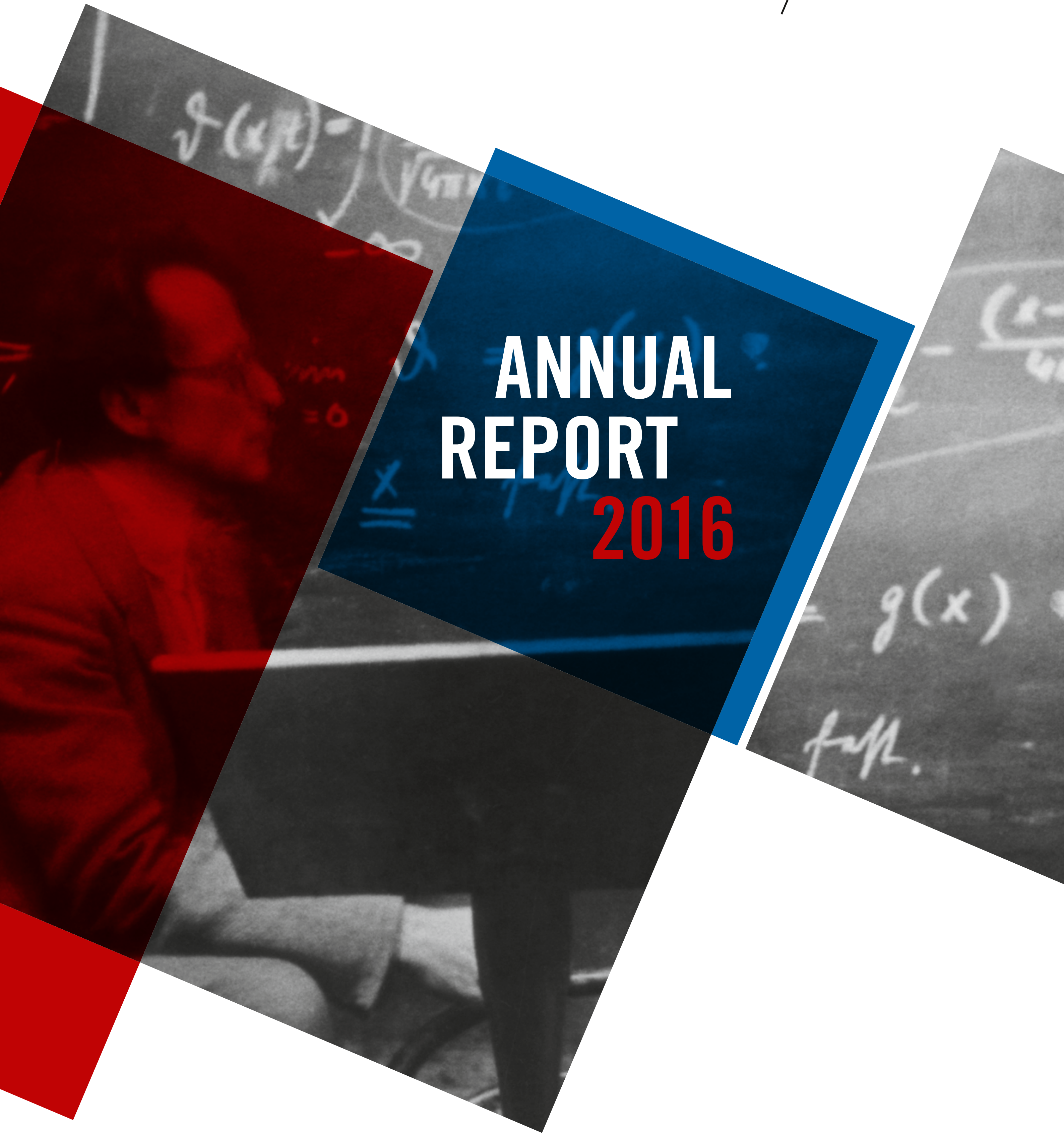
Erwin Schrödinger International Institute
for Mathematics and Physics

ESI

ANNUAL REPORT 2016



www.esi.ac.at

ESI

THE INSTITUTE PURSUES ITS MISSION THROUGH A VARIETY OF PROGRAMMES

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

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

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

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

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

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

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

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

ESI Annual Report 2016

Contents

Preface

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. While in the beginning the scientific focus of the ESI was on mathematical physics and mathematics, over the years the thematic spectrum of its scientific activities has been carefully extended, while maintaining high scientific standards. Today, the scientific profile of the ESI includes all theoretical, computational and experimental aspects of mathematics and physics. Since January 1, 2016, reflecting this steady extension of scope, the Institute carries the name *Erwin Schrödinger International Institute for Mathematics and Physics.*[1]

It is the Institute's foremost objective to advance scientific knowledge in mathematics and physics and to create an environment where scientists can exchange ideas and fruitful collaborations can unfold. The best way of achieving this goal is to ensure that the ESI continues to interweave leading international scholars, both in mathematics and physics, and 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. The Institute provides a place for focused collaborative research and aims at creating a fertile ground for new ideas.

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 a number of 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 organising 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;

[1] Already in 2008 the panel of the evaluation of the ESI at that time suggested that "consideration should be given to amending the name slightly by broadening the term "Mathematical Physics" in the title of the Institute.

(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; this JRF programme was restarted in January 2016;

(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 2016

The list of research areas in mathematics and physics covered by the scientific activities of the Erwin Schrödinger Institute in 2016 shows a wide variety: the following thematic programmes were in place

– *Measured Group Theory*
  January 18 – March 18, 2016
  (org.: Miklos Abért (Hungarian Academy of Sciences, Budapest), Goulnara Arzhantseva (U Vienna), Damien Gaboriau (ENS Lyon), Thomas Schick (U Göttingen), Andreas Thom (TU Dresden))

– *Mixing Flows and Averaging Methods*
  April 4 – May 25, 2016
  (org.: Péter Bálint (Technical U of Budapest), Henk Bruin (U Vienna), Carlangelo Liverani (U of Rome, Tor Vergata), Ian Melbourne (U of Warwick), Dalia Terhesiu (U of Exeter))

– *Nonlinear Flows*
  May 30 – July 15, 2016
  (org.: Eduard Feireisl (Czech Academy of Sciences and Charles U, Prague), Ansgar Jüngel (TU Vienna), Alexander Mielke (WIAS and Humboldt U, Berlin), Giuseppe Savaré (U Pavia), Ulisse Stefanelli (U Vienna))

– *Challenges and Concepts for Field Theory and Applications in the Era of LHC Run-2*
  July 18 – August 12, 2016
  (org.: André H. Hoang (U Vienna), Frank J. Petriello (NWU, Evanston), Iain W. Stewart (MIT, Cambridge))

– *Synergies between Mathematical and Computational Approaches to Quantum Many-Body Physics*
  August 29 – October 21, 2016 (org.: Ali Alavi (U Cambridge & MPI Solid State Research, Stuttgart), Sabine Andergassen (U Tübingen), Manfred Salmhofer (U Heidelberg), local organizer: Alessandro Toschi (TU 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 2016, 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:

– *Normal Numbers: Arithmetic, Computational and Probabilistic Aspects*
  November 14 – 18, 2016
  (org.: Christoph Aistleitner (TU Graz), Yann Bugeaud (U Strasbourg), Theodore Slaman (UC, Berkeley), Robert Tichy (TU Graz))

– *ESI/CECAM-Workshop: Water at Interfaces: From Proteins to Devices*
  November 29 – December 02, 2016
  (org.: Valentino Bianco (U Vienna), Ivan Coluzza (U Vienna), Barbara Capone (U Vienna), Christoph Dellago (ESI, U Vienna))

– *Current Trends in Descriptive Set Theory*
  December 12 – 16, 2016
  (org.: Sy Friedman (KGRC, U Vienna), Alexander Kechris (Caltech), Benjamin Miller (KGRC, U Vienna), Slawomir Solecki (U Illinois, Urbana-Champaign))

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

In the summer term Yann Brenier (CNRS, École Polytechnique, Palaiseau) gave a course and exercise class on *Optimal transport methods for Hamiltonian PDEs*. In the winter term Robin S. Johnson (U of Newcastle) gave a course on *Theoretical fluid dynamics and oceanic flows*.

In 2012, the Erwin Schrödinger Institute established the *Research in Teams Programme* as a new component in its spectrum of scientific activities. This 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 number of proposals, on themes of topical interest, was high. However, due to limited resources, the ESI Kollegium could only accept two of these applications for the year 2016, namely:

– Sergei A. Egorov (U of Virginia) and Christos N. Likos (U Vienna), *Soft matter under confinement: structural and dynamical properties*, April 1 – May 31, 2016.

– Ruggero Bandiera (U of Rome, La Sapienza), Nils Carqueville (ESI, U Vienna), Florian Schätz (U of Luxembourg), *Higher Algebraic Structures inspired by Topology & Geometry*, July 17 – August 14, 2016.

The Institute's Management

Kollegium and Scientific Advisory Board

The ESI is governed at the organizational and scientific level by a board ('Kollegium') of six scholars, necessarily 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. In the period January 1, 2016 - December 31, 2016, the Kollegium consisted of P. Chruściel (Physics), A. Constantin (Mathematics), C. Dellago (Physics), A. Hoang (Physics), I. Perugia (Mathematics), J. Schwermer (Mathematics). There were also some changes in the Kollegium: G. Arzhantseva left the Kollegium at the end of 2015 and P. Chruściel at the end of 2016. The ESI thanks both of them for their dedicated services over many years. All members of the Kollegium still 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 suggested by the Kollegium and appointed by the Rector of the University. In the year 2016, the ESI directorate consisted Joachim Schwermer (Director), Christoph Dellago (Deputy Director), and Ilaria Perugia (Deputy Director). At the end of 2016, Joachim Schwermer stepped down as director after many successful years in this position. The ESI and the entire mathematics and physics community are very grateful to Prof. Schwermer for his dedicated and very efficient service over the years. Starting Janusry 1, 2017 the ESI is managed by Christoph Dellago (Director), André Hoang (Deputy Director) and Ilaria Perugia (Deputy Director).

The scientific activities of the ESI are supervised by the Scientific Advisory Board (SAB). The SAB also reflects the international ties which are essential for the ESI. In 2016, the SAB consisted of: Denis Bernard (ENS Paris), Isabelle Gallagher (U Paris-Diderot), Helge Holden (U Trondheim) [chair], Daniel Huybrechts (U Bonn), 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 2016. After two terms of office, Isabelle Gallagher left the Board. The Institute is extremely thankful to her for many years of valuable advice and support. Mirjam Cvetic (U of Pennsylvania, Philadelphia) joined the Board on January 1, 2017, as a new member.

Administration

There was no change in the administration of the ESI in 2016. The current administrative staff - Sophie Kurzmann, Maria Marouschek and Beatrix Wolf - continued to work with its customary efficiency for the benefit of our visitors, research fellows and scientific staff.

Christoph Dellago May 20, 2017
Director
Erwin Schrödinger International Institute for Mathematics and Physics

The ESI in 2016: facts and figures

Management and Administration:

Director: Joachim Schwermer.

Kollegium: Joachim Schwermer (Director), Christoph Dellago (Deputy Director), Ilaria Perugia (Deputy Director), Piotr T. Chruściel, Adrian Constantin, André Hoang.

Administration: Sophie Kurzmann, Maria Marouschek, Beatrix Wolf (Head).

Computing and networking support: Sascha Biberhofer, Thomas Leitner.

International Scientific Advisory Board in 2016:

Denis Bernard (ENS Paris)	Christian Lubich (U Tübingen)
Isabelle Gallagher (U Paris-Diderot)	Stefano Ruffo (SISSA, Trieste)
Helge Holden (U Trondheim) [chair]	Catharina Stroppel (U Bonn)
Daniel Huybrechts (U Bonn)	Martin Zirnbauer (U Cologne)

Budget and visitors: In 2016, the support of ESI received from the Austrian Federal Ministry of Science, Research and Economy via the University of Vienna amounted to **€ 790 000**. In addition, the ESI obtained a total of € 218 988 in third party funds.

The total amount spent in 2016 on scientific activities was € 471 306 while the expenditures for administration (mainly salaries) and infrastructure (mainly rent) amounted to € 395 860.

The reconstruction works and investment in safety measures that were necessary in previous years are now completed. Hence, in contrast to previous years, only minor investments needed to be made in 2016.

The total number of scientists visiting the Erwin Schrödinger Institute in 2016 was 580, see pages 79–92.

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 resp. 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 2016 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 2016 is 89 [related to the activities in 2016: 77, related to the activities in previous years: 12], see pages 72–78 for details.

The Foundation ESI
President: Klaus Schmidt

Scientific Reports

Main Research Programmes

Measured Group Theory

Organizers: Miklos Abért (Hungarian Academy of Sciences, Budapest), Goulnara Arzhantseva (U Vienna), Damien Gaboriau (ENS Lyon), Thomas Schick (U Göttingen), Andreas Thom (TU Dresden)

Dates: January 18 – March 18, 2016

Budget: ESI € 44 240

Other sources:

- ERC Starting Grant "Analytic properties of infinite groups: limits, curvature, and randomness" of Goulnara Arzhantseva: € 21 147
- MAT EU-29/205 grant of Miklos Abért: € 5 926
- ERC Starting Grant "Geometry and Analysis of Group Rings" of Andreas Thom French ANR GAMME (ANR-14-CE25-0004 GAMME): € 10 403
- DFG Research Training Group "Modern Mathematical Methods of Quantum Physics" Göttingen: € 1 482
- Travel support by TU Dresden: € 10 000
- ERC Consolidator Grant 614195 of Thomas Schick: € 750
- Research Foundation Flanders (FWO): € 740

Report on the programme

Activities

The semester programme was organized around two main activities, a Winter School on February 1 – 12, 2016 and an International Conference on February 15 – 19, 2016. The prestigious Erwin Schrödinger Lecture given by Alexander Lubotzky (Hebrew University) was integrated into the conference week. It was a very successful event, directed towards a general audience of mathematicians and physicists.

Before and after these two main events, we organized various lecture courses by experts – some more directed towards PhD students, some more in form of presentation of very recent research results.

The Winter School was aimed at graduate students and other young researchers which are interested in, but not necessarily working on measured group theory. "Measured group theory" analyses groups and their actions via methods ranging from probability theory to topology through Lie theory and (pro)finite groups. This incorporates ergodic and measure theoretic tools and asymptotic invariants, such as L^2-invariants, the rank gradient, torsion growth, entropy, properties of random walks, and various spectral invariants. The school introduced the audience to various aspects of this thriving area.

The conference did bring together an impressive list of researchers from all over the world. It partly operated along the lines of a workshop at the Mathematische Forsch-ungsinstitut in Oberwolfach (Germany), that is, talks were mainly arranged during the meeting. We had ample time for discussions and therefore only a limited number of lectures. Not all interested were able to speak.

Specific information on the programme

The thematic programme was an established mix, both in its participant body and its directions, ranging from probability theory to topology through measured group theory and (pro)finite groups. It turns out that similar to previous activities in the topics (including workshops at Mathematisches Forschungsinstitut, Oberwolfach, at BIRS, Banff, and at AIM, Palo Alto) this mix worked out really well.

As a common subject line we study groups and group actions using ergodic and measure theoretic methods and incorporating asymptotic invariants, such as ℓ^2-invariants, the rank gradient, torsion growth, entropy, properties of random walks, and various spectral invariants. There are different approaches and angles that intersect in sometimes rather surprising and fruitful ways. A lot of these connections are yet to be discovered. At this point, the whole community still benefits from a more direct and continuous interaction. The 2 month program at ESI was ideal to promote and deepen this interaction.

The most important topics of the proposed program were:

1. ℓ^2-Betti numbers of groups, manifolds and measurable relations
2. Rank gradient, cost and homology growth for residually finite groups
3. Approximation of groups by finite structures: residually finite, sofic and hyperlinear groups
4. Measured group theory: orbit equivalence, weak containment, entropy-type invariants
5. Invariant random subgroups and non-free actions
6. Graph convergence and graphings
7. Stochastic processes on groups, graphs and their limits

Measured Group Theory studies groups through their measurable actions. It investigates classification, rigidity and invariants of (actions of) discrete countable or locally compact groups and the ways these are encoded in the orbit structures of the actions. The subject started with

Gromov who suggested the notion of measured equivalence as a common framework to relate and better understand the family of (cocompact and non-cocompact) lattices in a fixed Lie group. In the last 20 years, measured group theory has been developed intensely. It has also established new and sometimes quite unexpected connections between various areas, including geometric group theory, von Neumann algebras, asymptotic group theory, descriptive set theory, percolation on graphs and graph convergence.

Outcomes and achievements

Collaborations started and/or continued during this thematic programme (in alphabetical order):

- Vadim Alekseev: During my visit in ESI in February I have been collaborating with Martin Finn-Sell from Vienna and Rahel Brugger from Göttingen on two joint projects:

  1. Amenability and weak amenability of group actions on C*-algebras
     In this ongoing joint project with Martin Finn-Sell we introduce the notion of weak amenability of the group action on a C*-algebra and investigate the C*-algebraic criteria for different notions of amenability of the action. We prove that amenability and weak amenability pass from the group to the action and that in the presence of an invariant state amenability and weak amenability passes from the action back to the group, thus generalizing the well-known statements in the commutative case). We apply the results to characterise coarse geometric properties (and properties of the Roe algebra) of the box space of a residually finite weakly amenable group.
  2. Property (T) for von Neumann algebras of discrete measurable groupoids
     The aim of this joint work with Rahel Brugger is to characterize when the von Neumann algebra of a discrete measured groupoid has property (T). The question reduces to proving that the natural inclusion of the base space algebra into the groupoid algebra is corigid and rigid in the sense of Popa. We use the framework of strong extensions of measured groupoids as a convenient tool to the connection between property (T) of groupoids and corigidity of this inclusion of von Neumann algebras, and extend the rigidity criterion for this inclusion obtained by Adrian Ioana for equivalence relations generated by a free group action to the general framework of a discrete measurable groupoid.

- Goulnara Arzhantseva: I have continued the following collaborations:

  1. With D. Gruber (Neuchâtel) and Ch. Cashen (Vienna) on contraction properties of geodesics in graphical small cancellation groups. For instance, also together with D. Hume (Paris), we proved a local-to-global theorem for the contraction properties of geodesics in graphical small cancellation groups. This theorem lets us explicitly construct geodesics with prescribed contraction behavior, thus, establishing graphical small cancellation constructions as a major source of examples with the previously unexplored diversity of contracting behaviors in finitely generated groups.
  2. With A. Le Boudec (Louvain) on groups of finite asymptotic dimension. The concept has been introduced by Gromov and the area is currently very well developed. However, most of results and characterizations are about finitely presented groups.

We have analyzed some of the well-known infinitely presented groups and group constructions via limits of Gromov hyperbolic groups.

3. With M. Finn-Sell (Vienna), E. Guentner (Honolulu), M. Steenbock we have discussed questions related to the Atiyah conjecture and the Kaplansky zero-divisor conjecture for CAT(0) cubulable groups. This is a long-term project as this class of groups is extremely wide and both conjectures are understood in great details mostly for free groups only (we are focusing on non-amenable groups).

The following collaborations have started during the programme:

1. With M. Cavaleri (Rome) on metric approximations of groups. This is in line with his recent PhD thesis, where he suggests a general viewpoint on algorithmic issues within the class of sofic groups.
2. With L. Glebsky (Mexico) on metric approximations of Higman's group and related groups. He has given a mini-course on his recent results about the Higman group. This has naturally generated a lot of lovely discussions and (still to be developed) ideas.
3. With L. Paunescu (Bucharest) and O. Becker (Jerusalem) we have discussed questions related to stability of metric approximations. A recent joint work of O. Becker (Jerusalem) and A. Lubotzky (Jerusalem) generalizes my result with L. Paunescu (Bucharest) on the stability of commutator in permutations. Their generalization is very interesting, uses a combinatorial approach (we have used an ultraproduct approach), and has a bearing on some computer science problems. The questions on the stability of metric approximations are much more difficult in comparison with the questions on the existence of metric approximations such as soficity and hyperlinearity. We are only at the beginning of this research.

- Federico Berlai: During the trimester, I continued to collaborate with Martin Finn-Sell on unrestricted wreath products. In particular, we were interested in soficity of such construction. I discussed several times with Lev Glebsky on the same topic. Moreover, I discussed with Matteo Cavaleri regarding Folner functions, amenable and solvable groups. In collaboration with Michal Ferov and Martin Finn-Sell, we discussed about sofic groups and on the possibility of imposing additional conditions to their definition, to obtain a notion that would be, theoretically, more practical to handle.

- Christopher Cashen: I continued collaboration with Dominik Gruber and Goulnara Arzhantseva concerning small cancellation groups and generalizations of hyperbolicity.

- Matteo Cavaleri: I continued the collaboration with Goulnara Arzhantseva, in the sense that I followed her suggestions on my work. I collaborated with Federico Berlai to improve my works and his works, I started to collaborate with Liviu Paunescu and now we are part of the same project.

- Stefania Ebli: I attended the conference Measured Group Theory, 18 January – 18 March 2016, ESI, Vienna, as part of my master thesis research project, a collaboration of the department of mathematics of the University of Padua, in particular Prof. Lucchini, and the research group of Prof. G. Arzhantseva at the University of Vienna. During the period of the conference I continued my collaboration with the research group, in particular with Martin-Finn Sell. The main focus of our work are tilings for amenable groups, the Rokhlin Lemma for amenable groups and coarse tilings for actions of discrete groups.

- Dominik Gruber: I was able to continue ongoing work with Goulnara Arzhantseva (University of Vienna) and Christopher Cashen (University of Vienna) on our project about contraction of geodesics in infinitely presented graphical small cancellation groups. (The project is also joint with David Hume, Universit Paris-Sud.)

- Alexandre Martin: I had the opportunity to discuss with Lev Glebsky recent progress on the Higman group. His series of lectures on the Higman group was the opportunity to start a dialogue between more algebraic/combinatorial aspects of the subject and the recent geometric techniques I introduced to study this group.

  I had constructive discussions on problems of my interest with Lev Glebsky (Mexico), Robin Tucker-Drob (Rutgers), David Kerr (Texas A&M), Oren Becker (Jerusalem). I started a collaboration with Matteo Cavaleri (Rome), and now he is at the IMAR, my institution, with a temporary research position under my supervision. Together we are working on our project on sofic groups.

  As a frequent visitor to the University of Vienna, I was happy to continue my collaboration with Goulnara Arzhantseva. We have a work in progress, a sequel to our article "Almost commuting permutations are near commuting permutations".

  Parts of my new preprint, "Unitaries in ultraproduct of matrices", arxiv:1605.07101 were written during my stay at the ESI.

- Thomas Schick: I have continued the following collaborations:

  1. With Michael Puschnigg (Marseille) I studied the cyclic homology of operator algebras associated to groups. The goal is to extend the cyclic homological methods to discuss primary index obstructions also to their secondary counterpart. This should use the structure algebras of Higson and Roe or some of their relatives. Technical difficulties arise from the fact that in their original definition these algebras are not even seperable.

     Puschnigg explained the various ways of costructing smooth subalgebras, via derivations and their generalizations; and together with Paolo Piazza and Nigel Higson we are very exploring these posibilities in light of the (more challenging then usual) structure algebras.
  2. With Rudolf Zeidler (Göttingen) I discussed a project about homological and operator K-theoretic methods to obtain obstructions to positive scalar curvature via the use of submanifolds of high codimension, on manifolds with a suitable range of homotopy groups which vanish. This follows on recent work of Alexander Engel, and previous work of Rudolf Zeidler. We were able to obtain a relatively satisfactionary picture; putting the different aspects (homological, K-homological, operator K-theoretic) under one umbrella in the case of codimensions 1 and partly in codimension 2, and simplyfing the approach of Engel in higher codimensions. This should soon lead to a publication (which is in preparation).

  The following collaborations have started during the programme:

  1. With Markus Steenblock (U Vienna), I discussed all kind of aspects of the Zero-divisor conjecture. On the one hand, we discussed the known construction of potential counterexamples, based on work of Rips-Segev and Markus Steenblock. On the other hand, we discussed explained important aspects of Peter Linnell's, and my own work on the Atiyah conjecture. For instance, we showed the conjecture for

RAAGs and right angled Coxeter groups. It is surprising that despite these results, the conjecture is open for CAT(0) cubulable groups in general.

2. With Andrei Jaikin-Zapirain (Madrid) I discussed his recent ring theoretic approach to the Atiyah conjecture. This is complementary to previous ideas I had with Peter Linnell and should lead to new results on the Atiyah conjecture and the Lück approximation conjecture. In particular in light of base change from the field of rational numbers to larger ground fields
3. With Hanfeng Li (Buffalo), we discussed the Lück approximation conjecture for finite field coefficients, in light of his new dimension function for such coefficients and for sofic groups, based on the use of non-principal ultrafilters. In particular, we discussed new applications this method can have in geometry and algebra.
4. With Klaus Schmidt (Wien), we discussed how to extend the Lück approximation result from the L^2-Betti numbers to determoinants in suitable situations. This is a very delicate problem, as specific examples of Wolfgang Lück show; and even in the simplest cases no immediate results seem in reach. However, these questions do have important relations to number theory and dynamical systems; as exemplified by the work of Schmidt with Deninger

- Markus Steenbock: My research and discussions were centered around the Kaplansky zero divisor conjecture. I am interested in group theoretic constructions of potential counterexamples to the conjecture, and try to develop new tools to prove the conjecture for large classes of groups. One such possible tool could be CAT(0) cubulation, as the conjecture was recently shown for torsion-free Gromov hyperbolic CAT(0) cubulable groups. For the free group, Linnell showed the Atiyah conjecture on the ℓ^2-betti numbers by constructing a concrete Fredholm module. Since then, no other concrete construction of such a Fredholm module on more complicated geometric spaces could be found. With Goulnara Arzhantseva, Erik Guentner, and Martin Finn-Sell, we discussed the possibility of extending Linnell's construction to CAT(0) cube complexes. Erik Guentner explained a rough idea for constructions of Fredholm modules on CAT(0) cube complexes of a work in progress of his (with coauthors). Their Fredholm modules are not at all completely understood. A continuation in this line of thought should lead to a better understanding of both conjectures, and to the exploration of new proof strategies for CAT(0) cubulable groups. With Thomas Schick, I discussed all kind of aspects of the Zero-divisor conjecture. On the one hand, we discussed the known construction of potential counterexamples, based on work of Rips-Segev and myself. On the other hand, he explained important aspects of Linnell's, his, and others groundbreaking work on the Atiyah conjecture. For instance, they showed the conjecture for RAAGs and r.a. Coxeter groups. It is surprising that despite these results, the conjecture is open for CAT(0) cubulable groups in general. Andrei Jaikin-Zapirain explained his recent ring theoretic approach to the Atiyah conjecture. Both could lead to concrete projects for my postdoctoral research.
- Jiawen Zhang: During the programme, I have discussed with Prof. Eric Guentner maily on the asymptotic dimension and the asymptotic growth function of the CAT(0) cubical complex and the coarse median groups. He reminded me of some new results.

Upcoming Preprints:

- Adrien Le Boudec and Nicolas Matte Bon, *Subgroup dynamics and C*-simplicity of groups of homeomorphisms*, arXiv:1605.01651

- Matteo Cavaleri, *Computability of Følner sets*, in preparation.
- Goulnara Arzhantseva, Romain Tessera, *Admitting a coarse embedding is not preserved under group extensions*, arXiv:1605.01192.
- Goulnara Arzhantseva, Christopher Cashen, Dominik Gruber, and David Hume, *Contracting geodesics in infinitely presented graphical small cancellation groups*, arXiv:1602.03767.
- Lev Glebsky, *p-quotients of the G. Higman group*, arXiv:1604.06359.
- Łukasz Garncarek, *Mini-course: property of Rapid Decay* arXiv:1603.06730.
- László Pyber, *A CFSG-free analysis of Babai's quasipolynomial GI-algorithm*, arXiv:1605.08266.

  We obtain a weaker but still quasipolynomial version of Babai's famous GI-algorithm.
- Liviu Păunescu, *Unitaries in ultraproduct of matrices*, arxiv:1605.07101.

  We study various conditions under which a unitary in an ultraproduct of matrices is conjugated to an ultraproduct of permutations.

List of talks

The information can also be retrieved from
`http://www.uni-math.gwdg.de/schick/ESI16/esi16_3.html`

Mini-Courses

Lev Glebsky	On the Graham Higman group I - IV, January 20 – 29, 2016
Łukasz Garncarek	Property of Rapid Decay, I - IV, March 14 – 16, 2016

School, week 1: February 1 – 5, 2016

Brandon Seward	Sofic and Rokhlin entropy, I - IV
Gabor Elek	Sofic groups, I - III
Jesse Peterson	Character rigidity, I - IV
Yair Glasner	Spaces of subgroups and IRS, I - III
Andrei Jaikin-Zapirain	An algebraic proof of the strong Atiyah conjecture for free groups, I - III

School, week 2: February 8 – 12, 2016

Tsachik Gelander	Asymptotic invariants of Lattices in Lie groups, I - IV
Narutaka Ozawa	Noncommutative real algebraic geometry: Kazhdan property (T) and Connes embedding conjecture, I - IV
Robin Tucker-Drob	Borel and measured equivalence relations and trees, I - IV
François le Maître	Full groups, topological rank and cost, I - III
Todor Tsankov	Automorphism groups and their actions, I - III

Conference: February 15 – 19, 2016

Brandon Seward	Positive entropy actions of countable groups factor onto Bernoulli shifts
Uri Bader	An ergodic theoretical method for proving non-linearity of groups.
Narutaka Ozawa	A functional analysis proof of Gromov's polynomial growth theorem
Nicolas Matte Bon	Topological full groups of self-similar groups
Adrien le Boudec	Discrete and locally compact groups acting on trees
Hanfeng Li	Sofic mean length
Nikolay Nikolov	Right angled lattices in simple Lie groups
David Kerr	Tower decompositions for free actions of amenable groups

Harald Helfgott	Soficity, recurrence and short cycles of exponential maps (joint work with K. Juschenko)
Ben Hayes	A product formula for Pinsker Factors with application to completely positive entropy
Vadim Alekseev	Property (T) of discrete measured groupoids and their von Neumann algebras
László Tóth	Growth of rank, combinatorial cost and local-global convergence
Felix Pogorzelski	Ihara's zeta function for measured graphs
Mark Shusterman	Ranks of subgroups in boundedly generated groups
Alessandro Carderi	An exotic group as a limit of finite special linear groups
Anatoly Vershik	Standard filtrations and standard graphs in measure theory and representation theory
Aditi Kar	Gradients in Group Theory
Martin Finn-Sell	C*-exactness and almost quasi-isometric embeddings into groups
Rufus Willet	Dynamic Asymptotic Dimension
Alessandro Sisto	A central limit theorem for acylindrically hyperbolic groups
Rostislav Grigorchuk	Totally non-free actions, random subgroups and factor representations
Tim de Laat	Obstructions to coarse embeddability of expanders into Banach spaces
Agnes Backhaus	On the eigenvectors of random regular graphs and invariant random processes on the infinite tree
Swiatoslaw Gal	Order preserving actions, full topological groups, and uniform simplicity
Lukasz Grabowski	Borel Local Lemma
Alexandre Martin	The geometry of the Higman group
Alex Lubotzky	Erwin Schrödinger Lecture: Ramanujan complexes and topological expanders
Remi Boutonnet	Local spectral gap in simple Lie groups
Adam Timar	Indistinguishable clusters in random spanning forests
Oren Becker	Equations in permutations and locally testable groups
Martin Schneider	A Ramsey-type characterization ofamenability for topological groups
Roman Sauer	A measurable version of simplicial volume

Individual talks

Yuri Neretin	Groups of hierarchomorphisms of trees and related Hilbert spaces
Anatoly Vershik	The absolute boundary of the random walks on the groups and graphs
Matteo Cavaleri	Computability of Flner sets and sofic approximations
John Wilson	Informal talk on profinite groups
Thomas Schick	Strange values of L2-Betti numbers for positive characteristic
Rudolf Zeidler	Secondary index theory, positive scalar curvature and torsion in the fundamental group

Publications and preprints contributed

Goulnara Arzhantseva, Romain Tessera, *Admitting a coarse embedding is not preserved under group extensions*, arxiv:1605.01192.

Goulnara Arzhantseva, Christopher Cashen, Dominik Gruber, and David Hume, *Contracting geodesics in infinitely presented graphical small cancellation groups*, arXiv:1602.03767.

Łukasz Garncarek, *Mini-course: property of Rapid Decay*, arXiv:1603.06730.

Lev Glebsky, *p-quotients of the G. Higman group*, arXiv:1604.06359.

Andrei Jaikin-Zapirain, *The base change in the Aityah and the Lück approximation conjectures*, preprint.

Adrien Le Boudec and Nicolas Matte Bon, *Subgroup dynamics and C*-simplicity of groups of homeomorphisms*, arXiv:1605.01651.

László Pyber, *A CFSG-free analysis of Babai's quasipolynomial GI-algorithm*, arXiv:1605.08266.

Invited scientists

Miklos Abért, Vadim Alekseev, Andrei Alpeev, Goulnara Arzhantseva, Agnes, Backhausz, Uri Bader, Oren Becker, Federico Berlai, Arindam Biswas, Nicolas Matte Bon, Mohamed, Bouljihad, Remi Boutonnet, Rahel Brugger, Mike Cantrell, Pierre Caprace, Alessandro Carderi, Christopher Cashen, Matteo Cavaleri, Paulina Cecchi, Joan Claramunt, Anton Claunitzer, Luiz Gustavo Cordeiro, Kajal Das, Marcus de Chiffre, Tim de Laat, Michal Doucha, Ebli Stefania, Gabor Elek, Mikhail Ershov, Michal Ferov, Martin Finn-Sell, Marzieh Forough, Florian Funke, Damien Gaboriau, Swiatoslaw Gal, Lukasz Garncarek, Alejandra Garrido, Tsachik Gelander, Maxime Gheysens, Jakub Gismatullin, Yair Glasner, Lev Glebsky, Gil Goffer, Lukasz Grabowski, Rostislav Grigorchuk, Dominik Gruber, Erik Guentner, Francois Gueritaud, Mark Hagen, Ben Hayes, Harald Helfgott, Jan Hladky, Andrei Jaikin-Zapirain, Lison Jacoboni, Aditi Kar, David Kerr, Yoshikata Kida, Steffen Kionke, Anna Krogager, Konrad Krolicki, Gabriella Kuhn, Adrien le Boudec, Waltraud Lederle, Lehner Franz, Francois le Maitre, Arie Levit, Hanfeng Li, Yash Lodha, Alex Lubotzky, Daniel Luckhardt, Elia Manara, Michal Marcinkowski, Amine Marrakchi, Alexandre Martin, Sam Mellick, Andras Meszaros, Wolfgang Moens, Shahar Mozes, Nikolay Nikolov, Narutaka Ozawa, Liviu Paunescu, Ulrich Pennig, Jesse D. Peterson, Thibault Pillon, Antoine Pinochet-Lobos, Felix Pogor-zelski, Michael Puschnigg, Laszlo Pyber, Gerhard Racher, Florin Radulescu, Roman Sauer, Thomas Schick, Jan-Christoph Schlage-Puchta, Klaus Schmidt, Martin F. Schneider, Cagri Sert, Mark Shusterman, Brandon Seward, Alessandro Sisto, Tatiana Smir-nova-Nagnibeda, Gabor Somlai, Jan Spakula, Markus Steenbock, Krzysztof Swiecicki, Yuhei Suzuki, Nora Gabriella Szoke, Maud Szusterman, Matan Tal, Tamas Terpai, Romain Tessera, Adam Timar, László Márton Tóth, Todor Tsankov, Robin Tucker-Drob, Yoshimichi Ueda, Manuael Urbina Moreano, Alain Valette, Peter Verraedt, Anatoly Vershik, Mate Vizer, Phillip Wesolek, John Wilson, Rufus Willett, Konrad Wrobel, Enxin Wu, Rudolf Zeidler, Jiawen Zhang

Mixing Flows and Averaging Methods

Organizers: Péter Bálint (Technical U of Budapest), Henk Bruin (U Vienna), Carlangelo Liverani (U of Rome II, Tor Vergata), Ian Melbourne (U of Warwick), Dalia Terhesiu (U of Exeter)

Dates: 4 April – May 25, 2016

Budget: A brief summary of the sources of funding is as follows.

ESI	€ 49 760
Start-up grant Bruin	€ 28 140
Department of Stochastics, TU Budapest	€ 800
Institute of Mathematics, TU Budapest	€ 1 100
Rényi Institute, Budapest	€ 1 100
FWF (non-material: hire of Skylounge)	
Total:	€ 80 900

Of the original € 30 000 from the start-up grant, € 1 860 remained unused and was reimbursed; hence the amount € 28 140. The support of TU Budapest and the Rényi Institute has gone directly into reimbursing some of the participants, and hence not via ESI.

Report on the programme

Activities

International research in smooth ergodic theory is increasingly focusing on the ergodic and mixing properties of continuous time dynamical systems, that is, measure-preserving flows. Recent advances on the mixing properties of chaotic flows have opened up the possibilities for studying the separation of time scales or spatially extended dynamical phenomena, and thus for the applications to models related to statistical physics. One of the key tools here is averaging theory, with the fast motion often modeled by a strongly chaotic flow.

These topics were well-represented in the mini-courses listed below. Recent results on exponential mixing for examples of fundamental physical importance such as Lorentz gases and the Lorenz attractor were described in the mini-courses by Araújo (Lorenz) and Baladi/Demers (Lorentz). A striking result of Tsujii in 2016 on exponential mixing for three-dimensional volume-preserving Anosov flows was presented in a hastily-arranged three hour course during the first main workshop. Exponential mixing for geodesic flows was covered in the survey mini-course by Pollicott. Averaging theory was the subject of mini-courses by de Simoi and Kelly. The mini-course by Kelly included the first application of rough path theory (the precursor of Hairer's Fields medal winning work on regularity structures) to deterministic (non-stochastic) dynamical systems. The mini-course by Gouëzel described applications of operator renewal theory to dynamical systems.

General information remains available on http://math.bme.hu/∼mixflow/. The programme included:

- A one-day Budapest-Vienna Ergodic Theory workshop (BudWiSer), see section "List of talks". These workshops between the mathematics institutes of Budapest University of Technology and Economics and the University of Vienna have been organised monthly, alternatingly in Budapest and Vienna, since 2012. Since the central theme of this seminar is billiards dynamics, in all its aspects, it was a natural choice to include this event in the Theme Semester.
- Three workshop weeks, with respective titles **Thermodynamic Formalism and Mixing**, **Statistical properties of dynamical systems**, and **Hyperbolic Dynamics and Statistical Physics** (in which the life-time contributions of Prof. D. Szász received special attention). The speakers of especially this last workshop included many of the world leading as well as foremost protagonists of the field, such as Dolgopyat, Katok, Pesin and Young. These workshop comprised 60 talks altogether, see section "List of talks".
- Two mini-course weeks, with leading speakers, in which both main techniques and major new developments were presented in detail.
  - Vítor Araújo (Federal U of Bahia)
    Stable Foliations (including exponential mixing for the classical Lorenz attractor)
  - Viviane Baladi (CNRS / U Pierre et Marie Curie) and Mark Demers (Fairfield U)
    Exponential mixing for two-dimensional Sinai billiard flows (otherwise known as Lorentz gases)
  - Jacopo de Simoi (U Paris Diderot)
    Limit theorems and statistical properties of some fast-slow systems (including and greatly developing the theory of averaging)

- Sébastien Gouëzel (CNRS / U de Nantes)
  Quantitative estimates for nonuniformly hyperbolic dynamical systems (including a survey of operator renewal theory and applications to mixing rates for dynamical systems)
- David Kelly (Courant Institute)
  Rough paths and fast-slow systems (including the fast application of rough path theory to deterministic dynamical systems)
- Yakov Pesin (Penn State U)
  SRB-Measures
- Mark Pollicott (U of Warwick)
  Geodesic/Anosov Flows (including exponential mixing)
- Omri Sarig (Weizmann Institute)
  Thermodynamic formalism

Among the new results were exponential mixing of the Lorenz flow and planar billiard flows. These were presented in detail in the lectures of Araújo and Baladi & Demers respectively. In addition, the lecture series of Masato Tsujii on the mixing rates of volume preserving flows in dimension three fit in this category too. For organisational reasons, however, we were forced to schedule this series in the first workshop week.

Apart from these, the informal student feedback was exceptionally good on the mini-courses by Gouëzel on the role of Banach algebras and Wiener Lemmas in renewal theory, and by Sarig, presenting and motivating thermodynamic formalism from a mathematics as well as physics viewpoint. More classical theory on SRB measures and on geodesic flows were presented by Pesin and Pollicott, respectively. Finally, averaging methods and connections to fast-slow systems and tools to approach these were presented by de Simoi and by Kelly.

There were well over 30 participants in the minicourses. Some lecture notes are available on http://math.bme.hu/∼mixflow/students.html.

Specific information on the programme

Young participants for mini-courses and otherwise:

Mini-Course week 1

Name	Affiliation	Position
B. Kasun Fernando Akurugo	U of Maryland, College Park	PhD student
Kamel Belarif	LMBA, U Brest	PhD student
Steven Berghout	U Leiden	PhD student
Michael Bromberg	Chalmers, Gothenburg	Postdoc
Peyman Eslami	U Warwick	Postdoc
Luc Gossart	U de Grenoble	PhD student
Natalia Jurga	U Bristol	PhD student
Vuksan Mijovic	U of St. Andrews	PhD student
Roman Nikiforov	U Kiev	PhD student
Fanni Selley	BME Budapest	PhD student
Sascha Troscheit	St Andrews	PhD student
Michael Tsiflakos	U Vienna	PhD student
Polina Vytnova	Queen Mary U of London	Postdoc

Khadim Mbacke War	SISSA Trieste	PhD student
Meagan E Woodford	Houston U	PhD student
Nasab Yassine	LMBA, U Brest	PhD student
Agnieszka Zelerowicz	Penn State U	PhD student

Mini-Course week 2

Name	Affiliation	Position
Alex Blumenthal	Courant Institute, NYU	PhD student
Seth William Chart	U of Victoria	PhD Student
Rhiannon Dougall	U of Warwick	PhD student
Peyman Eslami	U of Warwick	Postdoc
Olli Hella	U of Helsinki	PhD student
Alexey Korepanov	U of Warwick	Postdoc
Zemer Kosloff	U of Warwick	Postdoc
Julien Sedro	Orsay, Paris	PhD student
Fanni Selley	BME Budapest	PhD student
Tanja Schindler	U Bremen	PhD student
Dmitry Todorov	U Marseille	Postdoc
Michael Tsiflakos	U Vienna	PhD student
John Peter Wormell	UNSW, Australia	PhD student
Jing Zhou	U of Maryland, College Park	PhD student

Further participation of young researchers:

Name	Affiliation	Position
Alexander Adam	Jussieu Paris	PhD student
Jernej Činč	U Vienna	PhD student
Hanna Oppelmayer	Chalmers, Gothenburg	PhD student
Gabriel Strasser	U Vienna	PhD student
Andras Nemedy Varga	BME Budapest	PhD student

Outcomes and achievements

Among the collaborations that participants have begun or continued at the Institute, we make a selection. For collaborations that already led to a preprint or publication, we refer to section “Publications and preprints contributed”.

1. Oliver Butterley & Khadim War commenced work on a paper with the provisional title “Open Sets of Exponentially Mixing Anosov Flows”. This is partly inspired by the talks of Masato Tsujii.

2. Vítor Araújo & Ian Melbourne continued work on a paper on “Mixing properties for Lorenz attractors without smooth stable foliation”.

3. Ian Melbourne & Marta Tyran-Kaminska continued work on a paper on “Limit theorems for intermittent maps with infinite measure”.

4. Henk Bruin, Mark Demers & Mike Todd made further progress on the paper “Hitting and escaping statistics: mixing, targets and holes”, which should come out shortly. This paper explores the link between hitting time statistics and open system, proving generalised recurrence theorems.

5. Mark Holland & Mike Todd made further progress on the paper “Weak convergence to extremal processes and record events for non-uniformly hyperbolic dynamical systems”. This considers record times (the most extreme event observed up to a give time) for dynamical systems - in particular it applies extremal process theory to dynamics for the first time.

6. Henk Bruin, Dalia Terhesiu & Mike Todd made preliminary progress on a project “Renewal Theory and Thermodynamic Formalism for Flows”, leading to a grant proposal on this topic.

7. Neil Dobbs & Mike Todd initiated conversations for potential work on statistical stability. One direction here is extending the results of Baladi-Benedicks-Schnellmann, which give sharp results on the continuity of measures, to a wider class of systems and for other kinds of measures (eg measure of maximal entropy).

8. Mike Todd & Roland Zweimüller had discussions on Extreme Value Theory, leading to a grant proposal. These preliminary discussions concern a new, more direct, approach to Extreme Value Theory in dynamics, replacing the long and short range mixing conditions usually applied.

9. For Viviane Baladi & Mark Demers, the stay at ESI gave them the opportunity to continue discussions with about measures of maximal entropy for Sinai billiard maps and flows. The goal is to implement the anisotropic Banach space method for transfer operators in this setting to get existence, uniqueness, and exponential mixing. Progress was made, especially in the discrete-time case.

10. Henk Bruin, Dmitry Dolgopyat, Ian Melbourne, Péter Nándori & Dalia Terhesiu had extensive discussions on “Mixing for infinite measure flows” (following on from talk by Melbourne on this topic) which seems to lead to 2 methods:
1) One solution which exploits purely probabilistic arguments;
2) One solution which exploits analytic arguments (via operator theory techniques).

11. Peyman Eslami was working on a project related to “coupling for weighted piecewise expanding maps” part of which was developed and written at ESI. During the programme he also benefitted greatly from the workshops and conferences as well as discussions with Carlangelo Liverani, Mark Demers, Péter Bálint, Jacopo de Simoi, Ian Melbourne, Sébastien Gouëzel, Mike Todd and Neil Dobbs.

List of talks

Budapest-Vienna Seminar, April 8, 2016

Program on http://www.mat.univie.ac.at/∼zweimueller/BudWiSer/Budwiser.html

Maciej Wojtkowski	Integrable and chaotic Gaussian thermostats on some homogeneous spaces
Jozef Bobok	(Quasi)similarity of polygonal billiards
Balázs Bárány	Ledrappier-Young formula and exact dimensionality of self-affine measure

Mini-Courses 1, April 18 – 22, 2016

Program on http://math.bme.hu/∼mixflow/BLT_minicourse1.pdf

Vítor Araújo	Stable Foliations, I - III
Yakov Pesin	SRB-Measures, I - III
Mark Pollicott	Geodesic/Anosov Flows, I - III
Omri Sarig	Thermodynamic formalism, I - III
Richard Sharp	Growth of closed geodesics on regular covers of negatively curved manifolds

First Workshop: Thermodynamic formalism and mixing, April 25 – 29, 2016

Program on http://math.bme.hu/∼mixflow/BLT_Workshop1.pdf

Wael Bahsoun	Mixing rates and limit theorem for random intermittent maps
Keith Burns	Mixing properties of the Weil-Petersson geodesic flow
Vaughn Climenhaga	Equilibrium states for geodesic flow in nonpositive curvature
Peyman Eslami	Coupling for piecewise expanding maps
Frédéric Faure	Global normal form and asymptotic spectral gap for open partially expanding maps
Godo Iommi	Phase transitions for suspension and geodesic flows
Michael Jakobson	Ergodic properties of some attractors with countable Markov partitions
Tom Kempton	Ergodic Theory of the Scenery Flow and Self-Affine Sets
Benoît Saussol	Linear response in the intermittent family
Mark Holland	Almost sure convergence of maxima for chaotic dynamical systems
Mike Todd	Continuity in thermodynamic formalism
Masato Tsujii	Exponential mixing for generic volume-preserving Anosov flows in dimension three, I - III
Paulo Varandas	Contributions to the thermodynamic formalism of semigroup actions
Evgeny Verbitzkiy	Random Continued Fraction Expansions

Mini-Courses 2, May 2 – 6, 2016

Program on http://math.bme.hu/∼mixflow/BLT_minicourse2.pdf

Viviane Baladi & Mark Demers	Exponential mixing for two-dimensional Sinai billiard flows. I - IV
Sébastien Gouëzel	Quantitative estimates for non uniformly hyperbolic dynamical systems, I - III
David Kelly	Rough paths and fast-slow systems
Jacopo de Simoi	Limit theorems and statistical properties of some fast-slow systems, I - III
Mikko Stenlund	Quasistatic dynamical systems

Second Workshop: Statistical properties of dynamical systems, May 9 – 13, 2016

Program on http://math.bme.hu/∼mixflow/BLT_Workshop2.pdf

Jon Aaronson	Rational ergodicity of discrepancy skew products and the asymptotics of affine random walks
Leonid Bunimovich	Where and when orbits of the most chaotic systems prefer to go
Jean-Pierre Conze	Martingales and cumulants for algebraic $\mathbb{Z}^d$-actions on shift-invariant subgroups of $\mathbb{F}^{\mathbb{Z}^d}$
Dmitry Dolgopyat	Local Limit Theorem for Markov chains
Gary Froyland	Hölder continuity of Oseledets splittings for semi-invertible cocycles
Alexander Grigo	Applications of billiard-like systems
Yves Guivarc'h	On Fréchet's law and some extreme value properties for multivariate affine random walk
David Kelly	Fast-slow systems with chaotic noise
Alexey Korepanov	Homogenization for families of skew products

Zemer Kosloff	Intersection local times for random walks and some questions in ergodic theory
Matthew Nicol	A dichotomy for the distribution of returns times and extremes or uniformly hyperbolic systems
Françoise Pène	Quantitative recurrence for slowly mixing hyperbolic systems
Tomas Persson	Shrinking targets
Jacopo de Simoi	Birkhoff conjecture and spectral rigidity of planar convex domains
Damien Thomine	Potential kernel, hitting probabilities and limit distributions
Imre Péter Tóth	Equidistribution for standard pairs in planar dispersing billiard flows
Andrew Török	Almost sure convergence of maxima for chaotic dynamical systems
Marta Tyran-Kaminska	Convergence to bivariate Levy processes and limit theorems in infinite ergodic theory
Sandro Vaienti	On a few statistical properties of intermittent sequential systems

Conference: Hyperbolic Dynamics and Statistical Physics, May 17 – 21, 2016

Program on http://math.bme.hu/∼szasz75/BLT_Szasz75.pdf

Viviane Baladi	Exponential decay of correlations for Sinai billiard flows
Henk Bruin	The Dolgopyat inequality for BV observables
Leonid Bunimovich	Isospectral transformations of multidimensional systems and networks
Mark Demers	Escape rates and limiting distributions for intermittent maps with holes
Carl Dettmann	How sticky is the chaos/order boundary?
Dmitry Dolgopyat	Piecewise linear Fermi-Ulam pingpongs
László Erdös	Local law of addition of random matrices
Thomas Gilbert	Revisiting the derivation of Fourier's law of heat conduction in the Kipnis-Marchioro-Presutti model
Anatole Katok	Flexibility program for quantitative properties of hyperbolic dynamical systems
Konstantin Khanin	On KPZ universality and renormalization
Yuri Kifer	Some extensions of the Erdös-Rényi Law of Large Numbers
Carlangelo Liverani	Random Lorentz Gas
Jens Marklof	Spherical averages in the space of marked lattices
Ian Melbourne	Mixing for infinite measure flows
Péter Nándori	The first encounter of two billiard particles of small radius
Stefano Olla	Energy transport in acoustic and non-acoustic chains
Yakov Pesin	Building thermodynamics for non-uniformly hyperbolic maps
Zsolt Pajor-Gyulai	Stochastic approach to anomalous diffusion in two dimensional, incompressible, periodic, cellular flows.
Klaus Schmidt	Expansiveness, homoclinic and periodic points for algebraic $\mathbb{Z}^d$-actions
Nándor Simányi	Doma Szász and the Boltzmann-Sinai Hypothesis
Károly Simon	On the dimension of diagonally affine self-affine sets
Bálint Tóth	Tagged particle diffusion in deterministic dynamics
Benjamin Weiss	Limit theorems for positive processes
Maciej Wojtkowski	The system of falling balls revisited
Lai-Sang Young	Lyapunov exponents of some random dynamical systems

Publications and preprints contributed

The following publications and (arXived) preprints were completed at or shortly after the duration of the programme.

1. Henk Bruin, Jozef Bobok, *Constant slope maps and the Vere-Jones classification*, arXiv:1602.06905, Entropy **18(6)**, 234, 2016, See also`http://www.mat.univie.ac.at/~bruin/papers/constantslope.pdf`.

2. Henk Bruin, Dalia Terhesiu, *The Dolgopyat inequality in BV for non-Markov maps*, arXiv: 1604.07013, see also `http://www.mat.univie.ac.at/~bruin/papers/AFU.pdf`, Accepted in Stochastic and Dynamics (will appear shortly).
3. Henk Bruin, I. Melbourne, Dalia Terhesiu, *Rates of mixing for nonMarkov infinite measure semi-flows*, arXiv:1607.08711. see also http://www.mat.univie.ac.at/∼bruin/papers/BMT.pdf
4. Péter Bálint, Fanni Sélley, *Mean field coupling of identical expanding circle maps*, to appear in Journal of Statistical Physics,
5. Péter Bálint, Thomas Gilbert, Péter Nándori, Imre Péter Tóth, Domokos Szász, *On the Limiting Markov Process of Energy Exchanges in a Rarely Interacting Ball-Piston Gas*, J. Stat. Phys, 166 (2017), no. 3-4, 903-925, arXiv:1510.06408.
6. Vaughn Climenhaga, Stefano Luzzatto, Yakov Pesin, *The geometric approach for constructing Sinai-Ruelle-Bowen measures*, J. Sat. Phys. 166 (2017), no. 3-4, 467-493. 37D25 (58), `http://www.ams.org/mathscinet/search/publications.htmlst`.
7. Vaughn Climenhaga, Yakov Pesin, *Building thermodynamics for non-uniformly hyperbolic maps*, `https://www.math.uh.edu/~climenha/doc/nuh-thermodynamics.pdf`.
8. Matthew Nicol, Andrew Török, Sandro Vaienti, *Central limit theorems for sequential and random intermittent dynamical systems*, arXiv:1510.03214.
9. Wael Bahsoun, Benoît Saussol, *Linear response in the intermittent family: differentiation in a weighted C^0-norm*, Discrete Contin. Dyn. Syst. 36 (2016), no. 12, 6657-6668, arXiv:1512.01080.
10. O. Butterley, K. War, *Open Sets of Exponentially Mixing Anosov Flows*, Preprint 2017, arXiv:1609.03512.
11. Ian Melbourne, Dalia Terhesiu, *Renewal theorems and mixing for non Markov flows with infinite measure.* Preprint January 2017. arXiv:1701.08440.
12. Henk Bruin, Mark F. Demers, Mike Todd, *Hitting and escaping statistics: mixing, targets and holes.* Preprint 2017, arXiv:1609.01196.

Invited scientists

Jon Aaronson, B. Kasun Fernando Akurugodage, Alexander Adam, Ana Anusic, Vitor Araújo, Wael Bahsoun, Viviane Baladi, Péter Bálint, Balázs Bárány, Kamel Belarif, Steven Berghout, Alex Blumenthal, Jozef Bobok, Michael Bromberg, Henk Bruin, Alexander Bufetov, Leonid Bunimovich, Keith Burns, Oliver Butterley Seth William Chart, Jernej Cinc, Vaughn Climenhaga, Jean-Pierre Conze, Mark Demers, Jacopo de Simoi, Carl Dettman, Neil Dobbs, Dmitry Dolgopyat, Rhiannon Dougall, Lázló Erdös, Peyman Eslami, Frédéric Faure, Bastien Fernandez, Gary Froyland, Thomas Gilbert, Sebastien Gouëzel, Luc Gossart, Gernot Greschonig, Alexander Grigo, Yves Guivarc'h, Olli Hella, Mark Holland, Godofredo Iommi, Michael Jakobson, Natalia Jurga, Charlene Kalle, Fernando Kasun, Anatole Katok, Svetlana Katok, Gerhard Keller, David Kelly, Thomas Kempton, Yuri Kifer, Konstantin Khanin, Alexey Korepanov, Zemer Kosloff, François Ledrappier, Marco Lenci, Carlangelo Liverani, Jens Marklof, Ian Melbourne, Vuksan Mijovic, Peter Nándori, Matthew Nicol, Roman Nikiforov, Stefano Olla, Zsolt Pajor-Gyulai, Françoise Pène, Tomas Persson, Yakov Pesin, Mark Pollicott, Omri Sarig, Benoît Saussol, Tanja Schindler, Klaus Schmidt, Julien Sedro, Fanni Sélley, Richard Sharp, Nándor Simányi, Karoly Simon, Mikko Stenlund, Domokos Szász, Dalia Terhesiu, Damien Thomine, Mike Todd, Dmitry Todorov, Bálint Tóth, Imre Péter Tóth, Andrew Török, Sascha Troscheit, Michael Tsiflakos, Masato Tsujii, Marta Tyran-Kaminska, Sandro Vaienti, Paulo Varandas, András Némedy Varga, Evgeny Verbitskiy, Polina Vytnova, Khadim Mbacke War, Benjamin Weiss, Maciej Wojtkowski, Meagan E Woodford, John Peter Wormell, Nasab Yassine, Lai-Sang Young, Agnieszka Zelerowicz, Jing Zhou, Roland Zweimüller.

Nonlinear Flows

Organizers: Eduard Feireisl (Czech Academy of Sciences and Charles U, Prague), Ansgar Jüngel (TU Vienna), Alexander Mielke (Weierstrass Institute and Humboldt U, Berlin), Giuseppe Savaré (U Pavia), Ulisse Stefanelli (U Vienna)

Dates: May 30 – July 15, 2016

Budget: ESI € 45 440,
FWF DK *Dissipation and Dispersion in Nonlinear PDEs* € 2 770,
Other grants (U. Stefanelli) € 1 950

Report on the programme

The thematic programme has brought together researchers from nonlinear functional analysis, calculus of variations, partial differential equations, geometric evolution, and stochastics around the common goal of investigating variational structures in nonlinear evolution systems.

The search, identification, and use of such structures has recently emerged as a mainstay in a variety of different and sometimes distant fields including evolutionary PDEs, modeling of mechanical and biological phenomena, fluid and transport dynamics, quantum and classical dynamics, stochastic behavior of many-particle systems, geometric evolution, Hamiltonian, dissipative and rate-independent flows, and evolution in metric spaces.

The thematic programme has contributed the right stage for bringing together ideas and methods between the different sides of the community. A number of trends clearly emerged. These include

- Gradient-flow analysis in discrete, quantum, and stochastic systems,
- Entropy methods for cross/reaction-diffusion systems and long-time asymptotics,
- Relation between geometry and dissipativity for evolution in abstract spaces,
- Dynamics of singularities, nonlocalities, and interfaces.

The outcomes of the thematic programme include a number of exciting new results, see the ones exemplified below.

Activities

The general philosophy of the Thematic Programme has been that of maximally fostering scientific collaborations by allowing plenty of time for discussions and communication. This has been realized by blocking all seminar activities in the mornings and leaving the afternoons free. Arranging such a schedule has not been always easy, especially during the two workshops. Still, the feedback from the participants on this point has been extremely positive.

The Thematic Programme included a range of different activities, which indeed started already in March 2016 and culminated across the seven weeks from 31.05.2016 to 15.07.2016.

In order to prepare students to fruitfully attend the Thematic Programme, two master courses and a proseminar have been organized in the Spring Semester 2016. Ulisse Stefanelli presented in the course *Topics in nonlinear evolution* (250060 VO) some reference material in functional analysis, partial differential equations, and gradient flows. This partially served as introduction to the master course on *Optimal transport methods for hamiltonian PDEs* (250120 VO) and the combined Proseminar (250121 PS) given by Yann Brenier, who has been *Senior Research Fellow* at the ESI during the Spring Semester. A group of master and PhD students of the Faculty of Mathematics took indeed all three courses.

The backbone of the programme have been the six minicourses by Eric Carlen, Eduard Feireisl, Luigi Ambrosio, Andrea Braides, Pierre Degond, and José Antonio Carrillo (chronological order). The purpose of these lecture series was that of allowing the audience to get a fresh, operative glance to exciting new fields. This has been realized by all lecturers by balancing new information with classical background and by explicitly taking the open issues to the forefront. This approach has both favored interaction between colleagues (very often lectures have been followed by extended, informal discussion session in the afternoons) and allowed students to pose questions and get involved. This part of the program has attracted the attention of the local community: a consistent number of nonregistered faculty members and students often attended specific minicourses.

The main events of the Thematic Programme have been the two workshops. These featured 33 and 17 talks each. The second workshop has qualified as *satellite event* to the 7th European Congress of Mathematics, Berlin 18-22.07.2016.

Eventually, a number of discussion groups have gathered in the afternoons. Most of these were completely informal and have been organized on the spot. As a matter of example we can mention the session by Filip Rindler explaining his recent groundbreaking result on so-called A-free measures. In addition to these, seminars by Karl-Theodor Sturm and Augusto Visintin have been officially organized and announced.

Outcomes and achievements

The Thematic Programme has hosted around 90 mathematicians from 13 countries in Europe, Japan, USA, Canada, and Saudi Arabia. It succeeded in fostering scientific exchange across different themes and allowed for the fruitful cross-fertilization of state-of-the-art techniques.

The feedback from the participants has been extremely positive. The opportunity of sharing ideas, learn, and discuss in such an informal environment has been much appreciated. A great number of new collaborations have been started, some of which already produced results. Here are some examples:

- Alexander Mielke and Ansgar Jüngel started working on gradient-flow structures of spin drift-diffusion systems. Jan Maas and Eric Carlen found the occasion to make decisive progresses on the understanding of gradient structures for Lindblad equations. A preprint on this issue is already online, see below.

- Dmitry Vorotnikov and Goro Akagi started a far-reaching investigation on gradient flows with respect to the Hellinger-Kantorovich metric. Together with Yann Brenier a new project on motion and stability of an overdamped inextensible string (via gradient flows) has also been initiated. Geodesic convexity of entropy functionals with respect to the Hellinger-Kantorovich distance is also the focus of a new collaboration between Giuseppe Savaré and Alexander Mielke.

- Florentine Fleißner and Giuseppe Savaré worked together on a celebrated conjecture by Ennio De Giorgi on minimizing movements (Conjecture 1.1, E. De Giorgi, *New problems on minimizing movements*, Boundary value problems for partial differential equations and applications, 81–98, RMA Res. Notes Appl. Math., 29, Masson, Paris, 1993).

- Tomáš Roubíček and Ulisse Stefanelli addressed a new model for the description of lithospheric faults under large deformations. This discussion was continued during a subsequent visit by Tomáš Roubíček in Vienna.

- Leonard Kreutz and Manuel Friedrich have also obtained new results on discrete-spin systems. The collaboration goes on and they plan to meet again in March 2017 in Vienna.

- One-dimensional carbon structures and crystal frustration are the subjects of a new collaboration between Ulisse Stefanelli and Giuliano Lazzaroni. Edoardo Mainini and Francesco Patacchini have proceeded in the understanding of the fine geometry of one-dimensional, finite discrete systems under long-range interactions.

- Bianca Stroffolini and Elisa Davoli have started a new collaboration on A-quasiconvexity, Young measures, and homogenization problems in Carnot groups. Such subriemannian structures are relevant to a variety of physical situations including Berry's phase problem, swimming micro-organisms, and perception modeling.

- Nonlocal parabolic equations have linked Maurizio Grasselli with Stefano Melchionna (in the case of Cahn-Hilliard equations) and Eduard Feireisl (hydrodynamic models and phase-field crystals).

- Philippe Laurençot started working on the flow generated by the coagulation-fragmentation equation for some specific choices of the kinetic coefficients to show the existence of self-similar solutions.

- Elisabetta Rocca and Stefano Melchionna have started studying sharp-interface limits in coupled Cahn-HilliardDarcy system modeling tumor growth. Some results are already submitted, see the preprint list.

Workshop 1 on *Entropy methods, dissipative systems, and applications* has been stimulating a project for a follow-up, specialized workshop co-organized by Jean Dolbeault, which will take place in 2018.

Contacts started during the Thematic Programme eventually turned into joint funding applications. Riccardo Scala and Francesco Bonaldi submitted proposal FWF-Lise-Meitner fellowships under the co-application of Ulisse Stefanelli.

Eventually, Tomáš Roubíček decided to apply for a *Senior Research Fellowship* at the ESI and will spend the Spring Semester 2017 in Vienna, teaching a course on *Mathematical Methods in Continuum Mechanics of Solids*. His research plan focuses on interactions with the Faculty of Mathematics and the Faculty of Earth Sciences, Geography and Astronomy.

List of talks

Lecture Series

Eric Carlen:

Functional inequalities and evolution equations. I - II

Abstract: Functional inequalities are an essential tool for understanding the behavior of solutions of PDE's and other sorts of evolution equations. At the same time, monotonicity along various evolution processes can often be used to prove functional inequalities. This course will focus on some recent examples in which this interplay between evolution processes and functional inequalities has been fruitful, and it will also introduce some open problems in the field. There will a special emphasis on stability results for sharp inequalities.

Eduard Feireisl:

Compressible fluid flows, new results and perspectives. I - III

Abstract: We discuss several new results concerning well/ill posedness questions in the context of compressible fluid flows. We identify a large class of problems describing the behavior of inviscid flows for which there exist infinitely many solutions or even infinitely many dissipative solutions satisfying the energy inequality. We relate these results to the theory of viscous fluids and identify certain problems in the inviscid theory as the vanishing viscosity limit. Finally, we discuss a proper choice of suitable admissibility criteria that would imply well-posedness of the problem.

Luigi Ambrosio:

Sobolev and BV functions in metric measure spaces. I - III

Abstract: In the lectures I will describe recent development of calculus in metric measure spaces, revisiting old and new points of view in the theory of Sobolev and BV functions. I will show how tools from Calculus of Variations, Optimal Transport and PDE allow to establish powerful equivalence results between ”Eulerian” and ”Lagrangian” notions, even in the broad context of metric measure spaces. I will mostly rely on papers written in collaboration with Simone Di Marino, Nicola Gigli and Giuseppe Savaré.

Andrea Braides:

Variational motion in heterogeneous media. I - III

Abstract: I will consider the problem of defining an effective variational motion for oscillating energies. The minimizing-movement scheme or implicit Euler scheme is a commonly used method to define gradient-flow type dynamics in a variational framework and can be adapted to this problem, obtaining effective motions that in general depend on the interaction between time and space scales. I will review general theorems that link those effective motions to that of the Gamma-limit of the oscillating energies. After a simple example in one dimension, I will concentrate on geometric motion of interfaces as gradient-flow type dynamics for (continuous and discrete) perimeter energies, highlighting different ways in which local minima of heterogeneous perimeter energies affect the corresponding effective motion.

Pierre Degond:

Fluid models for collective dynamics. I - II

Abstract: Collective dynamics appears ubiquitously in nature, from bird flocks to the swimming of sperm. Collective dynamics creates emergent patterns at a scale orders of magnitude larger than those of the individual agents. The deciphering of the mechanisms underpinning the emergence of these large scale structures requires the ability to coarse-grain the models from the particle scale to the population scale. In this series of lectures we will explore some of the mathematical difficulties that arise when trying to coarse-grain particle models of collective dynamics and that contribute to the forging of new mathematical tools in kinetic theory.

José Antonio Carrillo:

Minimizing interaction energies: nonlocal potentials and nonlinear diffusions. I - II

Frist Workshop: Entropy Methods, Dissipative Systems, and Applications,
June 13 – 17, 2016

Nassif Ghoussoub	Optimal Brownian martingale transports
Dejan Slepčev	Euler sprays and Wasserstein geometry of the space of shapes

Christian Kuehn	On the interface between analysis and numerics for pattern-forming reaction-diffusion systems
Klemens Fellner	On global existence and equilibration of a nonlinear reaction-diffusion system
Laurent Desvillettes	Convergence to equilibrium for complex balance reaction diffusion equations with boundary equilibria: an example
Agnieszka Świerczewska	Polymeric flows and transport equation with non-local terms
Giambattista Giacomin	Small noise and long time phase diffusion in stochastic limit cycle oscillators
Eric Carlen	Rates of relaxation to steady states for some hypocoercive kinetic equations
Daniel Matthes	Spatially discrete fourth order diffusion equations with the correct long-time asymptotics
Eduard Feireisl	Entropy methods in compressible fluid modelling
Piotr Gwiazda	Measure-valued solutions to compressible models of fluid mechanics
Sebastian Schwarzacher	Improved time-differentiability for incompressible p-fluids
Yann Brenier	From hyperbolic to parabolic systems through nonlinear time rescaling
Stephan Luckhaus	Problem: can one derive an elastic free energy from a Langevin dynamics for particles?
Jean Dolbeault	Entropy methods and nonlinear diffusions: functional inequalities on manifolds and on weighted Euclidean spaces
Irene Fonseca	Quantum dots and dislocations: dynamics of materials defects
Gilles Francfort	About plastic slips and uniqueness in small strain elasto-plasticity
Paolo Piovano	Wulff-shape emergence in graphene
Riccarda Rossi	On the WED approach to gradient flows in metric spaces
Jesus Sierra	An optimal transportation approach to the Bohmian kinetic equation
Dmitry Vorotnikov	Hellinger-Kantorovich gradient flows in spatial population dynamics
Juan Luis Vazquez	Entropy methods for nonlinear diffusion equations of porous medium type. Results and challenges
Edoardo Mainini	Gradient flow approach to fractional interaction equations
Christian Schmeiser	Hypocoercivity and dominating reaction limit for a reaction-kinetic model
Gianni Dal Maso	Existence and uniqueness of dynamic evolutions for a peeling test in dimension one
Giuliano Lazzaroni	A bridging mechanism in the homogenisation of brittle composites with soft inclusions
Manuel Friedrich	Korn inequalities for special functions of bounded deformation
Otmar Scherzer	Evolution by non-convex flows
Goro Akagi	Allen-Cahn type equation with strong irreversibility
Giulio Schimperna	On some singular variants of the Cahn-Hilliard model
Julian Fischer	Global existence and weak-strong uniqueness of renormalized solutions to entropy-dissipating reaction-diffusion systems
Georgy Kitavtsev	Asymptotic decay, rupture and entropy consistent methods for PDEs describing liquid jets and films
Tomáš Roubíček	Modelling of various phase transformations in ferroic solids, in particular magnetic shape-memory materials

Second Workshop: Variational and Hamiltonian Structures: Models and Methods, July 11 – 14, 2016

Marta Lewicka	From Monge-Ampere anomalies to shape formation
Jan Maas	Gradient flow structures for density matrices
Karl-Theodor Sturm	Gradient flows on time-dependent metric measure spaces and super-Ricci flows
Matthias Liero	Gradient structures for reaction-diffusion systems and optimal entropy-transport problems

Barbara Niethammer	Coarsening in a model with local interactions
Marco Morandotti	Relaxation of disarrangement densities
Tomáš Roubíček	Waves in solids involving inelastic processes and their efficient numerical approximation
Francesco Patacchini	Convergence of a particle method for diffusive gradient flows in one dimension
Antonio Segatti	Variational models for nematic shells
Elisa Davoli	Homogenization of integral energies under periodically oscillating differential constraints
Bianca Stroffolini	A tour of Lipschitz truncations
Edoardo Mainini	Stability of carbon nanotubes: a variational approach
Philippe Laurençot	Convergence to self-similarity for a thin film Muskat problem
Manuel Friedrich	The geometry of C_{60}
Michael Herrmann	Hysteresis and propagating lattice interfaces
Georgy Kitavtsev	Surface energies arising in microscopic modelling of martensitic transformations

Individual Talks

Karl-Theodor Sturm	Super-Ricci flows for metric-measure spaces
Augusto Visintin	Structural stability of quasilinear flows via evolutionary Γ-convergence

Publications and preprints contributed

G. Akagi, S. Melchionna, *A variational approach to non-potential perturbations of doubly nonlinear gradient flows of nonconvex energies*, preprint 2016.

G. Akagi, M. Efendiev, *Allen-Cahn equation with strong irreversibility*, preprint 2016.

G. Akagi, S. Melchionna, U. Stefanelli, *Weighted Energy-Dissipation approach to dou-bly-nonlinear problems on the half line*, J. Evol. Equ., 2017, to appear.

Eric A. Carlen, Jan Maas, *Gradient flow and entropy inequalities for quantum Markov semigroups with detailed balance*, arXiv:1609.01254.

L. Desvillettes, K. Fellner, B. Q. Tang, *Trend to equilibrium for reaction-diffusion systems arising from complex balanced chemical reaction networks*, SIAM J. on Mathematical Analysis, to appear.

K. Fellner, B. Q. Tang, *Explicit exponential convergence to equilibrium for nonlinear reaction-diffusion systems with detailed balance condition*' Nonlinear Analysis, to appear.

M. Friedrich, P. Piovano, U. Stefanelli, *The geometry of C_{60}: a rigorous approach via Molecular Mechanics*, SIAM J. Appl. Math. 76 (2016), 2009–2029.

D. Grandi, U. Stefanelli, *Existence and linearization for the Souza-Auricchio model at finite strains*, Submitted, 2016.

D. Grandi, U. Stefanelli, *Finite plasticity in $P^T P$. Part II: quasistatic evolution and linearization*, Submitted, 2016

E. Mainini, H. Murakawa, P. Piovano, U. Stefanelli, *Carbon-nanotube geometries as optimal configurations*, Submitted, 2016.

S. Melchionna, E. Rocca, *Varifold solutions of a sharp interface limit of a diffuse interface model for tumor growth*, arXiv:1610.04478.

L. Minotti, G. Savaré, *Viscous corrections of the Time Incremental Minimization Scheme and Visco-Energetic Solutions to Rate-Independent Evolution Problems*,
arXiv:1606.03359.

Invited scientists

Franz Achleitner, Goro Akagi, Luigi Ambrosio, Anton Arnold, Stefano Bianchini, Fran-cesco Bonaldi, Andrea Braides, Katharina Brazda, Eric Carlen, Jose Antonio Carrillo de la Plata, Maria C. Carvalho, Cecilia Cavaterra, Li Chen, Gianni Dal Maso, Esther Daus, Elisa Davoli, Pierre Degond, Laurent Desvillettes, Jean Dolbeault, Emanuele Dolera, Eduard Feireisl, Klemens Fellner, Julian Fischer, Florentine Fleiner, Irene Fonseca, Dominik Forkert, Gilles Francfort, Manuel Friedrich, Adriana Garroni, Nassif Ghoussoub, Giambattista Giacomin, Diego Grandi, Maurizio Grasselli, Piotr Gwiazda, Susanna Haziot, Michael Herrmann, Gaspard Janko-wiak, Ansgar Jüngel, Georgy Kitavtsev, Leonard Kreutz, Christian Kuehn, Giuliano Lazzaroni, Philippe Laurencot, Michel Ledoux, Marta Lewicka, Matthias Liero, Stefano Lisini, Stephan Luckhaus, Jan Maas, Edoardo Mainini, Peter Markowich, Daniel Matthes, David Melching, Stefano Melchionna, Gwenael Mercier, Martin Michalek, Alexander Mielke, Marco Morandotti, Lukas Neumann, Barbara Niethammer, Francesco Patacchini, Petr Pelech, Paolo Piovano, Dirk Praetorius, Ronald Quirchmayr, Vincenzo Recupero, Filip Rindler, Elisabetta Rocca, Riccarda Rossi, Tomas Roubíček, Michele Ruggeri, Giuseppe Savare, Otmar Scherzer, Giulio Schimperna, Christian Schmeiser, Sebastian Schwarzacher, Antonio Segatti, Jesus Sierra, Jakub Slavik, Dejan Slepcev, Ulisse Stefanelli, Bianca Stroffolini, Karl-Theodor Sturm, Agnieszka Swierczewska, Luis Manuel Tovar Sanchez, Juan Luis Vazquez, Augusto Visintin, Dmitry Vorotnikov, Marie-Therese Wolfram

Challenges and Concepts for Field Theory and Applications in the Era of LHC Run-2

Organizers: André H. Hoang (U Vienna), Frank Petriello (Northwestern U, Evanston), Iain W. Stewart (Massachusetts Institute of Technology, Cambridge)

Dates: July 18 – August 12, 2016

Budget: ESI € 34 240,
Faculty for Physics, University of Vienna: € 3 360

Report on the programme

The ESI programme *Challenges and Concepts for Field Theory and Applications in the Era of LHC Run-2* took place during the middle of the second phase of the Large Hadron Collider (LHC) experiment, which is characterized by a proton-proton center-of-mass energy of 13 TeV and a luminosity of $\mathcal{L} \sim 1 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$. The increased energy and luminosity with respect to Run-1, together with the detector and trigger upgrades carried out in the year 2014, lead to higher precision and an increased reach in searches for new physics. One example is the study of the properties of the Higgs boson, where measurements of its mass and signal strengths have already surpassed the Run-1 results with only a fraction of the data analyzed, and where new decay channels such as $t\bar{t}$+Higgs have become accessible. Another example is the study of the top quark, where the increased collision energy makes high-statistics analyses of boosted top-quark topologies possible, and also allows for more diverse measurements of its mass. On the other hand, recent hopes of a discovery of a new particle with a mass of around 750 GeV, which appeared in the low-statistics Run-1 data of the CMS and ATLAS collaborations in the di-photon channel, were shown to be due to statistical fluctuations. The lack of any direct evidence of new physics in the current analyses emphasizes strongly that higher precision for Standard

Model theoretical predictions are in high demand, particularly for the strong interaction effects dominant at the LHC due to the proton-proton initial state.

The theme of the programme was therefore well received by the particle physics phenomenology community, and a large fraction of the world experts in collider physics of the strong interactions were present in Vienna to attend the workshop. The programme successfully created a common framework where established senior researchers, postdocs and students from five key directions in precision collider physics came together to exchange new ideas, collaborate and foster further progress in the field. These key directions were:

- Jets with massive quarks;
- Mathematics and phenomenology of scattering amplitudes;
- Precision QCD in singular phase space regions;
- Multiple parton interactions and Monte Carlo event generators;
- Exploration of new frontiers with jet substructure.

All of these themes profited from the presence of experts in classic perturbative quantum chromodynamics (QCD) and resummation methods, as well as from leaders in the field of effective field theory, most notably Soft-Collinear-Effective Theory (SCET).

Activities and Organization

The programme was built around the five main subjects mentioned in the first section. More details on these topics and the related contributions and discussions that occurred during the programme are explained in more detail below. In the organization of the programme we also accounted for suggestions and ideas of participants to add to the richness and the success of the previous 2013 ESI programme "Jets and Quantum Fields for the LHC and Future Colliders" (organized by Prof. Hoang and Prof. Stewart), which was attended by many of the participants of this programme. As it was impossible to confine each issue to a single specific time span due to the relatively short duration of the program and the divergent time constraints of the senior participants, we provided all available information to the invited physicists on the programme web page at `http://www.univie.ac.at/esi-lhc/index.html` already at an early stage of the planning. This allowed the participants to better coordinate their stays to enable collaborations and overlaps between participants. As for the 2013 ESI jets programme, we gave leading experts which confirmed their participation the opportunity to nominate postdoctoral researchers and very promising PhD students to be invited to the workshop, either for collaboration, to present work themselves, or to allow them to create contacts to other senior participants. This asset of the program planning was highly appreciated and contributed a lot to a real working and productive atmosphere.

An important organizational goal of the programme was to avoid the formal and fast-paced environment of a conference or of a regular presentation workshop. Rather we intended to create - continuously for the whole time of the program - an inspiring and stimulating atmosphere with an emphasis on communication, discussion and sufficient time for brainstorming and actual work on either existing projects or new ideas. To achieve this there were two pre-planned scheduled presentations each week which took place on Tuesdays and Thursdays at 10:30 a.m. by leading scientists on a particular subject which were of high interest to the participants of that week. To allow for additional participant request, during each week additional talks were organized on Wednesdays at 10:30 a.m. on shorter notice. The talks were based on blackboard lecture-style presentations that allowed for on-the-spot discussions and interactions with the audience. Some of the presentations were shared among competing research groups to make the respective approaches and ideas as transparent as possible and to allow for discussion on debated issues. This format was very successful, and led to a number of very lively open discussions that continued later on the blackboards around the ESI site. On average each presentation session lasted for 2 to 2.5 hours. One other tool of communication for the programme was a wiki page linked to the programme webpage located at `https://wiki.univie.ac.at/display/esiLHC/Challenges+and+Concepts+for+Field+Theory+and+Applications+in+the+Era+of+LHC+Run-2` that allowed the participants to upload information, links and presentation notes freely for sharing them to the other participants.

Concerning financial support, the programme kindly received 15 man-months of per diems equivalent to EUR 36.000,00 through the Erwin-Schrödinger-Institute. Additional funds of EUR 3.360,00 were provided by the Faculty of Physics of the University of Vienna to cover the local expenses of PhD students attending the workshop. These were distributed among the (external) participants following the guideline of providing about 50% coverage of business days for permanently employed physicists (professors, staff, faculty), about 75% coverage of business days for postdoctoral researchers, and full coverage for PhD students. Overall, three undergraduate and eleven PhD students participated in the programme, which was almost double the number compared to the 2013 ESI jet programme. Professor Stewart also received support from the City of Vienna and University of Vienna as a Erwin Schrödinger Visiting Professor.

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

Specific Information on the programme

1. **"Jets with Massive Quarks":**

   Taking into account the effects of finite quark masses makes the theoretical description of jets is substantially more involved because the quark mass represents an additional physical scale that complicates the interplay of the hard, collinear and soft modes present for the jet dynamics for massless quarks. Thus, overall, the treatment of massive quarks for jet observables is currently in a much less developed stage and for many cases the correct and systematic resummation of large logarithmic terms and the proper factorization approach is not yet known.

   A particular important application is top quark physics where the mass of the top quark $m_t \approx 173$ GeV is so large that calculations in the massless approximation are not even approximately correct and new approaches have to be applied. Moreover, the description is further complicated by the fact that the lifetime of the top quark due to the weak interaction is so large that for many applications a factorized approach in the narrow width approximation where top production and decay are factorized fails. In perturbation theory at the parton level the current state-of-the-art allows for fully differential next-to-next-to-leading order QCD calculations for stable top quarks and the next-to-leading order QCD calculations for predictions where the top quark decay is fully accounted for.

Interestingly, these sophisticated calculations only have very little impact on the precision in the measurements of the top quark mass, which is an important input parameter for many other theoretical predictions, particularly involving the Higgs boson. This is because observables that are very sensitive to the value of the top quark mass have kinematic top mass dependence and are, since the top quark is a parton, very sensitive to additional non-perturbative effects. The systematic treatment of these non-perturbative effects is quite limited and restricted so aspects such as quark mass effects in parton distribution functions [1] and fragmentation functions [2]), which have, however, no impact on top quark mass measurements. During the program the issue of quark masses in jet observables was discussed quite intensively. Moritz Preisser gave a presentation on a new approach where the currently applied reconstruction methods for top quark mass measurements, which are based on Monte-Carlo simulations and thus have substantial theoretical error, which could not be quantified up to now, is calibrated with respect to a systematic hadron-level factorized prediction based on a SCET factorization theorem that allows for a full theoretical control over the non-perturbative effects [3, 4] in the reconstructed top invariant mass distribution. The calibration approach was demonstrated for e^+e^- collisions, and may allow for theoretical uncertainties in the top quark mass measurements for proper short-distance schemes at the level of a a few hundred MeV, if the method can be extended to the case of proton-proton collisions. A instructive discussion also took place concerning the question how precise the top quark pole mass, a specific perturbative quark mass definition, may be determinined in principle, motivated by the recent work from Martin Beneke [5]. The answer is related to studies of structures in the perturbative series at very high orders and can be studied using the mathematics for asymptotic and divergent series applied to the perturbation theory carried out in a non-Abelian quantum gauge field theory.

One article related to the top quark mass calibration method has appeared in [54] and has already been published as a Physical Review Letters. A second related article giving a detailed account of the MSR top mass scheme has also been recently completed [55].

Another article related to work carried out in this area has also appeared on factorization and massive quark effects for the transverse momentum and beam thrust spectrums in Drell-Yan [56], combining both NNLL resummed precision with NNLO fixed order boundary conditions.

2. **"Scattering Amplitudes: from Mathematics to Phenomenology":** This topic focused on the development of new ideas in the computation of scattering cross sections at higher orders in perturbation theory and their application to LHC phenomenology. The progress in the field of precision radiative corrections over the past decade has been breathtaking. What was once considered impossible has become commonplace. The calculation of next-to-leading order QCD cross sections for processes with numerous final-state particles is now a completely solved problem, and current theoretical developments indicate that a similar era may be entered soon for next-to-next-to-leading order calculations, with the development of powerful new subtraction schemes to handle infrared singularities for fully differential cross sections [6, 7, 8]. At the same time, the demands imposed upon precision theory by Run II of the LHC require continued progress at this same rapid rate. New communities of theorists have begun to answer the challenge posed by these demands, and several groups were represented at the workshop.

   During the workshop there was much discussion and progress on mathematical techniques for precision calculations. Leonardo Vernazza gave a talk on amplitudes in the high energy limit, discussing work he and others at the workshop were doing on the computation of three-loop large logarithms in the $s \gg t$ limit, where s and t are the Mandelstam variables for two-to-two scattering. This calculation exploits non-linear evolution equations and includes new effects present at next-to-next-to-leading logarithmic order, such as the mixing between states with a different number of Reggeized gluons. This work has appeared in preprint form in [59]. In addition two papers [57, 58] were produced on the algebraic and analytic structure of Feynman integrals. In the first the mathematical structure of cut Feymnan integrals in dimensional regularization were analyzed using multivariate residue calculus techniques. In the second a coaction map was defined on Feynman integrals that generalizes the known coaction on multiple polylogarithms, and admits a diagrammatic representation in terms of action on Feynman graphs.

Another area which generated a lot of discussion at the workshop was that of non-global logarithms. These logarithms arise from measurements that are simultaneously sensitive to multiple scales in different regions of the final state phase space. During the workshop we had talks by two competing groups, represented by Ian Moult and Ding Yu Shao, on the use of effective field theory methods for categorizing and summing such logarithms to all orders in perturbation theory. The two advocated different and complementary approaches to the problem, with Moult discussing the use of resolution variables to identify a convergent expansion for these effects, and Shao discussing an approach that characterizes the infinite tower of logarithms mathematically as an infinite operator mixing matrix with dominant effects near the diagonal. Work by Moult and co-authors that was partly carried out during the workshop has appeared in [60].

3. **"Precision Theory for Unraveling the Identity of the Higgs Boson":**

Run I of the LHC culminated with the discovery of the Higgs boson, ending the decades-long search for this particle. Although a hazy outline of this particle as a spin-zero boson with couplings roughly consistent at the 20-30% level with the Standard Model predictions has emerged [9, 10, 11, 12], the detailed investigation of the properties of the Higgs boson will be a major theme of the LHC Run II. These studies are becoming increasingly limited by our understanding of the Standard Model theory. Predictions for Higgs boson production rates at the LHC are famously sensitive to large quantum corrections [13, 14]. These uncertainties currently limit the achievable sensitivity to deviations from the Standard Model to the 15% level, while many motivated extensions of the Standard Model that address outstanding puzzles such as the nature of dark matter or the hierarchy problem predict deviations that are much smaller [15]. Current activities to address these limitations include efforts to compute the Higgs boson production cross section to the next-to-next-to-next-to-leading order [16, 17], one order beyond any other hadron-collider calculation ever attempted, and new applications of effective field theory to resum certain classes of large corrections that plague Higgs boson predictions in the presence of final-state phase space cuts [18, 19, 20]. This effort spans numerous subfields of particle theory, and the workshop brought together many experts to make progress in this area.

One example of an observable that plays a key role in calibrating Higgs cross sections for precision coupling measurements is the Higgs-p_T spectrum. At the workshop Hua-Xing Zhu gave a talk about his impressive recent calculation of the three-loop rapidity anomalous dimension [33] based on a new calculational friendly rapidity regulator [32]. He also presented first results from ongoing work being carried out with other participants on exploiting these results for a next-to-next-to-next-to-leading log resummed calculation of the Higgs-p_T spectrum. Another talk was presented by Pier Monni on carrying out the resummation directly in momentum space for this observable using numerical techniques. This has implications for properly assessing the residual theoretical uncertainty for missing higher order terms. On this topic, a preprint [61] was posted by another group of workshop participants developing analytic techniques for carrying out momentum space resummation using anomalous dimension equations in SCET.

Another example of developing new techniques for higher precision calculations are two papers on helicity operator bases that benefited from work done during the ESI workshop [62, 63]. This work pertains to power suppressed contributions to cross sections, which may start to become a limiting factor once higher order resummation has been achieved at leading power. In these two papers complete subleading power bases for hard scattering operators were constructed for first quark current processes, and then for production of a Higgs boson by gluon fusion. The authors used SCET helicity operators which exploit spinor-helicity ideas from the amplitude community to make this construction possible.

4. **"Precision QCD in Singular Regions":**

   With new mathematical advances in perturbative calculations of amplitudes, the identification and field theoretic separation of non-perturbative effects, the development of techniques to sum singular and dominant contributions from higher orders, many observables have become tools to test our understanding of QCD very accurately and to measure QCD parameters with very small uncertainties. Classic research fields where such "precision QCD" has been conducted are event-shape distributions in electron-positron annihilation [21, 22] or deep-inelastic scattering in electron-proton collisions [23]. Among the most important quantities measured from these processes are the strong coupling and the parton distribution functions [24, 25, 26], the momentum distribution of quarks and gluons inside the highly energetic colliding protons. With new recent developments also processes in proton-proton collisions at the LHC are turning into tools to study QCD at the precision level and to measure QCD quantities important to make predictions for other processes.

   In this part of the program continuing efforts concerning classic precision observables were combined with new emerging ones that become accessible to highly accurate predictions and measurements. Among the new directions are connections between p_T and invariant mass distributions, how physical properties of jets depend on different choices of the jet-axis (e.g. broadening axis vs. thrust axis [27]) or how varying jet-algorithms affect jet measurements beyond the next-to-leading order approximation [28, 29]. Further interesting fields of study are related to having simultaneous theoretical control of several different observable variables within multi-differential distributions, and Lisa Zeune gave a well received talk about her work in this area.

   Another research topic which the ESI workshop was very beneficial in advancing was the study of power corrections in the N-jettiness subtraction approach to higher-order calculations [30, 31]. This idea uses newly-developed understanding of the singular limits of event shapes in QCD to facilitate the precision next-to-next-to-leading order calculations required by numerous LHC analysis. The leading groups working in this direction were represented at this workshop and were able to collaborate very effectively within the pleasant environment of the ESI. This has led to two recent preprints that have been submitted for publication in refereed journals [65, 66].

5. **"Multiple Parton Interactions, Underlying Event, and Monte Carlo Generators":**

Most theoretical work on high-energy hadronic collisions focuses on the energetic radiation that tracks the underlying quarks and gluons and forms jets, however it is also experimentally established that for certain observables significant corrections occur from soft hadronic activity. Within a single proton-proton collision this softer radiation is often referred to as the "underlying event". The physics of the underlying event is not well studied theoretically since it is commonly believed to be outside the scope of traditional perturbative QCD calculations for the primary hard collision. Nevertheless, it produces significant contamination on many jet-based measurements, such as jet-p_T measurements and jet-mass distributions. This part of the workshop program focused on obtaining more precise and first principle description of these soft radiation effects by bringing together researchers working in three distinct fields. This included people working on multiple parton interactions (MPI), where a secondary hard partonic collision occurs in the same proton collision [34, 35], as well as Monte Carlo experts who have implemented MPI based models in computer programs, and which have been tuned to reproduce the soft radiation underlying event components in LHC data [36, 37, 38, 39, 40]. It also included those studying soft models of underlying event [41] and contributions that are outside the factorization framework, often referred to as factorization violating contributions [42, 43, 44]

During the workshop there were several talk and much discussion in this area. Jonathan Gaunt spoke about the role of Glauber interactions in factorization violation, and his work on proving factorization for processes with two hard interactions. Work he and others partially carried out at the workshop also has appeared in [64]. Iain Stewart presented a talk about his derivation of a complete Lagrangian description of factorization violating interactions [45]. This setup holds promise for enabling a rigorous description of underlying event type contributions in LHC collisions. Finally there were three talks on different aspects of Monte Carlo shower programs for LHC collisions. Simone Alioli talked about the Geneva program that has a higher precision perturbative treatment of the shower, and the key impact of simultaneously including a model for MPI effects (from the Pythia shower) to obtain agreement with experimental measurements of the observables like beam thrust that are sensitive to underlying event effects. Simon Platzer gave a general overview of recent parton shower developments, with a focus on the Herwig framework. Finally, David Soper discussed a theoretical modification needed for parton showers to properly carry out resummation of threshold logarithms.

6. **"Exploring New Frontiers with Jet Substructure":**

Jet substructure, the study of the dynamics and distribution of radiation inside a jet, is an important tool for characterizing the nature of hard collisions and the evolution of colored partons into hadrons. For example, when heavy particles such as W or Z bosons are produced with large energies at the LHC their hadronic decay products are collimated into a single fat jet. From the fat jet's substructure one can distinguish these boosted heavy objects from energetic light-quark or gluon jets. This part of the workshop program focused on novel techniques for carrying out calculations for jet substructure observables, as well as investigating proposals for observables with new and interesting properties [46, 47, 48, 49, 50, 51, 52, 53].

During the workshop there was a dedicated set of talks and discussion aimed at new methods that have been developed to sum logarithms of the jet radius in jet processes. Changing the radius directly modifies the allowed radiation inside a jet and also strongly impacts the relationship with other scales in theoretical calculation. Three different groups that had written recent papers on this topic gave back-to-back presentations, including Mrinal Dasgupta, Andrew Hornig, and Piotr Pietrulewicz. This allowed for a direct exchange of ideas and comparison of different approaches. It also enabled differences to be elucidated between the inclusive jet case with single logarithms and the exclusive jet case with double logarithms.

A collaboration was initiated at the workshop by Neill, Scimemi, and Waalewijn on the role of jet axes for transverse momentum dependent jet fragmentation, resulting in the paper [67]. They showed that by using a different definition of the jet axes, referred to as the broadening axes, that a simpler framework emerges for studying the transverse momentum spectrum of hadrons in jets. In contrast to the traditional framework this approach does not have rapidity divergences, and it also remains universal for processes with a different number of measured jets.

Finally, in the paper [68] participant Yang-Ting Chien and co-author Ivan Vitev presented a calculation of the momentum sharing and angular separation for subjets reconstructed in heavy ion collisions. Jet substructure techniques hold much promise for studying jets propagating through the medium created in heavy ion collisions, and this work further broadened the range of topics discussed at the workshop.

Outcomes and achievements

At the time of writing of this report 15 preprints [54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68] have been generated which are intended for publication in regular scientific journals, and 3 of these have already been officially published [54, 60, 61]. They either acknowledge partial support of the Erwin-Schrödinger-Institute or were actually prepared and written during the ESI workshop. The number of preprints and publications related to the ESI workshop “Jets and Quantum Fields for LHC and Future Colliders” will increase further since work that we are aware of that is related to the ESI program has not yet appeared publically in preprint form. There have been many new collaborations formed directly related to the ESI workshop.

List of talks

Week 1: July 19 – 21, 2016

Jonathan Gaunt	Glauber, Underlying Event and Factorization
Simone Aioli	Underlying Event & Monte Carlo Generators
Andrea Banfi	2 Jet Rate at NNLL Using ARES Resummation
Lisa Zeune	Multi-Differential Cross Sections with Resummation
Moritz Preisser	Monte Carlo Top Quark Mass Calibration

Week 2: July 25 – 28, 2016

Iain Stewart	Operator Formalism For Glauber Exchange
Mrinal Dasgupta	Jet Radius Resummation I
Andrew Hornig	Jet Radius Resummation II
Piotr Pietrulewicz	Jet Radius Resummation III
HuaXing Zhu	P_T Resummation

Week 3: August 2 – 4, 2016

Simon Plätzer	Developments for Parton Shower
Ulrich Schubert	Multi-Loop Virtual Corrections
David Soper	Summation of Threshold Logarithms in Parton Showers
Ian Moult	Non-Global Logarithms I
Ding Yu Shao	Non-Global Logarithms II

Week 4: August 9 – 11, 2016

Pier Monni	Transverse momentum Resummation in Direct Space
Leonardo Vernazza	Amplitudes in the High Energy Limit

Invited scientists

Simone Alioli, Andrea Banfi, Christian Bauer, Thomas Becher, Martin Beneke, Radja Boughezal, Amyas Chew, Yang-Ting Chien, Mrinal Dasgupta, Bahman Dehnadi, Markus Diehl, Claude Duhr, Markus Ebert, Einan Gardi, Jonathan Gaunt, Marco Guzzi, André H. Hoang, Andrew Hornig, Andrea Isgro, Ambar Jain, Elizabeth Jenkins, Daekyoung Kang, Tomas Kasemets, Christopher Lee, Daniel Lechner, Christopher Lepenik, Zoltan Ligeti, Aneesh Manohar, Gautam Sonny Mantry, Vicent Mateu, Thomas Mehen, Bernhard Mistlberger, Pier Monni, Ian Moult, Duff Austin Neill, Aditya Pathak, Ben Pecjak, Frank Petriello, Piotr Pietrulewicz, Simon Plätzer, Moritz Preisser, Massimiliano Procura, Thomas Rauh, Anton Rebhan, Lorena Rothen, Daniel Samitz, Ignazio Scimemi, Ulrich Schubert-Mielnik, Lais Sarem Schunk, Ding Yu Shao, Dave Soper, Gregory Soyez, Maximilian Stahlhofen, George Sterman, Iain Stewart, Frank Tackmann, Kerstin Tackmann, Leonardo Vernazza, Gherardo Vita, Alexey Vladimirov, Wouter Waalewijn, Angelika Widl, Hua Xing Zhu, Lisa Zeune

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Synergies between Mathematical and Computational Approaches to Quantum Many-Body Physics

Organizers: Ali Alavi (U Cambridge & MPI Solid State Research, Stuttgart), Sabine Andergassen (U Tübingen), Manfred Salmhofer (U Heidelberg), Alessandro Toschi (TU Vienna, local organizer)

Dates: August 29 – October 21, 2016

Budget: ESI € 20 720

Report on the programme

The traditional goal of mathematical physics is to prove mathematically rigorous statements about physically interesting models. Ingredients in a proof of a mathematical statement may also be useful beyond the specific situation of that proof if they elucidate mathematical structures or reveal properties that must be obeyed by the solution to the problem, hence can serve to benchmark and improve approximate approaches. Ideally (and sometimes really), methods of constructing solutions mathematically also suggest algorithms which can then be applied in practice. Conversely, the development of algorithms and computational methods has provided many interesting problems and ideas for mathematical studies.

Many-body theory, and especially quantum many-body theory, is a crucial ingredient in our understanding of complex physical systems. While enormous progress has been made over the last few decades, theorists still face great challenges in attempting to predict physical properties in and away from equilibrium. Traditional approaches like wave-function-based variational methods, density functional theory, perturbative and resummation-based quantum field theory, and conserving approximations based on Luttinger-Ward functionals, have in recent years been extended and complemented by new approaches, such as quantum Monte Carlo (QMC), dynamical mean field theory (DMFT), functional Renormalization Group (fRG), and tensor network states. Each of these methods has its strengths and weaknesses, so their comparison in specific model systems, and an assessment of their mathematical standing, is essential for progress. Some methods have also been combined recently.

The ESI programme *Synergies between Mathematical and Computational Approaches to Quantum Many-Body Physics* contributed to advancing the state of matters in this respect, focusing on techniques of quantum field theory and quantum many-body theory in its applications to fundamental aspects of materials science and cold quantum gases.

Activities

The programme was initially planned for a period of two months, September/October 2016. Due to an unusual accumulation of high-level workshops at several research centers in the world (among them Aachen, Frascati, Oberwolfach) in September, 2016, the main activities of the ESI programme were started in mid-September. The structure of the program was to hold a school first, in order to allow young researchers to get an exposition of important current techniques in the field, and then a workshop, in which state-of-the-art results were presented. At the beginning of the programme, we also included the Young Researches Meeting of the Vienna-based Special Research Area on Computational Materials Science *Vicom* ("Spezialforschungsbereich F41" funded by the Austrian Science Fund (FWF)), which was co-organized by Florian Libisch (TU Vienna). While the bulk of attendance was centered around the weeks of the school and the workshop, a number of key participants stayed for longer periods of time, for individual exchange and collaboration.

Specific information on the programme

The School

The school took place from September 26 to 30, 2016, providing an introductory overview and the comparison mentioned above: Lectures on Quantum Monte Carlo techniques were presented by *Ali Alavi* (Full Configuration-Interaction QMC), *Lode Pollet* (Diagrammatic Monte Carlo, in particular in application to the Fermi polaron), and *Fakher Assaad* (fermionic QMC). Dynamical mean-field theory was exposed together with its extensions in lectures by *Karsten Held* (Dynamical mean-field theory), *Emanuel Gull* (Dynamical Cluster Approximation), and *Philip Werner* (Extended DMFT for screened local and for Coulomb interactions). Resummation methods were presented by *Georg Kresse*. Lectures on the functional renormalization group were given by *Walter Metzner* (Functional RG approach to interacting fermion systems), *Carsten Honerkamp* (Applications of fRG to two-dimensional systems) and *Nils Wentzell* (High-frequency asymptotics of the vertex function). *Roman Orus* gave an introductory lecture on tensor networks states and methods.

The Workshop

The workshop took place from October 3 to 7, 2016, with presentations allowing to compare and discuss mathematical proofs and applied work.

Christoph Kopper discussed a proof of convergence of the gradient expansion for the effective action and the operator product expansion of scalar quantum field theory to all orders in perturbation theory. This result is relevant for applications because gradient expansions have been widely used in functional RG methods, to formulate the effective action. Moreover, the proof really uses the flow equations of the functional RG, albeit in the Polchinski form, i.e. for the amputated connected Green functions, not the irreducible vertex functions mostly used in numerical studies (this is no loss of generality as they are related by a Legendre transform).

Christian Lubich discussed the mathematical theory of dynamical low-rank approximations for evolution equations, a topic closely related (and partly based on) mathematical tensor decomposition developed by W. Hackbusch and collaborators and applied to many-body Schrödinger equations, as well as to the tensor network methods used in mathematical and theoretical physics. The latter were also the topic of *Jens Eisert*'s talk, which also touched aspects of complexity theory, and the question whether the area law for the entanglement entropy is expected to hold in gapless quantum systems. The entanglement entropy and the Ryu-Takayanagi conjecture were also subject of *Stefan Kehrein*'s talk. He described his approach for simple (non-interacting) systems based on Wegner's flow equations for Hamiltonians. *Maurits Haverkort* spoke about entanglement in quantum materials and efficient numerical methods for its study.

Edwin Langmann presented mathematical results about transport in a quenched Luttinger model obtained by bosonization techniques. On the physics side, *Jan van Delft* spoke about nonequilibrium steady-state transport through quantum impurity models, which he calculated using a combination of numerical renormalization group and density-matrix RG. *Jonas Lampart* reported on mathematical results that (under restrictive conditions) justify time-dependent density functional theory. *Laszlo Erdös* presented mathematical results on the matrix Dyson equation in random matrix theory.

Variational methods were discussed in a number of mathematical talks: *Ulisse Stefanelli* showed results on crystalline properties of systems made of carbon, *Jakob Yngvason* presented new results about the incompressibility of quantum fluids, *Mathieu Lewin* spoke about the Lieb-Oxford bounds, in particular the question of optimal constants, relevant for rigorous Thomas-Fermi theory, and *Robert Seiringer* presented a mathematical proof of stability of a fermionic many-particle system with contact interactions, a prototypical system used in the physics of cold atomic gases, in particular in the description of the Fermi polaron. Besides the solution to this question, this result also provides a rigorous justification of the Tan relations, which provide the exact large-momentum asymptotics of observables in such a gas.

On the physics side, *Tilman Enss* presented results about the Fermi polaron obtained by T-matrix resummation and functional RG techniques, which provide detailed information about its dynamics which are consistent with results from diagrammatic Monte Carlo, and explain current experimental results quantitatively, as well as an approach to ferromagnetism in imbalanced Fermi systems. *Jean-Bernard Bru* presented a generalization of determinant bounds based on noncommutative Hölder estimates, which extend the range of rigorous proofs of convergence for expansions of the effective action for fermionic systems, an essential tool in showing that functional RG can be done rigorously by convergent expansion methods. *Andreas Eberlein* discussed a nematic quantum phase transition in two-dimensional systems, and *Pawel Jakubczyk* presented results about the Berezinskii-Kosterliz-Thouless approach. In this case there is a question whether amplitude fluctuations are correctly captured in a certain truncation of the functional RG hierarchy of equations. *Giulio Schober* presented results about interaction effects in the Rashba model, a prototypical model for spin-orbit coupling and the resulting topological excitations in the superconducting state.

The relation of DMFT and Luttinger-Ward techniques was discussed in the talks of *Alessandro Toschi, Michael Potthoff*, and *Giorgio Sangiovanni*; this concerned, on the one hand, specific tests whether certain conserving approximations are also useful in specific systems, on the other, the properties of self-energy functional theory, which has also been used in combination with DMFT.

List of young researchers

Poster presentations by

Cornelia Hille (U Tübingen)	Construction and comparison of effective low-energy interactions for different three-orbital cuprate models
Johannes Hofmann (U Würzburg)	Edge instabilities of topological superconductors
Agnese Tagliavini (U Tübingen)	High-frequency asymptotics of the vertex function: diagrammatic parametrization and algorithmic implementation
Demetrio Vilardi (MPI-FKF - Stuttgart)	DMF^{2}RG: Beyond dynamical mean field theory with the functional renormalization group

Young researchers who participated without contributing a poster:

Martin Braß (U Heidelberg)
Patrick Chalupa (TU Vienna)
M. Drescher (U Heidelberg)
Patrik Gunaker (TU Vienna)
Benedikt Hartl (TU Vienna)
Josef Kaufmann (TU Vienna)
Petra Pudleiner (TU Vienna)
Daniel Springer (TU Vienna)
Clemens Watzenböck (TU Vienna)

Informal exchange and collaboration

Several participants of the workshop did not speak at the workshop (among them Volker Bach, Horst Knörrer and André-Marie Tremblay) but contributed crucially to informal discussions about ongoing projects, such as quantum dynamics of many-body systems, and how to treat strong correlations in many-body systems.

Outcomes and achievements

List of discussions and projects pursued at the programme:

Andreas Eberlein, Alessandro Toschi: *Quantum critical properties of 2D frustrated magnets*
Andreas Eberlein, N. Barisic: *Electronic scattering properties in cuprates*
Tilman Enss, Andreas Eberlein: *diffusive transport*
Tilman Enss, Pawel Jakubczyk, Horst Knörrer: *BKT-physics in the O(2)-Model*
Tilman Enss, Lode Pollet: *Fermi-Polarons and Bold Diagrammatic Monte Carlo*
Horst Knörrer, Manfred Salmhofer: *Self-energies in many-fermion systems at real time*
Walter Metzner, Demetrio Vilardi, Alessandro Toschi: *DMF^{2}RG applied to the 2D Hubbard model in the strong coupling limit*
Pawel Jakubczyk, Alessandro Toschi: *Limit of the Kosterlitz-Thouless theory in 2D systems*
Micheal Potthoff, Alessandro Toschi, Giorgio Sangiovanni: *Multivaluedness of the Luttinger-Ward func-*

tional representation
Giorgio Sangiovanni, Daniel Springer, Alessandro Toschi: *Calculation of spin-spin correlation functions in realistic systems*
Andre-Marie Tremblay, Giorgio Sangiovanni, Alessandro Toschi, T. Schäfer: *Two-particle self-consistency of strong-coupling theories*
Jan von Delft, Alessandro Toschi, Andreas Eberlein: *Asymptotic structures of the vertex function in relation to the parquet equations*

The school and workshop were successful in that they provided exactly the kind of mutual instruction and exchange that is needed for progress in this field. The workshop has furthered the collaboration on combining methods, such as the combination of DMFT and functional RG, as well as the discussion among people pursuing mathematical and computational approaches (e.g. in the context of the long-standing fermionic sign problem of quantum Monte Carlo approaches, where the comparison with proof techniques for convergent expansions has suggested new approaches to this problem).

This ESI programme was appreciated by participants as giving rise to new ideas for improving and extending both mathematical and computational techniques in quantum many-body theory. We expect it to have a lasting impact on the field.

List of talks

Young Researchers Meeting of the SFB Vicom: September 22 – 23, 2016

Stefaan Cottenier	Everything you need to remember about density-functional theory and its reliability (Video)
Menno Bokdam	Role of Polar Phonons in the Photo-Excited State of Metal Halide Perovskites
M. Bichler	DFT Study of the (012) Surface of Hematite
B. Kim	Electronic structure and magnetic properties of Sr3Ir2O7
Christiane de Morais-Smith	Graphene: the good, the bad, the nano & the pseudo
J. Hofmann	Systematic tests of down folding schemes
Agnese Tagliavini	High-frequency asymptotics of the vertex function
Chris Wolverton	The Open Quantum Materials Database
Tobias Schäfer	Quartic scaling MP2 for solids: A step towards vertex corrections
Stefan Donsa	Anderson localization of a one-dimensional Bose-Einstein condensate after long-time expansion
K. Prikopa	GW Bandgap database
Daniela Kraft	Self-Assembly in Soft Matter Systems
Qin Lin	Study of nucleation kinetics in the Fe-Cu system with Forward Flux Sampling
C. Karner	Phases of two-dimensional patchy rhombi
Emanuele Locatelli	Single-File Escape of Colloidal Particles from Microfluidic Channels

School: September 26 – 30, 2016

Ali Alavi	Full Configuration Interaction Quantum Monte Carlo
Ali Alavi	Applications of FCIQMC to strongly correlated ab initio systems: from the Cr2 molecule to cuprates
Karsten Held	Dynamical mean field theory
Karsten Held	Dynamical vertex approximation
Walter Metzner	Functional renormalization group approach to interacting fermion systems I
Walter Metzner	Functional renormalization group approach to interacting fermion systems II
Carsten Honerkamp	Functional RG for (some) two-dimensional materials

Nils Wentzell	High-frequency asymptotics of the vertex function: diagrammatic parametrization and algorithmic implementation
Emanuel Gull	Introduction to DCA I
Emanuel Gull	Introduction to DCA II
Philipp Werner	DMFT for models with dynamically screened local interactions
Philipp Werner	Extended DMFT for models with long-range Coulomb interactions
Georg Kresse	Approximate methods for the correlation energy: the basics
Georg Kresse	Approximate methods for the correlation energy: the random phase approximation and improvements
Lode Pollet	An introduction to diagrammatic Monte Carlo: polaron systems and beyond I
Lode Pollet	An introduction to diagrammatic Monte Carlo: polaron systems and beyond II
Fakher Assaad	Recent progress in fermion Monte Carlo: deconfined phases and phase transitions
Roman Orus	Introduction to Tensor Network states and methods

Workshop: October 3 – 7, 2016

Christoph Kopper	Bounds and Convergence statements deduced from Flow Equations
Christian Lubich	Dynamical low-rank approximation
Tilman Enss	Fermi polarons and the ferromagnetic instability
Giulio Schober	Functional renormalization and mean-field approach to multiband systems with spin-orbit coupling: Application to the Rashba model with attractive interaction
Stefan Kehrein	Flow Equation Holography
Edwin Langmann	Non-equilibrium physics and transport in a quenched Luttinger liquid
Laszlo Erdös	The matrix Dyson equation in random matrix theory
Jonas Lampart	Can quantum dynamics be described by the density only?
Andreas Grüneis	Reducing finite size errors in correlated many-electron theory calculations of solids
George Booth	Sampling wavefunctions in the thermodynamic limit
Robert Seiringer	Decay of correlations and absence of superfluidity in the disordered Tonks-Girardeau gas
Jakob Yngvason	2D electrostatics and incompressibility of quantum fluids
Andreas Eberlein	Transport at the Ising-nematic quantum critical point in two-dimensional metals
Pawel Jakubczyk	Amplitude Fluctuations in the Berezinskii-Kosterlitz-Thouless phase
Ulisse Stefanelli	Stable carbon configurations
Mathieu Lewin	Lieb-Oxford inequality, Jellium and the Uniform Electron Gas
Jean-Bernard Bru	Universal Bounds for Large Determinants from Non-Commutative Hölder Inequalities in Fermionic Constructive Quantum Field Theory
Jens Eisert	Tensor network states as tools for mathematical and computational approaches to quantum many-body physics
Jan von Delft	Nonequilibrium steady-state transport through quantum impurity models - a hybrid NRG-DMRG treatment
Frithjof Anders	A chemically driven quantum phase transition in a two-molecule Kondo system: Combining density functional theory with the numerical renormalization group
Alessandro Toschi	Quantum field theory at the two-particle level: Challenges and perspectives
Micheal Potthoff	Nonequilibrium self-energy-functional theory
Giorgio Sangiovanni	Breakdown of dressed perturbation theory and divergencies of the irreducible vertex in many-electron systems
Jan Tomczak	Space-time separation of electronic correlations
Maurits Haverkort	The importance of electronic entanglement and multiplets in the dynamics of quantum materials and an efficient method to study them

Publications and preprints contributed

There will be publications whose first ideas were discussed or developed during the school and the workshop. A preliminary list includes the following preprints and manuscripts in preparation:

N. Wentzell, G. Li, A. Tagliavini, C. Taranto, G. Rohringer, K. Held, A. Toschi, S. Andergassen, *High-frequency asymptotics of the vertex function: diagrammatic parametrization and algorithmic implementation*, arXiv:1610.06520.

T. Schäfer, A. Toschi, and A. Eberlein, *Magnetic fluctuations in the cuprates; role of frustration.*

C. Watzenböck, M. Edelmann, D. Springer, G. Sangiovanni, A. Toschi, *Magnetic dynamics in the different families of iron pnictides and chalcogenides.*

C. Hille X. Cao, C. Honerkamp, P. Hansmann, S. Andergassen, *Multi-orbital correlation effects in the Emery model.*

Fabian B. Kugler, Jan von Delft, *Multiloop functional renormalization group that sums up all parquet diagrams,* arXiv:1703.06505.

Invited scientists

Stefan Adams, Ali Alavi, Frithjof Anders, Fakher Assaad, Volker Bach, George Booth, Martin Bra, Jean-Bernard Bru, Patrick Chalupa, Andreas Deuchert, Andreas Eberlein, Jens Eisert, Tilman Enss, Laszlo Erdös, Harald Grosse, Andreas Grneis, Emanuel Gull, Patrik Gunacker, Benedikt Hartl, Maurits Haverkort, Karsten Held, Cornelia Hille, Johannes Hofmann, Carsten Honerkamp, Pawel Jakubczyk, Anna Kauch, Josef Kaufmann, Stefan Kehrein, Horst Knörrer, Christoph Kopper, Georg Kresse, Dai Kubota, Jonas Lampart, Edwin Langmann, Mathieu Lewin, Christian Lubich, Simon Mayer, Walter Metzner, Thomas Moser, Roman Orus, Lode Pollet, Michael Potthoff, Petra Pudleiner, Manfred Salmhofer, Giorgio Sangiovanni, Giulio Schober, Robert Seiringer, Daniel Springer, Ulisse Stefanelli, Agnese Tagliavini, Jan Tomczak, Alessandro Toschi, Andre-Marie Tremblay, Kambis Veschgini, Demetrio Vilardi, Jan von Delft, Clemens Watzenböck, Philipp Werner, Christof Wetterich, Jakob Yngvason

Workshops organized independently of the Main Programmes

Normal Numbers: Arithmetic, Computational and Probabilistic Aspects

Organizers: Christoph Aistleitner (TU Graz), Yann Bugeaud (U Strasbourg), Theodore Slaman (UC, Berkeley), Robert Tichy (TU Graz)

Dates: November 14 – 18, 2016

Budget: ESI € 13 200

Report on the workshop

In this workshop we discussed recent developments in the area of normal numbers, with a particular focus on questions regarding the construction and efficient computation of such numbers. The concept of normal numbers goes back to Émile Borel (1909) who called a real number x a *normal number* in base b if all possible digits in the expansion of x with respect to the base b occur with asymptotic frequency $1/b$, if all possible digits in the expansion with respect to the base b^2 occur with asymptotic frequency $1/b^2$, digits in base b^3 with frequency $1/b^3$, and so on. This is known to be equivalent to the fact that the sequence $(xb^n)_{n\geq 1}$ is uniformly distributed modulo 1, and thus the discrepancy of this sequence can be used as a quantitative measure of normality. A real number x is called *absolutely normal* if it is normal with respect to all possible bases $b = 2,3,4,5,\ldots$. Borel showed that almost all numbers x are absolutely normal with respect to the Lebesgue measure; however, it is very difficult to give a construction of such a number. A first approach in this direction is due to W. Sierpiński (1917) without giving a "formal" algorithm for producing absolutely normal numbers. Later, A. Turing (1935) did provide an algorithm to solve the problem. Its flaw, as Turing pointed out, was that it was too slow to implement in practice; we now would say that it is doubly-exponential. In the 1960's, W.M. Schmidt provided a significant advancement by giving a general algorithmic method to exhibit real numbers normal to some bases and not normal to others. In particular, he gave a different algorithm to compute a real number which is absolutely normal, but not one which was faster. It took until the 21-st century to obtain a polynomial time algorithm for constructing absolutely normal numbers.

In our workshop several of the leading scientists in this field of mathematics, together with experts from related mathematical fields, came together to present and discuss recent results in this area, and to formulate new challenging problems for the future. The participants of the workshop represented many different mathematical disciplines, including number theory, mathematical logic, Fourier analysis, Diophantine approximation, complexity theory, the theory of finite automata, ergodic theory, uniform distribution theory and discrepancy theory, and the theory of systems of numeration. Thus the program of the workshop was very comprehensive, and we are convinced that all the participants found it interesting. Many of the participants expressed their impression that it was a particularly enjoyable and informative workshop.

Activities

The workshop schedule consisted of 3 introductory talks, 18 regular research talks and a mini-talk session for young participants. The introductory talks were scheduled at the beginning of the workshop, and were intended as a common reference point for the remaining time of the workshop, and as an introduction to the field for the young scientists. Several participants told us that they found these introductory talks to be very useful, in particular, in view of the fact that scientists from many different areas of mathematics were present at the workshop. The mini-talk session also was a success, with several young scientists using the informal setting of this session as a possibility to present themselves and their research interests to the scientific community.

Specific information on the workshop

Several PhD students and young Post-Docs were present at the workshop. Due to time restrictions most of them (with some exceptions) did not have the possibility of giving a full research talk, but, as mentioned above, each of them had the possibility to introduce herself/himself in the mini-talk session. Also, some of the young participants of the workshop came from other mathematical areas and have not worked on normal numbers so far; these young scientist had the opportunity to get to know a new branch of mathematics, and probably some of them will contribute to the field in the future. Several of these young researchers mentioned that they found the introductory talks very helpful, since otherwise as non-experts in the field they might have been lost in the research talks from the very beginning of the workshop.

Outcomes and achievements

We made an effort to compile a workshop schedule which was not too tight and which gave the participants the opportunity for exchange, discussions and collaboration. The atmosphere during the workshop was very positive, and during the breaks it was a common sight to find two or more researchers (who often had not met each other in person before) discussing a topic on one of the blackboards. We are convinced that the workshop initiated new collaboration among some of the participants; for example this is the case for the group from Argentina (around Veronica Becher) and the group in Graz (around Robert Tichy), whose members had not met each other personally before. Verónica Becher spent a whole month at the ESI and visited the TU Graz twice during that period for joint collaboration with Robert Tichy and Adrian Scheerer. Of course it is too early now to decide on the long-lasting impact of our workshop, but we are convinced that several mathematical papers were initiated during the workshop, and that the foundation stone for several fruitful collaborations was laid during this workshop.

Nicolás Alvarez (Universidad del Sur, Argentina), Verónica Becher (Universidad de Buenos Aires) and Olivier Carton (Université Paris-Diderot) worked on their joint paper "Finite-state independence and normal sequence". They consider the previously defined notion of finite-state independence and focus specifically on normal words. They characterise finite-state independence of normal words in three different ways, using three different kinds of finite automata running on infinite words (Büchi automata): finite automata with two input tapes, shufflers and selectors. They give an algorithm to construct a pair of finite-state independent normal words. Unfortunately the algorithm has doubly exponential computational complexity.

Verónica Becher (Universidad de Buenos Aires) and Adrian-Maria Scheerer (TU Graz) worked together on "An algorithm to compute an absolutely normal number with the expected discrepancy". They give an algorithm to construct an absolutely normal number x such that for every integer base b greater than or equal to 2, the discrepancy of the sequence $\{b^k x\}_{k\geq 0}$ coincides with the discrepancy associated to almost all real numbers. This algorithm improves substantially the work done by Mordechay Levin in 1979.

List of talks

Christoph Aistleitner	**Introductory talk 1:** Connections in normal number theory
Verónica Becher	**Introductory talk 2:** Constructions of normal numbers and their computation
David H. Bailey	On the normality of Stoneham numbers, π and $\log(2)$
Manfred Madritsch	Construction of numbers which are normal with respect to a shift-invariant measure
Jean-Marie De Koninck & Imre Katai	New approaches in the construction of normal numbers
Yann Bugeaud	**Introductory talk 3:** Normal numbers: recent results and open problems

Theodore Slaman	Normality in Different Integer Bases
Dong Han Kim	A new complexity function of repetition and irrationality exponents
Tomas Persson	Fourier dimension and equidistribution
Jan Reimann	Irrationality Exponent, Hausdorff Dimension and Effectivization
Olivier Carton	Finite state machines and normality
Joel Rivat	The Thue-Morse sequence along squares is normal
Joseph Vandehey	Skew-products, automata, and normality
Teturo Kamae	Between normal numbers and random numbers
Ai-Hua Fan	Martingale method in the study of the almost convergence of ergodic series
El Houcein El Abdalaoui	On the Erdös flat polynomials problem
Mario Neumüller	Metrical star discrepancy bounds for subsequences of digital Kronecker-sequences
Anne Bertrand-Mathis	Normal Numbers : what we know about Pisot bases and dynamical systems
Elvira Mayordomo & Jack Lutz	Efficient Computation of Absolutely Normal Numbers
Hajime Kaneko	Algebraic independence of real numbers related to beta expansion and beta representation
Adrian Scheerer	(Absolute) Normality for continued fractions and beta expansions
Bill Mance	Normality of different orders for the Cantor series expansions

Invited scientists

Christoph Aistleitner, Nicolas Alvarez, Michael Baake, David Bailey, Verónica Becher, Anne Bertrand-Mathis, Yann Bugeaud, Olivier Carton, Michael Coons, Michael Drmota, Arnaud Durand, El Houcein El Abdalaoui, Ai-Hua Fan, Peter Grabner, Sigrid Grepstad, Teturo Kamae, Hajime Kaneko, Imre Kátai, Dong Han Kim, Jean-Marie de Koninck, Simon Kristensen, Gerhard Larcher, Thomas Lachmann, Lingmin Liao, Jack Lutz, Manfred Madritsch, Bill Mance, Antoine Marnat, Elvira Mayordomo, Mario Neumller, Satyadev Nandakumar, Tomas Persson, Jan Reimann, Joel Rivat, Adrian Scheerer, Theodore A. Slaman, Leonhard Summerer, Cathy Swaenepoel, Niclas Technau, Robert F. Tichy, Joseph Vandehey

ESI/CECAM-Workshop: Water at Interfaces: From Proteins to Devices

Organizers: Valentino Bianco (U Vienna), Ivan Coluzza (U Vienna), Barbara Capone (U Vienna), Christoph Dellago (ESI, U Vienna)

Dates: November 29 – December 2, 2016

Budget: ESI € 6 240, CECAM: € 12 000

Report on the workshop

The properties of water at biological/inorganic interfaces or in confinement have received large attention in recent years by the scientific community due to their fundamental role in biochemical processes and for their technological applications.

On larger scales, water-membrane interplay is relevant for technological and medical applications. According to recent data, one person in six lacks the access to clean water, making the purification of waste waters a serious technological and political challenge for the coming years. At the molecular scale structure of water at the interface of hydrophobic surfaces has important implications for the protein properties. Moreover, The formation of a hydrogen bond network around a protein could be related to changes in the protein tertiary structure and, consequently, of its biological function.

Water also governs the rate at which proteins, nucleic acids and membranes recognize ligands and molecules. Accurate models are of fundamental importance for drug design.

At low temperatures, the dynamics of water near protein surfaces instead are highly relevant for the safe preservation of organic material. In fact, water-protein interactions may influence the phases of the water itself, a feature that is exploited by several proteins to promote or impede the formation of ice. For example, experimental and numerical results show that long-range protein-water interactions play an important role in explaining the hyperactive antifreeze protein activity of insects. Some fungal spores, among the most abundant organic spores observed in the atmosphere, are known to use ice nucleation proteins to facilitate water nucleation.

Rationalizing the behavior of water in biological environment may provide the key to understand many of the complex self-organizing mechanisms of biological matter.

The main goal of this workshop was to gather leading scientists, from a wide spectrum of disciplines ranging from biophysics to material sciences, working on modeling and also experimental aspects of water at interfaces and at different length scales. On the long term, the aim of this workshop was to catalyze interdisciplinary collaborations that integrate our knowledge on different length scales and coarse-grained modeling to address the study of large bio-molecular/polymeric systems and of the design of new functionalized materials.

Activities

The workshop was organized jointly by the Erwin-Schrödinger-Institute for Mathematics and Physics and DaCAM, the Austrian node of CECAM (European Center for Atomic and Molecular Computation). CECAM is a European organisation for the promotion of particle based simulations with headquarters in Lausanne and nodes in several European cities including Vienna. The main activities of CECAM (www.cecam.org) are the organisation of workshops, conferences, school and tutorials in fields ranging from physics, chemistry and molecular biology to materials science and engineering.

The workshop was attended by about 30 scientists from outside Vienna and many members from the local community, including master students, doctoral students and postdocs. There was a total of 23 invited and contributed talks, each of which was 45 minutes long (35 minutes of talk followed by 10 minutes of discussion). Coffee breaks and an extended lunch break of 2 hours gave participants plenty of opportunities for informal interactions and group discussions. Instead of having a dedicated poster session, posters were available in the main hallway of the ESI at all times during the workshop.

Specific information on the workshop

The discussions at the workshop revolved not only about scientific questions, but also touched on the needs of the community. In particular, it became clears the community should address the following issues:

1. *Needs for computational infrastructure*

   One clear message that was repeated in several contributions was that all the studies require large scale HPC facilities to be performed. The accurate water models on the market at the moment are still very expensive to simulate at the space and time scales needed for the problems addressed. Interesting solutions have been presented during the workshop with innovative minimalistic models that, while maintaining the necessary accuracy, could be a game changer on the computational costs side.

2. *Needs for networking*

   The networking was one the main objectives of the workshop. In fact, the main motivation was to gather leading scientists, from a wide spectrum of disciplines ranging from biophysics to material sciences, working on modeling and experimental aspects of water at interfaces and at different length scales. We believe that the state of the art in water modeling is now sufficiently mature to address important applications in the fields aforementioned, hence the timeliness of this meeting was optimal and the location ideal with many local groups working on related problems. The meeting provided the ideal opportunity to gather scientists, both with a theoretical as well as experimental background, that are interested and willing to discuss different approaches and issues to make an advance in this relevant field.

3. *Needs for event organization*

   The success of the meeting and the feedback of many participants that appreciated the novel wide interdisciplinary program suggests that it would be important to transform such an isolated event into a recurrent meeting opportunity either yearly or every two years.

Furthermore, from the program of the workshop it is immediately clear that the topic is highly interdisciplinary and has a wide spectrum of social and industrial impacts. For instance, water sanitation is one of the goals set by the United Nations and in order to reach such goal we need a better understanding of the properties of water at the interface of novel materials used as filters (e.g. graphene). For medical applications the field of drug design is in desperate need of a better understanding of the effect of water on the description of protein-protein and protein-drug interactions. The solution of the latter could open the way to a larger use of computational methods to speed up and the reduce the costs of the search for new drugs. Finally, the ice nucleation properties of water have enormous repercussion to our planet from food and organ preservation to the understanding of large scale climate models. All these topics above have been extensively discussed during the meeting and there was an opportunity to have a debate on the role of science in the development of sustainable technologies.

Outcomes and achievements

The key points discussed during the workshop were the following:

1. The importance of water behavior close to inorganic interfaces was a central theme at the workshop. On the one side the discussion focused on the dynamical properties of recent filtration membranes applied in water desalination, sanitation and transport phenomenon in fuel cells. On the other side, we discussed about the general properties of hydrophobic surfaces, introducing a strongly interdisciplinary session with contributions ranging from biology all the way to atmospheric science.

   The studies presented showed the remarkable experimental and theoretical advances in the understanding and exploitation of the properties of ions dissolved in water. Overall, the speakers presented interesting new concepts to control the transport of ions and exploit such control to either remove the ions (desalination) or to store energy (fuel cells).

2. The accurate description of the solvation of bio-molecules was another central theme of the workshop. In particular, during the workshop we discussed current problems and future perspectives of water models regarding both equilibrium and dynamical properties of proteins. Moreover, current computational and conceptual challenges related to ice nucleation and ice inhibition materials, important in fields like cryo-preservation of tissues and frozen food storage, among which proteins play an important role, were discussed. An important conclusion of the discussions was that in order to further advance the field it is necessary to improve our current representation of water polarization properties and to reduce the computational cost of the simulations.

3. A special session was dedicated to a general discussion on the impact of water studies both in the scientific community and, more in general, to society.

This workshop demonstrated the growing importance of interfacial water in many fields of science among which there are physics, biology, medicine, water treatment, atmospheric science, engineering. This field of study has been emphasized in recent publications but, contrary to bulk water, it was subject only lately of few meetings. The central goal of this workshop was to gather leading scientists, from a wide spectrum of disciplines ranging from biophysics to material sciences, working on modeling and experimental aspects of water at interfaces and at different length scales. We believe that the workshop fully achieved this aim.

The long term goal of this workshop is to catalyze interdisciplinary collaborations that integrate our knowledge on different length scales and coarse-grained modeling to address the study of large biomolecular/polymeric systems and of the design of new functionalized materials. Based on the discussion stimulated and the feedback obtained form the participants, we believe that also this objective was reached.

List of talks

Rahul Raveendran Nair	Molecules at two-dimensional interfaces and capillaries
Sandrine Lyonnard	Water Confined in Fuel Cell Membranes
Laurent Joly	Water friction on graphene and boron nitride surfaces: insight from ab initio molecular dynamics
Maarten Biesheuvel	Water desalination using Capacitive Electrodes: from Carbon Nanotube Membranes to Activated Carbon Suspensions – Concepts and Mean-field Transport Theory
Huib Bakker	Structure and dynamics of water molecules at protein surfaces
Giancarlo Franzese	A Multiscale Approach for Water at Bio-Nano Interfaces
Valentino Bianco	The role of water in the selection of stable proteins at ambient and extreme thermodynamic conditions
Giorgio Schirò	Unveiling the Role of Hydration Water in the Onset of Protein Structural Dynamics
Biman Bagchi	Protein Hydration Dynamics and Hydrophobic Force Law
Xavier Barril	The Quasi-Bound State of Protein-Ligand Complexes. Implications in Drug Discovery
Max Paoli	The Role of Science for Sustainable Development
Sylvie Roke	Snapshots of Ion Induced Long-range Structure in Aquous Systems
Francesco Mallamace	An NMR study on the hydrophilic and hydrophobic interactions
Simone Meloni	The Salvinia Paradox: how the hydrophilic patches help keeping the plants surface dry
Fabio Bruni	The putative liquid-liquid transition is a liquid-solid transition in water confined in MCM
Martin Chaplin	Just how anomalous is interfacial water?
Othmar Steinhauser	Water Dynamics near biological surfaces studied by Shell-Resolved Computational Spectroscopy
Martina Havenith	THz spectroscopy and Solvation Science
Ana Vila Verde	Supra-additive slowdown of water rotation by outer-sphere ion pairs
Hinrich Grothe	Biological Ice Nucleation in the Atmosphere and the Biosphere
Klaus Liedl	Water Ordering at Protein Interfaces and Consequences for Biomolecular Recognition
Eduardo Sanz	The Role of the Ice-water Interface in Homogeneous Ice Nucleation
Alexander Bittner	Imaging thin water layers on single viruses

Invited scientists

Mandana Azmi, Biman Bagchi, Huib Bakker, Xavier Barril, Biswajit Basu, Daniel Braun, Valentino Bianco, Mateusz Bieniek, Maarten Biesheuvel, Alexander Bittner, Fabio Bruni, Barbara Capone, Martin Chaplin, Ivan Coluzza, Christoph Dellago, Giancarlo Franzese, Miquel Garcia-Rates, Arthur Garon, Alberto Giacomello, Hinrich Grothe, Martina Havenith, Laurent Joly, Klaus Liedl, Emanuele Locatelli, Wenping Lyu, Sandrine Lyonnard, Francesco Mallamace, Simone Meloni, Rahul Raveendran Nair, Massimo Paoli, Sylvie Roke, Eduardo Sanz Garcia, Giorgio Schiró, Christian Schröder, Othmar Steinhauser, Antonio Tinti, Ana Vila Verde

Current Trends in Descriptive Set Theory

Organizers: Sy Friedman (KGRC, U Vienna), Alexander Kechris (Caltech), Benjamin Miller (KGRC, U Vienna), Slawomir Solecki (U Illinois, Urbana-Champaign)

Dates: December 12 – 16, 2016

Budget: ESI € 15 520

Report on the workshop

The organizers of this one-week-long workshop are thankful for the opportunity to have gathered many of the world's leading descriptive set theorists to Vienna for a very enjoyable and successful meeting. The ESI provided excellent facilities and administrative help for our group of roughly fourty international participants (in addition to many from the local mathematical community). The meeting emphasized recent trends in descriptive set theory, including Borel combinatorics, Borel equivalence relations, generalized descriptive set theory, model-theoretic techniques, and properties of Polish groups, as well as connections with ergodic theory and functional analysis. The goal was to disseminate the latest results in the field, while simultaneously providing an opportunity for collaboration between the many participants.

Activities

The workshop began with an introductory lecture, whose purpose was to bring the local community up to speed on the main results to be used throughout the workshop. Thereafter, we had between two and four lectures per day on the latest research in the subject, with plenty of time for collaboration and further discussion in-between.

Specific information on the workshop

Among the participants were twelve PhD students: G. Basso (University of Lausanne), A. Bernshteyn (University of Illinois, Urbana-Champaign), F. Calderoni (University of Turin), J. Grebik (Czech Academy of Sciences), T. Ibarlucia (University of Lyon I), V. Kiss (Eötvös Loránd University), V. Kovařík (Charles University), D. Nagy (Eötvös Loránd University), M. Poór (Eötvös Loránd University), D. Sziraki (Central European University), L. Vuilleumier (University of Lausanne), and K. Wrobel (Texas A&M University). There were also six postdocs: M. Doucha (Czech Academy of Sciences), V. Gregoriades (TU Darmstadt), A. Kwiatkowska (University of Bonn), P. Schlicht (University of Bonn), K. Slutskyy (University of Illinois, Chicago), and Z. Vidnyánszky (Rényi Institute). Many local PhD students and postdocs also attended the meeting. Two of the most advanced postdocs (A. Kwiatkowska and P. Schlicht) gave lectures on their work, and all of the PhD students and postdocs had the opportunity to hear about the latest results in descriptive set theory, as well as to meet and interact with many of the top researchers in the field.

Outcomes and achievements

F. Calderoni and L. Motto Ros competed their work on the universality of group embeddability.

R. Camerlo, R. Carroy, and A. Marcone continued their work on embeddings and epimorphisms.

V. Gregoriades discussed his work on the Dyck and Preiss separation theorems with D. Lecomte.

S. Jackson continued his work on the undecidability of embeddability of the free part of the Bernoulli shift action of $\mathbb{Z}^2$ on $2^{\mathbb{Z}^2}$ into a subshift of finite type.

V. Kovařík and W. Kubis solved an open problem of the former concerning $c_0(\Gamma)$.

M. Malicki initiated collaborations with M. Doucha and O. Kwiatkoska.

P. Schlicht and S. Uhlenbrock continued their joint work on variants of the Lebesgue density theorem.

J. Zapletal will add a section to his upcoming based on conversations he had at the meeting with V. Kanovei. He also discussed the existence of *p*-points in the iterated Silver model with D. Chodounsky, which eventually led to a proof of the consistency of the inexistence of p-points in the presence of a large continuum, a longstanding open question.

List of talks

Benjamin Miller	Introductory lecture
Clinton Conley	Følner tilings via matchings
Steven Jackson	The subshift of finite type and graph homomorphism questions
Vladimir Kanovey	Definable countable sets of reals with and without definable elements
David Kerr	Entropy and continuous orbit equivalence
Aleksandra Kwiatkowska	Cyclically dense conjugacy classes and topological similarity for groups of measurable functions
Francois Le Maître	L^1 full groups
Dominique Lecomte	Applications of the representation theorem for Borel sets
Philipp Schlicht	Applications of long games in generalized descriptive set theory
Maciej Malicki	There is no universal Polish metric group with a bi-invariant metric. A short proof
Andrew Marks	Descriptive set theory and geometrical paradoxes
Robin Tucker-Drob	Bounded generation and cost
Asger Törnquist	Definability and disjointness modulo various ideals on ω
Jindrich Zapletal	Σ^*_1 definability of sets with applications
Todor Tsankov	Metric Scott analysis
Anush Tserunyan	Edge slides and ergodic actions

Publications and preprints contributed

R. Camerlo, R. Carroy, A. Marcone, *Linear orders: when embeddability and epimorphism*, arXiv:1701.02020 [math.LO].

V. Gregoriades, *The Dyck and Preiss separation uniformly*.

F. Calderoni and L. Motto Ros, *Universality of group embeddability.*

S. Gao, S. Jackson, E. Krohne, and B. Seward, *Continuous combinatorics of abelian group actions.*

P. Schlicht, D. Schrittesser, S. Uhlenbrock, and T. Reinert, *Variants of the Lebesgue density theorem.*

J. Zapletal, *Borel reducibility invariants in higher set theory.*

Invited scientists

Gianluca Basso, Anton Bernshteyn, Filippo Calderoni, Raphaël Carroy, Riccardo Camerlo, David Chodovnsky, Clinton Conley, Gabriel Debs, Michal Doucha, Marton Elekes, Sy Friedman, Vera Fischer, Jan Grebik, Vassilios Gregoriades, Osvaldo Guzman Gonzalez, Tomas Ibarlucia, Steven Jackson, Vladimir

Kanovey, David Kerr, Viktor Kiss, Marlene Koelbing, Vojtech Kovarik, Wieslaw Kubis, Aleksandra Kwiatkowska, Dominique Lecomte, Francois Le Maitre, Maciej Malicki, Alberto Marcone, Andrew Marks, Benjamin Miller, Diana Carolina Montaya Amaya, Luca Motto Ross, Donát Nagy, Mark Poór, Jean Saint-Raymond, Philipp Schlicht, Kostya Slutskyy, Slawomir Solecki, Daniel Soukup, Dorottya Sziraki, Stevo Todorcevic, Todor Tsankov, Anush Tserunyan, Robin Tucker-Drob, Sandra Uhlenbrock, Zoltán Vidnyánszky, Judith Virtbauer, Louis Vuilleumier, Konrad Wrobel, Jindrich Zapletal, Miroslav Zeleny

Research in Teams

RiT Project 1: Christos N. Likos et al: Soft Matter under Confinement: Structural and dynamical Properties

Collaborators: Sergei A. Egorov (U of Virginia) and Christos N. Likos (U Vienna)

Dates: 1 April – May 31, 2016

Budget: ESI € 4 800

Report on the project

Scientific Background

A detailed microscopic understanding of the structural, thermodynamic, and dynamic behavior of soft matter systems confined in nanopores and slits of various geometries is of both fundamental and practical importance [1, 2]. One particular example of such confined soft matter systems involves disc-shaped particles in various pores [3] which are essential for understanding confined discotic liquid crystals [4] and, as such, have been extensively studied via experiments [2] computer simulations [5, 6, 7, 8], and theory [3, 8, 9, 10].

The primary focus of the above studies has been on the ordering and surface tension of the disc-shaped particles at the confining surface and the concomitant effect of the geometrical confinement on the isotropic-nematic-columnar phase behavior of the corresponding liquid crystal. In particular, it has been shown that both the shape of the particles [5] and the wall-particle interaction potential [6, 7] strongly affect the observed surface ordering. More specifically, for disc-shaped particles confined in a planar slit, two types of wall ordering are typically distinguished [11]: planar anchoring (or "edge-on", with the director parallel to the wall) and homeotropic anchoring (or "face-on", with the director normal to the wall). Clearly, the ability to control and switch the type of anchoring is crucial for developing practical applications of confined discotic liquid crystals, such as optical compensation films [4]. From the experimental point of view [2] the two most common control parameters that can be used to control the anchoring type are temperature and density. The former parameter can be used to tune the strength of the wall-particle interaction. Along these lines, it has been shown [7] that switching from a hard wall (which excludes the particles completely) to an "adsorbent" wall (which excludes only the centers of mass of the particles) promotes switching of surface ordering of disc-shaped particles from homeotropic to planar. Concomitantly, the hard walls facilitate isotropic-nematic transition relative to the bulk (capillary nematization), while adsorbent walls delay this transition (capillary isotropisation). By contrast, using the density as the control parameter was shown to have little to no effect on the surface ordering [5]. In this connection, it is important to emphasise that all the aforementioned studies have modeled the disc-shaped particles either as strictly hard (completely impenetrable) objects [5, 7, 8] or as (only slightly) softer repulsive entities [6] of the type corresponding to Gay-Berne [12] oblate ellipsoids. In the case of ultrasoft interaction-potentials employed in modeling macroparticles one would expect a much stronger effect of density on surface-ordering. The purpose of the present collaborative research project is to study precisely such a system, and to establish a clear connection between coarse-grained models of soft, penetrable discs and real physical systems of stiff ring polymers for which the Physics of the model can be materialised.

Project aims and scope

The major aims of the present collaborative project can be listed as follows:

1. To extend the coarse-grained model of semiflexible ring polymers (previously developed in the group of Prof. Likos to study their behavior in the bulk [13]) to the case of confinement by flat walls;

2. To utilize the prior experience of Prof. Egorov with Density Functional Theory (DFT) methods for semiflexible polymers [14, 15, 16] with the goal of combining the strengths of simulation and DFT approaches for the present project;

3. To perform a combined simulation–DFT study of semiflexible ring polymers under planar confinement with the specific focus on the wall-induced structuring and its thermodynamic aspects, as provided by the calculation of the surface tension, easily accessible within the DFT framework.

We now describe the main steps taken to achieve these aims in greater detail. Our microscopic model is based on recently obtained anisotropic effective pair potentials, which were introduced in order to coarse-grain semiflexible ring polymers of various chain lengths [13], whereby each ring was represented by a soft penetrable disc. The model has been validated by comparing its structural predictions in the bulk with the corresponding results of full monomer-resolved computer simulations. It was shown that for the short- and intermediate-length ring polymers, with a contour- to persistence-length ratio of $l/l_p \cong 6.7$, the model is capable of reproducing the essential structural properties of a bulk system nearly quantitatively, while the longer rings (at high concentrations) were shown to undergo conformational changes which cannot be reproduced by an effective anisotropic soft-disc model. Accordingly, in the present study we consider precisely those soft discs which mimic intermediate-length ring polymers with $l/l_p \cong 6.7$ and focus on their structural properties and self-organization under confinement between planar walls.

Clearly, any systematic study of a confined system requires the knowledge of its corresponding behaviour in the bulk as a reference. In this connection, it is important to note that the aforementioned simulation study [13] of the bulk system has shown no indication of either isotropic-nematic or isotropic-columnar ordering phase transition, at least in the density range that was considered. Given the absence of the ordering phase transitions in the bulk for our model, we instead focus on the anchoring type and surface tension of the disc-shaped particles at the confining wall. We address these two problems by employing a combination of computer simulations and DFT. Both methods have their advantages and disadvantages and therefore can be used in a complementary fashion. Thus, simulations, at least in principle, produce exact results for a given microscopic model, except for the inevitable statistical noise. However, this advantage comes at a high computational cost, because very long runs are required in order to reduce the noise level. By contrast, DFT calculations are relatively cheap, but involve unavoidable approximations. Hence, the accuracy of the DFT predictions must be tested and validated by comparison with computer simulations. Another significant advantage of the DFT approach comes from the fact that this method is based on minimizing the free energy, and, as such, allows a straightforward determination of various thermodynamic observables, which are notoriously difficult to obtain from computer simulations. For example, it is very computationally demanding to obtain surface tension of semiflexible polymers at a hard wall from simulations, while in DFT this quantity can be calculated relatively easily [14]. In view of the above, in the present work we employ a judicious combination of these two methods. Specifically, given the availability of extensive simulation results for the bulk coarse-grained system [13], we begin by developing and testing the DFT approach in the bulk. The anisotropic total and direct pair correlation functions in the bulk are obtained by combining the hypernetted chain (HNC) closure with the Percus method of treating one given disc as a "test particle" exerting the external potential (simply the effective coarse-grained pair potential in this case) on all the other [17]. Once the simulation and DFT predictions for the pair distribution functions are compared and the accuracy of the DFT in the bulk is confirmed, we proceed to study the structural properties of the confined system.

In order to carry out the DFT calculations in confinement, we use the bulk direct pair correlation functions as input, treat the hard planar confining wall(s) as the source of the external potential, and compute the wall-induced one-particle density of rings. For spherical particles such an approach has been previously successfully used to study the distribution of spherical solvents around two colloids [18, 19]. Once again, the accuracy of the DFT method is confirmed by direct comparison with the simulation results. Our key finding for the confined system is that the surface ordering of the soft discs at a hard planar wall switches from homeotropic to planar with increasing density. This interesting and important effect was observed both in computer simulations and in DFT and is in stark contrast to confined hard discs, where, as mentioned earlier, density has little effect on the type of surface anchoring, and the latter is largely controlled by the wall-disc interaction potential (in the present case, only hard walls are considered).

Outcomes and achievements

The main results of the joint research project can be summarised as follows. We have performed a combined theoretical and computational study of the effective models arising from a coarse-graining of stiff ring polymers, putting DFT-approaches and integral equation theories in the bulk and in confinement at a strong test and examining the structural properties of isotropic ring fluids close to planar walls. We have shown that for DFT computations in the bulk MFT strongly overestimates the strength of the interactions, while the application of the HNC closure to anisotropic systems offers a description which is in very good agreement with simulation results for all densities investigated. The HNC approach in the bulk gives us a prediction for the full anisotropic pair-correlation function, as well as for the direct-pair correlation function. The latter is useful to apply DFT to predict the one-particle density of rings in the vicinity of a wall. We found that by increasing density one can induce a reorientation of the effective rings in the vicinity of a wall, which prefer to orient themselves parallel to the surface (planar) for low densities ρ and reorient orthogonal to the wall (homeotropic) for higher values of ρ. This unusual phenomenon is observed in DFT as well as in computer simulations and is in stark contrast to confined hard discs, where the surface structure is mostly controlled by the interaction potential between the rings and the wall, while density has little effect. Future directions will focus on the occurrence of ordered phases (nematic or columnar) and on the behavior of such systems under non-equilibrium conditions, where the type of anchoring is expected to affect the rheological properties of the system, such as viscosity or transport coefficients.

Publications and preprints contributed

P. Poier, S. Egorov, Ch. Likos, R. Blaak, *Concentration-induced planar-to-homeotropic anchoring transition of stiff ring polymers on hard walls*, published in the journal of The Royal Society of Chemistry, http://dx.doi.org/10.1039/c6sm01453d, 2016.

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RiT Project 2: Ruggero Bandiera et al: Higher Algebraic Structures inspired by Topology & Geometry

Collaborators: Ruggero Bandiera (U of Rome, La Sapienza), Nils Carqueville (ESI, U Vienna), Florian Schätz (U of Luxembourg)

Dates: July 17 – August 14, 2016

Budget: ESI € 4 720

Report on the project

Scientific Background

Our project focused on higher algebraic structures associated to the unit interval $[0,1]$, and related topics. Two of us (R. Bandiera and F. Schätz) previously constructed and studied an interesting morphism φ between two important algebraic structures associated to the unit interval $[0,1]$, cf. [BS1]:

- The differential forms $\Omega^\bullet([0,1])$ on $[0,1]$, equipped with the de Rham differential and the wedge product.
- The Whitney forms on $[0,1]$, given by

$$\Omega^\bullet_W([0,1]) = \{at + b(1-t) \,|\, a,b \in \Bbbk\} \oplus \{c\,dt \,|\, c \in \Bbbk\} \subset \Omega^\bullet([0,1]).$$

  This subcomplex of $\Omega^\bullet([0,1])$ can be equipped with the structure of a homotopy associative and homotopy commutative, i.e. C_∞, algebra structure, see [M,FM,CG].

Let us remark that $\Omega^\bullet_W([0,1])$, equipped with the C_∞-algebra structure, can be regarded as a discretized version of the dg algebra of differential forms $\Omega^\bullet([0,1])$. Moreover, by extension of scalars from $\Bbbk$ to a differential graded Lie algebra $\mathfrak{g}$, $\Omega^\bullet([0,1];\mathfrak{g})$ encodes flat $\mathbb{Z}$-graded connection on $[0,1]$, while $\Omega_W([0,1];\mathfrak{g})$ encodes a groupoid canonically associated to $\mathfrak{g}$, the Deligne groupoid of $\mathfrak{g}$, which plays a central role in deformation theory.

Project aims and scope

The aim of the project was to develop further instances of the interaction between higher algebraic structures, topology and geometry. Our project proposal consisted of two parts:

1. Whitney forms on the interval,
2. Towards higher Knizhnik-Zamolodchikov-connections.

We mostly focused – and made progress – on the first part. Our main aim there was to investigate questions raised by the construction of the morphism φ from differential forms to Whitney forms. One interesting aspect of φ is its relation to the Eulerian idempotent E from Lie theory, see [BS1]. The Eulerian idempotent is a canonical projector from the free associative algebra on generators $x_1,\dots,x_n$ to the free Lie algebra $x_1,\dots,x_n$, and it plays an important role in the theory of linear ODEs, thanks to its appearance in the classical Magnus expansion, cf. [MP,S].

The second part revolved around potential generalizations of the Knizhnik-Zamolodchikov connections, or KZ-connections for brevity. These are natural flat connections over the configuration spaces of points in $\mathbb{C}$, with important applications to the study of braid groups and Drinfeld associators. Due to time constraints, we did not make substantial progress in this part, but hope to return to it in the future.

Another aspect of our stay was the interaction with the local scientific community. To this end, R. Bandiera and F. Schätz each delivered one talk, and we organized discussion sessions with Daniel Scherl and Gregor Schaumann (both in the team of N. Carqueville).

Outcomes and achievements

The main outcome of our work related to the research in team project, is a formula for the image of the element $x_1 \cdots x_n$ in the free associative algebra under the Eulerian idempotent E. More precisely, we provide closed formulas for the coeffcients of

$$E(x_1 \cdots x_n) \in \text{the free Lie-algebra on } x_1, \dots, x_n$$

with respect to a certain basis $\mathcal{B}_n$ of the space spanned by those Lie words, which contain each of the generators $x_1, \dots, x_n$ precisely once. The space of such Lie words naturally arises in the study of the Lie operad. Our solution relies on two key insights:

i) The passage from (Lie) words to trees – which brings us to the world of pre-Lie algebras. A pre-Lie algebra structure on a vector space V is a bilinear operation $\triangleright$, whose associator $A(x,y,z) := x \triangleright (y \triangleright z) - (x \triangleright y) \triangleright z$ is symmetric in the first two arguments.

ii) The reformulation of a recursive problem in terms of a differential equation. This step is an extension of the classical umbral calculus, and we believe it is of independent interest. In fact, we use it also to solve the problem of computing the pre-Lie logarithm in the free pre-Lie algebra on one generator.

The recent preprint [BS2] contains these and further results.

References

[BS1] R. Bandiera and F. Schätz, *How to discretize the differential forms on the interval*, preprint, `arXiv:1607.03654`.

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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 whose stays in Vienna are financed by the Austrian Ministry of Education, Science and Culture and the U of Vienna. 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 2016:

Yann Brenier (CNRS, École Polytechnique, Palaiseau):
Optimal transport methods for hamiltonian PDEs
Lectures (250 120 VO) and Exercise Classes (250 121 PS): April 14 – June 30, 2016
Thursday and Friday 13:15 – 14:45 (lecture) and 15:00 – 15:45 (tutorial)

Lecture Courses, Winter Term 2016/17:

Robin S. Johnson (Newcastle University):
Theoretical fluid dynamics and oceanic flows
Lectures and Exercise Classes (250 059 VU): October 6 – December 9, 2016
Tuesday 9:30 – 11:30 (lecture) and Thursday 9:30 – 10:30 (tutorial)

Visitors associated with Senior Research Fellowships

Xianglong Duan (École Polytechnique, Palaiseau), June 12 – 19, 2016
Thomas Gallouët (École Polytechnique, Palaiseau), June 27 – July 1, 2016

Yann Brenier: Optimal transport methods for hamiltonian PDEs

Course

In the last 25 years, optimal transport theory, which lies between Calculus of Variations, Probability and Geometry, has been used many times to address non-linear elliptic PDEs, such as the real Monge-Ampere equation, or parabolic equations such as the heat equation and many nonlinear generalizations. Its link with conservative, hamiltonian and hyperbolic PDEs is much less documented. The aim of my course was to cover two important examples: namely the Euler equations of incompressible fluids, which goes back to the 18th century (few years before Monge introduced the first optimal transport problem) and the Born-Infeld equations of Electromagnetism which goes back to 1934 and has been revisited in the 90s by High Energy Physicists. Concerning the Euler equations, in the first part of the course, I started from the unusual idea to associate the model of ideal incompressible fluid in continuum mechanics to the fully discrete concept of permutation, by thinking of an incompressible fluid moving in a cube just as a continuous version of a finite sequence of K permutations exchanging N^3 subcubes of same volume, viewing, of course, K and N as very large integers. Although this viewpoint is not inspired by any physical submodeling of a real fluid, it is however fully consistent at the mathematical level (as already well known in the theory of dynamical systems where such approximations have been used a lot in the last century). The advantage of this approach, in my opinion, is to show how the Euler model, designed in 1755, is close to the theory of optimal transport, as initiated by Monge in 1780. It also provides a very down-to-earth introduction, just by formally passing to the continuous limit, to the famous interpretation, by V.I. Arnold, in 1966, of the Euler model in terms of geodesic curves along the group of volume preserving diffeomorphisms of the cube. Then, I explained how the corresponding problem of finding minimizing geodesic curves can be rephrased as a (generalized) optimal transport problem leading to a convex minimization problems on a the space of probability measures on paths

along the cube, with suitable constraints on their margins. I showed how this leads to a definite result of existence and (unexpected) uniqueness for the pressure gradient driving the optimal incompressible motion, using compactness and convex duality tools.
In the second part of the course, I switched to the apparently unrelated subject of the theory of non-linear electromagnetism designed by Max Born and Leopold Infeld in 1934. As a matter of fact, the connection can be established through the concept of optimal transports of curves, which makes the Born-Infeld model a natural interpolation between the linear theory of Maxwell, in classical Electromagnetism, and the model of strings by Nambu and Goto, in high energy physics. I showed how the Born-Infeld equations can be treated as a symmetric system of first order evolution equations, through a suitable extension of the equations by adding the energy and momentum conservation laws, while relaxing the algebraic relations linking energy and momentum to the electromagnetic field. In this framework, an unexpected connection can be made between the Born-Infeld model, which has been quite popular in high energy physics in the last 20 years (through the concept of D-branes) and the more conventional theory of Magnetohydrodynamics which plays a very important role in many concrete applications.
The course was concluded by several very interesting talks delivered by students on topics mostly related to its first part (history of the Euler equations, applications of the Euler equations to Geophysics, generalization of the Euler equations by Camassa and Holm,...).

Research

During my stay at the ESI, I worked on various topics related to the thematic programme run by Professor Stefanelli and his co-organizers. I invited my PhD student, Xianglong Duan, and, my Postdoc, Thomas Gallouët, to ESI for one weak each. With Xianglong Duan I worked on a paper mentioned at"Publications and preprints contributed". A second one is in preparation. I enjoyed very exciting discussions with several visitors, in particular with Professor Vorotnikov, concerning mean curvature flows and optimal transport theory. I am very grateful to the ESI and to Professor Stefanelli for making my stay very enjoyable and fruitful.

Publications and preprints contributed

Y. Brenier, X. Duan, *From conservative to dissipative systems through quadratic change of time with application to the curve-shortening flow*, https://arxiv.org/abs/1703.03404 [math.AP].

T. Gallouët, Q. Mérigot, *A Lagrangian scheme for the incompressible Euler equation using optimal transport*, https://arxiv.org/pdf/1605.00568.pdf, [math.NA].

Robin S. Johnson: Theoretical fluid dynamics and oceanic flows

Course

The material covered in this course is described below, being an introduction to fluid dynamics, the classical water-wave problem with some applications to oceanography. The ideas were presented via lectures, but further detail, additional calculations, and associated examples, were presented in the examples classes. Handouts were available at the start of each class (reproducing the screens used for the lectures).

Basic ideas and governing equations: Definition of a fluid; the continuum hypothesis; streamlines and particle paths; material derivative; acceleration; Eulerian & Lagrangian formulations; equation of mass conservation; incompressibility; hydrostatic equilibrium; Eulers equation; vorticity and rotation; Helmholtzs equation; irrotational flow; circulation; Bernoullis equation; pressure equation; stream function. *The classical water-wave problem I:* Boundary conditions for water waves; rôle and importance of non-dimensionalisation & scaling. *Asymptotic expansions:* Short introduction to asymptotic expansions with a parameter: basic definitions and elementary techniques. *The classical water-wave problem*

II: Rôles of the parameters to define different classes of problem; introduction to some classical results. *Oceanic flows:* Introduction to the nature of these flows: complexity, geometry, rotation; simple approximations used by oceanographers; aims of a mathematical approach. Formulation of the Pacific Equatorial Undercurrent wave problem, and the nature of the Antarctic Circumpolar Current; presentation of some recent results.

Research

I have been pursuing an intensive investigation for the last three years or so, encouraged by Professor Adrian Constantin, into the rôle that classical fluid dynamics the ideas and techniques might have in the study of physical oceanography. This has already produced results in the areas of: waves on the Pacific Equatorial Undercurrent (EUC), exact solutions that model an equatorial undercurrent and also the Antarctic Circumpolar Current (ACC), and the nonlinear, three dimensional flows in the neighbourhood of the EUC.
In the current phase of this work, undertaken during the stay at ESI, the first task was to put the finishing touches to the nonlinear, 3D work, and to submit this for publication; the methods developed here introduce a novel technique for tackling these types of problem. However, the main thrust of the work whilst visiting ESI was to investigate the possibility of developing a systematic approximation of the full governing equations (Euler with vorticity and in a rotating, spherical coordinate frame) to describe *gyres*. These are large areas of water that flow in a roughly circular pattern and which dominate the central regions of our open oceans; there are five large ones in particular (two in the Pacific Ocean, two in the Atlantic Ocean, and one in the Indian Ocean), and many smaller ones. It turned out that the classical approximation associated with shallow water i.e. a thin layer of fluid on the surface of a sphere the Earth was sufficient to allow progress. This produced a new way of describing gyres: fully nonlinear, in a rotating frame and expressed in spherical coordinates, producing gyres of any required size and with any appropriate velocity distribution. A general approach was developed, involving a new variant of the vorticity equation, coupling the rotation of the Earth to the underlying motion of the seas; some simple, relevant, exact solutions were obtained and described. A paper presenting this work was prepared for publication and has been submitted. In the last few days of the visit, the problem of describing waves on the ACC was initiated; the flow of the ACC, and the waves thereon, are known to play a significant rôle in the development of the overall climate conditions. This investigation is still at an early stage, but the results so far look encouraging.

Lecture Notes

The lecture course (described above) was generated from an initial text that was prepared specially for the course; this text is available.

Publications and preprints contributed

A. Constantin, R.S. Johnson, *A nonlinear, three dimensional model for ocean flows, motivated by some observations of the Pacific Equatorial Undercurrent and thermocline*, 2016, submitted.

A. Constantin, R.S. Johnson, *Large gyres as a shallow-water asymptotic solution of Eulers equation in spherical coordinates*, 2016, submitted.

Erwin Schrödinger Lectures 2016

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.

Speaker: Alex Lubotzky (Hebrew University of Jerusalem and ETH - Institute of Theoretical Studies, Zurich)

Alex Lubotzky holds the Maurice and Clara Weil chair in Mathematics at the Einstein Institute of Mathematics of the Hebrew University Jerusalem.

Date: February 18, 2016

Alex Lubotzky: Ramanujan complexes and topological expanders

Abstract
Expander graphs in general, and Ramanujan graphs, in particular, have played a major role in computer science in the last 4 decades and more recently also in pure mathematics. In recent years a high dimensional theory of expanders is emerging. A notion of topological expanders was defined by Gromov who proved that the complete d-dimensional simplical complexes are such. He raised the basic question of existence of such bounded degree complexes of dimension $d > 1$. This question was answered recently (by T. Kaufman, D. Kazdhan and A. Lubotzky for d=2 and by T. Kaufman and S. Evra for general d) by showing that the d-skeleton of (d+1)-dimensional Ramanujan complexes provide such topological expanders. We will describe these developments and the general area of high dimensional expanders.

Speaker: Norbert Schappacher (Institut de Recherche Mathématiques Avancée, Université de Strasbourg)

Norbert Schappacher holds a chair in mathematics at the University of Strasbourg; he is director of the GDR 3398 "Histoire de mathématiques" and chief editor of the "Revue d'histoire des mathématiques".

Date: December 10, 2016

Norbert Schappacher: Mathematics, Physics, the search for a new man, and French-German politics - Claude Chevalley's challenges in the 1930s

Abstract
Claude Chevalley (1909 - 1984) is principally known today as the excellent and influential mathematician of the twentieth century that he was. Apart from several seminal research contributions (for instance in class field theory, and the theory of the groups which today bear his name), he is particularly remembered as one of the founding fathers of the Bourbaki enterprise and as author of groundbreaking books, such as *The Algebraic Theory of Spinors* (1954).
Few mathematicians and physicists are aware, however, that Chevalley has also attracted the attention of general historians because of his activity as a member of the French "non-conformist" political group *Ordre Nouveau* between 1931 and 1938, and as a go-between with leftist-national groups in Germany. It turns out that understanding Chevalley's idea of the modern scientist is impossible without also taking into account his political texts and actions in the 1930s.
The aim of the talk will thus be to explain the coherent overall project which drove Chevalley in the 1930s, illustrating at the same time the two aspects - mathematics and politics - which characterized Chevalley's trips to Germany during that decade, before he left the European scene for Princeton in 1938

Simons Junior Professor Nils Carqueville

In 2013, following a suggestion of the hiring committee, the Rektor of the University of Vienna offered the Simons Junior Professorship at the ESI to Nils Carqueville (then at the Simons Center for Geometry and Physics, Stony Brook University). He accepted the call. Formally a member of the Faculty of Mathematics at Vienna University, he started his position at the ESI on March 1, 2014.

Teaching

Nils Carqueville taught the following courses within the general course programme of the University of Vienna.

Summer Term 2016:

Topological Quantum Field Theory 2
Lecture Course, 2h, 250115 VO: March 1 – June 30, 2016 Thursday 11:15 - 12:45

Course description: This was a continuation of part 1 of the lecture course in the previous winter term. The main topics were 2-dimensional defect TQFT and 3-dimensional TQFT.

Introduction to knot theory
Lecture Course, 2h, 250116 VO: March 1 – June 30, 2016 Friday 13:15 - 14:45

Course description: In this course we discussed how complicated it is to classify knots and we learned about different kinds of knot invariants, in particular the Jones and Alexander polynomials. The more recent developments of quantum invariants via Hopf algebras were introduced. To obtain a systematic understanding of knot invariants, we learned about the concept of finite-type invariants and the combinatorial description of these. With Gregor Schaumann.

Linear algebra and geometry 1
Tutorial, 2h, 250028 UE: March 1 – June 30, 2016 Thursday 11:15 - 12:45

Course description: Tutorial for the homonymous lecture course.

Winter Term 2016/17:

From Classical Physics to Factorisation Algebras
Seminar, 2h, 250084 SE: October 1, 2016 – January 31, 2017 Monday 15:15 - 16:45

Course description: This seminar, intended for theoretical physicists and mathematicians alike, aimed to motivate one of the modern rigorous approaches to quantum field theory: factorisation algebras. In the first half of the term, we introduced a number of classical physical theories in the Langrangian formalism concisely, including the point particle in curved space, electromagnetism, Yang-Mills theory, and Chern-Simons theory. In a shorter, second part, we discussed the path integral in QFT as well as its functorial axiomatisation. Finally, in the third part we motivated and introduced (pre-)factorisation algebras, and discussed several examples.

Introduction to linear algebra and geometry
Lecture course, 4h, 250013 VO: October 1, 2016 – January 31, 2017 Tuesday 09:25 - 11:15 and Thursday 09:45 - 11:15

Course description: Introduction to basic abstract algebra to first-year students, part of a three-term cycle.

Introduction to linear algebra and geometry
Tutorial, 2h, 250014 UE: October 1, 2016 – January 31, 2017 Thursday 15:00 - 16:30

Course description: Tutorial for the homonymous lecture course.

Research

In 2016 the research of Nils Carqueville focused on a long-term programme of generalised orbifolds of 3-dimensional TQFT, involving Gray categories with duals, categorifications of Frobenius algebras, homological knot invariants, higher groupoid actions, and topological quantum computation.

Further activities

In August 2016, Nils Carqueville organised a small four-day workshop on "Topological Quantum Computation" in the Styrian Mountains. He also welcomed into his group Albert Georg Passegger as a Master student and Daniel Scherl as a PhD student, and obtained funding for a postdoc to join the group in March 2017.

For one month in July and August 2016, Nils Carqueville also participated in the ESI "Research in Teams" programme, together with Ruggero Bandiera (U of Rome, La Sapienza) and Florian Schätz (U of Luxembourg). The aim of the project was to deepen the interaction of higher algebraic structures, topology and geometry in the context of Whitney forms on the interval. This built on previous work by Bandiera and Schätz, and in particular produced a new understanding of the Eulerian idempotent. Various joint seminars and discussions were held, with active input also from Gregor Schaumann and Daniel Scherl (both members of Carqueville's group); all members of the programme also participated in a workshop on gauged linear sigma models at TU Vienna. The programme also led to new projects on higher structures in 2-categories between Carqueville and Schätz, and in hindsight it served as preparation of a joint application for a Lise Meitner Fellowship for Schätz to come to Vienna.

Visits from: Claudia Scheimbauer (MPIfM Bonn), Alberto Cattaneo (U Zurich), Manuel BäŁrenz (U Bamberg), Paul Wedrich (Imperial College London), Florian SchäŁtz (U Luxembourg), Huiyi Hu (Google).

Visits to: U Lancaster (colloquium talk), King's College London (seminar talk), U Bonn (speaker at workshop "Categorification"), Centre for Quantum Geometry of Moduli Spaces (seminar talk), U Aarhus (colloquium talk), U Hamburg (seminar talk), MPIfM Bonn (seminar talk), U Jena (speaker at workshop "Classical and quantum symmetries in mathematics and physics"), LMU Mnchen München (seminar talks), U Luxembourg (colloquium talk), Institute of Science and Technology Austria (seminar talk), Heriot-Watt University (seminar talk).

List of talks given by guest scientists

Claudia Scheimbauer (MPIfM Bonn)	Factorization algebras
Alberto Cattaneo (U Zurich)	Perturbative quantum gauge theories on manifolds with boundary
Manuel Bärenz (U Bamberg)	The half-twist

List of talks given by guest scientists in the course of the Simons Lecture Series

Claudia Scheimbauer (MPI Bonn)	Operads, factorization algebras, and (topological) quantum field theory with a flavor of higher categories
Paul Wedrich (Imperial College London)	Knot homologies and higher representation theory
Florian Schätz (U Luxembourg)	Mathematical aspects of the BV formalism

Publications and preprints contributed

N. Carqueville, Daniel Murfet, *Adjunctions and defects in Landau-Ginzburg models*, Advances in Mathematics **289** (2016), 480–566, [arXiv:1208.1481 [math.AG]].

N. Carqueville, Catherine Meusburger, Gregor Schaumann, *3-dimensional defect TQFTs and their tricategories*, [arXiv:1603.01171 [math.QA]].

N. Carqueville, *Lecture notes on 2-dimensional defect TQFT*, [arXiv:1607.05747 [math.QA]].

Junior Research Fellows Programme

The Junior Research Fellowship Programme supports external or local graduate students and recent postdocs (at most 5 years past receiving their PhD) to work on a project of their own in mathematics or physics that is either connected to a research direction carried out at the University of Vienna or to an ESI thematic programme. The ESI provides support for a Junior Research Fellow to work at the ESI for a time period between one and four months.

Riccardo Scala: Renormalization in dislocation mechanics

Riccardo Scala (U Pavia): September 1 – December 27, 2016

Report

The main topics of my research during the four-month stay at ESI were the analysis of a 2-dimensional model for dislocations, and its connection with finite-plasticity. The work carried on during the period in Vienna had previously initiated by me and coauthors, Ilaria Lucardesi (École des Mines de Nancy, Nantes, France), Marco Morandotti (TUM, Munich, Germany), and Davide Zucco (Politecnico di Torino, Turin, Italy), and then finalized in November 2016. In the meanwhile I had strong interactions with Prof. Ulisse Stefanelli (University of Vienna) and other researchers from his group. We had then the opportunity to start collaborations on some analysis of models of finite plasticity, and their connections with dislocations and damage. In particular we initiated two works, one consisting in the mathematical justification of a linear model for plasticity, obtained as the approximation by a finite elastoplastic network subjected to smaller and smaller deformations. On the other hand, we studied a model of plasticity coupling damage. This analysis started in collaboration with Prof. Jan Zeman (Czech Technical University of Prague) and David Melching (University of Vienna), and is still a work in progress.

Dislocations are line *defects* in crystals related to the discontinuity of the displacement and stress tensor (see, e.g., [N]). Their presence is observed in materials as crystals and metals, and because of their nature are considered responsible for the plastic behaviour of deformations of the solid. In single crystals these lines might appear as isolated loops as well as complex networks called *clusters*. Our approach and analysis was based on the so called *core radius* approach. The setting consists in considering a 2-dimensional open set, crossed by screw dislocations, representing the section of a cylinder containing vertical dislocations. Thus, the dislocations in turn become points in the section. This setting was first introduced in [CG], and then considered in many other recent works by many authors. The *core radius* approach consists in putting a disk $B_\varepsilon(x)$ with a small radius ε centered at the dislocation point x, and then considering a quadratic energy of the deformation outside such ball. This is required as the strain is not square integrable around a dislocation, as the energy is proved to diverge as $|\log\varepsilon|$ as the radius ε goes to zero. The core radius approach is a very common method to treat energies which are singular in the neighbourhood of points (lines or surfaces). Similar approaches have been used also for the Ginzburg-Landau functionals (see, e.g., [SS]), and is the standard method in order to analyse the asymptotic behaviour of the energies. Indeed, using ad hoc rescaling, one is lead to study the limit of such energies in terms of Γ-convergence and homogenization (see, e.g., [GLP], [P]).

Since the energy diverges as $|\log\varepsilon|$, it is usually common to rescale the functional by dividing by $|\log\varepsilon|$. We propose a new approach, consisting by considering the functionals $F^\varepsilon = E^\varepsilon - N|\log\varepsilon|$, where E^ε is the elastic energy of a deformed medium containing N dislocations. In some sense, with the rescaling obtained by dividing by $|\log\varepsilon|$, one looses informations on the position of the dislocations. Our renormalisation, which consists on subtracting the leading term in the asymptotic of the energy as ε goes to 0, leads to a different Gamma limit whose form and value strongly depends on the position of the dislocations and on the Dirichlet boundary datum of the deformation. In [LMSZ] we show that F^ε converges to a specific functional F^0, which provides important informations on the mutual interactions of dislocations. First, we show that with a fixed Dirichlet boundary condition, the dislocations tends to remain inside the domain, far from the boundary. Moreover they tend to stay apart each others, a behaviour that is observed in simulations and experiments, and is mathematically proved and well-known for other dislocations settings.

In November 2016 I started a collaboration with Prof. Ulisse Stefanelli (University of Vienna) consisting on the analysis of the nonlinear model for plasticity proposed in [MM2] and its behaviour for *small deformations*. As usual in finite plasticity, the model is based on the *multiplicative decomposition* of the deformation gradient $F = F_{el}F_p$ in an elastic and plastic part. The elastic energy depends on the elastic part F_{el} and its minors, while the plastic part of the deformation gradient plays a crucial role for hardening properties of the material. Usually in these models the energy satisfies suitable coerciveness and growth conditions, and is bounded from below by the norm of suitable space derivatives of F_p (see, e.g., [MM1]). In [MM2] the energy contains a regularising term of the form $\|\mathrm{curl} F_p\|^q_{L^q}$. We then consider this model, and in the spirit of [MS], we assume that the deformation gradient takes the form $F = I + \varepsilon\nabla u$, with ε a small parameter. According to the growth condition of the energetic terms, we rescale them multiplying by a suitable negative power of ε and then consider the limit as ε tends to 0 in terms of Γ convergence. Our contribution relies on the result stating that the rescaled functional converges to a limit which provides a linear model for plasticity involving a quadratic term in $\mathrm{curl} F_p$. The quantity $\mathrm{curl} F_p$ is somehow related to the presence (density) of dislocations inside a crystal. This connection is still to be clarified mathematically (for instance by homogenisation techniques) and is the object for future works.

In the meanwhile, we begun a new work with the aim of defining a model which, together with plasticity, could take into account also the *damage* of an elastic body. There are already linear models considering such coupling, but none of them is versatile for large deformations. The final target of this work is to provide the existence of a quasistatic evolution driven by an energy functional depending on the variables F_{el}, F_p, and z, a positive valued function whose role is to describe the state of damage of the material. We follow the abstract theory of rate-independent systems [MR], and adapt some standard results to our situations according with suitable coerciveness conditions on our functionals. This is still a work in progress, and we hopefully plan to carry on and to enlarge to other future collaborations.

References

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Preprint *http://cvgmt.sns.it/paper/3209/*.

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[P] M. Ponsiglione, *Elastic energy stored in a crystal induced by screw dislocations: from discrete to continuous*, SIAM J. Math. Anal., **39**(2), 449–469, (2007).

[SS] E. Sandier, S. Serfaty, *Limiting vorticities for the Ginzburg-Landau equations*, Duke Math. J., **117**, (2003), 403-446.

Publications and preprints contributed

I. Lucardesi, M. Morandotti, R. Scala, D. Zucco, *The location of a dislocation in a single crystal with prescribed Dirichlet boundary datum*, submitted (2016),
Preprint *http://cvgmt.sns.it/paper/3209/.*

R. Scala and U. Stefanelli, *Linearization in incremental finite plasticity*, in preparation.

D. Melching, R. Scala, U. Stefanelli, J. Zeman, *Damage model for plastic materials at finite strains*, in preparation.

Seminars and colloquia outside main programmes and workshops

387 seminar and colloquia talks have taken place at the ESI in 2016.

2016 02 18, A. Lubotzky: Erwin Schrödinger Lecture: ”Ramanujan complexes and topological expanders”
2016 02 29, C. Scheimbauer: “Simons Lecture Series: Operads, factorization algebras, and (topological) quantum field theory with a flavor of higher categories”, I
2016 03 01, C. Scheimbauer: “Simons Lecture Series: Operads, factorization algebras, and (topological) quantum field theory with a flavor of higher categories”, II
2016 03 02, C. Scheimbauer: “Simons Lecture Series: Operads, factorization algebras, and (topological) quantum field theory with a flavor of higher categories”, III
2016 03 03, C. Scheimbauer: “Simons Lecture Series: Operads, factorization algebras, and (topological) quantum field theory with a flavor of higher categories”, IV
2016 03 04, C. Scheimbauer: “Simons Lecture Series: Operads, factorization algebras, and (topological) quantum field theory with a flavor of higher categories”, V
2016 03 15, E. Lieb: “A Pfaffian formula for monomer-dimer partition functions”
2016 07 19, F. Schätz: “The unit interval, Bernoulli numbers, and the Magnus expansion”
2016 07 22, R. Bandiera: “Higher Deligne groupoids”
2016 10 17, P. Wedrich: “Knot homologies and higher representation theory”, I
2016 10 18, P. Wedrich: “Knot homologies and higher representation theory”, II
2016 10 19, P. Wedrich: “Knot homologies and higher representation theory”, III
2016 10 20, P. Wedrich: “Knot homologies and higher representation theory”, IV
2016 10 21, P. Wedrich: “Knot homologies and higher representation theory”, V
2016 11 09, E. Lieb: “A liquid-solid phase transition in a simple model for swarming”
2016 12 16, N. Schappacher: Erwin Schrödinger Lecture: “Mathematics, Physics, the search for a new man, and French-German politics - Claude Chevalley’s challenges in the 1930s”

ESI Research Documentation

ESI research in 2016: publications and arXiv preprints

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

AGS = Measured Group Theory
ASA = Synergies between Mathematical and Computational Approaches to Quantum Many-Body Physics
BLT = Mixing Flows and Averaging Methods
DCC = ESI/CECAM-Workshop: Water at Interfaces: From Proteins to Devices
FMS = Nonlinear Flows
HPS = Challenges and Concepts for Field Theory and Applications in the Era of LHC Run-2
IS = Individual Scientists
JRF = Junior Research Fellow
MF = Current Trends in Descriptive Set Theory
RIT = Research in Teams
SRF = Senior Research Fellows
TSB = Normal Numbers: Arithmetic, Computational and Probabilistic Aspects

THEMATIC PROGRAMMES

Measured Group Theory (AGS)

L. Garncarek, *Mini-course: property of rapid decay*, arXiv:1603.06730 [math.GR].

Ś. R. Gal, J. Gismatullin, *Uniform symplicity of groups with proximal action*, arXiv:1602.08740 [math.GR].

A. Le Boudec, N. Matte Bon, *Subgroup dynamics and C^*-simplicity of groups of homeomorphisms* , arXiv: 1605.01651 [math.GR].

Ł. Grabowski, T. Schick, *On computing homology gradients over finite fields*, arXiv: 1410.1693 [math.GT].

M. Cavaleri, *Computability of Følner sets*, arXiv: 1606.04293 [math.GR].

G. Racher, *On weak compactness in Fourier algebras*.

Mixing Flows and Averaging Methods (BLT)

V. Araújo, I. Melbourne, *Existence and smoothness of the stable foliation for sectional hyperbolic attractors*, arXiv:1604.06924 [math.DS].

H. Bruin, D. Schleicher, *Hausdorff dimension of biaccessible angles for quadratic polynomials*, http://www.mat.univie.ac.at/ bruin/papers/Biac.pdf,Preprint 2012 and revised 2016 [.pdf].

H. Bruin, J. Bobok, *Constant slope maps and the Vere-Jones classification*, arXiv:1602.06905 [math.DS], Entropy **18(6)**, 234, 2016,
see also http://www.mat.univie.ac.at/ bruin/papers/constantslope.pdf.

H. Bruin, D. Terhesiu, *The Dolgopyat inequality in BV for non-Markov maps*, arXiv:1604.07013 [math.DS], see also `http://www.mat.univie.ac.at/$\sim$bruin/papers/AFU.pdf`, Accepted in Stochastic and Dynamics (will appear shortly).

H. Bruin, I. Melbourne, D.Terhesiu, *Rates of mixing for nonMarkov infinite measure semiflows*, arXiv:1607.08711 [math.DS], see also `http://www.mat.univie.ac.at/$\sim$bruin/papers/BMT.pdf`.

P. Bálint, F. Sélley, *Mean field coupling of identical expanding circle maps*, to appear in Journal of Statistical Physics.

P. Bálint, T. Gilbert, P. Nándori, I. P. Tóth, D. Szász, *On the Limiting Markov Process of Energy Exchanges in a Rarely Interacting Ball-Piston Gas*, J. Stat. Phys, 166 (2017), no. 3-4, 903-925, arXiv:1510.06408 [math.DS].

V. Climenhaga, S. Luzzatto, Y. Pesin, *The geometric approach for constructing Sinai-Ruelle-Bowen measures*, J. Sat. Phys. 166 (2017), no. 3-4, 467-493. 37D25 (58), `https://www.math.uh.edu/~climenha/doc/srb-measures-survey.pdf`.

V. Climenhaga, Y. Pesin, *Building thermodynamics for non-uniformly hyperbolic maps*, `https://www.math.uh.edu/~climenha/doc/nuh-thermodynamics.pdf`.

T. Gilbert, *Heat conduction and the nonequilibrium stationary states of stochastic energy exchange processes* arXiv:1703.01240 [cond-mat.stat-mech].

M. Nicol, A. Török, S. Vaienti, *Central limit theorems for sequential and random intermittent dynamical systems*, arXiv:1510.03214 [math.DS].

W. Bahsoun, B. Saussol, *Linear response in the intermittent family: differentiation in a weighted C^0-norm*, Discrete Contin. Dyn. Syst. 36 (2016), no. 12, 6657-6668, arXiv:1512.01080 [math.DS].

O. Butterley, K. War, *Open Sets of Exponentially Mixing Anosov Flows*, Preprint 2017, arXiv:1609.03512.

I. Melbourne, D. Terhesiu, *Renewal theorems and mixing for non Markov flows with infinite measure.* Preprint January 2017. arXiv: 1701.08440.

H. Bruin, M. F. Demers, M. Todd, *Hitting and escaping statistics: mixing, targets and holes.* Preprint 2017, arXiv:1609.01196.

Nonlinear Flows (FMS)

G. Akagi, M. Efendiev, *Allen-Cahn equation with strong irreversibility*, preprint 2016.

G. Akagi, S. Melchionna, U. Stefanelli, *Weighted Energy-Dissipation approach to dou-bly-nonlinear problems on the half line*, J. Evol. Equ., 2017, to appear.

E. A. Carlen, J. Maas, *Gradient flow and entropy inequalities for quantum Markov semigroups with detailed balance*, arXiv:1609.01254 [math.OA].

L. Desvillettes, K. Fellner, B. Q. Tang, *Trend to equilibrium for reaction-diffusion systems arising from complex balanced chemical reaction networks*, SIAM J. on Mathematical Analysis, to appear.

K. Fellner, B. Q. Tang, *Explicit exponential convergence to equilibrium for nonlinear reaction-diffusion systems with detailed balance condition*' Nonlinear Analysis, to appear.

M. Friedrich, P. Piovano, U. Stefanelli, *The geometry of C_{60}: a rigorous approach via Molecular Mechanics*, SIAM J. Appl. Math. 76 (2016), 2009–2029.

D. Grandi, U. Stefanelli, *Existence and linearization for the Souza-Auricchio model at finite strains*, Submitted, 2016.

D. Grandi, U. Stefanelli, *Finite plasticity in $P^T P$. Part II: quasistatic evolution and linearization*, Submitted, 2016

E. Mainini, H. Murakawa, P. Piovano, U. Stefanelli, *Carbon-nanotube geometries as optimal configurations*, Submitted, 2016.

S. Melchionna, E. Rocca, *Varifold solutions of a sharp interface limit of a diffuse interface model for tumor growth*, arXiv:1610.04478 [math.AP].

L. Minotti, G. Savaré, *Viscous corrections of the Time Incremental Minimization Scheme and Visco-Energetic Solutions to Rate-Independent Evolution Problems*, arXiv:1606.03359 [math.AP].

Challenges and Concepts for Field Theory and Applications in the Era of LHC Run-2 (HPS)

Y.-T. Chien, I. Vitev, *Probing the hardest branching of jets in heavy ion collisions*, arXiv:1608.07283 [hep-ph].

M. A. Ebert, F. F. Tackmann, *Resummation of Transverse Momentum Distributions in Distribution Space*, JHEP **1702**, 110 (2017), arXiv:1611.08610 [hep-ph].

S. Gangal, J. R. Gaunt, M. Stahlhofen, F. J. Tackmann, *Two-Loop Beam and Soft Functions for Rapidity-Dependent Jet Vetoes*, arXiv:1608.01999 [hep-ph].

A. Vladimirov, *Soft factors for double parton scattering at NNLO*, arXiv:1608.04920 [hep-ph].

M. Butenschoen, B. Dehnadi, A. H. Hoang, V. Mateu, M. Preisser and I. W. Stewart, *Top Quark Mass Calibration for Monte Carlo Event Generators*, Phys. Rev. Lett. **117**, no. 23, 232001 (2016), arXiv:1608.01318 [hep-ph].

A. H. Hoang, A. Jain, C. Lepenik, V. Mateu, M. Preisser, I. Scimemi and I. W. Stewart, *The MSR Mass and the $O(\Lambda_{\rm QCD})$ Renormalon Sum Rule*, arXiv:1704.01580 [hep-ph].

P. Pietrulewicz, D. Samitz, A. Spiering and F. J. Tackmann, *Factorization and Resummation for Massive Quark Effects in Exclusive Drell-Yan*, arXiv:1703.09702[hep-ph].

S. Abreu, R. Britto, C. Duhr and E. Gardi, *The algebraic structure of cut Feynman integrals and the diagrammatic coaction*, arXiv:1703.05064 [hep-th].

S. Abreu, R. Britto, C. Duhr and E. Gardi, *Cuts from residues: the one-loop case*, arXiv:1702.03163 [hep-th].

S. Caron-Huot, E. Gardi and L. Vernazza, *Two-parton scattering in the high-energy limit*, arXiv:1701.0524 [hep-ph].

A. J. Larkoski, I. Moult and D. Neill, *The Analytic Structure of Non-Global Logarithms: Convergence of the Dressed Gluon Expansion*, JHEP **1611**, 089 (2016), arXiv:1609.04011 [hep-ph].

I. Feige, D. W. Kolodrubetz, I. Moult and I. W. Stewart, *A Complete Basis of Helicity Operators for Subleading Factorization*, arXiv:1703.03411 [hep-ph].

I. Moult, I. W. Stewart and G. Vita, *A Subleading Operator Basis and Matching for* $gg \to H$, arXiv:1703.03408 [hep-ph].

M. Diehl, J. R. Gaunt and K. Schnwald, *Double hard scattering without double counting*, arXiv:1702.06486 [hep-ph].

I. Moult, L. Rothen, I. W. Stewart, F. J. Tackmann and H. X. Zhu, *Subleading Power Corrections for N-Jettiness Subtractions*, arXiv:1612.00450 [hep-ph].

R. Boughezal, X. Liu and F. Petriello, *Power Corrections in the N-jettiness Subtraction Scheme*, arXiv:1612.02911 [hep-ph].

D. Neill, I. Scimemi and W. J. Waalewijn, *Jet axes and universal transverse-momentum-dependent fragmentation*, arXiv:1612.04817 [hep-ph].

Synergies between Mathematical and Computational Approaches to Quantum Many-Body Physics (ASA)

N. Wentzell, G. Li, A. Tagliavini, C. Taranto, G. Rohringer, K. Held, A. Toschi, S. Andergassen, *High-frequency asymptotics of the vertex function: diagrammatic parametrization and algorithmic implementation*, arXiv:1610.06520.

T. Schäfer, A. Toschi, and A. Eberlein, *Magnetic fluctuations in the cuprates; role of frustration.*

C. Watzenböck, M. Edelmann, D. Springer, G. Sangiovanni, A. Toschi, *Magnetic dynamics in the different families of iron pnictides and chalcogenides.*

C. Hille X. Cao, C. Honerkamp, P. Hansmann, S. Andergassen, *Multi-orbital correlation effects in the Emery model.*

Fabian B. Kugler, Jan von Delft, *Multiloop functional renormalization group that sums up all parquet diagrams,* arXiv:1703.06505.

WORKSHOPS

Normal Numbers: Arithmetic, Computational and Probabilistic Aspects (TSB)

N. Alvarez, V. Becher, O. Carton, *Finite-state Independence and Normal Sequences*, arXiv: 1702.00320 [cs.FL].

V. Becher, Adrian-Maria Scheerer, Theodore Slaman, *On absolutely normal numbers and their discrepancy estimate*, arXiv:1702.04072 [math.NT],[cs.OH].

V. Becher, Sergio A. Yuhjtman, *On absolutely normal and continued fraction normal numbers*, arXiv:1704.03622 [math,NT].

F. Ekström, T. Persson, *Hausdorff dimension of random limsup sets*, arXiv: 1612.07110 [math. CA].

El Houcein el Abdalaoui, *On the Erdös flat polynomials problem*, arXiv:1609.03435 [math.CO].

Current Trends in Descriptive Set Theory (MF)

R. Camerlo, R. Carroy, A. Marcone, *Linear orders: when embeddability and epimorphism*, arXiv: 1701.02020 [math.LO].

V. Gregoriades, *The Dyck and Preiss separation uniformly*.

F. Calderoni and L. Motto Ros, *Universality of group embeddability*, arXiv: 1702.03787v2 [math.LO].

S. Gao, S. Jackson, E. Krohne, and B. Seward, *Continuous combinatorics of abelian group actions.*

P. Schlicht, D. Schrittesser, S. Uhlenbrock, and T. Reinert, *Variants of the Lebesgue density theorem.*

J. Zapletal, *Borel reducibility invariants in higher set theory.*

RESEARCH IN TEAMS PROGRAMME (RIT)

P. Poier, S. Egorov, Ch. Likos, R. Blaak, *Concentration-induced planar-to-homeotropic anchoring transition of stiff ring polymers on hard walls*, published in the journal of The Royal Society of Chemistry, `http://dx.doi.org/10.1039/c6sm01453d`, 2016.

R. Bandiera, F. Schätz, *Eulerian idempotent, pre-Lie logarithm and combinatorics of trees*, arXiv:1702.08907 [math.CO].

SENIOR RESEARCH FELLOWS PROGRAMME (SRF)

Y. Brenier, X. Duan, *From conservative to dissipative systems through quadratic change of time with application to the curve-shortening flow*, arXiv:1703.03404 [math.AP].

T. Gallouët, Q. Mérigot, *A Lagrangian scheme for the incompressible Euler equation using optimal transport*, arXiv:1605.00568 [math.NA].

A. Constantin, R.S. Johnson, *A nonlinear, three dimensional model for ocean flows, motivated by some observations of the Pacific Equatorial Undercurrent and thermocline*, 2016, submitted.

A. Constantin, R.S. Johnson, *Large gyres as a shallow-water asymptotic solution of Eulers equation in spherical coordinates*, 2016, submitted.

SIMONS JUNIOR PROFESSOR NILS CARQUEVILLE

N. Carqueville, Daniel Murfet, *Adjunctions and defects in Landau-Ginzburg models*, Advances in Mathematics **289** (2016), 480–566, arXiv:1208.1481 [math.AG].

N. Carqueville, Catherine Meusburger, Gregor Schaumann, *3-dimensional defect TQFTs and their tricategories*, arXiv:1603.01171 [math.QA].

N. Carqueville, *Lecture notes on 2-dimensional defect TQFT*, arXiv:1607.05747 [math.QA].

JUNIOR RESEARCH FELLOWS PROGRAMME (JRF)

I. Lucardesi, M. Morandotti, R. Scala, D. Zucco, *The location of a dislocation in a single crystal with prescribed Dirichlet boundary datum*, submitted (2016). Preprint http://cvgmt.sns.it/paper/3209/.

R. Scala and U. Stefanelli, *Linearization in incremental finite plasticity*, in preparation.

D. Melching, R. Scala, U. Stefanelli, J. Zeman, *Damage model for plastic materials at finite strains*, in preparation.

ESI research in previous years: additional prints and arXiv preprints

The following papers complement the ESI preprints already taken into account in the previous years.
ABCF = 4th Central European Relativity Seminar, 2014
BDF = Algebraic quantum field theory: Its status and its future, 2014
EPDI = European Post-Doctoral Fellow
FGK = Forcing, Large Cardinals and Descriptive Set Theory, 2013
RYZ = Topological phases of quantum matter, 2014

P.T. Chruściel, M. Hörzinger, *Compact singularity-free Kerr-Newman-de Sitter instantons*, arXiv:1612.08569 [gr-qc], ABCF.

P.T. Chruściel, *Long time existence from interior gluing*, arXiv:1612.04523 [gr-qc], ABCF.

L. Bieri, P.T. Chruściel, *Future-complete null hypersurfaces, interior gluings, and the Trautman-Bondi mass*, arXiv:1612.04359 [gr-qc], ABCF.

Ch. Hilweg, F. Massa, D. Martynov, N. Mavalvala, P.T. Chruściel, P. Walther, *Gravitationally induced phase shift on a single photon*, arXiv: 1612.03612 [gr-qc], ABCF.

P.T. Chruściel, E. Delay, *Non-singular spacetimes with a negative cosmological constant: II. static solutions of the einstein-maxwell equations*, arXiv:1612.00281 [gr-qc], ABCF.

P.T. Chruściel, *Anti-gravity à la Carlotto-Schoen*, arXiv:1611.01808 [gr-qc], ABCF.

P.T. Chruściel, E. Delay, *On Carlotto-Schoen-type scalar-curvature gluings*, arXiv:1611.00893 [gr-qc], ABCF.

C. Jiang, F. Günther, J. Wallner, H. Pottmann, *Measuring and controlling fairness of triangulations*, to appear in Advances in Architectural Geometry, Springer-Verlag, 2016, EPDI 2015.

A.I. Bobenko, F. Günther, *Discrete complex analysis on planar quad-graphs.*, to appear in Advances in Discrete Differential Geometry, Springer-Verlag, Berlin Heidelberg New York, Pages 57-132, 2016, http://link.springer.com/chapter/10.1007/978-3-662-50447-5_2, EPDI 2015.

Ch. J. Fewster, *An analogue of the Coleman-Mandula theorem for quantum field theory in curved spacetimes*, arXiv: 1609.02705 [math-ph], BDF.

P. Holy, P. Lücke, *Simplest possible locally definable well-orders*, published in the Journal of Fundamenta Mathematicae 236, Warszawa, 2017, Pages 101-139, FGK.

T.A. Loring, F. Vides, *Local Matrix Homotopies and Soft Tori*, arXiv: 1605.06590 [math.OA], RYZ.

List of all visitors in 2016

580 scientists have visited the ESI in 2016.

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

AGS = Measured Group Theory
ASA = Synergies between Mathematical and Computational Approaches to Quantum Many-Body Physics
BLT = Mixing Flows and Averaging Methods
DCC = ESI/CECAM-Workshop: Water at Interfaces: From Proteins to Devices
FMS = Nonlinear Flows
HPS = Challenges and Concepts for Field Theory and Applications in the Era of LHC Run-2
IS = Individual Scientists
JRF = Junior Research Fellow
MF = Current Trends in Descriptive Set Theory
RIT = Research in Teams
SRF = Senior Research Fellows
TSB = Normal Numbers: Arithmetic, Computational and Probabilistic Aspects

Aaronson Jon, Tel-Aviv U; 08.05.2016 - 22.05.2016, BLT;
Abert Miklos, Rényi Institute, Budapest; 31.01.2016 - 20.02.2016, AGS;
Achleitner Franz, TU Vienna ; 30.05.2016 - 15.07.2016, FMS;
Adam Alexander, UPMC, Paris; 30.04.2016 - 06.05.2016, BLT;
Adams Stefan, U of Warwick; 19.09.2016 - 27.09.2016, ASA;
Aistleitner Christoph, TU Graz; 13.11.2016 - 18.11.2016, TSB;
Akagi Goro, Tohoku U/TU Munich; 31.05.2016 - 17.06.2016, FMS;
Akurugodage Kasun Fernando Buddhima, U of Maryland, College Park; 16.04.2016 - 26.04.2016, BLT;
Alavi Ali, MPI Stuttgart; 25.09.2016 - 30.09.2016, ASA; 11.10.2016 - 13.10.2016, ASA;
Alekseev Anton, ; 21.01.2016 - 23.01.2016, IS;
Alekseev Vadim, U Göttingen; 30.01.2016 - 25.02.2016, AGS;
Alexandre Martin, U Vienna; 18.01.2016 - 18.03.2016, AGS;
Alioli Simone, CERN, Geneva; 18.07.2016 - 29.07.2016, HPS;
Alpeev Andrei Viktorovich, St. Petersburg State U; 31.01.2016 - 20.02.2016, AGS;
Alvarez Nicolás, U Nacional del Sur, Bahia Blanca, Argentina; 13.11.2016 - 19.11.2016, TSB;
Ambrosio Luigi, Scuola Normale Superiore, Pisa; 15.06.2016 - 24.06.2016, FMS;
Anders Frithof, TU Dortmund; 02.10.2016 - 10.10.2016, ASA;
Anusic Ana, U of Zagreb; 23.05.2016 - 27.05.2016, BLT;
Araújo Vitor, U Federal da Bahia, Salvador, Brazil; 17.04.2016 - 22.04.2016, BLT;
Arnold Anton, TU Wien; 30.05.2016 - 03.07.2016, FMS;
Assaad Fakher, U of Würzburg; 29.09.2016 - 30.09.2016, ASA;

Azmi Mandana, U Vienna; 01.12.2016 - 01.12.2016, DCC;
Baake Michael, U Bielefeld; 12.11.2016 - 16.11.2016, TSB;
Bach Volker, TU Braunschweig; 26.09.2016 - 28.09.2016, ASA;
Backhausz Agnes, Eötvös Loránd U, Budapest; 14.02.2016 - 19.02.2016, AGS;
Bader Uri, Weizmann Institut, Rehovot; 14.02.2016 - 19.02.2016, AGS;
Bagchi Biman, SSCU, I.I. SC., Bengaluru, India; 27.11.2016 - 02.12.2016, DCC;
Bahsoun Wael, Loughborough U; 24.04.2016 - 29.04.2016, BLT;
Bailey David H., U of California, Davis; 12.11.2016 - 19.11.2016, TSB;
Bakker Huib J., AMOLF, Amsterdam; 29.11.2016 - 01.12.2016, DCC;
Baladi Viviane, CNRS, Paris; 01.05.2016 - 21.05.2016, BLT;
Bálint Peter, Technical U Budapest; 08.04.2016 - 09.04.2016, BLT; 18.04.2016 - 22.04.2016, BLT; 01.05.2016 - 22.05.2016, BLT;
Bandiera Ruggero, U of Rome, La Sapienza; 18.07.2016 - 16.08.2016, RIT;
Banfi Andrea, U Sussex; 17.07.2016 - 22.07.2016, HPS;
Barany Balasz, BUTE Budapest; 08.04.2016 - 08.04.2016, BLT; 16.05.2016 - 18.05.2016, BLT;
Barril Xavier, ICREA & U of Barcelona; 29.11.2016 - 02.12.2016, DCC;
Basso Gianluca, U de Lausanne; 11.12.2016 - 17.12.2016, MF;
Bauer Christian, Lawrence Berkeley National Lab; 17.07.2016 - 22.07.2016, HPS;
Becher Thomas, U Bern; 02.08.2016 - 12.08.2016, HPS;
Becher Veronica, U de Buenos Aires; 11.11.2016 - 19.11.2016, TSB; 19.11.2016 - 17.12.2016, IS;
Becker Oren, Hebrew U of Jerusalem; 31.01.2016 - 21.02.2016, AGS;
Belarif Kamel, LMBA, U Brest; 17.04.2016 - 22.04.2016, BLT;
Beneke Martin, TU Munich; 01.08.2016 - 07.08.2016, HPS;
Berghout Steven, Leiden U; 17.04.2016 - 22.04.2016, BLT;
Berlai Federico, U Vienna; 18.01.2016 - 18.03.2016, AGS;
Bernard Denis, CNRS, Paris; 24.06.2016 - 26.06.2016, SAB;
Bernshteyn Anton, U of Illinois, Urbana-Champaign; 11.12.2016 - 17.12.2016, MF;
Bertrand-Mathis Anne, U of Poitiers ; 13.11.2016 - 22.11.2016, TSB;
Bianchini Stefano, SISSA, Trieste; 26.06.2016 - 01.07.2016, FMS;
Bianco Valentino, U Vienna; 29.11.2016 - 02.12.2016, DCC;
Bieniek Mateusz, The Francis Crick Institute & Kingś College London; 26.11.2016 - 02.12.2016, DCC;
Biesheuvel Maarten, WETSUS; 29.11.2016 - 01.12.2016, DCC;
Biswas Arindam, U Paris Sud XI, Orsay; 30.01.2016 - 09.02.2016, AGS;
Bittner Alexander, Ikerbasque, Bilbao; 29.11.2016 - 02.12.2016, DCC;
Blumenthal Alex, Courant Institute of Mathematical Science, New York; 30.04.2016 - 16.05.2016, BLT;
Bobok Josef, Czech Technical U Prague; 05.04.2016 - 09.04.2016, BLT;
Bonaldi Francesco, U de Montpellier; 31.05.2016 - 08.06.2016, FMS; 31.05.2016 - 08.06.2016, FMS; 10.07.2016 - 15.07.2016, FMS;
Booth George, Kings College London; 03.10.2016 - 07.10.2016, ASA;
Boughezal Radja, Argonne National Laboratory, USA; 13.07.2016 - 14.08.2016, HPS;
Bouljihad Hohamed, UMPA, Lyon; 01.02.2016 - 12.02.2016, AGS;
Boutonnet Remi, U Bordeaux 1; 07.02.2016 - 20.02.2016, AGS;
Braides Andrea, U of Rome Tor Vergata; 26.06.2016 - 01.07.2016, FMS;
Brass Martin, U Heidelberg; 25.09.2016 - 01.10.2016, ASA;
Braun Daniel, U Vienna; 29.11.2016 - 02.12.2016, DCC;

Brazda Katharina, U Vienna; 06.06.2016 - 15.07.2016, FMS;
Brenier Yann, CNRS, Palaiseau; 12.04.2016 - 30.04.2016, SRF; 19.05.2016 - 06.07.2016, SRF;
Bromberg Michael, Bristol U; 15.04.2016 - 22.04.2016, BLT;
Bru Jean-Bernard, U of Basque Country; 02.10.2016 - 09.10.2016, ASA;
Brugger Rahel, U Göttingen; 31.01.2016 - 19.02.2016, AGS;
Bruin Henk, U Vienna; 04.04.2016 - 08.04.2016, BLT; 18.04.2016 - 25.05.2016, BLT;
Bruni Fabio, U di Roma Tre; 30.11.2016 - 02.12.2016, DCC;
Bufetov Alexander, CNRS, Marseille; 14.05.2016 - 23.05.2016, BLT;
Bugeaud Yann, U de Strasbourg; 11.11.2016 - 18.11.2016, TSB;
Bunimovich Leondi, Georgia Institute of Technology, Atlanta; 09.05.2016 - 22.05.2016, BLT;
Burns Keith, Northwestern U, Evanston; 16.04.2016 - 01.05.2016, BLT;
Butterley Oliver, ICTP, Trieste; 24.04.2016 - 21.05.2016, BLT;
Calderoni Filippo, U di Torino; 11.12.2016 - 17.12.2016, MF;
Camerlo Riccardo, DIMAT - Polytechnico of Turin; 11.12.2016 - 16.12.2016, MF;
Cantrell Mike, U of Illinois at Chicago; 31.01.2016 - 13.02.2016, AGS;
Caprace Pierre-Emmanuel, UC Louvain, IRMP; 31.01.2016 - 05.02.2016, AGS; 21.02.2016 - 24.02.2016, AGS;
Carderi Alessondro, TU Dresden; 31.01.2016 - 20.02.2016, AGS;
Carey Alan L., ANU Canberra; 23.08.2016 - 28.08.2016, IS;
Carlen Eric, Rutgers U, Piscataway; 31.05.2016 - 09.06.2016, FMS; 11.06.2016 - 30.06.2016, FMS;
Carpone Barbara, U Vienna; 29.11.2016 - 02.12.2016, DCC;
Carrillo Jose Antonio, Imperial College London; 27.06.2016 - 01.07.2016, FMS;
Carroy Raphaël, KGRC, U Vienna; 12.12.2016 - 16.12.2016, MF;
Carton Oliver, U Paris Diderot; 13.11.2016 - 18.11.2016, TSB;
Carvalho Maria da Conceicao, U of Lisbon/U of Rutgers; 12.06.2016 - 25.06.2016, FMS;
Cashen Christopher, U Wien; 18.01.2016 - 18.03.2016, AGS;
Cavaleri Matteo, Sapienza Roma/U Vienna; 01.02.2016 - 19.02.2016, AGS;
Cavaterra Cecilia, U degli Studi di Milano; 06.06.2016 - 10.06.2016, FMS;
Cecchi B. Paulina, U of Santiago de Chile (USACH); 30.01.2016 - 14.02.2016, AGS;
Chalupa Patrick, TU Vienna; 26.09.2016 - 07.10.2016, ASA;
Chaplin Martin, London South Bank U; 28.11.2016 - 02.12.2016, DCC;
Chart Seth, U of Victoria; 01.05.2016 - 07.05.2016, BLT;
Chen Li, ; 03.06.2016 - 30.06.2016, FMS;
Chew Amyas, MIT, Cambridge; 20.07.2016 - 12.08.2016, HPS;
Chien Yang-Ting, Los Alamos National Laboratory; 25.07.2016 - 29.07.2016, HPS;
Chodounsky David, Academy of Sciences of The Czech Republic, Prague; 11.12.2016 - 16.12.2016, MF;
Cinc Jernej, U Vienna; 08.04.2016 - 22.05.2016, BLT;
Claramunt Joan, U Autónoma de Barcelona (UAB); 31.01.2016 - 14.02.2016, AGS;
Claußnitzer Anton, TU Dresden; 31.01.2016 - 14.02.2016, AGS;
Climenhaga Vaughn, U of Houston; 24.04.2016 - 30.04.2016, BLT;
Coluzza Ivan, U Vienna; 29.11.2016 - 02.12.2016, DCC;
Conley Clinton T., Carnegie Mellon U, Pittsburgh; 10.12.2016 - 17.12.2016, MF;
Conze Jean-Pierre, IRMAR, U of Rennes 1; 08.05.2016 - 15.05.2016, BLT;
Coons Michael, U of Newcastle, Callaghan; 12.11.2016 - 23.11.2016, TSB;
Cordeiro Luiz Gustavo, U of Ottawa; 27.01.2016 - 23.02.2016, AGS;
Dal Maso Gianni, SISSA, Trieste; 12.06.2016 - 22.06.2016, FMS;
Das Kajal, Ecole Normale Superieure de Lyon; 30.01.2016 - 12.02.2016, AGS;

Dasgupta Mrinal, U Manchester; 24.07.2016 - 29.07.2016, HPS;
Daus Esther, TU Vienna; 13.06.2016 - 17.06.2016, FMS;
Davoli Elisa, U Vienna; 30.05.2016 - 15.07.2016, FMS;
Debs Gabriel, Institut Mathematique de Jussieu, Paris; 11.12.2016 - 17.12.2016, MF;
De Chiffre Marcus, TU Dresden ; 31.01.2016 - 19.02.2016, AGS;
Degond Pierre, Imperial College London; 05.07.2016 - 08.07.2016, FMS;
Dehnadi Bahman, U Vienna; 18.07.2016 - 12.08.2016, HPS;
Dekimpe Karel, KU Leuven; 23.05.2016 - 27.05.2016, IS;
De Koninck Jean-Marie, U Laval, Quebec; 13.11.2016 - 17.11.2016, TSB;
de Laat Tim, KU Leuven; 14.02.2016 - 19.02.2016, AGS;
Demers Mark, Fairfield U; 01.05.2016 - 21.05.2016, BLT; De Simoi Jacopo, U de Paris 7; 02.05.2016 - 11.05.2016, BLT;
Desvillettes Laurent, U Paris Diderot; 12.06.2016 - 17.06.2016, FMS; 10.07.2016 - 12.07.2016, FMS;
Dettmann Carl, U of Bristol; 14.05.2016 - 22.05.2016, BLT;
Deuchert Andreas, IST Austria; 05.10.2016 - 07.10.2016, ASA;
Diehl Markus, DESY, Hamburg; 06.08.2016 - 14.08.2016, HPS;
Dingyu Shao, ITP, U of Bern; .0731.2016 - 13.08.2016, HPS;
Dobbs Neil, U Geneva; 08.05.2016 - 13.05.2016, BLT;
Dolera Emanuele, U di Pavia; 23.06.2016 - 03.07.2016, FMS;
Dolgopyat Dmitry, U of Maryland, College Park; 09.05.2016 - 25.05.2016, BLT;
Doubeault Jean, U Paris-Daupine; 13.06.2016 - 17.06.2016, FMS;
Doucha Michal, Czech Academy of Science, Prague; 31.01.2016 - 12.02.2016, AGS; 12.12.2016 - 15.12.2016, MF;
Dougall Rhiannon, U of Warwick; 17.04.2016 - 23.04.2016, BLT;
Duan Xianglong, Ecole Polytechnique, Palaiseau; 13.06.2016 - 19.06.2016, SRS;
Duhr Claude, Cern, Geneva; 24.07.2016 - 05.08.2016, HPS;
Durand Arnaud, U Paris sud; 13.11.2016 - 18.11.2016, TSB;
Eberlein Andreas, Harvard U; 02.10.2016 - 12.10.2016, ASA; 18.10.2016 - 23.10.2016, ASA;
Ebert Markus, DESY, Hamburg; 18.07.2016 - 29.07.2016, HPS;
Ebli Stefania, U of Padova; 20.01.2016 - 18.03.2016, AGS;
Egorov Sergei, U of Virginia; 01.04.2016 - 31.05.2016, RIT;
Eisert Jens, FU Berlin; 06.10.2016 - 06.10.2016, ASA;
El Abdalaoui El Houcein, U of Rouen Normandy; 13.11.2016 - 18.11.2016, TSB;
Elek Gabor, Lancaster U; 31.01.2016 - 06.02.2016, AGS;
Elekes Márton, Rényi Institute, Budapest; 11.12.2016 - 16.12.2016, MF;
Enss Tilman, U Heidelberg; 02.10.2016 - 07.10.2016, ASA;
Erdös László, IST Austria; 20.05.2016 - 20.05.2016, BLT; 04.10.2016 - 04.10.2016, ASA;
Ershov Mikhail, U of Virginia, Charlottesville; 14.02.2016 - 20.02.2016, AGS;
Eslami Peyman, U of Warwick; 17.04.2016 - 22.05.2016, BLT;
Fan Ai Hua, U Picardie, Amiens; 13.11.2016 - 17.11.2016, TSB;
Faure Frédéric, U Grenoble Alpes; 17.04.2016 - 01.05.2016, BLT;
Feireisl Eduard, Academy of Sciences of the Czech Republic, Prague; 05.06.2016 - 17.06.2016, FMS;
Fellner Klemens, U Graz; 07.06.2016 - 21.06.2016, FMS; 11.07.2016 - 15.07.2016, FMS;
Fernandez Bastien, CNRS, Paris; 01.05.2016 - 05.05.2016, BLT;
Ferov Michal, U Vienna; 18.01.2016 - 18.03.2016, AGS;
Finn-Sell Martin, U Vienna; 10.01.2016 - 18.03.2016, AGS;
Fischer Julian, MPI Leipzig; 06.06.2016 - 12.06.2016, FMS;

Fischer Vera, KGRC, U Vienna; 12.12.2016 - 16.12.2016, MF; Fleissner Florentine, TU Munich; 30.05.2016 - 03.06.2016, FMS; 20.06.2016 - 24.06.2016, FMS; 04.07.2016 - 08.07.2016, FMS;
Fonseca Irene, Carnegie Mellon U, Pittsburgh; 12.06.2016 - 17.06.2016, FMS;
Forkert Dominik, IST Austria; 11.07.2016 - 14.07.2016, FMS;
Forough Marzieh, Institute for Research in fudamental Sciences (IPM), Tehran; 31.01.2016 - 13.02.2016, AGS;
Francese Giancarlo, U de Barcelona; 29.11.2016 - 01.12.2016, DCC;
Francfort Gilles, U Paris Nord; 13.06.2016 - 24.06.2016, FMS;
Friedman Sy-David, KGRC, U Vienna; 12.12.2016 - 16.12.2016, MF;
Friedrich Manuel, U Vienna; 30.05.2016 - 15.07.2016, FMS;
Froyland Gary, U of New South Wales; 07.05.2016 - 11.05.2016, BLT;
Funke Jens, U Bonn; 06.02.2016 - 12.02.2016, AGS;
Gaboriau Damien, UMPA, ENS Lyon; 31.01.2016 - 06.02.2016, AGS; 14.02.2016 - 19.02.2016, AGS;
Gal Swjatoslaw, U Breslau; 01.02.2016 - 20.02.2016, AGS;
Gallouët Thomas, École Polytechnique, Palaiseau; 27.06.2016 - 01.07.2016, SFS;
Garcia Rates Miquel, Catalan Institute of Chemical Research, Tarragona; 28.11.2016 - 02.12.2016, DCC;
Gardi Einan, U Edinburgh; 31.07.2016 - 14.08.2016, HPS;
Garncarek Lukas, Polish Academy of Science, Warszawa; 13.03.2016 - 18.03.2016, AGS;
Garon Arthur, U Vienna; 29.11.2016 - 02.12.2016, DCC;
Garrido Alejandra, U of Geneva; 31.01.2016 - 05.02.2016, AGS;
Garroni Adriana, U of Rome; 13.06.2016 - 17.06.2016, FMS; 26.06.2016 - 01.07.2016, FMS;
Gaunt Jonathan, NIKHEF, Amsterdam; 18.07.2016 - 29.07.2016, HPS;
Gelander Yizhaq (Tsachik), Weizmann Institute, Rehovot; 07.02.2016 - 12.02.2016, AGS;
Gheysens Maxime, École polytechnique Fédérale de Lausanne; 31.01.2016 - 12.02.2016, AGS;
Ghoussoub Nassif, University of British Columbia; 29.05.2016 - 29.06.2016, FMS;
Giacomello Alberto, Sapienza U di Rome; 28.11.2016 - 02.12.2016, DCC;
Giacomin Giambattista, U Paris Diderot; 12.06.2016 - 17.06.2016, FMS;
Gilbert Thomas, U de Bruxelles; 15.05.2016 - 22.05.2016, BLT;
Gismatullin Jakub, U Wroclaw; 01.02.2016 - 19.02.2016, AGS;
Glasner Yair, Ben Gurion U of The Negev; 31.01.2016 - 15.02.2016, AGS;
Glebskiy Lev, IICO-UASLP, (U of San Luis Patosi, Mexico); 16.01.2016 - 20.03.2016, AGS;
Goffer Gil, Weizmann Institute, Rehovot; 31.01.2016 - 11.02.2016, AGS;
Gossart Luc, Institute Fourier, Grenoble; 17.04.2016 - 23.04.2016, BLT;
Gouëzel Sebastien, CNRS, U de Nantes; 01.05.2016 - 07.05.2016, BLT;
Grabner Peter, TU Graz; 14.11.2016 - 18.11.2016, TSB;
Grabowski Lukasz, U of Warwick; 07.02.2016 - 20.02.2016, AGS;
Grandi Diego, U Vienna; 15.06.2016 - 16.07.2016, FMS;
Grasselli Maurizio, Politecnico di Milano; 06.06.2016 - 10.06.2016, FMS;
Grbac Neven, U Rijeka; 06.03.2016 - 15.03.2016, IS;
Grebik Jan, Czech Academy of Science, Prague; 11.12.2016 - 16.12.2016, MF;
Gregoriades Vassilios, U of Turin; 11.12.2016 - 16.12.2016, MF;
Grepstad Sigrid, JKU Linz; 13.11.2016 - 16.11.2016, TSB;
Greschonig Gernot, PH Niederösterreich, Baden; 08.04.2016 - 08.04.2016, BLT; 17.05.2016 - 20.05.2016, BLT;
Grigo Alexander, U of Oklahoma, Norman; 08.05.2016 - 15.05.2016, BLT;
Grigorchuk Rostislav, Texas A & M University, College Station; 14.02.2016 - 19.02.2016,

AGS;
Grosse Harald, U Vienna; 03.10.2016 - 07.10.2016, ASA;
Grothe Hinrich, TU Vienna; 29.11.2016 - 02.12.2016, DCC;
Gruber Dominik, U de Neuchatel; 05.02.2016 - 22.02.2016, AGS;
Grúneis Andreas, MPI Stuttgart; 03.10.2016 - 07.10.2016, ASA;
Guentner Erik, U Hawaii; 15.02.2016 - 19.02.2016, AGS;
Guéritaud Francois, CNRS, Université de Lille-1/U Vienna; 15.02.2016 - 19.02.2016, AGS;
Guivarc'h Yves, IRMAR, U de Rennes 1; 08.05.2016 - 14.05.2016, BLT;
Gull Emanuel, U of Michigan, Ann Arbor; 25.09.2016 - 01.10.2016, ASA;
Gunacker Patrik, TU Vienna; 26.09.2016 - 30.09.2016, ASA;
Guzman Gonzalez Osvaldo, Cenro Ciencias Matemáticas, UNAM, Morelia; 11.12.2016 - 16.12.2016, MF;
Guzzi Marco, U of Manchaster; 24.07.2016 - 29.07.2016, HPS;
Gwiazda Piotr, Polish Academy of Science, Warsaw; 13.06.2016 - 14.06.2016, FMS;
Hagen Mark, U Cambridge; 20.01.2016 - 20.01.2016, AGS;
Hartl Benedikt, TU Wien; 26.09.2016 - 30.09.2016, ASA;
Havenith-Newen Martina, Ruhr U, Bochum; 29.11.2016 - 01.12.2016, DCC;
Haverkort Maurits, U Heidelberg; 05.10.2016 - 07.10.2016, ASA;
Hayes Benjamin Richard , U Vanderbilt; 13.02.2016 - 20.02.2016, AGS;
Haziot Susanna, U Vienna; 30.05.2016 - 15.06.2016, FMS;
Held Karsten, TU Vienna; 26.09.2016 - 07.10.2016, ASA;
Helfgott Harald, U Göttingen; 12.02.2016 - 20.02.2016, AGS;
Hella Olli, Helsinki U; 01.05.2016 - 06.05.2016, BLT;
Herrmann Michael, U of Münster ; 09.07.2016 - 15.07.2016, FMS;
Hille Cornelia, U Tübingen; 21.09.2016 - 05.10.2016, ASA;
Hladky Jan, Czech Academy of Science, Prague; 31.01.2016 - 05.02.2016, AGS;
Hoang André, U Vienna; 18.07.2016 - 12.08.2016, HPS;
Hofmann Johannes, U Würzburg; 21.09.2016 - 30.09.2016, ASA;
Holden Helge, Norwegian U of Science and Technology, Trondheim; 24.06.2016 - 26.06.2016, SAB;
Holland Mark, U of Exeter; 21.04.2016 - 29.04.2016, BLT;
Hornerkamp Carsten, RWTH Aachen; 26.09.2016 - 27.09.2016, ASA; 02.10.2016 - 03.10.2016, ASA;
Hornig Andrew, Los Alamos National Lab ; 24.07.2016 - 29.07.2016, HPS;
Huybrechts Daniel, U Bonn; 24.06.2016 - 27.06.2016, SAB;
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