6), Michael Hintermüller (Weierstrass Inst. Berlin), D. Russell Luke (U Göttingen)

Dates: January 28 – March 8, 2019

Budget: ESI € 51 840,
Vienna Doctoral School of "Mathematics" € 5 731,
Faculty of Mathematics of the University of Vienna € 2 380,
FWF € 500.

Report on the programme

Having its historical roots in the area of PDEs, the theory of monotone operators has flourished in functional and numerical analysis with the goal of answering deep theoretical questions on one hand and, on the other hand, with a focus on the development of algorithms. The theory of monotone operators stands at the junction between the study of variational problems, with particular instances related to optimization, game theory and control, on one side, and partial differential equations or quasi-variational inequalities on the other. The major aim of the thematic programme was to bring together leading researchers to synthesize advances in each of these areas, and explore new directions and applications. An equally important objective was to train the next generation of scientists with an awareness of the interconnections between these important areas.

The thematic programme brought together 107 scientists at the interface of three areas :

Advances in Monotone Operator Theory

The theory of monotone operators was relevant to this endeavour as it has been the principal tool and catalyst of the main areas addressed in this thematic program. A key topic within this theory concerns the representation of monotone operators by convex functions defined in the product space, where the product space refers to the Cartesian product of the domain and the co-domain of the operator. The connection with convex functions was discovered by Simon Fitzpatrick a quarter of a century ago, and is still generating intense research, both in the theoretical and the practical points of view. Progress in this topic (now called Fitzpatrick theory), is likely to provide new, simpler ways to formulate and efficiently solve problems involving maximal monotone operators. Consequently, a consistent component of the thematic programme was dedicated to theoretical advances in monotone operator theory.

Numerical Algorithms for Monotone Inclusions and Nonsmooth Optimization

One of the major aims of the thematic programme was to bring into focus the currently massive development of splitting algorithms for solving specific instances of monotone inclusions through a more general overview of the abstract structures shared by the disparate applications and algorithmic schemes. Over the past decade, many variants of the same general algorithmic schemes have been (re)discovered and proposed, and some of these have found unexpected applications. The open questions surrounding these algorithms are not only mathematically intrinsically beautiful but their resolution promises a real impact to the industrial world.

The thematic programme provided a good opportunity to survey the state of the art, to identify the most pressing open questions, to start new collaborations opening new frontiers for algorithms for monotone inclusions and convex optimization problems, and applications. Another topic which attracted a lot of attention was related to the development, the convergence analysis, the derivation of convergence rates, and the implementability of numerical algorithms for solving nonsmooth nonconvex optimization problems. A considerable progress in this field has been noticed, however, there are still many unsolved problems, in particular when it comes to the solving of nonsmooth nonconvex structured optimization problems.

Differential Inclusions and Control

Variational problems in PDEs and ODEs model phenomena throughout the natural and social sciences, and their mathematical analysis is intimately connected with monotone operators, functional analysis and PDE theory. Control systems and differential inclusions are well recognized tools used to describe dynamics of systems with multiple inputs and uncertainties.

Very recently, an important research effort was directed toward the so-called state constrained differential inclusions, where instead of asking trajectories to converge to an equilibrium point, one is interested by trajectories remaining in a prescribed closed set, or trajectories that can be approximated by those living in the interior of state constraints. Monotone operators may allow to handle a more general class of state constrained control systems. On the other hand, the classical questions arising in control theory related to stability of systems, their invariance properties, tracking of a prescribed trajectory by solutions of a system, output regulation, etc., do involve construction of a control synthesis, or, more generally, of selections of set-valued maps enjoying some monotonicity properties formulated in terms of monotone operators. The exchange of expertise to deal with the above mentioned questions was very fruitful.

Activities

During the thematic programme, 2 workshops and 3 series of lectures for young scientists were organised. A complete account of all activities is accessible at the webpage:
`https://www.univie.ac.at/projektservice-mathematik/e/?event=mmmot`

In the first week of the programme (January 28 - February 1), we organized a workshop entitled “Nonsmooth and Variational Analysis” with 39 talks and 50 participants. The focus was on nonsmooth analysis and optimization, optimization with pde constraints and optimal control. We refer to Section “List of talks” for a complete list of the talks. On Monday we had the welcome reception and on Wednesday the workshop dinner.

In the second week of the programme (February 4 - February 7), we organized 4 lecture series in the area of “Optimal Control and PDE Constrained Optimization”. The lecturers were Piermarco Cannarsa (U Roma “Tor Vergata”), Hélene Frankowska (U Paris 6), Michael Hintermüller (Weierstrass Inst. Berlin), and Fredi Tröltzsch (TU Berlin). We refer to Section “List of talks” for the titles of the four lectures.

In the fourth week of the programme (February 21 - February 22), we organized 2 lecture series in the area of “Numerical Methods in Nonsmooth Optimization”. The lecturers were Peter Richtarik (KAUST/U Edinburgh) and Marc Teboulle (U Tel Aviv). We refer to Section “List of talks” for the titles of the two lectures.

In the fifth week of the programme (February 5 - March 1), we organized a second workshop entitled “Numerical Algorithms in Nonsmooth Optimization” with 40 talks and 52 participants. The focus was on numerical methods for nonsmooth convex and nonconvex optimization problems and optimal control. We refer again to Section “List of talks” for a complete list of the talks. On Monday we had the welcome reception and on Wednesday the workshop dinner.

In the sixth week of the programme (March 4 - March 6), we organized 2 lecture series in the area of “Variational Analysis and Numerical Methods in Nonsmooth Optimization”. The lecturers were Aris Daniilidis (U Santiago de Chile) and Jean-Christophe Pesquet (U Paris-Saclay). We refer to Section “List of talks” for the titles of the two lectures.

List of young researchers, prae- and post-docs

External participants: Sebastian Banert (KTH Stockholm), Vincenzo Basco (U Paris 6), Matus Benko (JKU Linz), Arian Berdellima (U Göttingen), Julien Bernis (U Bretagne Occ.), Pedro Borges Melo (IMPA Rio de Janeiro), Minh Dao (U Newcastle), Owari Keita (Ritsumeikan U), Pham Duy Khanh (U Santiago de Chile), Florian Lauster (U Göttingen), Eric Legler (TU Chemnitz), Yura Malitsky (U Göttingen), Nimit Nimana (Khon Khaen U), Hui Ouyang (UBC Kelowna), Ernest K. Ryu (UCLA), Matthew Tam (U Göttingen), Elise Weill (INRIA Paris-Saclay), Enrico Wegner (U Maastricht)

Registered local participants: Axel Böhm (U Vienna), Elisa Davoli (U Vienna), Caroline Geiersbach (U Vienna), Laura Kanzler (U Vienna), Dang-Khoa Nguyen (U Vienna), Dennis Meier (U Vienna), Tiago Montanher (U Vienna), Tu Vuong Phan (U Vienna), Teresa Scarinci (U Vienna), Michael Sedlmayer (U Vienna)

Their contribution and benefits: The following young researchers gave talks at ESI within the thematic programme: Sebastian Banert (KTH Stockholm), Minh Dao (U Newcastle), Yura Malitsky (U Göttingen), Ernest K. Ryu (UCLA), Matthew Tam (U Göttingen).

All of the external junior participants received per diems by ESI. The very consistent program of lecture series was addressed in particular to young researchers and has received support from the Vienna Doctoral School of “Mathematics”. Additional benefits were the stimulating workshop talks and the opportunities to discuss and exchange ideas with prominent senior and other junior researchers.

Outcomes and achievements

The programme has provided a welcome opportunity to continue and finalize ongoing research activities and to initiate new collaborations. Some examples are mentioned below:

Recent progress on the link between optimization algorithms and dissipative dynamic systems, as well as the impact of time scaling on their convergence rates, has been the subject of several constructive discussions HEDY ATTOUCH has had with JÉRÔME BOLTE, RADU I. BOŢ, JONATHAN ECKSTEIN, JUAN PEYPOUQUET, and SILVIA VILLA.

VINCENZO BASCO worked on completing his paper with HÉLENE FRANKOWSKA on Hamilton–Jacobi–Bellman equations with time-measurable data and had extensive discussions with PIERMARCO CANNARSA on new aspects involving calculus of variations.

PIERNICOLA BETTIOL worked in particular with MARC QUINCAMPOIX and RICHARD VINTER on a Differential Games problem and on generalized necessary optimality conditions.

CORALIA CARŢIŞ had research discussions with SHOHAM SABACH about obtaining global rates of convergence for the augmented Lagrangian for nonconvex optimization problems, which will be continued.

PATRICK COMBETTES and ISAO YAMADA initiated a collaboration on topics on operator splitting and algorithms for monotone inclusions.

ERNÖ ROBERT CSETNEK, YURA MALITSKY, and MATTHEW TAM completed their work on a new algorithm for finding a zero in the sum of two monotone operators where one is assumed to be single-valued and Lipschitz continuous. Their algorithm naturally arises from a non-standard discretization of a continuous dynamical system associated with the classical Douglas-Rachford splitting algorithm.

One of the current research topics of ARIS DANIILIDIS is on self-constructed curves. Further extensions concern the relation between alternate projection methods for solving the convex feasibility problem and self-contracted sequences. This research, initiated during the ESI program, is the object of an on-going collaboration with AXEL BÖHM.

MINH DAO and Russell Luke initiated a collaboration on a submonotone property for set-valued operators with applications to proximal algorithms.

JONATHAN ECKSTEIN and PONTUS GISELSSON had an extensive discussion about the equivalence of projective splitting to some kind of ordinary operator splitting scheme without an explicit separator construction.

JONATHAN ECKSTEIN and PATRICK COMBETTES discussed applications of their recent work to imaging, data science, and stochastic programming.

SORIN-MIHAI GRAD discussed topics for possible collaboration with ORESTES BUENO (on monotone operators, more precisely on which of their properties could be extendable to quasi-dense monotone multifunctions) and MATHIAS STAUDIGL (on strong convergence of trajectories of dynamical systems associated to some splitting algorithms), among others.

RENÉ HENRION and BORIS MORDUKHOVICH initiated a collaboration the robust control of a sweeping process with probabilistic end-point constraints.

WOJCIECH KRYSZEWSKI had fruitful discussions with HÉLENE FRANKOWSKA, and worked on completing the paper on some new issues of viability and invariance of constrained evolution equations in Banach spaces, especially on those driven by systems of parabolic partial differential equations subject to local state-constraints and the Dirichlet or Neumann boundary value conditions.

SZILÁRD LÁSZLÓ had enlightening discussions with ULISSE STEFANELLI concerning the possibility of approximating the solutions of a second order dynamical system through solutions of a perturbation of this system. He also continued the collaboration with RADU I. BOŢ and ERNÖ ROBERT CSETNEK on the continuous version of the ADMM algorithm.

RUSSELL LUKE, SHOHAM SABACH and MATHIAS STAUDIGL have begun to collaborate on a proposal for a joint Marie Skłodowska-Curie Actions - Innovative Training Network combining nonsmooth analysis with game theory and their applications.

RUSSELL LUKE, SHOHAM SABACH and MARC TEBOULLE used the opportunity also to finish a grant proposal for a joint German-Israel cooperation grant on the theory of first-order algorithms for structured composite nonconvex optimization.

SHIN-YA MATSUSHITA discussed with HEDY ATTOUCH about the convergence rate analysis of the inertial proximal algorithms. He also discussed with WOTAO YIN about his recent work on the three-operators splitting algorithm.

WALAA MOURSI started a new collaboration with PONTUS GISELSSON on algorithms for monotone inclusion problems.

TEEMU PENNANEN had interesting discussions with MICHAEL HINTERMÜLLER and started making plans for future collaboration on optimization related to energy markets.

JEAN-CHRISTOPHE PESQUET and ELENA RESMERIŢĂ initiated a collaboration concerning models involving an ℓ_p penalty, where p is also viewed as a variable to be optimized.

ADRIAN PETRUŞEL and MICHEL THÉRA initiated a collaboration on applications of some variational analysis (metric regularity, Aubin continuity) concepts in the study of various stability properties related to fixed point and coincidence point theory.

GEORG PFLUG discussed with MICHAEL HINTERMÜLLER about stochatisc constrained optimization methods in Hilbert spaces and received the invitation for a talk at the Weierstrass Institute in Berlin.

MARC QUINCAMPOIX, TERESA SCARINCI, and VLADIMIR VELIOV discussed regularity conditions for affine control problems and planed joint work on this topic in May 2019 (hosted in Université de Bretagne-Occidentale, France).

STEPHEN SIMONS had a number of fruitful discussions with ORESTES BUENO, who pointed him to an example which provides a quasi dense maximally monotone linear operator whose Fitzpatrick extension is not quasldense.

ULISSE STEFANELLI discussed with SZILÁRD LÁSZLÓ some analytic issues concerning existence and convergence to equilibria of hamiltonian flows under a time-dependent, linear damping. The issue is to connect limiting behaviour of the systems under vanishing damping, which could deliver an approximation strategy.

THOMAS SUROWIEC and RUSSELL LUKE discussed the possibility of applying several deeper results of the limiting variational calculus to derive explicit formulae for coderivatives of compositions of projection and reflection operators. They also discussed the potential of applying modern first-order methods to PDE-constrained optimization under uncertainty.

MICHEL THÉRA disseminated his recent results on the concept of directional metric regularity with respect to a cone and had several discussions with other participants, in particular with RUSSELL LUKE on possible applications of these results to convergence analysis of algorithms.

FREDI TRÖLTZSCH and VLADIMIR VELIOV discussed future collaboration on sparse control of parabolic equations and the related regularity problems.

MICHAEL ULBRICH had fruitful discussions, in particular with DOMINIKUS NOLL on bundle methods and with colleagues who are active as PIs in the DFG priority program SPP 1962 working on related topics, especially MICHAEL HINTERMÜLLER, CHRISTIAN KANZOW, and THOMAS SUROWIEC.

List of talks

Workshop 1 on "Nonsmooth and Variational Analysis', January 28 – February 1, 2019

R. Tyrrell Rockafellar	Decomposition algorithms for generalized equation problems with elicitable monotonicity
Rafal Goebel	Lyapunov-like tools for pointwise asymptotic stability of a set of equilibria
Szilárd László	A second order dynamical approach with variable coefficients to nonconvex smooth minimization
Ewa Bednarczuk	On dynamical system related to a class of proximal primal-dual best approximation method
Franco Rampazzo	Higher order necessary conditions for impulsive optimal control problems: a set-separation approach
Vincenzo Basco	Necessary conditions for infinite horizon optimal control problems under state constraints and Hamilton-Jacobi-Bellman equations
Elsa Maria Marchini	Second order necessary conditions for infinite dimensional control problems
Piernicola Bettiol	A necessary condition in the calculus of variations and some applications
Michel Théra	Metric regularity and directional metric regularity of multifunctions
Xiao-qi Yang	On error bound moduli for locally Lipschitz and regular functions
Boris Mordukhovich	Criticality of Lagrange multipliers in conic programming with applications to superlinear convergence of SQP
Diethard Klatte	On extensions of Newton's method for equations and inclusions
Georg Pflug	Stochastic constrained optimization in Hilbert spaces with applications
D. Russell Luke	Variational analysis of random function iterations
Ulisse Stefanelli	The WIDE variational principle for nonlinear evolution
Adrian Petruşel	Variational analysis concepts in coincidence point theory
Marc Quincampoix	On a multiagent Bolza control problem
Hélène Frankowska	Domain invariance for local solutions of semilinear evolution equations in Hilbert spaces
Terence Bayen	About the minimal time crisis problem
Wojciech Kryszewski	Semigroup and resolvent invariance of convex sets
Shu Lu	Statistical inference for piecewise normal distributions and application to stochastic variational inequalities
Josef Hofbauer	Monotone operators and ODEs - some examples
Constantin Zălinescu	On Lagrange multipliers in convex entropy minimization
Stephen Simons	Quasidense multifunctions
Orestes Bueno	Remarks on p-cyclically monotone operators
Fredi Tröltzsch	Sparse optimal control for a semilinear heat equation with mixed control-state constraints
Vladimir Veliov	Metric regularity properties of the optimality mapping for ODE optimal control
Richard Vinter	Multifunctions of bounded variation and control theory applications
Asen Dontchev	Uniform strong regularity, Newton's method, and model predictive control
Carlos Rautenberg	Parabolic quasi-variational inequalities with gradient and obstacle type constraints

Samir Adly	Nonconvex degenerate sweeping process
René Henrion	Robust control of a sweeping process with probabilistic end-point constraints
Aris Daniilidis	Linear structure of Lipschitz functions that saturate their Clarke subdifferential
André Uschmajew	Critical points of quadratic low-rank optimization problems
Michael Hintermüller	A function space framework for structural total variation regularization with applications in inverse problems
Jose-Francisco Rodrigues	On a class of nonlocal variational and quasivariational inequalities
Juan-Enrique Martínez-Legaz	On the structure of higher order Voronoi cells
Teemu Pennanen	Convex duality in nonlinear optimal transport
Didier Aussel	New existence results for quasivariational inequalities on product spaces: why, what and how?

Lecture Series 1 on "Optimal Control and PDE Constrained Optimization", February 4 – 7, 2019

Fredi Tröltzsch	An introduction to the optimal control of nonlinear partial differential equations (I - III)
Hélène Frankowska	Optimal controls for evolution control systems (I - II)
Piermarco Cannarsa	Singularities of solutions to Hamilton-Jacobi equations (I - III)
Michael Hintermüller	Optimal control of nonsmooth structures (I - II)

Lecture Series 2 on "Numerical Methods in Nonsmooth Optimization", February 21 – 22, 2019

Marc Teboulle	Proximal methods in optimization (I - III)
Peter Richtarik	Introduction to randomized methods in convex optimization (I - III)

Workshop 2 on "Numerical Algorithms in Nonsmooth Optimization", February 25 – March 1, 2019

Hedy Attouch	Relaxed inertial proximal algorithms for monotone inclusions
Jérôme Bolte	A multi-proximal method for convex composite optimization
Shoham Sabach	Lagrangian-based methods for nonconvex optimization problems
D. Russell Luke	Convergence analysis of algorithms for inconsistent nonconvex feasibility
Aris Daniilidis	Self-contracted curves and extensions
Xiaoming Yuan	An inexact Uzawa algorithmic framework for nonlinear saddle point problems
Wotao Yin	Scaled relative graph: a rigorous $2D$ geometric tool for contractive and nonexpansive operators
Juan Peypouquet	Lagrangian penalization scheme with parallel forward-backward splitting
Marc Teboulle	Analysis of proximal methods for composite minimization
Christian Kanzow	Safeguarded augmented Lagrangian methods in finite and infinite dimensions
Peter Richtarik	SEGA: variance reduction via gradient sketching
Ion Necoară	Minibatch stochastic first order methods for composite convex optimization
Mathias Staudigl	On the convergence of stochastic forward-backward-forward algorithms with variance reduction in pseudo-monotone variational inequality problems
Coralia Carţiş	Dimensionality reduction techniques for global optimization
Immanuel Bomze	Non-convex min-max fractional quadratic problems under quadratic constraints: copositive relaxations
Amir Beck	On the convergence to stationary points of deterministic and randomized feasible descent directions methods
Volkan Cevher	Storage optimal semidefinite programming
Patrick Combettes	Between subdifferentials and monotone operators
Jonathan Eckstein	Projective splitting with cocoercive operators
Szilárd László	A gradient type algorithm with backward inertial steps for a nonconvex minimization

Otmar Scherzer	Convergence rates of first and higher order dynamics for solving linear ill-posed problems
Elena Resmeriţă	Sparsity regularization: a general non-convex approach
Shin-ya Matsushita	Rates of asymptotic regularity for the forward-backward splitting algorithm
Isao Yamada	An approximate simultaneous matrix-diagonalization via alternating projection
Walaa Moursi	Reflected resolvents in the Douglas-Rachford algorithm: order of the operators and linear convergence
Minh Dào	Adaptive Douglas-Rachford splitting algorithm and applications
Karl Kunisch	Monotone and primal-dual algorithms for optimization problems involving ℓ^p and ℓ^p-like functionals with $p \in [0,1)$
Michael Hintermüller	(Pre)Dualization, dense embeddings of convex sets, and applications in image processing
Stefan Ulbrich	Computing a subgradient for the solution operator of the obstacle problem and numerical realization
Dominikus Noll	Optimization strategies to control infinite-dimensional systems
Michael Ulbrich	An inexact bundle method for nonconvex nondifferentiable minimization in Hilbert space
Ernest K. Ryu	Uniqueness of DRS as the 2 Operator Resolvent-Splitting and Impossibility of 3 Operator Resolvent-Splitting
Thomas Surowiec	A primal-dual algorithm for PDE-constrained optimization under uncertainty
Matthew Tam	Forward-backward splitting without cocoercivity
Yura Malitsky	On a new method for monotone inclusions
Jean-Christophe Pesquet	Deep unfolded proximal interior point algorithm
Sebastian Banert	How to accelerate convex optimisation with machine learning
Silvia Villa	Thresholding gradient algorithms in Hilbert spaces: support identification and linear convergence
Pontus Giselsson	Performance estimation in operator splitting methods
Panos Patrinos	A universal majorization-minimization framework for the convergence analysis of nonconvex proximal algorithms
Tuomo Valkonen	First-order methods and model splitting techniques for non-convex non-smooth optimisation

Lecture Series 3 on "Variational Analysis and Numerical Methods in Nonsmooth Optimization", March 4 – 6, 2019

Jean-Christophe Pesquet	Stochastic splitting algorithms for solving monotone inclusions and convex optimization problems (I - III)
Aris Daniilidis	Exploring structure in variational analysis and optimization (I - III)

Publications and preprints contributed

M. D. Fajardo, S. M. Grad, J. Vidal, *New duality results for evenly convex optimization problems*, Optimization, A Journal of Mathematical Programming and Operations Research, arXiv:1904.10478 [math.OC].

B. S. Mordukhovich, *Avoiding critical multipliers and slow convergence of primal-dual methods for fully stable minimizers*, Journal of Nonlinear and Convex Analysis 20 (4), 2019, arXiv:1901.01469 [math.OC].

A. Daniilidis, G. Flores, *Linear structure of functions with maximal Clarke subdifferential*, SIAM Journal on Optimization 29 (2019), 511-521, arXiv:1809.00684 [math-FA].

E. R. Csetnek, Y. Malitsky, M. K. Tam, *Shadow Douglas–Rachford Splitting for Monotone Inclusions*, arXiv:1903.03393 [math.OC].

P. L. Combettes, *Monotone Operator Theory in Convex Optimization*, arXiv:1802.02694 [math-OC].

H. Attouch, Z. Chbani, H. Riahi, *Convergence rates of inertial proximal algorithms with general extrapolation and proximal coefficients*, HAL-02021322.

V. Basco, H. Frankowska, *Hamilton-Jacobi-Bellman equations with time-measurable data and infinite horizon*, Nonlinear Differential Equations and Applications NoDEA volume 26, Article number: 7 (2019), https://link.springer.com/article/10.1007/s00030-019-0553-y.

H.H. Bauschke, W. Moursi, X. Wang, *Generalized monotone operators and their averaged re-solvents*, submitted to SIAM Journal on Optimization, 2019, arXiv:1902.09827 [math.OC].

P. Bettiol, M. Quincampoix, R. Vinter, *Existence and characterization of the values of two player differential games with state constraints*, Applied Mathematics & Optimization volume 80, pages 765–799, https://link.springer.com/article/10.1007/s00245-019-09608-8.

P. Cannarsa, G. Da Prato, H. Frankowska, *Domain invariance for local solutions of semilinear evolution equations in Hilbert spaces*, http://math.scu.edu.cn/info/1062/5565.htm.

C. Carţiş, J. Fiala, B. Marteau, L. Roberts, *Shadow Douglas–Rachford Splitting for Monotone Inclusions*, Applied Mathematics & Optimization volume 80, pages 665–678, https://link.springer.com/article/10.1007/s00245-019-09597-8.

C. Carţiş, L. Roberts, *A derivative-free Gauss-Newton method*, arXiv:1710.11005 [math.OC].

P. L. Combettes, J.-C. Pesquet, *Lipschitz certificates for neural network structures driven by averaged activation operators*, arXiv:1903.01014 [math.OC].

J. Eckstein, P. R. Johnstine, *Single-Forward-Step Projective Splitting: Exploiting Cocoercivity*, arXiv:1902.09025 [math.OC].

C. Geiersbach, G. Pflug, *Stochastic constrained optimization in Hilbert spaces with applications*, submitted for publication to SIAM Journal on Optimization, 2019, DOI:10.1137/18M1200208.

W. Kryszewski, J. Siemianowski, *On some problems concerning viability and invariance for evolution equations in Banach spaces*, in preparation.

D. R. Luke, S. Sabach, M. Teboulle, *Optimization on Spheres: models and proximal algorithms with computational performance comparisons*, submitted to SIAM Journal on Mathematics of Data Science, 2019. DOI:10.1137/18M1193025.

N. P. Osmolovskii, V. M. Veliov, *Metric sub-regularity in optimal control of affine problems with free end state*, ORCOS.

A. Petruşel, G. Petruşel, *On some stability properties in fixed point theory*, Journal of Nonlinear and Convex Analysis, 2019.

S. Simons, *A stand-alone analysis of quasidensity*, in preparation.

E. K. Ryu, R. Hannah, W. Yin, *Scaled Relative Graph: Nonexpansive operators via 2D Euclidean Geometry*, arXiv:1902.09788 [math.OC].

R. Vinter, *Optimal control problems with time delays: constancy of the Hamiltonian*, SIAM Journal on Control and Optimization, 2019, DOI:10.1137/18M1173897.

W. Kryszewski, J. Siemianowski, *Constrained semilinear elliptic systems in R^N*, arXiv:2001.07272 [math.AP].

Invited scientists

Samir Adly, Hedy Attouch, Didier Aussel, Sebastian Banert, Vincenzo Basco, Terence Bayen, Amir Beck, Ewa Bednarczuk, Matus Benko, Arian Berdellima, Julien Bernis, Piernicola Bettiol, Axel Böhm, Jérôme Bolte, Immanuel Bomze, Benoit Bonnet, Pedro Henrique Borges de Melo, Radu I. Boţ, Orestes Bueno Tangoa, Piermarco Cannarsa, Coralia Carţiş, Volkan Cevher, Patrick Luis Combettes, Ernö Robert Csetnek, Aris Daniilidis, Minh Dao, Elisa Davoli, Asen Dontchev, Jonathan Eckstein, Hélene Frankowska, Caroline Geiersbach, Marina Ghisi, Pontus Giselsson, Massimo Gobbino, Rafal Goebel, Sorin-Mihai Grad, René Henrion, Josef Hofbauer, Michael Hintermüller, Christian Kanzow, Owari Keita, Pham Duy Khanh, Diethard Klatte, Wojciech Kryszewski, Karl Kunisch, Szilárd László, Florian Lauster, Eric Legler, Shu Lu, Russell Luke, Yura Malitsky, Elsa Maria Marchini, Juan Enrique Martínez-Legaz, Shin-ya Matsushita, Dennis Meier, Tiago Montanher, Boris Mordukhovich, Walaa Moursi, Ion Necoară, Dang-Khoa Nguyen, Nimit Nimana, Dominikus Noll, Hui Ouyang, Panos Patrinos, Teemu Penannen, Jean-Christophe Pesquet, Adrian Petruşel, Gabriela Petruşel, Juan Peypouquet, Georg Pflug, Tu Vuong Phan, Marc Quincampoix, Franco Rampazzo, Carlos N. Rautenberg, Elena Resmeriţă, Peter Richtarik, Terry Rockafellar, José Francisco Rodrigues, Ernest K. Ryu, Shoham Sabach, Teresa Scarinci, Otmar Scherzer, Michael Sedlmayer, Stephen Simons, Mathias Staudigl, Ulisse Stefanelli, Defeng Sun, Thomas Surowiec, Matthew Tam, Marc Teboulle, Michel Théra, Fredi Tröltzsch, Michael Ulbrich, Stefan Ulbrich, André Uschmajew, Tuomo Valkonen, Vladimir Veliov, Silvia Villa, Richard Vinter, Enrico Wegner, Elise Weill-Duflos, Isao Yamada, Xiao-qi Yang, Wenfang Yao, Wotao Yin, Xiaoming Yuan, Constantin Zălinescu.

Higher Spins and Holography

Organizers: Andrea Campoleoni (U Mons), Stefan Fredenhagen (U Vienna), Matthias R. Gaberdiel (ETH Zurich), Daniel Grumiller (TU Vienna), Mikhail A. Vasiliev (Lebedev Inst. Moscow)

Dates: March 11 – April 5, 2019

Budget: ESI € 35 499,
ÖAW € 2 380.

Report on the programme

The programme gathered experts in higher-spin (HS) gauge theories. These are (quantum) field theories involving a massless particle of spin two, that is a gravitation, together with (typically infinitely many) gauge fields of spin greater than two. An important motivation for their study originates from the long-standing difficulties encountered in the quantisation of gravity, which impel to explore extensions thereof that may have a better UV behaviour. Including fields of spin greater than two is mainly suggested by two observations: the constraints brought by a larger gauge symmetry may remove some UV divergences as supersymmetry does, and string theory does involve fields of arbitrary spin. HS gauge theories are indeed models of intermediate complexity with respect to these examples, and aspire to improve the UV behaviour of supergravity models without resorting to fully-fledged string theory and its plethora of additional particles.

The last years have seen enormous progress in the understanding of such theories: HS gauge theories have also been holographically related to conformal field theories (CFT). Their conjectured connections to string theory in a tensionless limit started to be explored quantitatively. The aim of the programme has been to build upon the recent achievements by bringing together experts in the field to stimulate important progress towards long-term goals like a quantum formulation of HS theories, a derivation of the HS AdS/CFT correspondence and the link to the tensionless limit of string theory.

Activities

The programme started with several introductory talks in the first week along with further selected seminar talks. This week, as well as the weeks 3 and 4 of the programme, had a deliberately light schedule of talks to facilitate research and interactions between the participants, typically with only one or two talks a day to bring the participants together and to initiate discussion.

Week 2 has been instead dedicated to a workshop with a full schedule of talks, to allow selected participants to share their last results with the full audience.

A public talk by Marc Henneaux has also been organised in the first week at the Academy of Sciences in the Theatre Lecture Hall.

The scientific activities were accompanied by a conference dinner in the second week.

The full programme is available at the conference webpage
http://quark.itp.tuwien.ac.at/~grumil/ESI2019/.

Specific information on the programme

Numerous younger researchers — international invitees as well as local participants — contributed to and profited from the programme. Here is an alphabetical list of 23 younger participants: Thomas Basile (Kyung Hee U), Nicolas Delporte (Orsay, LPT), David De Filippi (U Mons), Lorenz Eberhardt (ETH Zürich/IAS Princeton), Marc-Antoine Fiset (Oxford U/ETH Zürich), Oscar Fuentealba (CECS, Valdivia/Intl. Solvay Inst., Brussels), Sergio Hörtner (Madrid, Autonoma U), Anatoliy Korybut (Lebedev Inst.), Konstantinos Koutrolikos (Brown U), Olaf Krüger (U Vienna), Sucheta Majumdar (Brussels U and Intl. Solvay Inst., Brussels), Javier Matulich (Brussels U. and Intl. Solvay Inst., Brussels), Aditya Mehra (IIP, Brazil and Potsdam, Max Planck Inst.), Wout Merbis (Brussels U and Intl. Solvay Inst., Brussels), Nikita Misuna (Lebedev Inst.), Ruben Monten (IPhT, Saclay), Mojtaba Najafizadeh (IPM, Tehran), Pulastya Parekh (IIT Kanpur/ESI/CECS, Valdivia), Stefan Prohazka (Brussels U and Intl. Solvay Inst., Brussels/Edinburgh U), Jakob Salzer (U Barcelona/Harvard U), Takahiro Uetoko (Ritsumeikan U, Kusatsu), Raphaela Wutte (TU Vienna), Celine Zwikel (TU Vienna).

Eight of these researchers gave talks during our programme (Nicolas Delporte, David de Filippi, Lorenz Eberhardt, Oscar Fuentealba, Konstantinos Koutrolikos, Olaf Krüger, Nikita Misuna and Takahiro Uetoko).

Outcomes and achievements

The programme brought together established researchers and young scientists working on different aspects in the field of higher spins. The talks initiated lively discussions on new developments in the field and possible further directions. Besides the talks the ample time for discussions engendered several new collaborations and strengthened existing ones, as evident from the list of programme-related ESI preprints that have been initiated or progressed during the programme. We mention here selected additional outcomes:

- One of the programme participants, Pulastya Parekh, received an ESI Junior Fellowship that allowed close collaboration with one of the organizers, Daniel Grumiller, and eventually led to a research paper published in Phys.Rev.Lett., see https://doi.org/10.1103/PhysRevLett.123.121602

- Discussions between Maxim Grigoriev and one of the organizers, Stefan Fredenhagen, initiated the organisation of a thematic programme at ESI in 2021, focussing on the connection of higher spin gauge theories to mathematical questions in geometry.
- The programme has seen several contributions from experts on related fields which stimulated interesting discussions on possible connections. This includes Harold Steinacker's talk about matrix models as well as Vincent Rivasseau's talk on the tensor track.

List of talks

Week 1, Introductory and seminar talks, March 11 – 15, 2019

Dionysios Anninos	De Sitter Review
Arjun Bagchi	BMS on the Worldsheet: the story of Tensionless Strings
Joris Raeymaekers	Symmetric orbifolds and tensionless string field theory
Vincent Rivasseau	The Tensor Track
Carlo Iazeolla	Solving the Vasiliev equations: perturbative schemes, exact solutions, local vs. global aspects
Evgeny Skvortsov	Higher Spin Gravities and Deformation Quantization
Karapet Mkrtchyan	Looking for Partially-Massless Gravity
Ergin Sezgin	The spectrum of metric-affine gravitational theories
Marc Henneaux	Gravitation and Quantum Mechanics: the biggest crisis in modern physics? (Public talk at the Academy of Sciences)

Week 2, Workshop week, March 18 – 22, 2019

Bo Sundborg	Field theory compositeness, holographic gravity and higher spins
Euihun Joung	Conformal Higher Spin Theory: Linear spectrum=Symmetry
Dario Benedetti	Bilocal effective action for tensor models
Dmitry Ponomarev	On quantum correction in higher spin gravities
Alejandra Castro	3D gravity, Chern-Simons theory, and Wilson lines
Yurii Zinoviev	Massive higher spin supermultiplets in AdS_4
Stéphane Detournay	Anti anti-de Sitter black holes
Predrag Dominis Prester	Higher spins with the Moyal product?
Dmitri Sorokin	Can Chern-Simons or Rarita-Schwinger be a Volkov-Akulov Goldstone?
Yasuaki Hikida/Takahiro Uetoko	Rectangular W-algebras, extended higher spin gravity and dual coset CFTs
Rakibur Rahman	Massive and Massless Higher-Spin Fields in Nontrivial Backgrounds
Lorenz Eberhardt	Tensionless strings on AdS3
Mikhail Vasiliev	Higher-Spin Theories and Spin Locality
Tomáš Procházka	W-symmetry and instanton R-matrix
Marc Henneaux	Asymptotic symmetries of electromagnetism and gravity: a Hamiltonian study
Nicolas Delporte	Tensor Models: Looking for RG fixed points in $d > 1$
Massimo Taronna	Exchange Amplitudes and the Bootstrap
Jung-gi Yoon	Chaos in Three-dimensional Higher Spin Gravity
David de Filippi	Observables and boundary conditions in Vasiliev's higher spin gravity

Week 3, March 25 – 29, 2019

Dario Francia	Asymptotic symmetries: from low to high spins
Maxim Grogoriev	Gauge theories as Q-bundles
Harold Steinacker	Quantum space-time, higher spin and gravity from matrix models
Ricardo Troncoso	Hypergravity in five dimensions
Savdeep Sethi	The Status of the String Landscap
Wei Li	How to glue plane partitions to construct new VOAs/affine Yangians

Cheng Peng	SYK-like models, Higher-spins and Chaos
Konstantinos Koutrolikos	Higher spin supercurrents of matter supermultiplets
Antal Jevicki	HS Graphs and Vertices from Bilocal Holography
Nikita Misuna	On off-shell formulation of higher-spin equations
Oscar Fuentealba	Hypergravity in all odd spacetime dimensions

Week 4, April 1 – 5, 2019

Stefan Theisen	Weyl anomalies in the presence of irrelevant operators
Rajesh Gopakumar	A Worldsheet Dual for the Symmetric Orbifold
Massimo Porrati	Two applications of the infrared factorization of IR dynamics
Olaf Krüger	Constraints for $n > 3$ point vertices in 3D Higher Spin Theories
Jan Rosseel	Three-dimensional non-relativistic (super)gravity and higher spins

Publications and preprints contributed

P. Narayan, J. Yoon, *Chaos in Three-dimensional Higher Spin Gravity*, arXiv:1903.08761 [hep-th].

V. Jahnke, K.Y. Kim, J. Yoon , *On the Chaos Bound in Rotating Black Holes*, arXiv:1903.09086v2 [hep-th].

J. Matulich, S. Prohazka, J. Salzer, *Limits of three-dimensional gravity and metric kinematical algebras in any dimension*, arxiv:1903.09165 [hep-th].

J. Raeymaekers, *On tensionless string field theory in AdS3*, arXiv:1903.09647 [hep-th].

D. Ponomarev, E. Sezgin, E. Skvortsov, *On one loop corrections in higher spin gravity*, arXiv:1904.01042 [hep-th].

M. Henneaux, C. Troessaert, *The asymptotic structure of gravity at spatial infinity in four spacetime dimensions*, arXiv:1904.04495 [hep-th].

R. Aros, C. Iazeolla, P. Sundell, Y. Yin, *Higher spin fluctuations on spinless 4D BTZ black hole*, arXiv:1903.01399 [hep-th].

E. Joung, K. Mkrtchyan, G. Poghosyan, *Looking for partially-massless gravity*, arXiv:1904.05915 [hep-th].

I.L. Buchbinder, M.V. Khabarov, T.V. Snegirev, Y.M. Zinoviev, *Lagrangian formulation for the infinite spin N=1 supermultiplets in d=4*, arXiv:1904.05580 [hep-th].

S. Majumdar, *Ehlers symmetry in four dimensions*, arXiv:1904.08453 [hep-th].

S. Banerjee, J. Engelsöy, J. Larana-Aragon, B. Sundborg, L. Thorlacius, N. Wintergerst, *Quenched coupling, entangled equilibria, and correlated composite operators: a tale of two O(N) models*, arXiv:1903.12242 [hep-th].

I. Bandos, S. Lanza, D. Sorokin, *Supermembranes and domain walls in N=1, D=4 SYM*, arXiv:1905.02743 [hep-th].

José Figueroa-O'Farrill, Ross Grassie, Stefan Prohazka, *Geometry and BMS Lie algebras of spatially isotropic homogeneous spacetimes*, arXiv:1905.00034 [hep-th].

I.L. Buchbinder, S. James Gates. K.Koutrolikos, *Superfield continuous spin equations of motion*, DOI:10.1016

J. Yoon, *A Bound on Chaos from Stability*, arXiv:1905.08815 [hep-th].

N. Misuna, *On unfolded off-shell formulation for higher-spin theory*, arXiv:1905.06925 [hep-th].

R. C. Rashkov, *On some (integrable) structures in low-dimensional holography*, arXiv:1905.07190 [hep-th].

D. Chernyvsky, D. Sorokin, *Three-dimensional (higher-spin) gravities with extended Schroedinger and l-conformal Galilean symmetries*, arXiv:1905.13154 [hep-th].

Y. H. Qi, S. J. Sin, J. Yoon, *Quantum Correction to Chaos in Schwarzian Theory*, arXiv:1906.00996 [hep-th].

A. Campoleoni, D. Francia and C. Heissenberg, *On electromagnetic and colour memory in even dimensions*, arXiv:1907.05187 [hep-th].

M. Najafizadeh, *Supersymmetric Continuous Spin Gauge Theory*, arXiv:1912.12310 [hep-th].

S. Fredenhagen, O. Krüger, K. Mkrtchyan, *Restrictions for n-Point Vertices in Higher-Spin Theories*, arXiv:1912.13476 [hep-th].

S. Fredenhagen, O. Krüger, K. Mkrtchyan, *Vertex-Constraints in 3D Higher Spin Theories*, arXiv:1905.00093 [hep-th].

D. Grumiller, P. Parekh, M. Riegler, *Local quantum energy conditions in non-Lorentz-invariant quantum field theories*, arXiv:1907.06650 [hep-th].

K. Mkrtchyan, *On Covariant Actions for Chiral p-Forms*, arXiv:1908.01789 [hep-th].

L. Eberhardt, M.R. Gaberdiel, *Strings on* $AdS_3\times S^3\times S^3\times S^1$, arXiv:1904.01585 [hep-th].

W. Li, P. Longhi, *Gluing two affine Yangians of* $\mathfrak{gl}_1$, arXiv:1905.03076 [hep-th].

R. Rahman, *The Uniqueness of Hypergravity*, arXiv:1905.04109 [hep-th].

D. De Filippi, C. Iazeolla, P. Sundell, *Fronsdal fields from gauge functions in Vasiliev's higher-spin gravity*, arXiv:1905.06325 [hep-th].

H.C. Steinacker, *Scalar modes and the linearized Schwarzschild solution on a quantized FLRW space-time in Yang-Mills matrix models*, arXiv:1905.07255 [hep-th].

M. Ammon, M. Baggioli, S. Gray, S. Grieninger, *Longitudinal Sound and Diffusion in Holographic Massive Gravity*, arXiv:1905.09164 [hep-th].

A. Bagchi, A. Banerjee, P. Parekh, *The tensionless path from closed to open strings*, arXiv:1905.11732 [hep-th].

N. Delporte, V. Rivasseau, *Perturbative Quantum Field Theory on Random Trees*, arXiv:1905.12783 [hep-th].

T. Creutzig, Y. Hikida, T. Uetoko, *Rectangular W-algebras of types so(M) and sp(2M) and dual coset CFTs*, arXiv:1906.05872 [hep-th].

T. Creutzig, Y. Hikida, *Rectangular W-(super)algebras and their representations*, arXiv:1906.05868 [hep-th].

D. Grumiller, W. Merbis, *Near horizon dynamics of three dimensional black holes*, arXiv:1906.10694 [hep-th].

C. Sleight, *A Mellin Space Approach to Cosmological Correlators*, arXiv:1906.12302 [hep-th].

C. Sleight, M. Taronna, *Bootstrapping Inflationary Correlators in Mellin Space*, arXiv:1907.01143 [hep-th].

A. Dei, L. Eberhardt, M.R. Gaberdiel, *Three-point functions in* AdS_3/CFT_2 *holography*, arXiv:1907.13144 [hep-th].

U. Kol, M. Porrati, *Properties of Dual Supertranslation Charges in Asymptotically Flat Spacetimes*, arXiv:1907.00990 [hep-th].

H. Afshar, *Warped Schwarzian theory*, arXiv:1908.08089 [hep-th].

D. Grumiller, A. Pérez, M.M. Sheikh-Jabbari, R. Troncoso, C. Zwikel, *Spacetime structure near generic horizons and soft hair*, arXiv:1908.09833 [hep-th].

A. Aggarwal, A. Castro, S. Detournay, *Warped Symmetries of the Kerr Black Hole*, arXiv:1909.03137 [hep-th].

V.E. Didenko, O.A. Gelfond, A.V. Korybut, M.A. Vasiliev, *Limiting Shifted Homotopy in Higher-Spin Theory and Spin-Locality*, arXiv:1909.04876 [hep-th].

L. Eberhardt, T. Procházka, *The matrix-extended $W_{1+\infty}$ algebra*, arXiv:1910.00041 [hep-th].

O. Fuentealba, J. Matulich, R. Troncoso, *Hypergravity in five dimensions*, arXiv:1910.03179 [hep-th].

L. Eberhardt, M.R. Gaberdiel, R. Gopakumar, *Deriving the AdS_3/CFT_2 Correspondence*, arXiv:1911.00378 [hep-th].

H.C. Steinacker, *On the quantum structure of space-time, gravity, and higher spin in matrix models*, arXiv:1911.03162 [hep-th].

O. Hulik, J. Raeymaekers, O. Vasilakis, *Information recovery from pure state geometries in 3D*, arXiv:1911.12309 [hep-th].

S. Detournay, W. Merbis, G.S. Ng, R. Wutte, *Warped Flatland*, arXiv:2001.00020 [hep-th].

Invited scientists

Hamid Afshar, Martin Ammon, Dionysios Anninos, Luis Apolo, Cesar Arias, Arjun Bagchi, Thomas Basile, Dario Benedetti, Klaus Bering, Andrea Campoleoni, Alejandra Castro, Abishek Chowdhury, Sumit Das, David De Filippi, Nicolas Delporte, Stephane Detournay, Viacheslav Didenko Evgenevich, Lorenz Eberhardt, Marc-Antoine Fiset, Dario Francia, Oscar Fuentealba, Stefan Fredenhagen, Matthias Gaberdiel, Olga Gelfond, Rajesh Gopakumar, Maxim Grigoriev, Daniel Grumiller, Marc Henneaux, Yasuaki Hikida, Sergio Hörtner, Carlo Iazeolla, Antal Jevicki, Euhiun Joung, Yegor Korovin, Anatoliy Korybut, Konstantinos Koutrolikos, Olaf Krüger, Sailesh Lal, Wei Li, Iva Lovrekovic, Sucheta Majumdar, Javier Matulich, Wout Merbis, Nikita Misuna, Karapet Mkrtchyan, Ruben Monten, Mojtaba Najafizadeh, Pulastya Parekh, Cheng Peng, Alfredo Perez, Dmitri Ponomarev, Massimo Porrati, Predag Dominis Prester, Tomas Prochazka, Stefan Prohazka, Joris Raeymaekers, Rakibur Rahman, Radoslav Rashkov, Vincent Rivasseau, Jan Rosseel, Jakob Salzer, Maria Schimpf, Ergin Sezgin, Evgeny Skvortsov, Charlotte Sleight, Aditya Singh Mehra, Jiro Soda, Dmitri Sorokin, Harold Steinacker, Georg Stettinger, Bo Sundborg, Per Sundell, Massimo Taronna, David Tempo, Stefan Theisen, Ricardo Troncoso, Takahiro Uetoko, Orestis Vasilakis, Mikhail A. Vasiliev, Timm Wrase, Raphaela Wutte, Yihao Yin, Junggi Yoon, Yury Zinoviev, Celine Zwikel.

Optimal Transport

Organizers: Mathias Beiglböck (U Vienna), Alessio Figalli (ETH Zurich), Jan Maas (IST Austria), Robert McCann (U Toronto), Justin Solomon (MIT, Boston)

Dates: April 15 – June 14, 2019

Budget: ESI €67 526
The following additional sources were used for covering travel costs of programme participants and/or for costs associated to the workshops.

- FWF Special Research Program (F 65) *Taming Complexity in Partial Differential Systems*: € 1 884
- FWF Start Grant (Y 782) *Optimal Transport and Robust Hedging* held by Mathias Beiglböck: € 5 279
- ERC Consolidator Grant (721675) *Regularity and Stability in Partial Differential Equations* held by Alessio Figalli: € 5 587

- ERC Starting Grant (716117) *Optimal Transport and Stochastic Dynamics* held by Jan Maas: € 9 020

Report on the programme

The problem of Optimal Transport goes back to Monge in 1781: how should one transfer mass from a given initial distribution to a prescribed target distribution in such a way that the total transport cost is minimised? In modern mathematics, Optimal Transport plays a major role in developments at the interface of analysis, probability and geometry. Moreover, the field receives renewed interests by practitioners in data analysis, learning, computer graphics, and geometric modelling.

The programme brought together researchers working on Optimal Transport in diverse areas, such as stochastic analysis, mathematical finance, analysis in singular spaces, geometric inequalities, gradient flows, optimal random matching, optimal transport for density matrices, numerical methods, computer vision, and machine learning.

Activities

The following 1-week events took place during the programme:

- Introductory School: *Optimal Transport* (May 6–10, 2019)
- Workshop 1: *Optimal Transport: from Geometry to Numerics* (May 13–17, 2019)
- Workshop 2: *Optimal Transport in Analysis and Probability* (June 3–7, 2019)

Workshop 1 was preceded by a Special Lecture by Fields Medallist Alessio Figalli, which was very well attended by the Viennese mathematical community. In addition, 10 seminar talks by visiting scientists took place during the programme. The quality of the talks during the programme was very high.

Specific information on the programme

The **Introductory School** attracted approximately 60 PhD students and postdocs from all over the world. They attended excellent lecture series by leading scientists in the field.

Yann Brenier gave a stimulating course on optimal transport, hydrodynamics, and mean field games.

Robert McCann presented recent breakthroughs connecting optimal transport and general relativity.

Nicola Gigli taught an inspiring course on the Schrödinger problem, which is currently attracting a lot of interest from both theoretical and applied points of view.

Marco Cuturi gave an overview of important recent advances in computational optimal transport.

The school was complemented by 13 short lectures by junior participants, who presented their recent work. This format created a collaborative atmosphere with many scientific discussions among the participants.

The workshops brought together leading senior researchers as well as promising junior scientists working on optimal transport in different mathematical areas. Several talks in **Workshop 1** were devoted to the interplay of optimal transport and *geometric analysis*.

Andrea Mondino talked about quantitative geometric inequalities in non-smooth spaces based on the localisation method via L^1-optimal transport. Zoltan Balogh presented recent progress on Borell-Brascamp-Lieb inequalities in sub-Riemannian manifolds. An Alexandrov theorem for L^2 almost constant anisotropic mean curvature was presented by Cornelia Mihaila.

Another focus was on *applications of optimal transport in data science, computer vision and machine learning*. Bruno Lévy presented incompressible fluid simulations based on semi-discrete optimal transport. Carola Schönlieb talked about adversarial regularisers for inverse problems which are trained with an approximate Wasserstein loss. Motivated by applications to machine learning, Gabriel Peyré reviewed numerical algorithms for several optimization problems based on optimtal transport. This talk was closely related to the one by Marco Cuturi, who presented several regularization methods for optimal transport. Nicolas García Trillos discussed large sample asymptotics for the spectra of Laplacians on random geometric graphs arising in data science.

Discretisation in optimal transport and partial differential equations appeared in several lectures. Yann Brenier presented computationally efficient time discretisations of the Muskat model based on polar factorization of maps. Improved variational approximation schemes for Wasserstein gradient flows were discussed by Daniel Matthes. Martin Rumpf showed recent work on the computation of optimal transport on discrete metric measure spaces.

Giuseppe Buttazzo presented fundamental results on optimal transport between mutually singular measures. Alexander Mielke gave an overview of recent progress on the Hellinger-Kantorovich distance. *Multi-marginal optimal transport* featured prominently in the talks by Paola Gori-Giorgi on density functional theory, and by Virginie Ehrlacher, who presented a regularisation method.

Probabilistic aspects of optimal transport were present in the talk by Max von Renesse, who presented recent work on the Dean-Kawasaki Equation. This equation can be viewed as a stochastic heat equation with a singular multiplicative noise structure that is formally associated to a Brownian motion on the Wasserstein space. Martin Huesmann's lecture was devoted to large scale regularity for the Monge-Ampére equation. This investigation is partly motivated by applications to random matching problems. An infinite-dimensional version of the Gaussian matching problem was presented by Dario Trevisan.

Several talks in **Workshop 2** were motivated by *applications to economics and finance*. Sigrid Källblad presented work on stochastic control of measure-valued martingales. Alfred Galichon discussed the stable marriage problem and its relation to the Monge-Kantorovich problem. Nizar Touzi presented recent progress on the continuous-time principal-agent problem and extensions to mean-field games. Aaron Palmer presented recent work on a connection of stochastic optimal transport with optimal stopping. Young-Heon Kim focused on duality results for the optimal Skorokhod embedding problem.

A recurring theme was the *Schrödinger problem*, which appeared in talks by Soumik Pal on the difference between entropic cost and the optimal transport cost. Max Fathi used entropic regularization as a tool to obtain a new proof of the celebrated Caffarelli contraction theorem. The multi-marginal version of the Schrödinger problem was dicussed by Guillaume Carlier. Codina Cotar presented recent work relating sharp asymptotics for the minimum energy of optimal point configurations to asymptotics in multi-marginal optimal transport.

Optimal transport on networks was a key theme in various talks. Allen Tannenbaum presented applications of optimal transport to the robustness of networks, especially those connected to cancer. Different biological transport networks were discussed by Jan Haskovec, who presented a discrete-to-continuum limit result based on Γ-comvergence. This concept was also the main tool in the talk by Matias Delgadino on the mean field limit for gradient flow dynamics. Franca Hoffmann presented the Kalman-Wasserstein distance, which yields a gradient flow structure in the mean field for a class of interacting Langevin diffusions arising in optimization problems. José Carrillo gave an overview of primal-dual methods for the discretisation of gradient flows.

The interplay of *optimal transport, geometry, and heat flow* played a central role in several talks. Karl-Theodor Sturm showed gradient estimate for the heat flow in non-convex domains in metric measure spaces using subtle time change arguments. Giuseppe Savaré presented contraction and regularizing properties of the heat flow in metric-measure spaces, emphasizing the interplay between Hellinger-Kakutani, Wasserstein, and Hellinger-Kantorovich distances. Almut Burchard discussed a systematic method for differentiation of functionals along displacement interpolation. Federico Glaudo used a refined contractivity property of the heat flow to obtain new results on the behaviour optimal maps in the random matching problem. Bo'az Klartag presented complex generalizations of the classical Legendre transform, motivated by applications in Kähler geometry.

Outcomes and achievements

The ESI provided a stimulating environment for participants to discuss, collaborate, and start new initiatives. We include here a few samples.

- Mathieu Lewin and Robert Seiringer solved a problem on which they had been working with Elliott Lieb since 2015. They proved the equality of two models from statistical mechanics describing an infinite gas of classical electrons. For finitely many particles this can be recast as a multimarginal optimal transport problem with Coulomb cost. The result has already been published in Phys. Rev. B, where it was even selected as an *editor's suggestion*.

- Martin Brückenhof-Plückelman, Martin Huesmann, and Nicolas Juillet collaborated on the topics of peacocks and martingale optimal transport. A paper on these topics is currently in preparation.

- Florentine Flei ßner worked on gradient flows in the space of positive measures equipped with the Hellinger-Kantorovich distance and enjoyed stimulating discussions with Alexander Mielke and Giuseppe Savaré on this topic. She also started a joint work with Nicolas Garcia Trillos on Γ-convergence of gradient flows arising in data science.

- Inspired by various talks during the Programme, Young-Heon Kim started a research project on entropic regularization of optimal transport and the Schrödinger problem. He also had fruitful discussions with Soumik Pal, with whom he is planning to organise activities on Optimal Transport in the Pacific Northwest area in North America. Soumik Pal also enjoyed fruitful discussions on entropic regularization, which lead to several preprints and a submitted grant application.

- Almut Burchard and José-Antonio Carrillo had fruitful discussions on aggregation and non-local interaction equations.

- Bo'az Klartag had stimulating discussions with several programme participants related to the complex Legendre transform, which can be viewed as a local symmetry of the complex Monge-Ampere equation. During Workshop 2 he gave an inspiring talk on this topic.
- Zoltán Balogh, Alessio Figalli, and Alexandru Kristály started a fruitful collaboration on the isoperimetric problem and Sobolev inequalities on sub-Riemannian structures. The sharp isoperimetric inequality on Heisenberg groups (also known as the Pansu-conjecture) is proved only in a few special cases; in work in progress, Balogh, Figalli, and Kristály use arguments from the theory of optimal transport to handle this class of inequalities.
- Emanuela Radici continued her collaboration with Lorenzo Portinale on the topic of particle approximations of nonlinear evolution equations. She also started a new research project with Chiara Rigoni on a JKO scheme on Lorenz manifolds. This project is inspired by the lecture series at the introductory school by Robert McCann and Nicola Gigli.
- Eric Carlen and Jan Maas initiated a project on quantum versions of the Brascamp-Lieb inequalities. A paper is currently in preparation.
- Josef Teichmann worked at ESI on a link between discretizations of controlled dynamical systems (and their transport PDE version) on the one hand and deep feed foward neural networks on the other hand to show that randomly chosen layers produce families of functions which can solve any interpolation problem. This constitutes one way to explain the role of randomness in training procedures.
- Beatrice Acciaio had stimulating discussions with several other participants on numerical optimal transport, which lead to major progress in an ongoing work on generative adversarial networks using causal optimal transport.

List of talks

Introductory School on Optimal Transport, May 6 – 10, 2019

Nicola Gigli	Schrödinger problem and optimal transport, I - III
Robert McCann	Entropic convexity and the Einstein equation for gravity, I - III
Emanuela Radici	Deterministic particle approximation for scalar aggregation-diffusion equations with nonlinear mobility
Farhan Abedin	Exponential Convergence of Parabolic Optimal Transport on Bounded Domains
Krzysztof Ciosmak	Continuity of extensions of Lipschitz maps
Lorenzo Portinale	Homogenization of discrete optimal transport and beyond
Johannes Wiesel	Continuity of martingale optimal transport on the real line
Gudmund Pammer	Existence, Duality, and Cyclical monotonicity for weak transport costs
Caroline Moosmueller	Analysis of gene expression profiles via Wasserstein optimal transport on networks
Maryam Pouryahya	A Novel Integrative Network-based Clustering of Multiomics Data using the Wasserstein Distance
Yann Brenier	Optimal transport theory, hydrodynamics and mean field games, I - III
Katharina Hopf	1D Fokker-Planck equations with superlinear drift: a framework to cope with singularities
Mathias Hudoba de Badyn	Connections Between Mean-Field Games and Optimal Transport
Jaime Santos Rodríguez	Metric measure spaces with lower Ricci curvature bounds and its isometries

Dominik Forkert	Optimal Transport on Metric Graphs
Clément Steiner	On Intertwinings and Stability of Log-Sobolev Inequalities
Marco Cuturi	Computational optimal transport, I - III

Workshop 1 on "Optimal Transport: from Geometry to Numerics", May 13 – 17, 2019

Yann Brenier	Various formulations of the Muskat model
Cornelia Mihaila	Bubbling with L^2 almost constant mean curvature and an Alexandrov type theorem for crystals
Mikaela Iacobelli	From quantization of measures to weighted ultrafast diffusion equations
Marco Cuturi	On the several ways to regularize optimal transport
Nicolás García Trillos	Large sample asymptotics of spectra of Laplacians and semilinear elliptic PDEs on random geometric graphs
Gabriel Peyré	Optimal Transport for Machine Learning
Martin Huesmann	Optimal matching and quantitative linearization results for Monge-Ampere equations
Andrea Mondino	Optimal transport and quantitative geometric inequalities
Zoltan Balogh	Geometric inequalities via OMT
Bruno Lévy	Incompressible fluid simulation with semi-discrete optimal transport
Martin Rumpf	Computation of Optimal Transport on Discrete Metric Measure Spaces
Paola Gori-Giorgi	Beyond the optimal transport limit of density functional theory: dispersion interactions with fixed marginals
Virginie Ehrlacher	Marginal constrained optimal transport problem
Max von Renesse	Dean-Kawasaki Dynamics: Particle-ular solutions for an Ill-Posed SPDE
Dario Trevisan	An infinite dimensional Gaussian random matching problem
Carola-Bibiane Schönlieb	Wasserstein for learning image regularisers
Nassif Ghoussoub	Optimal controlled transports with free end times subject to import/export tariffs
Alexander Mielke	Transport versus growth and decay: the (spherical) Hellinger-Kantorovich distance between arbitrary measures
Daniel Matthes	Variational approximations of Wasserstein gradient flows (beyond minimizing movements)
Giuseppe Buttazzo	Optimal transport between mutually singular measures)

Workshop 2 on "Optimal Transport in Analysis and Probability", June 3 – 7, 2019

Allen Tannenbaum	Optimal Mass Transport with Applications to the Robustness of Networks and Machine Learning
Soumik Pal	On the difference between entropic cost and the optimal transport cost
Alfred Galichon	Gale-Shapley meet Monge-Kantorovich
Sigrid Källblad	Stochastic control of measure-valued martingales with applications to robust financ
Nizar Touzi	On the continuous-time Principal-Agent problem
Almut Burchard	How to take derivatives along displacement interpolants
Max Fathi	A new proof of the Caffarelli contraction theorem
Bo'az Klartag	Complex Legendre Duality
Giuseppe Savaré	Contraction and regularizing properties of heat flows in metric measure spaces
Karl-Theodor Sturm	Gradient estimates for the Neumann heat flow on non-convex domains of metric measure spaces
Matias Delgadino	Mean field limit by Gamma convergence
José Carrillo	Primal dual methods for Wasserstein gradient flows
Jan Haskovec	Rigorous continuum limit for the discrete network formation problem
Franca Hoffmann	Kalman-Wasserstein Gradient Flows
Young-Heon Kim	The Monge problem in Brownian stopping optimal transport
Aaron Palmer	Stochastic Transport with Optimal Stopping

Federico Glaudo	A criterion for the stability of optimal maps with applications to the random matching problem
Codina Cotar	Equality of the Jellium and Uniform Electron Gas next-order asymptotic terms for Coulomb and Riesz potentials
Julio Backhoff	Bayesian learning with Wasserstein barycenters
Guillaume Carlier	On the well-posedness of the multi-marginal Schrödinger system

Individual talks

Eric Carlen	Brascamp Lieb inequalities for fermions and non-commutative mass transport
Yvain Bruned	Geometric stochastic heat equations
Josef Teichmann	Machine Learning in Finance
Mathieu Lewin	Optimal Transport and Density Functional Theory
Florentine Fleißner	New results on the minimizing movement scheme for gradient flows
Alessio Figalli	On the regularity theory of optimal transport maps, I + II
Vitalii Konarovskyi	A particle model for Wasserstein type diffusion
Augusto Gerolin	An Optimal Transport approach for the Schrödinger Bridge problem and convergence of Sinkhorn algorithm
Edward Chien	Clustering with Ricci flow on graphs & Dynamical optimal transport on triangle meshes
Bertram Tschiderer	Trajectorial Otto calculus
Malcolm Bowles	Linear mass transfers and ergodic properties of their Kantorovich operators

Publications and preprints contributed

B. Acciaio and M. Munn. *Learning RNN-GANs via Causal Optimal Transport*, in preparation.

C. Cuchiero, M. Larsson, and J. Teichmann. *Deep neural networks, generic universal interpolation, and controlled ODEs*, arXiv:1908.07838 [math.OC].

M. Lewin, E. H. Lieb, and R. Seiringer. *Floating Wigner crystal with no boundary charge fluctuations*, Phys. Rev. B 100, 035127 (2019).

F. C. Fleißner, *A Minimizing Movement approach to a class of scalar reaction-diffusion equations* arXiv:2002.04496.

Invited scientists

Farhan Abedin, Beatrice Acciaio, Anton Arnold, Julio Backhoff, Zoltan Balogh, Daniel Bartl, Mathias Beiglböck, Zehor Belkhatir, Samuel Borza, Malcolm Bowles, Mathias Braun, Yann Brenier, Martin Brückerhoff-Plückelmann, Yvain Bruned, Almut Burchard, Giuseppe Buttazzo, Emanuele Caputo, Eric Carlen, Guillaume Carlier, José Carrillo de la Plata, Giulia Cavagnari, Edward Chien, Krzysztof Ciosmak, Sebastian Claici, Codina Cotar, Rafael Coyaud, Marco Cuturi, Matias Delgadino, Giacomo Di Gesu, Nicolo De Ponti, Georgios Domazakis, Wenkui Du, Virginie Ehrlacher, Hamza Ennaji, Max Fathi, Dario Feliciangeli, Alessio Figalli, Michael Fischer, Florentine Flei ßner, Dominik Forkert, Alfred Galichon, Nicolas Garcia Trillos, Carlo Gasparetto, Amirmasoud Geevechi, Augusto Gerolin Gavga, Nasif Ghoussoub, Nicola Gigli, Federico Glaudo, Paola Gori-Giorgi, Uri Grupel, Jan Haskovec, Franca Hoffmann, Katharina Hopf, David Hornshaw, Mathias Hudoba de Badyn, Martin Huesmann, Mikaela Iacobelli, Junchao Jia, Nicolas Juillet, Sigrid Källblad, Young-Heon Kim, Bo'az Klartag, Maike Klein, Michael Kniely, Vitalii Konarovskyi, Kazuhiro Kuwae, Tobias Lehmann, Bruno Lévy, Matthieu Lewin, Stefania Lisai, Jan Maas, Daniel Matthes, Robert McCann, Alexander Mielke, Cornelia Mihaila, Andrea Mondino, Caroline Moosmüller, Ekaterina Mukoseeva, Paul Esteban Navas Alban, Francesco Nobili, Soumik Pal, Aaron Palmer, Gabriel Peyré, Giulia Pilli, Lorenzo Portinale, Maryan Pouryahya, Emanuela Radici, Tobias Ried, Lorenz Riess, Chiara Rigoni, Martin Rumpf, Flavia Santarcangelo, Jaime Santos

Rodriguez, Giuseppe Savaré, Stefan Schrott, Carola-Bibiane Schönlieb, Robert Seiringer, Ulisse Stefanelli, Clément Steiner, Karl-Theodor Sturm, Luca Tamanini, Allen Tannenbaum, Josef Teichmann, Nizar Touzi, Dario Trevisan, Bertram Tschiderer, Andrei Velicu, Renato Velozo Ruiz, Ivan Yuri Violo, Max von Renesse, Daniel Virosztek, Johannes Wiesel, Jeremy Wu, Junjian Yang, Umberto Zerbinati, Kelvin Shungjian Zhang, Simon Zugmeyer.

Astrophysical Origins: Pathways from Star Formation to Habitable Planets

Organizers: Manuel Güdel (U of Vienna), Ramon Brasser (ELSI, Tokyo), Theresa Lüftinger (U of Vienna), Stephen Mojzsis (U of Colorado, Boulder)

Dates: June 17 – August 2, 2019

Budget: ESI € 33 614,
Europlanet € 9 000.

Report on the programme

Activities

The programme was set up with the interactive contributions of the participants themselves to ensure maximum interaction and allowing all beneficiaries to have the most intense and rewarding experience in Vienna. Before the event, participants were asked to contribute ideas, plans, topics of discussion and other wishes, and were further asked to potentially give tutorial lectures about their fields that would serve as the basis for interdisciplinary discussions. The participants also structured the program on the spot; each week's program was put together the week before after consulting with the participants about their plans and proposals for presentations. Several afternoons were left free for ad-hoc meetings between the entire team and any sub-teams, most of which were duly attended.
The programme lasted for seven weeks between June 17 and August 2, 2019. In total it included 55 participants from abroad, plus a further 10 local participants from the University of Vienna. Teams changed by the week, participants typically stayed for 1 - 2 weeks, with some remaining as long as 3-4 weeks (these were partially self-funded). Each week thus saw a mostly new team composed of scientists from different but overlapping disciplines.

Specific information on the programme

We organized the program summarised here on the topic of Astrophysical Origins: Pathways from Star Formation to Habitable Planets at the Erwin Schrödinger International Institute for Mathematics and Physics (ESI). In 2017 we applied for a thematic programme at ESI with the title: 'Astrophysical Origins: Pathways from Star Formation to Habitable Planets'. Our goal for this ESI thematic programme was to bring together a large number of researchers for introduction, to exchange views, to participate in brainstorming sessions, to initiate collaborations, or to work on publications and/or proposals during an extended time period of seven weeks. Our programme was designed as an interdisciplinary meeting bringing together astrophysicists, geologists, atmospheric scientists, (pre-biotic-)chemists, cosmochemists, and biologists, to discuss the potential places of the origin of life in the universe, the emergence of habitability on planets, and the conditions that lead to such environments. Given the breadth of this topic, we aimed to make the programme and the resulting list of attendees as inclusive as possible. The topic of planetary habitability is one of the most active in the field of astrophysics and planetary sciences, fostered enormously by the detection of thousands of exoplanets and by rapid progress in the research of solar-system planets, their geology and their atmospheric evolution. The search for life, and the community's attempts to gain a better understanding of how life originated on Earth, inspired us to cast a wide net when it came to the scientific disciplines of the invited researchers. Only by successfully combining astrophysics, planetary science, (prebiotic) chemistry and biology do we as a community stand a chance to make progress solving this difficult problem. This event was supported by ESI itself with 48 000 awarded to us after a competitive project proposal round in 2017. This source covered exclusively the per diem (80 per night) for the invited participants. We applied for a Europlanet supplement of 9 000 for additional guests and activities, which was granted on 11 September 2018.

Goals

The programme had the following goals: Bring together international scientists from many disciplines, nationalities and institutes to discuss an interdisciplinary approach to the question of habitability on Earth, other rocky planets, and the conditions leading to such environments. Discuss astrophysical factors that determine the fate of a planet's atmospheric evolution. These include stellar magnetic fields, winds, and radiation. Study the planetary interiors, their interaction with planetary surfaces and atmospheres, and the feedback between atmospheres and interiors such as outgassing processes. Discuss the chemistry from the protoplanetary disk stage to atmospheres and the early stages of life to understand its role and its preconditions in protoplanetary disks and planetary atmospheres.

Experience and Results

It is the opinion of the organizers that the event that we hosted at ESI developed into a great success. Feedback from attendees supports this conclusion. The scheme that naturally and spontaneously established itself was a daily schedule starting with a 1.5 hour introductory/educational lecture by one participant, typically lasting from 10:00 to 11:30, with full interactive discussions and participation from the audience. These lectures usually gave rise to additional team discussions for up to one more hour, in cases even covering the entire afternoon until 17:00. At times, another researcher gave a second lecture that lasted from 14:00 until 15:30, which would then lead to further interaction in a similar manner. Some afternoons were left free for smaller group discussions or for opportunities to develop new ideas and collaborations. We received feedback from many participants that they were excited by the programme and the possibility to develop interdisciplinary discussions and plans. Several specific plans developed from this gathering. The list below is necessarily incomplete because numerous smaller group interactions may have developed further plans. Among the most significant ones were: Plans came up to write extensive review articles on interdisciplinary topics that emerged from this programme. Specifically, we are discussing a series of papers in Space Science Reviews; the organizers are reviewing which topics were extensively discussed and would be appropriate for such reviews. One was identified already to be the conditions toward habitable planets around M dwarfs given their very different evolutionary timescales and their magnetic activity behavior compared to solar-type stars. Organizer R. Brasser is leading this topic with his new colleagues at the University of Vienna. This new project has only been made possible due to the interactions and discussions at ESI. Organizer R. Brasser has written a grant proposal with new colleagues that he met at ESI. Organizers S. J. Mojzsis and R. Brasser are writing a scientific

paper with new colleagues whom they met during the summer at ESI. Plans to continue these meetings in some ways every couple of years at different places were discussed extensively, but involve potentially a similar audience. A possible place could be the The Munich Institute for Astro- and Particle Physics (MIAPP) that planned to hold a planetary workshop of a similar kind in June 2020.
Specific team efforts toward collaborations: A few were listed above, and many more are ongoing. We have heard of several initiatives that may materialize in the coming months, to carry out research projects developed at ESI.

Specific highlights
Apart from many excellent and highly educational presentations and discussions, a couple of special highlights should be mentioned. We have hosted Dr. Daniel Whalen from the University of Portsmouth, presently a visiting professor at the University of Vienna, as a special guest from an area outside of the programme. He taught the attendees about the first stars and their supernovae. This presentation led to surprising insights into the first possible synthesis of water, rocky materials and therefore the first possible habitable planets in the Universe. Prof. Whalen is now preparing an ERC grant proposal partly including these aspects due to discussions at ESI. We also had a high-school student (age 17 years) participate for four weeks. He engaged in this effort to fulfill the requirement of a month of practical training outside school (a “Ferialpraktikum”). His tasks were, i) to follow the talks, try to understand and discuss with the participants; ii) conduct some simulations of planetary atmospheric chemistry and dynamics supervised by a local expert and ESI participant; and iii) writing a short report. He performed all these duties in an excellent manner and got sufficiently interested to register already for another month of practical work in the Vienna organizing group in summer 2020.

Social program
We set up a small social program in various weeks: A conference dinner in a typical, local Austrian restaurant in weeks 3, 4, 5, 6, 7. The first two were financially supported by ESI, for the other three we request financial support from Europlanet. A visit to the historical university observatory (now hosting the Department of Astrophysics) in week 5. A visit to the Vienna Natural History Museum with its large meteorite collection, introduced by its director, Prof. Christian Köberl, a collaborator of the organizing team, in week 4 (July 10).

Documentation
The meeting has been documented in the following ways: A private Google document was set up and made accessible to the participants to summarize the ongoing presentations and add further thoughts. A web page showing the ESI meeting and providing access to the PDF or PPT files presented during the meeting. These files can be found at the following web address: https://www.univie.ac.at/HabitabilityESI/ A couple of participants tweeted ongoing discussions after consent with the participants. The Earth Life Science Institute in Tokyo has mentioned the event at ESI on its PR webpages and social media accounts.

Summary and Conclusions
The ESI Thematic programme has raised the bar for a novel type of interdisciplinary discussions on planetary habitability and the large number of conditions leading to such environments. It has a lasting impact among the participants and has already led or will lead to novel, interdisciplinary collaborations. The lasting impression of this event is that it has already begun to shape the future direction of research in the field of planet formation and planetary habit-

ability. As such, to continue the momentum and to push science to new limits, further meetings of this caliber are already being planned and are highly anticipated by the attendees. We aim to host these future meetings at the ESI, if possible and granted, and, if successful, our planning will begin sooner so that a more extensive list of participants can be acquired. In closing, we hope that our bold idea and programme has benefited the ESI as much as it has us and its attendees and we look forward to working with ESI in the future.

List of talks

Week 2, June 24 – 28, 2019

Ken Rice	The role of disc self-gravity in the formation of stars and planets
Csaba Kiss	Planetesimal formatio
Eduard Vorobyov	Gravitoviscous protoplanetary disks with a dust component – modeling the early stages of planet formation
Ramon Brasser & Soko Matsumura	Rocky planet formation: Pebble accretion and other models
Brian Wood	Astrospheric Ly-a constraints on stellar winds and Updates on M-dwarfs
Valery Shematovich	Kinetic Monte Carlo approach to study atmospheric escape
Esa Kallio	Plasma environments of Solar System objects

Week 3, July 1 – 5, 2019

Oleg Kochukhov	Stellar magnetic fields
Rachel Osten	CMEs
Karan Molaverdikhani	Planetary atmospheres
Valdimir Airapetian	Relating Planetary atmospheres and Stellar activity
Christiane Helling	Clouds
Inga Kamp	Astrochemistry
Steve Mojzsis	Hadean Earth/geochemistry
Sudha Rajamani	Prebiotic and biochemistry

Week 4, July 8 – 12, 2019

Peter Woitke	Disk and planetary crusts/atmospheres
Nader Haghighipour	Planet formation
Athanasia Nikolaou	Magma oceans and outgassing
Akos Kereszturi	History of habitability in the solar system
Susanne Pfalzner	Planets in clusters
Christian Koeberl (director of NHM)	Early Archean impact record on Earth
Mareike Godolt	Habitability and atmospheric signatures of rocky extrasolar planets around cool stars
Sergei Nayakshin	Tidal Downsizing theory of planet formation, from the Solar System to ALMA planets
Ofer Cohen	Stellar/heliophysics

Week 5, July 15 – 19, 2019

Gaitee Hussain	Probing the evolution of PMS star magnetic fields as their discs dissipate
Nader Haghighipour	Open discussion on: Planet formation, water delivery and Late heavy Bombardments
Colin Johnstone	Planetary upper atmospheres
Sami Solanki	The Sun's magnetic field and variability

Caroline Dorn	Extrasolar planet chemistry and dynamics
Ildar Shaikhislamov	Hot extrasolar planets
Eduard Vorobyov	On the likelihood of planet formation via disk gravitational fragmentation
Dmitry Bisikalo	Hot Jupiter atmospheres
Nader Haghighipour	Open discussion on: Grand Tack, why it was created, and what it implied!

Week 7, July 29 – August 2, 2019

Maria Schönbächler	Building planets, protoplanetary disk evolution traced by isotopes in meteorites
Alison Hunt	The Timing of Rapid Core Cooling Events in the Early Solar System Revealed by the Pd-Ag Chronometer
Daniel Whalen	Primordial world, the dawn of planet formation in the early universe
Jeff Linsky	The interface between the outer heliosphere and the inner interstellar medium
Betram Bitsch	Pebble accretion and planet migration
Christian Rab	Proto-planetary/ planet forming disks - Interpreting ALMA observations

Publications and preprints contributed

K. Kislyakova, L. Noack, *Electromagnetic induction heating as a driver of volcanic activity on massive rocky planets* arXiv:2004.14041 [astro-ph.EP].

Invited scientists

Peter Abraham, Vladimir Airapetian, Vitaly Akimkin, Amanda Alexander, Igor Alexeev, Micha-el Bartel, Dmitry Bisikalo, Bertram Bitsch, Sudeshna Boro Saikia, Ramon Brasser, James Cadman, Ofer Cohen, Luciano Darriba, Odysseas Dionatos, Vera Dobos, Caroline Dorn, Rudolf Dvorak, Cosima Eibensteiner, Georg Feulner, Mareike Godolt, Lee Grenfell, Rodrigo Guadarrama, Manuel Güdel, Nader Haghighipour, Anneliese Haika, Carina Heinreichsberger, Christiane Helling, Alison Hunt, Gaitee Hussain, Meng Jin, Colin Johnstone, Evgenya Kalinicheva Sergeevna, Esa Kallio, Inga Kamp, Akos Kereszturi, Kristina Kislyakova, Christian Köberl, Oleg Kochukhov, Jeffrey Linsky, Theresa Lüftinger, Thomas Maindl, Soko Matsumura, Yanina Metodieva, Stephen Mojzsis, Karan Molaverdikhani, Sergei Nayakshin, Athanasia Nikolaou, Lena Noack, Rachel Osten, Susanne Pfalzner, Christian Rab, Sudha Rajamani, Ken Rice, Ines Ringeis, Sophie Alma Schallert, Marianne Schmid, Maria Schönbächler, Ildar Shaikhislamov, Simon Scheer, Denis Shulyak, Sami Solanki, Eduard Vorobyov, Sara Vulpius, Dan Whalen, Cornelia Weber, Peter Woitke, Brian Wood.

Quantum Simulation - from Theory to Application

Organizers: Tommaso Calarco (Forschungszentrum Jülich), Wolfgang Lechner (University of Innsbruck), Jörg Schmiedmayer (Technical University of Vienna), Philip Walther (University of Vienna)

Dates: September 2 – October 31, 2019

Budget: ESI € 42 720,
The ”PASQuanS Meeting” was partly financed by the PASQuanS project funded by the Horizon2020 Quantum Flagships of the European Commission.

Report on the programme

The aims of the thematic programme ”Quantum Simulation - from Theory to Application” was bringing together experimental and theoretical physicists with mathematicians and information scientists to make progress in the most fundamental aspects of quantum simulation, both from a theoretical perspective and how these can be implemented and tested in experiments. The goal was to update the roadmap for quantum simulation, which will serve as a guiding line for both researchers and funding organizations on the most important milestones to achieve in the next ten years. The ESI programme thus effectively serves as a "kick off" for the quantum simulation domain of the Quantum Technologies Flagship programme.

Another important goal was to educate local physics, math and informatics graduate students by organizing introductory lectures on various aspects of quantum simulation (e.g. non-equilibrium quantum dynamics, tensor-networks, high-TC superconductors, quantum annealing, quantum machine learning, experimental realizations of quantum simulators). And last but not least, we aimed at fostering academia-industry cooperation, which we consider as crucial to advance this field further (both, to define "real-life" use-cases and advancing quantum simulation machines by engineering efforts).

The scientific questions that were discussed include:

Foundations:

- The connection between simulability and complexity
- The connection between complexity and the quantum-classical border: Can one keep an analogue quantum simulator quantum when it becomes exceedingly complex? How can one read the quantum output of the simulator?
- The connection between limited state/operation fidelity and uncertainty of the simulation; quantum error correction for quantum simulators.
- Validation and verification of Quantum Simulators: How to benchmark quantum simulators vs. classical calculations and verify a speed-up due to quantum processes? How to verify the output of a quantum simulator if there are no classical means of calculating the result? How can we advance classical simulation methods that can be used to capture the functioning of the quantum simulator in certain regimes?
- Dynamical / non-equilibrium quantum simulation

Applications and implementation:

- Identification and classification of applications for quantum simulation
- Quantum machine learning: Intersections between quantum computation/simulation and machine learning
- Challenges for implementation on various platforms: Ultracold atoms, Ions, photonics-based Quantum Simulators, and Solid–State Quantum Simulators (Cavity QED, Josephson junctions, quantum dots, polariton condensates)

Activities

The programme lasted 2 months, within the preferred period from September to October 2019 and was structured as follows:

Scientific Conference

A five days scientific conference was the kick off to the programme. Participants included the world-leading experts in quantum simulation theory and experiment, as well as representatives from companies engaged in quantum simulation and computation.

Focus Weeks

We organized the visits of scientists to the ESI according to the various themes. We attempted to have participants with considerable overlap at the ESI at the same time. We had around 5-15 people per week. The weeks were structured as follows:

Focus Weeks in the ”Hardware Month”

- Sept 3 - 5, 2019: Conference ”Quantum Simulation”
- Sept 9 - 12, 2019: Quantum Networks
- Sept 17 - 20, 2019: Pros and cons of different platforms
- Sept 23 - 27, 2019: Benchmarking Software: Application Benchmarking

Focus Weeks in the ”Software Month”

- Sept 30 - Oct 4, 2019: Benchmarkting Software: Application Benchmarking
- Oct 7 - 11, 2019: Applications and Use-Cases
- Oct 14 - 18, 2019: Quantum Computing by Quantum Simulation
- Oct 21 - 25, 2019: Conference: Quantum Computing in Near Term
- Oct 28 - 31, 2019: Wrap-up

Industry workshops

We consider academia-industry cooperation as a key driver for advancing quantum simulation. On the one hand, engineering know-how is required to transform lab-demonstrators to robust machines and scaling them up, on the other hand, industry provides important use-cases for quantum simulation. We organized an industry session during the week September 23 – 27 as a part of the Flagship meeting of the PasquanS project.

Outcomes and achievements

Selection of collaborations that started during the thematic programme at the ESI:

- Maike Schön had a discussion with Naeimeh Mohseni about entanglement in adiabatic quantum computing with in the use of qubit ensembles vs in the LHZ gauge model, which ended up in new ideas for her work, and an revealing insight into the work of Robert Zeier about the symmetry criteria for quantum simulability of effective interactions.
- Wolfgang Lechner had a extensive discussion with Jan Budich about topological insulators and the LHZ architecture that resulted in a collaboration.

- Kilian Ender discussed with Thorge Müller about using near-term quantum hardware for variational optimization algorithms which might result in a collaboration with the DLR.
- Balint Koczor discussed with Philipp Aumann a way to implement the cosine of a matrix without having to do approximations, which can be helpful for his current work.
- Clemens Dlaska had discussions with Prof. Kenji Ohmori about quantum approximate optimization using Rydberg atoms, which may result in a collaboration.
- Andreas Hartmann had a conversation with Sofiene Jerbi about possible experimental realizations of counter-diabatic terms in near-term devices.

List of talks

Conference "Quantum Simulation", September 3 – 5, 2019

Maksym Serbyn	Quantum many-body scars in Rydberg-atom quantum simulator
Jens Eisert	Quantum advantages of quantum simulators
Peter Rabl	Quantum simulation of non-perturbative effects in (cavity) QED
Robert Zeier	Symmetry criteria for quantum simulability of effective interactions
Wolfgang Lechner	Quantum Optimization
Maxime Favier	Towards quantum simulation with laser-trapped circular Rydberg atoms
Sebastian Erne	Universal dynamics far from equilibrium
Wolfgang Duer	Influence of noise on quantum metrology (and ways around)
Christian Kokail	Variational Quantum Simulation and Verification
Jörg Schmiedmayer	Emergent quantum simulators

Conference "The Nature of Quantum Networks", September 9 – 12, 2019

Shabir Barzanjeh	Entangled microwave radiation and its application in quantum illumination (radar)
Johannes Majer	Superradiant emission from colour centres in diamond
Marta Estarellas	Simulating complex quantum networks with time crystals
Istvan Kovacs	A scalable network architecture
Chikako Uchiyama	Quantum energy transport under environmental engineering
Simone Montangero	Quantum Technologies using Rydberg Atoms
Michael Trupke	Quantum Network Module Technology with Spin Centres in Crystals
Yasser Omar	Quantum Link-Prediction in Complex Network
Sumeet Kathri	Practical figures of merit and thresholds for entanglement distribution in quantum networks
Michael Scheucher	Nonreciprocal Quantum Devices
Zoltan Zimboras	Short-time asymptotics of quantum walks on networks
Jörg Schmiedmayer	Quantum Nodes and Quantum Repeaters
Bill Munro	From today's QKD links to tomorrow quantum internet
Bruno Coutinho	On the robustness of a quantum internet
Miguel Navascues	Connector tensor networks: a renormalization-type approach to quantum certification
Andrew Briggs	Measuring and Tuning Quantum Devices by Machine Learning
Rupert Ursin	Quantum communication in fiber and space

PASQuanS Meeting, September 26 – 27, 2019

Marc Porcheron	Some research avenues to apply quantum simulation for solving hard combinatorial optimisation problems in the field of the smart-charging of electrical vehicles
Thomas Zander	Industrial Quantum Computing at Siemens

Elvira Shishenina	QC at Total: global program overview and inhouse development
Paolo Bianco	PASQuanS for Space, Aerospace and Defence: Where, When and What?

Conference "Quantum Computing in Near Term", October 21 – 25, 2019

Kenji Ohmori	Ultrafast many-body electron dynamics in an ultracold atomic BEC and Mott insulator lattice
Clemens Dlaska	Designing ground states of Hopfield networks for quantum state preparation
Philipp Aumann	Automated Design of Superconducting Circuits
Wojciech Roga	Compressive sensing, quantum annealing, and molecular vibronic spectroscopy
Bálint Koczor	Variational-State Quantum Metrology and Phase-Space Representations for Qubit and Qudit Systems
Yi-Ping Huang	Constrained many-body systems: emergent gauge symmetry in frustrated magnetism and constrained many-body dynamic
Oleksandr Kyriienko	Quantum inverse iteration algorithm for analogue quantum simulators

Individual talks

Marek Gluza	Quantum read-out for cold atomic quantum simulators
Spyros Sotiriadis	Correlation Functions of the Quantum Sine-Gordon Model in and out of Equilibrium
Hatem Elshatlawy	Difficult Use-Cases for Near-Term Quantum Computers
Simone Notarnicola	Quantum simulation of Abelian lattice gauge theories with interacting Rydberg atoms
Tommaso Calarco	Taming a very fat Schrödinger cat
Laura Baez	Practical quantum advantage of dynamical structure factors in analog quantum simulations
Ahmed Samir	Computer Simulations in Biology
Thomas Schulte-Herbrüggen	Control Engineering Taken to the Limits of Quantum Systems Theory - Framework, Recent Results, and Perspectives
Nicholas Chancellor	Continuous time quantum computing beyond adiabatic: quantum walks and fast quenches
Utkarsh Mishra	Dynamics of many-body quantum systems across the equilibrium quantum phase transitions
Bálint Koczor	Variational-State Quantum Metrology and Phase-Space Representations for Qubit and Qudit Systems
Naeimeh Mohseni	Error suppression in adiabatic quantum computing with qubit ensembles
Wojciech Roga	Molecular vibronic spectra from boson sampling and compressive sensing

Publications and preprints contributed

M. Bohmann, E. Agudelo, J. Sperling, *Probing nonclassicality with matrices of phase-space distributions*, arXiv:2003.11031 [quant-ph].

S. Notarnicola, M. Collura, S. Montangero, *Real-time-dynamics quantum simulation of (1+1)-D lattice QED with Rydberg atoms*, PHYSICAL REVIEW RESEARCH 2, 013288 (2020), arXiv:1907.12579 [cond-mat.quant-gas].

Invited scientists

Pitt Allmendinger, Cyril Allouche, Thomas Astner, Philipp Aumann, Thomas Ayral, Veera Bade, Maria Laura Baez, Shabir Barzanjeh, Daniel Barredo, Paolo Bianco, Sebastian Blatt, Martin Bohmann, Simone Borri, Andrew Briggs, Pietro Brighi, Antoine Browaeys, Tiffany Brydges, Jan Carl Budich, Libor

Caha, Tommaso Calarco, Francesco Cappelli, Nicholas Chancellor, Carsten Cleff, Bruno Coutinho, Andrew Daley, Chiara DÉrrico, Maurizio De Rosa, Bruno Desruelle, Clemens Dlaska, Wolfgang Dür, Jens Eisert, Ulrich Eismann, Hatem Elshatlawy, Kilian Ender, Sebastian Erne, Jerome Faist, Maxime Favier, Martin Franckie, Franck Ferreyrol, Marek Gluza, Nicola Goerke-Schwindt, Christian Groß, Germain Guiraud, Tobias Gulden, Michael Haider, Sargis Hakobyan, Dominik Hangleiter, Michael Hanks, Andreas Hartmann, David Headley, André Heinz, Yi-Ping Huang, Sicong Ji, Christian Jirauschek, Selim Jochim, Manoj Kumar Joshi, Sumeet Kathri, Wenzel Kersten, Konrad Kaufmann, Balint Koczor, Christian Kokail, Istvan Kovacs, Mahdi Kourehpaz, Augustine Kshetrimayum, Oleksandr Kyriienko, Thierry Lahaye, Wolfgang Lechner, Nicolo Lo Piparo, Johannes Mayer, Bertrand Marchand, Aude Martin, Richard Maulini, Davide Mazzotti, Utkarsh Mishra, Naeimeh Mohseni, Frederik Skovbo Moller, Simone Montangero, Felix Motzoi, Matthias Müller, Thorge Müller, William John Munro, Kae Nemoto, Simone Notarnicola, Kenji Ohmori, Yasser Omar, Julien Paris, Marta Pascual Estarellas, Johannes Popp, Marc Porcheron, Peter Rabl, Brice Ravon, Phila Rembold, Iolanda Ricciardi, Matteo Rizzi, Wojciech Roga, Christian Roos, Jun Rui, Deividas Sabonis, Ressa Said, Ahmed Samir, Neven Santic, Clément Sayrin, Michael Scheucher, Jörg Schmiedmayer, Barbara Schneider, Maike Schön, Thomas Schulte-Herbrüggen, Kai-Niklas Schymik, Maksym Serbyn, Elvira Shishenina, Mario Siciliani de Cumis, Augusto Smerzi, Pimonpan Sompet, Spyros Sotiriadis, Szilard Szalay, Yanko Todorov, Matthias Troyer, Michael Trupke, Chikako Uchihyama, Rupert Ursin, Rick van Bijnen, Matthias Weidemüller, Rafal Wilk, Jorge Yago Malo, Thomas Zander, Alessandro Zavatta, Robert Zeier, Zoltan Zimboras, Peter Zoller Pitt Allmendinger, Cyril Allouche, Thomas Astner, Philipp Aumann, Thomas Ayral, Veera Bade, Maria Laura Baez, Shabir Barzanjeh, Daniel Barredo, Paolo Bianco, Sebastian Blatt, Martin Bohmann, Simone Borri, Andrew Briggs, Pietro Brighi, Antoine Browaeys, Tiffany Brydges, Jan Carl Budich, Libor Caha, Tommaso Calarco, Francesco Cappelli, Nicholas Chancellor, Carsten Cleff, Bruno Coutinho, Andrew Daley, Chiara DÉrrico, Maurizio De Rosa, Bruno Desruelle, Clemens Dlaska, Wolfgang Dür, Jens Eisert, Ulrich Eismann, Hatem Elshatlawy, Kilian Ender, Sebastian Erne, Jerome Faist, Maxime Favier, Martin Franckie, Franck Ferreyrol, Marek Gluza, Nicola Goerke-Schwindt, Christian Groß, Germain Guiraud, Tobias Gulden, Michael Haider, Sargis Hakobyan, Dominik Hangleiter, Michael Hanks, Andreas Hartmann, David Headley, André Heinz, Yi-Ping Huang, Sicong Ji, Christian Jirauschek, Selim Jochim, Manoj Kumar Joshi, Sumeet Kathri, Wenzel Kersten, Konrad Kaufmann, Balint Koczor, Christian Kokail, Istvan Kovacs, Mahdi Kourehpaz, Augustine Kshetrimayum, Oleksandr Kyriienko, Thierry Lahaye, Wolfgang Lechner, Nicolo Lo Piparo, Johannes Mayer, Bertrand Marchand, Aude Martin, Richard Maulini, Davide Mazzotti, Utkarsh Mishra, Naeimeh Mohseni, Frederik Skovbo Moller, Simone Montangero, Felix Motzoi, Matthias Müller, Thorge Müller, William John Munro, Kae Nemoto, Simone Notarnicola, Kenji Ohmori, Yasser Omar, Julien Paris, Marta Pascual Estarellas, Johannes Popp, Marc Porcheron, Peter Rabl, Brice Ravon, Phila Rembold, Iolanda Ricciardi, Matteo Rizzi, Wojciech Roga, Christian Roos, Jun Rui, Deividas Sabonis, Ressa Said, Ahmed Samir, Neven Santic, Clément Sayrin, Michael Scheucher, Jörg Schmiedmayer, Barbara Schneider, Maike Schön, Thomas Schulte-Herbrüggen, Kai-Niklas Schymik, Maksym Serbyn, Elvira Shishenina, Mario Siciliani de Cumis, Augusto Smerzi, Pimonpan Sompet, Spyros Sotiriadis, Szilard Szalay, Yanko Todorov, Matthias Troyer, Michael Trupke, Chikako Uchihyama, Rupert Ursin, Rick van Bijnen, Matthias Weidemüller, Rafal Wilk, Jorge Yago Malo, Thomas Zander, Alessandro Zavatta, Robert Zeier, Zoltan Zimboras, Peter Zoller.

Workshops organized independently of the main programmes

Categorification in Quantum Topology and beyond

Organizers: Nils Carqueville (ESI, U Vienna), Anton Mellit (U Vienna), Paul Wedrich (Australian National U, Canberra)

Dates: January 7 – 18, 2019

Budget: ESI € 21 823,
FWF project P31705 € 13 550,
BE283001 of Nils Carqueville € 500.

Report on the workshop

The purpose of this workshop was to bring together young and established researchers in low-dimensional topology, representation theory, and mathematical physics working on categorified quantum invariants and related questions. Categorification is a flexible and powerful set of techniques, which produces insight about mathematical structures by viewing them as shadows of objects in a richer world, often described in terms of higher categories. Two focus points of the workshops were quantum link homologies in low-dimensional topology, and the programme of the higher representation theory of quantum groups.

Activities

A central goal of the workshops was to focus efforts towards the resolution of a major open problem, namely the categorification of quantum invariants of (links in) 3-manifolds. To this end, we invited world-leading experts to give **introductory mini-courses** on several facets of this problem during the first week. These were intended to create a common basis for discussion for researchers from different fields and the many junior participants, and to lead towards the **research talks** during the second week.

Thang Le gave a series of four lectures on the skein theory of links in 3-manifolds: the basis of our categorification objective and itself a very active area of research. Graduate student Juliet Cooke complemented these lectures in her talk by outlining constructions of skein algebras via factorization homology, after which David Jordan showed that closely related quantum character varieties are Azumaya. Hoel Queffelec and Krzysztof Putyra reported on progress towards the categorification of skein algebras and related questions.

Anthony Licata gave a series of four introductory lectures and one research talk, which showcased Bridgeland stability conditions as a powerful, and underused, tool to study actions of Artin braid groups on triangulated categories. Additionally he gave a colloquium talk at U Vienna on Khovanov's Heisenberg category, which also featured in the talk of PhD student Nicolle Sandoval Gonzalez on the categorical Boson–Fermion correspondence. Zsuzsanna Dancso reported on the related topic of quantizations and categorification of lattices.

Matthew Hogancamp gave a series of two lectures on Khovanov–Rozansky homologies and their relations to Hilbert schemes. He also moderated a lively discussion session at the end of the first workshop. Tina Kanstrup continued the discussion of Khovanov–Rozansky homology by reporting on progress in comparing them with a conjecturally equivalent construction of

Oblomkov–Rozansky. Eugene Gorsky explained the role of the Rouquier complex of the full twist braid in the geometry of Hilbert schemes of points on $\mathbb{C}^2$, while Erik Carlsson and Arik Wilbert focussed on the related topic of affine Springer fibres.

Sergei Gukov gave a series of three lectures on the categorification of Witten–Reshetikhin–Turaev invariants of 3-manifold from a physical perspective, leading to logarithmic CFT. Aleksandra Anokhina discussed asymptotic expressions for Khovanov–Rozansky polynomials and Ingmar Saberi provided a dictionary to help mathematicians to understand twists of supersymmetric field theories.

Higher representation theory featured prominently in the talks of Joel Kamnitzer and Raphael Rouquier on the categorification of tensor products, and in the talks of Daniel Tubbenhauer on finitary 2-representation theory, Joshua Sussan on p-dg structures, and by Pedro Vaz on the categorification of Verma modules. Catharina Stroppel and Emily Norton focused their talks on relation between higher categories and Cherednik algebras.

Topological field theories of the non-semi-simple kind were the topics of the talks of Anna Beliakova and Christian Blanchet. Jake Rasmussen explained how the (partial) $2+1+1$-dimensional TQFT provided by bordered Floer homology decategorfies to a $2+1$-dimensional TQFT studied by Donaldson and Petkova. Conversely, Louis-Hadrien Robert outlined a new combinatorial categorification of the Alexander polynomial that does not rely on Floer theory. Finally, Piotr Sulkowski provided additional insight into the knots–quivers correspondence from the perspective of topological strings.

The scientific programme was supplemented by a conference dinner, a 40th birthday party, and three early-morning sightseeing runs through Vienna.

Specific information on the workshop

Both weeks of the workshop were well-attended, including by doctoral students and early-career academics, some of whose travel expenses were supported by external funding.

The following Pre-docs attended the workshop: Rostislav Akhmechet, Saeid Aminian, Leon Barth, Johannes Berger, Alex Chandler, Juliet Cooke, Victor Godet, Nicolle Sandoval Gonzalez, Oscar Kivinen, Maciej Markiewicz, Shuang Ming, Grégoire Naisse, Pablo Sánchez Ocal, Tomasz Przezdziecki, David Reutter, Elia Rizzo, Oliver Singh, Kursat Sozer, Dominic Weiller, Yue Zhao, Zechuan Zheng.

After discussions between Alex Chandler (a PhD student) and Anton Mellit, Alex Chandler was invited for a postdoc position at the University of Vienna to work with Anton Mellit on categorification questions. Informally, we have learnt about three further postdoc positions that were offered and accepted subsequent to contacts during the workshop. Additionally one thesis committee was formed in this way.

Outcomes and achievements

We have received a very positive feedback from the participants in the email exchanges after the workshop.

All talks given during both workshop weeks were recorded with permission of the speakers (except for one, where the speaker did not give this permission) and made available on the conference website. They will continue to be hosted on the servers of the University of Vienna and linked to on the workshop website. During and after the workshops, the organisers received numerous emails from researchers worldwide, acknowledging the usefulness and high quality of the recordings.

We give a non-exhaustive list of further activities during and outcomes of the workshops:

New collaborations:

- Anton Mellit and Louis-Hadrien Robert on computation of Khovanov-Rozansky homologies.
- Louis-Hadrien Robert and Emmanuel Wagner on a combinatorial approach to non-semisimple invariants, which lead to a paper in preparation.
- David Jordan started to collaborate with Catharina Stroppel on applications of braided module categories to Heisenberg categorification of quantum groups.

Ongoing collaborations that were continued during the workshops:

- Erik Carlsson and Anton Mellit, on geometrization of their proof of the shuffle conjecture.
- Eugene Gorsky, Matthew Hogancamp and Anton Mellit, resulting in the preprint:

  E. Gorsky, M. Hogancamp, A. Mellit, K. Nakagane, *Serre duality for Khovanov-Rozansky homology*, arXiv:1902.08281 [math.RT]
- Louis-Hadrien Robert and Emmanuel Wagner, resulting in the preprint:

  L. H. Robert, E. Wagner, *Quantum categorification of the Alexander polynomial*, arXiv:1902.05648 [math.GT]
- Eugene Gorsky and Paul Wedrich, resulting in the preprint:

  E. Gorsky, P. Wedrich, *Evaluations of annular Khovanov-Rozansky homology*, arXiv:1904.04481 [math.GT]
- Grégoire Naisse and Krzysztof Putyra, on odd Khovanov homology
- Zsuzsanna Dancso and Tony Licata finished a paper:

  Z. Dancso, A. M. Licata, *Koszul Algebras and Flow Lattices*, arXiv:1905.03067 [math.CO]

Productive discussions highlighted by participants:

- Matthew Hogancamp, Anton Mellit and Emmanuel Wagner, on link splitting spectral sequence.
- Jacob Rasmussen, Piotr Sulkowski and Paul Wedrich, on relations between quantum invariants of knots and quivers.
- Domenico Fiorenza and Ingmar Saberi, on the Stolz-Teichner program, relevant to two PhD students of Fiorenza.
- Matthew Hogancamp, Anthony Licata and Joshua Sussan, on recovering Khovanov homology from Heisenberg categorifications.

- Anna Beliakova, Christian Blanchet, Nils Carqueville and Lorant Szegedy, on sources of non-semisimplicity in topological invariants.
- Eugene Gorsky, Joel Kamnitzer and Oscar Kivinen, on Coulomb branch constructions of Braverman-Finkelberg-Nakajima and their connections to affine Springer fibers and link invariants.
- Eugene Gorsky, Anton Mellit and Catharina Stroppel, on the relation between the Bernstein-Gelfand-Gelfand category O and Soergel bimodules.
- Erik Carlsson, Matt Hogancamp, Eugene Gorsky and Anton Mellit, on the structure of certain ideals appearing in the work of Mark Haiman, their graded resolutions and connections to Hilbert schemes of points on the plane and link homology.
- Emily Norton and Raphael Rouquier discussed properties of Deligne-Lusztig characters, which helped a new project on the computation of decomposition numbers in certain weight 2 blocks of finite groups of Lie type with Weyl group B_{2n}.
- Alexandra Anokhina had many discussions with other participants, which were helpful for a project on effective computation of the Khovanov-Rozansky homology and superpolynomials.
- Sergei Gukov highlighted many useful discussions at the workshop that were instrumental in his collaboration with Ciprian Manolescu.
- Discussions between Eugene Gorsky, Joel Kamnitzer and Paul Wedrich on annular foams and Hilbert schemes were helpful for the work of Cautis and Kamnitzer on the K-theoretic quantum Satake equivalence.

List of talks

Week 1: January 7 – 11, 2019

Anthony Licata	Braids and stability conditions, 1 - 4
Zsuzsanna Dancso	Quantised lattices and combinatorics
Thang Le	Skein algebras of surfaces, 1 - 4
Louis-Hadrien Robert	Categorification of 1 and of the Alexander polynomial
Nicolle Sandoval Gonzalez	Categorical Bernstein operators and the boson–fermion correspondence
Matthew Hogancamp	Curved Soergel bimodules and deformed Khovanov-Rozansky homology, 1 - 2
Juliet Cooke	Factorisation Homology and Skein Algebras
Tony Licata	Colloquium at Faculty of Mathematics: Khovanov's Heisenberg category
Hoel Queffelec	Surface skein algebras and categorification
Tina Kanstrup	Link homology and Hilbert schemes
Sergei Gukov	Categorification of WRT invariants of 3-manifolds, 1 - 2
Alexandra Anokhina	Why there are asymptotic analytic formulas for homological knot invariants?

Week 2: January 14 – 18, 2019

Anna Beliakova	Hopf algebras and non-semisimple 3D TQFTs
Anthony Licata	Geometric group theory and spherical twists
Sergei Gukov	Logarithmic CFTs and 3-manifolds
Ingmar Saberi	Supersymmetric field theories, invariants of manifolds, and nilpotence varieties
Jacob Rasmussen	Covering spaces and the decategorification of bordered Floer homology
Catharina Stroppel	DAHA actions on fusion algebras
Joel Kamnitzer	Categorification of tensor products and symplectic duality

David Jordan	Factorization homology and quantum cluster varieties
Krzysztof Putyra	A quantum colored sl(2) knot homology: three approaches, same invariant
Christian Blanchet	Invariants of links with flat connection from non restricted quantum $sl(2)$
Piotr Sułkowski	Topological strings, knots and quivers
Daniel Tubbenhauer	A primer on finitary 2-representation theory
Raphaël Rouquier	Higher tensor structures
Erik Carlsson	Affine Schubert calculus and diagonal coinvariants
Joshua Sussan	p-DG structures in higher representation theory
Arik Wilbert	Categorified tangle invariants and Springer fibers
Pedro Vaz	Categorification of Verma modules and beyond
Eugene Gorsky	The full twist category
Emily Norton	Do finite groups of Lie type and Cherednik algebras speak to each other?

Publications and preprints contributed

The following preprints have been authored by the participants since the workshop.

A. Anokhina, A. Morozov, A Popolitov, *Nimble evolution for pretzel Khovanov polynomials*, arXiv:1904.10277 [hep-th].

S. Assaf, N. Gonzalez, *Demazure crystals for specialized nonsymmetric Macdonald polynomials*, arXiv:1901.07520 [math.CO].

H. Azam, C. Blanchet, *Fukaya category of surfaces and mapping class group action*, arXiv:1903.11928 [math.GT].

P. Baumann, J. Kamnitzer, A. Knutson, *The Mirkovic-Vilonen basis and Duistermaat-Heckman measures*, arXiv:1905.08460 [math.RT].

A. Beliakova, M. Hogancamp, K. Putyra, S. Wehrli, *On the functoriality of sl(2) tangle homology* arXiv:1903.12194 [math.AT].

A. Chandler, A. Lowrance, R. Sazdanovic, V. Summers, *Torsion in thin regions of Khovanov homology*, arXiv:1903.05760 [math.GT].

S. Cautis, A. D. Lauda, J. Sussan, *Curved Rickard complexes and link homologies*, arXiv:1901.08195 [math.QA].

Z. Dancso, A. M. Licata, *Koszul Algebras and Flow Lattices*, arXiv:1905.03067 [math.CO].

Z. Daugherty, I. Halacheva, M. S. Im, E. Norton, *On calibrated representations of the degenerate affine periplectic Brauer algebra*, arXiv:1905.05148 [math.RT].

C. Frohman, J. Kania-Bartoszynska, T. Le, *Dimension and Trace of the Kauffman Bracket Skein Algebra*, arXiv:1902.02002 [math.GT].

N. Reshetikhin, C. Stroppel, B. Webster, *Schur-Weyl type duality for quantized gl(1—1), the Burau representation of braid groups and invariants of tangled graphs*, arXiv:1903.03681 [math.RT].

E. Gorsky, M. Hogancamp, A. Mellit, K. Nakagane, *Serre duality for Khovanov-Rozansky homology*, arXiv:1902.08281 [math.RT].

E. Gorsky, M. Hogancamp, P. Wedrich, *Derived traces of Soergel categories*, arXiv:2002.06110 [math.GT].

E. Gorsky, M. Mazin, M. Vazirani, *Recursions for rational q,t-Catalan numbers*, J. Combin. Theory Ser. A 173 (2020).

E. Gorsky, P. Wedrich, *Evaluations of annular Khovanov-Rozansky homology*, arXiv:1904.04481 [math.GT].

S. Gukov, C. Manolescu, *A two-variable series for knot complements*, arXiv:1904.06057 [math.GT].

S. Morrison, K. Walker, P. Wedrich *Invariants of 4-manifolds from Khovanov-Rozansky link homology*, arXiv:1907.12194 [math.QA].

E. Norton, *The Dipper-Du Conjecture Revisited*, arXiv:1904.11926 [math.RT].

G. Naisse, K. Putyra, *Odd Khovanov homology for tangles*, arXiv:2003.14290 [math.QA].

D. Reutter, J. Vicary, *High-level methods for homotopy construction in associative n-categories*, arXiv:1902.03831 [math.CT].

E. A. Reyes R., A. R. Fazio, *The Lightest Higgs Boson Mass of the MSSM at Three-Loop Accuracy*, arXiv:1901.03651 [hep-ph].

L. H. Robert, E. Wagner, *A quantum categorification of the Alexander polynomial*, arXiv:1902.05648 [math.GT].

O. Singh, *Distances between surfaces in 4-manifolds*, arXiv:1905.00763 [math.GT].

F. Costantino, Thang T. Q. Le *Stated skein algebras of surfaces*, arXiv:1907.11400 [math.GT].

Invited scientists

Rostislav Akhmechet, Saeid Aminian, Alexandra Anokhina, Leon Barth, Anna Beliakova, Johannes Berger, Christian Blanchet, Erik Carlsson, Nils Carqueville, Alex Chandler, Zsuzsanna Dancso, Anelo Raffaele Fazio, Domenico Fiorenza, Victor Godet, Evgeny Gorsky, Sergei Gukov, Kazuhiro Hikami, Quoc P Ho, Matthew Hogancamp, David Jordan, Joel Kamnitzer, Tina Kanstrup, Oscar Kivinen, Thang Le, Anthony Licata, Yongchao Lu, Maciej Markiewicz, Matthew McMillan, Anton Mellit, Alexandre Minets, Shuang Ming, Vincentas Mulevicius, Grégoire Naisse, Emily Norton, Can Ozan Oguz, Tomasz Przezdziecki, Krzysztof Putrya, Hoel Queffelec, Elia Rizzo, Jake Rasmussen, David Reutter, Louis-Hadrien Robert, Raphael Rouquier, Ingmar Saberi, Pablo Sanchez Ocal, Nicole Sandoval González, Oliver Singh, Kursat Sozer, Catharina Stroppel, Piotr Sulkowski, Joshua Sussan, Lóránt Szegedy, Daniel Tubbenhauer, Pedro Vaz, Emmanuel Wagner, Paul Wedrich, Dominic Weiller, Arik Wilbert, Yue Zhao, Zechuan Zheng.

Graduate School: Young Researchers Integrability School and Workshop 2019: A modern primer for 2D CFT

Organizers: Andrea Campoleoni (U Mons), Stefan Fredenhagen (U Vienna), Elli Pomoni (DESY Hamburg), Alessandro Sfondrini (ETH Zurich)

Dates: February 10 – 15, 2019

Budget:

Incomes	
ESI	20,199.53 €
GATIS+	7,000.00 €
Mathematical Physics Group budget/installation grant	3,996.65 €
ESI Association	1,000.00 €
MDPI Universe	500.00 €
Journal of Mathematical Physics	432.65 €
Faculty of Physics Vienna University	378.00 €
Total income	**33,506.83 €**

Expenditures	
Hotel costs speakers & 50 supported students	16,453.00 €
Catering lunch and coffee breaks	10,082.00 €
Travel costs speakers	1,506.53 €
Social dinner	2,240.00 €
Welcome reception and dinner	2,047.30 €
Student helpers	800.00 €
Cleaning costs	378.00 €
Total expenditure	**33,506.83 €**

Total number of participants (incl. speakers): 122

Note on GATIS+ funds: The GATIS+ funds were instrumental to enable us to offer a simple lunch to the students for the duration of the school. This was crucial because it would have been logistically very difficult for over 120 participants to get lunch individually in a relatively short time, and it would have been financially challenging for some of the students to pay for it, as not all students had access to a per diem or reimbursement from their home institution.

Report on the school

Activities

The Young Researchers Integrability School and Workshop (YRISW) is an ongoing series of meetings devoted to review the latest advances in exact techniques in theoretical physics, at the frontier with mathematics. Past editions have focused on exact results in certain two-dimensional quantum field theories and in string theory which can be tackled with the toolbox of integrable models. The aim of the 2019 school has been the investigation of two dimensional conformal field theories, i.e. of quantum field theories that possess conformal invariance at the quantum level. This is a central topic in theoretical physics, from high-energy to condensed-matter physics, and it has deep connections with mathematics.

The school consisted of 25 blackboard lectures of 45 minutes each, articulated over five lecture courses, as well as 10 hours of tutorial (for self study with the tutoring of the course instructors).

Specific information on the school

The school covered five major topics on two-dimensional conformal field theories

1. **Introduction to CFT$_2$** (Sylvain Ribault, IPhT Saclay, 7 lectures), providing an introduction to the basic principles and to some of the simplest models of two-dimensional conformal field theories.

2. **Wess-Zumino-Witten models** (Lorenz Eberhardt, ETH Zurich, 4 lectures), presenting this important class of conformal field theories, their classical action, current algebras, representations and modular invariance.

3. **W-algebras** (Thomas Creutzig, U Alberta, 4 lectures), introducing these algebras and their different realizations.

4. **Boundaries and defects** (Nils Carqueville, U Vienna, 4 lectures), providing an introduction to the algebraic and categorical description of boundaries and defects in 2d rational conformal field theories.

5.I **Deformations I: Conformal perturbation theory** (Marco Baggio, KU Leuven, 3 lectures), describing marginal deformations, the conformal manifold, and its relation to physical observables of the CFT.

5.II **Deformations II: $T\bar{T}$ deformation and integrable models** (Andrea Cavaglià, KC London, 3 lectures), describing relevant and irrelevant deformations that while breaking conformal invariance preserve infinitely many symmetries, resulting in an integrable theory.

Outcomes and achievements

The main outcome of the school was to introduce over 100 students to a set of topics of fundamental importance in theoretical physics. In some cases, advanced MSc students used this as a starting point for their PhD studies, targeting their research precisely along the lines of the school.

The lectures and lecture notes have been made available online at the school's website, `http://conf.itp.phys.ethz.ch/esi-school/`.

List of talks

Sylvain Ribault	Introduction to CFT2, I - VII
Lorenz Eberhardt	Wess-Zumino-Witten models, I - IV
Thomas Creutzig	W-algebras, I - IV
Marco Baggio	Deformations I, I - III
Nils Carqueville	Boundaries and defects, I - IV
Andrea Cavaglià	Deformations II, I - III

The detailed schedule of each course can be found online one the school's website, see `http://conf.itp.phys.ethz.ch/esi-school/schedule.html`.

Publications and preprints contributed

We are considering whether to publish the lecture notes of the school as a single volume.

R. Hernandez, J. M. Nieto, R. Ruiz, *The SU(2) Wess-Zumino-Witten spin chain sigma model*, arXiv:1905.05533 [hep-th].

Y. Jiang, S. Komatsu, E. Vescovi, *Structure Constants in N=4 SYM at Finite Coupling as Worldsheet g-Function*, arXiv:1906.07733 [hep-th].

Invited scientists

Theresa Abl (Durham University – UK), Nezhla Aghaei (University of Bern – Switzerland), Robert Allen (Cardiff University – UK), Joao Pedro Alves da Silva (EPFL – Switzerland), Prokopy Anempodistov (ITEP Moscow – Russia), Antonio Leite Antunes (University of Porto – Portugal), Constantin Babenko (Sorbonne Université – France), Marco Baggio (KU Leuven – Belgium), Vladimir Bashmakov (University of Milano-Bicocca – Italy), Sergio Benvenuti (SISSA – Italy), Diego Berdaja Suárez (University of Oxford – UK), Leo Bidussi (University of Edinburgh – UK), Roland Bittleston (DAMTP, University of Cambridge – UK), Riccardo Borsato (IGFAE - Santiago de Compostela – Spain), Jorrit

Bosma (ETH Zurich – Switzerland), Matteo Broccoli (AEI Potsdam – Germany), Andrea Campoleoni (University of Mons – Belgium), Nils Carqueville (University of Vienna – Austria), Andrea Cavaglià (King's College London – UK), Adam Chalabi (University of Southampton – UK), A. Ramesh Chandra (IISER Pune – India), Yifan Chen (LPTHE, Sorbonne Université – France), Pawel Ciosmak (University of Warsaw – Poland), Riccardo Conti (University of Torino – Italy), Thomas Creutzig (University of Alberta – Canada), Ariunzul Davgadorj (Masaryk University, Brno – Czech Republic), Hadewijch De Clercq (Ghent University – Belgium), David De Filippi (University of Mons – Belgium), Andrea Dei (ETH Zurich – Switzerland), Saskia Demulder (VUB Brussels & Swansea U. – UK), Pranav Diwakar (BITS Pilani – India), Patrick Dorey (Durham University – UK), Egor Dotsenko (ITEP Moscow – Russia), John Donahue (New York University – US), Sibylle Driezen (VUB Brussels & Swansea U. – UK), Lorenz Eberhardt (ETH Zurich – Switzerland), Harold Erbin (LMU Munich – Germany), David Erkinger (University of Vienna – Austria), Kara Farnsworth (CEICO Czech Academy of Sciences – Czech Republic), Gwenaël Ferrando (LPTENS Paris – France), Marc-Antoine Fiset (University of Oxford – UK), Stefan Fredenhagen (University of Vienna – Austria), Aleix Gimemez Grau (DESY – Germany), Tamas Gombor (MTA Wigner RCP – Hungary), Lucia Gomez Cordova (Perimeter Institute – Canada), Yegor Goncharov (University of Mons – Belgium), Sean Gray (TPI Jena – Germany), Linnéa Gräns Samuelsson (Institut de Physique Théorique – France), Andrej Grekov (ITEP, MIPT, Skoltech – Russia), Aliaksandr Hancharuk (Lebedev Physical Institute; MIPT – Russia), Dennis Hansen (ETH Zurich – Switzerland), Koichi Harada (The University of Tokyo – Japan), Carlo Heissenberg (SNS Pisa – Italy), Konstantin Hobuß (Leibniz Universität Hannover – Germany), Ondrej Hulik (CEICO, Charles University – Czech Republic), Filipp Isaenko (Higher School of Economics – Russia), Kasi Jaswin (ICTS-TIFR Bangalore – India), Nina Javerzat (LPTMS – France), Filip Jurukovic (Galician Institute of High Energy Physics – Spain), Dimitrios Katsinis (NKUA & NCSR Demokritos – Greece), Surbhi Khetrapal (Vrije University Brussels – Belgium), Aravinth Kulanthaivelu (University of Oxford – UK), Ajinkya Kulkarni (Université de Bourgogne – France), Zoltán Balasz Laczko (Queen Mary University of London – UK), Marton Kalman Lajer (MTA Wigner FK / ELTE – Hungary), Helder Larraguivel (University of Warsaw – Poland), Nat Levine (Imperial College London – UK), Christopher Lewis-Brown (Queen Mary University of London – UK), Jonas Linzen (Ruhr-Universität Bochum – Germany), Renann Lipinski Jusiskas (CEICO – Czech Republic), Ji Hoon Lee (Perimeter Institute – Canada), Rebecca Lodin (Uppsala University – Sweden), Laurens Lootens (Ghent University – Belgium), Yongchao Lu (Uppsala University – Sweden), Ratul Mahanta (HRI, HBNI – India), Konrad Martinek (University of Vienna – Austria), Takuya Matsumoto (Nagoya University – Japan), Sean McBride (University of California, Santa Barbara – US), Luka Megrelidze (Ilia State University – Georgia), Julian Miczajka (AEI Potsdam – Germany), Alexandre Minets (IST – Austria), Victor Mishnyakov (Moscow State University & ITEP – Russia), Karapet Mkrtchyan (AEI Potsdam – Germany), Fabrizio Nieri (DESY – Germany), Juan Miguel Nieto (Universidad Complutense de Madrid – Spain), Rongvoram Nivesvivat (University of Bonn – Germany), Christian Northe (JMU Würzburg – Germany), Yusuke Ohkubo (The University of Tokyo – Japan), Michel Pannier (Friedrich-Schiller-Universität Jena – Germany), George Pappas (National & Kapodistrian University of Athens – Greece), Mikhail Pavlov (LPI RAS – Russia), Giacomo Piccinini (Swansea University – UK), Alessandro Pini (DESY – Germany), Davide Polvara (Durham University – UK), Elli Pomoni (DESY – Germany), Antons Pribitoks (Trinity College Dublin – Ireland), Stefan Prohazka (ULB – Belgium), Lorenzo Quintavalle (ESY – Germany), Sylvain Ribault (PhT Saclay – France), Roberto Ruiz Gil (Universidad Compultense de Madrid – Spain), Paul Ryan (Trinity College Dublin – Ireland), Matteo Sacchi (University of Milano-Bicocca – Italy), Samuel Sánchez López (University of Amsterdam – Netherlands), Daniel Scherl (University of Vienna – Austria), Lukas Schneiderbauer (University of Reykjavik – Iceland), Fiona Seibold (ETH Zurich – Switzerland), Yuta Sekiguchi (University of Bern – Switzerland), Alessandro Sfondrini (ETH Zurich – Switzerland), Nika Sokolova (SPbSU & PNPI – Russia), Andrey Spiridonov (Moscow State University – Russia), Anne Spiering (Trinity College Dublin – Ireland), Vishnu TR (Chennai Mathematical Institute – India), Robijn Vanhove (Ghent University – Belgium), Orestis Vasilakis (ASCR, Institute of Physics, Prague – Czech Republic), Edoardo Vescovi (Imperial College London – UK), Matthias Volk (Niels Bohr Institute – Denmark), Daniel Westerfeld (Leibniz University Hannover – Germany), Freek Witteveen (University of Amsterdam – Netherlands), Alexander Yan (Lebedev Physical Institute – Russia), Yegor Zenkevich (Milano Bicocca University and ITEP Moscow – Russia), Hongbao Zhang (Vrije Universiteit Brussel – Belgium), Deliang Zhong (LPTENS Paris – France).

Operator Related Function Theory

Organizers: Alexandru Aleman (Lund U), Karlheinz Gröchenig (U Vienna), Kristian Seip (NTNU, Trondheim)

Dates: April 8 – 12, 2019

Budget: ESI € 10 560

Report on the workshop

The aim of this workshop was to explore recent advances in operator related function theory that result from the interaction with other mathematical disciplines and applied fields. The workshop focussed on major developments and open problems in the following interrelated topics.

(i) Reproducing kernel Hilbert spaces and interpolation,

(ii) Analysis for Dirichlet series and the Riemann zeta function,

(iii) Spectral theory and operator related function theory, and

(iv) Determinental point processes.

The workshop has brought together a number of top researchers from this field, and the participants delivered excellent talks at a very high level. The goal of the workshop was "to reexamine known results, discover new unexplored areas in classical operator related function theory, and to establish profound relations between problems arising in seemingly distant areas of mathematics". This goal was definitely accomplished, and several talks, e.g., by Baranov, Borichev, Ortega-Cerdà, presented solutions to old, open questions.

Activities

The workshop consisted of 25 talks of 45 minutes with ample breaks for discussion. When possible, the talks were grouped into thematic sessions. Selected talks served as an introduction to particular aspects of the workshop, notably the talks of Baranov (spectral synthesis of operators), Borichev (Szegö's problem), Nikolski (sign distribution of frames), and Ortega-Cerdà (Smale's question) had a detailed introductory part, before they moved to the state of the art.

(i) *Reproducing kernel Hilbert spaces and interpolation:* Properties of Hilbert space frames were presented in an excellent talk by N. Nikolskii. A. Haimi presented very strong results about interpolation and sampling in Fock spaces. Reproducing kernel methods play an important role in an old and honored problem in mathematical analysis, namely the spectral synthesis for continuous linear maps. From this point of view the differentiation operator on C^∞ is a notoriously difficult example. The complete solution of the spectral synthesis problem for this operator has been recently solved by A. Baranov and Y. Belov and was presented by the first author at this workshop.

Regarding abstract Hilbert function spaces with a (Nevanlinna-Pick) reproducing kernels, there were two very interesting contributions by M. Hartz and S. Richter about factorization in two different settings. A. Borichev presented an astounding solution to a long-standing question regarding the Szegö minimum problem. S. Nitzan and J-F. Olsen discussed uncertainty principles and Balian-Low-type theorems. Their talks were motivated by sampling problems occurring in applied mathematics.

(ii) *Analysis for Dirichlet series and the Riemann zeta function:* A full session of the workshop was devoted to the analysis of Dirichlet series and their connection to analytic number theory.

The talks of A. J. Harper, W. Heap, and O. F. Brevig manifested a fascinating interplay between the additive and multiplicative structure of the integers in different guises and involved an array of harmonic analysis, functional analysis, ergodic theory, and probability theory.

(iii) *Spectral theory and operator related function theory:* A. Poltoratski presented an approach to inverse spectral theory based on truncated Toeplitz operators, and G. Teschl talked about the famous KdV equation (the theory of water waves) and its connection to the inverse spectral problem. Y. Belov's contribution can also be included here, since it aims to construct a de Branges-type approach to the spectral theory of certain normal (not necessarily self-adjoint) matrices.

(iv) *Determinental point processes and random matrices:* Y. Ameur discussed models for the Coulomb gas, and H. Hedenmalm's presentation regarded random matrices in connection with a new type of determinental point processes (jellium).

Several talks on spectral theory (Teschl) and determinental point processes (Ameur, Hedenmalm) were motivated by problems in mathematical physics.

(v) There were a number of remarkable talks related to problems arising in seemingly distant areas of mathematics, for example the contributions of C. Badea, J. Ortega-Cerdá, H. Queffelec, or E. Saksman. Ortega-Cerdà presented an original approach motivated by Smale's question on the condition number of roots of polynomials.

Specific information on the workshop

The workshop offered several young researchers an opportunity to present their work. The following participants within six years after their Ph. D. gave a talk: O. F. Brevig, A. Haimi, M. Hartz, W. Heap, and J.-F. Olsen. In addition, many members of the local research groups in complex and harmonic analysis attended the workshop.

Outcomes and achievements

At this time we are aware of the following collaborations that were begun or continued during the workshop.

1. Ole Fredrik Brevig and Eero Saksman finished their paper on "Coefficient estimates for H^p-spaces with $0 < p < 1$, arXiv:1905.09547 and as an ESI preprint.

2. Iryna Egorova, Mateusz Piorkowski and Gerald Teschl worked on "On vector and matrix Riemann-Hilbert problems for KdV shock waves", a preprint is posted as arXiv:1907.09792.

3. Adam Harper and Eero Saksman continued their collaboration on proving convergence to chaos measures for the Riemann zeta function.

List of talks

Nikolai Nikolskii	On the sign distribution of Hilbert space frames
Shahaf Nitzan	Uncertainty Principles for Fourier Multipliers
Jan-Fredrik Olsen	Balian-Low type theorems for finite sequences
Antti Haimi	Strict density inequalities for sampling and interpolation in weighted spaces of holomorphic functions
William T. Ross	Range spaces of Toeplitz operators
Dragan Vukotic	Co-isometric and invertible weighted composition operators on general spaces of analytic functions
Hervé Queffélec	Compactification, and beyond, of composition operators by weights

Artur Nicolau	The Corona Theorem in Nevanlinna quotient algebras and interpolating sequences
Alexander Borichev	Szegö minimum problem
Catalin Badea	Kazhdan sets: between geometric group theory, harmonic analysis and operator theory
Anton Baranov	Differentiation invariant subspaces in the space of infinitely differentiable functions
Philippe Jaming	Mean convergence of prolate spheroidal wave function expansions
Eero Saksman	Decompositions of log-correlated fields with applications
Adam J. Harper	High moments of random multiplicative functions
Winston Heap	The maximum of the Riemann zeta function on the 1 - line
Ole Fredrik Brevig	Weissler's inequality for Dirichlet series
Michael Hartz	Smirnov class and common range of adjoint multipliers in the Drury-Arveson space
Stefan Richter	Free outer functions in complete Pick spaces
Marcus Carlsson	Nehari's theorem for convex domain Hankel operators in several variables
Hakan Hedenmalm	Planar orthogonal polynomials and related determinantal processes: random normal matrices and arithmetic jellium
Alexei Poltoratskii	Inverse spectral problems for canonical Hamiltonian systems
Joaquim Ortega-Cerdà	A sequence of polynomials with optimal condition number
Yuri Belov	Ordered structure for Cauchy-de Branges spaces
Yacin Ameur	A scale of boundary conditions for the Coulomb gas
Gerald Teschl	Riemann–Hilbert problems for the Korteweg–de Vries equation

Publications and preprints contributed

O. F. Brevig, E. Saksman, *Coefficient estimates for H^p spaces with* $0 < p < 1$, arXiv:1905.09547 [math.FA].

I. Egorova, M. Piorkowski, G. Teschl, *On vector and matrix Riemann-Hilbert problems for KdV shock waves*, arXiv:1907.09792 [nlin.SI].

H. Hedenmalm, S. Shimorin, *Gaussian analytic functions and operator symbols of Dirichlet type*, preprint.

Invited scientists

Alexandru Aleman, Yacin Ameur, Catalin Badea, Anton Baranov, Yurii Belov Sergeevich, Alexander Borichev, Ole Frederik Brevig, Dimitri Bytschenkoff, Marcus Carlsson, Mark Jason Celiz, Antti Haimi, Karlheinz Gröchenig, Michael Hartz, Adam Harper, Winston Heap, Hakan Hedenmalm, Philippe Jaming, Franz Luef, Artur Nicolau, Nikolai Nikolski, Shahaf Nitzan, Jan-Fredrik Olsen, Joaquim Ortega-Cerda, Alexei Poltoratskii, Hervé Queffelec, Stefan Richter, Isaac Alvarez Romero, José Luis Romero, William T. Ross, Eero Saksman, Kristian Seip, Gerald Teschl, Jordy Timo van Veldhoven, Dragan Vukotic.

Parton Showers, Event Generators and Resummation Workshop

Organizers: Simon Plätzer (U Vienna)

Dates: June 11– 14, 2019

Budget: ESI € 11 980,
Faculty of Physics, University of Vienna € 900.

Report on the workshop

Central to the quest of identifying new phenomena as small deviations from Standard Model of particle physics is the precise and detailed modeling of the complex dynamics associated to the experimentally observed final states. Especially for Quantum Chromodynamics, the theory of the strong interaction, fixed order perturbative calculations can only predict the coarse details dictated by an initial hard scattering

Any more fine-grained modeling requires resummed calculations, which take into account leading logarithmic contributions to all orders in the strong coupling constant. Controlling such contributions is central to precise predictions for physical spectra and the extraction of fundamental parameters.

- The **parton shower approach** is at the heart of versatile simulation packages for particle collider reactions, often referred to as Monte Carlo (MC) event generators. These programs are able to predict **realistic final states** as observed in experiments and describe physics with dynamics which span orders of magnitudes in relevant energy scales.
- The **resummation approach** is built on analytic understanding of emission of multiple QCD quanta, with **effective field theories** providing a key paradigm to separate the different energy scales in modern approaches. These calculations are not as versatile as parton shower algorithms, however they can cover terms beyond those included in simulation packages for fixed classes of observables.

Both approaches need to be supplemented by non-perturbative contributions, and accurate resummed calculations help to constrain the phenomenological methods required for these dynamics.

Central to the PSR workshop series is the goal to **foster a close link and exchange between the two communities**, which is become increasingly more important as analytic approaches become vital in constraining the accuracy of parton shower algorithms. Parton shower methods, on the other hand, become important for more complex resummations which need to resort to numerical methods, and several of these methodological aspects have been covered by the workshop program.

Activities

The workshop was composed of a **three-day core program** covering the forefront development in the resummation and parton shower communities. Three keynote talks provided an introduction to the status of parton shower development, the status of analytic resummation, as well as recent development in the subtraction method for fixed-order perturbative calculations in QCD. The latter subject is closely related to isolating infrared divergences in scattering amplitudes, which in turn are the origin of the logarithmically enhanced contributions addressed by resummation methods.

Several **dedicated sessions** of shorter talks have then been filling the remaining program, and lively discussions have been taking place in the coffee breaks and during a common dinner. A **new format in the spirit of a poster session** has been held in the hallway of the ESI, where young researches presented their work **on the blackboards** and got excellent opportunities to discuss with more senior researchers. The dedicated sessions have been addressing the newly developing paradigm of amplitude evolution, new methodology regarding Monte Carlo algorithms and the automation of calculations, as well as corrections beyond the leading power expansion usually taken into account. These topics have been complemented with sessions addressing more phenomenological applications including a focus on jet substructure methods, and thus provided a good mix of research stretching from fundamental aspects to applications.

After the three-day core workshop, a **satellite meeting** devoted to non-perturbative corrections has been taking place with a smaller subset of the participants of the core workshop. This one-day meeting was supported by the Faculty of Physics and the Particle Physics group of the University of Vienna, and was possible through ESI kindly providing the venue for another day. This meeting was rather informal: Some introductory talks were scheduled to trigger intense discussions, during which a newly developing approach on linking phenomenological models with constraints from effective field theories has been in the focus of the participant's interest. Understanding this link is vital to assess the impact of non-perturbative corrections on the extraction of fundamental parameters of the Standard Model.

Specific information on the workshop

The three overview talks kicking off the workshop have been held by senior researchers in the field. For the dedicated sessions the talks have been selected with a focus on the topic to be covered, but where possible younger researchers have been given priority over more senior researchers. In fact, 14 out of the 26 dedicated talks, and almost all (4/5) of the blackboard presentations have been covered by PhD students and young PostDocs. A summary and outlook talk was covered by retired Prof. Bryan Webber, one of the founding fathers of the field, who is still very active.

Outcomes and achievements

The participants of the workshop agreed that the edition held at ESI was one of the most effective ones in the series, and as such the main outcome is that the workshop fully served its goal of updating the community on the newest and most innovative developments in the field. Several participants at the workshop collaboratively work on projects and there was ample time for additional discussion within these project groups. Not only published results have been presented at the workshop but also several status updates on work in progress have been given, which is an important contribution to keeping the community up to date, involving discussions in between different groups which have provided important exchange on results presented at or shortly before the workshop.

List of talks

Steffen Schumann	Parton Showers and Event Generators Overview
Thomas Becher	Resummation Overview
Fabrizio Caola [via video]	Progress in Subtraction Schemes [joint work with Kirill Melnikov]
Jack Holguin	Parton Branching at Amplitude Level
Zoltan Nagy	Color Evolution in Parton Showers
Matthew De Angelis	News on Colour Evolution with CVolver
Stefan Keppeler	Multiplet bases – why and why not?
Marek Schoenherr	Electroweak Corrections and Parton Showers
Peter Skands	Coherent Showers in Coloured Resonance Decays
Jimmy Olsson	Resampling Algorithms for Hgh Energy Physics Simulations
Christian Bauer	A Quantum Algorithm for High Energy Physics Simulations
Judith Alcock-Zeilinger	Constructing Herimitian Young Operators
Andreas Papaefstathiou	Exploring Higher Dimensional Resummation

Markus Dieh	Double Parton Scattering: Theory Developments
Jennifer Smillie	High Energy Jets
Johannes Bellm	Jet Cross Sections at the LHC and the Quest for Precision
Richard Ruiz	Event-based Jet Vetoes
Francesco Hautmann	TMDs from Parton Branching
Mrinal Dasgupta	Top Tagging
Chang Wu	Jet Pull
Wouter Waalewijn	The Jet Shape at NLL'
Iain Stewart	Collinear Drop
Dingyu Shao	Jet TMDs and Non-global Logarithms
Luke Arpino	ARES for Three-jet Event Shape
Rudi Rahn	SoftServe
Daniel Reichelt	Resummed Predictions for Jet Resolution Scales
Sebastian Jaskiewicz	Factorization at Next-to-leading Power
Leonardo Vernazza	Resummation of NLP LLs near Threshold
Eric Laenen	NLP Threshold Logarithms at NLO and All Orders
Bryan Webber	Outlook
Andrea Banfi	Hadronization Corrections with ARES
Stefan Gieseke	Soft Models in Herwig
Aditya Pathak	Characterizing Event Generator Hadronization Models with Groomed Jet Mass
Cody Duncan	Spacetime Colour Reconnection

Publications and preprints contributed

For the present workshop this is hard to assess given the more conference-type setting.

M. Diehl, J. R. Gaunt, P. Ploessl, A. Schafer, *Two-loop splitting in double parton distributions*, SciPost Phys. 7, 017 (2019), https://scipost.org/, arXiv:1902.08019v2 [hep-ph].

Invited scientists

Simone Alioli, Judith Alcock-Zeilinger, Luke Arpino, Andrea Banfi, Christian Bauer, Thomas Becher, Johannes Bellm, James Black, Matteo Cacciari, Mrinal Dasgupta, Matthew De Angelis, Markus Diehl, Cody Duncan, Jeff Forshaw, Jonathan Gaunt, Stefan Gieseke, Francesco Hautmann, Marian Heil, André Hoang, Jack Holguin, Sebastian Jaskiewicz, Patrick Kirchgaesser, Anna Kulesza, Stefan Keppeler, Eric Laenen, Sergio Leal Gomez, Daniel Lechner, Leif Lönnblad, Maximilian Löschner, Zoltan Nagy, Graeme Nail, Jimmy Olsson, Andreas Papaefstathiou, Aditya Pathak, Simon Plätzer, Massimiliano Procura, Rudi Rahn, Christoph Regner, Daniel Reichelt, Ines Ruffa, Richard Ruiz, Daniel Samitz, Marek Schönherr, Steffen Schumann, Christian Schwinn, Dingyu Shao, Emma Simpson Dore, Andrzej Siodmok, Malin Sjodahl, Peter Skands, Jennifer Smillie, Iain Stewart, Rob Verheyen, Leonardo Vernazza, Wouter Waalewijn, Bryan Webber, Chang Wu, Lorenzo Zoppi.

Numeration and Substitution

Organizers: Henk Bruin (U Vienna), Clemens Heuberger (U Klagenfurt), Daniel Krenn (U Klagenfurt), Jörg Thuswaldner (U Leoben)

Dates: July 8 – 12, 2019

Budget: ESI € 12 800,
FWF Project P31950 (project leader H. Bruin) € 1 927,

FWF Project P27050 (project leaders L. Cristea and J. Thuswaldner) € 726,
FWF Project P28466 (project leader C. Heuberger) € 2 682,
FWF Project M2259 (project leader J. Jankauskas; J. Thuswaldner) € 452,
FWF Project P29910 (project leaders J. Thuswaldner and R. Tichy) € 439,
FWF Project W1230 (project leader W. Woess; J. Thuswaldner) € 920.

Report on the workshop

This workshop on *Numeration* forms the continuation of a successful series of workshops and conferences on this topic that was initiated in France around the turn of the millennium. It aims at bringing together researchers from all over the world with many different views on the subject. The atmosphere of the Erwin Schrödinger Institute contributed a lot to the success of the present workshop because of its infrastructure including offices for participants and a large number of blackboards that invite all participants to start mathematical discussions and collaborations during the time between the lectures.

Numeration refers to the arithmetic and symbolic representation of mathematical objects, such as the well-known decimal expansion of a real number. However, decimal expansions are by no means the only, or the oldest, or the most efficient way of representation. For instance, when it comes to data storage or particular operations we want to carry out, other kinds of representations prove to be more suitable. Another well-known example is furnished by continued fraction expansions, dating back to Greek mathematics, which are the method of choice for achieving rational approximations of real numbers. Their importance further increased due to applications in mechanics (resonance), mathematical analysis (normal forms, small divisor problems, KAM theory) and in complex dynamics. Variations of continued fraction algorithms (as for instance α-continued fractions, Rosen continued fractions, random continued fractions) continue to be developed and refined. Also in higher dimensions, the study of generalized continued fractions (such as Brun, Jacobi-Perron, Selmer and many others) with special emphasis on their dynamical, Diophantine, and combinatorial behavior are important objects of current investigations.

On the other hand, digit systems lend themselves to be generalized in various ways and objects such as β-expansions, Cantor expansions, canonical number systems, and shift radix systems. They show a great variety of interesting dynamical, geometric, and combinatorial properties and, as was observed only recently, have even links to complex dynamics.

Besides the well-known and numerous applications of numeration systems to computer arithmetics and cryptography further use emerges from computer-imaging in which smooth (or at least continuous) geometric objects need to be converted to discrete data in order to efficiently store and reproduce images. This leads to various algorithms in which both fractal geometry and special enumeration systems play crucial roles. It also remains a fascinating fact how many similarities exist between algorithmic approaches to fractal geometry, tiling spaces, complexity theory of symbolic dynamics, piecewise isometries such as interval exchange transformations, but also many problems in combinatorics. In this sense, the theory of numeration systems remains a unifying link between many areas of mathematics and computer science.

And it is the fact that numeration plays a role in so many different areas of mathematics and computer science that makes it particularly important to bring people that are interested in this multi-facetted topic together at workshops like the present one. Such workshops enable the participants to interlink their different viewpoints, to get an overview over the different directions of research, and often result in new and surprising connections that lead to new ideas which set the stage for new research projects. We think that the present workshop was successful in this sense and paved the way for further developments and collaborations on this fascinating topic.

Activities

When this workshop was planned one of the main aims of the organizers was to set up a program of lectures that is balanced in the sense that it covers all main research directions in the context of numeration on the one side and provides the possibility to give lectures for researchers in all stages of their career from doctoral students to experienced researchers. For this reason we invited four top notch scientists (María Isabel Cortez, Pascal Hubert, Anthony Quas, and Jeff Shallit) to provide key note talks of 60 minutes length. Here the talk of Shallit was addressed to a broader audience. Besides that we invited 30 researchers working in a variety of aspects of numeration and gave them the opportunity to give talks. Already in this group we tried to get a good balance between young and promising mathematicians and well-established ones. Finally, we advertised the conference on the internet to attract further participants in order to give contributed talks. To maintain a high quality of these contributed talks we asked a scientific committee to review the talks and selected the most suitable ones on the basis of their assessment. Apart from the organizers, this committee consisted of the following experts.

- Shigeki Akiyama, Tsukuba (Japan)
- Valérie Berthé, Paris (France)
- Christiane Frougny, Paris (France)
- Edita Pelantová, Prague (Czech Republic)
- Attila Pethő, Debrecen (Hungary)
- Michel Rigo, Liège (Belgium)
- Wolfgang Steiner, Paris (France)
- Robert Tichy, Graz (Austria)

Due to the efforts of this committee we were able to set up a very nice blend of lectures. Apart from the four key note talks, we assigned a 30 minutes slot to each talk.

As mentioned earlier, besides from the lectures, the workshop could greatly benefit from the inviting facilities of the ESI. These led to discussions and helped to initiate new collaborations.

Specific information on the workshop

In total 60 scientists participated in this workshop. There were 38 lectures, four of them had a length of 60 minutes, the remaining ones were 30 minutes lectures. This allowed us to set up a program without parallel sessions that left enough time for discussions. Traditionally, the numeration conferences are open for young researchers and try to give them the opportunity to present their research. The following list gives all PhD students and Post Docs that took part in this Numeration workshop. Each of them gave a lecture at the workshop.

- Myriam Amri (Post Doc)
- Celia Cisternino (PhD Student)

- Hana Dlouhá (PhD Student)
- Charles Fougeron (Post Doc)
- Jakub Krásenský (PhD Student)
- Nils Langeveldt (PhD Student)
- Marta Maggioni (PhD Student)
- Magdaléna Tinková (PhD Student)
- Tomàš Vávra (Post Doc)
- Benthen Zeegers (PhD Student)
- Shuqin Zhang (Post Doc)

We kept Wednesday evening free from lectures. This time was used by several participants for discussions on their research. Finally we want to mention the visit of the "Heurigen" on Thursday evening which was the "social event" of the workshop.

Outcomes and achievements

Traditionally, the Numeration workshops take place in a very relaxed atmosphere which makes it easier particularly for young researchers to approach other colleagues in order to pose questions or start collaborations. Also the present workshop led to many new inspirations and kindled the interest in new projects and topics of research. Numerous discussions took place at the ESI during the week of the workshop. Since it is impossible to keep track of every single discussion we just give a short selection of discussions and collaborations.

- M. Amri and L. Spiegelhofer discussed on the joint distribution of sum-of-digits functions for numeration systems that are defined in terms of linear recurrences.
- V. Berthé, S. Labbé, W. Steiner, and J. Thuswaldner discussed on convergence properties of the Selmer continued fraction algorithm. During the workshop they gained some new results on its convergence properties (in particular, on the (non)negativity of its second Lyapunov exponent).
- M. I. Cortez and O. Lukina started a project on orbit-equivalence for Bratteli-Vershik systems.
- J. Jankauskas and A. Kovács started discussions about matrix number systems with finiteness properties.
- D. Krenn and J. Shallit: k-regular sequences are defined by an underlying number system. In this joint work, decision properties (in the sense of theoretical computer science) are studied.
- H. Nakada and J. Thuswaldner discussed geodesic continued fractions and complex Farey tesselations in imaginary quadratic fields.
- J. Thuswaldner and S.-Q. Zhang continued their work on self-affine tiles (which are related to canonical number systems) that are homeomorphic to closed 3-balls.

We also initiated a possible OEAD or ERASMUS collaboration between Austria and Hungary. In particular, this was an idea of Attila Kovács from Budapest who has a strong background in Theoretical Computer Science. Besides that we discussed the possibility of applying for a COST project offered by the European Union that supports the organization of conferences. In the meantime, such an application has been submitted (main proposer is Manfred Madritsch from Nancy).

Another fact we want to mention is that during our workshop several participants asked for a continuation of the "Numeration" series. We are very happy that already during the time of the workshop a team of colleagues from The Netherlands around Karma Dajani and Charlene Kalle agreed to organize "Numeration 2020" in Utrecht. On top of this some colleagues from Lithuania showed interest in organizing the event in 2021.

List of talks

Christiane Frougny	Two applications of the spectrum of numbers
Wolfgang Steiner	Thue-Morse-Sturmian words and critical bases for ternary alphabets
Hitoshi Nakada	On the maximum value of entropy of α-continued fraction maps
Niels Langeveld	Continued fractions with a finite alphabet $\mathcal{A} \subset \mathbb{R}$
Benthen Zeegers	An extension of Lochs' Theorem to a class of random interval maps
Marie Lejeune	Computing the k-binomial complexity of the Thue-Morse word
Célia Cisternino	State complexity of the multiples of the Thue-Morse set
Jeffrey Shallit	Determining Repetition Thresholds via Logic and Numeration Systems
Pascal Hubert	Tiling Billards
Sebastién Labbé	From Sturmian to Wang shifts
Jeong-Yup Lee	Regular model sets on Pisot family substitution tilings in $\mathbb{R}^d$ with pure discrete spectrum
Ligia Loretta Cristea	On triangular labyrinth fractals
Paul Surer	A very general approach for representing integers
Tomáš Vávra	Continued β-fractions in the quadratic Pisot case
Hana Dlouha	Algorithms performing algebraic operations in multidimensional continued fraction representations
Marta Maggioni	Flipped α-continued fractions class of random interval maps
Magdaléna Tinková	Jacobi-Perron algorithm and indecomposable integers in the simplest cubic fields
Karma Dajani	Minkowski Normal Numbers
Dominik Kwietniak	Borel complexity of sets of normal numbers via generic points in subshifts with specification
Bill Mance	Descriptive Complexity in Cantor series
Jean-Paul Allouche	The zeta-regularized product of evil numbers
Lukas Spiegelhofer	Möbius orthogonality and the sum of digits in different bases
Myriam Amri	On the largest prime factors and strongly q-additive functions
Anthony Quas	Lyapunov exponents for Perron-Frobenius cocycles of Blaschke Products
Alexandra Skripchenko & Charles Fougeron	Lyapunov Spectrum for Triangle Partitions
Radhakrishnan Nair	Ergodic Theorems in positive characteristic time
Roman Nikiforov	Ergodic and fractal properties of the *GLS*-expansion of real numbers and generalizations
Attila Pethő	General shift radix systems and discrete rotation
Kevin Hare	The Entropy of Cantor–like measures
Shuqin Zhang	On self-affine tiles whose boundary is a sphere
Fabien Durand	Self-induced dynamical systems
Drew Ash	Speedups of Minimal Cantor Systems and Strong Orbit Equivalence
Lingmin Liao	Normal sequences with given limits of multiple ergodic averages

Wanlou Wu	The growth rate of periodic orbits and topological entropy
Sangtae Jeong	Ergodic functions over $\mathbb{Z}_p$
Attila Kovács	Lattice-based number expansions - past and present
Jakub Krásenský	Number Systems in Quaterions
Maria Isabel Cortez	Algebraic invariant of minimal Cantor systems

Publications and preprints contributed

S. Labbé, *Substitutive structure of Jeandel-Rao aperiodic tilings*, arXiv:1808.07768 [math.DS].

K. G. Hare, J. Jankauskas, *On Newman and Littlewood polynomials with prescribed number of zeros inside the unit disk*, arXiv:1910.13994 [math.NT].

V. Berthé, W. Steiner, and J. Thuswaldner, *On the second Lyapunov exponent of some multidimensional continued fraction algorithms*, in preparation.

D. Krenn and J. Shallit, *Decidability and k-Regular Sequences*, arXiv:2005.09507 [cs.FL].

J. Thuswaldner and S.-Q. Zhang, *Self-affine balls*, in preparation.

Invited scientists

Jean-Paul Allouche, Myriam Amri, Drew Ash, Valérie Berthé , Henk Bruin, Celia Cisternino, Maria Isabel Cortez, Ligia-Loretta Cristea, Karma Dajani, Hana Dlouha, Paulis Drungilas, Fabien Durand, Sébastien Ferenczi, Robbert Fokkink, Charles Fougeron, Christiane Frougny, Peter Grabner, Kevin Hare, Clemens Heuberger, Pascal Hubert, Jonas Jankauskas, Sangtae Jeong, Charlene Kalle, Attila Kovacs, Jakub Kr ásensky, Daniel Krenn, Dominik Kwietniak, Sébastien Labbé, Niels Langeveld, Jeong-Yup Lee, Marie Lejeune, Lingmin Liao, Benoit Loridant, Alejandro Maass, Manfred Madritsch, Marta Maggioni, Bill Mance, Radhakrishnan Nair, Hitoshi Nakada, Roman Nikiforov, Marco Pedicini, Edita Pelantova, Attila Pethő, Anthony Quas, Michel Rigo, Jeffrey Shallit, Alexandra Skripchenko, Lukas Spiegelhofer, Stepan Starosta, Wolfgang Steiner, Paul Surer, Jörg Thuswaldner, Robert Tichy, Madgalena Tinkova, Sascha Troscheit, Tomas Vavra, Wanlou Wu, Benthen Zeegers, Shuqin Zhang, Huilin Zhu.

STRONG-DM 2019, Searches, Theories, Results, Opportunities, and New Ideas for sub-GeV Dark Matter

Organizers: Brian Batell (U of Pittsburgh), Nicolás Bernal (U Antonio Nariño), Xiaoyong Chu (HEPHY Vienna), Alejandro Ibarra (TU Munich), Hye-Sung Lee (KAIST), Josef Pradler (HEPHY Vienna, chair), Tomer Volansky (Tel Aviv U)

Dates: August 5 - 16, 2019

Budget: ESI € 18 633,
Vienna Convention Bureau € 1 200 (Speaker support),
HEPHY € 1 300 (social program support),
Grant J. Pradler € 2 200 (social program support).

Report on the workshop

The STRONG-DM (Searches, Theories, Results, Opportunities, and New ideas for sub-GeV Dark Matter) program was a workshop dedicated to the discussion about particle Dark Matter. Despite a worldwide effort to detect dark matter at laboratories and significant progress in astrophysical and cosmological observation, little has been revealed about the concrete microphysical properties of particle dark matter. What is its mass? Is it one particle or are there more? Does it interact with new, hidden forces? What is the origin of its abundance? and why is the latter so close to the measured baryonic density?

This workshop focused on the renewed interest in dark matter solutions in the keV-GeV mass range. The mass range entails a rich cosmology, and requires dedicated experimental strategies. This workshop aimed at developing ideas that pave the way to the enable the discovery of dark matter if its mass resides in the keV-GeV mass bracket. During the course of the workshop, we also hosted a mini-conference "Light Dark World International Forum" with a denser program of presentations.

Overall the program dealt with the following topics, that have been addressed in talks:

- Cosmology and Astrophysical Signatures of Light Dark Matter,
- Dark Matter Production at High-Luminosity Colliders and at Fixed Target/Neutrino Experiments,
- Direct Detection of sub-GeV dark matter,
- Production of dark matter in the early universe,
- Dark matter self-interactions.

Activities

The STRONG-DM workshop schedule had 24 talks both by internationally renowned experts in the field and by younger scientists. The program featured one or two 1h overview talks in the morning, and up to three shorter presentations in the afternoon, all followed by an extended discussion time. The opening talk was given by Joshua Ruderman (NYU) whose travel we additionally supported through a grant by the Vienna Convention Bureau. Overall, the schedule of the workshop was organized in such a way to leave enough time for discussions among the participants, with an average of 4 talks per day.

At the beginning of the second week, we hosted the "Light Dark World International Forum", an annual 2-day meeting previously hosted in Korea (2016 & 2018) and at the US (2017), chaired by Hye-Sung Lee (Korea) and Brian Batell (Pittsburgh University). The conference-style meeting featured 17 talks by internationally renowned experts in the field, by younger scientists, and also by local participants.

Specific information on the workshop

There were 45 participants, including 5 international post-docs and 4 international prae-docs,

- Itay Bloch (prae-doc, Tel Aviv University)
- Nassim Bozorgnia (postdoc, Durham University)
- Timon Emken (postdoc, Chalmers University)
- Camilo Garcia-Cely (postdoc, DESY)
- Saniya Heeba (prae-doc, RWTH Aachen)

- Anastasia Sokolenko (prae-doc, University of Oslo)
- Tommi Tenkanen (postdoc, Johns Hopkins University)
- Laurent Vanderheyden (prae-doc, ULB)
- Wei Xue (postdoc, CERN)

In addition, local young researchers included,

- Michel Bertemes (prae-doc, HEPHY)
- Alberto Escalante del Valle (postdoc, HEPHY)
- Gianluca Inguglia (postdoc, HEPHY)
- Florian Reindl (postdoc, HEPHY)
- Lukas Semmelrock (postdoc, HEPHY)
- Armin Shayeghi (postdoc, University of Vienna)

Everyone in the list above gave a talk.

Outcomes and achievements

This workshop stood out from comparable workshops in this field by featuring an unusual international pan-EU mix of scientists: Australia (1), Canada (2), China (2), Colombia (1), Israel (3), Korea (2), and United States (10). Hence, thanks to the geographical median location between North America and Asia, STRONG-DM managed to bring together experts on the featured topics from around the globe. They were interacting with a sizable crowd of local participants and a total of 15 junior scientists. All the slides of the talks are made available via links from the ESI homepage of the workshop to the Indico sites `https://indico.cern.ch/e/STRONG-DM/` and `http://indico.cern.ch/e/LDW2019`.

Participants have also used this workshop to start new research projects that hopefully will lead to publications in the near future. As an exemplary list, below are some projects started by the coordinators of the workshop as those are the ones we could reliably track:

- N. Bernal, X. Chu and C. Garcia-Cely started collaborating on a project concerning dark matter self-interactions within the effective-range approach
- N. Bernal, X. Chu, S. Kulkarni, and J. Pradler started collaborating on self-interacting dark matter
- C. Boehm and J. Pradler started collaborating on sub-GeV dark matter in the light of precision probes and intensity frontier searches

List of talks

Week 1, August 5 – 9, 2019

Joshua Ruderman	Thermal Relic Targets
Tien-Tien Yu	Theory of dark matter-electron scattering
Hooman Davoudiasl	Ultra Light Boson Dark Matter and Event Horizon Telescope Observations of M87*

Camilo Garcia-Cely	Effective-Range Approach to Dark Matter Self-Scattering
Adam Ritz	EDMs and dark sectors
David McKeen	Light unstable dark matter and relic neutrinos
Wei Xue	Can the ANITA anomalous events be due to new physics?
Nassim Bozorgnia	The Dark Matter Component of the Gaia Sausage Structure
Andrei Derevianko	Probing dark sector with quantum sensors
Martti Raidal	Recent developments in understanding primordial black hole dark matter
Pyongwon Ko	Dark pion DM: WIMP vs. SIMP
Ulf Leonhardt	Cosmology in the laboratory
Thomas Hambye	Dark photon production of DM
Brian Thomas Batell	Flavor-specific scalar mediators
Ernest Ma	See-saw Dark Matter and Higgs Decay
Yu-Feng Zhou	Probing dark matter through cosmic-ray antiparticles

Week 2, August 12 – 16, 2019

Alexey Boyarsky	Decaying and warm DM, a status report
Sergei Gninenko	NA64: new results and prospects
Neelima Sehgal	CMB-HD: Probing Dark Matter Particle Properties with Ultra-High-Resolution CMB Lensing
Nicolás Bernal	Ultraviolet Freeze-in and Non-Standard Cosmologies
Haipeng An	Light fermionic dark matter and the Lyman-alpha constraint
Timon Emken	Direct detection of sub-GeV dark matter with strong interactions through a light mediator
Anastasia Sokolenko	Phenomenology of GeV-scale scalar portal
Gianluca Inguglia	First results and prospects for dark sector physics at Belle II
Tommi Tenkanen	Initial conditions for non-thermal dark matter production
Frank Deppisch	Neutrinoless Double Beta Decay and the Search for Lepton Number Violation
Florian Reindl	Cryogenic scintillating dark matter detectors with a particular focus on the CRESST experiment
Armin Shayeghi	Searching for light DM with molecular matter waves
Alberto Escalante del Valle	Search for dark sectors and long lived particles at the LHC
Yanou Cui	Cosmic Archaeology with Gravitational Waves from (Axion) Cosmic Strings
Lukas Semmelrock	Light dark states with electromagnetic form factors
Itay Bloch	Comagnetometers as a Probe to New Physics
Rouven Essig	Recent progress in direct detection of sub-GeV dark matter
Torsten Bringmann	Inverse direct detection: Novel constraints on light dark matter
Thomas Schwetz	Axion miniclusters and constraints from iso-curvature fluctuations
Laurent Vanderheyden	Dark matter direct detection is testing freeze-in
Saniya Heeba	Freezing-in of Light Scalars
Felix Kahlhoefer	Strongly interacting dark sectors in the early Universe and at the LHC
Céline Bœhm	From Large-Scale-Structures to Light dark matter, and back
Tomer Volansky	Dynamical Emergence of a Small cosmological constant

Publications and preprints contributed

S. Heeba, F. Kahlhoefer, *Probing the freeze-in mechanism in dark matter models with $U(1)'$ gauge extensions*, arXiv:1908.09834 [hep-ph].

R. Essig, J. Pradler, M. Sholapurkar, T. T. Yu, *On the relation between Migdal effect and dark matter-electron scattering in atoms and semiconductors*, arXiv:1908.10881 [hep-ph].

J. Herrero-Garcia, Y. Müller, T. Schwetz, *Astrophysics-independent determination of dark matter parameters from two direct detection signals*, arXiv:1908.07037 [hep-ph].

X. Chu, C. Garcia-Cely, H. Murayama, *A Practical and Consistent Parametrization of Dark Matter Self-Interactions*, arXiv:1908.06067 [hep-ph].

N. Bernal, F. Elahi, C. Maldonado and J. Unwin, *Ultraviolet Freeze-in and Non-Standard Cosmologies*, arXiv:1909.07992 [hep-ph].

Invited scientists

Haipeng An, Brian Batell, Nicolás Bernal, Michel Bertemes, Itai Bloch, Celine Boehm, Alexey Boyarsky, Nassim Bozorgnia, Torsten Bringmann, Xiaoyong Chu, Yanou Cui, Hooman Davoudiasl, Andrei Derevianko, Timon Emken, Rouven Essig, Camilo Alfredo Garcia Cely, Sergei Gninenko, Thomas Hambye, Saniya Heeba, Gianluca Inguglia, Felix Kahlhöfer, Pyungwon Ko, Jui-Lin Kuo, Hey-Sung Lee, Ulf Leonhardt, Zhiyuan Li, Wolfgang Lucha, Ernest Ma, David McKeen, Gerhard Petrakovics, Josef Pradler, Martti Raidal, Florian Reindl, Adam Ritz, Joshua Ruderman, Thomas Schwetz-Mangold, Neelima Sehgal, Lukas Semmelrock, Anastasia Sokolenko, Tommi Tenkanen, Laurent Vanderheyden, Tomer Volansky, Wei Xue, Tien-Tien Yu, Yufeng Zhou.

MAIA 2019: Multivariate Approximation and Interpolation with Applications

Organizers: Maria Charina (U Vienna), Karlheinz Gröchenig (U Vienna), Philipp Grohs (U Vienna), Johannes Wallner (TU Graz).

Dates: August 26 – 30, 2019

Budget: ESI € 18 400,
€ 1 760 used for the reception at ESI, covered by various grants of the organizers,
two participants used their own funding (one of which even declined the offered per diem), several Ph.D. students were funded by their advisors.

Report on the workshop

MAIA 2019 was the thirteenth event in a prestigious series of international conferences which take place every three years starting from 1983. As participation at the MAIA conferences has always been by invitation, the Erwin Schrödinger Institute was an ideal conference site. The main goal of this event was to reconnect and harmonize the classical directions of approximation theory with some of its modern rein-carnations, such as learning theory, compressed sensing, computational harmonic analysis, geometry processing, numerics of PDEs, sparse approximation, etc. These topics were united by several features: they are high-dimensional (thus “multivariate approximation and interpolation”), they are tied to specific applications (“and applications”), and they have a strong computational component.

The participants came from classical approximation theory and from several communities that build around emerging new directions. The status of MAIA in the international community is best highlighted by the participation of the editors-in-chief of the two leading journals in approximation theory (Wolfgang Dahmen, Constr. Approx., and Amos Ron, J. Approx. Th.).

Activities

The conference was attended by 60 invited scientists and many members of the local community. The scientific program consisted of eleven long talks of 50 minutes, 24 talks of 30 minutes, and a poster session with 11 posters. The participants put in a considerable effort to deliver clear and enlightening lectures and posters. Notably, many lecturers used the time honored blackboard style.

The schedule was grouped by the following topics:

(i) *Orthogonal polynomials*: Mihai Putinar lectured on recent advances in this classical area.

(ii) *Machine learning and deep learning*: the lectures of Helmut Bölcskei (deep neural networks), Ding-Xuan Zhou (approximation theory of convolutions nets), and Anthony Nouy (learning with tree networks) highlighted the role of approximation theory in the exploding field of machine learning and deep learning.

(iii) *Geometry processing*: Nira Dyn (non-linear subdivision schemes), Vladimir Protasov (regularity of subdivision schemes) and Tomas Sauer (generalized convolutions) explored new directions in geometry processing.

(iv) *Partial differential equations*: Wolfgang Dahmen (tensor approximation and high-dimensional diffusion equations) and Larry Schumaker (a new use of splines for solving PDEs) presented new approximation theoretic methods for the numerical solution of PDE.

(v) *Compressed sensing*: Holger Rauhut explored the recovery of high-dimensional functions with compressed sensing.

(vi) *Multivariate interpolation*: Len Bros offered new thoughts on the classical problem of interpolation with polynomials in several variables.

For each topic one or two 50-minute talks (as mentioned above) introduced and motivated a mathematical direction and then explained the state of the art. The 30-minute talks were then devoted to more specialized talks. The 30-minute talks in the afternoon on Monday, Tuesday, and Thursday were held in parallel sessions in the two lecture rooms at ESI.

Late Tuesday afternoon was devoted to a lively two-hour poster session in the corridor of ESI with 11 posters. The poster session offered early stage researchers a great opportunity to interact with senior mathematicians. The poster session was followed immediately by a reception in the common room of ESI, which guaranteed maximal attendance of the poster session.

Specific information on the workshop

Among the participants were several young researchers (several Ph.D. students or within five years after their Ph.D.):

Amir Anat, Tel Aviv University, Israel; Jason Celiz, University of Vienna, Austria; Benedikt Diederichs, University of Passau, Germany; Aleksandr Kozynenko, University of Dnjpro, Ukraine; Lars-Benjamin Maier, TU Darmstadt, Germany; Thomas Mejstrik, University of Vienna, Austria; Caroline Moosmüller, University of California, San Diego, USA; Nicolai Pastoors, TU Dortmund, Germany; Alberto Viscardi, University of Bologna, Italy; Felix Voigtländer, Catholic University of Eichstätt-Ingolstadt, Germany.

Four of them gave a talk and six of them presented a poster.

The conference was attended by members of the numerical harmonic analysis group at the University of Vienna and from the Acoustics Research Institute.

Outcomes and achievements

The schedule offered enough time for informal discussion, and led to intensive interaction between researchers who had not even known each other before the conference. The reply to our questionnaire was enthusiastic and we mention the following new or continued collaborations, some of which will definitely lead to preprints.

C. Conti, L. Romani, and H. Prautzsch started a new collaboration on the C^k analysis of non-stationary subdivision schemes at extraordinary points.

J.-L. Romoro, J. van Velthoven, and F. Voigtländer discussed the existence of frames of molecules in reproducing kernel Hilbert spaces.

D.-X. Zhou reported that the paper "Realizing spatial sparseness by deep ReLU nets with massive data", with C. Chui, etc. was partially carried out during his stay at ESI and will be soon submitted.

L. Schumaker and O. Davidov started a collaboration on error bounds for spline methods for numerical PDEs.

W. Dahmen and O. Mula finished the revision of their article "An Adaptive Nested Source Term Iteration for Radiative Transfer Equations".

L. Schumaker and U. Reif have started a collaboration on spline-based collocation methods on regular grids.

M. Charina, M. Putinar, and J. Stöckler continued their collaboration on real algebraic geometry for the construction of multivariate wavelets.

S. deMarchi and Len Bos worked on barycentric rational interpolation on a triangle.

P. Balacz, Acoustics Research Institute and A. Kunoth discovered their joint interest in the analysis of bat signals and have started an exchange of ideas.

List of talks

Mihai Putinar	Christoffel-Darboux analysis
Larry Schumaker	The Immersed Penalized Boundary Method for solving PDE's
Olga Mula	Optimal reduced model algorithms for data-based state estimation
Peter Binev	Near-optimal adaptive approximations
Shai Dekel	Artificial intelligence based approach to numerical PDE's
Reinhold Schneider	Reduced Isometry Property (RIP) for variational Monte Carlo methods
Jean-Louis Merrien	A simplex spline basis for the Alfeld split in $\mathbb{R}^n$
Oleg Davydov	Error bounds for a least squares meshless finite difference method
Lars-Benjamin Maier	Approximation of functions and functionals on submanifolds by ambient splines
Wolfgang Dahmen	Tensor approximability and high dimensional diffusion equations
Helmut Bölcskei	Fundamental limits of deep neural network learning
Nira Dyn	Non-linear subdivision schemes refining point-normal pairs
Bernard Mourrain	Decomposition of moment series
Benedikt Diederichs	Localizing functions and stability of Sparse Frequency Estimation
Hartmut Prautzsch	Cutting edge refinement
Ulrich Reif	Watertight trimmed NURBS surfaces
Holger Rauhut	Recovery of functions of many variables via compressive sensing
Ding-Xuan Zhou	Approximation theory of deep convolutional nets
Angela Kunoth	Recent results on empirical mode decomposition schemes
Anthony Nouy	Learning with tree tensor networks
Leonard Peter Bos	Multivariate polynomial interpolation and optimal designs
Vladimir Protasov	Regularity of multivariate wavelets and synchronizing automata
David Levin	Some remarks on multivariate approximation
Amos Ron	New insights into multivariate spline functions
Jesus Carnicer	Extensions of planar GC sets and syzygy matrices
Juan Manuel Pena	Conditioning, stability and accuracy in univariate and multivariate problems of approximation theory and C.A.G.D.

Hartmut Führ	Classification of Besov-type decomposition spaces
Alexandr Kozynenko	Piecewise constant approximation for multivariate functions
Tomas Sauer	Generalized Convolutions
Tom Lyche	Interesting Splits
Jose Luis Romero	Sampling multivariate functions along curves
Gerlind Plonka	Reconstruction of non-stationary signals by the generalized Prony method
Stefano de Marchi	Polynomial interpolation via mapped bases without resampling
Felix Voigtlaender	Approximation in $L_p(\mu)$ with deep ReLU neural networks
Marcin Bownik	Exponential frames and syndetic Riesz sequences

Interactive presentations by Anat Amir, Elena Berdysheva, Costanza Conti, Jeremy Levesly, Thomas Mejstrik, Maria Lucia Romani, Lucia Sampoli, Tomas Sauer, Alberto Viscardi, Felix Voigländer and NuHAG.

Publications and preprints contributed

M. Charina, V. Yu. Protasov, *Analytic functions in shift-invariant spaces and analytic limits of level dependent subdivision*, submitted to Journal of Fourier Analysis and Applications.

M. Charina, C. Conti, L. Romani, J. Stöckler, A. Viscardi, *Optimal Hölder-Zygmund exponent of semi-regular refinable functions*, Journal of Approximation Theory (the project was started at ESI in 2018, discussion of revision at ESI in 2019).

Invited scientists

Amir Anat, Elene Berdysheva, Julius Berner, Peter Binev, Carl de Boor, Leonard Peter Bos, Helmut Bölcskei, Marcin Bownik, Jesus Carnicer Alvarez, Mark Jason Celiz, Maria Charina, Costanza Conti, Mariantonia Cotronei, Wolfgang Dahmen, Oleg Davydov, Stefano de Marchi, Shai Dekel, Benedikt Diederichs, Nira Dyn, Martin Ehler, Hans Feichtinger, Michael Floater, Hartmut Führ, Arash Ghaani Farashani, Karlheinz Gröchenig, Kurt Jetter, Bert Jüttler, Andreas Klotz, Sarah Koppensteiner, Oleksandr Kozynenko, Angela Kunoth, David Levin, Jeremy Levesley, Tom Lyche, Lars-Benjamin Maier, Jean-Louis Merrien, Caroline Moosmüller, Bernard Mourrain, Olga Mula Hernandez, Anthony Nouy, Peter Oswald, Nicolai Pastoors, Juan Manuel Pena, Götz Pfander, Gerlind Plonka, Hartmut Prautzsch, Vladimir Protasov, Mihai Putinar, Christophe Rabut, Holger Rauhut, Ulrich Reif, José Luis Romero, Lucia Romani, Amos Ron, Maria Lucia Sampoli, Tomas Sauer, Reinhold Schneider, Larry Schumaker, Joachim Stöckler, Thomas Strohmer, Alberto Viscardi, Felix Voigtländer, Johannes Wallner, Ding-Xuan Zhou.

Modeling of Crystalline Interfaces and Thin Film Structures: A Joint Mathematics-Physics Symposium

Organizers: Ulrike Diebold (TU Vienna), Irene Fonseca (Carnegie Mellon U, Pittsburgh), Paolo Piovano (U Vienna)

Dates: November 11 – 15, 2019

Budget: ESI € 12 400,
other financial support: WWTF MODENA (http://modena.univie.ac.at) and FWF OSCI (http://osci.univie.ac.at) projects supported the salary as senior postdoc of the organizer P. Piovano.

Workshop website: https://www.univie.ac.at/esi_workshop_thin_films/

Report on the workshop

Scientific Background: The analysis of crystalline interfaces, such as thin films and grain boundaries, is crucial for the design, development, and application of various modern materials. During the epitaxial growth of thin films and the self-assembly of crystalline nanostructures, multi-scale phenomena take place and the microscopic morphology strongly impacts the material macroscopic properties. Any progress in the modeling of interface-pattern formations carries the potential for a significant technological impact.

Aim: The workshop aimed at presenting the state of the art and the most recent advancements in the derivation, validation, and implementation of reliable models for the characterization of interface crystalline morphologies. New results have been presented both at the analytical and at the experimental level. On the one hand interface morphologies have been analytically characterized as minimizers of configurational energies in the framework of the Calculus of Variations or as solutions of evolutionary PDEs. On the other hand solutions and challenges encountered in experiments when growing supported nanostructures for example by Molecular Beam Epitaxy (MBE) and Pulsed Laser Deposition (PLD) have been presented. Addressed topics include:

- Derivation of models for crystalline interfaces,
- Crystal-interface regularity and geometric properties,
- Thin-film growth and evolution of crystal interfaces,
- Growth challenges in experiments and applications to technology.

Activities

The detailed schedule of the workshop is available at https://www.univie.ac.at/esi_workshop_thin_films/schedule/. The workshop included 30 seminars held by internationally renowned scientists both physicists and mathematicians, including the keynote lecture held by Prof. David Srolovitz (City University of Hong Kong).

The seminars have been organized in 8 sections: 2 (1 in the morning and 1 in the afternoon) on Monday, Tuesday, and Thursday, and 1 on the mornings of Wednesday and Friday. All sections consisted of 4 talks apart from the morning section of Monday that included also the registration and the keynote lecture, and the morning section of Thursday after the social dinner including 3 talks. Every session started with a talk from a physicist followed by talks by mathematicians and included a coffee break of around 30 minutes. The time allocated to talks was 30 minutes plus 5 minutes for questions and comments, while the keynote lecture lasted 50 minutes plus 10 minutes for questions and comments. Approximately $\sim$2h have been allowed each day for the lunch break.

Wednesday afternoon has been left free to allow the attendees to collaborate in the ESI facilities and a visit to the lab (https://www.youtube.com/watch?v=S3xAwYo7Dqg) of Prof. Diebold's research group at the Institute of Applied Physics (TU Vienna) has been offered. A social dinner joined by almost all participants and supported by the ESI budget took place on Wednesday evening from 7pm at *Feuerwehr Wagner Heuriger* (http://www.feuerwehrwagner.at). A group picture was taken on Wednesday at the end of the morning section. Please refer to https://www.univie.ac.at/esi_workshop_thin_films/pictures/ for the group pictures and the various pictures taken during the social dinner, the coffee breaks, and the social dinner.

Specific information on the workshop

The workshop has been attended by 58 registered participants plus the 3 organizers listed below. All nonlocal participants among PhD students and postdocs (besides the speakers) have been provided or offered financial support for their visit.

Participants among PhD students: Katharina Brazda, Marco Bresciani, Maicol Caponi, Davide Carazzato, Sebastian Hensel, Randy Llerena, Mattia Magnabosco, Alice Marveggio, David Melching, Filippo Riva, Francesco Sapio, Thilo Simon, Emanuele Tasso.

Participants among postdocs: Stefano Almi, Laurent Betermin, Esther S. Daus, Elisa Davoli, Silvio Fanzon, Shokhrukh Kholmatov, Anastasia Molchanova, Valerio Pagliari, Michael Wolloch.

Participants with permanent positions: Roberto Alicandro (University of Cassino), Peter Bella (TU Dortmund), Giovanni Bellettini (University of Siena), Andrea Braides (University of Rome Tor Vergata), Antonin Chambolle (Ecole Polytechnique, CNRS), Marco Cicalese (Technical University Munich), Gianni Dal Maso (SISSA, Trieste), Patrick Dondl (University of Freiburg), Jim Evans (Iowa State University and Ames Laboratory - USDOE), Julian Fischer (IST Austria), Matteo Focardi (University of Firenze), Maria Stella Gelli (University of Pisa), Michael Goldman (CNRS, University of Paris 7), Giuliano Lazzaroni (University of Firenze), Giovanni Leoni (Carnegie Mellon University), Jian-Guo Liu (Duke University), Anne Bernand-Mantel (INSA Toulouse), Tevfik Onur Mentes (Elettra - Sincrotrone Trieste), Marco Morandotti (Politecnico di Torino), Massimiliano Morini (University of Parma), Cyrill Muratov (New Jersey Institute of Technology), Matteo Novaga (University of Pisa), Mariapia Palombaro (University of L'Aquila), Aldo Pratelli (University of Pisa), Guus Rijnders (University of Twente, the Netherlands), Michele Riva (Technical University of Vienna), Tomas Roubicek (Charles University, Prague), Bernd Schmidt (University of Augsburg), Tomas Sikola (Brno University of Technology), David Srolovitz (City University of Hong Kong), Ulisse Stefanelli (University of Vienna), Christian Teichert (Montanuniversität Leoben), Igor Velcic (University of Zagreb).

Outcomes and achievements

The workshop has been organized in such a way to provide all the participants with the opportunity to interact with each other. A selection of the collaborations that the participants have strengthened during the workshop include the following:

- R. Alicandro, G. Lazzaroni, and M. Palombaro continued their collaboration;
- G. Dal Maso and I. Fonseca started a research project in stochastic homogenization (also with R. Ferreira, KAUST and R. Venkatraman, CMU);
- G. Lazzaroni and P. Piovano evaluated a new collaboration;
- G. Lazzaroni and S. Almi continued their collaboration;
- J.-G. Liu and P. Piovano evaluated a new collaboration;

- P. Piovano and I. Velcic continued collaboration;
- B. Schmidt and P. Piovano evaluated a new collaboration.

Expected works:

- *Unraveling the role of dipolar versus Dzyaloshinskii-Moriya interaction in stabilizing compact magnetic skyrmions* by A. Bernand-Mantel, C. B. Muratov and T. M. Simon, Phys Rev B, in press (2020)
- *Microscopical justification of the Winterbottom shape* by I Velcic and P. Piovano, preprint (2019)
- *Paper in elaboration* by R. Alicandro, G. Lazzaroni, and M. Palombaro (2020)

List of talks

Roberto Alicandro	Derivation of linear elasticity from atomistic energies with multiple wells
Peter Bella	Wrinkling of a thin elastic sheet on a compliant sphere
Andrea Braides	Homogenization of oscillating networks
Giovanni Bellettini	Some results on the relaxation of the area functional for graphs in dimension two and codimension two
Antonin Chambolle	Crystalline evolution of mean-convex sets
Marco Cicalese	Does the N-clock model approximate the XY-model?
Gianni Dal Maso	On the jerky crack growth in elastoplastic materials
Patrick Dondl	Pinning of interfaces by localized dry friction
Jim Evans	Assembly and stability of nanoclusters during thin film deposition
Matteo Focardi	How a minimal surface leaves a thin obstacle
Maria Stella Gelli	Variational approach to the dynamics of multiphase models with density constraint
Michael Goldman	Connectedness of drops in convex potentials
Giuliano Lazzaroni	Discrete energies with surface scaling: interactions beyond nearest neighbours versus non-interpenetration
Giovanni Leoni	A sharp interface model for solid-state dewetting problems
Jian-Guo Liu	Dynamics of a degenerate PDE model of epitaxial crystal growth
Tevfik Onur Mentes	Ultra-thin Co films: structure and magnetism
Marco Morandotti	Analysis of a perturbed Cahn-Hilliard model for Langmuir-Blodgett films
Massimiliano Morini	The surface diffusion flow with elasticity in two and three dimensions
Cyrill Muratov	Chiral domain walls and domain wall tilt in ferromagnetic nanostrips
Matteo Novaga	The 0-fractional perimeter
Mariapia Palombaro	Derivation of linearised polycrystals from a 2D system of edge dislocations
Aldo Pratelli	On the optimization of Riesz-like potentials
Guus Rijnders	Novel Functionalities in Atomically Controlled Oxide Heterostructures by Pulsed Laser Deposition
Michele Riva	Growth of $In2O3(111)$ Films with Optimized Surfaces
Bernd Schmidt	Effective theories and energy minimizing configurations for heterogeneous multilayer
Tomas Sikola	Electronic transport properties of graphene doped by gallium – application of density functional theory
David Srolovitz	Grain Boundary Dynamics: a disconnection perspective
Christian Teichert	Interfaces between crystalline organic semiconductor nanostructures and 2D materials
Igor Velcic	Microscopical justification of the winterbottom shape
Barbara Zwicknagl	Low-volume fraction martensitic microstructures close to interfaces

Publications and preprints contributed

A. Bernand-Mantel, C. B. Muratov, T. M. Simon, *Unraveling the role of dipolar versus Dzyaloshinskii-Moriya interaction in stabilizing compact magnetic skyrmions*, Phys Rev B, in press (2020), arXiv:1906.05389 [cond-mat.mtrl-sci].

Expected papers:

Microscopical justification of the Winterbottom shape by I. Velcic and P. Piovano, preprint (2019).

Paper in elaboration by R. Alicandro, G. Lazzaroni, and M. Palombaro (2020).

Invited scientists

Roberto Alicandro, Stefano Almi, Peter Bella, Giovanni Bellettini, Anne Bernand-Mantel, Laurent Bétermin, Andrea Braides, Katharina Brazda, Marco Bresciani, Maicol Caponi, Davide Carazzato, Antonin Chambolle, Marco Cicalese, Gianni Dal Maso, Elisa Davoli, Ulrike Diebold, Patrick Dondl, James Evans, Silvio Fanzon, Julian Fischer, Matteo Focardi, Irene Fonseca, Maria Stella Gelli, Michael Goldman, Sebastian Hensel, Shokhrukh Kholmatov, Lami Kim, Giuliano Lazzaroni, Giovanni Leoni, Jian-Guo Liu, Randy Llerena, Mattia Magnabosco, Alice Marveggio, Anastasia Molchanova, Marco Morandotti, Massimiliano Morini, Cyrill Muratov, Matteo Novaga, David Melching, Tevfik Onur Mentes, Valerio Pagliari, Mariapia Palombaro, Paolo Piovano, Aldo Pratelli, Claudia Raithel, Guus Rijnders, Michele Riva, Filipo Riva, Tomas Roubicek, Francesco Sapio, Bernd Schmidt, Tomas Sikola, Thilo Simon, David J. Srolovitz, Ulisse Stefanelli, Emanuele Tasso, Christian Teichert, Matteo Tommasini, Igor Velcic, Michael Wolloch, Barbara Zwicknagl.

ESI Symposium: What is Life?

Organizers: Wolfgang L. Reiter (ESI, U Vienna), Klaus Schmidt (ESI, U Vienna), Jakob Yngvason (ESI, U Vienna)

Dates: November 18, 2019

Budget: ESI Association € 3 015

Report on the symposium

The event commemorated the appearance of Erwin Schrödinger's seminal book 'What is Life?' 75 years ago, based on his public lectures on 'The Physical Aspect of the Living Cell' at Trinity College, Dublin, in February 1943. This small book was very successful as an introduction to the molecular basis of heredity, and both Francis Crick and James Watson independently acknowledged it as a source of inspiration for their research which in 1953 led to their model of DNA.

Activities

The symposium occupied one afternoon with four lectures devoted to the historical background of Schrödinger's book, its subsequent influence in molecular biology and some very recent developments in this field. The lectures were followed by a reception at the ESI. The event was very well attended.

List of talks

Karl Sigmund, University of Vienna	75 Years of "What is Life?"
Peter Schuster, University of Vienna	From "What is Life?" to "All Life is Chemistry"
Dieter Schweizer, University of Vienna	Introducing Kim Nasmyth and his contributions to the understanding of "What is Life?"
Kim Nasmyth, Oxford University	From chromosomes to the aperiodic crystal: only half of the story

New Trends in the Variational Modeling and Simulation of Liquid Crystals

Organizers: Giovanni Di Fratta (TU Vienna), Michele Ruggeri (TU Vienna), Valeriy V. Slastikov (U Bristol), Arghir D. Zarnescu (BCAM, Bilbao)

Dates: December 2 – 6, 2019

Budget: ESI € 14 320,
FWF € 3 000,
TU Vienna € 500.

Report on the workshop

Liquid crystals are a vast and diverse class of materials, which exhibite properties intermediate between isotropic liquids and crystalline solids. On the one hand, they flow like liquids. On the other hand, their constituent molecules retain orientational order, which generates optical properties specific to solids.

The workshop brought together researchers working on various aspects of the mathematics of liquid crystals, with topics spanning from the physical and numerical modeling of liquid crystalline systems to rigorous analysis of major liquid crystal phenomena. More precisely, the topics addressed during the workshop were the following:

- Local density functional theory for liquid crystal systems, its use to determine equilibrium properties of liquid crystalline systems from first principles and its relation to continuum theories. Phenomenological and molecular descriptions of liquid crystal systems based on order parameters.

- The analysis of the Landau–de Gennes Q-tensor theory of liquid crystals, its relation to the Oseen–Frank director models, and the complementary descriptions of topological defects in these models. Topology and structure of defects in colloidal liquid crystalline systems. Variational theories for liquid crystal elastomers.

- Non-equilibrium phenomena in liquid crystalline systems: The Beris–Edwards and the Ericksen–Leslie dynamical models for liquid crystal flows. Biological systems with liquid crystalline characteristics in which the microorganisms behave as self-propelled particles (active nematics).

- Numerical simulation of static and dynamic phenomena in liquid crystals: numerical schemes for different approaches ranging from molecular dynamics to continuous models based on partial differentials equations (PDEs).

Activities

The workshop started on Monday, December 2 at 9:00 and ended on Friday, December 6 at 13:00, with a scientific program consisting of overall 26 talks. The workshop started with two one-hour introductory lectures on the physics and the mathematics of liquid crystals, given by Peter Palffy-Muhoray and Dmitry Golovaty, respectively. The lectures provided an introduction to the main workshop topics, especially for young participants (doctoral students and postdoctoral researchers) and members of the local scientific community. The slides of the introductory lectures, kindly made available by the lecturers, can be downloaded from the workshop website

https://www.asc.tuwien.ac.at/esi-liquidcrystals2019/

In the afternoon of Thurday, December 5, the workshop moved temporarily to TU Wien, where John Ball gave a lecture on the latest developments of the research on liquid crystals. The lecture took place at TU Wien in the frame of the *Distinguished PDE Lecture series*, organized by the *Vienna Center for Partial Differential Equations* (speaker: Ansgar Jüngel).

The remaining 23 talks consisted of scientific presentations by some of the participants, which gave a broad overview of the state of the art of the research in the field.

Specific information on the workshop

The workshop gave the opportunity to the local scientific community to interact with world leading experts and to get an insight into the latest advances and trends in the mathematics of liquid crystals. The workshop had a positive feedback from the local scientific community, with 16 local participants attending (in addition to the 41 invited external researchers). In particular, several members of two initiatives on PDEs currently active in Vienna (the Doctoral Program (DK) on *Dissipation and Dispersion in Nonlinear PDEs* and the Special Research Program (SFB) *Taming complexity in partial differential systems*, which foster collaborations between the mathematics departments of TU Wien, University of Vienna, and IST Austria) participated in the meeting.

Moreover, the meeting gave a great opportunity to younger researchers, i.e., post-docs (13 participants) and doctoral students (8 participants), to interact with senior researchers, i.e., researchers with permanent positions (36 participants).

The complete list of young researchers that attended the workshop is provided below:

- Postdoctoral researchers: Laurent Bétermin, Elisa Davoli, Giovanni Di Fratta, Amrita Ghosh, Georgy Kitavtsev, Yu Mei, Antonin Monteil, Valerio Pagliari, Paolo Piovano, Claudia Raithel, Michele Ruggeri, Jesus A. Sierra Nunez, Jamie M. Taylor.
- Doctoral students: Marco Bresciani, Razvan-Dumitru Ceuca, Michael Innerberger, Alice Marveggio, Carl-Martin Pfeiler, Dominik Stantejsky, Wojciech Tomczyk, Mehdi Trense.

Outcomes and achievements

The workshop was scheduled to provide all the participants with the opportunity to interact with each other. Since the workshop had participants from all over the world (43 participants from Europe, 13 participants from North America, 1 participant from Asia), the workshop provided a unique opportunity to foster contacts and collaborations.

A selection of the collaborations that the participants have begun or continued at the institute is provided below:

- Ivan Smalyukh discussed with Lech Longa about a possible collaboration on biaxial nematics in hybrid systems composed of liquid crystals and colloids.
- Lech Longa discussed with Valeriy Slastikov about a possible collaboration on the ground state analysis in a model elastic theory of the nematics twist bend.
- Wojciech Tomczyk worked with Lech Longa on a joint paper on *Generalized Landau-de Gennes theory of nematic-nematic twist bend phase transition*.
- Apala Majumdar discussed parts of an ongoing project on ferronematics with Giacomo Canevari and Bianca Stroffolini.
- Apala Majumdar had scientific discussions on the slip problem for nematohydrodynamics with Amrita Ghosh.
- Martin Kružík, inspired by the talk of John Ball, had some ideas about a possible topic for the diploma thesis of one of his students.
- Lou Kondic and Miha Ravnik discussed various ideas for future projects about computational methods for liquid crystals in the context of active matter.
- Giovanni Di Fratta and Valeriy Slastikov discussed with Alberto Fiorenza on the blow-up of Lebesgue norms.
- Michele Ruggeri discussed with Miha Ravnik about numerical methods for the coupled systems of PDEs which arise while modeling the optical and photonic properties of liquid crystals.
- Giovanni Di Fratta, Valeriy Slastikov, and Arghir Zarnescu started a new collaboration on multipole expansions in colloids.
- Razvan Ceuca and Giacomo Canevari discussed extensions of the design of colloids discussed in an article by Canevari and Zarnescu to a more physically relevant context of cage structures within a nematic environment.
- Giacomo Canevari and Jamie Taylor discussed an ε-regularity theory for the nonlocal to local limit that Jamie Taylor previously explored in his thesis, which was related also to his presentation at the workshop.
- Carlos García-Cervera and Tiziana Giorgi discussed several possible numerical and analytical projects dealing with the modeling of bent-core liquid crystals (BCLCs) phases. Among others, inspired by the talk of John Ball, the question of numerically studying the effects of different elastic constants in the moderate regime case (different but comparable constants) in the framework of the Oseen–Frank energy for BCLCs, and of the Q-tensor theory for nematic liquid crystals. Additionally, they discussed possible improvements related to the derivation of the so-called renormalized energy for the Gamma-limit they have derived, in collaboration with Sookyung Joo (Old Dominion University), to study the formation of vortices in the Smectic A modulated phase in BCLCs.
- Lia Bronsard, Stan Alama, and Tiziana Giorgi started discussing a new research project involving the modeling of the newly discovered twist-bend nematic phase in bent-core liquid crystals. The intention would be to rigorously analyze a coarse-graining elastic model, introduced by Shiyanovskii, Simonario, and Virga (Liquid Crystals 44, 1 (2017) 31–44), using tools from Calculus of Variations, to study the effects of boundary conditions and an applied magnetic field on the equilibrium states.

- Lia Bronsard discussed with Dominik Stantejsky, who is writing an article with Antonin Chambolle on results which extend a previous article of Stan Alama, Xavier Lamy, and herself.
- Lia Bronsard, Stan Alama, Xavier Lamy, and Dmitry Golovaty discussed parts of an ongoing project on stability of solutions.

List of talks

Peter Palffy-Muhoray	The physics of liquid crystals
Dmitry Golovaty	The mathematics of liquid crystals
Lech Longa	Twist-bend nematic phase from Landau–deGennes perspective
Georgy Kitavtsev	Solution patterns for active gel systems with a free evolving boundary
Peter J. Sternberg	A model problem for nematic-isotropic transitions with highly disparate elastic constants
Chun Liu	Transport and diffusion in biological environments
Jamie M. Taylor	Microscopic to macroscopic modelling in liquid crystals
Linda J. Cummings	Modeling and large-scale simulation of thin film liquid crystal flows
Elisabetta Rocca	Nonlinear electrokinetics in nematic electrolytes
Lidia Mrad	Toroidal self-assembly in columnar chromonic liquid crystals
Bianca Stroffolini	A free boundary problem for smectics (Lacaze experiment)
Miha Ravnik	Nematic structures for advanced optical performance: metamaterials, photonic crystals and cloaking devices
Tiziana Giorgi	Boundary vortex formation in polarization-modulated orthogonal smectic liquid crystals
Carlos J. García-Cervera	Undulations and switching mechanisms in smectic liquid crystals
Mikhail A. Osipov	Density functional approach to the molecular theory of rod-coil diblock copolymers
Mark Wilkinson	The Boltzmann equation for non-spherical particles
Ibrahim Fatkullin	Limit shapes for Gibbs ensembles of partitions
Ivan I. Smalyukh	Adaptive and active crystals of knot solitons
Apala Majumdar	Pattern formation in confined nematic systems
Radu Ignat	Vortices on 2D surfaces and applications
Antonio Segatti	Functional framework and topological defects in nematic shells
John M. Ball	Distinguished PDE Lecture 2019: Some mathematical problems of liquid crystals (at TU Vienna)
Giacomo Canevari	Effective free energies for polydisperse nematic colloids
Xavier Lamy	Saturn ring defect around a large colloid particle
Christos N. Likos	Hydrodynamics meets topology: Equilibrium and flow properties of ring polymers
Stan Alama	Thin film nematics with oblique anchoring and boojums

Invited scientists

Stanley Alama, John M. Ball, Laurent Bétermin, Marco Bresciani, Lia Bronsard, Giacomo Canevari, Razvan-Dumitru Ceuca, Linda J. Cummings, Elisa Davoli, Giovanni Di Fratta, Ibrahim Fatkullin, Carlos J. García-Cervera, Amrita Ghosh, Tiziana Giorgi, Dmitry Golovaty, Radu Ignat, Michael Innerberger, Ansgar Jüngel, Georgy Kitavtsev, Lou Kondic, Martin Kružík, Xavier Lamy, Christos N. Likos, Chun Liu, Lech Longa, Apala Majumdar, Alice Marveggio, Yu Mei, Antonin Monteil, Lidia Mrad, Mikhail A. Osipov, Valerio Pagliari, Peter Palffy-Muhoray, Carl-Martin Pfeiler, Paolo Piovano, Dirk Praetorius, Claudia Raithel, Miha Ravnik, Jonathan Robbins, Elisabetta Rocca, Michele Ruggeri, Giulio Schimperna, Antonio Segatti, Elyas Shivanian, Jesus A. Sierra Nunez, Valeriy V. Slastikov, Ivan I. Smalyukh, Dominik Stantejsky, Ulisse Stefanelli, Peter J. Sternberg, Bianca Stroffolini, Jamie M. Taylor, Wojciech Tomczyk, Mehdi Trense, Mark Wilkinson, Arghir D. Zarnescu.

Polarons in the 21st Century

Organizers: Jozef Devreese (U Antwerpen), Cesare Franchini (U Vienna), Georg Kresse (U Vienna), Jacques Tempere (U Antwerpen)

Dates: December 9 – 13, 2019

Budget: ESI € 8 960,
UNI Antwerpen € 1 842,
CECAM € 2 912,
CMS € 2 000.

Report on the workshop

Activities

This workshop has gathered together an interdisciplinary group of researchers working on polaron physics from different perspectives, including: (i) First-principles calculations, (ii) Quantum-field Hamiltonian approaches, (iii) Theoretical & mathematical models and (iv) Experiments, representative of the condensed-matter and ultracold atoms communities. The workshop has offered the opportunity to report the status of the art, discuss new ideas, developments and establish possible interactions among the different communities as specified in the 'Outcomes' section. Overall 8 presentations were given by female scientists (both senior and young ones).

Workshop Structure

Type of presentations: Overview talk (OT, 60 mins), invited talks (IT, 40 mins), contributed talks (CT, 20 mins), poster session (P) and open discussions (D at the end of each talks and during the coffee/tea breaks). The detailed schedule is given below (R=registration; O=Opening, C=Closing, L=Lunch, D=Dinner).

Day 1		Day 2		Day 3		Day 4		Day 5	
09:00-09:20	R	09:00-09:40	IT	09:00-09:40	IT	09:00-09:40	IT	09:00-09:40	IT
09:00-09:40	O	09:40-10:00	CT	09:40-10:20	IT	09:40-10:20	IT	09:40-10:20	IT
09:40-10:40	OT	10:00-10:20	CT	10:20-11:00	D	10:20-11:00	D	10:20-11:00	D
10:40-11:20	IT	10:20-11:00	D	11:00-11:40	IT	11:00-11:40	IT	11:00-11:40	IT
11:20-11:50	D	11:00-11:40	IT	11:40-12:20	IT	11:40-12:20	IT	11:40-12:00	IT
11:50-12:30	IT	11:40-12:20	IT	12:20-14:00	L	12:20-14:00	IT	12:00-12:20	C
12:30-14:00	L	12:20-14:00	L	14:00-14:40	IT	14:00-14:40	IT		
14:00-14:40	IT	14:00-14:40	IT	14:40-15:00	CT	14:40-15:00	CT		
14:40-15:00	CT	14:40-15:00	CT	15:00-15:30	D	15:00-15:30	D		
15:00-15:30	D	15:00-15:30	D	15:30-16:10	IT	15:30-16:10	IT		
15:30-16:10	IT	15:30-16:10	IT	16:10-16:30	CT	16:10-16:30	CT		
16:10-16:30	CT	16:10-16:30	CT						
		16:55-19:00	P	19:00-22:00	D				

Specific information on the workshop

Total number of participants: 60

Number professors and senior scientists: 28

Number of young scientists, prae- and post-docs: 3

Virtually all participants had the opportunity to present and discuss their research during the workshop. The post-docs gave invited talks (Martin Setvin, Michele Reticcioli, Sebastian Kokott, Joannis Koepsell), contributed talks (Giacomo Bighin, Carla Verdi, Julia Wiktor, Felix Rose, Matthew Wolf and Patrick Gono) and posters (Sabine Körbel, Matthias Meier, Ji Chen). There were also many PhD students that had the opportunity to present contributed talks (Iflah Laraib, Manuel Engel, Thomas Hahn) and posters (overall 10 students).

List of posters presented

Akash Singh	Engineering Defect Transition-Levels through van der Waals Heterostructure
Ji Chen	Interplay between small polarons and water on TiO_2 surfaces
Weng Hong Sio	Two-dimensional polarons: the case of monolayer BN
Igor Sokolović	Interactions of O_2 and CO molecules with small electronic polarons on the TiO_2 (110) surface
Matthias Meier	Polarons in Fe_2O_3: Affecting H_2O Diffusion and Desorption
Timour Ichmoukhamedov	Feynman path-integral treatment of the Bose polaron beyond the Fröhlich model
Juraj Krsnik	Electron scattering and bound states in the presence of polaronic impurities
Matthew Houtput	Beyond-Fröhlich Hamiltonian for large polarons in anharmonic solids
Manuel Engel	Electron-Phonon Interactions using the Projector-Augmented-Wave Method
Sabine Körbel	Polarons at ferroelectric domain walls in $BiFeO_3$
Supriti Ghorui	Optoelectronic Properties and Defect Physics of Lead-free Photovoltaic Absorbers $Cs_2Au^{(I)}Au^{(III)}X_6$ (X=I, Br)
Jiban Kangsabani	Lattice Dynamics and Electron-phonon coupling in Lead free Bi^{3+} Alloyed $Cs_2AgInCl_6$ Double Perovskite Nanocrystals
Luis Ardila	From polarons to bipolarons in Bose-Einstein condensates

List of young researchers prae- and post-docs as well as master students

Martin Setvin, Michele Reticcioli, Sebastian Kokott, Joannis Koepsell, Giacomo Bighin, Carla Verdi, Julia Wiktor, Felix Rose, Matthew Wolf, Patrick Gono, Sabine Körbel, Matthias Meier, Ji Chen, Akash Singh, Weng Hong Sio, Igor Sokolovic, Timour Ichmoukhamedov, Juraj Krsnik, Matthew Houtput, Iflah Laraib, Manuel Engel, Thomas Hahn, Supriti Ghorui, Jiban Kangsabanik, Luis Ardila, Vijaya Begum, Behnood Dianat, Michel Panhans, Jiban Kangsabanik, Elaheh Ghorbani, Sergey Artyukhin, Volker Karle.

Outcomes and achievements

The main outcome of the workshop is that researchers in the various communities, hitherto unaware of each others work, got to know each other and got information on what is going on in interdisciplinary polaron physics. This has lead to several new insights. A prominent example is the question of polaron formation dynamics. When an electron is introduced in the conduction band (by doping or UV irradiation), the polaron takes some time to form the cloud of phonons surrounding it. This was identified from the start as an interesting open problem. It is a question of importance since it can interfere with some probes of polaron physics: if the probe follows the pump too quickly, the polaron is not yet fully formed. If it follows too late, the polaron may already have decayed or scattered through many-body interactions into other states. In the workshop, we learned from researchers in ultracold atomic gases that they are able to study the polaron formation in a very controlled way using the condensates with a tunable interaction strength (adapted experimentally via Feshbach resonances). The first measurements, performed in the context of quantum gases, point the way to a resolution of the polaron formation in solids. The major methods to identify polaron formation using ab-initio methods were reviewed and updates given on the current development. The limitations of methods such as starting from an initial deformation or supercell methods, were outlined. The main problem was identified, and lies in the fact that the entanglement between the electron and the phonons is very difficult to take into account using a full ab-initio approach. For small polarons these entanglement effects are not very important, but at weaker coupling, for larger polarons, the entanglement turns out to become even dominant. The workshop also revealed the way ahead to solve this problem. The idea is to combining ab-initio calculations of the parameters of model Hamiltonians (electron-phonon couplings, phonon bands, ...) with semi-analytic methods that start from these Hamiltonians and provide a quantum mechanical description capable of fully taking the electron-lattice entanglement into account (such as diagrammatic Monte Carlo).

During the workshop many scientists has the chance to strengthen existing collaborations or to establish new collaborations, which will continue in the coming months/years and will results in common publications. Examples of specific collaborations:

1. Mapping diagrammatic Monte Carlo with first principles methods for small polarons, large polarons and angulon
2. Combining first principles calculations and experiments to describe the properties of polarons in real materials
3. Interpretation of infrared absorption spectroscopy with ab initio methods
4. Merging analytical approaches and atomistic calculations

List of talks

Jacques Tempere	Polaron physics through the XX and XXI centuries
Aaron Deskins	New perspective on magnetic polarons in antiferromagnetic Mott insulators from cold atoms
Christof Wöll	Polarons on Oxides Detected by Infrared-Reflection Absorption Spectroscopy (IR-RAS): The Case of TiO_2 and ZnO
Frank Ortmann	Vibrations and their Impact on Electronic and Transport Properties of Organic Materials
Stephan Lany	Direct first-principles calculation of polarons in Koopmans-corrected DFT
Iflah Laraib	Electronic structure of $YTiO_3$ and the charge transport through small polaron hopping
Feliciano Giustino	Looking inside a polaron
Manuel Engel & Thomas Hahn	Diagrammatic Monte Carlo for Polarons from First Principles
Jarvist Moore Frost	Polaron mobility and response functions in the Feynman variational approximation
Alison Walker	Multi scale modelling of organic devices and perovskite solar cells
Mikhail Lemeshko	Quasiparticle approach to molecules rotating in quantum solvents
Giacomo Bighin	Diagrammatic Monte Carlo approach to angular momentum in quantum many-body systems
Marco Grioni	ARPES signatures of polarons
Carla Verdi	Polaronic satellites in angle-resolved photoemission spectra from ab initio many-body calculations

Robert Seiringer	The Fröhlich polaron at strong coupling
Sergio Ciuchi	Disorder-induced polarons in strongly disordered metals (and doped oxides)
Alexander Shluger	Polarons and intrinsic electron and hole trapping in amorphous oxides
Cristiana Di Valentin	Polaronic effects in titanium and iron oxides by hybrid density functional theory calculations
Xiaoyang Zhu	Ferroelectric Polarons and Belgian Waffles in Lead Halide Perovskites
Julia Wiktor	Polarons in photoabsorbing materials: Role in solar cells and water-splitting devices
Richard Schmidt	Polaronic effects in condensed matter and atomic systems
Felix Rose	Disorder in order: simulating a random scattering potential with a randomless cold atom system
Elio Giamello	Charge carriers trapping in semiconducting metal oxides. The point of view of an EPR spectroscopist
Chris Van de Walle	Impact of small polarons on the properties of transition-metal oxides
Frédéric Chevy	The 2N+1 body problem: An impurity immersed in a strongly correlated fermionic superfluid
Jan Arlt	Universal dynamics of impurities in a Bose-Einstein condensate
Martin Setvin	Combined STM/AFM: Watching polarons at the atomic level
Xavier Gonze	Dynamical effects in zero-point renormalization of the band gap: connecting first-principles approach and Fröhlich model
Annabella Selloni	Localized and Delocalized Excess Electrons States in Reduced Anatase TiO_2
Matthew Wolf	Band-Electron vs. Polaron Mobility in Metal–Halide Perovskites
Serghei Klimin	Equilibrium and response properties of a many-polaron gas
Michele Reticcioli	Intrinsic polaron formation and influence on the surface chemical properties
Sebastian Kokott	Simulating Small Polarons from First Principles: The DFT supercell approach
Patrick Gono	Surface Polarons Reducing Overpotentials in the Oxygen Evolution Reaction

Publications and preprints contributed

By so far, there are not yet publications related to this activity but we are confident that in 2020 there will be common articles arising from the collaborative discussions developed during the workshop. For instance, some of the participants have been invited to write a review on polarons that will be submitted in 2020.

Invited scientists

Jan Arlt, Sergey Artyukhin, Vijaya Begum, Giacomo Bighin, Ji Chen, Frederic Chevy, Sergio Ciuchi, Aaron Deskins, Cristiana Di Valentin, Behnood Dianat, Ulrike Diebold, Manuel Engel, Stefano Falletta, Cesare Franchini, Elaheh Ghorbani, Supriti Ghorui, Elio Giamello, Feliciano Giustino, Patrick Gono, Xavier Gonze, Marco Grioni, Juan Guerra, Thomas Hahn, Kurt Hingerl, Matthew Houtput, Timour Ichmoukhamedov, Jiban Kangsabanik, Volker Karle, Sergei Klimin, Sebastian Kokott, Joannis Koepsell, Sabine Körbel, Georg Kresse, Juraj Krsnik, Stephan Lany, Iflah Laraib, Mikhail Lemeshko, Matthias Meier, Jarvist Moore Frost, Frank Ortmann, Michel Panhans, Luis A. Pena Ardila, Michele Reticcioli, Felix Rose, Richard Schmidt, Robert Seiringer, Annabella Selloni, Martin Setvin, Alexander Shluger, Weng Hong Sio, Igor Sokolović, Jacques Tempere, Chris Van de Walle, Enrico Varesi, Clara Verdi, Alison Walker Jensen, Julia Wiktor, Matthew Wolf, Christof Wöll, Xiaoyang Zhu.

Research in Teams

Research in Teams Project 1: Blackbody Radiation induced inertial Effects and collective Phenomena - Theoretical Basis and Experimental Feasibility

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

Dates: February 25 - March 1, June 2 - 8, and November 18 - 22, 2019

The report for this Research in Teams Project will be part of the Annual Report 2021, since it has been granted to take place in several stays during the years 2019, 2020 and 2021.

Research in Teams Project 2: Nonperturbative Construction of Quantum Field Theory Models

Collaborators: Harald Grosse (U Vienna), Raimar Wulkenhaar (University of Münster)

Dates: April 28 – May 3, June 13 – 18, July 28 – August 2, 2019

Budget: ESI € 1 200

Report on the project

Introduction

More than 15 years ago we started a program to study quantum field theory models over quantized space-time. The hope was to get a better understanding of quantum field theory models in general, since there is no non-trivial model constructed in four dimensions. The first models over quantized space-time had new singularities due to a mixing of high energy and low energy contributions. We solved this problem by introducing one more counter-term. The resulting Grosse-Wulkenhaar (GW) model has a non-trivial fixed point in parameter space. At the fixed point the model becomes a *dynamical matrix model* with measure

$$d\mu(\Phi) = \frac{1}{\mathcal{Z}} \exp\Big(- \mathrm{Tr}\Big(E\Phi^2 + \frac{\lambda}{4}\Phi^4\Big)\Big) d\Phi\,. \tag{1}$$

The external matrix E encodes the dynamics.

Later in 2009 during an appointment of Raimar Wulkenhaar (RW) as ESI Senior Research Fellow we showed in [4] that Ward identities allow to decouple the Schwinger-Dyson equations between moments of (1): The two-point function fulfills a closed *non-linear* singular integral equation for that function alone. In [5] we showed how to simplify this equation by techniques for *linear* singular integral equation of Carleman type. Moreover, the $2N$-point function turned out to be a weighted sum of products of N two-point functions, where the weights follow a recursion. Existence of a solution for these equations was proved via the Schauder fixed point theorem [6].

Considerable progress in 2016–2018 on the simpler $\lambda\Phi^3$-model [7, 8] and the $\lambda\Phi^4$-model in two dimensions [9] posed the following questions for this project:

1. How to complete the construction of all sectors of the $\lambda\Phi^3$-model in all relevant dimensions?
2. How to generalize the construction method [9] of the 2-dimensional $\lambda\Phi^4$ model to the 4-dimensional (GW) case?
3. What are the properties of the constructed 4-dimensional model, especially, is it non-trivial?

The scalar $\lambda\phi^4$-model on commutative space describes the Higgs field which produces the mass of the constituents of nature. The Higgs model is mathematically not understood and suffers from the triviality problem.

We were able to answer the above three questions. We completed the proof that the noncommutative $\lambda\phi^4$-model is non-trivial.

Current state of research and preliminary work

Because of difficulties to solve the above-mentioned integral equation of the $\lambda\Phi^4$-model we turned in 2016 our focus to the much simpler model were the $\lambda\Phi^4$ interaction term in (1) is replaced by $\lambda\Phi^3$ [7, 8]. This model is closely related to the Kontsevich model [10], which is known to be integrable.

In 2018 a breakthrough was achieved by Erik Panzer and RW who gave the explicit solution of the above-mentioned singular integral equation in the case where E in (1) has the spectrum of a 2-dimensional model [9]. The Dyson-Schwinger equation for the 2-point function was re-arranged into the boundary value problem for a holomorphic function in two variables. They gave a solution in terms of Lambert's W-function. Methods employed in [9] include the Hilbert transform, perturbation series and Lagrange-Bürmann re-summation. This success was completed by RW together with Jins de Jong and Alexander Hock. They proved in [11] that the solution of the recursion relation found in [5] for higher correlation functions is encoded in a combinatorial structure named 'Catalan tables'.

Work programme

For the Kontsevich model [10] there is a direct correspondence between topological sectors of the moments of (1), with $\lambda\Phi^4$ replaced by $\lambda\Phi^3$, and a procedure known as *topological recursion* [12]. During a first visit of RW from March 17 to March 22, 2019 at ESI, financed by the Cluster of Excellence 'Mathematics Münster', we completed the first version of a preprint [1] which took advantage of methods and results in topological recursion to solve the entire $\lambda\Phi^3$-model for any covariance. We noticed that renormalization effects modify the Virasoro constraints in a complicated way. We therefore planned for the first RIT stay from April 28 to May 3 to determine the commutation relations of our modified Virasoro generators.

Shortly before the second RIT visit June 13–18, a breakthrough with the solution of the general non-linear integral equation of the $\lambda\Phi^4$-model was achieved [2]. The second RIT visit was completely devoted to a further investigation of this result. In particular, we intended to discuss the possible triviality problem and to undertake first steps towards the solution of the Dyson-Schwinger equation for the $(1{+}1)$-point function.

For the third visit from July 28 to August 2 we planned to finish the solution of a Fredholm integral equation for the deformed spectral measure of the $\lambda\Phi^4$-model in four dimensions.

Outcomes and achievements

In our previous work on the $\lambda\Phi^3$-model [7, 8] we already obtained all *planar* contributions for a higher number of boundary components using Bell polynomials. During the first ESI visit of RW (before the RIT was approved) we completed with Alexander Hock a novel approach also to non-planar contributions. This approach was inspired by the *topological recursion* [12] of the Kontsevich model, but it has characteristic differences caused by the renormalization procedure. We found analogues of the loop insertion and loop annihilation operators and organized them into an algorithm which provides contributions of any topology. Our preprint [1] appeared one week after that ESI visit. It also identifies a Laplacian to compute intersection numbers of Chern classes on the moduli space of complex curves.

This first version of [1] left an open problem. The renormalization procedure in dimension $D \geq 2$ changed the operators which in dimension $D = 0$ generate the Witt algebra. During the first RIT stay we computed the commutation relations of the generators. The result went into a replacement of [1] that has been submitted. Moreover, we investigated the conjecture that the $\lambda\Phi^4$-model could be related to the two-matrix model. This conjecture was suggested by similarities between the solution of the recurrence relation of N-point functions in [11] and formulae for mixed correlation functions of the 2-matrix model [13].

Shortly later, guided by the possible relation to the 2-matrix model and an observation made by Alexander Hock concerning the solution [9] of the two-dimensional model, RW was able to solve the non-linear integral equation for the planar 2-point function of the $\lambda\Phi^4$-model in full generality. The result is given in a joint paper [2]. We proved that the two-point function is a rational function evaluated at roots of another rational function constructed from the spectrum of E. During the second RIT stay we started an investigation of the next Dyson-Schwinger equation for the planar $(1+1)$-point function. This turned out to be a difficult problem whose solution succeeded much later in [14].

The question of *non-triviality* of the $\lambda\Phi^4$-model on the 4-dimensional Moyal space was clarified during the third RIT stay. We solved a Fredholm integral equation established in [2] for a new effective measure that takes the interaction into account. While HG used a simple method, RW and Alexander Hock used computer algebraic methods. Both solutions agreed. The second one allowed to compare the full solution with the pertubation series. In this way we proved that the interaction changes the spectral dimension of the model to $4 - 2\frac{\arcsin(\lambda\pi)}{\pi}$. It is this dimension drop which avoids the triviality problem. Our results appeared, together with an appendix by Robert Seiringer, in [3].

Next steps concern the higher genus contributions and the relation of the integral equations to a possible topological recursion. A general method which relies on Cauchy matrices and their inverses has been found by Jörg Schürmann and RW in [14]. The connection of the partition function and the free energy to an integrable model remains to be clarified. And finally the transition from Euclidean space to Minkowski space-time is the big challenge.

To summarize, *we were able to solve the questions posed within this research in teams. We are grateful to ESI for hospitality.*

Publications and preprints contributed

[1] Harald Grosse, Alexander Hock and Raimar Wulkenhaar, "A Laplacian to compute intersection numbers on $M_{g,n}$ and correlation functions in NCQFT," e-Print: arXiv:1903.12526 [math-ph].

[2] Harald Grosse, Alexander Hock and Raimar Wulkenhaar, "Solution of all quartic matrix models," e-print arXiv:1906.04600 [math-ph].

[3] Harald Grosse, Alexander Hock and Raimar Wulkenhaar, "Solution of the self-dual Φ^4 QFT-model on four-dimensional Moyal space," JHEP **01** (2020) 081, e-Print: arXiv:1908.04543 [math-ph].

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[6] Harald Grosse and Raimar Wulkenhaar, "On the fixed point equation of a solvable 4D QFT model," Vietnam J. Math. **44** (2016) 153–180, e-print arXiv: 1505.05161 [math-ph].

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[8] Harald Grosse, Akifumi Sako and Raimar Wulkenhaar, "The Φ_4^3 and Φ_6^3 matricial QFT models have reflection positive two-point function," Nucl. Phys. B **926** (2018) 20, e-print arXiv:1612.07584 [math-ph].

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[12] Bertrand Eynard, *Counting Surfaces*, Prog. Math. Phys. **70** (2016).

[13] Bertrand Eynard and Nicolas Orantin, "Mixed correlation functions in the 2-matrix model, and the Bethe ansatz," JHEP **08** (2005) 028, e-print arXiv:hep-th/0504029.

[14] Jörg Schürmann and Raimar Wulkenhaar, "Towards integrability of the quartic analogue of the Kontsevich model," e-print arXiv:1912.03979 [math-ph].

Research in Teams Project 3: Global Bifurcation Techniques for Traveling Waves on Non-Compact Domains

Collaborators: Robin Ming Chen (U of Pittsburgh), Samuel Walsh (U of Missouri), Miles H. Wheeler (U Vienna)

Dates: May 20 – June 20, 2019

Budget: ESI € 4 800

Report on the project

Scientific Background

A *steady* or *traveling wave* is a solution to a time-dependent problem that translates at a fixed velocity without altering its shape. Examples include surface and internal waves in the ocean, ignition fronts in combustion theory, and even stripe patterns in animal fur. More generally, one can find waves of permanent configuration that evolve not by translation, but according to the action of more complicated symmetry groups. For instance, spiral waves solutions are observed in such diverse areas as Belousov–Zhabotinsky reactions [9,11] and cardiac arrhythmia [12].

Steady waves are often the primary source of intuition for the general dynamics of the systems that support them, and identifying the mechanisms permitting their existence as well as their stability or instability has been an enormously rich source of mathematics for centuries. Despite extensive study, many aspects of traveling waves remain poorly understood. A number of tools now exist for constructing waves in a neighborhood of a known explicit solution, but often the most interesting solutions — both mathematically and physically — lie outside the perturbative regime. Verifying the existence of these non-perturbative solutions, and understanding their qualitative properties, is far more difficult.

Bifurcation theory offers a robust strategy for finding nontrivial solutions. First, one searches for a curve of solutions that emanates from a trivial solution at some critical value of the parameter. Then, one continues the curve as far as possible and analyze the limiting behavior along it. This approach has been especially effective in the study of water waves, as well as areas ranging from mathematical biology [10] to nonlinear elasticity [8].

However when the underlying equation is posed on an unbounded domain, the classical machinery may likely fail since it relies strongly on compactness properties. In recent work, Chen, Walsh, and Wheeler developed a new analytic global bifurcation theoretic approach [4,5] that relaxes the compactness assumption as in [2,7], at the price of a new alternative in the global continuation. In the current project we aim to greatly extend the range of these tools with applications to important open problems in a variety of physical contexts.

Project aims and scope

The aim of the project was to advance the mathematical understanding of traveling waves by developing a powerful new tool in global bifurcation theory to prove the existence of large-amplitude waves. This project consisted of the following topics:

- center manifold reduction for quasilinear elliptic PDE.
- global bifurcation theory for monotone fronts.

The first part of the project focused on the local bifurcation. In particular, we were interested in devising a systematical way to classify all small solutions of quasilinear elliptic PDEs posed on an unbounded cylinder. The second part aimed to extend our earlier work [5] to prove the existence of large-amplitude fronts bearing certain monotonicity properties.

Another aim of the project is interaction with the local scientific community. To this end, Walsh delivered a colloquium talk at the University of Vienna. We attended several seminar talks and had frequent discussions with faculty members from the University of Vienna, including Adrian Constantin and Calin Martin.

Outcomes and achievements

The main outcome of this RiT project is related to the first topic, and is contained in the recent preprint [6]. In this work, we present a novel center manifold reduction theorem for quasilinear elliptic equations posed on infinite cylinders. This is done without a phase space in the sense that we avoid explicitly reformulating the PDE as an evolution problem. Under suitable hypotheses, the resulting center manifold is finite dimensional and captures all sufficiently small bounded solutions. Compared with classical methods, the reduced ODE on the manifold is easier to compute and more directly related to the original physical problem — we actually have considerable freedom in choosing the linear relationship between the original unknown and the quantity governed by the reduced ODE. For instance, when we study free boundary problems, we can arrange for the reduced ODE to directly govern the interface. In this way, the physical context remains in view even as we restrict to the center manifold. The analysis is conducted directly in Hölder spaces, which is often desirable for elliptic equations. We then use this machinery to construct small bounded solutions to a variety of systems. These include heteroclinic and homoclinic solutions of the anti-plane shear problem from nonlinear elasticity; exact slow moving invasion fronts in a two-dimensional Fisher–KPP equation; and hydrodynamic bores with vorticity in a channel. The last example is particularly interesting in that we find solutions with critical layers and distinctive "half cat's eye" streamline patterns.

The second proposed project is still ongoing, but substantial progress has been made during our stay in Vienna. It turns out that the global bifurcation theorem proved in [5] is most useful in practice when it is supplemented by a second result that rules out or clarifies the physical meaning of the new alternative. In [5], this was done for solitary wave solutions to fully nonlinear elliptic PDEs. Assuming some monotonicity properties of the waves, a "compactness or front" lemma was proved that totally characterizes how this alternative may occur. In the setting of front solutions, we have also obtained a characterization of this alternative. Roughly stated, a sequence of fronts with common asymptotic states is either pre-compact, or there exists a translated subsequence limiting locally to a front whose upstream or downstream state is distinct from the rest of the sequence. We call the latter scenario "heteroclinic degeneracy" or "triple conjugacy", the latter terminology referring to to Benjamin's theory of conjugate flows [1]. Combining this heteroclinic degeneracy result with the global bifurcation theory in [5] furnishes a powerful new tool that can be applied to give the first large-amplitude construction of front solutions to elliptic problems on infinite cylinders [3].

Publications and preprints contributed

R. M. Chen, S. Walsh, and M. H. Wheeler, *Center manifolds without a phase space for quasilinear problems in elasticity, biology, and hydrodynamics*, arXiv:1907.04370 [math.AP] (2019).

R. M. Chen, S. Walsh, and M. H. Wheeler, *Global bifurcation of monotone fronts for elliptic equations*, in preparation.

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[4] ——, *On the existence and qualitative theory for stratified solitary water waves*, C. R. Acad. Sci. Paris Sér. I Math., 354 (2016), pp. 601–605.

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Research in Teams Project 4: Underlying Flow Induced by Internal Water Waves

Collaborators: David Henry (U College Cork), Gabriele Villari (U of Florence)

Dates: June 1 – July 31, 2019

Budget: ESI € 9 360

Report on the project

Scientific Background

Determining the underlying fluid motion generated by a wave propagating on an interface is an intriguing and intensely challenging area of mathematical research which has important practical implications in the broad field of fluid mechanics. The motion of water is governed by a set of equations which are extremely complicated, which is not surprising when one considers the diverse and rich physical phenomena which may be exhibited by a given fluid body. However, recent mathematical advances have enabled researchers to make substantial progress in this field. From a theoretical perspective, water waves are a subject of immense difficulty and complexity due to the intractability of the governing equations to mathematical analysis. Accordingly, many investigations are pursued by way of observations from experiments or field data, although these approaches are fraught with uncertainty and indeterminacy.

In the past decade or so, fine properties of the underlying flow for periodic travelling surface water waves have been determined using various techniques from mathematical analysis and differential equations. It has been proven, both in the approximate linear regime using phase-plane analysis [CEV,CV], and for exact solutions of the fully nonlinear governing equations [C,H], that fluid particle paths throughout the fluid domain are uniformly non-closed. These results offer a prime illustration of how a careful theoretical treatment can definitively, and conclusively, elucidate delicate physical processes which evade other more applied research approaches.

Internal water waves are particularly interesting, and challenging, from both the mathematical and physical viewpoints. They arise where there is a jump in density between two fluid layers. This occurs in an oceanographical context, for instance, due to variations in temperature, salinity, or others fluctuations in the equations of state. Internal waves play a major role in the description of the dynamics of the oceans however, by their nature, they are inherently difficult to observe. This amplifies the relevance of pursuing theoretical investigations into their motion. Of course, accommodating wave motion at both an internal interface coupled with the free surface significantly magnifies the complexity of the resulting mathematical problem.

Project aims and scope

The aim of this research project was to investigate the fluid motion induced by internal water waves, coupled with surface waves, in the irrotational setting. It is assumed that the waves are periodic and travelling, linear, and possess uniform wavelengths and frequency. This project focused on three main aims:

1. **Derivation of dispersion relations** Dispersion relations for small-amplitude waves detail how the relative speed of the wave propagating on an interface varies with respect to certain parameters, such as: the mean-depth of the flow, the wavelength and, in the setting of internal waves, factors relating to the fluid stratification and the ratio of the magnitude of the internal/surface wave amplitudes. The first aim of this proposed project was to derive dispersion relations which describe the motion of an internal wave coupled with a surface wave.

2. **Underlying fluid motion for linear coupled internal and surface waves** As described above, quite recent mathematical research [CEV,CV] has conclusively disproved the long-held supposition that fluid particles follow closed trajectories for linear (small-amplitude) surface wave motion. It is quite remarkable, given the physical importance of such flows, that no analogous investigations had to this point been undertaken for internal wave motion: this is due to the additional complexity concomitant to coupling internal and surface wave motion. This scientific goal aimed to employ techniques and insight from fluid dynamics, and phase-plane analysis, to achieve a detailed overview of the underlying wave-field kinematics for internal waves coupled with surface waves.

3. **Particle trajectories** Following the Eulerian characterisation of wave-field kinematics for coupled internal and surface water waves, the next aim was to adopt a Lagrangian viewpoint in order to pursue a detailed description of fluid particle trajectories through subjecting the resulting system to a phase-plane methods, and mathematical analysis.

Outcomes and achievements

We began our research project by focusing on the governing equations describing inviscid and incompressible water waves in a two-layer fluid model, whereby an internal wave propagates on the interface separating two stably-stratified fluids of different density, along with the free-surface. The equations of motion, together with boundary conditions, were subjected to a suitable nondimensionalisation and scaling procedure, thereby obtaining the appropriate linearised governing equations. By considering compatibility conditions at both the internal and surface interfaces, new relations were derived which prescribe the dispersion of the waves and, additionally, the ratio of the amplitudes of the internal and surface waves. These relations prescribe a fascinating interplay between the surface and internal waves and, to the knowledge of the participants, are the first known derivation of a dispersion relation coupling surface and internal wave motion, intertwined with the ratio of wave amplitudes.

The linearisation procedure that was applied to the governing equations resulted in a description of velocity fields in both fluid layers, separately, in terms of disparate dynamical systems. The velocity fields must additionally satisfy appropriate matching conditions at the internal interface, and furthermore they depend strongly on values of the various physical parameters which are prescribed by the dispersion relations, and the ratio of the wave amplitudes. Following an analysis of the respective dynamical systems, it transpires that there are two qualitatively-distinct scenarios which may arise from various choices of the physical parameters. These scenarios correspond to the wave-crests of the internal wave coinciding with the wave-crests of the surface wave, which we call *in-phase* coupling; or the wave-crests of the internal wave coinciding with the wave-troughs of the surface wave, which we call *out-of-phase* coupling. Although they arise from a linearisation of the governing equations, the resulting dynamical systems themselves comprise nonlinear ordinary differential equations, and so an intricate phase-plane analysis was necessary in order to comprehensively elucidate the qualitative properties of the underlying fluid motion.

We reiterate that the complexity of the mathematical formulation of our problem is greatly increased by the coupling of the internal waves and surface waves: we do not adopt the standard 'rigid-lid', or infinite fluid domain, frameworks that are commonly employed when modelling internal waves. Accordingly, it was necessary to first undertake phase-plane analyses of the disparate dynamical systems (corresponding to the two fluid layers) separately, and then assemble our results in order to generate a coherent, and compatible, picture of the motion of the underlying fluid domain as a whole. The results we have obtained are fascinating, and the phase-plane analysis has revealed a beauty and structure in the system that would have been difficult to otherwise expose. In particular, phase-plane analysis furnishes us with an elegant visualisation of the transition process from *in-phase* to *out-of-phase* internal–surface wave coupling.

Finally, we subjected the velocity field to a mathematical analysis which revealed that fluid particle trajectories are not closed, in general, for coupled internal and surface waves. Furthermore, in contrast to surface waves, due to the physically complex scenario presented by the internal–surface wave coupling we have two qualitatively different particle trajectory motions corresponding to *in-phase* and *out-of-phase* coupling respectively. All the above mentioned results can be found in the manuscript [HV].

Publications and preprints contributed

[HV] D. Henry and G. Villari, Fluid motion and particle trajectories underlying coupled surface and internal linear waves, *in preparation*.

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[H] D. Henry, The trajectories of particles in deep-water Stokes waves, *IMRN* **2006** (2006), 1–13.

Research in Teams Project 5: Geodesic Equations on Mapping Spaces

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

Dates: June 17 – July 31, 2019

Budget: ESI € 6 480

Report on the project

The research team met for 6 weeks at the Erwin Schrödinger Institute in Vienna in the summer of 2019. During this time they continued previous collaborations on infinite-dimensional Riemannian geometry with a focus on geodesic equations on spaces of immersions. The following report is to a large extent extracted from the preprint `arXiv:1909.08657`, which resulted from the research-in-teams project.

Scientific Background

Many prominent partial differential equations (PDEs) in hydrodynamics admit variational formulations as geodesic equations on an infinite-dimensional manifold of mappings. These include the incompressible Euler, Burger, modified Constantin–Lax–Majda, Camassa–Holm, Hunter–Saxton, surface quasi-geostrophic and Korteweg–de Vries equations of fluid dynamics as well as the governing equation of ideal magneto-hydrodynamics. This serves as a strong motivation for the study of Riemannian geometry on mapping space. An additional motivation stems from the field of mathematical shape analysis, which is intimately connected to diffeomorphisms groups and other infinite-dimensional mapping spaces via Grenander's pattern theory and elasticity theory.

Project aims and scope

The variational formulations allow one to study analytical properties of the PDEs in relation to geometric properties of the underlying infinite-dimensional Riemannian manifold. Most importantly, local well-posedness of the PDE, including smooth dependence on initial conditions, is closely related to smoothness of the geodesic spray on Sobolev completions of the configuration space. This has been used to show local well-posedness of PDEs in many specific examples. An extension of this successful methodology to wider classes of PDEs requires an in-depth study of smoothness properties of partial and pseudo differential operators with non-smooth coefficients such as those appearing in the geodesic spray or, more generally, in the Euler–Lagrange equations. This was the topic of this research-in-teams project.

Outcomes and achievements

The main result of the project is that the geodesic equations of all Sobolev metrics of fractional order one and higher on spaces of diffeomorphisms and, more generally, immersions are locally well posed. This result builds on the recently established real analytic dependence of fractional Laplacians on the underlying Riemannian metric. It extends several previous results and applies to a wide range of variational partial differential equations, including the well-known Euler–Arnold equations on diffeomorphism groups as well as the geodesic equations on spaces of manifold-valued curves and surfaces. A simplified version of our main result reads as follows:

Theorem. *On the space of immersions of a closed manifold M into a Riemannian manifold $(N, \bar{g})$, the geodesic equation of the fractional-order Sobolev metric*

$$G_f(h,k) = \int_M \bar{g}\big((1+\Delta^{f^*\bar{g}})^p h, k\big)\mathrm{vol}^{f^*\bar{g}}, \qquad h,k \in T_f\mathrm{Imm}(M,N),$$

is locally well-posed in the sense of Hadamard for any $p \in [1,\infty)$.

Publications and preprints contributed

M. Bauer, P. Harms, P. W. Michor, *Fractional Sobolev metrics on spaces of immersions*, `arXiv:1909.08657 [math.DG]`

Research in Teams Project 6: Asymptotically AdS and Flat Spacetimes in 3-Dimensional Supergravities

Collaborators: Nihat Sadik Deger (Bogazici U, Bebek), Jan Rosseel (U of Vienna)

Dates: August 11 – September 15, 2019

Budget: ESI € 2 800

Report on the project

Scientific Background

Anti-de Sitter (AdS) spacetime is a maximally symmetric, constant curvature solution of the vacuum Einstein equations with negative cosmological constant. According to the renowned AdS/CFT holographic duality [M1998] a gravity theory in a D-dimensional AdS spacetime is equivalent to a $(\mathrm{D}-1)$-dimensional Conformal Field Theory (CFT) that lives on its boundary. This idea has been a major research theme in the last 20 years, which makes understanding asymptotically locally AdS (AlAdS) spacetimes a very important subject. In studying this conjecture, the three dimensional (3D) case is special since 2-dimensional CFTs are much better understood. This, together with the fact that gravity in 3D is technically easier to handle than higher-dimensional gravity, made the study of 3D gravity theories an active area of research, whose ultimate aim is to obtain a consistent, non-trivial toy model of quantum gravity.

Investigations of AlAdS spacetimes started in the 1980s [FG1985, HT1985] and it was found that [BH1986] for 3D Einstein gravity with a negative cosmological constant, appropriate boundary conditions can be defined, such that the canonical charges of the symmetries of the theory form 2 copies of the infinite dimensional Virasoro algebra with equal central charges. This discovery is a precursor of the AdS/CFT correspondence and has been fundamental in the study of the black hole solutions of the theory [BTZ1992]. An interesting extension of 3D Einstein gravity is to supplement it by the gravitational Chern-Simons term [DJT1982]. The resulting theory is called Topologically Massive Gravity (TMG) and attracted a lot of attention after the proposal that at a particular point of its parameter space and for specific boundary conditions it is dual to a chiral CFT, whose symmetries are generated by a single copy of the Virasoro algebra [LSS2008]. A similar holographic correspondence was also proposed for asymptotically flat spacetimes at null infinity [BT2010, B2010] which has been studied intensely in recent years. In this case the role of the Virasoro algebra is played by the infinite dimensional BMS algebra.

Project aims and scope

The aim of our project is to study various aspects of asymptotic symmetries in the context of 3D supergravities. This has not yet been explored much and since supersymmetry is a key ingredient of String/M-theory it is an important topic for study. One of our goals is to see effects of terms with higher than second order derivatives as well as of matter couplings. An important question that we would like to understand is whether such terms affect the set of allowed boundary conditions on bosonic as well as fermionic fields that give rise to well-defined conserved charges and non-trivial symmetry algebras. In general, these conditions depend on the theory and on the type of solutions that one would like to keep.

Since a Chern-Simons formulation of 3-dimensional supergravity models [AT1986] with higher derivative corrections is not known, unlike most of the earlier literature, such as [BBCHO1998, HMS2000], we will work in the metric formulation which is one of the novelties of this project. Moreover, this also makes our work applicable to other dimensions. The model we would like to study is the $N = (1,1)$ supersymmetric extended version of off-shell supersymmetric TMG with higher curvature terms [ABBOS2015] which exhibit a very rich parameter space with several critical points where logarithmic modes appear. We recently studied the supersymmetric multiplet structure of these theories at critical and ordinary points in [DMR2018] where we also obtained all linearized fermionic terms in the action which are needed for this project.

Outcomes and achievements

The most important outcomes of our collaboration are: i) choosing the appropriate method to be used, ii) understanding technical details of this method, iii) making a detailed road map for future investigations. There are various ways to compute symmetry algebras and charges and after a careful analysis we decided that the covariant phase space formalism [BB2002] is the most suitable one for our purposes. We studied this approach in detail and made progress in extending it for supergravities. In particular, we understood the construction of the Noether superpotential [HBS1999] within this formalism. Anderson's homotopy operator plays an important role in this computation and finding the fermionic analogue of this would be an important step in generalizing this method for supergravity. As a warm-up, in [DR] we would like to test our ideas first in a relatively simpler model, namely supersymmetric $N = (1,0)$ TMG [DK 1983]. It will be interesting to compare our results with earlier literature [ST2009, BBD2009, H2013, H2015] where different methods were used. We will pay special attention to the chiral point of the model where logarithmic modes appear and determine allowed boundary conditions on the fermionic fields. Once this is completed, we will have all the necessary tools to analyze $N = (1,1)$ off-shell supersymmetric TMG with higher curvature terms. There are several interesting directions to follow and in particular we would like to find the allowed sets of boundary conditions other than Brown-Henneaux that are compatible with supersymmetry and do a similar analysis for warped AdS, the second AdS with 1/4 supersymmetry and Minkowski vacua of this model [DNS2018].

During this collaboration at ESI one of us also finished a paper [AD2019] on the construction of exotic massive 3D gravities where such a model with up to 6th order derivatives was obtained.

Publications and preprints contributed

[DR] N.S. Deger and J. Rosseel, *Asymptotic Symmetries of Topologically Masive Supergravity*, arXiv:1909. 06305.

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Senior Research Fellows Programme

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

This year's programme was focused on the following Lecture Courses:

Lecture Courses, Summer Term 2019:

Andreas Buchleitner (Albert-Ludwigs-Universität Freiburg):
Quantum Theory II
Lecture Course 442635 VO: March 6 – April 9, 2019
Tuesday and Thursday: 11:00 - 12:30

Antoine Van Proeyen (KU Leuven):
Supergravity
Lecture Course 260091 VU: March 7 – 29, 2019
Thursday and Friday 13:15 - 14:15

Visitors and Guest Speakers within the Senior Research Fellowship framework:

Magnus Tournoy (KU Leuven), March 1 – 31, 2019

Andreas Buchleitner – Complex Quantum Systems

Course

The course attendance was – in terms of numbers – a bit disappointing: Only two students attended from the very beginning, one being a Dozent in Physics and Mathematics at a Fachhochschule, the other one being a PhD student from one of the nearby experimental quantum optics groups. Notwithstanding, I did enjoy giving the lecture a lot, though adapted the selection of topics to the participants' interests and prior knowledge: I only kept the originally announced first chapter on time independent (higher order, to treat something less frequently taught in Advanced Quantum Theory lectures) perturbation theory, and then switched to Floquet theory, with some remarks on its relationship with the Jaynes Cummings model. I closed with a semiclassical treatment of the Floquet picture, elaborating on the underlying (extended) phase space stucture, and on phenomena which currently re-emerge in the scientific debate under the (fancy) label "time crystals". The PhD student finally asked for taking an exam, which I gave him after consultation with colleagues at the physics department.

Research

The weeks at ESI – which offers an environment ideal for focussed and concentrated work – were precious since they allowed me to push forward some unaccomplished work in many-particle transport theory, as well as on a debate I had been involved in recently on coherence phenomena in complex (even, possibly, biological) systems. The latter led to a manuscript which was finalised during my stay at ESI and has already appeared in print since, see Sec. Publications below. Part of the results of the former work are presently being prepared for publication.

Furthermore, I had the opportunity to debate science with Markus Arndt and his group, as well as with Robin Golser, Stefan Rotter, and Jörg Schmiedmayer. This will likely enhance my own group's links with physics@Vienna, on the long run.

Lecture Notes

The material which I covered in my lecture was assembled from different pieces of literature which are all well accessible. I therefore decided not to write independent lecture notes, for the time being. I could certainly reconsider if desirable from the perspective of ESI, and if given enough time.

Publications and preprints contributed

E.G. Carnio, H.-P. Breuer, and A. Buchleitner, *Wave-Particle Duality in Complex Quantum Systems*, J. Phys. Chem. Lett. **10**, 2121 (2019). arXiv:1904.11186 [quant-ph].

Antoine Van Proeyen: Supergravity

Course

Students, who have studied a preliminary course on basic supersymmetry, have been introduced to the basic ingredients of a supergravity theory. They first learned relevant ingredients of differential geometry, such as torsion and differential forms. Then they were shown how to obtain the first supergravity action ($\mathcal{N} = 1$, $D = 4$). The gauge structure was emphasized and generalized to conformal, and later superconformal symmetry. Kähler geometry was explained and the students learned how this appears in matter-coupled supergravity theories. Using the superconformal techniques they learned how the action, transformation laws and algebra of general $\mathcal{N} = 1$ matter-coupled supergravity are obtained.

This was done in 7 lectures of 90 minutes. Apart from the students, the audience contained also many researchers. After every lecture the students got an extended exercise to practice the material of the course. 9 students started with the exercises. 7 of them successfully finished all the exercises.

Research

During the visit several research subjects were discussed. A very timely subject is the appearance of de Sitter vacua in supergravity. Several conjectures ('de Sitter swampland conjecture', 'distance conjecture', ...) are related to which theories can exist in a quantum consistent string theory. During my stay we have discussed with Timm Wrase (T.U. Wien), who has been involved in the formulation of a refined de Sitter conjecture. Together with him and with Niccoló Cribiori, Magnus Tournoy and Christoph Roupec, we identified simple $\mathcal{N} = 1$ supergravity theories that are or are not in agreement with these conjectures, or are in agreement with recent measurements of the cosmological background. We have not yet reached a clear statement for publication.

With the same collaboration we have also discussed non-supersymmetric brane configurations is string theory. We looked especially at branes that intersect at arbitrary angles. We try to relate this to spontaneously broken supersymmetry and to recent formulations of non-linear supersymmetry. A first draft has been written. We hope to continue on this subject in the future.

Furthermore I discussed with several participants of the workshop ‘Higher Spins and Holography’. E.g. I had an interesting discussion with Dmitri Sorokin relating his recent work to an older paper of mine on supersymmetry versus supergravity for brane configurations.

On the last day an interesting discussion with Stefan Theisen was started on recent claims of anomalous conformal supergravity.

Lecture Notes

The lectures were based on my book

> D. Z. Freedman and A. Van Proeyen, *Supergravity*.
> Cambridge University Press, 2012.

The students got lecture notes as a specially prepared consistent text based on extracts of this book.

During this month, I also spent much time in the preparation of another related book, on $\mathcal{N} = 2$ supergravity, to be published in “Lecture Notes in Physics”.

Erwin Schrödinger Lectures 2019

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.

Douglas N. Arnold: Wave localization and its landscape

Speaker: Douglas N. Arnold (University of Minnesota)

Douglas N. Arnold is the McKnight Presidential Professor of Mathematics at the University of Minnesota. He is a research mathematician and educator specializing in computational mathematics. Prof. Arnold's research interests include numerical analysis, partial differential equations, mechanics, and in particular, the interplay between these fields. From 2001 through 2008, Prof. Arnold served as director of the Institute for Mathematics and its Applications (IMA) and, in 2009 and 2010, as President of the Society for Industrial and Applied Mathematics (SIAM).

Date: December 16, 2019

Abstract:
The puzzling phenonenon of wave localization refers to unexpected confinement of waves triggered by disorder in the propagating media. Localization arises in many physical and mathematical systems and has many important implications and applications. A particularly important case is the Schrödinger equation of quantum mechanics, for which the localization behavior is crucial to the electrical properties of materials. Mathematically it is tied to exponential decay of eigenfunctions of operators instead of their expected extension throughout the domain. Although localization has been studied by physicists and mathematicians for the better part of a century, many aspects remain mysterious. In particular, the sort of deterministic quantitative results needed to predict, control, and exploit localization have remained elusive. This talk will focus on major strides made in recent years based on the introduction of the landscape function and its partner, the effective potential. We will describe these developments from the viewpoint of a computational mathematician who sees the landscape theory as a completely unorthodox sort of a numerical method for computing spectra.

Junior Research Fellows Programme

Mattia Ornaghi: Dg enhancements via A_∞-categories

Mattia Ornaghi (U Milano): October 15, 2018 – February 15, 2019:

Report

The main project I developed during my stay at ESI concerns the study of the Dg enhancements of a triangulated category using the language of A_∞-categories.

In 1967 Jean-Louis Verdier and Alexander Grothendieck, introduced the notion of triangulated category. Such a definition was motivated to axiomatize the properties of derived categories of sheaves. Even if nowadays triangulated categories are widely studied they have serious drawbacks, for example the non-functoriality of the mapping cone or the non-existence of homotopy colimits and homotopy limits. These technical problems suggest the definition of pretriangulated dg-category i.e. a dg-category whose homotopy category is triangulated. We recall that a dg category is a category whose mapping spaces are endowed with the additional structure of a differential graded $\mathbb{Z}$-module. In a natural way we can define the notion of dg functors i.e. the ' right notion" of functors between two dg categories. Dg categories with dg functors form a category that we denote by **dgCat**. In different contexts we need to relax the strict associativity in favor of homotopy associativity. To encode this information we use the notion of A_∞-category, roughly speaking an A_∞-category is a dg-category associative up to homotopy. In same vein we have a notion of morphisms between A_∞ categories and, as in the case of dg-categories, we can form the category of A_∞ category that we denote by $\mathbf{A_\infty Cat}$. Clearly we have a natural inclusion $\mathbf{dgCat} \hookrightarrow \mathbf{A_\infty Cat}$.

Thanks to the work of Tabuada [3], we know that the category of dg categories has a model structure which allows to give a nice description of **Hqe**, the localization of **dgCat** by the class of quasi-equivalences. Actually, the category **Hqe** provides the correct framework to look for dg enhancements of triangulated categories and dg lifts of exact functors between triangulated categories. We remark that the triangulated categories of algebro-geometric nature such as: the unbounded derived category of quasi-coherent sheaves, the bounded derived category of coherent sheaves and the category of perfect complexes on an algebraic stack, they all possess a natural dg enhancements. This is not true in the case of other geometric categories, for example, the ones arising from symplectic geometry, in fact they come with an A_∞ enhancement and not with a dg one. This is the case of the Fukaya category which is related to lagrangian submanifolds of a smooth symplectic manifold. The interplay between triangulated categories of algebro-geometric or symplectic type is non-trivial and at the very forefront of modern geometry, as predicted by the celebrated homological version of the Mirror Symmetry Conjecture due to Kontsevich [1]. This pushes the attention to A_∞ categories and A_∞ functors.

Following the intuitions in my PhD thesis [2], during my stay at ESI I proved that the inclusion functor i gives rise to an equivalence: $\mathbf{Hqe} \simeq \mathsf{Ho}(\mathbf{A_\infty Cat})$, where $\mathsf{Ho}(\mathbf{A_\infty Cat})$ denotes the localization on the $\mathbf{A_\infty Cat}$ quasi-equivalences.
Moreover we proved the following bijection, for every dg categories $\mathbf{A}_1$, $\mathbf{A}_2$ and $\mathbf{A}_3$:

$$\mathbf{Hqe}(\mathbf{A}_1 \otimes \mathbf{A}_2, \mathbf{A}_3) \leftrightarrow \mathbf{Hqe}(\mathbf{A}_1, \mathrm{Fun}_{\mathrm{A_\infty Cat}}(\mathbf{A}_2, \mathbf{A}_3)).$$

Where $\mathrm{Fun}_{\mathrm{A}_\infty\mathrm{Cat}}(\mathbf{A}_2, \mathbf{A}_3)$ denotes the A_∞ functors between the dg categories $\mathbf{A}_2$ and $\mathbf{A}_3$. One can note that this result provides an explicit description of the internal Homs of dg categories in terms of A_∞ functors. We point out that this result was claimed by Kontsevich in the nineties but it was never proven in the literature.

As a side project I studied the derived categories of equivariant sheaves and the derived category of quotient scheme. Let G be a finite group acting on a smooth projective variety X. We can consider the category of G-equivariant coherent sheaves on X and the corresponding bounded derived category, which we denote by $\mathbf{D}^G(X)$. When the action is free, the quotient scheme X/G is smooth and $\mathbf{D}^G(X)$ turns out to be equivalent to the bounded derived category of the quotient $\mathbf{D}(X/G)$. This is no longer true when the action is not free. What I proved during my stay at ESI is a necessary and sufficient condition to lift an equivalence from a Fourier-Mukai functor between the derived categories of equivariant sheaves to an equivalence between the derived categories of the quotient schemes.

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Publications and preprints contributed

A. Canonaco, M. Ornaghi, P. Stellari, *Localizations of the category of A_∞ categories and internal Homs*, `arXiv:1811.07830` [math.AG], [math.CT].

F. Amodeo, R. Moschetti, M. Ornaghi, *A descent criterion for equivalences between equivariant derived categories*, `arXiv:1810.13290v2` [math.AG].

Jarrod Lewis Williams: Exact and Approximate Killing Symmetries in General Relativity

Jarrod Lewis Williams (Queen Mary U of London): November 1, 2018 – February 28, 2019:

Report

The notion of Killing symmetry is of fundamental importance in the theory of General Relativity (GR). Most of the known exact solutions of the Einstein field equations possess a Killing symmetry, and many spacetimes of interest can be characterised in terms of their defining symmetries. An illustrative example is that of the Kerr spacetime, which possesses two independent Killing vector fields, one timelike and one spacelike, arising from a single Killing spinor field. According to the celebrated theorem of Carter–Robinson, the Kerr solution is (modulo some technical assumptions) the unique such spacetime. Since many of the outstanding problems of GR are posed in the framework of an Initial Value Problem, it is of interest to know when a given initial hypersurface (i.e. a $3-$geometry describing spacetime "at an instant of time") will give rise to a spacetime possessing a Killing symmetry. For vacuum spacetimes, this can be done through the use of "Killing Initial Data" (or "KID") equations, the integrability of which is a necessary and sufficient condition for the existence of a spacetime Killing symmetry. The tensorial KID equations can be found in [1], and the spinorial KID equations were first derived in [2].

During my four-month stay at the Erwin Schrödinger Institute I investigated problems related to the existence of approximate and exact Killing symmetries on Lorentzian manifolds, in collaboration with Dr. J.A. Valiente Kroon. More specifically, I worked on the following two problems:

1. extending an existing notion of *approximate* Killing symmetry to black hole spacetimes,
2. identifying necessary and sufficient *algebraic* conditions for integrability of the spinorial KID equations.

Our approach to the first problem is based on that of Dain [3], in which the KID equations are replaced with a certain fourth-order elliptic *approximate KID* system, the solutions of which can be thought of as initial data for approximate spacetime Killing vectors. In previous work [4] we have shown that, for generic asymptotically-Euclidean initial hypersurfaces, there exists a unique solution to the approximate KID equation with certain prescribed asymptotics. Moreover, the solution coincides with a timelike Killing vector whenever such a vector exists —i.e. whenever the initial hypersurface is that of a stationary spacetime. The goal of the present work is to generalise the construction to allow for inner boundaries —when the inner boundary satisfies the appropriate trapping condition, the initial hypersurface can be thought of as that of an exterior black hole spacetime. During my time at the ESI we were able to identify a set of boundary conditions which are elliptic (in the sense of Loptatinki–Shapiro) for the approximate KID equation, and which allow one to reproduce the formal computations of the previous analysis. Work is currently in progress to determine for which class of functions the resulting elliptic boundary value problem admits a Fredholm alternative. Having done so, one can then construct solutions to the approximate KID equation, generalising the results of [4].

Dain's approach has also been applied to Killing spinors in [5]. Recall that a Killing spinor on a spacetime manifold is a symmetric $SL(2,\mathbb{C})$ spinor, κ_{AB}, satisfying the equation $\nabla_{A'(A}\kappa_{BC)} = 0$. Projecting onto an initial hypersurface, one obtains

$$\mathcal{D}_{(AB}\kappa_{CD)} = 0, \tag{1}$$

with $\mathcal{D}$ denoting the induced Sen connection. In [2] it has been shown that if κ_{AB} solves both (1) and the so-called *Buchdahl constraint*, then it can be extended to a Killing spinor on the vacuum spacetime development of the hypersurface. The goal of the second problem was to obtain necessary and sufficient conditions for the integrability of (1). This can be thought of as a higher-valence generalisation of the work in [6] on the integrability of the *three-surface twistor* equation. Similar methods have also been applied to the tensorial KID equations in [7]. Following [6], I was able to identify a new connection, $\nabla^{\mathcal{T}}$ —the *tractor connection* (see [8])— on an appropriately extended spinor bundle, with the property that solutions of (1) are in 1-1 correspondence with parallel sections of $\nabla^{\mathcal{T}}$. In order for a given spinor section to be parallel, it must at least be annihiliated by the curvature of $\nabla^{\mathcal{T}}$, and concomitants thereof. This latter condition therefore implies a hierarchy of necessary conditions for the existence of non-trivial solutions to (1), given by the vanishing of certain curvature invariants. Work is currently under way to determine whether these conditions are also sufficient for the existence of a solution to (1).

During my stay I benefited greatly from interactions with the Gravitational Physics Group of University of Vienna, whose weekly seminar I attended, and one of which I delivered on previous work titled "The Friedrich–Butscher method for the construction of initial data in GR".

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Publications and preprints contributed

Manuscripts on the above work are currently in preparation.

Zahra Ahmadian Dehaghani: Nonequilibrium Dynamics of Knotted Polymers in Elongational Flow

Zahra Ahmadian Dehaghani (Sharif U of Technology, Teheran): January 1, 2019 – April 30, 2019:

Report

Knots irreversibly exist in ring polymers however knot-like structures also occur in open-end polymers. They naturally form during biological processes like genome packing and replication in DNA [1] and protein [2]. Knots can also be artificially tied on DNA using optical tweezers [3] or by inserting them into confinement [4]. In equilibrium, topology drastically affects on properties of polymers like size [5] and also on dynamic properties like knot localization [6] and the dynamics of the knotting/unknotting process [7,8].

Knotted polymers applications in micro- and nano- devices bring novel questions and lead scientists to explore their nonequilibrium dynamics and hydrodynamic effects. Under the best studied case thus far, simple shear flow, knots can be untied and tied again [9]. Shear has been recently shown to delocalize knots by means of an intricate interplay between ring topology and hydridynamics [10].

Less is known about the interplay between knots and elongational flow. Here, we study elongational flow effects on localization and position of knots in polymers. To obtain this goal, Multi Particle Collision (MPC) method is used to simulate elongational flow. Despite advances in developing this method for shear flow, MPC method has not been used to simulate elongational flow.

Multi Particle Collision (MPC) method is a particle-based method for fluids which incorporates both thermal fluctuations and hydrodynamic effects. The solvent is modeled as a set of particles. This method consists of two steps: streaming and collision steps. To develop this model for elongational flow, the coordinates and the velocities of all particles need to be updated in order to represent a good approximation of planar elongational flow.

To update the coordinates, we use Kraynik and Reinelt method [11] to apply periodic boundary conditions. It guarantees that all points on the cell boundaries evolve exponentially in time. To apply this method, the box with all solvent particles need to be rotated before and rotated back after applying boundary conditions. This step is the most time-consuming part of the simulation and it is not efficient to simulate a big box with high numbers of the solvent particles. However, developing this method for GPU can solve this problem. To have a correct velocity field during collision step, we add and subtract elongational velocity field $\vec{V} = \dot{\varepsilon}(x\hat{x} - y\hat{y})$ before and after collision step. Here, $\dot{\varepsilon}$ represents strain rate.

To investigate a knotted polymer in elongational flow, we couple MD for polymer with MPC for solvent. We limit ourselves to short polymers with N=43 and study hydrodynamic effects on knotted (trefoil knot) polymer. We pin the polymer in the box. As expected, the polymer expands during the simulation for non-zero strain rate, the knot moves along the polymer toward the closer end and unties. The knot opens faster as the strain rate increases. The knot chirality does not influence the untying process.

The way we pin the polymer in the box has a measurable effect on untying process. First we pin the middle of the polymer in the middle of the box. This trap is frequently used to pin the polymer in experimental set up. This trap helps the knot to open faster by incorporating both swelling and moving the knot along the polymer. In the second type of trap, we pin two ends of the polymer in its extended state. Fixed ends reduce swelling and cause a slow untying. In addition to the type of trap and the strength of the flow, rigidity influences on untying process. Rigid knots swell faster than flexible knots and this speeds up the process.

Although at first glance this method is a good approximation for elongational flow, we assert that this model might leave some hydrodynamic effects behind. To explore this defect, we turn off hydrodynamics and investigate the knotted polymer in non-hydrodynamic elongational flow. We eliminate the streaming part for the solvent particles and insert some virtual solvent particles which contribute in collision step and exchange their velocity with polymer beads during the step. The new solvent particles also contribute in degree of freedom in thermostat. In the absence of hydrodynamics, the knot does not swell and it takes longer for knot to open. Similar results is observed in knotted polymer in absence of hydrodynamic effects [12].

During my research stay in Vienna, I learn to apply MPC method for shear and elongational flow. I also had good discussions with people who are expert in polymer physics. To perform the tasks in this project, I use high performance computing facilities which is provided by the

Vienna Scientific Cluster (VSC). Further work on the topic with the goal of a publication is under way.

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Publications and preprints contributed

In preparation

Arindam Biswas: Expander Graphs and Non-linear Spectral Gap

Arindam Biswas (U Vienna): January 1 – April 30, 2019:

Report

My work during my stay at the Erwin Schrödinger Institute focussed on the following research topics.

1. **Asymptotically approximate groups** (joint with Wolfgang Alexander Moens).
   Let G be any group and A be an arbitrary subset of G (not necessarily symmetric and not necessarily containing the identity). The h-fold product set of A is defined as

$$A^h := \{a_1.a_2...a_h : a_1, \dots, a_n \in A\}.$$

Let $r,l \in \mathbb{N}$. The set A is said to be an (r,l) approximate group in G if there exists a subset X in G such that $|X| \leqslant l$ and $A^r \subseteq XA$. The set A is an asymptotic (r,l)-approximate group if the product set A^h is an (r,l)-approximate group for all sufficiently large h. Recently, Nathanson in [10] showed that every finite subset A of an abelian group is an asymptotic (r,l') approximate group (with the constant l' explicitly depending on r and A). We generalised the result and showed that, in an arbitrary abelian group G, the union of k (unbounded) generalised arithmetic progressions is an asymptotic $(r,(4rk)^k)$-approximate group. Along the way, we also gave an alternate proof of Nathanson's result and from the alternate proof we deduced an improvement in the bound obtained by Nathanson on the explicit constant l'. See [11].

2. **Minimal additive complements** (joint with Jyoti Prakash Saha).
Given two non-empty subsets $W,W' \subseteq G$ in an arbitrary abelian group G, W' is said to be an additive complement to W if $W+W'=G$ and it is minimal if no proper subset of W' is a complement to W. The main motivation comes from the study of minimal nets in metric spaces and their analogous counterparts in the case of groups. The notion of minimal complements was introduced by Nathanson in [9], who also posed several questions on their existence and their inexistence. We state one of them:

Question 1 *"Let G be an infinite group, and let W be an infinite subset of G. Does there exist a minimal complement to W? Does there exist a complement to W that does not contain a minimal complement?"*

Previous work on this topic mainly focussed on $G=\mathbb{Z}$. See [2], [3] etc. During my stay at the ESI we worked on the finitely generated, abelian group case. We introduced the notion of "spiked subsets" and gave necessary and sufficient conditions for the existence of minimal complements for them. This provided a partial answer to the above Question 1. See [13].

3. **Asymptotic complements in the integers** (joint with Jyoti Prakash Saha).
Let W be a nonempty subset of the set of integers $\mathbb{Z}$. A nonempty subset C of $\mathbb{Z}$ is said to be an asymptotic complement to W if $W+C$ contains almost all the integers except a set of finite size. The set C is said to be a minimal asymptotic complement to W if C is an asymptotic complement to W, but $C \setminus \{c\}$ is not an asymptotic complement to W for every $c \in C$. Asymptotic complements have been studied in the context of representations of integers since the time of Erdos, Hanani, Lorentz and others (see [3] , [6] etc), while the notion of minimal asymptotic complements is due to Nathanson. In this work, we studied minimal asymptotic complements in $\mathbb{Z}$ and dealt with the following problem posed by Nathanson in [9]:

Question 2 *Let W be a finite or infinite set of integers.*

(a) Does there exist a minimal asymptotic complement to W?

(b) Does each asymptotic complement to W contain a minimal asymptotic complement?

See [12] for partial classification of sets possessing minimal asymptotic complements.

4. **Non-linear spectral gap**.
We studied expanders with respect to Hadamard spaces. We recall that an *expander* is an

infinite increasing sequence of bounded degree finite graphs that has the significant structural property of being simultaneously sparse and yet highly connected. Lafforgue in [5] was the first to construct super-expanders: classical expanders which are also expanders with respect to every uniformly convex normed space. This was followed by the work of Mendel–Naor in [7] and [8] who gave a different construction of super-expanders, using zig-zag product. Recently, new, explicit, classical expander sequences, coming from linear groups were obtained by Arzhantseva–Biswas in [1]. These are all large girth expanders. One of the main advantages of possessing these explicit graphs are: a sequence of connected, large girth graphs with bounded diameter-by-girth ratio, helps one to obtain a $CAT(1)$ space. The Euclidean cone of the $CAT(1)$ space is a Hadamard space. One can then show that each graph in the original sequence (looked as a simplicial complex, with an appropriate metric) embeds with $O(1)$ distortion in this Hadamard space.

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Pulastya Parekh: A deeper look into the tensionless strings vacua

Pulastya Parekh (Indian Institute of Technology Kanpur): Februar 1 – May 31, 2019:

Report

The initial idea of the ESI JRF project was to investigate how spacetime is affected by tensionless strings. This was to be addressed by studying the scattering amplitudes in the (Cachazo-He-Yuan) formalism. However, before we could address the problem of scattering amplitudes, the structure of the vacuum and the spectrum arising from it needed to be worked out. While working on this, we found that there were possibilities of multiple vacua, and hence we decided to work on the structures of each of them. This was not expected when the initial proposal for the project was made. In https://arxiv.org/abs/2001.00354, which was worked during the course of the project, we also studied the flipped vacuum which is connected to Ambitwistors, and therefore indirectly to CHY formalism. Hence my work in ESI can be interpreted as a prelude to what is mentioned in the proposal. Following this, the name of the project was changed from originally Scattering Tensionless Strings, and its Effect on Spacetime" to "A deeper look into the tensionless strings vacua".

During my 4 month stay at the Erwin Schrödinger International Institute for Mathematics and Physics as a Junior Research Fellow, I had worked on mainly two projects related to the Bondi-Metzner Sachs (BMS) symmetry. The Bondi-Metzner Sachs (BMS) group governs the asymptotic symmetries of at space at null innity. Incidentally, the algebra can also be identified as a singular limit of the conformal algebra. The three-dimensional BMS (BMS_3) algebra is isomorphic to the ultra-relativistic limit of the two-dimensional conformal algebra. The first project concerns the tensionless limit of string theory which exhibits the symmetry, and the second one deals with quantum null energy conditions in BMS field theories. I will discuss them one by one.

1. Tensionless strings:

The tensionless limit of string theory aims to probe the high-energetic behaviour of strings. The tensile string theory manifests the conformal symmetry on its two-dimensional worldsheet. In the limit the worldsheet metric becomes degenerate, and the formalism to solve the classical system was performed in [1]. Along with other collaborators, I have been able to verify that the symmetries of the worldsheet of the free closed bosonic tensionless string are indeed the BMS_3 [2]. In subsequent works [3, 4] we looked at the tensionless limit of the closed superstring and found the equivalent residual symmetry algebra, namely the Super-BMS (SBMS).

During my tenure at ESI, along with my collaborators Dr. Arjun Bagchi (Indian Inst. of Technology, Kanpur) and Dr. Aritra Banerjee (Kavli Institute of Theoretical Physics, Beijing), I inspected the physical spectrum of the tensionless string when one quantises the theory. The method of imposing the constraints determines the properties of the vacuum. We uncovered three possible vacua in the bosonic case: the ipped, induced and the oscillator vacuum. The oscillator vacuum, derived from natural harmonic oscillators, is a squeezed state with respect to the tensile vacuum. We show how a massive and a massless physical spectrum can be built from this vacuum. This has hints of a very large underlying gauge symmetry and points to a connection with higher spins. The ipped vacuum is linked to the ambitwistor strings [5].

The induced vacuum is obtained as an evolution of the tensile vacuum in the limit. This follows the induced BMS representations for massless modules. We show how the vacuum exhibiting this property, assumes the form of a boundary state and discuss the connection of tensionless strings to open strings. We also illustrate how the tensile spectrum collapses onto the induced vacuum like a Bose Einstein condensate. We claim that this is the worldsheet manifestation of the Hagedorn phase transition in string theory. This work has resulted in two publications in **Physical Review Letters.** [6] and in the **Journal of High Energy Physics** [7].

2. Quantum Null Energy Conditions:

This project was worked in collaboration with Prof. Daniel Grumiller (TU Wien) and Dr. Max Riegler (Université libre de Bruxelles and Harvard University). This was a follow-up work of [8] where properties of quantum null energy conditions (QNEC) of conformal field theories were studied in details. This energy condition gives us a bound on the entanglement entropy of two-dimensional conformal field theories:

$$2\pi\langle \mathcal{T}_{\pm\pm}\rangle \geq S'' + \frac{6}{c}S'^2$$

where $\langle \mathcal{T}_{\pm\pm}\rangle$ denotes expectation values of null projections of the energy-momentum tensor for a given state, $c > 0$ is the central charge of the unitary CFT$_2$, and S is the entanglement entropy (EE) of an arbitrary interval where one of the endpoints coincides with the locus at which the stress tensor is evaluated. Primes denote variations with respect to deformations of this endpoint into the same null direction as used for the projection on the left hand side of the above equation.

In this project we provided an example of local quantum energy conditions in quantum field theories that manifest the BMS$_3$ symmetry. In close analogy to the holographic results on the quantum null energy condition, we proved that our new energy conditions saturate for states in the field theory that are dual to vacuum solutions of three-dimensional Einstein gravity with vanishing cosmological constant. We approached this problem from a limiting perspective, by taking an ultra-relativistic contraction of the QNEC conditions in conformal field theory. We first obtained the expression for entanglement entropy through uniformization and finding the solution of the BMS equivalent of Hill's Equations (see [9] for details). This enabled us to obtain the saturation equations equivalent of the above equation, which is the special case where the inequality becomes an equality. We were able to prove from the saturation conditions, the inequalities for BMS for certain values of the central charges:

$$\begin{aligned} 2\pi\langle \mathcal{T}_L\rangle &\geq S_L'' + \frac{6}{c_L}S_L'^{\,2} \quad (c_L > 0, c_M = 0), \\ 2\pi\langle \mathcal{T}_M\rangle &\geq \dot{S}_M' + \frac{6}{c_M}\dot{S}_M^2 \quad (c_M \neq 0, c_L = 0). \end{aligned}$$

$\langle \mathcal{T}\rangle$ denotes the expectation values of the energy-momentum tensor, S_L and S_M the entanglement entropies when either central charges (c_L, c_M) vanishes. This is the first time such inequality was observed in field theories that do not manifest the Lorentz symmetry. A future direction from this project would be to take a field theory that inherently manifests this symmetry and find out the same without the limiting approach or holographic intuitions. This result was published in Physical Review Letters [10].

Acknowledgements:

I would like to thank Prof. Stefan Fredenhagen and Prof. Daniel Grumiller for being my mentors during the JRF fellowship. A major part of discussions was enabled during the thematic progamme "Higher spins and holography" in March/April 2019 also at the Erwin Schrödinger International Institute for Mathematics and Physics. I also would like to thank the secretaries at both ESI and TU Vienna, for making my stay in Vienna very smooth.

Publications and preprints contributed

A. Bagchi, A. Banerjee, P. Parekh, *The tensionless path from closed to open strings*, arXiv:1905.11732 [hep-th].

D. Grumiller, P. Parekh, M. Riegler, *Local quantum energy conditions in non-Lorentz-invariant quantum field theories*, arXiv:1907.06650 [hep-th].

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Sergio Hörtner: Hidden Symmetries of Gravity in Cosmological Scenarios and Applications to Holography

Sergio Hörtner: (U Autónoma de Madrid): March 1 – June 30, 2019:

Report

The project was dedicated to the study of the hidden symmetries of gravitational theories at the off-shell level on cosmological scenarios, with a special emphasis on Anti de Sitter background and potential implications for holography.

We found that, at the linearized level, duality is a symmetry of the action principle for gravity defined on Anti de Sitter background. The analysis required the use of the Hamiltonian formulation of the theory and the resolution of the differential constraints in terms of two potentials. Once they are introduced in the action principle, duality acts as rotations on these potentials. We argued that total derivative terms obtained in our formulation can be canceled out by AdS counterterms [2] introduced to have a well-defined action principle. Our result is in agreement with the conjecture [3] that linearized higher spin theories (including spin 2) defined on Anti de Sitter space-time possess a generalisation of electric-magnetic duality acting holographically as an $SL(2,Z)$ symmetry on two-point correlation functions of CFTs.

Apart from the production of this work, I also participated in the ESI thematic programme on "Higher spins and holography" celebrated from March 11 to April 5, 2019.

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Publications and preprints contributed

S. Hörnter, *Manifest Gravitational Duality Near Anti de Sitter Space-Time*, Frontiers in Physics, 10.3389/fphy.2019.00188.

Edward Mortimer: Approximations and computations in infinite groups

Edward Mortimer (U Nottingham): March 8 – April 5, 2019 and June 7 – July 7, 2019:

Report

Electron microscopy (EM) has been at the forefront of atomic-resolution imaging in recent decades, dominated by transmission EM (TEM) and scanning transmission EM (STEM). However, the use of highly energetic electrons (typically in the order of 100 keV) to image can have the adverse effect of damaging the sample material by creating defects. In graphene, one example is the Stone-Wales (SW) defect that is of interest due to changing the properties of the local environment through a 90 carbon-carbon bond rotation [1]. According to simulations, at low energies ($<$ 80 keV) it should be impossible to create SW as the amount of energy that can be transferred from the e^- beam is not sufficient to induce the structural change. However, recent imaging has proven otherwise by detecting these defects whilst imaging at 60 keV [2]. One hypothesised cause for this is the presence of an atom or molecule on the sample that enhances the transfer of energy from the e^- beam. These species are present due to non-ideal vacuum conditions in the microscope allowing gases into the column. The gas molecules themselves are not visible in the microscopy images, because of their movement that is faster than the time scale required for imaging. Atmospheric water vapour is the most important species as it is a ready source of hydrogen. If a hydrogen atom is impacted by an electron so that it scatters towards the material, it can act as an energy mediator. This can be seen by considering the substantial difference in transferred energy to a carbon through either direct or hydrogen mediated routes, see table 1.

	60 keV Accelerating Voltage	80 keV Accelerating Voltage
$e^- \rightarrow C$	11.6 eV	15.8 eV
$e^- \rightarrow H \rightarrow C$	39.5 eV	53.0 eV

Table 1: Difference in energy transferred from an electron to carbon either directly or through a hydrogen mediated interaction

From the beginning, my work in the Kotakoski group under Prof. Jani Kotakoski (U. Vienna) was focused on using their modified Nion UltraSTEM 100 to identify the formation of SW defects in graphene. Experiments were based around measuring the cross-section for defect formation at different accelerating voltages and under different atmospheric conditions.
Analysis of the large number of recorded images, necessary for sufficient statistics, is very laborious manually. To maximise efficiency and accuracy, a neural net developed by Dr Jacob Madsen [3] was employed. The neural net was trained on previous experimental images with defects present and was a perfect candidate to identify defects more accurately than the human eye.

Results

Images were taken at different pixel dwell times (16, 8, 4 and 2 μs), in an attempt to determine the impact this parameter has on defect detection. For these experiments, the accelerating voltage was set to 80 kV (corresponding to an electron energy of 80 keV) and hydrogen was leaked into the microscope column, up to a pressure of 10^{-7} mbar. Research was also focused on observing the defect creation probability dependence on the electron energy with and without hydrogen present. Three voltages (60, 70 and 80 keV) were chosen along with two pressures, 10^{-10} and 10^{-7} mbar, with the pressure increase being attributed to hydrogen gas being leaked into the objective area [4].
My stay at the ESI allowed me to investigate the influence of imaging parameters in STEM on the defect detection rates in a 2D material. We have shown that the choice of dwell time is vital, with longer dwell times showing a substantial apparent decrease in the defect cross section due to the healing of defects before their detection.
Alongside this the accelerating voltage dependence was explored. Defects were detected at 60 keV both with and without hydrogen present at comparable rates [p1]. Thus either the formation of these defects must have an alternate formation pathway at low accelerating voltages or not all created defects were observed in the experiments. These results, while not conclusive, have helped to develop our understanding on the requirements for observing such defects using STEM techniques.
The stay also significantly enhanced the collaboration between our research groups, which will be beneficial for both during the coming years.

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Publications and preprints contributed

[p1] manuscript in progress

Seminars and colloquia outside main programmes and workshops

532 seminar and colloquia talks have taken place at the ESI in 2019 including the following individual talks.

2019 04 19, Detlev Buchholz (U Göttingen): “Linking numbers in quantum field theory”
2019 05 13, Alessio Figalli (ETH Zurich): “On the regularity theory of optimal transport maps”
2019 06 19, Jos Uffink (U of Minnesota): “Schrödinger and the prehistory of the EPR argument”
2019 06 27, Ilse Fischer (U of Vienna): ESI Colloquium “Where are the bijections? Plane Partitions and Alternating Sign Matrices”
2019 12 16, Douglas N. Arnold (U of Minnesota): Erwin Schrödinger Lecture “Wave localization and its landscape”

ESI Research Documentation

ESI research in 2019: publications and arXiv preprints

The following codes indicate the association of publications and preprints with specific ESI activities:

ASG = Operated related Function Theory
CFG = Higher Spins and Holography
CMW = Categorification in Quantum Topology and beyond
DFP = Modeling of Crystalline Interfaces and Thin Film Structures: A Joint Mathematics-Physics Symposium
DGK = Astrophysical Origins: Pathways from Star Formation to Habitable Planets
IS = Individual Scientists
JRF = Junior Research Fellow
KTF = Polarons in the 21st Century
LCW = Quantum Simulation - from the Theory to Applications
LFB = Modern Maximal Monotone Operator Theory: From Nonsmooth Optimization to Differential Inclusions
MSF = Optimal Transport
PBV = Searches, Theories, Results, Opportunities, and New Ideas for sub-GeV Dark Matter
RFZ = New Trends in the Variational Modeling and Simulation of Liquid Crystals
RIT = Research in Teams
SP = Parton Showers, Event Generators and Resummation Workshop
SRF = Senior Research Fellows
THB = Numeration and Substitution
WGC = Multivariate Approximation and Interpolation with Applications (MAIA 2019)
WSF = YRISW 2019 "A modern Primer for 2D CFT"

THEMATIC PROGRAMMES

Modern Maximal Monotone Operator Theory: From Nonsmooth Optimization to Differential Inclusions (LFB)

M. D. Fajardo, S. M. Grad, J. Vidal, *New duality results for evenly convex optimization problems*, Optimization, A Journal of Mathematical Programming and Operations Research, arXiv:1904.10478 [math.OC].

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P. L. Combettes, *Monotone Operator Theory in Convex Optimization*, arXiv:1802.02694 [math-OC].

H. Attouch, Z. Chbani, H. Riahi, *Convergence rates of inertial proximal algorithms with general extrapolation and proximal coefficients*, HAL-02021322.

V. Basco, H. Frankowska, *Hamilton-Jacobi-Bellman equations with time-measurable data and infinite horizon*, Nonlinear Differential Equations and Applications NoDEA volume 26, Article number: 7 (2019), ,.

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P. Bettiol, M. Quincampoix, R. Vinter, *Existence and characterization of the values of two player differential games with state constraints*, Applied Mathematics & Optimization volume 80, pages 765–799.

P. Cannarsa, G. Da Prato, H. Frankowska, *Domain invariance for local solutions of semilinear evolution equations in Hilbert spaces*, XXX.

C. Carţiş, J. Fiala, B. Marteau, L. Roberts, *Shadow Douglas–Rachford Splitting for Monotone Inclusions*, Applied Mathematics & Optimization volume 80, pages 665–678.

C. Carţiş, L. Roberts, *A derivative-free Gauss-Newton method*, arXiv:1710.11005 [math.OC].

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J. Eckstein, P. R. Johnstine, *Single-Forward-Step Projective Splitting: Exploiting Cocoercivity*, arXiv:1902.09025 [math.OC].

C. Geiersbach, G. Pflug, *Stochastic constrained optimization in Hilbert spaces with applications*, submitted for publication to SIAM Journal on Optimization, 2019, DOI:10.1137/18M1200208.

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D. R. Luke, S. Sabach, M. Teboulle, *Optimization on Spheres: models and proximal algorithms with computational performance comparisons*, submitted to SIAM Journal on Mathematics of Data Science, 2019. DOI:10.1137/18M1193025.

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A. Petruşel, G. Petruşel, *On some stability properties in fixed point theory*, Journal of Nonlinear and Convex Analysis, 2019.

S. Simons, *A stand-alone analysis of quasidensity*, in preparation.

E. K. Ryu, R. Hannah, W. Yin, *Scaled Relative Graph: Nonexpansive operators via 2D Euclidean Geometry*, arXiv:1902.09788 [math.OC].

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P. Narayan, J. Yoon, *Chaos in Three-dimensional Higher Spin Gravity*, arXiv:1903.08761 [hep-th].

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C. Cuchiero, M. Larsson, J. Teichmann, *Deep neural networks, generic universal interpolation, and controlled ODEs* arXiv:1908.07838 [math.OC].

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A. Anokhina, A. Morozov, A Popolitov, *Nimble evolution for pretzel Khovanov polynomials*, arXiv:1904.10277 [hep-th].

S. Assaf, N. Gonzalez, *Demazure crystals for specialized nonsymmetric Macdonald polynomials*, arXiv:1901.07520 [math.CO].

H. Azam, C. Blanchet, *Fukaya category of surfaces and mapping class group action*, arXiv:1903.11928 [math.GT].

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S. Morrison, K. Walker, P. Wedrich *Invariants of 4-manifolds from Khovanov-Rozansky link homology*, arXiv:1907.12194 [math.QA].

E. Norton, *The Dipper-Du Conjecture Revisited*, arXiv:1904.11926 [math.RT].

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H. Hedenmalm, S. Shimorin, *Gaussian analytic functions and operator symbols of Dirichlet type*, preprint.

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R. Essig, J. Pradler, M. Sholapurkar, T. T. Yu, *On the relation between Migdal effect and dark matter-electron scattering in atoms and semiconductors*, arXiv:1908.10881 [hep-ph].

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S. Hörnter, *Manifest Gravitational Duality Near Anti de Sitter Space-Time*, Frontiers in Physics, 10.3389/ fphy.2019.00188.

ESI research in previous years: additional publications and arXiv preprints

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

ABR = Quantum Physics and Grvity, 2017
CSR = Bivariant K-theory in Geometry and Physics, 2018
CMF = Advances in Chemical Reaction Network, 2018
DFS = New Trends in the Variational Modeling of Failure Phenomena, 2018
EDPI IS = European Post-Doctoral Fellow, Individual Scientists, 2015

GNB = Rigidity and Flexibility of Geometric Structure, 2018
JRF = Junior Research Fellows, 2018
MAB = Geometry and Representation Theory, 2017
OST = Matrix Models for Noncommutative Geometry and String Theory, 2018
PSH = Numerical Analysis of Complex PDE Models in the Sciences, 2018
RFZ = New Trends in the Variational Modeling and Simulation of Liquid Crystals, 2018
RIT = Research in Teams
SJP = Simons Junior Professor Nils Carqueville
SRF = Senior Research Fellow
WHP = Nonlinear Water Waves - an Interdisciplinary Interface, 2017
WTW = Moonshine, 2018

F. Pipa, N. Paunkovic, M. Vojinovic, *Entanglement-induced deviation from the geodesic motion in quantum gravity*, Journal reference: Jour. Cosmol. Astropart. Phys. 09, 057 (2019), DOI: https://doi.org/10.1088/1475-7516/2019/09/057, arXiv:1801.03207 [gr-qc], ABR.

C. Bourne, A. L. Carey, M. Lesch, A. Rennie, *The KO-valued spectral flow for skew-adjoint Fredholm operators*, arXiv:1907.04981 [math.KT], CSR.

C. Bourne, H. Schulz-Baldes, *On Z_2-indices for ground states of fermionic chains*, arXiv:1905.11556 [math-ph], CSR.

Y. Li, V. Romanovski, *Hopf Bifurcations in a Predator-Prey Model with an Omnivore*, DOI: 10.1007/s12346-019-00333-9, CMF.

M. Bonacini, E. Davoli, M. Morandotti, *Analysis of a perturbed Cahn-Hilliard model for Langmuir-Blodgett films*, arXiv:1809.07566 [math.AP], DFS.

I. Lucardesi, M. Morandotti, R. Scala, D. Zucco, *Upscaling of screw dislocations with increasing tangential strain*, arXiv:1808.08898 [math.AP], DFS.

E. Davoli, R. Ferreira, C. Kreisbeck, *Homogenization in BV of a model for layered composites in finite crystal plasticity*, arXiv:1901.11517 [math.AP], DFS.

E. Davoli, I. Fonseca, P. Liu, *Adaptive image processing: first order PDE constraint regularizers and a bilevel training scheme*, arXiv:1902.01122 [math.AP], DFS.

F. Günther, C. Jiang, H. Pottmann, *Smooth polyhedral surfaces*, DOI: 10.1016/j.aim.2020.107004, EDPIS.

V.M. Aricheta, *Supersingular Elliptic Curves and Moonshine*, arXiv:1809.07421 [math.NT], GNB.

A. Chattopadhyaya, J.R. David, *Properties of dyons in $\mathcal{N} = 4$ theories at small charges*, arXiv:1810.12060 [hep-th], GNB.

A. Carnevale, M. Cavaleri, *Partial Word and Equality problems and Banach densities*, arXiv:1811.11134 [math.GR], JRF.

P. Wirnsberger, C. Dellago, D. Frenkel, A. Reinhardt, *Theoretical prediction of thermal polarisation*, arXiv:1804.03624 [cond-mat.stat-mech]. Phys. Rev. Lett. **120**, 226001, 2018,
see also https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.120.226001, JRF.

M. Nazarov, E. Sklyanin, *Cherednik operators and Ruijsenaars-Schneider model at infinity*, arXiv:1703.02794, MAB.

A. Stern, C. Xu, Signature change in matrix model solutions, arXiv:1808.07963 [hep-th], OST.

V. Kazeev, I. Oseledets, M. Rakhuba, Ch. Schwab *Quantized tensor FEM for multiscaleproblems: diffusion problems in two andthree dimensions*, Research Report No. 2020-33,June 2020 of the Seminar für Angewandte Mathematik, ETH Zurich, https://math.ethz.ch/sam/research/reports.html?id=906, PSH.

H. Bruin, D. Terhesiu, M. Todd, *The pressure function for infinite equilibrium measures*, Israel Journal of Mathematics, (), 1-52, DOI 10.1007/s11856-019-1887-1 http://link.springer.com/article/10.1007/s11856-019-1887-1, RIT 2017.

I. Cheltsov, J. Park, C. Shramov, *Delta invariants of singular del Pezzo surfaces*, arXiv:1809.09221 [math.AG], RIT 2018.

I. Cheltsov, J. Park, C. Shramov, H. Ahmadinezhad, *On geometry of Fano 3-fold hypersurfaces*, in preparation, RIT 2018.

I. Cheltsov, J. Park, C. Shramov, H. Ahmadinezhad, *Double Veronese cones with* 28 *nodes*, in preparation, RIT 2018.

A. Gasull, A. Geyer, V. Mañosa, *Periodic traveling waves for perturbed partial differential equations.*, in preparation, RIT 2018.

A. Gasull, A. Geyer, F. Mañosas, *Chebyshev Criteria for Abelian integrals with applications to perturbations of periodic non-autonomous ODEs.* in preparation, RIT 2018.

A. Gasull, V. Mañosa, *Periodic orbits of discrete and continuous dynamical systems via Poincaré-Miranda theorem*, arXiv:1809.06208 [math.DS], RIT 2018.

S. Almi, G. Lazzaroni, I. Lucardesi, *Crack growth by vanishing viscosity in planar elasticity*, arXiv:1906.02631 [math.AP], RFZ.

S. Alama, L. Bronsard, D. Golovaty, X. Lamy, *Saturn ring defect around a spherical particle immersed in nematic liquid crystal*, arXiv:2004.04973 [math.AP], RFZ.

M. Morandotti, F. Solombrino, *Mean-Field analysis of multi-population dynamics with label switching*, preprint, RFZ.

Y. Brenier, *The initial value problem for the Euler equations of incompressible fluids viewed as a concave maximization problem*, Comm. Math. Phys. 364 (2018), no. 2, 579–605, arXiv:1706.04180 [math.AP], SRF16.

Y. Brenier, X. Duan, *From conservative to dissipative systems through quadratic change of time, with application to the curve-shortening flow*, Arch. Ration. Mech. Anal. 227 (2018), no. 2, 545–565, arXiv:1703.03404 [math.AP], SRF16.

Y. Brenier, X. Duan, *An integrable example of gradient flow based on optimal transport of differential forms*, Calc. Var. Partial Differential Equations 57 (2018), no. 5, Art. 125, 16 pp, arXiv:1704.00743 [math.AP], SRF16.

D. Henry, K. Kalimeris, E. I. Părău, J.-M. Vanden-Broeck, E. Wahlén (Editors), *Nonlinear Water Waves, An Interdisciplinary Interface*, Birkhäuser series: Tutorials, Schools, and Workshops in the Mathematical Sciences, https://www.springer.com/series/15641, https://doi.org/10.1007/978-3-030-33536-6, WHP.

L. Beneish, M. H. Mertens, *On Weierstrass mock modular form and a dimension formula for certain vertex operator algebras*, arXiv:1910.06942 [math.NT], WTW.

List of all visitors in 2019

1116 scientists have visited the ESI in 2019.

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

ASG = Operated related Function Theory
CFG = Higher Spins and Holography
CMW = Categorification in Quantum Topology and beyond
DFP = Modeling of Crystalline Interfaces and Thin Film Structures: A Joint Mathematics-Physics Symposium
DGK = Astrophysical Origins: Pathways from Star Formation to Habitable Planets
IS = Individual Scientists
JRF = Junior Research Fellow
KTF = Polarons in the 21st Century
LCW = Quantum Simulation - from the Theory to Applications
LFB = Modern Maximal Monotone Operator Theory: From Nonsmooth Optimization to Differential Inclusions MSF = Optimal Transport
PBV = Searches, Theories, Results, Opportunities, and New Ideas for sub-GeV Dark Matter
RFZ = New Trends in the Variational Modeling and Simulation of Liquid Crystals
RIT = Research in Teams
SAB = Scientific Advisory Board
SP = Parton Showers, Event Generators and Resummation Workshop
SRF = Senior Research Fellows
THB = Numeration and Substitution
WGC = Multivariate Approximation and Interpolation with Applications (MAIA 2019)
WSF = YRISW 2019 “A modern Primer for 2D CFT”

Abedin Farhan, Michigan State U, East Lansing; 2019-05-05 - 2019-05-17, 2019-05-29 - 2019-06-08, MSF19
Abl Theresa, Durham U; 2019-02-08 - 2019-02-18, WSF19
Abraham Péter, Konkoly Observatory, Budapest; 2019-06-16 - 2019-06-19, 2019-07-01 - 2019-07-10, DGK
Acciaio Beatrice, London School of Economics; 2019-05-12 - 2019-05-30, MSF19
Adly Samir, U Limoges; 2019-01-26 - 2019-02-01, LFB19
Afchar Hamid Reza, TU Vienna; 2019-03-11 - 2019-04-05, CFG19
Aghaei Nezhla, U Bern; 2019-02-10 - 2019-02-16, WSF19
Ahmadian Dehaghani Zahra, Sharif U of Technology, Tehran; 2019-01-01 - 2019-04-30, JRF
Airapetian Vladimir, NASA, Washington; 2019-06-29 - 2019-07-11, DGK
Akhmechet Rostislav, U Virginia; 2019-01-06 - 2019-01-12, CMW19

Akimkin Vitaly, INASAN, Moscow; 2019-07-28 - 2019-08-03, DGK
Alama Stan, McMaster U, Hamilton; 2019-11-29 - 2019-12-08, RFZ19
Alcock-Zeilinger Judith, U Tübingen; 2019-06-11 - 2019-06-15, SP19
Alekseev Igor, Lomonosov State U, Moscow; 2019-06-30 - 2019-07-07, DGK
Aleman Alexandru, U Lund; 2019-04-07 - 2019-04-12, ASG19
Alexander Amanda, U of Colorado, Boulder; 2019-06-30 - 2019-07-12, DGK
Alicandro Roberto, U of Cassino; 2019-11-10 - 2019-11-15, DFP19
Alioli Simone, U Milano-Bicocca; 2019-06-10 - 2019-06-13, SP19
Allen Robert, Cardiff U; 2019-02-10 - 2019-02-16, WSF19
Allmendinger Pitt, IR Sweep, Zürich; 2019-09-06 - 2019-09-06, LCW19
Allouche Jean-Paul, CNRS, Paris; 2019-07-07 - 2019-07-14, THB19
Almi Stefano, U Vienna; 2019-11-11 - 2019-11-15, DFP19
Alvarez Romero Isaac, U Vienna; 2019-04-08 - 2019-04-12, ASG19
Alves da Silva Joao, EPFL Lausanne; 2019-02-10 - 2019-02-16, WSF19
Ameur Yacin, U Lund; 2019-04-07 - 2019-04-14, ASG19
Aminian Saeid, U Prague; 2019-01-07 - 2019-01-18, CMW19
Ammon Martin, U Jena; 2019-03-21 - 2019-03-30, CFG19
Amri Myriam, U Leoben; 2019-07-07 - 2019-07-12, THB19
An Haipeng, Thsinghua U; 2019-08-05 - 2019-08-17, PBV19
Anat Amir, Tel Aviv U; 2019-08-25 - 2019-08-31, WGC19
Anempodistov Prokopii, MEPHI, Moscow; 2019-02-09 - 2019-02-16, WSF19
Anninos Dionysios, KCL, London; 2019-03-10 - 2019-03-15, CFG19
Anokhina Aleksandra, ITEP, Moscow; 2019-01-06 - 2019-01-19, CMW19
Antunes Antonio, U Porto; 2019-02-10 - 2019-02-16, WSF19
Ardila Luis, ITP Hannover; 2019-12-08 - 2019-12-14, KTF19
Arlt Jan, U Aarhus; 2019-12-08 - 2019-12-12, KTF19
Arnold Anton, TU Vienna; 2019-04-18 - 2019-06-07, MSF19
Arnold Douglas, U of Minnesota; 2019-12-15 - 2019-12-24, ESL2019
Arpino Luke, U Sussex; 2019-06-10 - 2019-06-14, SP19
Artyukhin Sergey, IIT; 2019-12-09 - 2019-12-13, KTF19
Ash Drew, Albion College; 2019-07-07 - 2019-07-13, THB19
Astner Thomas, TU Vienna; 2019-09-03 - 2019-10-31, LCW19
Attouch Hedy, U Montpellier; 2019-02-24 - 2019-03-02, LFB19
Aumann Philipp, U Innsbruck; 2019-10-21 - 2019-10-25, LCW19
Aussel Didier, U Perpignan; 2019-01-31 - 2019-02-01, LFB19
Babenko Constantin, Sorbonne U, Paris; 2019-02-10 - 2019-02-16, WSF19
Backhoff Julio, U Vienna; 2019-05-06 - 2019-05-10, 2019-06-03 - 2019-06-07, MSF19
Bade Veera, Atos France, Bezons; 2019-09-25 - 2019-09-27, LCW19
Badea Catalin, U Lille; 2019-04-07 - 2019-04-13, ASG19
Baez Maria Laura, MPI Dresden; 2019-09-30 - 2019-10-13, LCW19
Bagchi Arjun, IITK, Kanpur; 2019-03-11 - 2019-03-15, CFG19
Baggio Marco, KU Leuven; 2019-02-10 - 2019-02-16, WSF19
Ball John, Heriot-Watt U, Edinburgh; 2019-12-04 - 2019-12-06, RFZ19
Balogh Zoltan, U Bern; 2019-05-11 - 2019-05-18, MSF19
Banert Sebastian, KTH Stockholm; 2019-02-20 - 2019-03-02, LFB19
Banfi Andrea, U Sussex; 2019-06-10 - 2019-06-14, SP19
Baranov Anton, St. Petersburg State U; 2019-04-07 - 2019-04-14, ASG19
Barredo Daniel, CNRS, Palaiseau; 2019-09-25 - 2019-09-27, LCW19
Bartel Michael, CERN, Geneva; 2019-06-17 - 2019-08-02, DGK

Barth Leon, Ruhr U, Bochum; 2019-01-13 - 2019-01-20, CMW19
Bartl Daniel, U Vienna; 2019-04-15 - 2019-06-14, MSF19
Barzanjeh Shabir, ISTA, Klosterneuburg; 2019-09-09 - 2019-09-12, LCW19
Basco Vincenzo, Sorbonne U, Paris; 2019-01-27 - 2019-02-08, LFB19
Bashmakov Vladimir, U Milano-Bicocca; 2019-02-10 - 2019-02-16, WSF19
Basile Thomas, Kyung Hee U, Seoul; 2019-03-13 - 2019-03-23, CFG19
Batell Brian, U Pittsburgh; 2019-08-04 - 2019-08-16, PBV19
Bauer Christian, LBL, Berkeley; 2019-06-10 - 2019-06-13, SP19
Bauer Martin, Florida State U, Tallahassee; 2019-06-16 - 2019-07-13, 2019-07-22 - 2019-07-31, RIT0419
Bayen Térence, U Montpellier; 2019-01-28 - 2019-02-01, LFB19
Becher Thomas, U Bern; 2019-06-10 - 2019-06-15, SP19
Beck Amir, Tel Aviv U; 2019-02-24 - 2019-03-01, LFB19
Bednarczuk Ewa, Polish Academy of Science, Warsaw; 2019-01-27 - 2019-02-01, LFB19
Begum Vijaya, U Duisburg; 2019-11-24 - 2019-12-14, KTF19
Beiglböck Mathias, U Vienna; 2019-04-18 - 2019-06-16, MSF19
Beliakova Anna, U Zürich; 2019-01-07 - 2019-01-18, CMW19
Belkhatir Zehor, MSKCC, New York; 2019-05-05 - 2019-05-11, MSF19
Bella Peter, TU Dortmund; 2019-11-11 - 2019-11-15, DFP19
Bellettini Giovanni, U Siena; 2019-11-10 - 2019-11-15, DFP19
Bellm Johannes, U Lund; 2019-06-10 - 2019-06-13, SP19
Belov Yurii, St. Petersburg State U; 2019-04-07 - 2019-04-13, ASG19
Benedetti Dario, U Paris Sud, Orsay; 2019-03-17 - 2019-03-22, CFG19
Benko Matúš, JKU, Linz; 2019-01-28 - 2019-02-01, LFB19
Benvenuti Sergio, SISSA, Trieste; 2019-02-10 - 2019-02-16, WSF19
Berdeja Suarez Diego, U Oxford; 2019-02-09 - 2019-02-16, WSF19
Berdellima Arian, Georg-August-U, Göttingen; 2019-01-26 - 2019-02-08, LFB19
Berdysheva Elena, U Giessen; 2019-08-25 - 2019-08-29, WGC19
Berestycki Nathanaël, U Vienna; 2019-02-11 - 2019-02-15, WSF19
Berger Johannes, Universität Hamburg; 2019-01-06 - 2019-01-12, CMW19
Bering Klaus, Masaryk U, Brno; 2019-03-28 - 2019-03-29, CFG19
Bernal Nicolás, U Antonio Narino, Bogota; 2019-08-05 - 2019-08-16, PBV19
Bernand-Mantel Anne, INSA Toulouse; 2019-11-12 - 2019-11-15, DFP19
Berner Julius, U Vienna; 2019-08-26 - 2019-08-30, WGC19
Bernis Julien, U Brest; 2019-02-03 - 2019-02-08, LFB19
Bertemes Michel, HEPHY Vienna; 2019-08-12 - 2019-08-13, PBV19
Berthé Valérie, CNRS, Paris; 2019-07-08 - 2019-07-12, THB19
Betermin Laurent, U Vienna; 2019-11-11 - 2019-11-15, DFP19
Betermin Laurent, U Vienna; 2019-12-02 - 2019-12-06, RFZ19
Bettiol Piernicola, U Bretagne Occidentale; 2019-01-27 - 2019-02-02, LFB19
Bianco Paolo, Airbus, Portsmouth; 2019-09-25 - 2019-09-27, LCW19
Bidussi Leo, U Edinburgh; 2019-02-10 - 2019-02-12, WSF19
Bighin Giacomo, ISTA, Klosterneuburg; 2019-12-09 - 2019-12-12, KTF19
Binev Peter, U of South Carolina, Columbia; 2019-08-25 - 2019-08-31, WGC19
Bishop Gino, U of Saarland; 2019-10-20 - 2019-10-26, LCW19
Bisikalo Dmitry, RAS, Moscow; 2019-07-14 - 2019-07-19, DGK
Biswas Arindam, U Vienna; 2019-01-01 - 2019-05-11, JRF0219
Bitsch Bertram, MPIA, Heidelberg; 2019-07-28 - 2019-08-03, DGK
Bittleston Roland, U Cambridge; 2019-02-10 - 2019-02-16, WSF19
Black James, Durham U; 2019-06-10 - 2019-06-14, SP19

Blanchet Christian, U Paris-Diderot; 2019-01-07 - 2019-01-18, CMW19
Blatt Sebastian, MPI Quantum Optics, Garching; 2019-09-25 - 2019-09-27, LCW19
Bloch Itai, Tel Aviv U; 2019-08-10 - 2019-08-16, PBV19
Boehm Celine, U Sydney; 2019-08-11 - 2019-08-16, PBV19
Bohmann Martin, National Institute of Optics, Pozzuoli; 2019-09-01 - 2019-09-14, LCW19
Bolte Jérôme, U Toulouse Capitole; 2019-03-23 - 2019-03-25, LFB19
Bomze Immanuel, U Vienna; 2019-01-28 - 2019-03-08, LFB19
Bonnet Benoît, U Aix-Marseille; 2019-02-03 - 2019-02-07, LFB19
Borges de Melo Pedro Henrique, U Federal, Rio de Janeiro; 2019-01-27 - 2019-02-06, 2019-02-25 - 2019-03-01, LFB19
Borichev Alexander, U Aix-Marseille; 2019-04-05 - 2019-04-12, ASG19
Boro Saikia Sudeshna, U Vienna; 2019-06-17 - 2019-08-02, DGK
Borri Simone, National Institute of Optics, Pozzuoli; 2019-09-05 - 2019-09-07, LCW19
Borsato Riccardo, Santiago de Compostela U; 2019-02-12 - 2019-02-16, WSF19
Borza Samuel, Durham U; 2019-06-02 - 2019-06-08, MSF19
Bos Leonard, U Verona; 2019-08-25 - 2019-08-30, WGC19
Bosma Jorrit, ETH Zürich; 2019-02-10 - 2019-02-16, WSF19
Bot Radu Ioan, U Vienna; 2019-01-28 - 2019-03-08, LFB19
Bowles Malcolm, U of British Columbia, Kelowna; 2019-05-05 - 2019-06-08, MSF19
Bownik Marcin, University of Oregon; 2019-08-26 - 2019-08-30, WGC19
Boyarsky Alexey, Leiden U; 2019-08-10 - 2019-08-14, PBV19
Bozorgnia Nassim, Durham U; 2019-08-04 - 2019-08-10, PBV19
Braides Andrea, U Tor Vergata, Rome; 2019-11-10 - 2019-11-15, DFP19
Brasser Ramon, ELSI, Tokyo; 2019-06-16 - 2019-06-21, 2019-06-24 - 2019-06-28, 2019-07-19 - 2019-07-26, DGK
Braun Mathias, U Bonn; 2019-06-02 - 2019-06-07, MSF19
Brazda Katharina, U Vienna; 2019-11-11 - 2019-11-15, DFP19
Brenier Yann, CNRS, Paris; 2019-05-01 - 2019-05-21, MSF19
Bresciani Marco, U Vienna; 2019-11-11 - 2019-11-15, DFP19
Bresciani Marco, U Vienna; 2019-12-03 - 2019-12-05, RFZ19
Bressan Alberto, Penn State; 2019-06-10 - 2019-06-16, SAB19
Brevig Ole, NTNU, Trondheim; 2019-04-08 - 2019-04-13, ASG19
Briggs Andrew, U Oxford; 2019-09-11 - 2019-09-13, LCW19
Brighi Pietro, ISTA, Klosterneuburg; 2019-09-03 - 2019-09-05, LCW19
Bringmann Torsten, U Oslo; 2019-08-11 - 2019-08-16, PBV19
Broccoli Matteo, MPI, Potsdam-Golm; 2019-02-09 - 2019-02-16, WSF19
Bronsard Lia, McMaster U, Hamilton; 2019-11-29 - 2019-12-08, RFZ19
Browaeys Antoine, CNRS, Palaiseau; 2019-09-25 - 2019-09-27, LCW19
Bruin Henk, U Vienna; 2019-07-08 - 2019-07-12, THB19
Bruned Yvain, U Edinburgh; 2019-04-15 - 2019-04-19, MSF19
Brydges Tiffany, U Innsbruck; 2019-09-25 - 2019-09-27, LCW19
Brückerhoff-Plückelmann Martin, U Vienna; 2019-06-03 - 2019-06-07, MSF19
Buchholz Detlev, U Göttingen; 2019-04-03 - 2019-04-06, IS19
Buchleitner Andreas, U of Freiburg; 2019-03-18 - 2019-04-18, SRF0219
Budich Jan Carl, TU Dresden; 2019-09-23 - 2019-10-04, LCW19
Bueno Orestes, U del Pacifico, Lima; 2019-01-27 - 2019-02-03, LFB19
Burchard Almut, U Toronto; 2019-06-02 - 2019-06-07, MSF19
Buttazzo Giuseppe, U Pisa; 2019-05-12 - 2019-05-18, MSF19
Bytchenkoff Dimitri, U Lorraine; 2019-04-08 - 2019-04-12, ASG19

Böhm Axel, U Vienna; 2019-01-28 - 2019-02-25, LFB19
Bölcskei Helmut, ETH Zürich; 2019-08-26 - 2019-08-29, WGC19
Cacciari Matteo, LPTHE, Paris; 2019-06-10 - 2019-06-13, SP19
Cadman James, U Edinburgh; 2019-06-23 - 2019-07-06, DGK
Caha Libor, SAS, Bratislava; 2019-09-04 - 2019-09-05, 2019-10-16 - 2019-10-18, 2019-10-23 - 2019-10-25, LCW19
Calarco Tommaso, FZ Jülich; 2019-09-16 - 2019-09-20, 2019-09-25 - 2019-09-27, 2019-10-21 - 2019-10-25, LCW19
Campoleoni Andrea, U Mons; 2019-02-10 - 2019-02-17, WSF19
Campoleoni Andrea, U Mons; 2019-03-10 - 2019-03-22, CFG19
Canevari Giacomo, U Verona; 2019-12-01 - 2019-12-07, RFZ19
Cannarsa Piermarco, U Tor Vergata, Rome; 2019-02-03 - 2019-02-09, LFB19
Caponi Maicol, TU Dresden; 2019-11-10 - 2019-11-15, DFP19
Cappelli Francesco, National Institute of Optics, Pozzuoli; 2019-09-03 - 2019-09-07, LCW19
Caputo Emanuele, SISSA, Trieste; 2019-05-05 - 2019-05-17, 2019-06-01 - 2019-06-08, MSF19
Carazzato Davide, SNS Pisa; 2019-11-10 - 2019-11-15, DFP19
Carlen Eric, Rutgers U; 2019-04-16 - 2019-04-20, MSF19
Carlier Guillaume, CEREMADE, Paris; 2019-06-02 - 2019-06-12, MSF19
Carlsson Marcus, U Lund; 2019-04-09 - 2019-04-11, ASG19
Carnicer Álvarez Jesús, U Zaragoza; 2019-08-25 - 2019-08-30, WGC19
Carrillo de la Plata Jose Antonio, Imperial College, London; 2019-06-02 - 2019-06-10, MSF19
Cartis Coralia, U Oxford; 2019-02-25 - 2019-02-27, LFB19
Castro Alejandra, U Amsterdam; 2019-03-17 - 2019-03-22, CFG19
Cavaglia Andrea, KCL, London; 2019-02-11 - 2019-02-16, WSF19
Cavagnari Giulia, U Pavia; 2019-06-02 - 2019-06-07, MSF19
Celiz Mark Jason, U Vienna; 2019-04-08 - 2019-04-12, ASG19
Celiz Mark Jason, U Vienna; 2019-08-26 - 2019-08-30, WGC19
Ceuca Razvan-Dumitru, BCAM, Bilbao; 2019-12-01 - 2019-12-07, RFZ19
Cevher Volkan, EPFL Lausanne; 2019-02-25 - 2019-02-28, LFB19
Chalabi Adam, U Southampton; 2019-02-11 - 2019-02-15, WSF19
Chambolle Antonin, Ecole Polytechnique, Palaiseau; 2019-11-11 - 2019-11-14, DFP19
Chancellor Nicholas, Durham U; 2019-10-06 - 2019-10-17, LCW19
Chandler Alex, North Carolina State U; 2019-01-05 - 2019-01-12, CMW19
Chandra A. Ramesh, IISER Pune; 2019-02-10 - 2019-02-16, WSF19
Charina Maria, U Vienna; 2019-08-26 - 2019-08-30, WGC19
Chen Ji, Peking U; 2019-12-08 - 2019-12-14, KTF19
Chen Ming, U Pittsburgh; 2019-05-20 - 2019-06-19, RIT0219
Chen Yifan, Sorbonne U, Paris; 2019-02-10 - 2019-02-15, WSF19
Chevy Frédéric, ENS Paris; 2019-12-08 - 2019-12-12, KTF19
Chien Edward, MIT, Cambridge; 2019-05-12 - 2019-05-24, MSF19
Chowdhury Abhishek, TU Wien; 2019-03-11 - 2019-03-22, CFG19
Chu Xiaoyong, HEPHY Vienna; 2019-08-05 - 2019-08-16, PBV19
Cicalese Marco, TU Munich; 2019-11-11 - 2019-11-14, DFP19
Ciosmak Krzysztof, U Oxford; 2019-05-04 - 2019-05-18, 2019-06-02 - 2019-06-08, MSF19
Ciosmak Pawel, U Warsaw; 2019-02-10 - 2019-02-16, WSF19
Cisternino Celia, U Liege; 2019-07-07 - 2019-07-12, THB19
Ciuchi Sergio, U L'Aquila; 2019-12-07 - 2019-12-14, KTF19
Claici Sebastian, MIT, Cambridge; 2019-06-02 - 2019-06-08, MSF19
Cleff Carsten, Menlosystems, Martinsried; 2019-09-05 - 2019-09-07, LCW19

Cohen Ofer, U of Massachusetts, Lowell; 2019-07-08 - 2019-07-14, DGK
Conti Constanza, U Florence; 2019-08-25 - 2019-08-30, WGC19
Conti Riccardo, U Torino; 2019-02-10 - 2019-02-16, WSF19
Cortez Maria Isabel, U de Chile, Santiago; 2019-07-07 - 2019-07-20, THB19
Cotar Codina, University College London; 2019-05-15 - 2019-06-08, MSF19
Cotronei Mariantonia, U Mediteranea, Reggio Calabria; 2019-08-26 - 2019-08-31, WGC19
Coutinho Bruno, IDT, Lisbon; 2019-09-08 - 2019-09-15, LCW19
Coyaud Rafael, ENPC, Paris; 2019-05-11 - 2019-05-19, MSF19
Creutzig Thomas, U Alberta, Edmonton; 2019-02-10 - 2019-02-16, WSF19
Cristea Ligia-Loretta, U Graz; 2019-07-07 - 2019-07-12, THB19
Csetnek Robert, U Vienna; 2019-02-01 - 2019-03-08, LFB19
Cui Yanou, UC Riverside; 2019-08-11 - 2019-08-18, PBV19
Cummings Linda, NJIT, Newark; 2019-12-02 - 2019-12-06, RFZ19
Cvetic Mirjam, UPenn, Philadelphia; 2019-06-15 - 2019-06-16, SAB19
D'Errico Chiara, U Florence; 2019-09-05 - 2019-09-07, LCW19
Dahmen Wolfgang, U of South Carolina, Columbia; 2019-08-26 - 2019-08-30, WGC19
Dajani Karma, Utrecht U; 2019-07-07 - 2019-07-13, THB19
Dal Maso Gianni, SISSA, Trieste; 2019-11-10 - 2019-11-16, DFP19
Daley Andrew, U Strathclyde, Glasgow; 2019-09-25 - 2019-09-27, LCW19
Dancso Zsuzsanna, U Sydney; 2019-01-06 - 2019-01-18, CMW19
Daniilidis Aris, U de Chile, Santiago; 2019-01-27 - 2019-02-02, 2019-02-24 - 2019-03-06, LFB19
Dao Minh, U Newcastle; 2019-02-23 - 2019-03-01, LFB19
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Das Sumit Ranjan, U Kentucky; 2019-03-10 - 2019-03-16, CFG19
Dasgupta Mrinal, U Manchester; 2019-06-10 - 2019-06-14, SP19
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De Clercq Hadewijch, Ghent U; 2019-02-10 - 2019-02-16, WSF19
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De Ponti Nicolo, U Pavia; 2019-05-12 - 2019-05-17, 2019-06-02 - 2019-06-07, MSF19
De Rosa Maurizio, National Institute of Optics, Pozzuoli; 2019-09-03 - 2019-09-07, LCW19
Deger Nihat Sadik, Boğaziçi University; 2019-08-11 - 2019-09-15, RIT0519
Dei Andrea, ETH Zürich; 2019-02-10 - 2019-02-16, WSF19
Dekel Shai, Tel Aviv U; 2019-08-25 - 2019-08-30, WGC19
Del Re Lorenzo, Georgetown U; 2019-09-04 - 2019-09-30, 2019-12-02 - 2020-01-31, JRF0319
Delgadino Matias Gonzalo, Imperial College, London; 2019-06-03 - 2019-06-12, MSF19
Delporte Nicolas, U Paris Sud; 2019-03-09 - 2019-02-23, CFG19
Demulder Saskia, Vrije U Brussels; 2019-02-09 - 2019-02-16, WSF19
Derevianko Andrei, U of Nevada, Reno; 2019-08-04 - 2019-08-11, PBV19
Deskins Aaron, Worcester Polytechnic Institute; 2019-12-08 - 2019-12-14, KTF19
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Detournay Stephane, Vrije U Brussels; 2019-03-17 - 2019-03-22, CFG19

Di Fratta Giovanni, TU Vienna; 2019-12-02 - 2019-12-06, RFZ19
Di Valentin Cristiana, U Milano-Bicocca; 2019-12-10 - 2019-12-13, KTF19
Dianat Behnood, U Modena; 2019-12-08 - 2019-12-12, KTF19
Didenko Viacheslav, Lebedov Physical Institute, Moscow; 2019-03-14 - 2019-03-24, CFG19
Diebold Ulrike, TU Vienna; 2019-12-10 - 2019-12-13, KTF19
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Diwakar Pranav, Birla Institute of Technology and Science, Pilani; 2019-02-09 - 2019-02-16, WSF19
Dlaska Clemens, U Innsbruck; 2019-10-20 - 2019-10-24, LCW19
Dlouhá Hanka, CTU Prague; 2019-07-07 - 2019-07-12, THB19
Dobos Vera, Konkoly Observatory, Budapest; 2019-07-07 - 2019-07-16, DGK
Domazakis Georgios, National and Technical U of Athens; 2019-05-05 - 2019-05-10, MSF19
Donahue John, NYU, New York; 2019-02-10 - 2019-02-15, WSF19
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Dontchev Assen, U of Michigan, Ann Arbor; 2019-01-27 - 2019-02-02, LFB19
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Elshatlawy Hatem, U of Freiburg; 2019-09-01 - 2019-11-01, LCW19
Emken Timon, CUT, Göteborg; 2019-08-04 - 2019-08-16, PBV19
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Erbin Harold, LMU Munich; 2019-02-10 - 2019-02-16, WSF19
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Faist Jerome, ETH Zürich; 2019-09-05 - 2019-09-06, LCW19
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Fathi Max, CNRS, Paris; 2019-06-02 - 2019-06-11, MSF19

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Favier Maxime, Collège de France, Paris; 2019-09-01 - 2019-09-06, LCW19
Fazio Angelo Raffaele, U Nacional de Colombia, Bogota; 2019-01-07 - 2019-01-13, CMW19
Feichtinger Hans G., U Vienna; 2019-08-26 - 2019-08-30, WGC19
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Ferenczi Sebastien, Institut de Mathematiques de Marseille; 2019-07-07 - 2019-07-12, THB19
Ferrando Gwenaël, ENS Paris; 2019-02-10 - 2019-02-16, WSF19
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Feulner Georg, Potsdam Institute For Climate Impact Research; 2019-06-16 - 2019-06-22, DGK
Figalli Alessio, ETH Zürich; 2019-05-10 - 2019-05-16, MSF19
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Fleissner Florentine, TU Munich; 2019-04-16 - 2019-06-07, MSF19
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Focardi Matteo, U Florence; 2019-11-11 - 2019-11-15, DFP19
Fokkink Robbert, TU Delft; 2019-07-08 - 2019-07-12, THB19
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Forkert Dominik, ISTA, Klosterneuburg; 2019-04-18 - 2019-06-14, MSF19
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Frankowska Helene, CNRS, Paris; 2019-01-26 - 2019-02-09, LFB19
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Fuentealba Oscar, CECS, Valdivia; 2019-03-17 - 2019-04-05, CFG19
Führ Hartmut, RWTH Aachen; 2019-08-27 - 2019-08-29, WGC19
Gaberdiel Matthias, ETH Zürich; 2019-03-27 - 2019-04-06, CFG19
Galichon Alfred, NYU, New York; 2019-06-02 - 2019-06-03, MSF19
Garcia Cely Camilo Alfredo, DESY Hamburg; 2019-08-04 - 2019-08-16, PBV19
Garcia Cervera Carlos, UC, Santa Barbara; 2019-12-01 - 2019-12-07, RFZ19
Garcia Trillos Nicolas, U of Wisconsin-Madison; 2019-05-12 - 2019-05-24, MSF19
Gasparetto Carlo, SISSA, Trieste; 2019-05-05 - 2019-05-10, MSF19
Gaunt Jonathan, CERN, Geneva; 2019-06-11 - 2019-06-13, SP19
Geevechi Amirmasoud, U Toronto; 2019-05-05 - 2019-05-10, MSF19
Geiersbach Caroline, U Vienna; 2019-01-29 - 2019-03-08, LFB19
Gelfond Olga, Lebedov Physical Institute, Moscow; 2019-03-09 - 2019-03-24, CFG19
Gelli Maria Stella, U Pisa; 2019-11-10 - 2019-11-16, DFP19
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Ghaani Farashahi Arash, U Leeds; 2019-08-25 - 2019-08-30, WGC19
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Giamello Elio, U Torino; 2019-12-10 - 2019-12-13, KTF19
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Gigli Nicola, SISSA, Trieste; 2019-05-05 - 2019-05-08, MSF19
Gimenez Grau Aleix, DESY Hamburg; 2019-02-10 - 2019-02-16, WSF19
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Giselsson Karl Pontus, Lund U; 2019-02-23 - 2019-03-02, LFB19
Giulini Domnico, Leibniz U; 2019-06-14 - 2019-06-16, SAB19
Giustino Feliciano, U of Texas, Austin; 2019-12-09 - 2019-12-13, KTF19
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Gninenko Sergei, CERN, Geneva; 2019-08-11 - 2019-08-15, PBV19
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Goebel Rafal K., Loyola U, Chicago; 2019-01-26 - 2019-02-03, LFB19
Goerke-Schwindt Nicola, MPI Quantum Optics, Garching; 2019-09-25 - 2019-09-27, LCW19
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Golovaty Dmitry, U of Akron; 2019-12-01 - 2019-12-07, RFZ19
Gombor Tamas, WIGNER RCP, Budapest; 2019-02-10 - 2019-02-16, WSF19
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Gonzalez-Diez Gabino, U Autonoma de Madrid; 2019-07-31 - 2019-08-08, IS19
Gonze Xavier, UCLouvain; 2019-12-10 - 2019-12-13, KTF19
Gopakumar Rajesh, TIFR, Bangalore; 2019-03-31 - 2019-04-05, CFG19
Gori Giorgi Paola, U Amsterdam; 2019-05-15 - 2019-05-17, MSF19
Gorskiy Evgeny, UC Davis; 2019-01-13 - 2019-01-19, CMW19
Gorsky Mikhail, U Stuttgart; 2019-01-13 - 2019-01-19, CMW19
Grabner Peter, TU Graz; 2019-07-07 - 2019-07-11, THB19
Grad Sorin-Mihai, U Vienna; 2019-01-28 - 2019-03-08, LFB19
Grans Samuelsson Linnea, IPhT Saclay; 2019-02-10 - 2019-02-16, WSF19
Gray Sean, U Jena; 2019-02-10 - 2019-02-16, WSF19
Grekov Andrei, SKOLTECH Moscow; 2019-02-10 - 2019-02-16, WSF19
Grenfell John Lee, German Aerospace Centre, Berlin; 2019-06-24 - 2019-06-28, DGK
Grigoriev Maxim, Lebedov Physical Institute, Moscow; 2019-03-18 - 2019-04-05, CFG19
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Grupel Uri, U Innsbruck; 2019-06-02 - 2019-06-09, MSF19
Gröchenig Karlheinz, U Vienna; 2019-04-08 - 2019-04-12, ASG19
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Grünwald Michael, U of Utah, Saltlake City; 2019-06-11 - 2019-06-20, IS19
Guadarrama Rodrigo, U Vienna; 2019-06-27 - 2019-08-02, DGK
Guerra Juan, U Giessen; 2019-12-08 - 2019-12-13, KTF19

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Gukov Sergei, Caltech, Pasadena; 2019-01-10 - 2019-01-15, CMW19
Gulden Thobias, ISTA, Klosterneuburg; 2019-09-04 - 2019-09-04, LCW19
Güdel Manuel, U Vienna; 2019-06-17 - 2019-08-02, DGK
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Hahn Thomas, U Vienna; 2019-12-09 - 2019-12-13, KTF19
Haider Michael, TU Munich; 2019-09-06 - 2019-09-07, LCW19
Haika Anneliese, WAA, Vienna; 2019-08-11 - 2019-08-24, DGK
Haimi Antti, OEAW, Vienna; 2019-04-08 - 2019-04-12, ASG19
Hakobyan Sargis, Alpes Lasers, Saint-Blaise; 2019-09-05 - 2019-09-07, LCW19
Hambye Thomas, Vrije U Brussels; 2019-08-04 - 2019-08-13, PBV19
Hancharuk Aliaksandr, Lebedov Physical Institute, Moscow; 2019-02-10 - 2019-02-18, WSF19
Hangleiter Dominik, FU Berlin; 2019-09-25 - 2019-09-27, LCW19
Hanks Michael, NII, Tokyo; 2019-09-08 - 2019-09-14, LCW19
Hansen Dennis, ETH Zürich; WSF19
Harada Koichi, U Tokyo; 2019-02-10 - 2019-02-16, WSF19
Hare Kevin, U Waterloo; 2019-07-06 - 2019-07-13, THB19
Harms Philipp, U of Freiburg; 2019-06-16 - 2019-07-31, RIT0419
Harper Adam, U Warwick; 2019-04-07 - 2019-04-13, ASG19
Hartmann Andreas, U Innsbruck; 2019-10-15 - 2019-10-19, LCW19
Hartz Michael, FernU Hagen; 2019-04-07 - 2019-04-15, ASG19
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Haslinger Philipp, TU Vienna; 2019-02-26 - 2019-02-28, 2019-06-04 - 2019-06-07, 2019-11-19 - 2019-11-21, RIT0119
Hautmann Francesco, U Oxford; 2019-06-10 - 2019-06-15, SP19
Headley David, U of Saarland; 2019-10-20 - 2019-10-26, LCW19
Heap Winston, University College London; 2019-04-07 - 2019-04-13, ASG19
Hedenmalm Haakan, KTH Stockholm; 2019-04-07 - 2019-04-14, ASG19
Heeba Saniya, RWTH Aachen; 2019-08-12 - 2019-08-17, PBV19
Heil Marian, Durham U; 2019-06-10 - 2019-06-15, SP19
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Heinz André, MPI Quantum Optics, Garching; 2019-09-25 - 2019-09-27, LCW19
Heissenberg Carlo, SNS Pisa; 2019-02-10 - 2019-02-16, WSF19
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Henneaux Marc, Vrije U Brussels; 2019-03-13 - 2019-03-22, CFG19
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Henry David, UC Cork; 2019-06-01 - 2019-07-31, RIT0319
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Hikida Yasuaki, Kyoto U; 2019-03-18 - 2019-03-24, CFG19
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Hobuss Konstantin, Leibniz U; 2019-02-10 - 2019-02-16, WSF19
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Holguin Jack, U Manchester; 2019-06-10 - 2019-06-14, SP19

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Hulik Ondrej, CEICO Prague; 2019-02-10 - 2019-02-17, WSF19
Hunt Alison, ETH Zürich; 2019-07-27 - 2019-08-03, DGK
Hussain Gaitee, ESO, Garching; 2019-07-08 - 2019-08-02, DGK
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Iacobelli Mikaela, ETH Zürich; 2019-05-10 - 2019-05-16, MSF19
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Inguglia Gianluca, HEPHY Vienna; 2019-08-12 - 2019-08-14, PBV19
Innerberger Michael, TU Vienna; 2019-12-02 - 2019-12-06, RFZ19
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Isaenko Filipp, National Research U, Moscow; 2019-02-10 - 2019-02-16, WSF19
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Ji Sicong, U Vienna; 2019-09-02 - 2019-09-05, LCW19
Jia Junchao, London School of Economics; 2019-05-12 - 2019-06-02, MSF19
Jirauschek Christian, TU Munich; 2019-09-05 - 2019-09-07, LCW19
Jochim Selim, U Heidelberg; 2019-09-26 - 2019-09-27, LCW19
Johnstone Colin, U Vienna; 2019-06-17 - 2019-08-02, DGK
Jordan David, U Edinburgh; 2019-01-13 - 2019-01-16, CMW19
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Juillet Nicolas, U Strasbourg; 2019-05-26 - 2019-05-30, MSF19
Jurukovic Filip, Santiago de Compostela U; 2019-02-10 - 2019-02-16, WSF19
Jüngel Ansgar, TU Vienna; 2019-12-02 - 2019-12-06, RFZ19
Jüttler Bert, JKU, Linz; 2019-08-27 - 2019-08-30, WGC19
Kaan Ekin, U Vienna; 2019-02-11 - 2019-02-15, WSF19
Kahlhöfer Felix, RWTH Aachen; 2019-08-11 - 2019-08-16, PBV19
Kalinicheva Sergeevna Evgeniia, RAS, Moscow; 2019-06-30 - 2019-07-06, DGK
Kalle Charlene, Leiden U; 2019-07-07 - 2019-07-12, THB19
Kallio Esa, Aalto U; 2019-06-23 - 2019-06-29, DGK
Kamnitzer Joel, U Toronto; 2019-01-13 - 2019-01-20, CMW19
Kamp Inga, U Groningen; 2019-06-23 - 2019-07-18, DGK
Kangsabanik Jiban, IIT Bombay; 2019-12-06 - 2019-12-15, KTF19
Kanstrup Tina, U Aarhus; 2019-01-06 - 2019-01-13, 2019-01-07 - 2019-01-18, CMW19

Kanzow Christian, U Würzburg; 2019-02-24 - 2019-03-01, LFB19
Karle Volker, ISTA, Klosterneuburg; 2019-12-09 - 2019-12-13, KTF19
Kasi Jaswin, TIFR, Bangalore; 2019-02-10 - 2019-02-17, WSF19
Katsinis Dimitiros, U Athens; 2019-02-10 - 2019-02-16, WSF19
Kaufmann Konrad, MPI Göttingen; 2019-09-26 - 2019-09-30, LCW19
Keppeler Stefan, U Tübingen; 2019-06-10 - 2019-06-15, SP19
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Kerschbaumer Clemens, U Vienna; 2019-02-11 - 2019-02-15, WSF19
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Khanh Pham Duy, U de Chile, Santiago; 2019-01-26 - 2019-03-03, LFB19
Khatri Sumeet, LSU, Lousiana; 2019-09-08 - 2019-09-14, LCW19
Khetrapal Surbhi, Vrije U Brussels; 2019-02-10 - 2019-02-15, WSF19
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Kim Young-Heon, U of British Columbia, Kelowna; 2019-05-05 - 2019-06-08, MSF19
Kirchgaesser Patrick, KIT, Karlsruhe; 2019-06-10 - 2019-06-14, SP19
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Kitavtsev Georgy, SKOLTECH Moscow; 2019-12-01 - 2019-12-07, RFZ19
Kivinen Oscar, UC Davis; 2019-01-07 - 2019-01-18, CMW19
Klartag Boaz, Weizmann Institute, Rehovot; 2019-06-02 - 2019-06-08, MSF19
Klatte Diethard, U Zürich; 2019-01-27 - 2019-02-01, LFB19
Klein Maike, TU Vienna; 2019-05-06 - 2019-05-10, 2019-06-03 - 2019-06-07, MSF19
Klimin Serghei, U Antwerpen; 2019-12-01 - 2019-12-15, KTF19
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Kniely Michael, ISTA, Klosterneuburg; 2019-05-13 - 2019-05-17, MSF19
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Koczor Balint, U Oxford; 2019-10-15 - 2019-10-25, LCW19
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Kokail Christian, IQOQI, Innsbruck; 2019-09-04 - 2019-09-06, 2019-09-25 - 2019-09-27, LCW19
Kokott Sebastian, FHI der MPG Berlin; 2019-12-08 - 2019-12-13, KTF19
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Kondic Lou, NJIT, Newark; 2019-12-01 - 2019-12-06, RFZ19
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Korovin Yegor, Vrije U Brussels; 2019-03-10 - 2019-03-15, CFG19
Korybut Anatolii, Lebedov Physical Institute, Moscow; 2019-03-10 - 2019-03-24, CFG19
Kourehpaz Mahdi, TU Vienna; 2019-09-02 - 2019-10-31, LCW19
Koutrolikos Konstantinos, Brown U, Providence; 2019-03-20 - 2019-04-03, CFG19
Kovacs Istvan, CEU, Budapest; 2019-09-04 - 2019-09-10, LCW19
Kovàcz Attila, ELTE Budapest; 2019-07-08 - 2019-07-12, THB19
Kozynenko Oleksandr, U Dnjpro; 2019-08-25 - 2019-08-30, WGC19
Krasensky Jakub, CTU Prague; 2019-07-06 - 2019-07-12, THB19
Krenn Daniel, AAU, Klagenfurt; 2019-07-07 - 2019-07-11, THB19
Kresse Georg, U Vienna; 2019-12-09 - 2019-12-13, KTF19
Kristaly Alexandru, Babes-Bolyai U, Cluj-Napoca; 2019-05-15 - 2019-05-17, MSF19
Krsnik Juraj, IFS, Zagreb; 2019-12-08 - 2019-12-13, KTF19
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Krüger Olaf, U Vienna; 2019-03-11 - 2019-04-05, CFG19
Kshetrimayum Augustine, FU Berlin; 2019-09-24 - 2019-09-27, LCW19
Kulanthaivelu Aravinth, U Oxford; 2019-02-10 - 2019-02-15, WSF19

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Kulkami Ajinkya, U Bourgogne; 2019-02-10 - 2019-02-16, WSF19
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Kuo Jui-Lin, HEPHY Vienna; 2019-08-05 - 2019-08-16, PBV19
Kuwae Kazuhiro, U Fukuoka; 2019-06-02 - 2019-06-08, MSF19
Kwietniak Dominik, Jagiellonian U, Krakow; 2019-07-07 - 2019-07-13, THB19
Kyriienko Oleksandr, U of Exeter; 2019-10-07 - 2019-10-13, 2019-10-20 - 2019-10-25, LCW19
Källblad Sigrid, KTH Stockholm; 2019-05-10 - 2019-06-14, MSF19
Körbel Sabine, Trinity College, Dublin; 2019-12-09 - 2019-12-13, KTF19
Labbé Sebastien, U Bordeaux; 2019-07-06 - 2019-07-13, THB19
Laczko Zoltan Balazs, QMU London; 2019-02-10 - 2019-02-16, WSF19
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Lahaye Thierry, CNRS, Palaiseau; 2019-09-25 - 2019-09-27, LCW19
Lajer Marton Kalman, WIGNER RCP, Budapest; 2019-02-10 - 2019-02-16, WSF19
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Lamy Xavier, U Paul Sabatier, Toulouse; 2019-11-30 - 2019-12-07, RFZ19
Langeveld Niels, Leiden U; 2019-07-07 - 2019-07-12, THB19
Lany Stephan, NREL, Golden; 2019-12-08 - 2019-12-14, KTF19
Laraib Iflah, U Delaware; 2019-12-08 - 2019-12-14, KTF19
Laszlo Szilard Csaba, U Cluj-Napoca; 2019-01-27 - 2019-02-03, 2019-02-25 - 2019-03-01, LFB19
Lauster Florian, U Göttingen; 2019-01-26 - 2019-02-08, LFB19
Lazzaroni Giuliano, U Florence; 2019-11-10 - 2019-11-15, DFP19
Le Thang, GATECH, Atlanta; 2019-01-06 - 2019-01-12, CMW19
Leal Gómez Sergio, U Vienna; 2019-06-11 - 2019-06-14, SP19
Lechner Daniel, U Vienna; 2019-06-11 - 2019-06-14, SP19
Lechner Wolfgang, U Innsbruck; 2019-09-01 - 2019-09-06, 2019-09-24 - 2019-09-27, LCW19
Lee Hey-Sung, KIAS, Seoul; 2019-08-04 - 2019-08-17, PBV19
Lee Jeong-Yup, Catholic Kwandong U; 2019-07-07 - 2019-07-12, THB19
Lee Ji Hoon, Perimeter Institute, Waterloo; 2019-02-10 - 2019-02-17, WSF19
Legler Eric, TU Chemnitz; 2019-02-20 - 2019-02-23, LFB19
Lehmann Tobias, U Leipzig; 2019-06-02 - 2019-06-07, MSF19
Lejeune Marie, U Liege; 2019-07-07 - 2019-07-12, THB19
Lemeshko Mikhail, ISTA, Klosterneuburg; 2019-12-09 - 2019-12-13, KTF19
Leonhardt Ulf, Weizmann Institute, Rehovot; 2019-08-01 - 2019-08-16, PBV19
Leoni Giovanni, Carnegie Mellon U, Pittsburgh; 2019-11-09 - 2019-11-14, DFP19
Levesley Jeremy, U Leicester; 2019-08-24 - 2019-08-31, WGC19
Levin David, Tel Aviv U; 2019-08-24 - 2019-08-30, WGC19
Levine Nat, Imperial College, London; 2019-02-09 - 2019-02-16, WSF19
Lewin Mathieu, CNRS, Paris; 2019-04-21 - 2019-04-27, MSF19
Lewis-Brown Christopher, QMU London; 2019-02-10 - 2019-02-16, WSF19
Li Wei, Chinese Academy of Sciences, Beijing; 2019-03-17 - 2019-04-06, CFG19
Li Zhiyuan, Georg-August-U, Göttingen; 2019-08-06 - 2019-08-07, PBV19
Liao Lingmin, U Paris-Est; 2019-07-07 - 2019-07-12, THB19
Likos Christos, U Vienna; 2019-12-06 - 2019-12-06, RFZ19
Linsky Jeffrey, U of Colorado, Boulder; 2019-07-21 - 2019-08-03, DGK
Linzen Jonas, Ruhr U, Bochum; 2019-02-06 - 2019-02-16, WSF19
Lipinski Jusinskas Renann, Czech Academy of Sciences, Prague; 2019-02-10 - 2019-02-16, WSF19
Lisai Stefania, Heriot-Watt U, Edinburgh; 2019-05-05 - 2019-05-12, 2019-06-02 - 2019-06-08, MSF19

Liu Chun, IIT, Chicago; 2019-12-02 - 2019-12-04, RFZ19
Liu Jian-Guo, Duke; 2019-11-09 - 2019-11-15, DFP19
Llerena Randy, U Vienna; 2019-11-11 - 2019-11-15, DFP19
Lo Piparo Nicolo, NII, Tokyo; 2019-09-08 - 2019-09-14, LCW19
Lodin Rebecca, Uppsala U; 2019-02-10 - 2019-02-16, WSF19
Longa Lech, Jagiellonian U, Krakow; 2019-12-01 - 2019-12-08, RFZ19
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Lovrekovic Iva, Imperial College, London; 2019-03-13 - 2019-03-16, CFG19
Lu Shu, U of North Carolina, Chapel Hill; 2019-01-27 - 2019-02-02, LFB19
Lu Yongchao, Uppsala U; 2019-01-06 - 2019-01-12, CMW19
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Lucha Wolfgang, OEAW, Vienna; 2019-08-05 - 2019-08-16, PBV19
Luef Franz, NTNU, Trondheim; 2019-04-08 - 2019-04-12, ASG19
Luke Russell, U Göttingen; 2019-01-27 - 2019-02-01, 2019-02-24 - 2019-03-02, LFB19
Lyche Tom, U Oslo; 2019-08-25 - 2019-08-30, WGC19
Lönnblad Leif, Lund U; 2019-06-10 - 2019-06-17, SP19
Löschner Maximilian, KIT, Karlsruhe; 2019-06-10 - 2019-06-14, SP19
Lüftinger Theresa, U Vienna; 2019-06-17 - 2019-08-02, DGK
Ma Ernest, UC Riverside; 2019-08-06 - 2019-08-20, PBV19
Maas Jan, ISTA, Klosterneuburg; 2019-04-15 - 2019-06-14, MSF19
Maass Alejandro, U of Chile; 2019-07-07 - 2019-07-13, THB19
Maaß Benjamin, TU Berlin; 2019-11-19 - 2019-11-21, RIT0119
Madritsch Manfred, U Lorraine; 2019-07-07 - 2019-07-12, THB19
Maggioni Marta, Leiden U; 2019-07-07 - 2019-07-12, THB19
Magnabosco Mattia, SNS Pisa; 2019-11-10 - 2019-11-15, DFP19
Maier Lars-Benjamin, TU Darmstadt; 2019-08-25 - 2019-08-30, WGC19
Majer Johannes, TU Vienna; 2019-09-09 - 2019-09-13, LCW19
Majumdar Apala, U Strathclyde, Glasgow; 2019-12-01 - 2019-12-06, RFZ19
Majumdar Sucheta, Vrije U Brussels; 2019-03-24 - 2019-03-30, CFG19
Malitskyi Yurii, U Göttingen; 2019-02-23 - 2019-03-08, LFB19
Marchini Elsa Maria, Politecnico Milano; 2019-01-28 - 2019-02-01, LFB19
Markiewicz Maciej, U Warsaw; 2019-01-06 - 2019-01-13, CMW19
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Martinek Konrad, U Vienna; 2019-02-11 - 2019-02-15, WSF19
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Marveggio Alice, ISTA, Klosterneuburg; 2019-11-11 - 2019-11-15, DFP19
Matsuhita Shin-ya, Akita Prefectural U, Yurihonjo City; 2019-02-24 - 2019-03-02, LFB19
Matsumoto Takyua, Nagoya U; 2019-02-10 - 2019-02-17, WSF19
Matsumura Soko, U Dundee; 2019-06-16 - 2019-06-29, DGK
Matthes Daniel, TU Munich; 2019-05-15 - 2019-05-17, MSF19
Matulich Javier, Vrije U Brussels; 2019-03-24 - 2019-04-06, CFG19
Maulini Richard, Alpes Lasers, Saint-Blaise; 2019-09-05 - 2019-09-07, LCW19
Mazzotti Davide, PPQSense, Campi Bisenzio; 2019-09-05 - 2019-09-07, LCW19
McBride Sean, UC, Santa Barbara; 2019-02-10 - 2019-02-16, WSF19
McCann Robert, U Toronto; 2019-05-05 - 2019-05-11, MSF19
McKeen David, Triumf, Vancouver; 2019-08-05 - 2019-08-16, PBV19
McMillan Mathew, UCLA; 2019-01-06 - 2019-01-19, CMW19
Mei Yu, Gran Sasso Science Institute, L'Aquila; 2019-12-01 - 2019-12-08, RFZ19

Meier Dennis, U Vienna; 2019-01-28 - 2019-03-08, LFB19
Meier Matthias, TU Vienna; 2019-12-09 - 2019-12-13, KTF19
Mellit Anton, U Vienna; 2019-01-07 - 2019-01-18, CMW19
Meng Jin, Seti Institute, Palo Alto; 2019-07-21 - 2019-07-26, DGK
Mentes Tevfik Onur, Elettra, Trieste; 2019-11-13 - 2019-11-15, DFP19
Merbis Wout, Vrije U Brussels; 2019-03-16 - 2019-03-24, CFG19
Merrien Jean-Luis, INSA, Rennes; 2019-08-25 - 2019-08-30, WGC19
Metodieva Yanina, U Vienna; 2019-06-17 - 2019-08-02, DGK
Michor Peter, U Vienna; 2019-06-17 - 2019-07-31, RIT0419
Miczajka Julian, AEI Golm; 2019-02-10 - 2019-02-16, WSF19
Mielke Alexander, WIAS, Berlin; 2019-05-13 - 2019-05-17, MSF19
Mihaila Cornelia, U of Chicago; 2019-05-12 - 2019-05-18, MSF19
Minets Alexandre, ISTA, Klosterneuburg; 2019-01-07 - 2019-01-18, CMW19
Minets Alexandre, ISTA, Klosterneuburg; 2019-02-11 - 2019-02-15, WSF19
Ming Shuang, UC Davis; 2019-01-06 - 2019-01-16, CMW19
Mishniakov Viktor, Moscow State U; 2019-02-07 - 2019-02-16, WSF19
Mishra Utkarsh, Institute of Fundamental and Frontier Science, Chengdu; 2019-10-03 - 2019-10-13, LCW19
Misuna Nikita, Lebedov Physical Institute, Moscow; 2019-03-17 - 2019-03-31, CFG19
Mkrtchyan Karapet, MPI, Potsdam-Golm; 2019-02-10 - 2019-02-15, WSF19
Mkrtchyan Karapet, MPI, Potsdam-Golm; 2019-03-14 - 2019-03-22, CFG19
Mohseni Naeimeh, MPI, Erlangen; 2019-09-30 - 2019-10-28, LCW19
Mojzsis Stephen, U of Colorado, Boulder; 2019-07-01 - 2019-07-20, DGK
Molaverdikhani Karan, MPIA, Heidelberg; 2019-07-01 - 2019-07-12, DGK
Molchanova Anastasia, U Vienna; 2019-11-11 - 2019-11-15, DFP19
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Moore Frost Jarvist, Imperial College, London; 2019-12-09 - 2019-12-13, KTF19
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Morini Massimiliano, U of Parma; 2019-11-10 - 2019-11-16, DFP19
Mortimer Edward, U of Nottingham; 2019-03-08 - 2019-04-05, 2019-06-07 - 2019-07-08, JRF0519
Motzoi Felix, None; 2019-09-25 - 2019-10-08, LCW19
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Mrad Lidia, Mount Holyoke College, South Hadley; 2019-12-01 - 2019-12-06, RFZ19
Mukoseeva Ekaterina, SISSA, Trieste; 2019-05-05 - 2019-05-12, MSF19
Mula Hernandez Olga, Dauphine U, Paris; 2019-08-24 - 2019-08-30, WGC19
Mulevicius Vincentas, U Hamburg; 2019-01-06 - 2019-01-12, CMW19
Munro William John, NTT BRL, Kanagawa; 2019-09-08 - 2019-09-15, LCW19
Muratov Cyrill, NJIT, Newark; 2019-11-08 - 2019-11-18, DFP19
Müller Matthias, FZ Jülich; 2019-10-07 - 2019-10-11, LCW19
Müller Thorge, DLR, Köln; 2019-10-20 - 2019-10-25, LCW19
Nagy Zoltan, DESY Hamburg; 2019-06-10 - 2019-06-13, SP19
Nail Graeme, U Edinburgh; 2019-06-08 - 2019-06-15, SP19

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Nakada Hitoshi, Keio U; 2019-07-05 - 2019-07-13, THB19
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Navas Paul, TU Dortmund; 2019-05-06 - 2019-05-10, MSF19
Nayakshin Sergei, U Leicester; 2019-07-07 - 2019-07-19, DGK
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Nemoto Kae, NII, Tokyo; 2019-09-06 - 2019-09-15, LCW19
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Nicolau Artur, U Autonoma, Barcelona; 2019-04-07 - 2019-04-13, ASG19
Nieri Fabrizio, DESY Hamburg; 2019-02-10 - 2019-02-16, WSF19
Nieto Juan Miguel, U Complutense de Madrid; 2019-02-10 - 2019-02-16, WSF19
Nikiforov Roman, Dragomanov National U, Kiev; 2019-07-07 - 2019-07-12, THB19
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Nikolski Nicolas, U Bordeaux; 2019-04-07 - 2019-04-12, ASG19
Nimana Nimit, Khon Kaen U; 2019-02-20 - 2019-03-06, LFB19
Nitzan Shahaf, GATECH, Atlanta; 2019-04-07 - 2019-04-12, ASG19
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Olsen Jan-Fredrik, U Lund; 2019-04-07 - 2019-04-11, ASG19
Olsson Jimmy, KTH Stockholm; 2019-06-11 - 2019-06-13, SP19
Omar Yasser, ISTL, Lisbon; 2019-09-07 - 2019-09-12, LCW19
Ortega-Cerda Joaquim, U Barcelona; 2019-04-10 - 2019-04-13, ASG19
Ortmann Frank, TU Dresden; 2019-12-08 - 2019-12-10, KTF19
Osipov Mikhail, U Strathclyde, Glasgow; 2019-12-02 - 2019-12-06, RFZ19
Osten Rachel, Johns Hopkins U, Baltimore; 2019-06-30 - 2019-07-13, DGK
Oswald Peter, INS, Bonn; 2019-08-25 - 2019-09-01, WGC19
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Owari Keita, Ritsumeikan U, Kusatsu; 2019-02-27 - 2019-02-02, LFB19
Pagliari Valerio, U Vienna; 2019-11-11 - 2019-11-15, DFP19
Pagliari Valerio, U Vienna; 2019-12-02 - 2019-12-05, RFZ19
Pal Soumik, U of Washington, Seattle; 2019-06-02 - 2019-06-16, MSF19
Palffy-Muhoray Peter, Kent State U; 2019-12-01 - 2019-12-07, RFZ19
Palmer Aaron, U of British Columbia, Kelowna; 2019-05-27 - 2019-06-09, MSF19
Palombaro Mariapia, U L'Aquila; 2019-11-10 - 2019-11-14, DFP19
Panhans Michel, TU Dresden; 2019-12-08 - 2019-12-13, KTF19
Pannier Michel, U Jena; 2019-02-10 - 2019-02-17, WSF19
Papaefstathiou Andreas, U Amsterdam; 2019-06-10 - 2019-06-15, SP19

Pappas George, U Athens; 2019-02-10 - 2019-02-17, WSF19
Parekh Pulastya, IITK, Kanpur; 2019-02-01 - 2019-06-01, JRF0619
Paris Julien, MyCryoFirm, Fontenay Sous Bois; 2019-09-25 - 2019-09-27, LCW19
Pascual Estarellas Marta, NII, Tokyo; 2019-09-08 - 2019-09-14, LCW19
Pastoors Nicolai, TU Dortmund; 2019-08-25 - 2019-08-30, WGC19
Pathak Aditya, U Vienna; 2019-06-11 - 2019-06-14, SP19
Patrinos Panagiotis, KU Leuven; 2019-02-24 - 2019-03-01, LFB19
Pavlov Mikhal, Lebedov Physical Institute, Moscow; 2019-02-10 - 2019-02-16, WSF19
Pedicini Marco, U Roma Tre; 2019-07-07 - 2019-07-12, THB19
Pelantovà Edita, CTU Prague; 2019-07-07 - 2019-07-12, THB19
Peng Cheng, Brown U, Providence; 2019-03-17 - 2019-03-31, CFG19
Pennanen Teemu, KCL, London; 2019-01-29 - 2019-02-02, LFB19
Perez Alfredo, CECS, Valdivia; 2019-03-22 - 2019-04-05, CFG19
Pesquet Jean-Christophe, UPC; 2019-02-24 - 2019-03-07, LFB19
Pethö Attila, U Debrecen; 2019-07-09 - 2019-07-13, THB19
Petrakovics Gerhard, OEAW, Vienna; 2019-08-05 - 2019-08-16, PBV19
Petrusel Adrian, Babes-Bolyai U, Cluj-Napoca; 2019-01-27 - 2019-02-03, LFB19
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Peypouquet Juan, U de Chile, Santiago; 2019-02-24 - 2019-03-02, LFB19
Peyré Gabriel, CNRS, Paris; 2019-05-13 - 2019-05-15, MSF19
Peña Ferrandez Juan Manuel, U Zaragoza; 2019-08-25 - 2019-08-30, WGC19
Pfalzner Susanne, FZ Jülich; 2019-07-07 - 2019-07-13, DGK
Pfander Götz, KU Eichstätt; 2019-08-27 - 2019-08-29, WGC19
Pfeiler Carl-Martin, TU Vienna; 2019-12-02 - 2019-12-06, RFZ19
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Queffélec Hervé, U Lille; 2019-04-07 - 2019-04-13, ASG19
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Robert Louis Hadrien, U Genève; 2019-01-06 - 2019-01-18, CMW19
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Surer Paul, Boku Vienna; 2019-07-08 - 2019-07-12, THB19
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Velozo Ruiz Renato, U Cambridge; 2019-05-05 - 2019-05-11, MSF19
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Verdi Carla, U Vienna; 2019-12-09 - 2019-12-13, KTF19
Verheyen Rob, Radboud U; 2019-06-10 - 2019-06-14, SP19
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Vescovi Edoardo, Imperial College, London; 2019-02-10 - 2019-02-16, WSF19
Villa Silvia, U Genova; 2019-02-25 - 2019-03-01, LFB19
Villari Gabriele, U Florence; 2019-06-01 - 2019-07-28, RIT0319
Vinter Richard, Imperial College, London; 2019-01-29 - 2019-02-01, LFB19
Violo Ivan Yuri, SISSA, Trieste; 2019-05-05 - 2019-05-17, 2019-06-02 - 2019-06-07, MSF19
Virosztek Daniel, ISTA, Klosterneuburg; 2019-05-13 - 2019-05-13, MSF19
Viscardi Alberto, U Bologna; 2019-08-25 - 2019-08-31, WGC19
Voigtländer Felix, KU Eichstätt; 2019-08-25 - 2019-08-30, WGC19
Volansky Tomer, Tel Aviv U; 2019-08-10 - 2019-08-16, PBV19
Volk Matthias, NBI, Copenhagen; 2019-02-10 - 2019-02-16, WSF19
Vorobyov Eduard, U Vienna; 2019-06-24 - 2019-08-03, DGK
Vukotic Jovsic Dragan, U Autonoma de Madrid; 2019-04-07 - 2019-04-12, ASG19
Vulpius Sara, FU Berlin; 2019-07-23 - 2019-07-31, DGK
Waalewijn Wouter, U Amsterdam; 2019-06-10 - 2019-06-14, SP19
Wagner Emmanuel, U Bourgogne; 2019-01-12 - 2019-01-19, CMW19
Walker Alison, U Bath; 2019-12-08 - 2019-12-13, KTF19
Wallner Johannes, TU Graz; 2019-08-25 - 2019-08-30, WGC19
Walsh Samuel, U of Missouri, Columbia; 2019-05-20 - 2019-06-20, RIT0219
Walther Philip, U Vienna; LCW19
Webber Bryan, U Cambridge; 2019-06-10 - 2019-06-14, SP19
Weber Cornelia, U Vienna; 2019-06-17 - 2019-08-02, DGK
Wedrich Paul, ANU, Canberra; 2019-01-07 - 2019-01-18, CMW19
Wegner Enrico, Maastricht U; 2019-02-24 - 2019-03-02, LFB19

Weidemüller Matthias, U Heidelberg; 2019-09-26 - 2019-09-27, LCW19
Weill-Duflos Elise, UPC; 2019-02-03 - 2019-02-08, LFB19
Weiller Dominic, ANU, Canberra; 2019-01-05 - 2019-01-18, CMW19
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Wheeler Miles, U Bath; 2019-05-20 - 2019-06-20, RIT0219
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Wiktor Julia, CUT, Göteborg; 2019-12-08 - 2019-12-15, KTF19
Wilbert Arik, U Melbourne; 2019-01-06 - 2019-01-20, CMW19
Wilk Rafal, Toptica Photonics AG, Graefelfing; 2019-09-25 - 2019-09-27, LCW19
Witteveen Freek, U Amsterdam; 2019-02-10 - 2019-02-15, WSF19
Woitke Peter, U St. Andrews; 2019-06-29 - 2019-07-14, DGK
Wolf Beatrix, U Vienna; 2019-10-25 - 2019-11-03, LCW19
Wolf Matthew, U Bath; 2019-12-08 - 2019-12-13, KTF19
Wolloch Michael, TU Vienna; 2019-11-11 - 2019-11-15, DFP19
Wood Brian, NRL, Washington; 2019-06-23 - 2019-06-27, DGK
Wrase Timm, TU Vienna; 2019-03-11 - 2019-04-05, CFG19
Wu Chang, U Genova; 2019-06-11 - 2019-06-15, SP19
Wu Jermey, Imperial College, London; 2019-06-03 - 2019-06-12, MSF19
Wu Wanlou, U Paris-Est; 2019-07-07 - 2019-07-12, THB19
Wulkenhaar Raimar, U Münster; 2019-03-17 - 2019-03-22, IS19
Wulkenhaar Raimar, U Münster; 2019-04-28 - 2019-05-03, 2019-06-13 - 2019-06-18, 2019-07-28 - 2019-08-02, RIT0619
Wutte Raphaela, TU Vienna; 2019-03-11 - 2019-04-04, CFG19
Wöll Christof, KIT, Karlsruhe; 2019-12-09 - 2019-12-14, KTF19
Xue Wei, CERN, Geneva; 2019-08-04 - 2019-08-14, PBV19
Yago Malo Jorge, U Strathclyde, Glasgow; 2019-09-22 - 2019-09-28, LCW19
Yamada Isao, Titech, Tokyo; 2019-02-24 - 2019-03-01, LFB19
Yan Alexander, ITEP, Moscow; 2019-02-10 - 2019-02-16, WSF19
Yang Junjian, TU Vienna; 2019-05-07 - 2019-06-14, MSF19
Yang Xiaoqi, PolyU, Hong Kong; 2019-01-27 - 2019-02-02, LFB19
Yao Wenfang, PolyU, Hong Kong; 2019-01-27 - 2019-02-02, LFB19
Yin Wotao, UCLA; 2019-02-23 - 2019-03-02, LFB19
Yin Yihao, Nanjing U; 2019-03-10 - 2019-03-23, CFG19
Yngvason Jakob, U Vienna; SYMP2019
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Yu Tien-Tien, U of Oregon, Eugene; 2019-08-05 - 2019-08-14, PBV19
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Zhao Yue, UC Davis; 2019-01-06 - 2019-01-21, CMW19

Zheng Zechuan, ENS Paris; 2019-01-06 - 2019-01-12, CMW19
Zhong Deliang, ENS Paris; 2019-02-10 - 2019-02-16, WSF19
Zhou Dingxuan, City U of Hong Kong; 2019-08-25 - 2019-08-31, WGC19
Zhou Yufeng, Chinese Academy of Sciences, Beijing; 2019-08-04 - 2019-08-10, PBV19
Zhu Huilin, Xiamen U; 2019-07-09 - 2019-07-13, THB19
Zhu Xiaoyang, Columbia University, New York; 2019-12-08 - 2019-12-12, KTF19
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Zoppi Lorenzo, U Amsterdam; 2019-06-10 - 2019-06-14, SP19
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van Bijnen Rick, U Innsbruck; 2019-09-25 - 2019-09-27, LCW19
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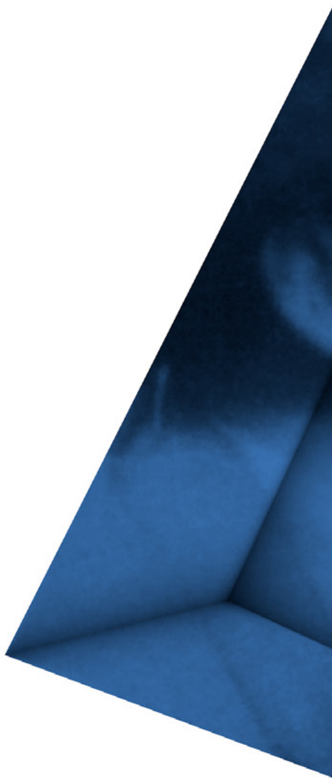

Publisher: Christoph Dellago, Director, The Erwin Schrödinger International Institute for Mathematics and Physics, University of Vienna, Boltzmanngasse 9, 1090 Vienna / Austria. **Editorial Office:** Christoph Dellago, Beatrix Wolf. **Cover-Design:** steinkellner.com **Photos:** Österreichische Zentralbibliothek für Physik, Philipp Steinkellner. **Printing:** Berger, Horn.