

ESI

Erwin Schrödinger International Institute
for Mathematical Physics



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$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \Delta \Psi + V \Psi$$

Scientific Report for 2013

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Preface

The Institute and its Mission in 2013

Starting from its beginnings in 1993, the Erwin Schrödinger International Institute for Mathematical Physics (ESI) has always remained true to its commitment: promoting and supporting original scholarship in mathematics and physics at the highest international level through fruitful interactions between scientists from these disciplines. These aims include, in particular, to support research at the U of Vienna, to contribute to its international visibility and appeal, and to stimulate the scientific environment in Austria. On June 1, 2011, as a consequence of a political decision, the ESI was turned into a research centre within the U of Vienna. The institutional transition of the ESI from an independent research institute to a “Forschungsplattform” at the U of Vienna was a complicated process but is now finished. The owner of the building in which the ESI is located, together with the U of Vienna, had to take serious measures to fulfill the requirements for workplace safety and fire prevention and protection. However, the Institute has continued to function during the radical changes to its status and the ongoing construction work at its location. The quality of the programmes was undiminished.

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 organizing *workshops* and *summer schools* at shorter notice;
- (c) by a programme of *Senior Research Fellows* (SRF), who give lecture courses at the ESI for graduate students and post-docs;
- (d) a programme of *Research in Teams*, which offers teams of 2 to 4 *Erwin Schrödinger Institute Scholars* the opportunity to work at the Institute for periods of 1 to 4 months;
- (e) by inviting *individual scientists* who collaborate with members of the local scientific community.

It is the Institute’s foremost objective to advance scientific knowledge ranging over a broad band of fields and themes in mathematics and physics. Creating a space where fruitful collaborations and the exchange of ideas between scientists can unfold is decisive.

In 2013, the Simons Foundation, located in New York, approved funding for the Erwin Schrödinger International Institute for Mathematical Physics to support the five-year appointment of a Simons Junior Professor in Mathematics or Mathematical Physics. During September and October 2013 internal and external evaluations of the 71 applications took place, and as a result seven shortlisted candidates were invited for a research talk at the ESI and respective interviews. Finally, following a suggestion of the hiring committee, the Rector of the U of Vienna offered the Simons Junior Professorship at the ESI to Nils Carqueville (SUNY, Stony Brook). He accepted

the call. Formally a member of the Faculty of Mathematics, he will assume his position at the ESI on March 1, 2014. His first lecture course, titled “Introduction into topological quantum field theory”, will start at the beginning of the summer term.

Scientific activities in 2013

The list of research areas in mathematics and physics covered by the scientific activities of the Erwin Schrödinger Institute in 2013 shows a remarkable variety: the following thematic programmes, supplemented by five additional workshops, were in place

- *Teichmüller Theory*
organized by L. Funar (U Grenoble), Y. Neretin (U Vienna), A. Papadopoulos (U Strasbourg), R. Penner (UCLA), January 28 - April 21, 2013
- *The Geometry of Topological D-branes, Categories and Applications*
organized by S. Gukov (Caltech), A. Kapustin (Caltech), L. Katzarkov (U Vienna), Y. Soibelman (Kansas State U), April 22 - July 6, 2013
- *Jets and Quantum Fields for LHC and Future Colliders*
organized by A. Hoang (U Vienna), I. W. Stewart (MIT Boston), July 1 - 31, 2013
- *Forcing, Large Cardinals and Descriptive Set Theory*
organized by S. Friedman (U Vienna), M. Goldstern (TU Vienna), A. Kechris (Caltech), J. Kellner (U Vienna), W. H. Woodin (UC Berkeley), September 9 - October 18, 2013
- *Heights in Diophantine Geometry, Group Theory and Additive Combinatorics*
organized by R. Tichy (U Graz), J. Vaaler (U Texas, Austin), M. Widmer (U Graz), U. Zannier (U Pisa), October 21 - December 20, 2013

This report provides ample evidence that the quality of the scientific programmes was high. Longer thematic programmes and the open approach to research they offer and encourage form a fundamental pillar of the work of the ESI. The Institute provides a place for focused collaborative research and aims to create the fertile ground for new ideas.

In addition, workshops, conferences, and summer schools were organized, as well as visits of individual scholars who collaborated with scientists of the U of Vienna and with the local research community.

- *Word Maps and Stability of Representations*
organized by G. Arzhantseva (U Vienna), N. Monod (EPF Lausanne) A. Valette (U Neuchâtel), April 11 - 13, 2013
- *ESI 20th Anniversary: Two Decades at the Interface of Mathematics and Physics - The [Un]reasonable Effectiveness of Mathematics in the Natural Sciences*
organized by G. Arzhantseva, P. Chruściel, A. Constantin, J. Schwermer, F. Verstraete, J. Yngvason (all Kollegium ESI, U Vienna), jointly with W. Reiter (Foundation ESI) and K. Schmidt (Foundation ESI), April 29 - 30, 2013
- *ESI School and Conference: Geometry and Quantization, GEOQUANT 2013*
organized by P. Bieliavsky (U Louvain), H. Grosse (U Vienna), R. Kobayashi (Nagoya U), M. Schlichenmaier (U Luxembourg), A. Sergeev (Steklov Mathematical Institute, Moscow), O. Sheinman (Steklov Mathematical Institute, Moscow), W. Zhang (Chern Institute of Mathematics, China), August 19 - 30, 2013

- *Complexity and Dimension Theory of Skew Product Systems*
organized by H. Bruin (U Vienna), T. Jäger (U Dresden), R. Zweimüller (U Vienna),
September 16 - 20, 2013
- *Advances in the Theory of Automorphic Forms and their L - Functions*,
organized by D. Jiang (U Minnesota), P. Sarnak (Princeton), J. Schwermer (U Vienna),
F. Shahidi (Purdue U), October 16 - 26, 2013

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

In May-June 2013, Vladimir Korepin (SUNY, Stony Brook) gave a course of eight lectures on *The Algebraic Bethe Ansatz*. In the summer term, Simon Scott (King's College, London) gave a mini-course on *Logarithmic Topological Quantum Field Theory, Torsion, and Trace Invariants*. In the fall term Werner Ballmann (U Bonn) lectured on *Symmetric Spaces* whereas Ludwik Dabrowski (SISSA, Trieste) gave a course on *Spinors: Classical and Quantum*.

By January 1, 2012, the Erwin Schrödinger Institute had established the *Research in Teams Programme* as a new component in its spectrum of scientific activities. The programme provides an opportunity to work at the Institute in Vienna for periods of 1 to 4 months, in order to concentrate on new collaborative research in mathematics and theoretical 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 Kollegium could only accept five of these applications for the year 2013 [see pages 51–63 for details]. Other teams are already accepted for the year 2014.

The composition of the International Scientific Advisory Board of the ESI changed by the end of the year 2013. After two terms of office, John Cardy (Oxford) left the Board. The Institute is extremely thankful to him for many years of valuable advice and support. Daniel Bernard (Paris), Christian Lubich (Tübingen) and Catharina Stroppel (Bonn) joined the Board on January 1, 2014, as new members.

There was no change in the administration of the ESI in 2013. In spite of the ongoing construction work at the ESI in 2013 the current administrative staff - Alexandra Katzer, Beatrix Wolf and Maria Marouschek - continued to work with their customary efficiency towards our visitors, research fellows and scientific staff.

Joachim Schwermer

February 5, 2014

Director

Erwin Schrödinger International Institute for Mathematical Physics

The ESI in 2013

Director of the Research Centre ESI at the U of Vienna: Joachim Schwermer.

Kollegium of the Research Centre ESI at the U of Vienna: Joachim Schwermer (ESI Director), Goulmara Arzhantseva (ESI Deputy Director), Jakob Yngvason (ESI Deputy Director), Piotr T. Chruściel, Adrian Constantin, Frank Verstraete.

Administration: Alexandra Katzer (Head of Administration), Maria Marouschek, Beatrix Wolf.

Computing and networking support: Sascha Biberhofer, Andreas Čap, Thomas Leitner.

International Scientific Advisory Board in 2013:

John Cardy (Oxford)

Isabelle Gallagher (Paris)

Helge Holden (Trondheim)

Daniel Huybrechts (Bonn)

Horst Knörrer (Zürich)

Vincent Rivasseau (Orsay)

Herbert Spohn (Munich)

Budget and visitors: In 2013 the support of ESI from the Austrian Federal Ministry of Science and Research received via the U of Vienna was €790 000. The total spending on scientific activities in the year 2013 was €371 058 and on administration, infrastructure, and reconstruction work €412 042.

The number of scientists visiting the Erwin Schrödinger Institute in 2013 was 641, see pages 86–99.

ESI research documentation: Following the ubiquitous arXiv server usage by the international scientific community, the ESI Kollegium has decided to stop the local ESI preprint server and to track the ESI research outcome using the arXiv database and the published articles. This new procedure is effective by January 2014. Therefore, in 2013, the year of transition to the new system, the ESI research documentation contains both the preprints contributed to the local ESI server and the arXiv submitted preprints. Moreover, publications appeared in 2013 but related to past ESI activities, starting from 2011, have been tracked 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 2013 is 74, see pages 82–85 for details.

The Foundation ESI

President: Klaus Schmidt

Honorary President: Walter Thirring

Scientific Reports

Main Research Programmes

Teichmüller Theory

Organizers: Louis Funar (U Grenoble), Athanase Papadopoulos (U Strasbourg), Bob Penner (U Aarhus and Caltech), Yurii Neretin (U Vienna and ITEP Moscow)

Dates: January 28 – April 21, 2013

Budget: ESI € 36 040, ESF (€ 19 000), NSF through the GEAR programme (€ 16 000 + € 16 000), and additional funding by JSPS (€ 20 000), French GDR Tresses (€ 7 000), ANR ModGroup (€ 5 000)

Report on the programme

Classically, Teichmüller theory is the study of moduli for complex structures on surfaces with its applications to low-dimensional topology, algebraic topology, hyperbolic geometry, representations of discrete groups in Lie groups, symplectic geometry, topological quantum field theory, string theory, and to many other fields. The fact that Teichmüller theory makes connections with several areas in mathematics follows in part from the diversity and the richness of the structures that Teichmüller space itself carries. Indeed, this space can be seen as a space of equivalence classes of hyperbolic metrics, as a space of equivalence classes of conformal structures, and as a space of equivalence classes of representations of the fundamental group of a surface into $SL(2, \mathbb{R})$ and these points of view endow Teichmüller space with various interesting metrics, a natural complex structure, a symplectic structure, a real analytic structure, an algebraic structure, cellular structures, various boundary structures, a natural action by the mapping class group (which is properly discontinuous in the case of finite-type surfaces and which is not in the case of infinite-type surfaces), explicit coordinates, interesting geodesic and horocyclic flows on the quotient Riemann moduli space, a quantization theory of its Poisson structure, and the list goes on and on. The subject of Teichmüller theory is growing at an exceptional rate, and new ideas and new connections between all these domains have emerged recently. The special period included work on all these subjects, as well as on Kleinian groups, flat connections, cluster algebras, and quantum topology, and the interactions with algebraic geometry, physics and dynamical systems.

Activities

The main activities of the ESI program on Teichmüller theory consisted of the following:

1. A workshop on Teichmüller theory.
2. Series of lectures given by various invited scientists all over the trimester.

3. Seminar talks.
4. A one-week long master class consisting of 5 mini-courses directed to PhD students and post-docs.
5. A workshop on Teichmüller theory in relation with physics and quantization.

The first workshop

The workshop covered the major recent advances in the theory, including the analytic and the metric aspects, the quasi-conformal theory, the mapping class group actions, the geometry of curves and curve complexes and the relations with moduli spaces, the algebra-geometric aspects, surface group representations, and the higher Teichmüller theory. The following is a list of the major subjects presented and discussed at the workshop:

1. Ideal triangulations of the Milnor fibers of plane curve singularities and the variation of the corresponding complex structure.
2. The study of the shape of the subset of moduli space consisting of surfaces whose systoles fill by using combinatorial methods and an appropriate graph.
3. Rigidity and local rigidity of curve complexes equipped with mapping class group actions.
4. The geodesic flow on Teichmüller space: the flow near the boundary strata and applications to the calculation of the exponent of the number of periodic orbits near the boundary.
5. The stratification of the moduli space of curves endowed with a nonzero Abelian differential and the problem of whether such strata are $K(G, 1)$.
6. A tensorial description of the Goldman Lie algebra of a surface and the embedding of the largest Torelli group (in the sense of Putman) into a completion of the Goldman-Turaev Lie bialgebra. The relation with the Morita traces.
7. The canonical real-valued function on the moduli space determined by the spectral theory of the Bergman metric, which was introduced by Kawazumi and Zhang and the relation with the Arakelov-Green function, the pointed harmonic volume, and the height of Ceresa's cycle.
8. The generalization of Teichmüller's classical mapping problem for plane domains to three-space.
9. The geometry of representations of the fundamental group of a surface into $SU(2, 1)$ and a dictionary between the theories of minimal surfaces in RH^3 and minimal Lagrangian surfaces in CH^2 .
10. The study of shear coordinates of hyperbolic surfaces including analytic formulation without divergences for shear deformations and weighted ideal length sums, the symplectic geometry of shears and weighted ideal length sums, the definition of an elementary 2-form for shear weights, the relation to the symplectic structure on decorated measured foliation space, a distances-sum formula for the Riemannian pairing of shears and an exact relation for distances between lines in the classical modular tessellation.
11. The relation between the modular group, indefinite binary quadratic form, dessins d'enfants and the universal Teichmüller space.

12. Deformations and rigidity properties of circle diffeomorphisms in relation with the universal Teichmüller space.
13. The relation between the space of convex polygons in the real projective plane (up to projective transformations) and the space of polynomial holomorphic cubic differentials on the complex plane (up to complex affine transformations). Connections with the study of meromorphic Higgs bundles over the projective line and with the Stokes phenomenon for meromorphic connections.
14. The new pressure metric on the Hitchin component in the space of (conjugacy classes of) representations of a closed surface group into $PSL(n, R)$ and on more general deformation spaces. An application to the fact that the Hausdorff dimension of the limit set varies analytically over deformation spaces of convex cocompact Kleinian groups.
15. For a finite volume hyperbolic manifold with non-empty totally geodesic boundary, the study of the distribution of the time for the geodesic flow to hit the boundary and of the moments of the associated random variable in terms of the orthospectrum.
16. Compactifications of real projective structures via marked length spectrums and Patterson-Sullivan geodesic currents.
17. Operads and their actions on moduli spaces and the cellulations of these spaces.
18. Dilogarithm identities on moduli spaces and relations with identities of Basmajian, McShane and Bridgeman.
19. Relations between affine 3-manifolds, Lorentzian and hyperbolic geometry, and the classification problem for quotients of P^3 by groups of affine transformations.

The second workshop

The workshop covered the major recent advances in Teichmüller theory and its interactions with physics, including quantization of Teichmüller theory, clusters, quantum symmetry, Feynman diagrams, TQFT, and Liouville theories. The following is a list of the major subjects presented and discussed at the workshop:

1. Classical and semi-classical TQFTs.
2. Infinite symmetric group, their relation with the universal Teichmüller theory, topological field theories, and Feynman diagrams.
3. Representations of mapping class groups, from TQFT and from the Goldman-Turaev algebra point of views. The infinitesimal version of the Dehn-Nielsen theorem.
4. Tropical geometry.
5. Quantum continued fractions, Penner's lambda coordinates and the geometry of the Teichmüller space.
6. Quantization of Teichmüller space via mirror symmetry, M -brane theory and string theory, new dualities between moduli spaces and knot invariants.
7. Generalizations of higher Teichmüller theory (a.k.a. the study of framed flat $SL(n)$ connections on punctured surfaces) to 3- and higher-dimensional manifolds with boundary.

8. The Ptolemy-Thompson groups, the Funar-Sergiescu computation of the central extension of the Ptolemy-Thompson group arising in the quantum universal Teichmüller space. New relations with the Kashaev quantization of the universal Teichmüller space and with the relative abelianization of the braided Ptolemy-Thompson group of Funar and Kapoudjian.
9. Thurston's gluing equations in $\mathrm{PGL}(n, \mathbb{C})$ and applications to quantum topology, including the duality between the shape coordinates and the Ptolemy coordinates of Garoufalidis-Thurston-Zickert. The shape coordinates and Ptolemy coordinates as 3-dimensional analogues of the X- and A-coordinates on higher Teichmüller spaces dues to Fock and Goncharov.
10. Algorithms for counting intersections of normal curves and a matrix presentation of mapping class groups.
11. Quantum symmetry and homological representations of braid groups.

The series of lectures by R. Kashaev were on Quantum Teichmüller theory. The specific content was the following: The groupoid of ideal triangulations of punctured surfaces; Penner's coordinates in the decorated Teichmüller space; Ratio coordinates; Quantization and Faddeev's quantum dilogarithm; Length spectrum of simple closed curves; 3-dimensional symmetries and dihedral angles; Partition functions on shaped triangulations; Quasi-classical behavior and hyperbolic volume.

The master-class

- N. A'Campo, The Riemann Roch theorem;
- S. Lelièvre, Dynamics of translation surfaces;
- K. Ohshika, Deformation spaces of Kleinian groups;
- H. Parlier, The geometry of surfaces and their deformation spaces;
- J. Marché, Character varieties and 3-dimensional topology.

In the attendance there were more than 20 PhD students, from Europe, Asia and America. Although some of the advanced lectures were difficult for them to follow, the students have certainly gained some useful experience for their own research. They learned about the newest ideas and the most active problems in the area. It was also the occasion for them to encounter several mathematicians from all over the world and to discuss with them about their work. The contacts they made will be very helpful for them when they will need specific help in their research, to be informed about the new events, and even when they will be looking for a job.

Outcomes and achievements

The following papers come out from this activity (preliminary versions are indicated).

- [1] A. Papadopoulos and S. Yamada, *A remark on the projective geometry of constant curvature spaces*.
- [2] N. A'Campo and A. Papadopoulos, *On Klein's so-called non-Euclidean geometry*.
- [3] N. A'Campo and A. Papadopoulos, *On transitional geometries*.
- [4] L. Ji, A. Papadopoulos, and S. Yamada, *Harmonic maps and Teichmüller theory*.
- [5] L. Ji, A. Papadopoulos, and N. A'Campo, *On Grothendieck's construction of Teichmüller space*.

- [6] L. Ji, A. Papadopoulos, and N. A'Campo, *Grothendieck-Teichmüller theory*.
- [7] A. Papadopoulos and R. C. Penner, *Hyperbolic metrics, measured foliations and pants decompositions for non-orientable surfaces*.
- [8] A. Papadopoulos, *Actions of mapping class groups*, In: Handbook of group actions (L. Ji, A. Papadopoulos and S.-T. Yau, ed.) Higher Education Press and International Press, Beijing and Boston, 2014.

Invited scientists:

Norbert A'Campo, Jorge Acosta, Toshiyuki Akita, Vincent Alberge, Daniele Alessandrini, Joergen E. Andersen, Javier Aramayona, Ivan Babenko, Mohamed Amine Bahayou, Andrzej Bis', Adara Blaga, Carl Friedrich Bödigheimer, Matin Bridgeman, Richard Canary, Charalampos Charitos, Francesco Costantino, George Daskalopoulos, Robin de Jong, Kelly Delp, Tudor Dimofte, Valentina Disarlo, Jerome Dubois, David Dumas, Matthew Durham, Todd Drumm, Ivan A. Dynnikov, Federica Fanoni, Ariadna Fossas, Michihiko Fujii, Ege Fujikawa, Koji Fujiwara, Louis Funar, Sourav Ghosh, William Goldman, Francois Gueritaud, Laurent Guieu, Sergei Gukov, Subhojoy Gupta, Thomas Haettel, Ursula Hamenstädt, Maria Hempel, Oussama Hijazi, Andy Huang, Lizhen Ji, Chris Judge, Anders Karlsson, Yasushi Kasahara, Rinat Kashaev, Nariya Kawazumi, Steven Kerckhoff, Hyun Kyu Kim, Inkang Kim, Erina Kinjo, Teruaki Kitano, Hiroki Kodama, Toshitake Kohno, Takayuki Koike, Julien Korinman, Mustafa Korkmaz, Yusuke Kuno, Dan Latcu, Samuel Lelievre, Anna Lenzhen, Ezra Levy, Qionglng Li, Lixin Liu, John Loftin, Arun Maiti, Sara Maloni, Jason Manning, Julien Marche, Bruno Martelli, Gregor Masbaum, Katsuhiko Matsuzaki, Greg McShane, Chikako Mese, Masato Mimura, Hideki Miyachi, Gabriele Mondello, Thomas Morzadec, Junichi Mukuno, Bjoern Mützler, Yoshikazu Nagata, Yurii Neretin, Duc-Manh Nguyen, Ryosuke Nomura, Ken'ichi Ohshika, Susovan Pal, Frederic Palesi, Ioannis Papadoperakis, Athanase Papadopoulos, Hugo Parlier, Robert Penner, Bram Petri, Wolfgang Pitsch, Romain Ponchon, Renate Quehenberger, Kasra Rafi, Nikolai Reshetikhin, Sebastian Reyes-Carocca, Julien Roger, Stephane Sabourau, Ahmad Said, Masatoshi Sato, Carlos Scarinci, Andrea Seppi, Vlad Sergiescu, Hiroshige Shiga, Leone Slavich, Weixu Su, Zhe Sun, Yuuki Tadokoro, Kazuto Takao, Ser Peow Tan, Jing Tao, Jeremy Toulisse, Georgios Tzapogas, Alice-Barbara Tumpach, Muhammed Uludag, Matti Vuorinen, Cormac Walsh, Anna Wienhard, Scott A. Wolpert, Binbin Xu, Sumio Yamada, Oyku Yurttas, Ayberk Zeytin, Christian Zickert.

The Geometry of Topological D-branes, Categories, and Applications

Organizers: Sergei Gukov (Caltech), Anton Kapustin (Caltech), Ludmil Katzarkov (U Vienna), Yan Soibelman (Kansas State U)

Dates: April 22 – July 6, 2013

Budget: ESI € 48 480

Report on the programme

Over the last several years, a variety of new categorical structures have been discovered by physicists. Furthermore, it has become transparently evident that the higher categorical language is beautifully suited to describing cornerstone concepts in modern theoretical physics.

The goal of this project was to develop these structures even further. As we head into the second decade of the 21st century, modern geometry and theoretical physics are more intertwined than ever before. The convergence of ideas from mathematics and physics is accelerating at the same time as elementary particle physics is on the cusp of a profound revolution to be brought about by the new experimental results coming out of the Large Hadron Collider (LHC). These will serve to identify among the multitude of theoretical possibilities currently open, which ones best

address quantum field theory at the high energy scale. At the same time, a lot of mathematical work remains to be done to provide a suitable framework for the new physical theories that are being proposed. The geometric objects which we investigate today are the foundations for such a framework: homological mirror symmetry is the mathematical realization of dualities among supersymmetric theories and higher categories are the mathematical foundation for quantum field theories. These new flavors of geometry, in which categorical structures play a primordial role, will certainly continue to play a fundamental role in the 21st century theoretical physics. Developing these new categorical structures was the main goal of the ESI activity Geometry of Topological D-Branes, Categories, and Applications.

Activities

The ESI program on the Geometry of Topological D-Branes, Categories, and Applications was based on several series of lectures and three workshops.

1. The first workshop was mainly on Matrix factorizations. Ballard, Favero, Isik, Deliu, Toda, Buchweitz, Shipman, Donovan were among speakers. The main outcome are new Landau-Ginzburg model approaches to stability conditions and Homological projective duality.
2. The second workshop was on Birational Geometry and Geometric Invariant Theory. The speakers included Kawamata, Dolgachev, Halpern-Leinster, Segal, Horjia, Katzarkov, Dimitrov, Haiden, Noll. The main result is a new categorical approach to dynamical systems outlined by Katzarkov, Haiden, Noll.
3. Third workshop was on Higher Categories and Topological Quantum Field Theories. The speakers included Pantev, Vaqie, Calderaru, Polschuck. The main outcome is a new higher symplectic structures approach to defining higher dimensional Donaldson-Thomas invariants as well as new results on Noncommutative Hodge theory.

Besides the workshops there were series of lectures by A. Kapustin, R. Buchweitz, M. Thaddeus, A. Okounkov, A. Ahmedov, J. Sawon.

The program had a broader impact. It served as a perfect opportunity for dissemination of results and encouragement a wave of young, early career researchers to join these projects. The wide range of topics appearing in Homological Mirror Symmetry research necessitates venues for the open exchanges of ideas in order for graduate students and early career researchers to stay afloat on current topics. The subject has developed extremely rapidly in recent years, and periodic conferences and focused activity periods are necessary to engage young researchers.

We focus now on the intellectual merit of the project.

Dynamical Systems and Categories

Recent work of Cantat-Lamy on the Cremona group and Blanc-Cantat on dynamical spectra suggests that there is a deep parallel between the study of groups of birational automorphisms on one hand, and mapping class groups on the other. Under this parallel, the dynamical degree of a birational map plays the role of the entropy of a pseudo-Anosov map. We consider these developments from the perspective of derived categories and their groups of autoequivalences. In a striking series of papers Gaiotto-Moore-Neitzke and Bridgeland-Smith have established a connection between Teichmüller theory and the theory of stability conditions on triangulated categories. An analogy between the Teichmüller geodesic flow and the wall crossing on the space of stability conditions had been noticed previously in the works of Kontsevich and Soibelman.

We took all these discoveries further. First, we defined and studied entropy in the context of triangulated and A_∞ -categories. More specifically we construct and study a categorical version of the notion of *dynamical entropy*. Dynamical entropy typically arises as a measure of the

complexity of a dynamical system. This notion exists in a variety of flavors, e.g. the Kolmogorov-Sinai measure-theoretic entropy, the topological entropy of Thurston and Gromov, algebraic entropy, etc. In analogy with these notions, we define the entropy of an exact endofunctor of a triangulated category with a generator.

In the case of saturated (smooth and proper) A_∞ -categories we prove the following foundational results:

Theorem 1 *In the saturated case, the entropy of an endofunctor may be computed as a limit of Poincaré polynomials of Ext-groups.*

This result is connected to classical dynamical systems:

Theorem 2 *In the saturated case (under a certain generic technical condition), there is a lower bound on the entropy given by the logarithm of the spectral radius of the induced action on Hochschild homology.*

We develop further the parallel with dynamical systems. We build on the following basic correspondences:

- 1) geodesics \leftrightarrow stable objects.
- 2) compactifications of Teichmüller spaces \leftrightarrow stability conditions.
- 3) classical entropy of pseudo-Anosov transformations \leftrightarrow categorical entropy.
- 4) categories \leftrightarrow differential equations.

We record our findings in the following table:

Category	Stable objects	Stab. cond.	Density of phases	Diff. eq.
A_n		$e^{P(z)}(dz)^2$	NO	$\left(\left(\frac{d}{dz}\right)^2 + e^{P(z)}\right) f = 0$
\hat{A}_n		$q(z)(dz)^2$	YES	Schrödinger eq.
$Tot \begin{pmatrix} A_2 \\ \downarrow \\ C \end{pmatrix}$	Spectral networks	$H^0(K^2) \oplus H^0(K^3)$	YES	Lax pair

Connection with differential equations and algorithms

We developed further the connection between categories and differential equations. Figure 1 suggests that one can study the WKB approximation of flat connections via harmonic maps to buildings.

The corresponding categories are given by singularities of the harmonic map, the so-called spectral networks. This project makes a connection between categories and differential equations. We show that there is an interpretation of the higher dimensional Cremona group and certain groups of autoequivalences.

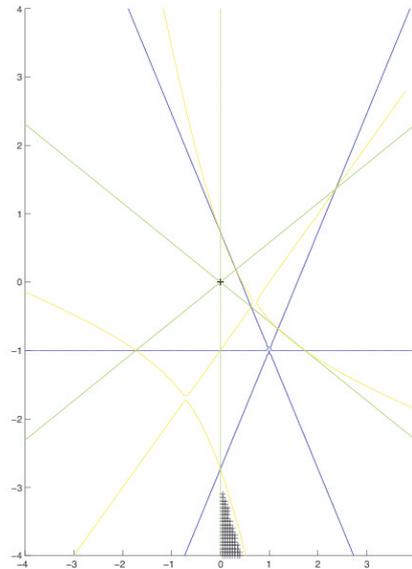


Figure 1: Harmonic maps to Buildings and WKB.

In such a way we approach a classical question in Algebraic Geometry posed by Enriques in 1886 - show that the higher dimensional Cremona group is not simple.

The following conjectures came out of our work. They should be seen as a harmonic representative analogue of the classical Hodge theoretic harmonic representative theorem and the beginning of developing of theory of Stability Hodge Structures.

Conjecture 1 *The singularities of the harmonic map to a building determines a 3-dimensional CY category C .*

We also establish a possibility of studying stability conditions of C .

Conjecture 2 *There exists a component of the moduli space of stability conditions of C which contains $H^0(K^2) \oplus H^0(K^3)$.*

In general, we expect this component to contain the base of the Hitchin system. The connection with differential equations goes even further.

Conjecture 3 *The behavior of the Stokes factors and resurgence phenomenon for the Lax pair of the Hitchin system determines the wall crossing on the component of the moduli space of stability conditions of C containing $H^0(K^2) \oplus H^0(K^3)$.*

Another striking conjecture describes the connection with the theory of algorithms and $P \neq NP$ problem.

Conjecture 4 *There exists a connection between categorical complexity and BSS machines. Under proper set up BSS machines compute generation times of categories.*

Stability Hodge structures and moduli spaces of Landau-Ginzburg models

This part of the project was developed with Konsevich, Pantev and Simpson.

The moduli space of Stability conditions (and more generally SHS) can be included in a twistor type of family with a “Dolbeault” type space as the zero fiber. This zero fiber is nothing else but the moduli space of complex structures. This interplay of nonabelian and noncommutative Hodge theory suggests far reaching geometric applications.

After adding a geometrically meaningful compactification, the above considerations provide us with a new geometric entity - stability Hodge structures. These structures have a huge potential toward geometric applications. The moduli space of stability conditions of a triangulated category, C , is, in general, a very complicated space, possibly with “fractal” boundary. However, HMS predicts that for the derived category of coherent sheaves on a Calabi-Yau variety, X , the moduli space of mirror dual Calabi-Yau manifolds is embedded in a locally closed cone of this moduli space of stability conditions. Therefore, characterizing the Hodge structures of mirror dual CY manifolds can be achieved through understanding Hodge structures on the category. This characterization is a largely unsolved open problem that can be addressed through the introduction of stability Hodge structures.

Classically the moduli space of pure Hodge structures has a compactification by mixed Hodge structures (MHS) which can be studied through limiting DT invariants and the related wall-crossing formulas (WCF). In the case of three dimensional CY manifolds there are different types of MHS. In the cusp case, the deepest degeneration corresponds to a t -structure which is an extension of Tate motives.

A different MHS corresponds to conifold points. In this case, one does not have a reasonable enough integrable system to work with, hence one tries to approximate algebraicity by associating a subcategory of vanishing three spheres. This locally produces the Betti moduli space discussed above. This Betti moduli space corresponds to the WCF of the category of vanishing cycles. In order to consider the interaction with the rest of the category, one must understand global WCF.

Stability Hodge structures are a categorical realization of the picture above, obtained by incorporating two main ingredients: a divisor at infinity parameterizing the degenerate limiting stability conditions (limiting Mixed Hodge structures), and data recording relative wall-crossing formulas - vanishing cycles for the degeneration.

A large supply of stability Hodge structures and their geometric cores is provided by the extended and complex moduli of complex Landau-Ginzburg models. The next project we propose, aims to understand the local structure of such moduli spaces and to organize the Hodge theoretic information parametrized by these moduli. A Landau-Ginzburg model is determined by a pair (Y, w) , where Y is a complex quasi-projective variety, and $w : Y \rightarrow \mathbb{A}^1$ is a holomorphic function on Y . When Y has a trivial canonical class $K_Y \cong \mathcal{O}_Y$, the category of matrix factorizations $\mathbf{MF}(Y, w)$ of the potential w can be viewed as the category of coherent sheaves on a smooth compact non-commutative Calabi-Yau variety.

The first step is to show that the versal deformation space of such a non-commutative Calabi-Yau, that is the versal deformation space of the category $\mathbf{MF}(Y, w)$, is unobstructed. This result extends the classical Tian-Todorov theorem to the non-commutative context. The result is natural from the point of view of mirror symmetry. Indeed, a Landau-Ginzburg pair (Y, w) as above will typically arise as the mirror of a symplectic manifold (X, ω_X) underlying a projective Fano variety. The homological mirror symmetry conjecture predicts that the Fukaya category $\mathbf{Fuk}(X, \omega_X)$ of (X, ω_X) will be equivalent to the category $\mathbf{MF}(Y, w)$. In particular, the deformation theories of the Fukaya category and of the category of matrix factorizations will be identified, and versal deformation space of the Fukaya category is manifestly smooth since it is

an open cone in the space of harmonic 2-forms on X .

By the work of Orlov the category $\mathbf{MF}(Y, w)$ is the coproduct of the categories of singularities of the singular fibers of w . This interpretation indicates that flat deformations of the geometric data (Y, w) will not necessarily give rise to flat deformations of $\mathbf{MF}(Y, w)$. Indeed, when we deform (Y, w) geometrically, the singularities of fibers of w can coalesce and more importantly can run away to infinity. This suggests that we should only consider geometric deformations of (Y, w) that are anchored at infinity. Indeed, if $((Z, f), D_Z)$ is a compactification of (Y, w) with a normal crossings boundary, then the deformations of the pair (Z, f) that fix the boundary divisor D_Z will give deformations of (Y, w) for which the associated categories $\mathbf{MF}(Y, w)$ vary flatly. This allows us to study the moduli of $\mathbf{MF}(Y, w)$ by studying the deformations of the compactification (Z, f) .

The main geometric input is the following theorem which we proved:

Theorem 3 *Let Z be a smooth projective variety, $f : Z \rightarrow \mathbb{P}^1$ a flat morphism, and $D_Z \subset Z$ a reduced anti-canonical divisor with strict normal crossings. Assume moreover that $\text{crit}(f)$ does not intersect the horizontal part of D_Z , that the vertical part of D_Z coincides with the scheme theoretic fiber $f^{-1}(\infty)$ of f over $\infty \in \mathbb{P}^1$. Let \mathcal{M} be the versal space parametrizing deformations of (Z, f) keeping D_Z fixed. Then \mathcal{M} is smooth.*

To prove Theorem 3 we identify the L_∞ -algebra that controls the relevant deformation theory and show that this L_∞ -algebra is homotopy abelian. We argue that, as in the case of compact Calabi-Yau manifolds, the latter statement can be reduced to a Hodge theoretic property: the double degeneration property for the Hodge-to-De Rham spectral sequence associated with the complex of f -adapted logarithmic forms. By definition, a meromorphic a -form α on Z with poles at most on D_Z is called an f -adapted logarithmic form if both α and $\alpha \wedge df$ have logarithmic poles along D_Z . If $\Omega_Z^a(\log D_Z, f)$ denotes the sheaf of f -adapted logarithmic forms, then the double degeneration property is given by

Theorem 4 *Let $a \geq 0$. Under the assumptions of Theorem 3, the dimension*

$$\dim_{\mathbb{C}} \mathbb{H}^a(Z, [\Omega_Z^\bullet(\log D_Z, f), c_1 \cdot d_{DR} + c_2 \cdot df \wedge (\bullet)])$$

is independent of the choice of $(c_1, c_2) \in \mathbb{C}^2$.

Our proof of this statement relies on the method of Deligne-Illusie and on a topological argument for limits of logarithmic complexes. A different proof and generalization of the double degeneration theorem was recently given by Esnault, Sabbah, Yu, and Saito. The double degeneration property together with an analysis of the homological mirror correspondence predict the following

Conjecture 5 *Let (Y, w) be an n -dimensional Landau-Ginzburg mirror of a symplectic Fano variety (X, ω_X) of complex dimension n . Suppose (Z, f) is a compactification of (Y, w) . Then*

$$h^{p, n-q}(X) = \dim_{\mathbb{C}} \mathbb{H}^p(Z, \Omega_Z^q(\log D_Z, f)),$$

for all p, q .

Training and professional development

This project had a strong educational component. The programme gave an immense opportunity for young participants to learn, interact and start collaborations with the leading experts in the

area. Long time collaborations and connections were established. Several joint projects were initiated.

We have found that the following format works very well: (1) Intense introductory lectures; (2) Offering projects (based on selection of people).

The following papers and projects came out from this activity

1. Ludmil Katzarkov, Ernesto Lupercio, Laurent Meersseman, Alberto Verjovsky, *Non-commutative toric varieties*, arXiv:1308.2774.
2. George Dimitrov, Fabian Haiden, Ludmil Katzarkov, Maxim Kontsevich, *Dynamical systems and categories*, arXiv:1307.8418.
3. Matthew Ballard, Dragos Deliu, David Favero, Umut Isik, Ludmil Katzarkov, *Homological projective duality via variation of geometric invariant theory quotients* arXiv:1306.3957.
4. Sergey Galkin, Ludmil Katzarkov, Anton Mellit, Evgeny Shinder, *Minifolds and phantoms*, arXiv:1305.4549.
5. Matthew Ballard, Colin Diemer, David Favero, Ludmil Katzarkov, Gabriel Kerr, *The Mori program and non-Fano toric homological mirror symmetry*, arXiv:1302.0803.
6. George Dimitrov, Ludmil Katzarkov, *Non-semistable exceptional objects in hereditary categories*, arXiv:1311.7125.
7. Ludmil Katzarkov, Alexander Noll, Pranav Pandit, Carlos Simpson, *Harmonic maps to buildings and singular perturbation theory*, arXiv:1311.7101.

The following research projects are ongoing and have been generated by this ESI programme.

8. Alexander Efimov, Fabian Haiden, Umut Isik, *Categorical complexity and algorithms*.
9. Matthew Ballard, Colin Diemer, David Favero, Gabriel Kerr, Maxim Kontsevich, *HMS and strips VGIT correspondence*.
10. Alexander Noll, Pranav Pandit, Carlos Simpson, *Differential equations and categories*.
11. Tony Pantev, Bertrand Toen, *High dimensional DT invariants*.
12. Elizabeth Gasparim, Lino Grama, Ludmil Katzarkov, *Symplectic nonalgebraic LG models*.
13. Alexander Efimov, Dmitrii Kaledin, *Noncommutative Hodge structures and applications*.
14. Ludmil Katzarkov, Maxim Kontsevich, Tony Pantev, *LG models and noncommutative Hodge structures*.

Invited scientists:

Nicolas Addington, Anar Ahkmedov, Alonso-Garcia Maria Emilia, Jeffrey Armstrong, Hugo Bacard, Matthew Ballard, Arend Bayer, Marcello Bernardara, Anthony Blanc, Christian Böhning, Michele Bolognesi, Hans-Christian von Bothmer, Ragnar-Olaf Buchweitz, Christopher Brav, Alberto Canonaco, Andrei Caldararu, Francisco-Jesus Castro-Jimenez, Nils Carqueville, Patrick Clarke, Dragos Deliu, Colin Diemer, Igor Dolgachev, Ron Donagi, Will Donovan, Brent Doran, Eleonore Faber, David Favero, Noah Gian-siracusa, William Gillam, Herwig Hauser, Benjamin Hennion, Lutz Hille, Paul Horja, Victoria Hoskins, Shinobu Hosono, David Jensen, Dmitri Kaledin, Anton Kapustin, Alex Kasprzyk, Ludmil Katzarkov, Yujiro Kawamata, Bumsig Kim, Young Rock Kim, Johanna Knapp, Henning Krause, Alexander Kuznetsov, Helmut Lenzen, Hwayoung Lee, Yijia Liu, Wendy Lowen, Valery Lunts, Alexander Noll, Andrei Okounkov, Genki Oouchi, Tony Pantev, Alexander Polishchuk, Daniel Pomerleano, Anatoly Preygel, Victor

Przhiyalkorskiy, Marco Robalo, Emanuel Scheidegger, Claudia Scheimbauer, Olaf Schnuerer, Ed Segal, Artan Sheshmani, Eric Sharpe, Nicolo Sibilla, Maxim Smirnov, Pawel Sosna, Johan Steen, Paolo Stellari, Atsushi Takahashi, Michael Thaddeus, Yukinobu Toda, Hokuto Uehara, Michel Vaquie, James Wallbridge, Paul Wedrich.

Jets and Quantum Fields for LHC and Future Colliders

Organizers: Andre H. Hoang (U Vienna), Iain W. Stewart (MIT)

Dates: July 1 – August 3, 2013

Budget: ESI € 31 920, Faculty of Physics of U Vienna (€ 2 940), MISTI Global Seed Funds – MIT (\$ 4 016)

Report on the programme

Jets are the most common objects observed in high energy particle collider experiments. They consist of a number of very energetic collimated stable hadrons, and the distribution and shape of jets can be used to learn about the high-energy process that took place at very short distances when the initial particles collided. An understanding of jets is therefore the basis of carrying out many of the measurements made at modern collider experiments, such as the Large-Hadron-Collider (LHC) currently taking data at CERN, and other current or planned collider facilities such as the B-factories or a future Linear Collider (LC). The properties of jets and a precise theoretical understanding of jets are particularly important in the search for new types of fundamental interactions and particles beyond the Standard Model. Here a high degree of precision is required to distinguish whether jets were produced from the decay of these new elementary particles or from known Standard Model ones.

In the past 30 years a substantial body of knowledge has been worked out on jet definitions, jet properties, and the computation of higher order radiative corrections based on the theory of strong interactions known as Quantum Chromodynamics (QCD). Within this classic approach to the physics of jets, mathematical proofs of factorization remained somewhat cumbersome and a number of conceptual issues related e.g. to the problem of factorization violation, the issue how to treat rapidity singularities, how to consistently treat heavy quarks, how to treat power corrections, or how to theoretically describe the substructure of jets could not be addressed in any systematic manner. With the advent of the method of “Soft-Collinear-Effective Theory” (SCET), which is a field-theoretic approach based on a Lagrangian formulation of jet physics, many of the results of the classic jet approach could be derived for the first time or re-derived, and a number of problems became accessible at the conceptual as well as at the computational level. Interestingly, many of the key experts in jet physics have been either brought up with the classic approach to jet physics or the SCET method, and hence partly still belong to different communities. One of the reasons for this is historical, since the SCET community grew out of experts in effective field theory methods, and because originally the most exciting developments and applications of the SCET method were made in the context of problems related to the decay of B-mesons in the field of flavor physics, which was outside the main interests of classic jet physicists.

At this time active interactions and fruitful collaborations between representatives of the classic jet approach and the SCET method are becoming more common, but further development is desirable. One of the aims of the programme was to bring together leading experts in the classic jet approach and the SCET method in the productive and high-profile environment of the Erwin Schrödinger Institute and to initiate and support interaction and an exchange of views and ideas. The primary goal of the programme was initiating and stimulating interesting theoretical work on jets. In the last few years the progress in jet physics has been very rapid, partly due to

the plethora of jet data from the LHC that has stimulated theoretical innovations and new fundamental ideas. A number of these hot topics were explored at the programme.

Activities

The ESI programme “Jets and Quantum Fields for LHC and Future Colliders” was build around the five main subjects: “Higgs physics”, “Event-shapes”, “Factorization and factorization violation”, “Jet substructure”, and “Rapidity singularities”. These subjects are explained in more detail in the subsections below, and they are some of the most important current topics related to the physics of jets. They are also attractive to representatives from various communities and therefore ideal topics to be addressed during the programme. Moreover, in the organization prior and during the programme care was taken to account for suggestions and ideas of participants to add to the richness and the success of the programme. As it turned out to be impossible to confine the subject to specific time spans due to the relative short duration of the programme, we took care of providing all available information to the invited physicists on the web page already at an early stage prior to the programme, so that the participants could plan and coordinate their stays in the best possible way concerning intended collaborations or overlaps with other participants. The invited leading experts were further given the opportunity to nominate postdoctoral researchers and, in particular, very promising PhD students to be invited, either for collaboration, to present work themselves, or to allow them to create contacts to other senior participants.

One of the most important goals of this ESI programme was to avoid the formal and fast-paced environment of regular conferences and workshops. Rather our programme was intended to provide an inspiring and stimulating atmosphere with an emphasis on communication, discussion and sufficient time for brain storming and actual work. There were two pre-planned scheduled talks each week (Tuesdays and Thursdays at 10:30am) by leading scientists. To allow for specific demands and the wishes by participants, each week a third talk was organized (Wednesdays at 10:30am) on short notice. All talks were based on black board lecture-style presentations that allowed for immediate on-the-spot discussions and interactions. Some of the talks were presented together by competing groups to make the respective approaches and ideas as transparent as possible. This format was very successful and informative, and lead to very lively open discussions which frequently continued throughout the afternoon on the wide blackboard spaces available at the ESI. On average each presentation lasted more than 2 hours. Another tool of communication was a specialized wiki page, homepage: <http://www.univie.ac.at/esijet/>, wikipage: <https://www.univie.ac.at/physikwiki/index.php/Information:ESIJet> that allowed the participants to themselves freely post information, links to notes or publications related to the presentations or new ideas which were of interest for the discussion.

Concerning financial support, the 15 man-months of per diems available through the Erwin Schrödinger Institute were distributed among the external participants following the guideline of providing about 50% coverage of business days for permanently employed physicists (professors, staff), about 75% coverage of business days for postdoctoral researchers, and full coverage of business days for PhD students. Overall, eight PhD students participated at the workshop. Additional funds were provided by the Faculty of Physics of the U of Vienna to confer local expenses of PhD students (Ilya Feige, Daniel Kolodrubetz, Pier Monni, Emily Nardoni, Ian Moulton). Moreover, students from the MIT (Dan Kolodrubetz, Ian Moulton, Emily Nardoni, Aditya Pathak) had their airfare costs partly covered by the MISTI Global Seed Funds grant “Probing a new energy frontier with jets at the Large Hadron Collider”, MIT number 2654001, on which André Hoang and Iain Stewart are two of the co-principal investigators.

The feedback of the participants about the organization and the very unique format of the programme was overwhelmingly positive, and all participants expressed the desire to have an-

other workshop at the Erwin Schrödinger Institute in Vienna in the near future. The participants were also very positive about the ESI working environment and, in particular, about the support provided by the ESI administration.

Specific information on the programme

(i) Jets and Higgs Boson Production The theoretical description of the production and the decay of the Higgs boson at the Large-Hadron-Collider (LHC) is one of the most important current problems in jet physics. The Higgs boson with a mass of 125 GeV was discovered by the ATLAS and CMS experiments in the summer of 2012. This discovery and plans for future measurements have had an enormous impact on the field of particle physics, confirming the key component of the Standard Model through the mechanism for spontaneous symmetry breaking which produces the electromagnetic and weak forces in their known forms. The Higgs also provides a mechanism to answer another fundamental question, of how matter particles get their mass, including everything from leptons like the tau, to quarks like top-quark which is the heaviest known fundamental particle. To test this mass generation mechanism requires measurements in many Higgs production and decay channels, such as $H \rightarrow WW$, $H \rightarrow ZZ$, $H \rightarrow \tau\tau$, and $H \rightarrow \gamma\gamma$. A crucial aspect of these measurements is that they are also made specifying a particular number of final state jets, $H + 0$ jets, $H + 1$ jet, $H + 2$ jets, etc, and the physics of these jets and their impact on the potential measurements of the mass generation mechanism must therefore be well understood. This aspect of theory that is required to describe the Higgs boson was a main topic at this ESI programme.

Participants working on Higgs related jet physics were present throughout the programme, with a particular concentration in the first and last weeks, and several presentations were given during this time. During the first week an overview of the current status from a broad range of directions was given by Frank Petriello, including both higher order perturbative calculations, the state of the art in resummation of large logs to all orders in perturbation theory, as well as techniques used to assess theoretical uncertainties that describe our understanding of what is still missing from the current theoretical description. This was followed by a talk on technical aspects of the current state of the art in next-to-next-to-leading order perturbative calculations for proton collisions producing $H + 1$ jet given by Radja Boughezal. Finally, we had a detailed talk by Jon Walsh on the structure of large logarithms, including current achievements and open issues. In the last week, three competing groups presented talks on state of the art results for next-to-next-to-leading-logarithmic resummations (and beyond) in Higgs production. These talks were given by Andre Banfi, Frank Tackmann, and Thomas Becher, and addressed both the issue of accounting for finite jet radii, as well as those associated to large logarithms and rapidity divergences (discussed below). Finally, the formal mathematical proof of the factorization theorem for Higgs production was rigorously debated (this discussion was motivated by the talks, but given the duration, primarily took place outside the 2 hour talk window). Although the contributions still causing mathematical disagreements are numerically very small, and are only relevant beyond the order where the calculations have been carried out explicitly, they are still conceptually important.

Three articles related to jets and the Higgs boson have appeared where work was done that was connected to the ESI programme. This includes the NNLL'+NNLO analysis performed in [2], which has carried out the most extensive perturbative calculations to date and also addresses the issue of correlations between theoretical uncertainties in different observables. In [5] the impact of finite top and bottom masses was studied for the $H + 0$ jet distribution. Finally, in [6] an analysis was carried out to match a full parton shower in the POWHEG program to NNLO inclusive Higgs production. [6 talks, 3 papers]

(ii) Factorization and Factorization Violation Proofs of factorization in the cross section describing the production and evolution of jets are the conceptual basis for systematic perturbative calculations, the summation of large logarithmic terms, the maintenance of gauge invariance, and the consistent parametrization of non-perturbative effects. Well established cases of factorization are the formulation of the parton distribution functions, which is crucial for all experiments at the LHC, the separation into hard and soft functions for production threshold cross sections, and in certain cases the separation into hard, jet and soft functions for jet production including a variable that vanishes for a particular number of exclusive jets. To extend the systematic field theoretic treatment of jets further, proofs of factorization and the study of the intrinsic limits of factorization are an important facet of the current research in jet physics. Making progress in the study of factorization and its violations is quite difficult since the associated theoretical examinations touch the roots of the current understanding of the strong interactions.

There were six talks dedicated to extensions of factorization, factorization violation, and to theoretical issues for which a factorization approach does not exist at this time. In the talks by John Donoghue, Iain Stewart, and Rodrigo German new insights into effects of factorization violation were discussed related to quark and gluon modes that break factorization in certain circumstances. Matteo Cacciari and Greg Soyes gave presentations on the problems of pileup and the underlying event which limit the precision of LHC measurements and for which currently no factorization description exists. Einar Gardi discussed an extension of soft gluon exponentiation to the case of multi-jet production and Ilya Feige talked about a novel on-shell approach to factorization. Adam Leibovich and Tom Mehen presented new results concerning double parton fragmentation in quarkonium production. Finally, Piotr Pietrusewicz discussed how factorization needs to be extended once the effects of heavy quark masses (charm, bottom and top quarks) are taken into account systematically within the factorization framework. A new work on an accurate measurement of the charm quark mass was published in [1], and a theoretical calculation at NNLL order relevant for an accurate measurement of the top quark mass at a future Linear Collider was published in [11]. In [8], factorization was used to carry out a calculation of the transverse-momentum spectrum of electroweak bosons near threshold at NNLO. [8 talks, 3 papers]

(iii) Event-Shapes Event-shapes are observables which quantify how jet-like events are that arise in high energy collisions. They belong to observables that are infrared-safe, for which factorization is often proven and well-established, and for which predictions are possible with a very high level of precision via high-order perturbative computations. Event shapes are therefore ideal observables to measure theoretically well-defined parameters of jets and the strong interaction in general such as the strong coupling α_s or non-perturbative matrix elements related to soft gluon effects. For a number of event-shapes such as thrust, very sophisticated and high-order theoretical predictions exist reaching the NNLL order level, where the treatment of subtle and tiny effects become necessary.

There were 4 presentations related to event shapes. Chris Lee gave a detailed review lecture on the status and recent advances in event shapes calculations pin-pointing issues that are still unresolved. Vicent Mateu discussed how the angular dependence of produced jets can be systematically included in current theoretical predictions and that factorization is not affected by considering angular-dependence. Finally, Andrew Larkoski showed that relaxing some of the crucial constraints on event shapes can still lead to calculable observables. At the time of this report 4 publications have appeared based on work on event-shapes carried out at the workshop: [3] represents the work discussed by Vicent Mateu, [10] presents new two-loop calculations for the description of heavy quark final states and [15] presents new calculations for a novel event shape that makes predictions for electron-proton deep inelastic scattering. Finally, in [9] results for

single soft gluon emission for a soft radiation were computed at two-loops. [3 talks, 4 papers]

(iv) Rapidity Singularities A key concept of quantum field theory is the separation of length and energy scales. This concept is connected to the dimension or importance of operators by the concepts of effective field theory, and every known quantum field theory can be viewed as an effective field theory from this point of view. Due to Lorentz invariance the relevant quantity determining these scales is the invariant mass of fluctuations in almost all known quantum field theories of particle physics. Applications of renormalization group techniques allows quantities defined at different invariant mass scales to be connected to each other. In the SCET framework this invariant mass renormalization group greatly facilitates the resummation of large logarithms in various cross sections.

For certain jet cross sections and observables it turns out that a resummation in invariant mass is insufficient to handle all large logarithms, or put another way, a quantity other than invariant mass is required to distinguish degrees of freedom in the effective field theory. This quantity is known as rapidity and is related to the polar angle between particles. Recently methods have been developed to treat the resulting rapidity singularities and formulate rapidity renormalization group methods that allow for the same powerful predictions as the classic invariant mass results.

A key issue related to exploring processes sensitive to rapidity singularities is to define observables that probe jets in a manner that allows for the resulting calculations to be tractable. In a talk by Duff Neill at the ESI programme an observable of this type was defined for the first time, exploiting the ability to choose a different axis for each jet and thus avoid complicated recoil effects between jets. These rapidity singularities also were treated in one publication related to the ESI programme, in Higgs+0 jet production in [2], where it was found that estimating unknown higher order terms related to logarithms produced by these rapidity singularities gives an important contribution to the size of the estimated theoretical uncertainties. [1 talk, 1 paper]

(v) Jet Substructure The majority of applications of quantum field theory to jets seek to describe the distribution of jets and connect their properties back to the underlying short distance process from a hard collision event. With the advent of the LHC a new sub-field of jet physics has emerged which studies the substructure within a single jet, rather than the overall jets appearing in the event itself. Substructure methods can be used to distinguish whether a jet was produced by a massive colorless particle like an electroweak or Higgs gauge boson, as opposed to a primary energetic quark or gluon that carry color charges. Thus jet substructure can play a crucial role in both measurements and searches for new physics.

At the ESI programme Simone Marzani presented a talk about direct quantum field theory calculations of jet substructure observables. This research direction is crucial in order for us to go beyond simple Monte Carlo models, and obtain a reliable understanding of jet substructure that can be fully exploited at the LHC. The proceedings article [14] was published reviewing points also given in his talk. This theme of jet substructure was widely discussed during the ESI programme. In a later week, another talk was given in the area of jet substructure by Wouter Waalewijn. He discussed new advances made by defining Track Functions in quantum field theory. These functions allow jets to be studied utilizing information that goes beyond the relativistic four-momentum of particles. In particular, the particles within jets can be probed through the electromagnetic charge of the particles (which are detected by tracks in dedicated apparatus experimentally), and using his formalism the resulting observables can be predicted within the framework of quantum field theory. [2 talks, 1 proceedings article]

(vi) **Other Topics** Research not related to the main subjects but which participants found interesting to work on and discuss during the ESI programme includes that in the articles: [13, 7, 4].

Outcomes and achievements

At the time of writing of this report 17 preprints [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18] have been produced which are intended for publication in regular scientific journals, and 5 of these have already been officially published [1, 3, 6, 7, 9]. They either acknowledge partial support of the Erwin Schrödinger Institute or were actually prepared and written during the ESI programme. There is also one proceedings article containing a writeup of a presentation given at the ESI [14]. The number of preprints and publications related to the ESI programme “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 programme has not yet appeared publicly in preprint form.

There have been many new collaborations formed directly related to the ESI programme. A few examples include that by Ahmad Idibi and Michael Fickinger (subject “Factorization breaking effects in QCD”), by Andrew Larkoski and Gregory Soyez (subject “Jet multiplicity”), by Iain Stewart, Emily Nardoni, and Jon Walsh (subject “Characterizing Large Logs in Higgs production”), by Adam Leibovich, Tom Mehen, and Massimiliano Procura (subject “Distinguishing Color Singlet and Color Octet production with Jet Substructure Methods”), and by Andre Hoang, Iain Stewart, Piotr Pietrulewicz, and Aditya Pathak (subject “Resummation with Primary and Secondary Massive particles for Kinematic Distributions in Top Production”).

List of presentations

Frank Petriello, Raja Boughezal, Jon Walsh:	Higgs production with jet vetos
John Donoghue, Iain Stewart:	Does the Higgs reggeize? Regge and Glauber
German Rodrigo:	Factorization violation
Simone Marzano:	Jet substructure
Vicent Mateu:	Oriented event shapes
Matteo Cacciari, Gregory Soyez:	Pileup and the underlying event
Andrew Larkoski:	Unsafe but calculable: ratio observables in perturbative QCD
Einan Gardi:	Soft gluon exponentiation theorem for the multi-leg case
Chris Lee:	Bekannte bekannte and bekannte unbekante in jet and event shapes
Wouter Waalewijn:	Track functions for calculating track-based observables
Ilya Feige:	An on-shell approach to factorization
Adam Leibovich, Tom Mehen:	Double parton fragmentation for quarkonium
Duff Neil:	The broadening axis: taming recoil in jets
Duff Neil, Piotr Pietrulewicz:	Mass modes in thrust
Andrea Banfi, Frank Tackmann, Thomas Becher:	Higgs production with a jet veto: resummation

Papers and preprints contributed:

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Invited scientists:

Andrea Banfi, Christian Bauer, Thomas Becher, Guido Bell, Radja Boughezal, Mathias Butenschön, Matteo Cacciari, Gennaro Corcella, Mrinal Dasgupta, Bahman Dehnadi, John Donoghue, Ilya Feige, Michael Fickinger, Einan Gardi, Jonathan Gaunt, Andre Hoang, Andrew Hornig, Ahmad Idilbi, Ambar Jain, Daekyoung Kang, Jihun Kim, Daniel Kolodrubetz, Andrew Larkoski, Christopher Lee, Adam Leibovich, Zoltan Ligeti, Sonny Mantry, Simone Marzani, Vincent Mateu Barreda, Tom Mehen, Pier Monni, Ian Moulton, Emily Nardony, Duff Austin Neill, Aditya Pathak, Benjamin Pecjak, Francis John Petriello, Piotr Pietrulewicz, Moritz Preisser, Massimiliano Procura, Emanuele Re, German Rodrigo, Lorena Rothen, Daniel Samitz, Matthew Schwartz, Gregory Soyez, Maximilian Stahlhofen, Iain Stewart, Frank Tackmann, Wouter Waalewijn, Jonathan Walsh, Giulia Zanderighi, Hua Xing Zhu.

GEOQUANT 2013

Organizers: Harald Grosse (U Vienna), Ryoichi Kobayashi (Nagoya U), Martin Schlichenmaier (Luxembourg U), Armen Sergeev (Steklov Mathematical Institute, Moscow), Oleg Sheinman (Steklov Mathematical Institute, Moscow), Weiping Zhang (Chern Institute of Mathematics, Tianjin)

Dates: August 19 – 30, 2013

Budget: ESI € 26 000

Report on the programme

The main scientific direction presented at the School–Conference was *Geometric Quantization* understood in a broad sense. This field is a direction of ongoing intensive mathematical research. Some of the appearing mathematical problems originate from inside the mathematical theory. In addition, particularly during the last years, a number of challenging mathematical problems came from theoretical physics. It was the scientific goal of the Geoquant conference to address some of these problems. The following topics were covered in Vienna:

- Concepts of differential and complex geometry arising in quantization;
- Relations between quantization and the geometry of moduli spaces;
- Algebraic aspects of quantization, in particular, infinite-dimensional Lie algebras and groups and their representations;
- Asymptotic geometric analysis;
- Relations with modern theoretical physics;
- K3 surfaces, conformal field theory;
- Non-commutative quantum field theory.

Activities

The School/International Conference on Geometry and Quantization was a two weeks activity. The first week was a school intended to enable young scientists to enter the field. The second week was an international scientific conference. In total 80 people participated in the event, including 34 lecturers and speakers.

The School/International Conference in Vienna was the 5th GEOQUANT event. The previous conferences were held in: (a) Japan, Tokyo-Nagoya, 2005, (b) Russia, Moscow, 2007, (c) Luxembourg, Luxembourg City, 2009, (d) China, Beijing-Tianjin, 2011.

Specific information on the programme

The format of this activity is different from the usual 2 or 3 months research programmes. It consists of one week school and one week conference. Nevertheless, both weeks had a thematic focus on geometric methods in relation to quantization.

Moreover, despite the sometimes quite tight schedule of 50 minutes talks on the conference and 1 hours lectures at the school there were a lot of very lively scientific discussions also going on outside of the lecture hall. As it is a good tradition at the ESI, people gathered at all blackboards on its floors.

School week

During the school 7 lecture courses were presented. Six of the courses lasted for 3 times one hour. As it has been proven very effective in former schools organized in the frame of the GEOQUANT activity, regular discussion sessions were foreseen in the late afternoon. They were quite frequented. There the participants asked the lecturers additional questions in a less formal way, demanded for more background information or even presented themselves certain supplementary information.

The following **lecture courses** were given

- Yael Fregier (MIT, USA; Lens, France), *Moduli spaces of algebraic structures and Maurer-Cartan equations*
- Harald Grosse (U Vienna, Austria), *An introduction to non-commutative quantum field theory*
- Alexander Kuznetsov (Steklov Mathematical Institute, Moscow, Russia), *Derived categories of coherent sheaves and moduli spaces*
- Yoshihiro Ohnita (Osaka City U, Japan), *Hamiltonian stability problem of Lagrangian submanifolds in Kähler manifolds*
- Vincent Rivasseau (Paris, France), *Random Tensors*
- Boris Shoikhet (Antwerp, Belgium), *About deformations*
- Katrin Wendland (U of Freiburg, Germany), *K3 surfaces: Geometry, conformal field theory and number theory*

Conference week

The following **invited talks** were presented in the conference week:

1. Anton Alekseev, Geneva, Switzerland, *Logarithms and deformation quantization*
2. Ugo Bruzzo, Trieste, Italy, *Stacky resolutions of moduli spaces of instantons*
3. Detlev Buchholz, Göttingen, Germany, *The resolvent algebra: a new approach to canonical quantum systems*
4. Miroslav Engliš, Prague, Czech Republic, *Spectral triples and Toeplitz operators*
5. Jürgen Fuchs, Karlstad, Sweden, *Three-dimensional topological field theories on manifolds with boundaries and defects*
6. Hajimi Fujita, Tokyo, Japan, *Equivariant local index and transverse index for circle action*

7. Tomohiro Fukaya, Sendai, Japan, *The coarse Baum-Connes conjecture for relatively hyperbolic groups*
8. Alexey Gorodentsev, Moscow, Russia, *Mukai Lattices*
9. Brian Hall, Notre Dame, USA, *The large- N limit of the Segal-Bargmann transform on unitary groups*
10. Alexander Karabegov, Abilene, USA, *On Gammelgaards formula for a star product with separation of variables*
11. Will Kirwin, Cologne, Germany, *Complex-time evolution in geometric quantization*
12. Ryoichi Kobayashi, Nagoya, Japan, *Hamiltonian volume minimizing property of maximal torus orbits in complex projective space*
13. Gandalf Lechner, Leipzig, Germany, *Non-local perturbations of hyperbolic PDEs and QFT models on non-commutative spacetimes*
14. Xiaonan Ma, Paris, France, *Flat vector bundle and Toeplitz operators*
15. George Marinescu, Cologne, Germany, *Equidistribution of random zeros on complex manifolds*
16. Shin-Ichi Oguni, Matsuyama, Japan, *On the coarse Baum-Connes conjecture*
17. Alexey Parshin, Moscow, Russia, *Base change and automorphic induction in the Langlands theory*
18. Armen Sergeev, Moscow, Russia, *Quantum Calculus and non-commutative Bloch theory*
19. Andrei Shafarevich, Moscow, Russia, *Quantization conditions on Riemann surfaces and spectral series of non-selfadjoint operators*
20. Georgy Sharygin, Moscow, Russia, *Full symmetric Toda system and Bruhat order*
21. Dimitry Talalaev, Moscow, Russia, *On deformation quantization of integrable systems,*
22. Alejandro Uribe, U Michigan, USA, *The exponential map of the complexification of $Ham(M, \omega)$ in the real-analytic case*
23. Michele Vergne, Paris, France, *An Euler-MacLaurin formula for the equivariant index of a transversally elliptic operator*
24. Siye Wu, Hong Kong, China, *Hitichin's equation on a non-orientable manifold*
25. Tilmann Wurzbacher, Metz/Bochum, France/Germany, *Integration of vector fields on supermanifolds and applications*
26. Takahiko Yoshida, Tokyo, Japan, *Equivariant local index and symplectic cut*
27. Xiangyu Zhou, Beijing, China, *Some results on the L^2 -extension problem*

Outcomes and achievements

The conference and school attracted mathematicians from Europe, Russia, China, USA and other places. It fostered the international collaboration of mathematicians working in the field, gave cross-fertilizations of different communities in the area, and helped to bundle the efforts of researchers.

We got an extremely good feedback from the participants, expressing that it is a conference on timely topics, that they got inspired a lot, and that new interactions were created. In particular, the participants urged us to continue with this type of school-conference. We got much more applications for attendance than we could accommodate at the ESI.

In fact, we intend to run further GEOQUANT conferences in different countries. The next one is foreseen for 2015. As every time we plan to move the focus enough to explore different aspects of this fast developing and exciting field.

Invited scientists:

Anton Alekseev, Francesca Arici, Masaki Asano, Tatyana Barron, Iulia Beloshapka, Adam Biggs, Ugo Bruzzo, Detlev Buchholz, Xiongwei Cai, Hector Castejon-Diaz, Oscar Chavez Molina, Simone Camosso, Dragos Deliu, Miroslav Englis, Anton Fonarev, Yael Fregier, Jürgen Fuchs, Hajimi Fujita, Tomohiro Fukaya, Akito Futaki, Alexey Gorodentsev, Harald Grosse, Dmitry Gurevich, Brian Hall, Pedram Hekmati, Johannes Huebschmann, Oleksandr Iena, Noriaki Ikeda, Hiroshi Iriyeh, Mehmet Umut Isik, Benoit Jubin, Igor Kanatchikov, Alexander Karabegov, Hovannes Khudaverdian, Shin Kikuta, William Kirwin, Ryoichi Kobayashi, Christian Köhler, Alexander Kuznetsov, Giovanni Landi, Sylvain Lavau, Gandalf Lechner, Hui Li, Xiaonan Ma, George Marinescu, Jouko Mickelsson, Stepan Moskaliuk, Elena Netay, Igor Netay, Takahiro Noda, Shin-Ichi Oguni, Yoshihiro Ohnita, Alexey Parshin, Albert Georg Passegger, Nina Prudova, Jian Qiu, Vincent Rivasseau, Hirofumi Sasahira, Armen Sergeev, Andrey Shafarevich, Georgy Sharygin, Oleg Sheynman, Boris Shoykhet, Martin Schlichenmaier, Michael Stiller, Thomas Strobl, Ryosuke Takahashi, Dmitry Talalaev, Matteo Tommasini, Alejandro Uribe, Yuri Ustinovsky, Michele Vergne, Katrin Wendland, Siye Wu, Tilmann Wurzbacher, Takahiko Yoshida, Jochen Zahn, Huiping Zhang, Xiangyu Zhou.

Forcing, Large Cardinals and Descriptive Set Theory

Organizers: Sy David Friedman (KGRC, U Vienna), Martin Goldstern (TU Vienna), Alexander S. Kechris (Caltech), W. H. Woodin (UC Berkeley)

Dates: September 9 – October 18, 2013

Budget: ESI € 32 320

Report on the programme

Forcing was invented by Paul Cohen in the 1960's to demonstrate that a failure of Cantor's continuum hypothesis is consistent with the usual system of axioms ZFC for set theory. Since then this technique has been used to establish the consistency with ZFC of an immense range of other statements, not only from abstract set theory but also from "mainstream" areas of mathematics. Sometimes more than the consistency of ZFC is required for such a result; one very often assumes (and often needs to assume) the consistency of ZFC together with a *strong axiom of infinity* or *large cardinal axiom*. Together with the methods of inner model theory, it is often the case that when a statement is unprovable in ZFC then its consistency with the ZFC axioms is not only derivable from but in fact equivalent to the consistency of ZFC together with an appropriate large cardinal axiom.

The work on independence results in set theory through the use of large cardinal axioms and forcing can even be applied to statements about definable sets of real numbers, the central topic of descriptive set theory. However as descriptive set theory has developed it has become apparent that many of its aspects are immune to the independence results that apply to other areas of set theory and these aspects lead to profound connections with areas of mathematics such as ergodic theory and functional analysis. In recent years the emphasis in descriptive set theory has therefore shifted to results which are provable in ZFC, and the study of independence has been replaced by a study of *unclassifiability*, whereby it is shown that classification problems in mathematics do *not* admit a reasonable set of invariants.

Activities

This 6-week programme divided naturally into two parts. The first 3 weeks were devoted to forcing and large cardinals (FLC) and the last 3 weeks to descriptive set theory (DST). The

first part culminated in the FLC workshop in week 3 and the second part began with the DST workshop in week 4; both of these workshops hosted about 30 foreign and 20 local participants. The FLC workshop featured about 20 talks and the larger DST workshop about 30 talks.

The first two weeks brought several leading researchers in large cardinal forcing who interacted very well with the local set-theorists: James Cummings, Menachem Magidor, and Ralf Schindler. Naturally, these people stayed on for the FLC workshop in week 3. Four descriptive set-theorists who arrived for the DST workshop in week 4 stayed on at the ESI for two additional weeks: Su Gao, Christian Rosendal, Slawek Solecki and Asger Törnquist.

Specific information on the programme

(i) Tree properties In the first two weeks Cummings and Magidor collaborated with local researchers Fontanella and Friedman on the study of the tree property. Specifically they considered Gitik's work on obtaining the tree property at $\aleph_{\omega+2}$ with \aleph_ω strong limit from optimal assumptions (improving earlier work of Friedman-Halilović). Friedman had suggested that Gitik's methods might solve the key open question of how to additionally have the tree property at $\aleph_{\omega+1}$, as the method appeared to avoid the pitfalls of other approaches. They were initially encouraged by the fact that a simplification of Gitik's forcing does indeed yield the tree property at $\aleph_{\omega+1}$, however this simplification is not sufficient to yield the desired result. Indeed after further lengthy discussions they concluded that Gitik's method cannot work, as it produces a weak square sequence, which is enough to kill the tree property.

Fontanella and Magidor also looked at the tree property, but instead for \aleph_{ω^2+1} . Earlier work of Magidor and Shelah established strong forms of stationary reflection at this cardinal. The new result is that these strong forms are also consistent with the tree property. This is witnessed by the same model that Magidor-Shelah used, so the work was to provide a deeper analysis of that model.

(ii) Core models and coding Schindler collaborated in the first two weeks with local researchers Friedman and Schritterser in an effort to obtain a parameter-free version of Steel's result that strong cardinals are sufficient to obtain the projective measurability and uniformization properties. The strategy was heavily based on coding over core models, which led the three of them to carefully study to what extent coding methods are available in the presence of strong cardinals. Earlier work of Friedman had established a number of such results, however the problem at hand demanded stronger coding theorems which Friedman's techniques could not handle.

Indeed in the end Schindler and Schritterser showed that the stronger version of coding required for the proof cannot be done. The argument is based on core model ideas of Schindler. It was a good lesson for the three of them and resulted in a subsequent article in which coding over core models is thoroughly discussed and the possibilities and impossibilities are clearly described.

(iii) The Forcing and Large Cardinals Workshop This was a very relaxed and interesting workshop featuring 19 lectures on a wide range of aspects of forcing and large cardinal set theory (a 20th lecture was cancelled due to Arthur Apter's regrettably late notice of his inability to attend). Some highlights: Chodounsky told us of the current state of the still-unsolved Katowice problem (Can the powerset of ω mod finite and the powerset of ω_1 mod finite be isomorphic?). Holy showed us how to get a Σ_1 wellorder of $H(\kappa^+)$ with 2^κ large when $\kappa = \kappa^{<\kappa}$. Borodulin-Nadzieja discussed his work with (our local researcher) Farkas and Plebanek on the geometry of analytic P -ideals. Cummings, Sinapova and Unger each presented cutting-edge results in singular cardinal combinatorics. Sakai and Viale discussed strong forcing axioms. On the more applied side, we heard talks from Koszmider and Dzamonja related to Banach spaces and from

Kojman and Rinot on large graphs. And Mildenerger presented her subtle work on iterated forcing needed to analyze near-coherence classes of ultrafilters.

(iv) The Descriptive Set Theory Workshop This remarkable workshop presented 30 talks and evidenced the vitality and rapid growth of this area of set theory. In addition to the senior researchers Bartoszynski, Dodos, Gao, Jackson, Kanovei, Rosendal, Solecki and Törnquist, the workshop featured an astounding group of new descriptive set theory PhD's who are already obtaining deep and striking results at the start of their careers. Some highlights: Bartosova exposed her striking work on unique amenability, Kwiatkowska revealed surprising properties of the pseudo-arc and both Aaron Hill and Su Gao discussed rank one measure-preserving transformations. Ground-breaking results were presented by Asger Törnquist who solved long-standing open questions concerning almost disjoint families, by Andrew Marks, who recently obtained the best results on Martin's conjecture regarding Turing-invariant functions, by Marcin Sabok, who established the unclassifiability of separable C^* -algebras and by Slawek Solecki, who recently obtained a far-reaching generalization of earlier work on the Ramsey theory of trees.

Outcomes and achievements

Below are some information regarding preprints that were prepared as a result of the programme, important results obtained, and specific collaborations that took place.

- Borodulin-Nadzieja, Piotr: joint with B. Farkas, "Representations of analytic P -ideals in Banach spaces and in Polish groups" (20 pages).
- Elekes, Marton: joint with V. Kiss, Z. Vidnyanszky, "Ranks on the Baire class α functions" (25 pages). Thanks to discussions with various participants (Solecki, Dodos, Debs, ...) a significant progress was made. In particular, vary nicely-behaved ranks on the Baire α classes have been found and an essentially optimal generalization of the classical results of Louveau and Kechris about ranks on the Baire class 1 functions have been obtained.
- Farah, Ilijas: joint with M. Magidor, "Omitting types in logic of metric structures is hard" (19 pages).
- Friedman, Sy-David: joint with R. Schindler, D. Schrittesser, "Coding over core models" (17 pages), submitted.
- Holy, Peter: joint with Ph. Luecke, "Locally Lightface Σ_1 -definable Well-Orders Of $H(\kappa^+)$ " (25 pages). We have obtained the following result. Assume $V = L$. For any regular uncountable cardinal κ that is not the successor of a singular cardinal, there is a forcing extension in which 2^κ has any reasonably prescribed value λ , cofinalities up to λ agree between the forcing extension and L and there is a Σ_1 -definable wellorder of $H(\kappa^+)$ using only κ as a parameter. Further discussions took place about generalized almost disjoint coding with David Schrittesser and Philipp Luecke and with Sy Friedman about future work in the Outer Model Programme.
- Ikegami, Daisuke: "Inner models from logics". Further useful discussions, with Ralf Schindler, were on the Necessity Maximality Principle for local statements due to Hamkins. It was observed by Ralf Schindler that $ZFC +$ "NMP for local statements" is equiconsistent with $ZFC +$ "There exist a proper class of Woodin cardinals" (the implication from large cardinals to BNMP was already known by Hamkins).
- Kanovei, Vladimir: "On countable cofinality of definable chains in Borel partial orders" (6 pages). We prove that in some cases definable chains of Borel partial orderings are necessarily countably cofinal.

- Leiderman, Arkady: joint with S.S. Gabrielyan and J. Kakol, “The strong Pytkeev property for topological groups and topological vector spaces”, submitted to Monatshefte für Mathematik.
- Rosendal, Christian: “Large scale geometry of metrisable groups” (50 pages +).
- Schrittester, David: joint with Sy Friedman and Ralf Schindler, “Coding over core models” (17 pages). Further fruitful discussions with Asger Törnquist on the lifting problem of the automorphism group of a measure space and with Yurii Khomskii on problems in the separation of ideals in the projective hierarchy.
- Selivanov, Victor: joint with Matthias Schroeder, “More hierarchies of qcp_0 -spaces”.
- Sinapova, Dima: joint with Spencer Unger, “Scales in Combinatorics at \aleph_ω ” (6 pages). We are analyzing the pcf structure in the model of our paper “Combinatorics at \aleph_ω ”. Our conjecture is that our model will show the consistency of not SCH and no very good scale.
- Tsaban, Boaz: joint with Arnold W. Miller, Lyubomyr Zdomskyy, “Selective covering properties of product spaces, II: γ spaces” (24 pages). In addition, with Zdomskyy, we characterized exactly when Hurewicz spaces remain Hurewicz in an extension of the universe by Cohen forcing, thus solving a problem of Scheepers and Tall.

Invited scientists:

Hiroshi Ando, Alesandro Andretta, Carolin Antos-Kuby, Giorgio Audrito, Joan Bagaria, Dana Bartosova, Tomek Bartoszynski, Kostas Beros, Piotr Borodulin-Nadzieja, Riccardo Camerlo, David Chodounsky, James Cummings, Udayan (Dario) Darji, Gabriel Debs, Vincenzo Dimonte, Pandelis Dodos, Gregor Dolinar, Ohad Drucker, Mirna Dzamonja, Katsuya Eda, Marton Elekes, Ilijas Farah, Barnabas Farkas, Arthur Fischer, Vera Fischer, Laura Fontanella, Sy David Friedman, Sakae Fuchino, Su Gao, Misha Gavrilovich, Martin Goldstern, Mohammad Golshani, Jan Grebik, Vassilis Gregoriades, Aaron Hill, Stefan Höffner, Radek Honzik, Peter Holy, Daisuke Ikegami, Steve Jackson, Istvan Juhasz, Adriane Kaïchouh, Vladimir Kanovey, Asaf Karagila, Ahmad Karimi, Jakob Kellner, Juliette Kennedy, Yurii Khomskii, Menachem Kojman, Piotr Koszmider, Vadim Kulikov, Aleksandra Kwiatkowska, Arkady Leiderman, François Le Maître, Stefane Le Roux, Philipp Lücke, Martino Lupini, Menachem Magidor, Maciej Malicki, Alberto Marcone, Andrew Marks, Alejandro Mejia, Andrea Medini, Heike Mildenberger, Assaf Rinot, Christian Rosendal, Marcin Sabok, Hiroshi Sakai, Grigor Sargsyan, Ralf Schindler, Scott Schneider, David Schrittester, Matthias Schröder, Brandon Seward, Dima Sinapova, Kostya Slutsky, Miodrag Sokic, Slawomir Solecki, Lajos Soukup, Anda-Ramona Tanasie, Fabio Tonti, Victor Torres Perez, Asger Törnquist, Boaz Tsaban, Todor Tsankov, Robin Tucker-Drob, Spencer Unger, Jouko Vninen, Boban Velickovic, Jonathan Verner, Matteo Viale, Zoltan Vidnyansky, Philip Welch, Phillip Wesolek, Jay Williams, Wolfgang Wohofsky, Tin Lok Wong, Lyubomyr Zdomskyy, Samuel Ziegler, Yizheng Zhu.

Heights in Diophantine Geometry, Group Theory and Additive Combinatorics

Organizers: Robert Tichy (TU Graz), Jeffrey Vaaler (U Texas at Austin), Martin Widmer (Royal Holloway, U of London), Umberto Zannier (Scuola Normale Superiore, Pisa)

Dates: October 21 – December 20, 2013

Budget: ESI € 32 320, FWF (€ 4 000)

Report on the programme

Heights are a fundamental tool in many branches of number theory that allow the quantification of the arithmetic complexity of an algebraically defined object. Whereas in Diophantine

geometry heights have become an indispensable tool the use of heights in group theory and additive combinatorics is a rather new development. However, recent work of Breuillard, Bourgain, Chang, Konyagin, Shparlinski, and others indicate that heights might become a very valuable tool in geometric group theory and additive combinatorics, not only to prove but also to formulate the problems in a broader and more conceptual context. One aim of this program was to deliver a common platform for all of these communities as we believe that this will lead to fruitful interactions in the future.

The famous Lehmer conjecture is possibly the central problem in the theory of heights, and some of its variations have interpretations in low-dimensional topology, potential theory, and geometric group theory. Lehmer's original conjecture asserts that the height of an algebraic number when multiplied by its degree is either zero or uniformly bounded away from zero. Dobrowolski's Theorem from 1976, although still a standing mile stone, has been pushed much further, most notably by the deep work of Amoroso, David, and Zannier.

Indeed, for many special cases the Lehmer conjecture is proven, and for some interesting cases (e.g., for totally real, totally p -adic, or abelian extensions of \mathbb{Q}) even the much stronger Bogomolov property, which states that the height itself is either zero or uniformly bounded away from zero, has been established. Bombieri and Zannier have shown that for some infinite extensions of \mathbb{Q} a further strengthening, the so-called Northcott-property, also holds. The Northcott-property is a crucial ingredient in many finiteness statements in Diophantine geometry and arithmetic dynamics. Progress has also been made on the higher dimensional geometric versions of the Lehmer conjecture. The latter has interesting applications, e.g., it is used in many instances of the so-called Zilber-Pink conjectures on unlikely intersections, as in Bombieri, Masser and Zannier's work.

Regarding connections with geometric group theory the recent work of Breuillard is particularly striking. Breuillard has established uniform versions of the Tits alternative regarding the existence of free subgroups in linear groups. To this end he introduced a normalized height on the set of k -tuples of invertible matrices taken up to conjugation, and proved a Bogomolov type lower bound for k -tuples generating a non virtually solvable subgroup. Some of the key ingredients for this lower bound are of Diophantine nature, namely: Bilu's Equidistribution Theorem, a theorem of Zhang and Masser and Wüstholz' effective Arithmetic Nullstellensatz.

Heights have also found their way into additive combinatorics. Bourgain, Konyagin, and Shparlinski studied growth expansion properties of product sets of bounded height in \mathbb{Q} . Later Bourgain and Chang investigated sum-product phenomena for subsets of algebraic integers of bounded degree, and also growth expansion properties of product sets of algebraic integers of bounded degree and bounded height.

Other intensively studied questions are the appearance of certain structures in difference sets: a famous example is Sárközy's Theorem that in any subset of the (positive) integers of positive (upper) density there exist two distinct elements whose difference is a square. This means that the set of squares is intersective in \mathbb{Z} . So far intersective sets have mostly been studied over \mathbb{Z} but of course the concept can be formulated whenever one has a group and a notion of density on this group. In particular one can study intersective sets over any global field (or even over any subgroup of \mathbb{Q} that satisfies the Northcott property) using the natural density induced by the height. This has recently been done by Le and Spencer in the setting of global function fields.

Activities

The main activity of the programme was a workshop on November 25 - 29, 2013 with 14 talks of 45 minutes and 13 talks of 30 minutes, including a series of three lectures of Breuillard with the focus on the interplay of geometric group theory and Diophantine geometry. The complete list of lectures is given below. A mini-workshop organized by Clemens Fuchs was devoted to explicit

problems in Diophantine analysis and geometry. Several participants of the main workshop spent a further week at the ESI for a third workshop (with only two talks per day) collaborating on specific problems and discussing important research question in the field. In particular, we point out that Gisbert Wüstholz (ETH Zürich) spent several weeks at the ESI. Some of the speakers were co-financed by the FWF-grants of C. Fuchs and R. Tichy.

Specific information on the programme

There were talks and discussions in a wide range of topics including Diophantine geometry, geometric group theory, additive combinatorics, and Diophantine approximation. We shall give a few more details on three main topics of this programme.

Lehmer type problems, Bogomolov property, and Northcott property. In the last decade various interesting and difficult questions have been proposed on the properties of Bogomolov and Northcott for subfields of $\overline{\mathbb{Q}}$ of infinite degree, most notably by Amoroso, Bombieri, David, and Zannier. Many talks were devoted to these properties and several teams started or continued joint projects on height bounds and related issues (Fili-Pottmeyer, Fili-Grizzard, Habegger-Grizzard-Pottmeyer, Grizzard-Vaaler, Vaaler-Widmer). Rémond proposed conceptual generalizations of Lehmer’s conjecture and weaker variants thereof. Amoroso has already obtained some first results in this direction, see his preprint below.

Geometric group theory and connections to Diophantine geometry. As mentioned above, Breuillard has established uniform versions of the Tits alternative for finitely generated subgroups of $GL_d(K)$, using results and methods from Diophantine geometry.

Breuillard gave a series of three excellent 45-minutes lectures on his work and proposed various important open problem that might be approached using further input from Diophantine geometry. This resulted in various discussions, and hopefully will lead to new collaborating teams beyond the number theory community.

Furthermore, Benjamin Klopsch gave a beautiful survey talk on representation zeta functions for arithmetic groups revealing some unexpected appearances of height zeta functions.

Heights and additive combinatorics. Unfortunately, two invitees working on additive combinatorics had to cancel their participation on short notice. Therefore, this topic was less represented than planned originally. However, we had interesting and stimulating talks by Sharplinski on “unlikely intersection”-problems over finite fields that can be tackled by effective versions of Hilbert’s Nullstellensatz, and by Le on intersective polynomials and Diophantine approximation.

Outcomes and achievements

During this programme various collaborations were started or continued, see the list below. This special trimester had also great influence on the career development of Austrian and foreign PhD-students and young postdocs. In particular, Christopher Frei (now a postdoc and Humboldt-fellow in Munich), Fabrizio Barroero (PhD-student in Graz and soon a postdoc at Scuola Normale Superiore in Pisa) and Dijana Kreso (PhD-student in Graz) should be mentioned here.

In the following we list preliminary research papers which were influenced by this ESI-programme or on which the authors have worked during their stay at the ESI. Collaborations that were initiated or continued during this programme are marked by an asterisk.

Francesco Amoroso:

On a conjecture of G. Rémond, preprint (2014); <http://hal.archives-ouvertes.fr/hal-00932275>.

Yuri Bilu:

Computing Integral Points on $X_n s^+(p)$, joint with A. Bajolet, revision of arXiv:1212.0665, [http:](http://)

[//arxiv.org/abs/1212.0665](http://arxiv.org/abs/1212.0665).

Diophantine Analysis on Modular Curves, in progress.

Emmanuel Breuillard:

Diophantine properties of nilpotent Lie groups, part II, joint with M. Aka, L. Rosenzweig and N. de Saxce, in progress.

Ulrich Derenthal:

Cox rings, joint with I. Arzhantsev, J. Hausen, A. Laface, submitted.

Paul Fili:

*Height bounds under splitting conditions, joint with Lukas Pottmeyer, in progress.

Christopher Frei:

O-minimality on twisted universal torsors and Manin's conjecture over number fields, joint with M. Pieropan, preprint, http://www.mathematik.uni-muenchen.de/~frei/manin_dp4_a3a1.pdf

*On the number of integers that are the sum of k units, joint with M. Widmer und V. Ziegler, in progress.

Robert Grizzard:

*Small points and free abelian groups, joint with P. Habegger and L. Pottmeyer, in progress.

*Height bounds under splitting conditions, joint with P. Fili, in progress.

*On points of small height in $\overline{\mathbb{Q}}$, joint with J.D. Vaaler, preprint.

Kálmán Györy:

Potential collaborations, based on very useful and stimulating conversations with many participants, including J.H.Evertse, D.Masser, Y.Bugeaud and R. von Kaenel.

Lajos Hajdu:

On a conjecture of Schäffer concerning the equation $S_k(x) = y^n$, in progress.

On the diophantine equation $1 + 2^a + x^b = y^n$, joint with I. Pink, in progress.

*On the correlation clustering of the integers, joint with A. Petthő, in progress.

David Masser:

*Polarization estimates for abelian varieties, joint with G. Wüstholz, in progress.

*Bounded height problems and Silverman specialization theorem, joint with F. Amoroso and U. Zannier, in progress.

Attila Petthő:

*On the correlation clustering of the integers, joint with L. Hajdu, in progress.

Ákos Pintér:

A diophantine problem related to the power sums, in progress.

Lukas Pottmeyer:

*Small points and free abelian groups, joint with R. Grizzard and P. Habegger, in progress.

*Height bounds under splitting conditions, joint with P. Fili, in progress.

Igor Shparlinski:

*Discriminants of fields generated by polynomials of given height, joint with R. Dietmann, N. Katz and A. Ostafe, in progress.

Subgroups generated by polynomials in finite fields, joint with D. Gómez-Pérez, preprint 2013, <http://arxiv.org/abs/1309.7378>

Polynomials values in small subgroups of finite fields, preprint, 2014, <http://arxiv.org/abs/1401.0964>.

Jeff Vaaler:

*On points of small height in $\overline{\mathbb{Q}}$, joint with R. Grizzard, preprint.

*Small generators of number fields II, joint with M. Widmer, in progress.

Martin Widmer:

Diophantine approximation, flows on homogeneous spaces and counting, in progress.

*Small generators of number fields II, joint with J.D. Vaaler, in progress.

*On the number of integers that are the sum of k units, joint with C. Frei and V. Ziegler, in progress.

A possible future project, joint with Ulrich Derenthal, is about the Manin conjecture for the symmetric square of \mathbb{P}^n over number fields.

Gisbert Wüstholtz:

*A note on the conjectures of Andre-Oort and Pink, submitted

*On a problem of Diego Marques on elliptic integrals, preprint 2013.

Invited scientists:

Shabman Akhtari, Francesco Amoroso, Fabrizio Barroero, Paloma Bengoechea, Victor Beresnevich, Yuri Bilu, Emmanuel Breuillard, Yann Bugeaud, Laura Capuano, Sara Checcoli, Pietro Corvaja, Sinnou David, Ulrich Derenthal, Rainer Dietmann, Andrej Dujella, Christian Elsholtz, Jan-Hendrik Evertse, Paul Fili, Christopher Frei, Clemens Fuchs, Aurelien Galateau, Robert Grizzard, Walter Gubler, Kàlmàn Györy, Lajos Hajdu, Christoph Hutle, Benjamin Klopsch, Dijana Kreso, Michel-Julien Laurent, Thái Hoàng Lê, David Masser, Roland Paulin, Attila Pethö, Patrice Philippon, Akos Pinter, Lukas Pottmeyer, Nicolas Ratazzi, Gael Rémond, Adrian Scheerer, Igor Shparlinski, Pavel Snurnitsyn, Cam Stewart, Leonhard Summerer, Petra Tadić, Valerio Talamanca, Robert Tichy, Jeffrey Thunder, Jeff Vaaler, Sanju Velani, Francesco Veneziano, Carlo Viola, Rafael von Känel, Mingxi Wang, Martin Widmer, Gisbert Wüstholtz, Shou-Wu Zhang, Volker Ziegler, Evgeniy Zorin.

Workshops organized independently of the Main Programmes

ESI Anniversary - Two Decades at the Interface of Mathematics and Physics The [Un]reasonable Effectiveness of Mathematics in the Natural Sciences

Organizers: Goulnara Arzhantseva, Piotr Chruściel, Adrian Constantin, Joachim Schwermer, Frank Verstraete, Jakob Yngvason (all Kollegium ESI, U Vienna), jointly with Wolfgang Reiter (Foundation ESI) and Klaus Schmidt (Foundation ESI)

Dates: April 29 – 30, 2013

Budget: ESI € 8 384,77

Report on the workshop

The years 1990–1993, preceding the official foundation of the Erwin Schrödinger International Institute for Mathematical Physics (ESI) in Vienna, had been a time of intense preparations involving many mathematicians and physicists. Walter Thirring, Peter Michor, and Heide Narnhofer, acting on behalf of the scientific community, played a decisive role in the foundational period of ESI and beyond. Their initiative was well taken up by the Ministry of Science and Research in Austria. One year before the official opening of ESI a Conference on “Interfaces between mathematics and physics” was held in Vienna in March 1992. From the outset, the ESI has put particular emphasis on fruitful interactions between mathematics and other disciplines, in particular, mathematical physics. With the 20th anniversary occurring in April 2013, the ESI celebrated this event with a Symposium, entitled “*ESI Anniversary – Two Decades at the Interface of Mathematics and Physics – The [Un]reasonable Effectiveness of Mathematics in the Natural Sciences*”. It was necessary to utilize this moment, as it were, not only to celebrate the rich heritage of the Institute but also to position the ESI for the future. The topics of the lectures given at this occasion ranged over a broad band of themes which relate different fields within mathematics and mathematical physics or themes manifesting the outreach of mathematics beyond its own borders.

During the opening ceremony, **Susanne Weigelin-Schwiedrzik, Vice Rector for Research and Career Development of the U of Vienna**, underlined the unique role the Erwin Schrödinger International Institute for Mathematical Physics fills in (post-) graduate education and scientific research in mathematics and physics at the U of Vienna, in Austria, and on an international level.

In his opening words, the **Director of the ESI, Joachim Schwermer**, gave a brief overview of the institutional structure of the ESI, now turned into a research centre at the U of Vienna, and the various programmatic pillars of its scientific activities. However, as he explicitly pointed out, in securing the future, one has to give careful consideration to ways in which the ESI arrangements might be made more stable as it goes into a period of various challenges regarding its financial resources.

Finally, **Marta Sanz-Solé, the President of the European Mathematical Society**, drew attention to the position the ESI has within the international scientific community of scholars as a research Institute with a specific unique character. The Institute is a place that is very conducive to research and, at the same time, integrates scientific education and research.

The following talks were given during the Symposium:

David Ruelle [IHES, Bures-sur-Yvette, France]

Post-human mathematics

Abstract: Present day mathematics is a human construct, where computers are used more and more but do not play a creative role. This situation may change however: computers may become creative, and since they function very differently from the human brain they may produce a very different sort of mathematics. We discuss what this post-human mathematics may look like, and the philosophical consequences that this may entail.

Elliott Lieb [Princeton U, Princeton, USA]

The mathematics and physics of the Bose Gas

Abstract: One of the ways in which mathematics and physics interact strongly is the quantum mechanical many-body problem, specifically the Bose gas. Some rigorous results will be reviewed, including those that were influenced by ESI. Since it is the 50th anniversary of the Lieb-Liniger model, which is now an active experimental area, this topic, too, will be briefly recalled.

Alain Connes [Collège de France, Paris, France]

Variability, time and the quantum

Abstract: I will explain how the mathematical notion of “real variable” is best encoded by the quantum mechanical formalism of self-adjoint operators in Hilbert space. After this mathematical preliminary I will explain how one can conceive of the flow of time as emerging, using the Kubo-Martin-Schwinger condition, from one fundamental aspect of the quantum world which is intrinsic and irreducible variability.

Michael Douglas [State U of New York, Stony Brook, USA]

String theory and the real world

Abstract: Superstring theory is the leading candidate for a theory unifying the fundamental interactions of nature. Yet, after almost 30 years of work, we have no clear experimental evidence for or against the claim that it describes our world. Why do we believe it? What are the prospects for testing it?

Jeremy Gray [The Open U, Milton Keynes, UK]

“The soul of the fact” – Poincaré and proof

Abstract: Throughout his working life Henri Poincaré was concerned to promote the understanding of mathematics and physics. This is as apparent in his views about geometry, his conventionalism, and his theory of knowledge, as it is in his work on electricity and optics, on number theory, and function theory. This talk will argue that this is one of the ways Poincaré discharged his responsibilities as a scientist, and that it accounts not only for a surprising degree of unity in his work but also gives it its distinctive character – at once profound and elusive.

Reinhard Werner [Leibniz U, Hannover, Germany]

How spectral properties may be irrelevant in the long run

Abstract: A simple model system is presented in which the spectral type depends very sensitively on a parameter: pure point, absolutely continuous and singular spectrum each hold for a dense set of values, although all finite time expectations depend continuously on the parameter. Therefore any spectral type is consistent with the dynamics in any long (but finite) run. Of course, this merely points out the lack of exchangeability of the infinite time limit and limits in the parameter, which is a fairly common occurrence. Related phenomena are the lack of direct relevance of ergodicity for establishing approach to equilibrium and the high (quantum-) computational complexity of finding the ground state of a large quantum system as opposed to the low complexity of simulating the dynamics. With regard to the last problem one may well

ask: If Nature does not find the ground state on any reasonable time scale, why should I care about it? This poses the challenge to come up with mathematical notions which have more to say about quantum dynamics on finite time scales.

Wolfgang Lück [Hausdorff Institute, Bonn, Germany]

An introduction to L^2 -Betti numbers and their applications

Abstract: Betti numbers of closed manifolds are classical invariants in topology. Atiyah proposed a generalization, called L^2 -Betti numbers, for the universal covering of closed manifolds taking the operation of the fundamental group into account. These invariants have analytic interpretations in terms of the heat kernel as well as topological interpretations in terms of simplicial homology. They can also be defined for more general spaces and for groups. They have striking applications to various prominent beautiful problems in differential geometry, topology and group theory, where on the first glance these invariants do not seem to appear. We will discuss a selection of such problems indicating where the L^2 -Betti numbers occur as an important tool in their solutions.

Yuri Tschinkel [Courant Institute, New York, USA]

Diophantine equations and their hidden symmetries

Abstract: The structure of solutions of diophantine equations is often governed by symmetries invisible from the shape of the equations. I will discuss representative examples of this phenomenon, involving linear algebraic groups and Galois groups.

Peter Goddard [Institute for Advanced Study, Princeton, USA]

Algebras, groups, and strings

Abstract: Aspects of the interweaving development of the study of infinite-dimensional algebras, such as the Virasoro algebra and Kac-Moody algebras, and of string theory will be reviewed to illustrate the symbiotic relationship between mathematics and theoretical physics.

External invited visitors/speakers:

Jean-Pierre Bourguignon, John Cardy, Alain Connes, Michael Douglas, Peter Goddard, Jeremy Gray, Nigel Hitchin, Helge Holden, Daniel Huybrechts, Horst Knörrer, Elliott Lieb, Wolfgang Lück, Herbert Spohn, Vincent Rivasseau, David Ruelle, Marta Sanz-Sole, Yuri Tschinkel, Reinhard Werner.

Word maps and stability of representations

Organizers: Goulmara Arzhantseva (U Vienna), Nicolas Monod (EPF Lausanne), Alain Valette (U Neuchâtel)

Dates: April 11 – 13, 2013

Budget: ESI € 0, Swiss NSF Sinergia grant (CHF 7 303,22), and U Vienna (€ 484,06)

Report on the workshop

The goal of this 3 days intensive workshop was to bring together specialists both in mathematics and in mathematical physics working on topics related to Ulam’s stability of representations and a general “almost implies near” phenomenon. An elementary example of a result of interest is as follows: almost commuting matrices are near matrices which commute. The word-map in this example is taking the commutator word of group elements. More general words can be considered and the results go beyond just complex matrices and the operator norm (which is used to quantify “almost”).

We aimed also to explore a relation to metric approximations of discrete groups. In particular, this concerns nowadays famous concepts of soficity and hyperlinearity which can be viewed as the existence of such an “almost” object. In the same example above this is about the existence of a metric approximation of group elements by almost commuting matrices. Themes discussed during the workshop included, but were not limited to, geometric, analytic, combinatorial, algorithmic, and computational aspects of the following major classes of infinite groups:

Sofic and linear sofic groups, Hyperlinear groups, Random groups, Ulam stable and strongly Ulam stable groups, Weakly amenable groups and groups with Kazhdan’s property (T).

The workshop attracted many young mathematicians ($\sim 60\%$) and world wide experts from diverse research areas such as geometric group theory, algebraic groups and K-theory, L^2 -invariants, quantum information theory, operator algebras, logic, and theoretical computer science. The workshop was well attended by many local scientists from different research institutions, e.g. from the Faculty of mathematics and the Faculty of physics of U Vienna as well as from the Vienna center for quantum science and technology.

The workshop was a part of an Austrian-Swiss research network on Sofic groups of Goulnara Arzhantseva (U Vienna), Nicolas Monod (EPF Lausanne), and Alain Valette (U Neuchâtel) supported by the Swiss National Science Foundation under Sinergia grant, CRSI22-130435.

Specific information on the workshop

The research during the workshop included progress on the following topics: word maps of groups and algebras (e.g. p -adic and finite simple groups), weak hyperlinear and weak sofic groups, analysis of metric approximations of the celebrated Higman group (the first example of an infinite finitely presented group with no non-trivial finite quotients), investigation of large combinatorial structures. Here are some details.

Word maps

Recent results devoted to word maps on simple groups and polynomial maps on simple associative and Lie algebras were given by **Eugene Plotkin (Bar-Ilan)**. The focus was on a uniform approach to word maps and parallelism/distinction between the theories. He formulated the Borel-type theorems for word maps over simple Lie algebras and associative algebras, and distinguished the cases of Engel maps modeled on Lie algebras and algebraic groups.

New characterizations of primitive elements and free factors in free groups, which are based on the distributions they induce on finite groups were established by **Doron Puder (Jerusalem)** and **Ori Parzanchevski (Jerusalem)**. For every finite group G , a word w in the free group on k generators induces a word map from G^k to G . One says that w is measure preserving with respect to G if given uniform distribution on G^k , the image of this word map distributes uniformly on G . It is easy to see that primitive words (words which belong to some basis of the free group) are measure preserving w.r.t. all finite groups, and several authors have conjectured that the two properties are, in fact, equivalent. Parzanchevski-Puder recently proved this conjecture. The main ingredients of the proof include random coverings of Stallings graphs, algebraic extensions of free groups, and Mobius inversions. The methods yield the stronger result that a subgroup of F_k is measure preserving if and only if it is a free factor. As an interesting corollary of this result a question on the profinite topology of free groups has been resolved and it was shown that the primitive elements of F_k form a closed set in this topology.

Martin Kassabov (Cornell) discussed the images of a word maps for p -adic groups like $G = SL_n(\mathbb{Z}_p)$. The main result was that for a fixed word w and sufficiently large p the image of w is very large and satisfies $G = (w(G))^3$. The exponent 3 is the best possible in general, however sometime it can be improved to 2. He also discussed analogs of this result for discrete groups

like $SL_n(\mathbb{Z})$. This is based on joint works with N. Avni, T. Gelnader, A. Shalev, N. Nikolov. Frobenius already observed that the irreducible characters of a group determine the number of times each group element is obtained as a commutator. More generally, the distribution induced by any word map has a presentation as a combination of irreducible characters, called its Fourier expansion. **Ori Parzanchevski (Jerusalem)** presented formulas which regard the Fourier expansion of words in which some letters appear twice. These formulas give simple proofs for classical results, as well as new ones. This is a joint work with Gili Schul.

Metric approximations of groups

Linear sofic groups and linear sofic algebras have been recently introduced by **Liviu Paunescu (Bucharest)** and **Goulnara Arzhantseva (Vienna)**. In particular, they proved that a group is linear sofic if and only if its group algebra is linear sofic. Linear soficity for groups is a priori weaker than soficity but stronger than weak soficity. They discussed problems in proving that linear sofic groups are sofic or that linear sofic groups satisfy Kaplansky's direct finiteness conjecture.

Glebsky-Rivera introduced the notion of a weak sofic group and used this notion in the context of profinite topology on a finitely generated free group. **Jakub Gismatuline (Wroslaw)** determined connections between weak soficity and recent results of Nikolov and Segal on profinite groups. He also presented similar results about (weak) hyperlinear groups and the Bohr topology.

Lev Glebsky (Mexico) considered groups $H_{q,n} = \langle a, b, w \mid b^{-1}ab = a^q, b = w^{-1}aw, w^n = 1 \rangle$, $q \in \mathbb{N}$ and $n \in \mathbb{N} \cup \{\infty\}$. He calls $H_{q,n}$ the Higman groups. It is due to Higman that all finite dimensional representations of $H_{2,\infty}$ are cyclic (a and b are represented by the unit matrix). On the other hand any $H_{q,\infty}$ has an almost representation on $\mathbb{Z}_p = \{0, 1, \dots, p-1\}$ as follows: $a : t \rightarrow t+1 \pmod p$, $b : t \rightarrow qt \pmod p$ and $w : t \rightarrow q^t \pmod p$. He discussed the problem of the estimating the number of the short cycles in the dynamical system generated by $f(x) = q^x \pmod p$ and it's relation with the properties of $H_{q,n}$.

Stability of representations

Some variations on Ulam stability have been reviewed by **Andreas Thom (Leipzig)**. He presented a result established in a joint work with Marc Burger and Narutaka Ozawa and a recent progress on character rigidity that he had obtained in a joint work with Jesse Peterson.

Related topics

Quantum computers, if built, promise the efficient solution of many challenging computational problems using quantum algorithms. The natural configuration space for a quantum computer is the n -fold tensor product of C^2 , which represents n qubits. A quantum algorithm is then product of quantum gates, i.e., unitaries acting on at most 2 qubits at a time. **Tobias J. Osborne (London)** described how the quantum algorithm of quantum simulation, which provides an efficient method to simulate the dynamics of quantum spin systems, naturally exploits an "almost implies near" phenomena. In this case the dynamics is given by an almost local automorphism of the quasi-local algebra which is then near to a product of quantum gates. This observation has lead to a rich family of refinements, generalizations, and conjectures quantifying the interplay between almost locality and the corresponding "product locality". There are also connections with coarse geometry and index theory.

Motivated by the Benjamini-Schramm non-unicity of percolation conjecture **Kate Juschenko (Nashville)** studies the following question. For a given finitely generated non-amenable group Γ , does there exist a generating set S such that the Cayley graph (Γ, S) , without loops and

multiple edges, has non-unique percolation, i.e., $p_c(\Gamma, S) < p_u(\Gamma, S)$? She proved that this is true if Γ contains an infinite normal subgroup N such that Γ/N is non-amenable. Moreover for any finitely generated group G containing Γ there exists a generating set S' of G such that $p_c(G, S') < p_u(G, S')$. In particular, this applies to free Burnside groups $B(n, p)$ with $n \geq 2, p \geq 665$. She also explored how various non-amenability numerics, such as the isoperimetric constant and the spectral radius, behave on various growing generating sets in the group. Some application of the above results to group C^* -algebras were given. This is a joint work with T. Nagnibeda-Smirnova.

Present day technologies flood us with information, much of which takes the form of huge graphs. For various reasons (e.g., sheer size, but not only that) it is impossible to carry out any profound computations regarding these graphs. What can we do instead? One possibility is to fix a small integer k and see what k -vertex subgraphs of the graph at hand are distributed like. Two main types of questions suggest themselves: (i) Which distributions on k -vertex graphs are possible? (ii) Given this what this distribution is, what global conclusions about the graph can be drawn? In the same way many other combinatorial structures can be studied locally, e.g. permutations, partially ordered sets, tournaments, simplicial complexes and more. **Nati Linial (Jerusalem)** discussed some of what is known and still unknown about these questions.

List of talks

Eugene Plotkin	Word maps for algebras
Liviu Paunescu	Linear sofic groups and algebras
Lev Glebsky	Almost representations of Higman's groups and cycles in repeated exponentiation mod n .
Tobias J. Osborne	Almost implies near phenomena in quantum computation and complex quantum systems
Jakub Gismatuline	On hyperlinear and sofic groups via profinite and Bohr topology
Andreas Thom	Ulam stability and character rigidity
Doron Puder	Measure preserving words are primitive
Martin Kassabov	Images of word maps in p -adic groups
Kate Juschenko	Small spectral radius and percolation constants on non-amenable Cayley graphs
Ori Parzanchevski	Fourier expansion of word maps
Nati Linial	Local geometry of large combinatorial structures

Preprints contributed:

Y. Antolin, D. Dreesen, *The Haagerup property is stable under graph products*, [arXiv:1305.6748](https://arxiv.org/abs/1305.6748).

Invited scientists:

Goulnara Arzhantseva, Yago Antolin-Pichel, Federico Berlai, Christopher Cashen, Jakub Gismatullin, Lev Glebsky, Antoine Gournay, Lukasz Grabowski, Dominik Gruber, Pierre-Nicolas Jolissaint, Kate Juschenko, Martin Kassabov, Nathan Linial, Daniel Nagaj, Damain Osajda, Tobias J. Osborne, Ori Parzanchevski, Liviu Paunescu, Thibault Pillon, Eugene Plotkin, Tanya Plotkin, Doron Puder, Jan Spakula, Markus Steenbock, Andreas Thom, Alain Valette, Simone Virili, Valentin Zauner, Rudolf Ziegler.

Complexity and dimension theory of skew products systems

Organizers: Henk Bruin (U Vienna), Tobias Oertel-Jäger (TU Dresden), Roland Zweimüller (U Vienna)

Dates: September 16 – 20, 2013

Budget: ESI € 3 600, DFG Scientific Network (€ 10 000), and OeAD Bilateral collaboration scheme Vienna-AGH Krakow (€ 2 000).

Report on the workshop

Skew products form an important class of dynamical systems, both from the theoretical and from the applied point of view. In the description of real-world processes, they are used to model dynamical systems which are subject to the influence of external time-varying factors, a situation which naturally appears in many applications. On the theoretical side, the study of skew products has given impetus to many other areas of mathematics, including partially hyperbolic dynamics, the rotation theory of toral homeomorphisms, Schrödinger operators with quasiperiodic potentials and the analysis of fractal graphs. Questions related to dimension theory and multifractal analysis arise frequently in this area, but rigorous statements are still rare and many important problems remain open.

Since the academic year 2012, the Deutsche Forschungsgemeinschaft (DFG) funds a Scientific Network program called “Skew products dynamics and multifractal analysis” in which established dynamicists, as well as PhD students and postdocs, of the universities of Bremen, Erlangen-Nürnberg and Dresden work together on the dynamic features of skew-product systems, most notably on “Strange Nonchaotic attractors”. The current workshop was the second meeting of this network, and took the opportunity to include Austria in this German-language based enterprise. Organizer Roland Zweimüller is the Vienna representative of this Scientific Network.

Central topics of this meeting were (i) *Multiplicatively forced concave maps*, which serve as models for many non-standard bifurcations in skew product systems, (ii) *Thermodynamic formalism for skew product systems*, and (iii) *Topological complexity*. A more detailed description of the key topics is given in the following.

- **Multiplicatively forced concave maps.** Even very simple skew product systems exhibit a number of new non-standard bifurcation phenomena, like the two-step scenario for the random Hopf bifurcation, bubbling bifurcations or the non-smooth saddle-node bifurcation. In all these examples, it has turned out that multiplicatively forced concave maps can serve as simplified models which allow to develop feasible approaches in a less complex setting. The workshop focused on dimensional properties of bifurcating attractors and on the study of multifractal aspects of the bifurcation pattern.
- **Thermodynamic formalism for skew product system.** Thermodynamic formalism is one of the most powerful tools for studying the complexity and multifractal properties of dynamical systems. Originating in statistical physics, it is nowadays well-developed for deterministic dynamical systems with a sufficient amount of chaoticity. For skew products a refined approach which takes their fibered structure into account yields additional information.
- **Topological complexity.** Topological entropy (the exponential growth rate of the number of distinguishable orbits) is the best known measurement of complexity of a topological dynamical system. However, for minimal systems and for many skew product systems with minimal basis, subexponential growth rates occur. These can also be quantified and used

to classify dynamical systems. Interestingly, the analysis of just a few orbits sometimes enables conclusions about the global complexity of the system.

Activities

This one-week workshop offered two mini-courses (with a total of three 90 minute lectures each), plus 18 individual talks (three of which were 90 minute survey talks). In addition, time for in-depth discussions had been allocated.

Specific information on the workshop

In accordance with the network's basic objective of bringing together young researchers, the meeting involved 8 pre-docs and 11 post-doc researchers.

Subgroups of the Scientific Network work on different questions. Besides offering an opportunity to pursue ongoing cooperations, the annual meeting is meant to systematically review past activities, and to discuss and coordinate future work.

A further specific aim of the current workshops was to present the activities of the Scientific Network to a wider audience of dynamicists, and to establish contacts with selected groups from Eastern European countries, with a strong tradition in branches of topological dynamics which offer promising new perspectives on some of the skew-product systems of central interest here.

In addition to the official list of participants, further local mathematicians have attended the lectures, and so have several colleagues from the Budapest ergodic theory group. The Vienna group runs a monthly joint seminar with Budapest, see <http://mat.univie.ac.at/~zweimueller/BudWiSer/Budwiser.html>.

Outcomes and achievements

To judge from the feedback of many participants, the attempt to initiate an in-depth exchange between the groups working on specific questions for (sometimes fairly specific) skew-products and representatives of abstract topological dynamicists was very successful.

Recent work directly related to discussions during the ESI workshop includes these preprints:

Lorenzo Diaz, Katrin Gelfert, Michal Rams, *Abundant rich phase transitions in step skew products*, arXiv:1303.0581.

Johannes Jaerisch, *Conformal fractals for normal subgroups of free groups*, arXiv:1203.4301v6.

Manuel Stadlbauer, *Coupling for random topological Markov chains*, preprint.

Matus Dirbak, *Minimal extensions of flows with amenable acting groups*, (24 pages), submitted.

as well as several ongoing projects like, for example,

Johannes Jaerisch, Hiroki Sumi, *Multifractal formalism for random complex dynamical systems*.

Manuel Stadlbauer, Johannes Jaerisch, *Kesten's criterion for random walks on graphs*.

While it is hard to provide a serious short-term assessment of the overall impact, we are confident that further work will confirm the transformative effect of this event.

List of talks

Minicourses

- | | |
|-------------------|---|
| Piotr Oprocha | Topological Complexity |
| Manuel Stadlbauer | Thermodynamic formalism for fibered systems |

Regular talks

Sergiy Kolyada	On topological entropy: when positivity implies infinity
Louis Block	Topological entropy of continuous topologically transitive maps of the interval
Maik Gröger	An entropy-like notion for low-complexity systems
Lubomir Snoha	Minimal sets of fibre-preserving maps in graph bundles
Roman Hric	Topological sequence entropy
Kurt Falk	Hyperbolic manifolds with dimension gap
Fritz Colonius	Entropy notions in control theory
Gerhard Keller	Bifurcations in chaotically driven maps with multiplicative forcing
Katrin Gelfert	Multiple phase transitions in non-hyperbolic dynamics
Lorenzo Diaz	Robust existence of non-hyperbolic ergodic measures: flip-flops in blenders
Matus Dirbak	Transitive cocycles and minimal extensions
Johannes Jaerisch	Lyapunov spectra for normal subgroups of Kleinian groups
Christoph Kawan	Entropy in control theory and nonautonomous dynamics
Bernd Stratmann	Extreme value laws for maximal cuspidal windings
Charlene Kalle	Local dimensions for the infinite Bernoulli convolution
Karoly Simon	Slices of generalized Sierpinski carpets
Tobias Jäger	Minimal set of torus homeomorphisms
Evgeny Verbitskiy	Expansivity and homoclinic points in algebraic dynamics

The slides of several of the lectures and mini-courses will remain available on the Network's websites¹, which also include a webpage about the ESI-workshop².

Invited scientists:

Ana Anusic, Louis Block, Jan Boronski, Henk Bruin, Oliver Butterley, Fritz Colonius, Lorenzo Diaz, Matus Dirbak, Tomasz Drwiega, Fredrik Ekström, Kurt Falk, Gabriel Fuhrmann, Katrin Gelfert, Gernot Greschonig, Maik Gröger, Michael Hofbauer-Tsiflakos, Roman Hric, Johannes Jaerisch, Charlene Kalle, Christoph Kawan, Gerhard Keller, Marc Kessebmer, Zdenek Kocan, Sergii Koliada, Tomasz Kulaga, Tobias Oertel-Jäger, Piotr Oprocha, Atsuya Otani, Alejandro Passeggi, Peter Raith, Tony Samuel, Klaus Schmidt, Karoly Simon, Lubomir Snoha, Manuel Stadlbauer, Sonja Stimac, Bernd Stratmann, Domokos Szasz, Dalia Terhesiu, Evgeny Verbitskiy, Anna Zielicz, Roland Zweimüller.

Advances in the theory of automorphic forms and their L-functions

Organizers: Dihua Jiang (U Minnesota), Peter Sarnak (Princeton U), Joachim Schwermer (U Vienna), Freydoon Shahidi (Purdue U)

Dates: October 16 – 25, 2013

Budget: ESI € 26 428,37

Report on the workshop

The theory of automorphic forms has its roots in the early nineteenth century in the works of Gauss, Jacobi, Kummer, Eisenstein and others. The subject experienced a vast expansion and reformulation following the work of Siegel, Selberg, Harish-Chandra, and Langlands, in the 1970's, and remains a major focal point of development in number theory and algebraic

¹ <http://www.math.tu-dresden.de/~enpdyn/network/network.html>

² <http://www.math.tu-dresden.de/~enpdyn/workshop2013/WS2013.html>

geometry, with applications in many diverse areas, including combinatorics and mathematical physics.

In the last decade there have been a number of advances in the theory of automorphic forms and their L -functions that have resolved long outstanding problems, for example, Ngo Bao Chau's proof of the fundamental lemma, Arthur's work on endoscopy and the classification of automorphic representations for classical groups, and the work on the cohomology of Shimura varieties and related Galois representations as well as new and surprising cases of functoriality established by Cogdell and his collaborators. At the same time these advances - through both the results obtained and the innovative methods introduced - have opened up very important new directions for research. It was the main goal of this workshop to survey work on some of these new directions, their crossroads and their possible applications to problems in number theory and geometry. A major part of this activity was set up in honor of the 60th Birthday of James W. Cogdell.

The main areas dealt with in this workshop were the following:

1. Langlands functoriality beyond endoscopy – Among the many fundamental insights of Langlands are the following : [(a)] Automorphic representations of a given reductive group G defined over an algebraic number field k occur in packets (L -packets or Arthur packets), parametrized by representations of the hypothetical global Weil-Deligne group in the Langlands dual group ${}^L G$.

[(b)] It is necessary to consider the automorphic representations of all reductive groups together, and, in particular, their relations, the most important of which are predicted by the principle of functoriality.

These insights are fundamental though their complete realization is still a very distant dream. As predicted by Langlands, the general principle of functoriality would imply relations between automorphic representations that lie much deeper than the relations of endoscopy whose understanding has been the main focus of research for the last decades. Serious, but very preliminary, work, has now begun on these relations.

2. On the classification of automorphic representations for classical groups - A -packets – The work of Arthur on endoscopy and the classification of global automorphic representations for classical groups has natural local implications. More precisely, in order to establish a classification for the discrete spectrum of split classical groups defined over a number field one divides the “potential local candidates” for the global automorphic representations in question into A -packets. The local multiplicity formula in A -packets is fundamental to compute the multiplicity formula in the discrete spectrum.

3. Applications of endoscopy to the geometry and arithmetic of Shimura varieties – The recent work of Arthur on the structure of automorphic representations of classical groups has important applications to the understanding of the cohomology of Shimura varieties, both de Rham and étale. In addition, new results can be expected on base change for classical groups and for the transfer of automorphic representations between inner forms. Finally, these results have applications in the cohomology theory of arithmetic groups, using its interpretation in terms of the automorphic spectrum. Indeed, automorphic forms have a deep connection with the geometry of the underlying locally symmetric spaces and vice versa, where, for example, the boundary behavior of cohomology classes represented by derivatives of Eisenstein series or residues of such can be applied to the study of special values of automorphic L -functions.

4. Rankin-Selberg theory, converse Theory and explicit constructions – In the language of automorphic representations, the classical method of Rankin-Selberg integrals

has been vastly extended to provide integral representations, and hence analytic information, about many families of automorphic L -functions. Beside that, the descent method of Ginzburg, Rallis and Soudry had a far reaching impact on establishing the Langlands correspondence relating cuspidal generic automorphic representations of a classical group to those of a suitable general linear group. This is the inverse of functoriality proved by Cogdell, Kim, Piatetski–Shapiro and Shahidi using the converse theory of Rankin product L -functions (due to Cogdell and Piatetski–Shapiro). Explicit construction of endoscopy for classical groups within this theory as developed by Jiang and his collaborators is part of this general approach. Finally one should mention the intense activity by Hundley–Sayag and Asgari–Shahidi on extending the problems discussed here, both descent and functoriality, for general spin groups $GSpin$ and GL_n .

5. Eisenstein series, L -functions and their special values – The theory of Eisenstein series for general reductive groups continues to be fundamental in the theory of automorphic forms. In particular, it has introduced a vast family of L -functions through its constant term, i.e., intertwining operators. Further study of non-constant terms of these series has led to the development of the Langlands–Shahidi method which has played a central role in establishing new examples of functoriality. Among these L -functions for number fields are those for which one may be able to state and prove results concerning their special critical values, some with full agreement with Deligne’s conjecture.

Activities

The workshop started off with **two mini-courses** to lay foundations, in particular, for young researchers for more research oriented results covered in later talks. Shahidi discussed in his course “*Eisenstein series and L -functions*” the theory of Eisenstein series and its consequences in the study of automorphic L -functions. In his treatment he emphasized the case of inner forms of the underlying algebraic group. Neven Grbac studied in his course “*Cohomology of arithmetic groups and automorphic forms*” the space of automorphic forms on an the adelic points of a reductive group defined over an algebraic number field and its use in the study of the cohomology of arithmetic groups. In his discussion he included the decomposition of the space of automorphic forms along the cuspidal support, Langlands’ spectral theory and Arthur’s classification for the L^2 - part, and the filtration of the space of automorphic forms obtained by Franke. He illustrated these notions and results by dealing with the example of the split symplectic group of rank 2.

Trace Formulas

In his talk “Beyond endoscopy via the trace formula,” **Ali Altug (Columbia U)** took up the paper, “Beyond endoscopy,” by Langlands in which he had proposed an approach to (ultimately) attack the general functoriality conjectures by means of the trace formula. For a (reductive algebraic) group G over a global field F the strategy, among other things, aims at detecting those automorphic representations of G for which the L -function, $L(s)$, has a pole at $s = 1$. The method suggested is using the trace formula together with an averaging process to capture these poles. In the first non-trivial case $G = GL(2)$ Altug discussed the analytic problems caused by the volumes of tori and singularities of orbital integrals in the averaging process. Then he described how one can use an approximate functional equation in the trace formula to resolve these issues and use the trace formula in analytic applications, in particular, the one suggested in Langlands’ work “Beyond endoscopy”.

Another aspect of trace formulas was discussed in **Yiannis Sakellaridis’s (Rutgers U)** talk “Non-standard comparisons of trace formulas”: by a non-standard comparison between (relative)

trace formulas one means one where the scalar “transfer factors” are substituted by non-scalar “transfer operators”. The problem of global triviality of transfer factors now becomes a problem of proving a Poisson summation formula for such non-scalar operators. He gave the adelic analysis behind such a non-standard comparison of the Kuznetsov trace formula for $G = PGL(2)$ and Jacquet’s relative trace formula for $T \backslash G/T$, where T is a nontrivial torus, leading to a new proof of Waldspurger’s theorem on toric periods.

Subsequently, **Erez Lapid (Weizmann Institute)** dealt with “Algebraic and analytic aspects of Arthur’s non-invariant trace formula” where he covered recent joint work with Tobias Finis.

Arithmetic Applications

In his talk “Period formula and congruent number problem” **Ye Tian (Chinese Academy of Sciences, Beijing)** dealt with the following classical number theoretic problem: the congruent number problem is to determine if a given positive integer is the area of a right triangle with rational sides. For any given integer k , he succeeded in constructing infinitely many square-free congruent numbers with exactly k prime factors. The construction involved the explicit formula of Waldspurger’s period formula and Yuan-Zhang-Zhang’s Gross-Zagier formula.

Wei Zhang (Columbia U) dealt with “Heegner points and a Birch-Swinnerton Dyer conjecture”

He proved a conjecture of Kolyvagin in 1991 on p -indivisibility of (derived) Heegner points over ring class fields on elliptic curves and certain primes p . Together with the general Gross-Zagier formula on Shimura curves proved by Yuan-Zhang-Zhang, he obtained an application to the refined Birch-Swinnerton Dyer conjecture in the analytic rank one case.

Henry Kim (U Toronto) dealt with “Artin representations for GSp_4 attached to real analytic Siegel cusp forms of weight $(2, 1)$ ” (joint work with T. Yamauchi): Let F be a vector-valued real analytic Siegel cusp eigenform of weight $(2, 1)$ with the eigenvalues $\frac{-5}{12}$ and 0 for the two generators of the center of the algebra consisting of all $Sp_4(\mathbb{R})$ -invariant differential operators on the Siegel upper half plane of degree 2. Under the several assumptions such as the integrality of Satake parameters, he constructed a unique Artin representation of type GSp_4 associated to F .

In his talk “On level one algebraic cusp forms of classical groups”, **Gaetan Chenevier (Palaiseau)** gave an overview about his recent work with David Renard in which they determined the number of level 1, polarized, algebraic regular, cuspidal automorphic representations of GL_n over \mathbb{Q} of any given infinitesimal character, for essentially all $n \leq 8$. For this, they computed the dimensions of spaces of level 1 automorphic forms for certain semisimple \mathbb{Z} -forms of the compact groups $SO(7)$, $SO(8)$, $SO(9)$, and G_2 and determined Arthur’s endoscopic partition of these spaces in all cases. They also gave applications to the 121 even lattices of rank 25 and determinant 2 found by Borchers, to level one self-dual automorphic representations of GL_n with trivial infinitesimal character, and to vector valued Siegel modular forms of genus 3. Parts of their results are conditional to certain expected results in the theory of twisted endoscopy.

Automorphic Forms and Automorphic L - Functions

Since a major part of this activity was set up in honor of the 60th Birthday of James W. Cogdell **Peter Sarnak (IAS and U Princeton)** gave in his talk “Automorphic forms and L -functions after Cogdell and Piatetski-Shapiro” a broad overview over the seminal work of James Cogdell in the theory of automorphic forms and automorphic L -functions, with special emphasis on the joint contributions with Piatetski-Shapiro. The spectrum of topics ranges over a broad band of

themes, including Converse Theorems, Functoriality, Bessel Functions and Stability of Gamma-Factors.

Roman Holowinsky (Ohio State U) discussed “Hybrid subconvexity for convolutions of the symmetric square.” Let f be a holomorphic cusp form of full level and weight k and g a holomorphic newform of prime level p and fixed weight. With k and p large and varying, he proved hybrid subconvexity bounds for the convolution of the symmetric square of f with g via a first moment method. This is joint work with Ritabrata Munshi and Zhi Qi.

Freydoon Shahidi (Purdue U) presented recent work on “Arthur parameters and L -functions.” The study of L -functions appearing in the constant terms of Eisenstein series through the analytic properties of the series as initiated by Langlands and pursued later through the Langlands-Shahidi method, when combined with functoriality, can lead to rather complete results on analytic properties of these L -functions. In his talk Shahidi mentioned one instance of this where Arthur’s recent work can be used to establish this for exterior and symmetric square L -functions for $GL(n)$, due to Grbac, as well as for Asai L -functions, using the work of Mok, which is a joint work with Grbac.

The talk by **Lei Zhang (Boston College)** covered “Tensor product L -functions of quasi-split classical groups” whereas **Chung Pang Mok (McMaster U)** dealt with “Order of poles of certain Langlands-Shahidi L -functions and endoscopy classification.”

Daniel File (Muhlenberg College) reported on his joint work on “Test vectors and central values for $GL(2)$ ” with Ameya Pitale and Kimball Martin. By determining local test vectors for Waldspurger functionals for GL_2 , in the case where both the representation of GL_2 and the character of the degree two extension are ramified, they obtain an explicit version of Waldspurger’s formula relating twisted central L -values of automorphic representations on GL_2 with certain toric period integrals.

Ju-Lee Kim (MIT Boston) covered in her talk “Characters of unipotent representations of a semisimple p -adic group” some recent work, with special emphasis on the explicit computation of characters.

Michael Harris (U Paris VI) covered in his talk “Whittaker periods, motivic periods, and special values of tensor product L -functions” recent joint work with H. Grobner. They show that, under certain regularity and polarization hypotheses, the Whittaker period of a cuspidal cohomological of GL_n over an imaginary quadratic number field can be given a motivic interpretation, and can also be related to a critical value of the adjoint L -function of related automorphic representations of unitary groups. The resulting expressions for critical values of the Rankin-Selberg and adjoint L -functions are compatible with Deligne’s conjecture.

Rankin-Selberg Theory, Converse Theory and Explicit Constructions

David Soudry (Tel Aviv U) reported on “On local descent to unitary groups”. Let E/F be a quadratic extension of p -adic fields. Starting with an irreducible, supercuspidal representation τ of $GL_m(E)$, whose local Asai L -function has a pole at $s = 0$, he associated with it, by the local descent method, an irreducible, supercuspidal, generic representation σ of the quasi-split unitary group $U_m(F)$, attached to E/F , such that the local gamma factor of σ twisted by $\tau \otimes \lambda$ has a pole at $s = 1$, where λ is a character of E^* extending the quadratic character of F^* , associated with E/F . This is a joint work with Y. Tanay.

Dihua Jiang (U Minnesota) discussed in his talk the relations between the construction

theory of automorphic forms that he has developed through a series of work with his co-workers, and the recent endoscopy classification theory of square-integrable automorphic forms obtained by J. Arthur and C.-P. Mok, based on the fundamental work of B.-C. Ngo and J.-L. Waldspurger and others. In particular, he discussed his principle of endoscopy correspondence, which constructs endoscopy transfers via integral transforms with automorphic kernel functions. Such explicit constructions are expected to have applications to special values of certain automorphic L -functions and to other interesting problems in arithmetic and geometry.

In her talk “Degenerate Eisenstein series on $GL_{m+n}(\mathbb{A}_{\mathbb{Q}})$ ” **Marcela Hanzer (U Zagreb)** dealt with recent results obtained with Goran Muic. They determined poles in the right-half plane and images of degenerate Eisenstein series for $GL_n(\mathbb{A}_{\mathbb{Q}})$ induced from a character on a maximal parabolic subgroup. As an application they were able to determine poles of degenerate Eisenstein series for the real Lie group $GL_n(\mathbb{R})$.

Arithmetic of Shimura varieties and locally symmetric spaces

Tony Scholl (DPMMS Cambridge) discussed in “Plectic cohomology of some Shimura varieties and special values of L -functions” joint work with Jan Nekovar (Paris VI). He described an enrichment (partly conjectural, partly unconditional) of the usual structures on cohomology groups of certain Shimura varieties, which he called “plectic cohomology”. As a result he obtained motivic interpretations of special values of L -functions in some new cases.

Peter Scholze (Bonn U) discussed in his talk “On torsion in the cohomology of locally symmetric varieties” the p -adic geometry of Shimura varieties with infinite level at p : they are perfectoid spaces, and there is a new period map defined at infinite level. As an application, he dealt with some far reaching new results on torsion in the cohomology of locally symmetric spaces, and, in particular, the existence of Galois representations in this setup.

The talks by **Günter Harder (MPI Mathematics Bonn)** and **Joachim Schwermer (U Vienna)** both dealt with arithmetic questions which originate in the study of the cohomology of arithmetic groups and its description via Eisenstein series. Harder discussed “The arithmetic meaning of the second term in the constant term of a rank one Eisenstein series”. Rationality results regarding the underlying cohomology classes often lead to interesting arithmetic results on special values of automorphic L -functions. In reverse, the existence of cuspidal automorphic forms whose corresponding L -functions have specific analytic properties can imply the very existence of non-trivial residual Eisenstein cohomology classes. Schwermer made this evident in the case of cuspidal forms for GL_2 in his “Remarks on cohomology classes for arithmetic groups represented by residues of Eisenstein series.”

Simon Marshall (Northwestern U) applied in his talk the endoscopic classification of automorphic forms on $U(3)$ due to J. Rogawski to prove a case of a conjecture of Sarnak and Xue on cohomology growth in the case of congruence manifolds attached to $U(2, 1)$.

In his talk “Gross-Prasad conjecture and theta correspondence” **Wee Teck Gan (Singapore)** deduced the Fourier-Jacobi case of the local Gross-Prasad conjecture for unitary groups from the Bessel case proved by Beuzart-Plessis. This is achieved through establishing two conjectures of D. Prasad on theta correspondences for unitary groups of almost equal rank.

Invited scientists:

Salim Altug, Mahdi Asgari, Brandon Bate, Tobias Berger, Don Blasius, Gaetan Chenevier, James W. Cogdell, Julio Cesar Bueno de Andrade, Daniel File, Solomon Friedberg, Wee-Teck Gan, David Goldberg,

Neven Grbac, Harald Grobner, Marcela Hanzer, Guenter Harder, Michael Harris, Roman Holowinsky, Dihua Jiang, Eyal Kaplan, Henry Kim, Julee Kim, Steffen Kionke, Jing Feng Lau, Erez Lapid, Simon Marshall, Colette Moeglin, Matias Moya Giusti, Chung Pang Mok, Goran Muic, Chufeng Nien, Takayuki Oda, Ravi Raghunathan, Eitan Sayag, Yiannis Sakellaridis, Peter Sarnak, Gordan Savin, Freydoon Shahidi, David Soudry, Tony Scholl, Peter Scholze, Joachim Schwermer, Ye Tian, Paul-James White, Shunsuke Yamana, Jun Yu, Lei Zhang, Wei Zhang.

Research in Teams

By January 1, 2012, the Erwin Schrödinger Institute had established the *Research in Teams Programme* as a new component in its spectrum of scientific activities. The programme offers teams of 2 to 4 *Erwin Schrödinger Institute Scholars* the opportunity to work at the Institute in Vienna for periods of 1 to 4 months, in order to concentrate on new collaborative research in mathematics and mathematical physics. The interaction between the team members is a central component of this programme. In 2013 the programme confirmed its usefulness and effectiveness: the competition among applicants was high and the outcomes are numerous.

Marcella Hanzer and Goran Muic: Eisenstein Series

Collaborators: Marcella Hanzer (U Zagreb) and Goran Muic (U Zagreb)

Dates: January 13 – February 10, 2013

Budget: ESI € 4 240

Scientific Background

Theory of automorphic forms and Langlands program is one of the central areas of mathematics today with many applications in number theory and arithmetic algebraic geometry. The most important classes of automorphic forms are Eisenstein series which are used in many ways such as for construction of L -functions [10, 11, 9], construction of square-integrable automorphic forms [1, 2, 8], and determination of cohomology of discrete subgroups [5].

Project aims and scope

We planned to determine poles and images of degenerate Eisenstein series attached to maximal parabolic subgroups of GL_n over the ring of adèles of \mathbb{Q} . This problem has two parts: 1) its combinatorial part of determination of poles of inverses of normalization factors [10] and 2) its representation theoretic part of determination of poles of normalized intertwining operators [8]. The combinatorial part of the problem was planned to be handled by methods already used in a similar (but easier) context [7]. For the second problem, we use some methods of Mœglin and Waldspurger [8], as well as local information of degenerate principal series on $GL_n(\mathbb{R})$ obtained by Howe and Lee [3]. We also planned to determine Eisenstein series to $GL_n(\mathbb{R})$. In this way, we planned to describe degenerate Eisenstein series in a more classical context of a reductive Lie groups which is useful for certain types of applications in analytic number theory. Although there exists a theory of Eisenstein series on real reductive groups [6] for some time, the poles of such Eisenstein series, although important for the application in number theory, are almost a complete mystery. We planned to use adelic methods to settle this in part. Adelic methods are more suitable for computation of the constant term of an Eisenstein series, and usage of representation theory in determination of poles of the same. We expect possible application in the theory of cohomology of discrete subgroups [5].

Outcomes and achievements

During our one month stay in January and February of 2013, we wrote a 37 pages long paper [4], see the preprint [2415] at the ESI preprint server or on [arXiv:1302.0513](https://arxiv.org/abs/1302.0513). In this paper we determine completely poles and images of degenerate Eisenstein series attached to maximal parabolic subgroups of GL_n over the ring of adèles of \mathbb{Q} . Interestingly, although degenerate

Eisenstein series considered are not square-integrable and therefore they have huge constant terms, they have at most simple poles. This is a result of many cancellations in the constant term which we handled by a careful combinatorial analysis of the certain sums of normalization factors. At the points where degenerate Eisenstein series have simple poles, the images in the space of automorphic forms are irreducible. This is a result of very specific properties of normalizing operators and their images for real and p -adic GL_n . This part of the work is extremely elegant as opposed to usually very combinatorial computations such as those of [8]. At the points where no poles occur, the image is the full degenerate principal series from which Eisenstein series is constructed. Next, we have studied the restriction of degenerate Eisenstein series to $GL_n(\mathbb{R})$. This requires to use special types of functions from the induced representation to construct degenerate Eisenstein series and to restrict to $GL_n(\mathbb{R})$. This process required a construction of certain discrete subgroups of $GL_n(\mathbb{R})$ using open compact subgroups of $GL_n(\mathbb{A}_f)$, where \mathbb{A}_f is the ring of finite adèles of \mathbb{A} . Even with this in our hands, the restriction is non-trivial since it is controlled by the fact whether or not certain normalized intertwining operator is zero or not on certain very specific function from the local degenerate principal series. At this point the usual representation of p -adic groups is not very helpful, but we were able to transform involved integrals to the form from which we could apply local Godement Jacquet theory to see that they are never zero. After this final obstacle we obtained poles and images for degenerate Eisenstein series on $GL_n(\mathbb{R})$ unconditionally. This concludes description of the results and achievements during our one month stay at the ESI. We would like to mention that this work would not be completed without useful discussions with Joachim Schwermer and members of his team working on automorphic forms in Vienna.

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Vladimir N. Remeslennikov et al: On the first-order theories of free pro- p groups, group extensions and free product groups

Collaborators: Montserrat Casals-Ruiz (U of Oxford), Ilya Kazachkov (U of Oxford), Vladimir N. Remeslennikov (Siberian Branch of the Russian Academy of Science)

Dates: February 17 – March 16, 2013

Budget: ESI € 6 640

Scientific Background

Model theory is a branch of mathematics that studies algebraic structures from the viewpoint of mathematical logic. An important trend in model theory that goes back to Tarski and Robinson is the model-theoretic and logical analysis of concrete structures and their first-order theories.

Traditionally, the main problems in model theory are the classification of structures elementarily equivalent to a given one and the decidability of the theory. Recall that the first-order (or elementary) theory of a structure is the set of all first-order sentences it satisfies; a first-order theory is decidable if there is an algorithm to decide whether or not a given sentence is true in the structure. To show the depth of these problems, we note that as equations are the simplest type of sentences of a language, the question of decidability of the elementary theory of a structure (or its fragment) can be regarded as a vast generalization of the Diophantine problem.

Among the most prominent and classical examples in the study of fields are pioneering results of Tarski on elementary theories of algebraically closed and real closed fields as well as the work of Ax-Kochen and Ershov on the first-order theories of Henselian valued fields.

In the language of groups, some of the most fundamental questions on the elementary equivalence of groups were formulated for groups from classical varieties (with special emphasis on free objects of the variety) and classical linear groups; namely to characterize groups elementarily equivalent to

- classical linear groups: GL , SL , PGL and PSL ;
- Abelian groups, Nilpotent groups;
- free groups - this problem is nowadays known as Tarski problem; and
- free pro- p groups.

In [M61], Mal'cev began the study of the elementary theory of classical linear groups. More precisely, he showed that two classic linear groups (SL , PSL , GL , PGL) over a field of characteristic zero are elementarily equivalent if and only if they are isomorphic. He also proved the undecidability of the elementary theories of the classic linear groups over integers and stressed the importance of understanding the elementary theory of the groups $PSL(2, \mathbb{Z})$ and $SL(2, \mathbb{Z})$.

The first goal of the project was to address Mal'cev question and describe the class of finitely generated groups elementarily equivalent to $GL(2, \mathbb{Z})$, $SL(2, \mathbb{Z})$, $PGL(2, \mathbb{Z})$ and $PSL(2, \mathbb{Z})$.

The question on the elementary theory of free groups formulated by Tarski around 1945 piloted a lot of research in group theory. Over the years, the work on Tarski problems resulted in a development of a multitude of techniques and established new connections between model theory, geometry and group theory as well as opened a way to obtain qualitatively new class of examples of stable and homogeneous theories. The solution of Tarski problem was obtained in a sequence of long, deep and technical works by Sela and Kharlampovich-Miasnikov, see [Se06] and [KhM06] and references therein, and it is considered to be one of the most important results in the model theory of groups.

The classification of groups elementarily equivalent to abelian groups was given by W. Szmielew in [Sz55]. In her beautiful work, she uses certain invariants to classify abelian groups up to elementary equivalence. In the variety of nilpotent groups, the situation is much more complex and only partial results are known. The elementary classes have only been described for free nilpotent R -groups (where R is a binomial ring), see [MS11] and for the groups of unitriangular matrices $UT_n(R)$ (where R is an associative ring with unit), see [Bel99].

In the class of profinite groups the problem of elementary classification is widely open. The only (partial) result due to Jarden and Lubotzky, [JL08], gives a solution to the classification problem restricted to the class of finitely generated profinite groups: the authors prove that two finitely generated profinite groups are elementarily equivalent if and only if they are isomorphic. This result relies on the deep work of N. Nikolov and D. Segal, [NS07a, NS07b], which, in turn, uses the classification of finite simple groups.

The analogue of Tarski problem for free pro- p groups, that is the problem of describing (abstract) groups elementarily to a free pro- p group, has been in the Siberian School of Algebra and Logic since at least 1970, [E70] and is currently wide open. In our view, the lack of success in tackling this problem in the previous decades is primarily due to the fact that its solution, in broad strokes, should combine the techniques developed for the solution of Tarski problem as well as the work of Ax-Kochen and Ershov on p -adic fields and the results of Nikolov and Segal on finitely generated profinite groups.

The second aim of our work was to advance in the understanding of the elementary theory of the free pro- p group.

Project aims and scope

Our project had two distinguished goals:

1. Our first goal is to study the elementary theory of certain group extensions and apply these results to study the classical linear groups $PSL(2, \mathbb{Z})$, $SL(2, \mathbb{Z})$, $PGL(2, \mathbb{Z})$ and $GL(2, \mathbb{Z})$ and describe finitely generated groups elementarily equivalent to any of the aforementioned groups. The importance of studying the first-order properties of these groups was stressed in the seminal work of A. Malcev [M61] on the elementary theory of linear groups.
2. As we have already mentioned above, the problem of understanding the elementary theory of a free pro- p group is currently among the most well-known and important open problem in model theory of groups. Our second goal is to begin a systematic study of the first-order theory of a free pro- p group of finite rank.

Outcomes and achievements

Goal 1. During our stay we addressed a problem of Mal'cev's on the description of groups elementarily equivalent to classical linear groups of dimension 2. Namely, in our work we characterize finitely generated groups elementarily equivalent to $SL_2(\mathbb{Z})$, $PSL_2(\mathbb{Z})$, $PGL_2(\mathbb{Z})$ and $GL_2(\mathbb{Z})$. The main technique is to use short exact sequences and relate the theory of the factors to determine the elementary theory of the group. In particular, we characterize finitely generated models of the elementary theory of $SL_2(\mathbb{Z})$ as central extensions of finitely generated models of the theory of $PSL_2(\mathbb{Z})$ by the cyclic group of order 2 given by an explicit cocycle. In order to describe the aforementioned cocycle, one needs to obtain a complete description of the second cohomology group $H^2(H, \mathbb{Z}_2)$ over the cyclic group of order 2, here H is a hyperbolic tower. More precisely, we show:

Theorem 1 *The second cohomology group $H^2(H, \mathbb{Z}_2)$, where H is a tower and \mathbb{Z}_2 is the cyclic group of order two is isomorphic to $\mathbb{Z}_2 \times \mathbb{Z}_2^r$, where r is the height of the tower.*

*A finitely generated group G is elementarily equivalent to $SL_2(\mathbb{Z})$ if and only if G is the central extension of a hyperbolic tower H over $PSL_2(\mathbb{Z}) \simeq \mathbb{Z}_2 * \mathbb{Z}_3$ by \mathbb{Z}_2 defined by the cocycle $(1, 0, \dots, 0) \in H^2(H, \mathbb{Z}_2)$.*

The corresponding results are now being prepared for publication in our preprint [CK13].

Goal 2. At the ESI, we begun a systematic study of the elementary theory of a free pro- p group. As we discussed above, this is an ambitious long-term project that requires a combination of ideas and techniques from the model-theoretical study of the field of p -adic numbers as well as deep study of the associated free \mathbb{Q}_p -Lie algebra and its nilpotent quotients.

The p -adic numbers can be viewed as an inverse limit of the finite rings $\mathbb{Z}/p^k\mathbb{Z}$. In their influential work Ax-Kochen and Ershov made use of valuation theory over fields as well as of classical results of Krull, Kaplansky and Ostrowskii to establish a relation, given by Hensel's lemma, between the elementary theory of the field of p -adic numbers and the theories of the set of finite rings $\mathbb{Z}/p^k\mathbb{Z}$ and to describe the structure of the saturated model of the theory as "generalized" formal power series. These model-theoretic results resolved a well-known problem of Artin on solutions of some forms over the p -adic numbers and later were used by Denef to answer Serre and Oesterle's question on the rationality of several Poincare series associated to algebraic sets over the p -adics.

Analogously, free pro- p groups can be viewed as inverse limits of free nilpotent pro- p groups. In our preprint [CFKR13] we introduce the class of well-structured nilpotent R -algebras and groups and study their elementary theory. In particular we describe the elementary class and give an axiomatisation of the corresponding first-order theories.

The class of well-structured nilpotent R -groups is rather wide and, in particular, contains both free nilpotent and unitriangular groups. Our results provide uniform approach to all previously known results on the model theory of nilpotent R -groups and generalize the works of Miasnikov-Sohrabi and Belegardek, [MS11, Bel99]. Here is an outline of our main result in the context of algebras, a similar statement is true for groups,

Theorem 2 (Characterisation Theorem) *Let $A = A(R)$ be a well structured R -algebra and let B be a ring. Then $B \equiv A$ if and only if B is an abelian deformation (by some symmetric 2-cocycle) of the algebra $A(S)$, where $S \equiv R$.*

The second goal of our project is to deduce an analogue of the Henselianity condition for groups and to establish a relation between the theory of a free pro- p group and the theories of its

nilpotent quotients. In order to do so one needs to have a deep understanding of one-variable equations over a free pro- p group. The latter, is an interesting and important question on its own right, its study was initiated by Kochloukova and Zalesski in [KZ11]. In our preprint [CKR13b], we demonstrate some of the inherent differences in studying equations over discrete and \mathbb{Q}_p -powered groups and prove that extension of centralizers of a free \mathbb{Q}_p -group need not be residually free \mathbb{Q}_p -group.

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Raimar Wolkenhaar et al: Exactly solvable quantum field theory in four dimensions

Collaborators: Harald Grosse (U Vienna), Gandalf Lechner (U Leipzig), Raimar Wolkenhaar (U Münster)

Dates: February 25 – April 5, 2013

Guest Scientist visit: Keiichi R. Ito (Kyoto U), March 11 – 21, 2013

Budget: ESI € 2 720, Gandalf Lechner was paid by a FWF project.

Scientific background

In order to cure the old problems of local quantum field theories it was suggested to add quantum gravity effects leading to quantized space-time. The mathematical framework relevant for the formulation of quantum fields defined over quantized space-time is noncommutative geometry [1]. Quantum field theory as defined by the Wightman, Haag-Kastler or Osterwalder-Schrader axioms relies on the manifold structure of space-time. In giving up the manifold one has to adapt the axioms. A reasonable replacement is not yet available. First attempts in this direction focussed on Euclidean quantum field theories on noncommutative manifolds. Because of their functional integral realization, such models are easy to define: It suffices to specify a parametrization of the fields and an action functional for them which involves the product in a noncommutative algebra. This topic started around 1996 with Filk’s Feynman rules for deformed Euclidean space, and in 1999 many authors showed perturbative one-loop renormalisability of a number of models. Shortly later Minwalla, van Raamsdonk and Seiberg discovered a severe problem at higher loop order, the so-called ultraviolet/infrared mixing.

A possible way to cure this problem for the ϕ_4^4 -model has been found by us in previous work [2]. It leads to an action functional which has 4 relevant/marginal operators $Z, \mu^2, \lambda, \Omega$ (instead of 3):

$$S = \int_{\mathbb{R}^4} dx \left(\frac{Z}{2} \phi(-\Delta + \Omega^2 \tilde{x}^2 + \mu^2) \phi + \frac{Z^2 \lambda}{4} \phi \star \phi \star \phi \star \phi \right) (x) . \quad (1)$$

We have been able to show that the resulting model is renormalisable up to all orders in perturbation theory. In addition a new fixed point appears at $\Omega = 1$. In contrast to the usual ϕ_4^4 -theory, the running coupling constant is one-loop bounded. The group around Rivasseau then showed that for the critical case $\Omega = 1$ the β -function vanishes up to three loop order [3], and finally succeeded in proving $\beta = 0$ up to all orders in perturbation theory [4]. In this way, the Landau pole problem is tamed.

Vanishing of the β -function is often a consequence of integrability. It was therefore conjectured that the model (1) at critical frequency $\Omega = 1$ has a chance to be constructed. This approach was proposed by us in [5]. By extending the Ward identities and Schwinger-Dyson equations used by Disertori-Gurau-Magnen-Rivasseau in [4], we derived a self-consistent non-linear integral equation for the renormalised 2-point function of the model (1). This is a non-perturbative equation, which we solved perturbatively up to third order in the coupling constant.

Project aims and scope

Two-dimensional gravity can be formulated as a one-matrix model with partition function $\mathcal{Z} = \int dM \exp(-\sum_n \alpha_n \text{tr}(M^n))$. The integral is over $(\mathcal{N} \times \mathcal{N})$ -hermitean matrices, and the α_n are scalar coefficients which may depend on \mathcal{N} . In the double scaling limit $\alpha_n = \mathcal{N}t_n$ and $\mathcal{N} \rightarrow \infty$, the partition function becomes a series in (t_n) which can be expressed in terms of the τ -function for the Korteweg-de Vries (KdV) hierarchy (see [6] for a review). There is another approach to topological gravity in which the partition function is a series in (t_n) with coefficients given by intersection numbers of complex curves. Witten conjectured [7] that the partition functions of the two approaches coincide. This conjecture was proven by Kontsevich [8] who achieved the computation of the intersection numbers in terms of weighted sums over ribbon graphs (fat Feynman graphs), which he proved to be generated from the Airy function matrix model (Kontsevich model)

$$\mathcal{Z}[E] = \frac{\int dM \exp\left(-\frac{1}{2}\text{tr}(EM^2) + \frac{i}{6}\text{tr}(M^3)\right)}{\int dM \exp\left(-\frac{1}{2}\text{tr}(EM^2)\right)}, \quad (2)$$

where $i^2 = -1$ and E is a positive hermitean matrix related to the series (t_n) by $t_n = (2n-1)!!\text{tr}(E^{-(2n-1)})$. The large- \mathcal{N} limit of (2) gives the KdV evolution equation, thus proving Witten's conjecture.

The simplest quantum field theory on a four-dimensional noncommutative manifold given by the action (1) can be written as a matrix model

$$\mathcal{Z}[E, J, \lambda] = \frac{\int dM \exp\left(\text{tr}(JM) - \text{tr}(EM^2) - \frac{\lambda}{4}\text{tr}(M^4)\right)}{\int dM \exp\left(-\text{tr}(EM^2) - \frac{\lambda}{4}\text{tr}(M^4)\right)}. \quad (3)$$

The matrix E is fixed by the identification with the noncommutative field theory, and the external source J is used to generate the correlation functions. In several improvements of our preprint [9], the applicants achieved the exact solution of (3) for $0 \leq \lambda \leq \frac{1}{\pi}$. This solution constitutes the first example of a quantum field theory in four dimensions, albeit locality and Poincaré symmetry seem to be lost. The solution raised many questions, which were studied during the ‘‘Research in Teams’’ at ESI. The most puzzling one is that the applicants have no clue why the solution works: What sort of integrability is behind (3), playing the rôle of the KdV hierarchy of (2)? Is there an interpretation of (3) in Algebraic geometry, playing the rôle of intersection numbers of (2)?

Outcomes and achievements

These 6 weeks were very intensive and from our point of view, very successful. At the beginning we finished our long paper [9], which was put to the arXiv and has been accepted for publication in *Commun. Math. Physics*. We were able to find an exact solution of a nontrivial new matrix model (3). We proved that for E not a multiple of the identity matrix, the planar 2-point function satisfies a closed non-linear equation for that function alone, and that all higher planar correlation functions are obtained from a universal algebraic recursion formula in terms of the 2-point function and the distinct eigenvalues of E . Moreover, we proved that renormalizability of the 2-point function implies both renormalizability of all higher correlation functions and vanishing of the β -function. This is another instance of the close connection between (a weak sort of) scale invariance and integrability.

During the common studies we reformulated the model in coordinate space and studied the limit of strong noncommutativity. In this limit we obtained a field theory, which obeys Euclidean invariance and locality. Together with Gandalf Lechner we studied the question of reflection positivity of the correlation functions. We found that this is closely related to the question whether the diagonal 2-point function is a Stieltjes function (sufficient) or completely positive (necessary). Whether this is the case remains still open. All relies on the solution of a nonlinear integral equation, which we proved to exist, but analyticity properties of the solution are not known. This coordinate and momentum space representation of the model will lead to a second shorter publication [10], which will be finished soon and put to the ESI arXiv.

In addition, we started studies of the analogous model in two space-time dimensions, which is work in progress [11]. We have derived a fixed point equation the solution of which would imply the exact solution of the model. Unfortunately, this equation is singular in the infrared regime so that the techniques to prove existence of the solution in the four-dimensional case [9] cannot be carried over to two dimensions.

On the questions mentioned at the end of the last subsection we had interesting discussions with Prof. Vincent Rivasseau from Paris-Sud. He will join us in our attempts to get a deeper insight into the structure of our solution. This interaction with Vincent was possible through ESI and is highly appreciated by us.

In addition, Prof. Keiichi R. Ito from Kyoto visited ESI from March 11 – 21, 2013. He was very interested in our work and we had a number of fruitful discussions. One of us (R.W.) obtained an invitation to visit Japan.

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Jan Spakula et al: Nuclear dimension and coarse geometry

Collaborators: Erik Guentner (U Hawaii at Manoa), Ján Špakula (U Vienna then, now U Southampton), Rufus Willett (U Hawaii at Manoa)

Dates: May 20 – June 20, 2013

Budget: ESI € 4 320

Scientific Background

C^* -algebras are collections of operators on Hilbert space. Associated to any locally compact group G , there is a (reduced) group C^* -algebra $C_r^*(G)$; understanding the fine structure of this algebra is tantamount to understanding the unitary representation theory of G , an important problem in both mathematical physics and pure mathematics.

There are other important motivations for understanding $C_r^*(G)$. First, thanks to higher index theory and the noncommutative geometry program of Alain Connes [4], understanding the group C^* -algebras $C_r^*(G)$ and similar C^* -algebras associated to group actions and coarse geometry has very important applications in the topology of higher dimensional manifolds; this aspect is organized by the *Baum-Connes conjecture* [2]. Second, Winter and Zacharias [9] have recently introduced an important invariant of C^* -algebras called *nuclear dimension*; although it has led to great advances in the Elliott program [5] to classify simple C^* -algebras, this property is poorly understood with regards to the examples coming from groups, group actions, and coarse geometry, that are most important in applications to topology and geometry.

Project aims and scope

The aim of the project was to further advance understanding of nuclear dimension and the C^* -algebras associated to groups, group actions, and topological spaces that are important in applications to geometry and topology.

Outcomes and achievements

We worked on the following areas during our stay at the ESI. The new results mentioned were discovered during our stay, or very shortly afterwards.

- In an effort to better understand the representation theory of free and hyperbolic groups, we extensively studied boundary actions. Unfortunately, these investigations did not yield substantial new results, but we are hopeful that they might still in future. We were, however, able to unify results of various authors (for example, [7]) on complementary series representations, weak amenability, a-T-menability on free groups, and hope to publish a survey article covering this material soon. Furthermore, this study of the boundary actions led Špakula to study the properties of the Green metric on hyperbolic groups, which has resulted in showing that it satisfies sharp boundary formulas relevant to the construction of representations. The preprint is available at <http://www.personal.soton.ac.uk/js2m12/preprints.html>.
- Guentner and Willett continued their joint work with Guoliang Yu on decompositions of group actions. In particular, we showed that the C^* -algebra associated to a group action has finite nuclear dimension under very natural finite dimensionality assumptions (related to finite asymptotic dimension in the coarse geometric world, and amenability of the action) on the action and space. This result will form part of a memoir currently being worked on by Guentner, Willett and Yu. The lecture series available at <http://math.hawaii.edu/~rufus/Papers.html> summarizes much of this work.
- Guentner and Willett continued their joint work with Paul Baum on exotic crossed products associated to group actions, expanders, and Gromov monster groups [6, 1]. This resulted in the paper [arXiv:1311.2343](https://arxiv.org/abs/1311.2343).
- All three participants studied invariance of K -theory under different exotic completions of group algebras, showing by extending Kasparov's descent techniques that this is always the case for completions associated to certain natural matrix coefficient decay conditions. This may be combined with work of Alcides Buss and Siegfried Echterhoff [3] to produce a joint (five author) paper covering these and other results.
- Špakula and Willett continued their work on maximal and reduced C^* -algebra completions associated to groupoids and coarse geometric spaces [8]. We answered a long-standing open question about non-amenable groupoids (available at <http://math.hawaii.edu/~rufus/Preprints.html>); we are hoping to develop this more before publication.

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Alan Carey et al: Non-commutative geometry and spectral invariants

Collaborators: Alan Carey (ANU), Jens Kaad (FSM Paris), Harald Grosse (U Vienna)

Dates: May 27 – June 23, 2013

Budget: ESI € 4 160, the Australian Research Council (€ 1 500 for airfare A. Carey).

Scientific Background

Over twenty years ago Bøllé et al [2] showed that under certain conditions on the Hamiltonian of a supersymmetric quantum system, there is a regularized Witten index and it equals minus the jump in the (regularized) Krein spectral shift function from quantum scattering theory. The latter was shown to be precisely the spectral flow function in [1]. Some of Carey’s previous work in non-commutative geometry involves techniques that use relative trace class perturbations just as arise in the work of Bøllé et al. This appears not to be a coincidence but rather results from a recent convergence of ideas from non-commutative geometry with the kind of index problems studied in the 1980s and now becoming relevant again due to new examples and progress such as that made in Kaad’s thesis [5].

The issue unresolved at this time is the topological meaning of the quantum mechanical Witten index in the non-Fredholm case. It is real valued and so not a Fredholm index in the usual sense. There is clearly a connection with non-unital index theorems using the techniques of noncommutative geometry (see the article by Carey, Gayral, Rennie and Sukochev arxiv:1107.0805) [3].

Project aims and scope

The aim is to develop in detail the theory of a new spectral invariant which we call the homological index and to find examples where it is non-trivial. We believe that we have to develop an homology theory and dual cohomology theory and pair them to produce a function on the cyclic homology of a certain algebra. This would generalize results in Kaad’s thesis and also relate directly to the Witten index studied in the 90s. The homological index is detecting geometric information that is more subtle than can be understood using conventional index theory.

To understand the geometric content we study Dirac type operators that generalize those considered in the 80s and exist in all dimensions (not just one and two dimensions as in earlier work).

There is a map from the unbounded Dirac theory to the bounded operator theory used for the homological index. This map will be understood in more depth and used to tie together the spectral invariants of the unbounded operators with the homological invariants.

Outcomes and achievements

There is a paper in preparation co-authored by Carey-Grosse-Kaad. In this paper we introduce a bicomplex whose homology is the object of interest for a study of the algebra generated by an

operator T that commutes with its adjoint modulo a Schatten class. There is a dual cohomology theory and the two can be paired to produce the homological index. This index generalizes the invariants studied in the 80s in connection with the Witten index and the R. Carey-Pincus principal function [4]. The developed homological framework makes it possible to investigate the invariance properties of the homological index under perturbations. This will facilitate future concrete computations of this invariant.

A class of Dirac operators was studied and shown to map to an algebra of the form studied in the homological index. Our method of proving that the homological index is not trivial is to use perturbation theory to give a formula for it. By scaling the Dirac operator by a parameter we can consider two scaling limits, the one at zero being the Witten index and the one at infinity being the anomaly. In a few cases it has been possible to show that the homological index is non-zero by computing the anomaly. Interestingly, the answer is expressed in terms of the components of the curvature in a fashion consistent with expectations from the theory of instantons. More examples need to be computed and this remains a topic for future research. Moreover the link to the spectral shift function was not established and that also will be a matter for future investigation.

Preprints contributed:

A. Carey, H. Grosse, J. Kaad, *Anomalies of Dirac type operators on Euclidean space*, arXiv:1310.1796.

A. Carey, J. Kaad, *Topological invariance of the homological index*, arXiv:1402.0475.

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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:

Mini-Lecture Courses, Summer Term 2013:

Vladimir Korepin (State U of New York, Stony Brook, USA), Summer 2013:

The Algebraic Bethe Ansatz

8 Lectures: May 28, 29, 31 and June 3 – 7, 2013, 10:00 - 12:00

Simon Scott (King's College, London), Summer 2013:

Logarithmic TQFT, torsion, and trace invariants

4 Lectures: June 5 – 14, Wednesday and Friday, 14:00 - 16:00

Sauro Succi (IAC-CNR, Rome), Summer 2013:

A crash-course on lattice Boltzmann (in his own city!)

2 Lectures: May 31 and June 3, 10:30 - 12:00

Lecture Courses, Winter Term 2013/14:

Hans Werner Ballmann (U Bonn, MPI of Mathematics Bonn), Winter 2013:

Symmetric Spaces

Lecture Course (250117 VO): Thursday 09:15 - 10:45 (lecture) and 11:00 - 11:45 (tutorial)

Ludwik Dąbrowski (SISSA), Winter 2013:

Spinors: classical and quantum. Elements of Noncommutative Riemannian Geometry

Lecture Course (260155 VO): Friday 10:30 - 12:00 (lecture) and 12:00 - 12:45 (tutorial)

Visitors and Guest Speakers within the Senior Research Fellowship framework:

Gudlaugur Thorbergsson (U of Cologne), November 20 – 26, 2013

Vladimir Korepin: The Algebraic Bethe Ansatz

Course

Quantum Inverse Scattering Method. An introduction to the general theory and discussion of recent developments. The course consisted of 10 lectures. There were about 14 participants in total.

The first lecture was devoted to construction of many-body eigenfunction [coordinate Bethe Ansatz] in Lieb-Liniger model, XXZ spin chain and massive Thirring model. Thermodynamic limit was considered, the ground state and excited states were constructed.

The second lecture was devoted to thermodynamic of Lib-Liniger model.

The third lecture was devoted to Sine-Gordon and massive Thirring model.

The fourth lecture was devoted to classical inverse scattering method: Lax representations and Hamiltonian aspects of evolutionary differential equations.

The fifth lecture was devoted to main constructions of quantum inverse scattering method: monodromy matrix, Yang-Baxter equations and trace identities.

The sixth lecture was devoted to thermodynamic limit of six vertex model [ice model]. Dependence of the bulk free energy on boundary conditions and relation to algebraic combinatorics.

The seventh lecture was devoted to Pauli principle for one dimensional interacting Bosons.

The eighth lecture was devoted to quantum determinant and antipode.

The ninth lecture was devoted to classification of quantum integrable models related to the same R-matrix.

The tenth lecture was devoted to lattice Lieb-Liniger model and lattice Sine-Gordon model.

The course covered first eight chapters of the book.

Research

I started a research project with the group of Professor Verstraete on relation between matrix product state and algebraic Bethe Ansatz. We have published a paper on quantum spin chains, now we work on the models of strongly correlated electrons: t-J model and Hubbard model.

So far, work started or completed at the ESI resulted in the following papers.

1) The Algebraic Bethe Ansatz and Tensor Networks, Vladimir Korepin, Valentine Murg and Frank Verstraete, [arXiv:1201.5627](https://arxiv.org/abs/1201.5627) and [arXiv:1201.5636](https://arxiv.org/abs/1201.5636), appeared in Phys. Rev. B 86, 045125 (2012), 552.

In this work we prove that matrix product states give exact results, when they are available. We calculated correlation functions in finite open spin chains.

2) Local convertibility and edge states in quantum many body systems Fabio Franchini, Jian Cui, Luigi Amico, Heng Fan, Mile Gu, Vladimir E. Korepin, Leong Chuan Kwek, Vlatko Vedral, submitted to Nature.

3) Finite-size effects from higher conservation laws for the one-dimensional Bose gas, Erik Eriksson, Vladimir Korepin, J. Phys. A: Math. Theor. 46 235002 (2013).

4) Classical Vs Quantum correlations in composite systems, Luigi Amico, Sougato Bose, Vladimir E. Korepin, Vlatko Bedrović, Int. J. Mod. Phys. B vol. 27 n. 1–3 (2013).

5) Quantum network teleportation for quantum information distribution and concentration, Yong-Liang Zhang, Yi-Nan Wang, Xiang-Ru Xiao, Li Jing, Liang-Zhu Mu, V. E. Korepin, Heng Fan, Phys. Rev. A 87, 022302 (2013).

Vladimir Korepin also intensively consulted all members of the research team of Professor Frank Verstraete on their current projects.

Simon Scott: Logarithmic TQFT, torsion, and trace invariants

Course

This was a short course of four sessions of two hours each given in June 2013.

Additive invariants on morphisms in the cobordism category may be viewed as being positioned between classical cobordism invariants (genera) and quantum cobordism invariants (TQFTs). The purpose of these lectures was to use logarithmic-functors to put in place a categorical framework for this class of semi-classical invariants and to use these structures to construct and compute exotic Milnor and Reidemeister torsions as characters of logarithmic representations. This may be viewed as a categorification of the theory of trace invariants associated to spectral zeta functions of pseudodifferential operators, and of their pasting formula with respect to a partition of the manifold over which they are defined.

The first lecture reviewed the role of analytic and Whitehead/Reidemeister torsion in cobordism theories since the 1950s seen from the modern viewpoint of topological quantum field theory (TQFT), setting out the structures that TQFT provides for a general formulation of topological torsion. In the second lecture a number of examples were worked out of the more general topological torsions being proposed. In particular, it was shown that the fundamental invariants of geometric and topological index theory arise this way. In the third lecture the detailed structure of log-TQFTs was explained in the general context of A_∞ categories. In the fourth lecture examples of the topological signature and Reidemeister torsion were presented as categorical instances of log-TQFT viewed as a functor from the nerve of the bordism category.

The audience were active and interested participants and a number of new ideas around this work were discussed. Since the theory is really entirely new, having to be built up from first principles, there are many new avenues to explore. From my view point, though brief, the lectures were interesting to both give and, as well, to receive many stimulating suggestions for this work.

Research

Though a brief visitor, for just six days, during my time at ESI I was able to make substantial progress in the completion of the article listed below, and to a number of new research directions currently being actively explored. One of the seminar participants who is on a new postdoc position is currently working on one of these conjectures. On a general level, it was a pleasure to spend time in the exceptional scientific environment provided by ESI. I am most grateful to the administrative staff at ESI and to the scientific governing board for their generous invitation.

- S. Scott, *Log-TQFT and torsion*, arXiv:1306.6941, submitted for journal publication.

Sauro Succi: A crash-course on lattice Boltzmann (in his own city!). Two viennese giants: Boltzmann and Schrödinger.

Course

To say it with Newton, we all sit on the shoulders of the giants. Among such giants, each of us selects his own heroes, mine being Ludwig Boltzmann (1844-1906) and Erwin Schroedinger (1887-1961). Incidentally, but in fact no so incidentally after all, both are from Vienna.

Ludwig Boltzmann is a lifelong presence in my scientific trajectory, since my early undergrad days, up to the bulk of my present day research, which deals with a subject that carries his name: the Lattice Boltzmann equation.

Erwin Schroedinger is less tied up to my first-hand scientific research, but still very special to me. For one, I will never forget the sense of deep admiration I experienced when I first made acquaintance with his equation, whose beauty strikes me today no less than it did back

then, more than three decades ago. Besides, Schroedinger's short and yet immensely influential 'What's Life?' remains one of the most inspiring books I have ever read.

With the above premises, it should not come as a surprise that I was truly honored and over-delighted to visit Vienna as an Erwin Schroedinger Senior Fellow, with special thanks to my esteemed colleague, Prof Christoph Dellago, as well as to the ESI Director, Prof Joachim Schwemer, for arranging this wonderful appointment.

The crash-course I gave on Lattice Boltzmann developed through a two lectures mini-series: two hours each day. The first day, I illustrated the basic ideas behind the method, the second one I tried to convey some feeling for advanced applications, with a special eye on those which I felt would best match the leading edge soft-matter activity taking place in Christoph-Christos (Dellago and Likos) groups. More in detail, the first lecture illustrated the basic principles of Lattice Gas Cellular Automata, the boolean ancestor of Lattice Boltzmann, while in the second I described the transition from many-particle boolean automata to single-particle Boltzmann discrete distributions on the lattice. In the third lecture, I presented the various families of lattice Boltzmann equations currently in use, and finally, in the fourth one, I illustrated some applications to multiphase fluids and colloidal flows.

Research

Protein folding and hydrodynamic correlations

As to collaborative research, among others, we focussed on the effects of hydrodynamic interactions (Lattice Boltzmann is especially good at simulating hydrodynamics at all scales) on the folding properties of biopolymers.

Protein folding is a prominent topic of modern research in chemical physics and physical chemistry. The basic question is overly fascinating: how does a sequence of many thousands monomers (the protein in its *primary* state) find its way towards its *native* configuration, the only one in which it can deliver its function, in a matter of milliseconds to seconds, given the disproportionate number of possible configurations it may visit in between? This needle in the haystack problem, also known as Levinthal paradox, is all but an academic curiosity: many serious diseases, such as mad cow, can be traced to defective folding of proteins.

The Levinthal paradox is no longer a conundrum; by now, it is well understood that proteins do not even think of sampling all possible configurations (which would take far longer than the age of the Universe!). Instead, they are guided in their search by a powerful light-beacon, known as free-energy

$$F = E - TS \quad (4)$$

where E is the energy, S the entropy and T the temperature of the system under consideration. The free-energy is the actual currency of natural phenomena, as it measures the cost of attaining a given state or configuration. This is given by its energy, E , in the first place, minus its accessibility in terms of the number of paths, so to say, taking to that configuration (the entropy S). Temperature measures the capability of the system to explore its landscape, hence it magnifies the entropic contribution. Thus, the highest the free-energy cost, the lowest the probability of attaining the corresponding state. As a result, free-energy minima are typically associated with stable, or long-lived metastable, operation. In view of this, the native state is believed to correspond to a global minimum of the free-energy, hence the protein "moves" in such a way as to minimize its free energy.

This is easier said than done, though: even though we are no longer confronted with the unmanageable complexity of the full configurational phase-space, the free-energy can still depend on

many variables, the so called order parameters or reaction coordinates, q_p , $i = 1, P$:

$$F = \mathcal{F}(q_1 \dots q_P) \quad (5)$$

For instance, a most natural order parameter is the end-to-end distance of the chain of monomers, basically the radius of gyration, R , of the polymer, which is clearly much larger in the unfolded configuration than in the folded one. Hence, one would expect the free-energy to be an increasing function of R .

The free-energy provides a dramatic reduction of the number of degrees of freedom, but still, navigation in the multi-dimensional landscape described by eq. (5) is not a walk in the park. Very ingenious techniques must be devised to attain the global minimum; incidentally Chris Dellago is one of world-leading figures in this sailing art, one more reason why I was keen on visiting.

Free energy is a well-defined notion only at equilibrium; far from equilibrium, the forces driving the protein towards its native structure acquire a dynamic component which can no longer be expressed as the gradient of a free energy landscape $\mathcal{F}(q_1 \dots q_P)$. Among others, hydrodynamic correlations, i.e. the back-reaction of the solvent on the protein induced by the motion of the protein itself, provide one such dynamical component.

How do these correlations affect the individual and, above all, collective pathway to folding, or, more generally, the protein space-time dynamics within, say, a cell? These are paramount questions at the forefront of modern quantitative biology.

Entry (Lattice) Boltzmann

The lattice Boltzmann equation is a minimal version of the original Boltzmann's equation, in which the dynamics of the (pseudo)-molecules takes places entirely on a discrete lattice. Provided such lattice is equipped with the proper symmetries, reflecting the basic mass-momentum conservation laws, as well as rotational invariance, the stylized Lattice Boltzmann dynamics can be shown to reproduce the Navier-Stokes equations of continuum fluid mechanics. Moreover, the lattice Boltzmann equation provides a very efficient computational tool to explore fluid motion across scales, from macroscopic fluid turbulence, all the way down to biopolymer translocation. Hence, all ingredients seem to be in place for a fruitful cooperation.

To this purpose, Ivan Coluzza and Marcello Sega, formerly in Rome, quickly familiarized with the lattice Boltzmann module provided in the open-source code Espresso, and started to produce preliminary results in a matter of days.

The main goal is to explore the folding problem with toy-proteins, i.e. stylized models of polymers interacting through simplified (but not simplistic) model potentials. At the outset, there are no compelling reasons to expect that hydrodynamic interactions would either anticipate or delay the folding process, hence computer simulations are essential to unveil this issue (for the key role of computer simulations in biology, see the 2013 Nobel Prize in Chemistry, to the Vienna-born M. Karplus, M. Levitt and A. Warshel).

Besides my delightful hosts, Prof Dellago and Prof Schwermer, I wish to express my most sincere gratitude to the ESI staff for their wonderful and warm-smiling hospitality, let alone a perfect organization throughout. My warmest thanks to them all, and ... auf Wiedersehen!

- I. Coluzza, D. Pisignano, G. Pontrelli and S. Succi, *Noise effects in electrospinning experiments: a computational study*, submitted.
- G. Pontrelli, D. Gentili, I. Coluzza, D. Pisignano and S. Succi, *Effects of non-linear rheology on the electrospinning process: a model study*, submitted.

Hans Werner Ballmann: Symmetric Spaces

Course

This was a lecture course on symmetric spaces from the point of view of differential geometry. Topics discussed in the lectures:

- 1) Riemannian geometry: Riemannian manifolds, Levi-Civita connection, parallel translation, geodesics, exponential map, curvature tensor, completeness, Bonnet-Myers, Hadamard-Cartan, Ambrose-Hicks, isometry groups, Myers-Steenrod.
- 2) Lie groups and Lie algebras: actions and Lie algebra, decomposition of semisimple Lie algebras, homogeneous spaces, principal bundles and connections.
- 3) Symmetric spaces: locally symmetric and symmetric spaces, transvections, Jacobi fields and Killing fields, Riemannian coverings and fundamental group of symmetric spaces, closed geodesics.
- 4) Symmetric pairs: associated principal bundles and canonical connections, geodesics, invariant tensor fields, curvature tensor, Ricci curvature and Killing form, holonomy.
- 5) Orthogonal symmetric Lie algebras: types, decomposition into irreducible ideals, duality and types of irreducible symmetric spaces, relation to classification of simple Lie algebras and their automorphisms.

To qualify for a grade, the students had to take part in the lectures and be visibly (and audibly) active in the tutorials. For the grade, they had to deliver blackboard talks on topics chosen by me: regularity of distance preserving maps, Killing fields (including Noether's theorem), rigid geometric structures and isometry groups. I was very happy with the talks, they were very well prepared and presented, and showed a high commitment and independence on the side of the students.

Research

In parallel to the lecture course I worked on a monograph on symmetric spaces which I write jointly with Gudlaugur Thorbergsson (Universität Köln). In support of this collaboration, Thorbergsson was invited to visit the ESI for one week. We used this time for intense discussions of the layout of the material and to advance several parts of the manuscript. We hope to finish the work on the manuscript during the calendar year 2014. I am very grateful to the ESI for the invitation to Thorbergsson.

I also worked on a textbook "Einführung in die Geometrie und Topologie" in which I discuss elementary topics from point set topology, differential topology, and differential geometry. I could advance this project considerably so that only some final editing seems to be missing. I hope to be able to finish my work on the manuscript soon.

The invitation to deliver the Erwin Schrödinger Lecture 2013, which took place on December 03 in the Boltzmann Lecture Hall of the ESI, is a great honour. When I received it, I thought that eigenvalues of Laplacians on surfaces is a topic which would be appealing to both, mathematicians and physicists. My recent interest in this area was arisen by the results of Jean-Pierre Otal and his students, who gave a very original proof of a long-standing conjecture of Peter Buser. The preparations for the lecture forced me to think about the problems surrounding Buser's conjecture and were very helpful for my understanding of the whole matter. I think that I can improve some of the previous results. This is going to be joint work with Henrik Matthiesen and Sugata Mondal.

Finally, I would like to mention that my work on the following two articles was very much advanced during my previous stay at the ESI:

- 1) Hans Werner Ballmann, Christian Bär, *Boundary value problems for elliptic differential operators of first order*, *Surveys in Differential Geometry* 17 (2012), 1–78.
- 2) Gilles Carron, Hans Werner Ballmann, Jochen Brüning, *Index theorems on manifolds with straight ends*, *Compositio Mathematica* 148 (2012), 1897–1968.

The stay at the ESI was very pleasant and enabled me to advance several of my projects considerably. I would like to thank the people at the ESI for making this possible.

Ludwik Dąbrowski: Spinors: classical and quantum. Elements of Noncommutative Riemannian Geometry

Course

In the first part of my lecture course starting from basic notions of multilinear algebra and differential geometry, the Dirac operator on a Riemannian spin manifold M was introduced. Its basic properties were described and then the concept of a spectral triple was formulated. The distinction between spin and spin_c structure was related to the charge conjugation (or the real structure).

The second part was devoted to the description of a number of additional properties of this canonical spectral triple, which permit to reconstruct fully the underlying geometry. In particular, it has been shown how to reconstruct the metric and the spin structure, and how to select among the Dirac-type operators the original Dirac operator by minimizing the Einstein-Hilbert action functional. In parallel the concept of the spectral triple and the additional properties as formulated by A. Connes in a fully noncommutative way were presented, so that certain noncommutative algebras can be used in place of the algebra of smooth functions on M . For that purpose some previous “layers” of noncommutative geometry were described briefly, that regard the (differential) topology and calculus, like the equivalence between (locally compact) topological spaces and C^* -algebras, and between vector bundles and finite projective modules, projectors and K theory, the Hochschild cohomology, noncommutative integral, and others.

In the last part of the course three important noncommutative examples were presented and discussed: the noncommutative torus, the almost commutative spectral triple which uncovers the hidden noncommutative geometry behind the Standard Model of elementary particles, and equivariant spectral triples on the quantum two-sphere with the quantum group symmetry $SU_q(2)$.

Due to the necessary selection among the wealth of available material some well established topics (e.g. the index theory) were only briefly mentioned, as well as just few indispensable facts from the theory of the (elliptic) Laplace operator. Such a choice hopefully permitted to arrive fast to an active and interesting fields of current research.

The only prerequisites for the course were the usual notions of multilinear algebra, differential geometry and Hilbert space operators. The presentation style was oriented towards the mathematical physicists, as the majority of the students and postdocs were from the department of physics and few from the department of mathematics.

I am planning to write up the presented material as lecture notes, hopefully in not too long period.

Research

During my stay at the ESI I managed to interact with the researchers from the U, among them

I should certainly mention Prof. Harald Grosse with whom we worked on a common research project.

I would also like to mention that during the third week of January 2014 I took the opportunity to hear several seminars of the workshop “Time-frequency Analysis” at the ESI, which certainly will be helpful to reveal various possible links with noncommutative geometry.

Moreover, I am very grateful to the ESI for the invitation of three researchers Jens KaaD (SISSA, Trieste), Pierre Martinetti (Naples) and Andrzej Sitarz (Krakow), each for one week of collaboration. With them I have started three interesting projects which I am confident will lead soon to new manuscripts and then publications.

The stay at the ESI was very stimulating and enabled me to advance several of my projects considerably. I would like to thank the ESI Director for this extraordinary opportunity and the staff of the ESI for creating so favorable working conditions.

Erwin Schrödinger Lecture 2013

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

Speaker: Hans Werner Ballmann (U Bonn, MPI of Mathematics Bonn)

Date: December 3, 2013

Hans Werner Ballmann: Small eigenvalues on hyperbolic surfaces

Abstract:

Eigenvalues of the Laplacian on closed hyperbolic surfaces are called small, if they lie below $1/4$, the bottom of the spectrum of the Laplacian on the hyperbolic plane. Buser showed that, for any $\varepsilon > 0$, the surface S of genus $g \geq 2$ carries a hyperbolic metric such that $\lambda_{2g-3} < \varepsilon$, where the eigenvalues are counted according to their magnitude. He also showed that $\lambda_{2g-2} \geq c > 0$, where c is independent of genus and hyperbolic metric, and conjectured that $c = 1/4$ is the best constant. I will discuss the conjecture of Buser, its recent solution by Otal and Rosas, and some related problems and results.

Seminars and colloquia

424 seminar and colloquia talks have taken place at the ESI in 2013

- 2013 01 17, G. Muic: On a construction of certain automorphic forms on $SL(2, \mathbb{R})$ and applications I
- 2013 01 23, G. Muic: On a construction of certain automorphic forms on $SL(2, \mathbb{R})$ and applications II
- 2013 01 30, M. Hanzer: The degenerate adelic Eisenstein series
- 2013 02 04, G. Mondello: Abelian differentials on curves of genus 3
- 2013 02 04, H. Parlier: Relative shapes of thick subsets of moduli space
- 2013 02 04, J. Aramayona: Finite rigid sets in curve complexes
- 2013 02 04, N. A'Campo: Ideal triangulations and variation of the complex structure by monodromy
- 2013 02 05, M. Vuorinen: Teichmüller's problem in space
- 2013 02 05, N. Kawazumi: The Goldman-Turaev Lie bialgebra and the largest Torelli group
- 2013 02 05, R. de Jong: On the Kawazumi-Zhang invariant of a compact Riemann surface
- 2013 02 05, U. Hamenstaedt: The Teichmüller flow near the boundary of strata
- 2013 02 06, J. Loftin: Minimal Lagrangian surfaces in CH^2
- 2013 02 06, K. Matsuzaki: Rigidity of groups of circle diffeomorphisms and Teichmüller spaces
- 2013 02 06, M. Hanzer: An explicit construction of some irreducible automorphic representations of GL_n
- 2013 02 06, M. Uludag: Binary quadratic forms as dessins
- 2013 02 06, S. Wolpert: Products of twists, geodesic-lengths and Thurston shears
- 2013 02 07, D. Dumas: Convex polygons, complex polynomials, and hyperbolic affine spheres
- 2013 02 07, I. Kim: Compactification of real projective and AdS^3 geometry
- 2013 02 07, M. Bridgeman: Moments of the boundary hitting function for geodesic flow
- 2013 02 07, R. Canary: A pressure metric for the Hitchin component
- 2013 02 08, C. B. Odigheimer: Homology operations for moduli spaces
- 2013 02 08, K. Rafi: Large scale rank in geometric topology
- 2013 02 08, S. Tan: A dilogarithm identity on moduli spaces of curves
- 2013 02 08, W. Goldman: Complete affine 3-manifolds, Lorentzian and hyperbolic geometry
- 2013 02 13, Y. Kuno: A generalization of Dehn twists, I
- 2013 02 13, Y. Kuno: A generalization of Dehn twists, II
- 2013 02 14, K. Fujiwara: Group actions on quasi-trees and its application, I
- 2013 02 14, K. Fujiwara: Group actions on quasi-trees and its application, II
- 2013 02 15, H. Kodama: Minimal C^1 -diffeomorphisms of the circle which admit fundamental domains, I
- 2013 02 15, H. Kodama: Minimal C^1 -diffeomorphisms of the circle which admit fundamental domains, II
- 2013 02 15, J. Tao: Trivalent graphs, thick surfaces and the shape of moduli spaces
- 2013 02 18, Y. Kasahara: On visualization of the linearity problem for mapping class groups of surfaces, I
- 2013 02 18, Y. Kasahara: On visualization of the linearity problem for mapping class groups of surfaces, II
- 2013 02 20, M. Mimura: Property $(TT)/T$ and homomorphism superrigidity into mapping class groups, I
- 2013 02 20, M. Mimura: Property $(TT)/T$ and homomorphism superrigidity into mapping class groups, II
- 2013 02 25, A. Papadopoulos: On Hilbert Problem IV
- 2013 02 25, F. Guéritaud: Contracting deformations of hyperbolic surfaces
- 2013 02 25, S. Yamada: On variational formulations of the Funk and Barbilian metrics
- 2013 02 26, H. Shiga: Holomorphic families of Riemann surfaces and monodromy, I
- 2013 02 26, H. Shiga: Holomorphic families of Riemann surfaces and monodromy, II
- 2013 02 28, H. Shiga: Holomorphic families of Riemann surfaces and monodromy, III
- 2013 03 01, L. Ji: A tale of two groups: arithmetic groups and mapping class groups, I
- 2013 03 01, L. Ji: A tale of two groups: arithmetic groups and mapping class groups, II
- 2013 03 04, H. Grosse: A solvable noncommutative quantum field theory in 4 dimensions (based on common work with R. Wulkenhaar, arXiv: 1205.0465)

- 2013 03 04, L. Ji: A tale of two groups: arithmetic groups and mapping class groups, III
- 2013 03 05, L. Ji: A tale of two groups: arithmetic groups and mapping class groups, IV
- 2013 03 05, S. Yamada: An introduction to geometric analysis of Teichmüller spaces, I
- 2013 03 06, S. Yamada: An introduction to geometric analysis of Teichmüller spaces, II
- 2013 03 06, S. Yamada: An introduction to geometric analysis of Teichmüller spaces, III
- 2013 03 07, S. Yamada: An introduction to geometric analysis of Teichmüller spaces, IV
- 2013 03 07, S. Yamada: An introduction to geometric analysis of Teichmüller spaces, V
- 2013 03 19, D. Alessandrini: The Teichmüller spaces of surfaces of infinite type, I
- 2013 03 19, H. Miyachi: The geometry of extremal length, I
- 2013 03 20, H. Miyachi: The geometry of extremal length, II
- 2013 03 20, H. Miyachi: The geometry of extremal length, III
- 2013 03 22, D. Alessandrini: The Teichmüller spaces of surfaces of infinite type, II
- 2013 03 22, D. Alessandrini: The Teichmüller spaces of surfaces of infinite type, III
- 2013 03 25, H. Parlier: The geometry of surfaces and their deformation spaces, I
- 2013 03 25, J. Marché: Character varieties and 3-dimensional topology, I
- 2013 03 25, K. Ohshika: Deformation spaces of Kleinian groups, I
- 2013 03 25, N. A'Campo: The Riemann-Roch theorem and applications, I
- 2013 03 26, H. Parlier: The geometry of surfaces and their deformation spaces, II
- 2013 03 26, J. Korinman: TQFT
- 2013 03 26, K. Ohshika: Deformation spaces of Kleinian groups, II
- 2013 03 26, N. A'Campo: The Riemann-Roch theorem and applications, II
- 2013 03 26, S. Lelièvre: Dynamics of translation surfaces, I
- 2013 03 27, H. Parlier: The geometry of surfaces and their deformation spaces, III
- 2013 03 27, J. Marché: Character varieties and 3-dimensional topology, II
- 2013 03 27, K. Ohshika: Deformation spaces of Kleinian groups, III
- 2013 03 27, N. A'Campo: The Riemann-Roch theorem and applications, III
- 2013 03 27, S. Pal: Analysis in Teichmüller spaces: regularity of Douady-Earle extensions
- 2013 03 27, T. Morzadec: Geodesic laminations on flat surfaces
- 2013 03 28, J. Marché: Character varieties and 3-dimensional topology, III
- 2013 03 28, J. Toulisse: AdS geometry of 3-manifolds
- 2013 03 28, K. Ohshika: Deformation spaces of Kleinian groups, IV
- 2013 03 28, M. Durham: Elliptic actions on Teichmüller Space
- 2013 03 28, N. A'Campo: The Riemann-Roch theorem and applications, IV
- 2013 03 28, S. Lelièvre: Dynamics of translation surfaces, II
- 2013 03 29, H. Parlier: The geometry of surfaces and their deformation spaces, IV
- 2013 03 29, J. Marché: Character varieties and 3-dimensional topology, IV
- 2013 03 29, S. Lelièvre: Dynamics of translation surfaces, III
- 2013 03 29, S. Lelièvre: Dynamics of translation surfaces, IV
- 2013 04 08, J. Klauder: Completing canonical quantization
- 2013 04 09, J. Klauder: Field quantization without divergences
- 2013 04 10, C. Walsh: The horofunction boundary of Teichmüller space, I
- 2013 04 10, Y. Neretin: Spaces of conjugacy classes and double cosets, I
- 2013 04 10, Y. Neretin: Spaces of conjugacy classes and double cosets, II
- 2013 04 11, C. Walsh: The horofunction boundary of Teichmüller space, II
- 2013 04 11, E. Plotkin: Word maps of algebras
- 2013 04 11, L. Glebsky: Almost representations of Higman's groups and cycles in repeated exponentiation mod n
- 2013 04 11, L. Paunescu: Linear sofic groups and algebras
- 2013 04 11, V. Sergiescu: Introduction to T group, old and new, I
- 2013 04 11, V. Sergiescu: Introduction to T group, old and new, II
- 2013 04 12, A. Thom: Ulam stability and character rigidity
- 2013 04 12, C. Walsh: The horofunction boundary of Teichmüller space, III
- 2013 04 12, D. Puder: Measure preserving words are primitive
- 2013 04 12, J. Gismatuline: On hyperlinear and sofic groups via profinite and Bohr topology
- 2013 04 12, M. Kassabov: Images of word maps in p -adic groups
- 2013 04 12, T. Osborne: Almost implies near phenomena in quantum computation and complex quantum systems

- 2013 04 12, Y. Neretin: Spaces of conjugacy classes and double cosets, III
- 2013 04 12, Y. Neretin: Spaces of conjugacy classes and double cosets, IV
- 2013 04 13, K. Juschenko: Small spectral radius and percolation constants on non-amenable Cayley graphs
- 2013 04 13, N. Linial: Local geometry of large combinatorial structures
- 2013 04 13, O. Parzanchevski: Fourier expansion of word maps
- 2013 04 15, G. Masbaum: TQFT and modular representations of mapping class groups
- 2013 04 15, Y. Neretin: Infinite symmetric group, checker topological field theories, and Feynmann diagrams
- 2013 04 16, I. Dynnikov: An algorithm to count intersections of normal curves and a matrix presentation of mapping class groups
- 2013 04 16, R. Kashaev: Quantum Teichmüller theory I
- 2013 04 16, R. Penner: Quantum continued fractions
- 2013 04 16, S. Gukov: Quantization of Teichmüller space via mirror symmetry
- 2013 04 17, H. Kim: The dilogarithmic central extension of the Ptolemy-Thompson group via the Kashaev quantization of the universal Teichmüller space
- 2013 04 17, N. Kawazumi: An infinitesimal version of the Dehn-Nielsen theorem
- 2013 04 17, R. Kashaev: Quantum Teichmüller theory II
- 2013 04 17, T. Dimofte: K -decompositions and framed flat connections on 3-manifolds
- 2013 04 18, C. Zickert: Thurston's gluing equations for $\mathrm{PGL}(n, \mathbb{C})$
- 2013 04 18, J. Andersen: Mapping class group invariant unitarity of Hitchin connection
- 2013 04 18, N. Reshetikhin: Semiclassical topological quantum field theories
- 2013 04 18, R. Kashaev: Quantum Teichmüller theory III
- 2013 04 19, F. Costantino: On an analytic family of representations of mapping class groups
- 2013 04 19, J. Roger: Quantum Teichmüller theory at a root of unity
- 2013 04 19, R. Kashaev: Quantum Teichmüller theory IV
- 2013 04 19, T. Kohno: Quantum symmetry in homological representations of braid groups
- 2013 04 29, A. Connes: Variability, time and the quantum
- 2013 04 29, D. Ruelle: Post-human mathematics
- 2013 04 29, E. Lieb: The mathematics and physics of the Bose Gas
- 2013 04 29, J. Gray: The soul of the fact – Poincaré and proof
- 2013 04 29, M. Douglas: String theory and the real world
- 2013 04 30, P. Goddard: Algebras, groups, and strings
- 2013 04 30, R. Werner: How spectral properties may be irrelevant in the long run
- 2013 04 30, W. Lück: An introduction to L^2 -Betti numbers and their applications
- 2013 04 30, Y. Tschinkel: Diophantine equations and their hidden symmetries
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ESI preprints in 2013

2405. Aditi Kar, Nikolay Nikolov: *Rank gradient for Artin groups and their relatives*, 8 pp.;
2406. Alex G. Benedict, Scott E. Field, Stephen R. Lau: *Fast evaluation of asymptotic waveforms from gravitational perturbations*, to appear in *Classical Quantum Gravity*;
2407. Nathaniel Pappas: *Arbitrary p -gradient values*, to appear in *J. Group Theory*;
2408. M. Măntoiu, D. Parra: *Compactness criteria for sets and operators in the setting of continuous frames*, 18 pp.;
2409. Yury A. Neretin: *On p -adic colligations and ‘rational maps’ of Bruhat–Tits trees*, 20 pp.;
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2415. Marcela Hanzer, Goran Muić: *On the Images and Poles of Degenerate Eisenstein Series for $GL(n, \mathbb{A}_{\mathbb{Q}})$ and $GL(n, \mathbb{R})$* , 37 pp.;
2416. Loukas Grafakos, Gerald Teschl: *On Fourier Transforms of Radial Functions and Distributions*, *J. Fourier Anal. Appl.* 19 (2013), 167–179;
2417. Gianpaolo Evangelista: *Warped Frames: Dispersive vs. Non-dispersive Sampling*, 12 pp.;
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2426. Yoshihiro Sawano, Kôzô Yabuta: *Weighted Estimates for Fractional Type Marcinkiewicz Integral Operators Associated to Surfaces*, 38 pp.;
2427. Yu. A. Neretin: *Several Remarks on Groups of Automorphisms of Free Groups*, 7 pp.;
2428. Harald Grosse, Raimar Wulkenhaar: *Self-Dual Noncommutative ϕ^4 -Theory in Four Dimensions is a Non-Perturbatively Solvable and Non-Trivial Quantum Field Theory*, 64 pp.;
2429. Harald Grosse, Raimar Wulkenhaar: *Solvable Limits of a 4D Noncommutative QFT*, 16 pp.;

ESI research in 2013: arXiv preprints and other publications

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

ARZ = Word Maps, and Stability of Representations
 BOZ = Complexity, and Dimension Theory of Skew Product Systems
 EPDI = European Post-Doctoral Institute fellow
 ESI20 = ESI Anniversary: Two Decades at the Interface of Mathematics and Physics
 FGK = Forcing, Large Cardinals, and Descriptive Set Theory
 FNP = Teichmüller Theory
 GKS = The Geometry of Topological D-Branes, Categories, and Applications
 GSCH = Summer School, GEOQUANT 2013
 HS = Jets and Quantum Fields for LHC and Future Colliders
 IS = Individual Scientists
 JS = Advances in the Theory of Automorphic Forms and their L-functions
 RIT = Research in Teams
 SAB = Scientific Advisory Board
 SRF = Senior Research Fellows
 TVW = Heights in Diophantine Geometry, Group Theory, and Additive Combinatorics

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- [2] G. Dimitrov, F. Haiden, L. Katzarkov, Maxim Kontsevich, *Dynamical systems and categories*, [arXiv:1307.8418](#), GKS.
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ESI research in previous years: additional arXiv preprints

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FG = Modern methods of Time - Frequency Analysis II (Thematic Programme 2012)

HBA-Fu = Dynamics of General Relativity: Black Holes and Asymptotics (Workshop 2012)

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- [3] P. T. Chruściel, J. Jezierski, J. Kijowski, *The Hamiltonian mass of asymptotically Schwarzschild-de Sitter space-times*, Phys. Rev. D87 (2013) 12, 124015, HBA-Fu.

List of all visitors in 2013

641 scientists have visited the ESI in 2013

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

ARZ = Word Maps, and Stability of Representations
BOZ = Complexity, and Dimension Theory of Skew Product Systems
EPDI = European Post-Doctoral Institute fellow
ESI20 = ESI Anniversary: Two Decades at the Interface of Mathematics and Physics
FGK = Forcing, Large Cardinals, and Descriptive Set Theory
FNP = Teichmüller Theory
GKS = The Geometry of Topological D-Branes, Categories, and Applications
GSCH = Summer School, GEOQUANT 2013
HS = Jets and Quantum Fields for LHC and Future Colliders
IS = Individual Scientists
JS = Advances in the Theory of Automorphic Forms and their L-functions
RIT = Research in Teams
SAB = Scientific Advisory Board
SRF = Senior Research Fellows
TVW = Height in Diophantine Geometry, Group Theory, and Additive Combinatorics

A'Campo Norbert, U Basel; 27.01.2013 - 10.02.2013, FNP; 02.03.2013 - 09.03.2013, FNP; 24.03.2013 - 01.04.2013, FNP;
Acosta Jorge, Rice U; 03.02.2013 - 09.02.2013, FNP;
Addington Nicolas, Duke U; 12.05.2013 - 18.05.2013, GKS;
Akhtari Shabnam, U Oregon; 24.11.2013 - 04.12.2013, TVW;
Akita Toshiyuki, Hokkaido U; 03.02.2013 - 12.02.2013, FNP;
Alberge Vincent, U Strasbourg; 03.02.2013 - 09.02.2013, FNP; 16.03.2013 - 30.03.2013, FNP;
Alessandrini Daniele, U Heidelberg; 31.01.2013 - 03.02.2013, FNP; 03.03.2013 - 30.03.2013, FNP;
Alekseev Anton, U Geneva; 25.08.2013 - 27.08.2013, GSCH;
Alonso-Garcia Maria Emilia, UCM, Madrid; 01.07.2013 - 15.07.2013, GKS;
Altug Salim Ali, Columbia U; 16.10.2013 - 23.10.2013, JS;
Andersen Jorgen E., Aarhus U; 17.04.2013 - 19.04.2013, FNP;
Ando Hirochi, ESI, U Vienna; 28.08.2013 - 28.02.2014, EPDI;
Andretta Alessandro, U Torino; 19.09.2013 - 27.09.2013, FGK;
Anusic Ana, U Zagreb; 15.09.2013 - 21.09.2013, BOZ;
Aramayona Javier, National U Ireland, Galway; 03.02.2013 - 08.02.2013, FNP;
Arici Francesca, SISSA, Trieste; 18.08.2013 - 30.08.2013, GSCH;
Asano Masaki, Osaka City U; 18.08.2013 - 27.08.2013, GSCH;
Asgari Mahdi, Cornell U; 16.10.2013 - 26.10.2013, JS;
Audrito Giorgio, U Torino; 21.09.2013 - 28.09.2013, FGK;
Babenko Ivan, U Montpellier II; 07.04.2013 - 13.04.2013, FNP;
Bagaria Joan, U Barcelona; 22.09.2013 - 28.09.2013, FGK;

Ballard Matthew, U Vienna; 01.06.2013 - 06.07.2013, GKS;
Ballmann Werner, U Bonn, Mathematik Institut; 01.10.2013 - 15.12.2013, SRF;
Banfi Andrea, U Sussex; 28.07.2013 - 03.08.2013, HS;
Bartosova Dana, U Bonn; 29.09.2013 - 04.10.2013, FGK;
Bartoszynski Tomek, National Science Foundation, Arlington; 02.10.2013 - 10.10.2013, FGK;
Barroero Fabrizio, TU Graz; 24.11.2013 - 07.12.2013, TVW;
Barron Tatyana, U Western Ontario, London; 25.08.2013 - 29.08.2013, GSCH;
Bate Brandon, Tel Aviv U; 16.10.2013 - 23.10.2013, JS;
Bauer Christian, Lawrence Berkeley National Lab; 21.07.2013 - 02.08.2013, HS;
Bayer Arend, U Edinburgh; 16.06.2013 - 03.07.2013, GKS;
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Bell Guido, U Oxford; 28.07.2013 - 03.08.2013, HS;
Beloshapka Iuliya, Moscow State U; 17.08.2013 - 01.09.2013, GSCH;
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Beresnevich Victor, U York; 24.11.2013 - 29.11.2013, TVW;
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Berlai Federico, U Vienna; 11.04.2013 - 13.04.2013, ARZ;
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Beros Konstantinos, U North Texas; 29.09.2013 - 05.10.2013, FGK;
Biggs Adam, U Manchester; 18.08.2013 - 30.08.2013, GSCH;
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Bis Andrzej, U Lodz; 03.02.2013 - 07.02.2013, FNP; 08.04.2013 - 12.04.2013, FNP;
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Blanc Anthony, U Montpellier 2; 23.06.2013 - 30.06.2013, GKS;
Blasius Don, UCLA - U California, Los Angeles ; 20.10.2013 - 27.10.2013, JS;
Block Louis, U Florida; 14.09.2013 - 21.09.2013, BOZ;
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Boughezal Radja, Argonne National Laboratory, USA; 01.07.2013 - 10.07.2013, HS;
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Bridgeman Martin, Boston College, Chestnut Hill; 05.02.2013 - 10.02.2013, FNP;
Bruin Henk, U Vienna; 16.09.2013 - 20.09.2013, BOZ;
Bruzzo Ugo, SISSA, Trieste; 25.08.2013 - 31.08.2013, GSCH;
Buchholz Detlev, U Göttingen; 25.08.2013 - 31.08.2013, GSCH; 31.08.2013 - 09.09.2013, IS;
Buchweitz Ragnar-Olaf, U Toronto, Scarborough; 02.06.2013 - 16.06.2013, GKS;
Bueno de Andrade Julio Cesar, IHES, Bures-Sur-Yvette; 16.10.2013 - 25.10.2013, JS;
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Cacciari Matteo, LPTHE, Paris; 07.07.2013 - 12.07.2013, HS;
Cai Xiongwei, U Luxembourg; 18.08.2013 - 24.08.2013, GSCH;
Caldararu Andrei, U Wisconsin-Madison; 23.06.2013 - 28.06.2013, GKS;
Camerlo Riccardo, DIMAT - Polytechnic Turin; 30.09.2013 - 04.10.2013, FGK;
Camosso Simone, U Bicocca, Milano; 18.08.2013 - 31.08.2013, GSCH;
Canary Richard, U Michigan; 03.02.2013 - 09.02.2013, FNP;

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Capuano Laura, Scuola Normale Superiore, Pisa; 24.11.2013 - 07.12.2013, TVW;
Cardy John, Oxford U; 27.04.2013 - 30.04.2013, SAB;
Carey Alan L., Australian National U, Canberra; 08.02.2013 - 11.02.2013, IS; 20.02.2013 - 23.02.2013, IS;
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Cashen Christopher, U Vienna; 11.04.2013 - 13.04.2013, ARZ;
Castejon Diaz Hector, U Luxembourg; 18.08.2013 - 31.08.2013, GSCH;
Castro-Jiménez Francisco-Jesus, U Sevilla; 06.06.2013 - 15.07.2013, GKS;
Charitos Charalampos, Agricultural U Athens; 03.02.2013 - 10.02.2013, FNP; 24.03.2013 - 29.03.2013, FNP;
Chavez-Molina Oscar, U.N.A.M., Cuernavaca; 17.08.2013 - 02.09.2013, GSCH;
Checcoli Sara, Institut Fourier; 24.11.2013 - 01.12.2013, TVW;
Chenevier Gaetan, CNRS, Palaiseau, France; 20.10.2013 - 26.10.2013, JS;
Chodounsky David, Academy Sciences the Czech Republic; 22.09.2013 - 27.09.2013, FGK; 07.10.2013 - 18.10.2013, FGK;
Clarke Patrick, U Philadelphia; 12.05.2013 - 18.05.2013, GKS;
Cogdell James W., Ohio State U, Columbus; 01.10.2013 - 31.10.2013, JS;
Colonius Fritz, U Augsburg; 15.09.2013 - 20.09.2013, BOZ;
Connes Alain, College de France; 29.04.2013 - 24.09.2013, ESI20;
Corcella Gennaro, INFN-Laboratori Nazionali di Frascati; 13.07.2013 - 19.07.2013, HS;
Correggi Michele, CIRM, Fondazione Bruno Kessler, Trento; 07.01.2013 - 11.01.2013, SCHW;
Corvaja Pietro, U Udine; 24.11.2013 - 05.12.2013, TVW;
Costantino Francesco, IRMA, U Strasbourg; 14.04.2013 - 19.04.2013, FNP;
Cummings James, CMU, Pittsburgh; 15.09.2013 - 28.09.2013, FGK;
Darji Udayan, U Louisville; 28.09.2013 - 05.10.2013, FGK;
Dasgupta Mrinal, U Manchester; 01.07.2013 - 14.07.2013, HS;
Daskalopoulos Georgios, Brown U, Providence; 18.03.2013 - 31.03.2013, FNP;
David Sinnou, U Paris 6; 24.11.2013 - 05.12.2013, TVW;
Debs Gabriel, Institut Mathematique de Jussieu; 28.09.2013 - 05.10.2013, FGK;
Dehnadi Bahman, U Vienna; 01.07.2013 - 31.07.2013, HS;
De Jong Robin, U Leiden; 03.02.2013 - 08.02.2013, FNP;
Deliu Dragos, U Vienna; 13.05.2013 - 24.05.2013, GKS; 01.06.2013 - 30.06.2013, GKS; 19.08.2013 - 23.08.2013, GSCH;
Delp Kelly, Buffalo State College, SUNY; 25.03.2013 - 01.04.2013, FNP;
Derenthal Ulrich, LMU München ; 25.11.2013 - 01.12.2013, TVW;
Diaz Lorenzo, PUC, Rio de Janeiro; 14.09.2013 - 24.09.2013, BOZ;
Diemer Colin, U Miami, Coral Gables; 14.05.2013 - 31.05.2013, GKS; 01.06.2013 - 06.07.2013, GKS;
Dietmann Rainer, U London; 24.11.2013 - 30.11.2013, TVW;
Dimofte Tudor, Institute for Advanced Study, Princeton; 14.04.2013 - 20.04.2013, FNP;
Dimonte Vincenzo, TU Vienna; 20.09.2013 - 11.10.2013, FGK;
Dirbak Matus, Matej Bel U; 15.09.2013 - 20.09.2013, BOZ;
Disarlo Valentina, IRMA, U Strasbourg; 23.03.2013 - 30.03.2013, FNP;
Dodos Panteleimon Ntontos, U Athens; 29.09.2013 - 05.10.2013, FGK;
Dolgachev Igor, U Michigan, Ann Arbor; 29.04.2013 - 26.05.2013, GKS;
Dolinar Gregor, U Ljubljana; 22.09.2013 - 28.09.2013, FGK;
Donagi Ron, Penn State U, State College; 31.05.2013 - 06.06.2013, GKS;
Donninger Roland, EPF Lausanne; 26.09.2013 - 28.09.2013, IS;
Donoghue John, U Massachusetts; 30.06.2013 - 06.07.2013, HS;
Donovan Will, U Edinburgh; 22.04.2013 - 05.07.2013, GKS;

Doran Brent, ETH Zürich; 22.05.2013 - 24.05.2013, GKS; 17.06.2013 - 30.06.2013, GKS;
Douglas Michael R., Stony Brook U, Simons Center for Geometry and Physics; 27.04.2013 - 30.04.2013, ESI20;
Drucker Ohad, The Hebrew U, Jerusalem; 29.09.2013 - 05.10.2013, FGK;
Drumm Todd, Howard U, Washington DC; 07.03.2013 - 14.03.2013, FNP;
Drwiega Tomasz, AGH U, Krakow; 16.09.2013 - 20.09.2013, BOZ;
Dubois Jerome, IMJ-PRG, U Paris-Diderot; 15.04.2013 - 18.04.2013, FNP;
Dujella Andrej, U Zagreb; 24.11.2013 - 30.11.2013, TVW;
Dumas David, U Illinois at Chicago; 03.02.2013 - 09.02.2013, FNP;
Dumbaugh Della, U Richmond; 17.10.2013 - 22.10.2013, IS;
Durham Matthew, U Illinois at Chicago; 24.03.2013 - 31.03.2013, FNP;
Dynnikov Ivan, V.A. Steklov Mathematical Institute; 14.04.2013 - 20.04.2013, FNP;
Džamonja Mirna, U East Anglia; 23.09.2013 - 27.09.2013, FGK;
Eda Katsuya, Waseda U; 09.09.2013 - 15.10.2013, FGK;
Ekström Fredrik, Lund U; 15.09.2013 - 20.09.2013, BOZ;
Elekes Marton, Renyi Institute, Budapest; 29.09.2013 - 04.10.2013, FGK;
Elsholtz Christian, TU Graz; 26.11.2013 - 30.11.2013, TVW;
Engliš Miroslav, Academy of Sciences, Prague; 25.08.2013 - 30.08.2013, GSCH;
Evertse Jan-Hendrik, U Leiden; 08.10.2013 - 12.10.2013, TVW; 24.11.2013 - 01.12.2013, TVW;
Faber Eleonore, U Toronto; 05.06.2013 - 15.06.2013, GKS;
Falk Kurt, U Bremen; 15.09.2013 - 20.09.2013, BOZ;
Fanoni Federica, U Fribourg; 03.02.2013 - 09.02.2013, FNP; 01.03.2013 - 31.03.2013, FNP;
Farkas Barnabas, U Wroclaw; 22.09.2013 - 28.09.2013, FGK;
Favero David, U Vienna; 22.04.2013 - 06.07.2013, GKS;
Feige Ilya, Harvard U; 16.07.2013 - 26.07.2013, HS;
Fickinger Michael, Johannes-Gutenberg U, Mainz; 07.07.2013 - 21.07.2013, HS;
File Daniel, Muhlenbeg College, Allentown, PA; 20.10.2013 - 26.10.2013, JS;
Fili Paul A., Oklahoma State U; 24.11.2013 - 03.12.2013, TVW;
Fischer Arthur, U Vienna; 09.09.2013 - 18.10.2013, FGK;
Fischer Vera, Kurt Gödel Research Center, U Vienna; 09.09.2013 - 18.10.2013, FGK;
Fontanella Laura, U Vienna; 09.09.2013 - 18.10.2013, FGK;
Fonarev Anton, Steklov Mathematical Institute, Moscow; 19.08.2013 - 31.08.2013, GSCH;
Fossas Ariadna, Institut Fourier; 12.04.2013 - 17.04.2013, FNP;
Fregier Yael, MIT, Cambridge; 18.08.2013 - 24.08.2013, GSCH;
Frei Christopher, Technische U Graz; 24.11.2013 - 06.12.2013, TVW;
Friedberg Solomon, Boston College; 20.10.2013 - 26.10.2013, JS;
Friedman Sy-David, U Vienna, KGRC Vienna; 09.09.2013 - 18.10.2013, FGK;
Friedrich Helmut, Max-Planck-Institut für Gravitationsphysik, Potsdam; 26.05.2013 - 31.05.2013, IS;
Frössling Helene, ICMS-International Centre for Mathematical Sciences, Edinburgh; 01.06.2013 - 09.06.2013, GKS;
Fuchino Sakae, Kobe U; 22.09.2013 - 02.10.2013, FGK;
Fuchs Clemens, U Salzburg; 08.10.2013 - 11.10.2013, TVW;
Fuchs Jürgen, Karlstads U; 21.08.2013 - 31.08.2013, GSCH;
Fujii Michihiko, Kyoto U; 15.04.2013 - 19.04.2013, FNP;
Fujikawa Ege, Chiba U; 03.02.2013 - 09.02.2013, FNP;
Fujita Hajime, Japan Women's U, Tokyo; 18.08.2013 - 31.08.2013, GSCH;
Fujiwara Koji, Kyoto U; 11.02.2013 - 22.02.2013, FNP;
Fukaya Tomohiro, Tohoku U, Sendai & U Paris 7; 25.08.2013 - 31.08.2013, GSCH;
Funar Louis, Institut Fourier, U de Grenoble; 28.01.2013 - 23.04.2013, FNP;
Futaki Akito, U Tokyo; 18.08.2013 - 24.08.2013, GSCH;
Galateau Aurelien, U Besancon; 25.11.2013 - 29.11.2013, TVW;

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Holden Helge, Norwegian U Science and Technology, Trondheim; 27.04.2013 - 29.04.2013, SAB;
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Magidor Menachem, Hebrew U, Jerusalem; 09.09.2013 - 09.10.2013, FGK;
Maiti Arun, MPI Leipzig; 24.03.2013 - 29.03.2013, FNP;
Malicki Maciej, Warsaw School Economics; 28.09.2013 - 04.10.2013, FGK;
Maloni Sara, U Paris Sud; 23.03.2013 - 31.03.2013, FNP;
Manning Jason, U at Buffalo; 25.03.2013 - 06.04.2013, FNP;
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Medini Andrea, KGRC, U Vienna; 30.09.2013 - 18.10.2013, FGK;
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Moskaliuk Stepan, National Academy Sciences Ukraine, Bogoljubov Institute for Theoretical Physics; 25.08.2013 - 31.08.2013, GSCH;
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Pottmeyer Lukas, TU Darmstadt; 24.11.2013 - 29.11.2013, TVW;
Preisser Moritz, U Vienna; 01.07.2013 - 03.08.2013, HS;
Preygel Anatoly, UC Berkeley; 13.05.2013 - 19.05.2013, GKS;
Procura Massimiliano, U Bern; 14.07.2013 - 28.07.2013, HS;
Prudova Nina, Higher School Economics, Moscow; 18.08.2013 - 25.08.2013, GSCH;
Przhiyalkovskiy Victor, Steklov Mathematical Institute; 12.05.2013 - 21.05.2013, GKS; 23.06.2013 - 05.07.2013, GKS;
Puder Doron, Hebrew U, Jerusalem; 10.04.2013 - 14.04.2013, ARZ;
Qiu Jian, U Luxembourg; 18.08.2013 - 24.08.2013, GSCH;
Quehenberger Renate, U für angewandte Kunst; 03.02.2013 - 08.02.2013, FNP;
Rafi Kasra, U Oklahoma; 04.02.2013 - 16.02.2013, FNP;
Raghunathan Ravi, IIT Bombay; 16.10.2013 - 26.10.2013, JS;
Raith Peter, U Vienna; 16.09.2013 - 20.09.2013, BOZ;
Ratazzi Nicolas, Université Paris Sud XI, Mathematiques; 24.11.2013 - 01.12.2013, TVW;
Re Emanuele, U Oxford; 26.07.2013 - 02.08.2013, HS;
Remeslennikov Vladimir, Sobolev Mathematical Institute; 18.02.2013 - 17.03.2013, RIT;
Rémond Gaël, CNRS-IMB, Talence; 24.11.2013 - 06.12.2013, TVW;
Reshetikhin Nicolai, UC, Berkeley; 13.04.2013 - 21.04.2013, FNP;
Reyes-Carocca Sebastian, U Autonoma Madrid; 22.03.2013 - 30.03.2013, FNP;
Rivasseau Vincent, Université Paris-Sud; 26.04.2013 - 30.04.2013, SAB; 19.08.2013 - 24.08.2013, GSCH;
Rinot Assaf, Bar-Ilan U; 22.09.2013 - 27.09.2013, FGK;
Robalo Marco, Univerity Montpellier 2; 22.06.2013 - 29.06.2013, GKS;
Rodrigo German, Inst. de Fisica Corpuscular, Valencia; 30.06.2013 - 06.07.2013, HS;
Roger Julien, Rutgers U; 14.04.2013 - 21.04.2013, FNP;
Rosendal Christian, U Illinois, Chicago; 29.09.2013 - 10.10.2013, FGK;

Rothen Lorena, U Bern; 29.07.2013 - 03.08.2013, HS;
Rougerie Nicolas, CNRS and U Grenoble 1; 07.01.2013 - 11.01.2013, SCHW;
Rowlett Julie, U Hannover; 26.09.2013 - 27.09.2013, IS;
Ruelle David, IHES, Bures-sur-Yvette; 28.04.2013 - 02.05.2013, ESI20;
Sabok Marcin, U Wroclaw; 29.09.2013 - 05.10.2013, FGK;
Sabourau Stephane, U Paris Est; 25.03.2013 - 29.03.2013, FNP;
Sagerschnig Katja, Australien National U, Canberra; 25.07.2013 - 08.02.2013, IS;
Said Ahmad, U Strasbourg; 24.03.2013 - 29.03.2013, FNP; 16.04.2013 - 23.04.2013, FNP;
Sakai Hiroshi, Kobe U; 22.09.2013 - 29.09.2013, FGK;
Sakellariadis Ioannis, Rutgers U, Newark; 16.10.2013 - 25.10.2013, JS;
Samitz Daniel, U Vienna; 01.07.2013 - 03.08.2013, HS;
Samuel Tony, U Bremen; 15.09.2013 - 20.09.2013, BOZ;
Sanz-Solé Marta, U Barcelona; 28.04.2013 - 02.05.2013, ESI20;
Sargsyan Grigor, Rutgers U; 21.09.2013 - 28.09.2013, FGK;
Sarnak Peter, Princeton U, Dept. Mathematics; 20.10.2013 - 24.10.2013, JS;
Sasahira Hirofumi, Nagoya U; 22.08.2013 - 31.08.2013, GSCH;
Sato Masatoshi, Gifu U; 03.02.2013 - 09.02.2013, FNP;
Savin Gordan, U Utah, Salt Lake City; 16.10.2013 - 26.10.2013, JS;
Sawon Justin, U North Carolina; 15.05.2013 - 07.07.2013, GKS;
Sayag Eitan S., Ben-Gurion U the Negev, Be'er Sheva; 15.10.2013 - 25.10.2013, JS;
Scarinci Carlos Yoshio Uehara, FAU Erlangen-Nürnberg; 14.04.2013 - 20.04.2013, FNP;
Scheerer Adrian-Maria, ETH Zürich; 24.11.2013 - 06.12.2013, TVW;
Scheidegger Emanuel, U Freiburg; 12.05.2013 - 25.05.2013, GKS;
Scheimbauer Claudia Isabella, ETH Zürich; 23.06.2013 - 30.06.2013, GKS;
Schindler Ralf, U Münster, Institut für mathematische Logik; 08.09.2013 - 28.09.2013, FGK;
Schlichenmaier Martin, U Luxembourg; 28.04.2013 - 30.04.2013, ESI20; 17.08.2013 - 31.08.2013, GSCH;
Schneider Scott, U Michigan; 29.09.2013 - 05.10.2013, FGK;
Schnürer Olaf, U Bonn; 11.05.2013 - 17.05.2013, GKS;
Scholl Anthony, U Cambridge; 17.04.2013 - 24.04.2013, IS; 21.10.2013 - 26.10.2013, JS;
Scholze Peter, U Bonn; 22.10.2013 - 23.10.2013, JS;
Schrittesser David, Westf. Wilhelms U Münster ; 09.09.2013 - 20.10.2013, FGK;
Schröder Matthias, KGRC, U Vienna; 30.09.2013 - 04.10.2013, FGK;
Schwartz Matthew, Harvard U; 14.07.2013 - 28.07.2013, HS;
Scott Simon, Kings College, London; 05.06.2013 - 14.06.2013, IS;
Segal Edward, Imperial College London; 12.05.2013 - 18.05.2013, GKS; 23.06.2013 - 27.06.2013, GKS;
Seppi Andrea, U degli Studi di Pavia; 24.03.2013 - 29.03.2013, FNP;
Sergeev Armen, Steklov Mathematical Institute, Moscow; 18.08.2013 - 31.08.2013, GSCH;
Sergiescu Vlad, Institut Fourier, St. Martin d'Herès; 09.04.2013 - 16.04.2013, FNP;
Seward Brandon, U Michigan; 29.09.2013 - 06.10.2013, FGK;
Shahidi Freydoon, Purdue U, West Lafayette; 15.10.2013 - 26.10.2013, JS;
Sharpe Eric, Virginia Tech, Blacksburg; 13.05.2013 - 22.05.2013, GKS;
Shafarevich Andrey, M. V. Lomonosov, Moscow State U; 25.08.2013 - 31.08.2013, GSCH;
Sharygin Georgy, M. V. Lomonosov Moscow State U; 25.08.2013 - 31.08.2013, GSCH;
Sheshmani Artan, MPI, Bonn; 20.05.2013 - 26.05.2013, GKS;
Sheynman Oleg, Steklov Mathematical Institute, Moscow; 18.08.2013 - 31.08.2013, GSCH;
Shiga Hiroshige, TITECH, Tokyo; 27.01.2013 - 13.03.2013, FNP;
Shoykhet Boris, U Antwerpen; 18.08.2013 - 25.08.2013, GSCH;
Shparlinski Igor, U New South Wales, Sidney; 24.11.2013 - 01.12.2013, TVW;
Sibilla Nicolo, MPI Bonn; 21.06.2013 - 29.06.2013, GKS;
Simon Károly, TU Budapest, Institute Mathematics Technical; 20.09.2013 - 20.09.2013, BOZ;
Sinapova Dima, U Illinois at Chicago ; 22.09.2013 - 28.09.2013, FGK;

Slavich Leone, U degli Studi di Firenze; 24.03.2013 - 29.03.2013, FNP;
Slutskyy Kostyantyn, U Copenhagen; 29.09.2013 - 05.10.2013, FGK;
Smirnov Maxim, ICTP, Trieste; 23.06.2013 - 29.06.2013, GKS;
Snoha Lubomir, Matej Bel U; 15.09.2013 - 20.09.2013, BOZ;
Snurnitsyn Pavel, Lomonosow Moscow State U; 23.11.2013 - 02.12.2013, TVW;
Sokic Miodrag, Caltech, Pasadena; 29.09.2013 - 02.10.2013, FGK;
Solecki Slawomir, U Illinois, Urbana, Department Mathematics; 30.09.2013 - 08.10.2013, FGK;
Sosna Pawel, U Hamburg; 12.05.2013 - 18.05.2013, GKS;
Soukup Lajos, Renyi Institute Mathematics, Budapest; 22.09.2013 - 27.09.2013, FGK;
Soyez Gregory, CEA Saclay; 08.07.2013 - 15.07.2013, HS;
Spakula Jan, U Vienna; 11.04.2013 - 14.04.2013, ARZ; 27.05.2013 - 30.06.2013, RIT;
Stadlbauer Manuel, U Federal da Bahia ; 15.09.2013 - 20.09.2013, BOZ;
Stahlhofen Maximilian, DESY, Hamburg; 30.06.2013 - 12.07.2013, HS;
Steen Johan, Norwegian U Science and Technology; 30.06.2013 - 06.07.2013, GKS;
Steenbock Markus, U Vienna; 11.04.2013 - 13.04.2013, ARZ;
Stimac Sonja, U Zagreb; 15.09.2013 - 21.09.2013, BOZ;
Stoppa Jacopo, U di Pavia; 26.09.2013 - 27.09.2013, IS;
Stratmann Bernd O., U Bremen; 15.09.2013 - 20.09.2013, BOZ;
Su Weixu, Fudan U, Shanghai; 29.01.2013 - 08.02.2013, FNP;
Succi Sauro, National Research Council Italy, Rome; 28.05.2013 - 04.06.2013, IS;
Sun Zhe, U Paris Sud; 03.02.2013 - 08.02.2013, FNP;
Soudry David, Tel-Aviv U ; 20.10.2013 - 25.10.2013, JS;
Spohn Herbert, TU München; 27.04.2013 - 30.04.2013, SAB;
Stellari Paolo, U degli Studi di Milano; 10.06.2013 - 28.06.2013, GKS;
Stewart Cameron L., U Waterloo; 23.11.2013 - 29.11.2013, TVW;
Stewart Iain, MIT, Cambridge; 29.06.2013 - 08.08.2013, HS;
Stiller Michael, U Hamburg; 19.08.2013 - 23.08.2013, GSCH;
Strobl Thomas, U Claude Bernard Lyon 1; 18.08.2013 - 26.08.2013, GSCH;
Szász Domokos, Budapest U Technology; 18.09.2013 - 20.09.2013, BOZ;
Tackmann Frank, DESY, Hamburg; 22.07.2013 - 02.08.2013, HS;
Tadic Petra, U Salzburg; 24.11.2013 - 01.12.2013, TVW;
Tadokoro Yuuki, Kisarazu National College Technology; 03.02.2013 - 09.02.2013, FNP;
Tian Ye, Academy Mathematics and Systems Science, Beijing; 16.10.2013 - 25.10.2013, JS;
Takahashi Atsushi, Osaka U ; 12.05.2013 - 16.05.2013, GKS;
Takahashi Ryosuke, Nagoya City U; 18.08.2013 - 31.08.2013, GSCH;
Takao Kazuto, Osaka U; 04.02.2013 - 09.02.2013, FNP;
Talalhev Dmitry, Moscow State U; 25.08.2013 - 31.08.2013, GSCH;
Talamanca Valerio, U Roma Tre; 24.11.2013 - 30.11.2013, TVW;
Tan Ser Peow, National U Singapore; 03.02.2013 - 08.02.2013, FNP;
Tanasie Anda-Ramona, KGRC, U Vienna; 09.09.2013 - 18.10.2013, FGK;
Tao Jing, U Oklahoma, Norman; 03.02.2013 - 16.02.2013, FNP;
Terhesiu Dalia, U Vienna; 16.09.2013 - 20.09.2013, BOZ;
Thaddeus Michael, Columbia U ; 01.06.2013 - 07.07.2013, GKS;
Thom Andreas, U Leipzig; 11.04.2013 - 13.04.2013, ARZ;
Thorbergsson Gudlaugur, U Cologne; 20.11.2013 - 26.11.2013, SRF;
Thunder Jeff, Northern Illinois U; 06.10.2013 - 12.10.2013, TVW; 24.11.2013 - 30.11.2013, TVW;
Tichy Robert, TU Graz; 15.10.2013 - 07.12.2013, TVW;
Toda Yukinobu, U Tokyo; 08.05.2013 - 05.06.2013, GKS;
Tommasini Matteo, U Luxembourg; 18.08.2013 - 31.08.2013, GSCH;
Tonti Fabio Elio, KGRC, U Vienna; 23.09.2013 - 04.10.2013, FGK;
Törnquist Asger, U Copenhagen; 29.09.2013 - 18.10.2013, FGK;

Torres-Perez Victor, KGRC, U Vienna; 09.09.2013 - 18.10.2013, FGK;
Toullisse Jeremy, U Paul Sabatier; 24.03.2013 - 29.03.2013, FNP; 14.04.2013 - 20.04.2013, FNP;
Tsaban Boaz, Bar-Ilan U; 29.09.2013 - 18.10.2013, FGK;
Tsankov Todor, U Paris 7; 29.09.2013 - 05.10.2013, FGK;
Tsapogas Georgios, U the Aegean ; 03.02.2013 - 08.02.2013, FNP;
Tschinkel Yuri, NYU, CIMS, New York ; 29.04.2013 - 01.05.2013, ESI20;
Tucker-Drob Robin, Rutgers U; 28.09.2013 - 05.10.2013, FGK;
Tumpach Barbara, U de Lille 1; 15.04.2013 - 25.04.2013, FNP;
Uehara Hokuto, Tokyo Metropolitan U; 11.05.2013 - 25.05.2013, GKS;
Uludag Muhammed, Galatasaray U; 03.02.2013 - 09.02.2013, FNP;
Unger Spencer, UCLA ; 21.09.2013 - 28.09.2013, FGK;
Uribe Alejandro, U Michigan, Ann Arbor; 22.08.2013 - 31.08.2013, GSCH;
Ustinovskiy Yury, Steklov Mathematical Institute, Moscow; 15.08.2013 - 23.08.2013, GSCH;
Vaaler Jeffrey D., U Texas; 23.11.2013 - 30.11.2013, TVW;
Valette Alain, U Neuchatel, Institut des Mathematiques; 10.04.2013 - 12.04.2013, ARZ;
Vaquie Michel, U Paul Sabatier, Toulouse; 24.06.2013 - 29.06.2013, GKS;
Väänänen Jouko, U Helsinki; 19.09.2013 - 25.09.2013, FGK;
Velani Sanju, U York; 24.11.2013 - 01.12.2013, TVW;
Velickovic Boban, U Paris Diderot; 22.09.2013 - 28.09.2013, FGK;
Veneziano Francesco, TU Graz; 24.11.2013 - 20.12.2013, TVW;
Verbitskiy Evgeny, Leiden U; 15.09.2013 - 22.09.2013, BOZ;
Vergne Michéle, CNRS, Institut de Mathématique de Jussieu, Paris; 25.08.2013 - 29.08.2013, GSCH;
Verner Jonathan, Charles U, Prague; 23.09.2013 - 27.09.2013, FGK;
Viale Matteo, U di Torino, Dipartimento di matematica; 23.09.2013 - 27.09.2013, FGK;
Vidnyanszky Zoltan, Eötvös Lorand U, Budapest; 02.10.2013 - 05.10.2013, FGK;
Viola Carlo, U di Pisa; 24.11.2013 - 01.12.2013, TVW;
Virili Simone, UAB, Barcelona; 11.04.2013 - 17.04.2013, ARZ;
von Känel Rafael, MPIM Bonn; 28.11.2013 - 01.12.2013, TVW;
Vuorinen Matti, U Turku; 04.02.2013 - 09.02.2013, FNP;
Waalewijn Wouter, UC San Diego; 19.07.2013 - 03.08.2013, HS;
Wallbridge James, MPI Bonn; 23.06.2013 - 28.06.2013, GKS;
Walsh Cormac, Inria, Ecole Polytechnique, Palaiseau; 09.04.2013 - 21.04.2013, FNP;
Walsh Jonathan, UC Berkeley; 01.07.2013 - 12.07.2013, HS;
Wang Mingxi, U Salzburg; 28.11.2013 - 30.11.2013, TVW;
Wedrich Paul, U Cambridge; 12.05.2013 - 18.05.2013, GKS;
Welch Philip, U Bristol; 22.09.2013 - 28.09.2013, FGK;
Wendland Katrin, U Freiburg; 17.08.2013 - 31.08.2013, GSCH;
Werner Reinhard F., Leibniz U Hannover; 28.04.2013 - 30.04.2013, ESI20;
Wesolek Phillip R., U Illinois at Chicago; 29.09.2013 - 05.10.2013, FGK;
White Paul-James, U Oxford; 16.10.2013 - 25.10.2013, JS;
Widmer Martin, Royal Holloway U London; 08.10.2013 - 12.10.2013, TVW; 24.11.2013 - 06.12.2013, TVW;
Williams Jay, Caltech, Pasadena; 29.09.2013 - 04.10.2013, FGK;
Willett Rufus, U Hawaii; 26.05.2013 - 23.06.2013, RIT;
Wohofsky Wolfgang, Vienna U Technology; 23.09.2013 - 04.10.2013, FGK;
Wolpert Scott, U Maryland; 03.02.2013 - 09.02.2013, FNP;
Wu Siye, U Hong Kong; 18.08.2013 - 30.08.2013, GSCH;
Wulkenhaar Raimar, U Münster; 25.02.2013 - 05.04.2013, IS; 28.04.2013 - 01.05.2013, IS;
Wüstholtz Gisbert, ETH Zürich; 17.11.2013 - 19.12.2013, TVW;
Wurzbacher Tilmann, Ruhr-U Bochum; 25.08.2013 - 31.08.2013, GSCH;
Xu Binbin, Institut Fourier, Saint Martin D'Herès; 23.03.2013 - 30.03.2013, FNP; 14.04.2013 - 21.04.2013,

FNP;

Yamada Sumio, U Tohoku ; 11.02.2013 - 14.03.2013, FNP;

Yamana Shunsuke, Kyushu U, Fukuoka; 15.10.2013 - 26.10.2013, JS;

Yoshida Takahiko, Meiji U; 25.08.2013 - 31.08.2013, GSCH;

Yu Jun, Institute for Advances Study, Princeton; 17.10.2013 - 26.10.2013, JS;

Yurttas Saadet Oyku, U Dicle; 23.03.2013 - 30.03.2013, FNP; 13.04.2013 - 20.04.2013, FNP;

Zahn Jochen, U Vienna; 19.08.2013 - 30.08.2013, GSCH;

Zanderighi Giulia, U Oxford; 29.07.2013 - 02.08.2013, HS;

Zdomskyy Lyubomyr, Kurt Gödel Research Center, Vienna, U Vienna; 09.09.2013 - 18.10.2013, FGK;

Zeidler Rudolf, U Wien; 11.04.2013 - 13.04.2013, ARZ;

Zeytin Ayberk, U Galatasaray; 03.02.2013 - 08.02.2013, FNP;

Zhang Huiping, Renmin U China, Beijing; 12.08.2013 - 28.08.2013, GSCH;

Zhang Lei, Boston College; 20.10.2013 - 24.10.2013, JS;

Zhang Shou Wu, Princeton U; 24.11.2013 - 30.11.2013, TVW;

Zhang Wei, Columbia U, New York; 16.10.2013 - 26.10.2013, JS;

Zhou Xiangyu, Chinese Academy Sciences, Beijing; 12.08.2013 - 28.08.2013, GSCH;

Zhu Huaxing, SLAC, Menlo Park; 14.07.2013 - 27.07.2013, HS;

Zhu Yizheng, U Münster; 22.09.2013 - 27.09.2013, FGK;

Zickert Christian, U Maryland; 14.04.2013 - 20.04.2013, FNP;

Ziegler Samuel, U Illinois at Chicago; 29.09.2013 - 05.10.2013, FGK;

Ziegler Volker, RICAM OeAW, Linz; 26.11.2013 - 30.11.2013, TVW;

Zielicz Anna, U Bremen; 15.09.2013 - 20.09.2013, BOZ;

Zmiaikou David, U Paris Sud; 12.09.2013 - 28.02.2013, IS;

Zorin Evgeniy, U York; 26.11.2013 - 29.11.2013, TVW;

Zweimüller Roland, U Vienna; 16.09.2013 - 20.09.2013, BOZ;

