ESI
Erwin Schrödinger International Institute
for Mathematical Physics

universität wien

Scientific Report for 2012

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Contents

Preface

The Institute and its Mission

The Erwin Schrödinger International Institute for Mathematical Physics (ESI) was founded in Vienna, Austria, in 1992, becoming fully operational in April 1993, and, on June 1, 2011, turned into a research centre within the University of Vienna. The mission of the Institute was and still is:

- to advance research in mathematics, physics and mathematical physics at the highest international level through fruitful interactions between scientists from these disciplines;
- to support research at the University of Vienna and surrounding universities and to stimulate the scientific environment in Austria.

The transition of the Erwin Schrödinger Institute from an independent research institute to a "Forschungsplattform" at the University of Vienna was a complicated process. It is still not finished. The owner of the building in which the ESI is located, together with the University of Vienna, still has to take serious measures to fulfill the requirements for safety at work and preventive fire protection. Moreover, there are far-reaching differences in operation as a consequence of the University's involvement in the running of the Institute. This includes issues concerning payments to participants, modifications to the premises and future funding prospects. However, the Institute has continued to function during the radical changes of its status. 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) by a programme of *Research in Teams*, which offers teams of two to four *Erwin Schrödinger Institute Scholars* the opportunity to work at the Institute for periods of one to four 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.

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

Having left behind the difficult period the ESI had to go through in the years 2010 and 2011, the ESI is again viewed as a leading international centre for research in the mathematical sciences.

This position has been achieved with a minimal deployment of resources, financial and human, certainly when compared with similar institutes in other countries. By its distinctive character, the ESI is a place that is very conducive to research.

Scientific activities in 2012

The list of research areas in mathematics and mathematical physics covered by the scientific activities of the Erwin Schrödinger Institute in 2012 shows a remarkable variety: the following thematic programmes, supplemented by eight additional workshops, were in place:

- *Automorphic Forms: Arithmetic and Geometry* (organized by J. Cogdell, C. Moeglin, G. Muic, J. Schwermer) January 3 – February 28, 2012,
- *K-theory and Quantum Fields* (organized by M. Ando, A. Carey, H. Grosse and J. Mickelsson) May 21 – July 27, 2012,
- *The Interaction of Geometry and Representation Theory* (organized by A. Čap, A. Carey, A. Gover, C. Graham, J. Slovak) September 3 – 14, 2012,
- *Modern Methods of time-Frequency Analysis* (organized by H. Feichtinger and K. Gröchenig) September 10 – December 15, 2012.

The pages of this report provide ample evidence that the quality of the scientific programmes was undiminished during and shortly after the radical changes the Institute had to face. 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 tries to create the fertile ground for new ideas.

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

- *Operator Related Function Theory* [org.: A. Aleman (U Lund), K. Seip (U Trondheim)], March 26 – 31, 2012
- *Higher Spin Gravity* [org.: M. Gaberdiel (ETH Zürich), D. Grumiller (TU Vienna), P. Kraus (UCLA), R. Rashkov (Sofia U)], April 10 – 20, 2012
- *Computational Inverse Problems* [org.: P. Maass (U Bremen). O. Scherzer (U Vienna)], April 23 – 27, 2012
- *Periodic Orbits in Dynamical Systems*, [org.: M. Baake (Bielefeld U), K. Schmidt (U Vienna), T. Ward (U East Anglia, Norwich)] May, 21 – 25, 2012
- *EMS - IAMP Summer School on Quantum Chaos*, [org.: N. Anantharaman (Orsay U), St. Nonnenmacher (U Paris-Saclay), Zeév Rudnick (Tel Aviv U), and St. Zelditch (Northwestern U)], July 30 – August 3, 2012.
- *Golod-Shafarevich Groups and Algebras and Rank Gradient* [org.: M. Ershov (U Virginia, Charlottesville), N. Nikolov (Oxford U)], August, 20 – 24, 2012
- *Recent Developments in the Mathematical Analysis of Large Systems* [org.: Ch. Hainzl (Tübingen), R. Seiringer (McGill), S. Teufel (Tübingen)], October 1 – 6, 2012

– *Dynamics of General Relativity: Black Holes and Asymptotics*, Follow-up of the programme "Dynamics of General Relativity" (July 4 – September 2, 2011) [org.: Lars Andersson (MPI Potsdam), Robert Beig (U Vienna), Mark Heinzle (U Vienna), Sascha Husa (U Balearic Islands)], December 10 - 21, 2012.

It is worthwhile noting that the Summer School on Quantum Chaos was jointly organized with the European Mathematical Society (EMS) and the International Association of Mathematical Physics (IAMP). This Instructional Workshop which combined introductory lecture courses by leading experts with more advanced seminars on topical research questions attracted more than 45 graduate students, post-docs and young researchers from all over the world.

As in previous years, within the *Senior Research Fellows* programme, the ESI offered lecture courses on an advanced graduate level. In January 2012, James Cogdell (Ohio State U, Columbus) finished his course on *L - Functions and Functoriality*. In the summer term, Detlev Buchholz (Göttingen) gave a course on *Fundamentals and Highlights of Algebraic Quantum Field Theory* whereas Eduard Feireisl (Academy of Sciences, Czech Republic) lectured on *Mathematics and Fluid Systems*.

By January 1, 2012, the Erwin Schrödinger Institute had established the *Research in Teams Programme* as a new component in its spectrum of scientific activties. The programme offers teams of two to four *Erwin Schrödinger Institute Scholars* the opportunity to work at the Institute in Vienna for periods of one to four 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. The number of proposals, on themes of topical interest, was high. However, due to limited resources, the Kollegium could only accept four of these applications for the year 2012 [see pages 49 - 56 for details]. The first scholars within this programme were at the ESI in June 2012. Other teams are already accepted for the year 2013.

The composition of the International Scientific Advisory Board of the ESI changed starting January 2012. As new members Isabelle Gallagher (Paris), Helge Holden (Trondheim) and Daniel Huybrechts (Bonn) joined the Board. By the end of 2012, after two terms of office and two extra years in difficult times, Nigel Hitchin (Oxford) left the Board. The Institute is extremely thankful to him for many years of valuable advice and support.

There was also a change in the administration of the ESI in 2012. On October 1, Isabella Janger, née Miedl, left the Institute (and Vienna) after many years of cheerful and very competent service, in particular, as head of administration, for the ESI. At the same time Maria Marouschek returned to the ESI office on a part time basis after her maternity leave. In spite of these changes the current administrative staff — Alexandra Katzer, Beatrix Wolf and Maria Marouschek — continues to work with its customary efficiency towards our visitors, research fellows and scientific staff.

Vienna, February 24, 2013

Joachim Schwermer
Director

The ESI in 2012

Director of the Research Centre ESI at the University of Vienna: Joachim Schwermer

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

Administration: Alexandra Katzer (Head of Administration), Isabella Janger (née Miedl) until Sep 30, Maria Marouschek from Oct 1, Beatrix Wolf

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

International Scientific Advisory Board in 2012:
John Cardy (Oxford)
Isabelle Gallagher (Paris)
Nigel Hitchin (Oxford)
Helge Holden (Trondheim)
Daniel Huybrechts (Bonn)
Horst Knörrer (Zürich)
Herbert Spohn (Munich)
Vincent Rivasseau (Orsay)

Budget and visitors: In 2012 the support of ESI from the Austrian Federal Ministry of Science and Research received via the University of Vienna was EUR 790.000. The total spending on scientific activities in the year 2012 was EUR 378.000 and on administration and infrastructure EUR 383.000.

The number of scientists visiting the Erwin Schrödinger Institute in 2012 was 697, and the number of preprints was 57.

The Foundation ESI
President: Klaus Schmidt
Honorary President: Walter Thirring

Scientific Reports

Main Research Programmes

Automorphic Forms: Arithmetic and Geometry

Organizers: James W. Cogdell (Ohio State U, Columbus), Colette Mœglin (U Paris VII), Goran Muić (U Zagreb), Joachim Schwermer (U Vienna)

Dates: January 3 – February 28, 2012.

Budget: ESI €38.080,–

Preprints contributed: [2404], [2403], [2402], [2401], [2400], [2399], [2398]

Report on the programme

Introduction

The theory of automorphic forms and their L-functions has a long history. The "Riemann" zeta function and its connection with prime numbers was investigated by Euler, and Dirichlet introduced L-functions to prove the infinitude of primes in arithmetic progressions. The theory of automorphic forms can be traced back at least to Jacobi and his work with theta functions and representations of integers by quadratic forms. These two subjects were joined by Riemann, who derived the analytic properties of the zeta function from the transformation law of Jacobi's theta series. The idea of a automophic (or modular) form and its attached L-function were formalized by Hecke in the early twentieth century. Concurrently with the work of Hecke, and at the same institution, Artin began to attach L-functions to more arithmetic objects, in his case representations of the Galois group, which led him to the formulation of the general reciprocity law. The realization that one could attach L-functions to more geometric objects, such as elliptic curves or varieties, was made by Hasse and Weil in the first half of the twentieth century. Siegel extended the notion of an automorphic form to higher dimensional complex varieties, namely the Siegel modular varieties, to study representations of quadratic forms by other quadratic forms, a vast generalization of the work of Jacobi.

There was a paradigm shift beginning in the middle of the twentieth century. The work of Gelfand and Piatetski-Shapiro connected the theory of automorphic forms to the theory of representations of algebraic groups, and the theory of automorphic representations was born. With this point of view, the theory of automorphic forms became the theory of automorphic representations of the adelic points of algebraic groups, and the concomitant local-global analysis gave rise to the local representation theory of p-adic groups and is responsible for many of the driving questions of that subject. In the 1970's Jacquet and Langlands recast Hecke's theory of L-functions of modular forms in the language of automorphic representations. Through thinking about automorphic L-functions and their relation to the theory of Eisenstein series,

Langlands outlined a programme, the so-called Langlands Programme, which has served as a guiding paradigm for much of the development of the field. This programme includes the local and global Langlands correspondences, Langlands' principle of functoriality, and the connection with the geometry of Shimura varieties. It also entails Langlands view of a non-abelian class field theory. These questions still drive the subject today and are intimately entwined with deep questions of arithmetic and geometry.

The purpose of the ESI Programme on Automorphic Forms: Arithmetic and Geometry was to take stock of the current state of the subject. There have been many fundamental breakthroughs over the past few years and the overarching goal of the Programme was to bring the major players in these breakthroughs together with those that are applying the results and young investigators. Perhaps the most spectacular breakthrough has been the completion of the "Fundamental Lemma" of Langlands by Ngô, Waldspurger and others and the application of this and the Arthur-Selberg trace formula by Arthur to give the endoscopic classification of both automorphic and local representations of classical groups. This is a spectacular establishment of a fundamental case of Langlands' Functoriality Principle. This breakthrough was the inspiration for two of the main themes of the Programme: "On the classification of automorphic representations for classical groups - A-packets" and "Applications of endoscopy to the geometry and arithmetic of Shimura varieties".

A second major breakthrough of note is the proof of the Sato-Tate Conjecture by Richard Taylor following previous work with Clozel, Harris, Shepard-Barron and others. Nominally a conjecture on the distribution of angles coming from the count of points on elliptic curves over finite fields, its proof combined techniques from automorphic forms and L-functions, potential automorphy and deformation theory of Galois representations. This provided our third theme: "Sato-Tate and connections with Galois representations".

There has been recent progress on the "Gross-Prasad Conjecture", our fourth theme. This is not a single conjecture, but rather a body of conjectures relating periods of automorphic forms to special values of L-functions, thus giving a direct connection between geometry (periods) and arithmetic (special values of L-functions) mediated by automorphc forms. Very recently, the Gross-Prasad conjecture for orthogonal groups has been proved by Waldspurger, and there have been further extensions and refinements of the conjectures due to Ichino and Ikeda and to Gan, Gross, and Prasad.

Activities

The programme ran through January and February of 2012. There were two more intensive periods centered around two workshops, each of two week duration, held from January 9–20 and then February 13–25. We did not try to coordinate the workshops and the themes of the programme. Too rigid coordination would have worked against a desire for "cross pollination" that comes with as broad a mix as possible of researchers as possible at any one time.

We had twenty three participants for the first workshop. Among these were twelve participants which were either recent PhD's or still graduate students. We concentrated the talks on Tuesdays and Thursdays, with four talks each day. These included a two talk series by James Arthur and a two talk series by Sophie Morel. Three talks were by recent PhD's and there was one graduate student talk.

In conjunction with this workshop, we had a cultural activity. There was a piano recital by Gülsin Onay, a Turkish State Artist. It was attended by the workshop participants, other members of the ESI community and two of the Turkish ambassadors in Vienna.

We had thirty five participants for the second workshop. The structure of this workshop was to have two talks a day, in the morning, every day of the workshop, leaving the afternoons for

discussion and collaboration. Besides the senior researchers that spoke we had lectures by two graduate students and two post-doctoral participants.

The participants in the two workshops were essentially disjoint, although there was some overlap of participants in the period between the two workshops.

Specific information on the programme

On the classification of automorphic representations for classical groups – A-packets. Perhaps the most spectacular recent breakthrough has been the completion of the "Fundamental Lemma" of Langlands by Ngô, Waldspurger and others and the application of this and the Arthur-Selberg trace formula by Arthur to give the endoscopic classification of both automorphic and local representations of classical groups. This is a spectacular establishment of a fundamental case of Langlands' Functoriality Principal. Through the theory of endoscopy, Arthur used the trace formula to classify local and automorphic representations of classical groups via transfer to $GL(n)$. This has had a myriad of applications.

During our first workshop, Arthur gave two lectures on his work, one focusing on the basic results and the second on applications. These were complemented by a lecture by Labesse on the history of the trace formula by revisiting the morning seminar from the 1983 special year at the IAS. Dihua Jiang then lectured on the construction of automorphic forms on classical groups, providing a concrete construction of series of the automorphic representations classified by Arthur. This work is all global.

In the second workshop, there was a focus on both global and local aspects of Arthur's classification. David Soudry spoke on CAP representations, which was complementary to the talk by his collaborator Jiang in the first workshop. Marcela Hanzer also spoke on construction of series of automorphic representations with a given Arthur parameter. The local aspects of Arthur's work on classification was represented by the talks of Lapid, Tadić and his student Matić.

There is another approach to Langlands' functoriality conjecture via the theory of L-functions, which complements and adds contrast to Arthur's work. This was represented in the first workshop by the talks of Shahidi, Tsai, File and Nien and in the second workshop by Gurevich and Savin.

Applications of endoscopy to the geometry and arithmetic of Shimura varieties. The work of Arthur on classification of representations of classical groups has had important applications to the understanding of the cohomology of Shimura varieties attached to classical groups through enhanced understanding of the cohomological automorphic representations. Besides applications to geometry, this also impacts the study of special values of L-fucntions and their rationality, since this is also intimately related to rational structures on cohomology. A related development is the so-called Kudla programme, relating automorphic forms, arithmetic intersection theory on Shimura varieties, and special values and derivatives of L-functions.

In the first workshop the geometry of Shimura varieties was highlighted in the two lectures of Sophie Morel, while rationality results played a significant role in the talk of Klosin. On the other hand, the Kudla programme was represented by the senior lecturer Yang and the younger researcher Hörmann.

During the second workshop, the geometry of Shimura varieties and relations with the arithmetic intersection theory was represented by the linked talks of Rapoport and Terstiege on their work with Zhang on the arithmetic fundamental lemma, an arithmetic version of Langlands fundamental lemma for the relative trace formula, as well as the lecture of Goertz on the geometry of Kazhdan-Lusztig varieties. Rationality results for special values of L-functions and rationality of automorphic representations were discussed in the lectures of Shin and Grobner. Explicit

constructions of arithmetic classes were given by Schimpf.

Sato-Tate and Galois representations. Despite our best efforts, the hope to have lectures on the proof of Sato-Tate did not materialize. A number of invitations were canceled at the last moment. However, we had two interesting lectures on Galois representations and relations with p-adic L-functions by Scholl in the first workshop with a talk on motives and Hida in the second workshop potentially p-ordinary abelian varieties. Hopefully we can return to the topic of Sato-Tate in a future programme.

The Gross-Prasad Conjecture. The Gross-Prasad Conjecture is not a single conjecture, but rather a body of conjectures relating periods of automorphic forms to special values of L-functions, thus giving a direct connection between geometry (periods) and arithmetic (specail values of L-functions) mediated by anutomorphic forms. Very recently, the Gross-Prasad conjecture for orthogonal groups has been proved by Waldspurger, and there have been further extensions and refinements of the conjectures due to Ichino and Ikeda and to Gan, Gross, and Prasad. For this part of the programme we were more successful and had many of the principal researchers in residence, particularly during February and the second workshop. Even though he did not speak, Waldspurger was in residence in February. Ichino was also in residence and during the second workshop Gan gave a talk on their joint work on the relationship of Gross-Prasad and the local theta correspondence. In addition, there were several researchers mentioned above who have worked on various aspects of the Gross-Prasad conjecture, periods of automorphic forms and L-functions. These include Lapid, Rapoport, Savin and Terstiege. So even though this topic was not well represented in the talks given in the workshop, it was a central theme of activity during the programme.

Outcomes and achievements

There were a number of collaborative teams present during the programme.

- Cogdell, Shahidi, and Tsai collaborated on a joint project on "Local Langlands conjecture for $GL(n)$ and the symmetric and exterior square ε-factors". Shahidi and Tsai spoke on this during the first workshop. There is a paper in progress that will acknowlledge the ESI. This paper is related to earlier work of Henniart on the local Langlands correspondence and the symmetric and exterior square L-function and there was interaction between parts of this team and Henniart during the second half of the programme.

- Rapoport and Terstiege continued a collaboration "On the arithmetic fundamental group in the miniscule case" (with W. Zhang). This was the topic of both their talks in the second workshop. This collaboration has resulted in an April 2012 preprint that acknowledges the ESI.

- Ichino and Gan collaborated on "Formal degrees and local theta correspondence" as part of our Gross-Prasad programme. This has resulted in an August 2012 preprint.

- Moeglin and Tadić collaborated on tempered representations for classical groups.

Besides these ongoing collaborations, the programme was instrumental in connecting young and established researchers. We mention two instances.

- Hörmann is a young researcher in the Kudla programme located in Freiburg and Yang is one of the senior researchers located in the US. They were aware of each others work, but

this programme was their first meeting and they held several working conversations during the first month of the programme when they were both in residence.

- Lehalleuer was a graduate student in Zürich who came to the programme explicitly to speak with Morel. On the last day of the first workshop, when there were no talks, these two filled every blackboard in both the long hall and the common room with their conversations.

Providing the opportunity for such interactions is one of the important missions of the ESI programmes.

Appendix. List of talks

First Workshop, January 2–20

Tony Scholl	DeRahm realizations of modular form motives
Dihua Jiang	Construction of automorphic forms for classical groups
Tonghai Yang	Period integrals of automorphic Green functions and derivatives of automorphic L-functions (after Luanli Zhao)
Jim Arthur	Endoscopic classification of representations: Statement of theorems
Chufeng Nien	γ–factors for cuspidal representations of general linear groups over a finite field
Freydoon Shahidi	Local Langlands conjecture for $GL(n)$ and the symmetric and exterior square ε–factors
Jean-Piere Labesse	The Friday Morning Seminar on the Trace Formula revisited
Jim Arthur	Classification of representations: On applications and proofs
Steffen Kionke	Lefschetz numbers of involutions on the special linear group over quaternion algebras
Sophie Morel	How to work with perverse sheaves
Kris Klosin	Congruences among automorphic forms on symplectuc groups and unitary groups and the Bloch–Kato conjecture
Fritz Hörmann	The arithmetic volume of orthogonal Shimura varieties
Tung-Lin Tsai	Stability of exterior square γ–factors for $GL(n)$
Sophie Morel	Mixed ℓ-adic complexes over $\mathbb{Q}$
Dan File	Bessel coeficients of induced representations of some classical groups
Goran Muić	Cuspidal automorphic representations with many unramified components fully induced

Second Workshop, February 13 - 25

David Soudry	On CAP-representations of orthogonal groups
Michael Rapoport	On the arithmetic fundamental lemma of Wei Zhang
Moshe Adrian	The local Langlands correspondence: from real to p-adic groups
Ulrich Terstiege	Computation of arithmetic intersection numbers for the arithmetic fundamental lemma
Susanne Schimpf	Goemetric construction of cohomology classes for cocompact arithmetically defined subgroups of $SL_n(\mathbb{C})$
Jing Feng Lau	Reducibility of certain induced representations of E_6 and E_7
Henry Kim	Logarithmic derivatives of Artin L-functions at $s = 1$
Haruzo Hida	Finiteness of potentially p-ordinary $\mathbb{Q}$-semisimple abelian varieties of $GL(2)$-type
Marcela Hanzer	An explicit construction of a certain class of automorphic representations with given Arthur parameter
Wee Teck Gan	Theta correspondence and the local Gross-Prasad conjecture
Gordan Savin	Finite Galois groups attached to automorphic representations
Marko Tadić	On tempered and square integrable representations of classical p-adic groups

Ulrich Goertz	Affine Kazhdan-Lusztig varieties in the Iwahori case
Nadya Gurevich	A "new way" integral for the standard L-function on G_2
Erez Lapid	A class of representations of GL_n over a p-adic field
Sug Woo Shin	Fields of rationality for automorphic representations
Harald Grobner	Rationality for critical L-values of GL_{2n}
Ivan Matić	Conservation relation for discrete series of metaplectic groups
Guy Henniart	On mod p representations of reductive p-adic groups

Invited scientists:
Moshe Adrian, James Arthur, Sascha Biberhofer, Przemyslaw Chojecki, Jim Cogdell, Daniel File, Wee Teck Gan, Angelika Geroldinger Ulrich Goertz, Harald Grobner, Nadya Gurevich, Marcela Hanzer, Guy Henniart, Haruzo Hida, Fritz Hörmann, Atsushi Ichino, Dihua Jiang, Vitezslav Kala, Henry Kim, Steffen Kionke, Sophie Koch, Krysztof Klosin, Jean-Pierre Labesse, Erez Lapid, Jing Feng Lau, Simon Pepin Lehalleur, Judith Ludwig, Jaime Lust, Ivan Matíc, Colette Moeglin, Sophie Morel, Goran Muić, Chufeng Nien, Martina Pflegpeter, Michael Rapoport, Gordan Savin, Susanne Schimpf, Joachim Schwermer, Anthony J. Scholl, Freydoon Shahidi, Sug Woo Shin, David Soudry, Marko Tadić, Ulrich Terstiege, Tung-Lin Tsai, Jean-Loup Waldspurger, Tong-hai Yang, Michael Zydor.

Students and post-docs amongst the invited scientists:
- Graduate Students: S. Biberhofer, P. Chojecki, A. Geroldinger, V. Kala, S. Kionke, S. Koch, S.P. Lehalleur, J. Ludwig, I. Matić, M. Pflegpeter, S. Schimpf, M. Zydor
- Post-docs: M. Adrian, D. File, H. Grobner, J. F. Lau, J. Lust, T-L. Tsai

K-theory and Quantum Fields

Organizers: Matthew Ando (U Illinois), Alan Carey (Australian National U), Harald Grosse (U Vienna), Jouko Mickelsson (U Helsinki)

Dates: May 21 – July 27, 2012

Budget: ESI €44.560,–

Preprints contributed: [2394], [2385], [2387], [2391]

Report on the programme

Organisation

Formal activity started on May 29 with a workshop of expository lectures many of which were aimed at assisting postdoctoral fellows and PhD students gain the necessary background for the research workshop in week 3. This was followed in week 2 (starting on June 4) by some advanced instructional lectures. Week 3 was a research workshop around the themes of generalised cohomology theories, categorical methods in topological quantum field theory and anomalies in string theory and supergravity.

Student presentations were made in the week June 18-22. There was then a reduction in activity until July 12 when formal lectures resumed with an intensive workshop from July 16 to July 20. There were some additional seminars on July 23.

The funding provided by ESI was split fairly evenly between support for more senior researchers on the one hand and students and postdoctoral fellows on the other.

A commonly expressed view of the participants was that all in all, this was a very important meeting for the unique mix of mathematicians and mathematical physicists. The organisers received many thanks for their work on the meeting and there was a common view that the ESI

provided excellent hospitality and a forum where interesting and productive interactions took place.

Scientific activity

In week one the participants were mostly junior researchers and the flavour of the interactions was primarily at the level of discussions on topics arising from the lectures. These introductory lectures attracted an audience of about 20 people over the week. A feature of the week was the discussion sessions in the afternoons where there was considerable interaction between the lecturers and the audience.

The talks divided more or less as expected into those dealing with the classification and description of topological quantum field theories, anomalies and anomaly cancellation in string theory and eleven dimensional super gravity (motivated by M-theory) and the mathematical underpinnings of index theory in its modern form, that is Kasparov theory. There were two research talks by Matthias Lesch on the latter theme.

In week two there were two longer series of lectures. The first was shared by Baum and Wang on K-homology and Kasparov theory and geometric cycles with applications to proving index theorems and their twisted versions and to twists arising from gerbes. The second series by Freed focussed on twists arising from orientability obstructions and their generalizations. These were assembled into a single approach using appropriate classifying spaces (spectra). Extensive notes were made available to the participants on the web.

Week three was devoted to research talks with the audience swelling to 35 at the peak. A diverse range of topics was covered and fitted well with the more introductory material of the first two weeks. The programme was structured so as to leave time in the afternoons for formal and informal discussion sessions. These proved both popular and effective with considerable interaction being generated. Fewer students stayed on in the week three, partly due to a shortage of funding for a longer stay, and partly because the lectures in the third week were a step up in level of difficulty.

There was a shift of direction for the second half of the programme beginning on July 12. Non-commutative methods and their application were a major new ingredient in this second workshop. The second half of the programme began with talks by Piotr Hajac on noncommutative lens spaces and their properties.

The main workshop reached its peak on July 16. First Michael Joachim gave a talk on classification of twists in K-theory, equivariant under proper and discrete actions and then Pierre Julg reported on progress on the Baum-Connes conjecture in the case of simple Lie groups of rank one. The K-theory talks continued on Tuesday, Richard Szabo talked about differential equivariant K-theory problems arising in the study of string orbifolds whereas Snigdhayan Mahanta gave a talk more on the purely mathematical side, on twisted K-theory in the bivariant setting (of J. Cuntz in the category of C^*-algebras).

Wednesday, July 18, was devoted to noncommutative methods and several new results were announced. These included an announcement by Raimar Wulkenhaar about a recent result (with Harald Grosse) on the construction of a nonperturbative noncommutative quantum field theory model in 4 dimensions. Branimir Cacic reported on a reconstruction theorem for almost commutative spectral triples, generalizing a theorem of Alain Connes for commutative spectral triples; the noncommutativity arising from a finite rank (gauge) bundle.

On Thursday Bram Mesland explained his recent work on a construction of KK-theory and its Kasparov product. He introduced the notion of a differentiable C^*-module and gave a direct algebraic construction of the Kasparov product in that setting. He also gave an application to a construction of gauge theory on a quantum sphere using correspondences in KK-theory. Martin

Schlichenmaier reported on his earlier work on Toeplitz quantization and a recent application of the method by J. Andersen to the construction of a unitary Hitchin connection on a vector bundle over Teichmüller spaces.

Finally, on Friday Pedram Hekmati extended earlier work on families index theory using the caleron correspondence to the case of secondary invariants. Raymond Vozzo talked about gerbes with abelian bands constructed using abelian extensions (not necessarily central) of infinite-dimensional Lie groups. As an application, he gave an alternative construction of the gerbe in higher dimensional nonabelian quantum gauge theory related to the Mickelsson-Faddeed extension.

In the final week Ryszard Nest gave a talk on Fredholm tuples and index theory, David Evans on modular invariants in conformal field theory and their relation to twisted equivariant K-theory.

A feature of both workshops was the large number of new and unpublished results that were announced.

Comments on particular research directions

May-June participants. Gabriel Baditoiu and Steve Rosenberg continued work on Lie bialgebras and Lax pair equations. In particular, they used work of Etingof-Kazhdan to explore functorial properties of their own constructions. Much of the original work (published in CMP) was done during an earlier stay at ESI three years ago. In fact, because of Gabriel's difficult financial constraints in Romania, this is their first opportunity to work face to face since the last stay at ESI.

There was a particular synergy in the talks of Constantin Teleman and Christoph Schweigert, and a large overlap of interest of Freed, Teleman and Schweigert in extended structures in topological field theories and their higher categorical description. This group of researchers also had quite a few interesting and important discussions, in particular about the relation of the Witt group of modular categories and four-dimensional anomalous theories.

Schweigert also discussed with Ezra Getzler aspects of moduli spaces of Riemann surfaces (systems of generators and relations) that are relevant for ongoing work with Jürgen Fuchs and Carl Stigner on correlation functions in logarithmic rational conformal field theories. In paricular these new results are relevant to boundary conditions in three-dimensional topological field theories.

There was a lot of interest sparked by the talks of Dan Freed on twists in string theory and orientifolds. These overlapped with those of Urs Schreiber providing different perspectives on related questions. Thomas Nicklaus, David Gepner, Urs Schreiber and Danny Stevenson formed a group discussing aspects of these lectures and continued some joint work on upcoming articles which Urs Schreiber also presented in part in his talks. These articles are about higher bundle theory and the relation to background data and anomalies in gauge theories. There were overlaps with the work of Jesse Wolfson and many other participants of the workshop which led to some interesting discussions particularly with Christoph Schweigert about bundles of conformal field theories and certain families in the moduli spaces.

Stevenson worked on a continuation of a project, started in 2010 with Schreiber and Nikolaus, on the foundations of principal ∞-bundles, which are the ultimate generalization of bundle gerbes. They have described a general abstract theory of these objects within an arbitrary ∞-topos, and have also described presentations of these in categories of simplicial presheaves. Two papers, describing the details of this general abstract theory and the corresponding presentations were in the final stages of preparation, and became public on the arXiv at the beginning of July.

Ezra Getzler had useful conversations with participants at the workshop on derived geometry and the best framework for working with it. This is a central issue in the modern theory of

stacks. This work, which has as its goal to bring methods from analytical geometry into higher stack theory, is aimed at incorporation of ideas from derived geometry.

Dan Freed continued his long-running discussions with Constantin Teleman, which at the moment focus on issues around 3-dimensional topological field theory. There was progress understanding the structure of spin theories, the relation with 2-dimensional conformal field theories, and a categorical construction necessary for the story. He also had very informative discussions with Matt Ando and David Gepner about some issues in homotopy theory related to Type II superstring theory. The notes he wrote in conjunction with his lectures forced a rethink of the story worked out over three years ago and helped tremendously the prospects for a paper on the subject. He also had many interesting chats with many of the other participants, including Alan Carey, Ezra Getzler, Christoph Schweigert, John Francis, Urs Schreiber, Steve Rosenberg, and Jesse Wolfson.

Alan Carey, Paul Baum and Bai-Ling Wang continued their collaboration on twisted geometric cycles for CW-complexes. These play a role in the mathematical understanding of D-brane charges. These discussions broadened to include Zeinalian with regard to a possible interpretation of a class of pseudo-differential operators that appeared in Baum's talk as the generators of a kind of heat operator in the Carnot geometry, where one uses Brownian motions that are tangent to the contact planes in some weak sense.

Mahmoud Zeinalian had lengthy discussions with John Francis about modeling the space of maps from one manifold X into another. On the one hand, one obtains such a model by integrating over X the chains on the n-fold loop space of the traget manifold, as he described in his talk on factorization homology. On the other hand, this is achieved by the higher Hochschild complex, modeled over X, of the differential forms on the target, via a generalization of Chen iterated integrals, that Zeinalian and collaborators worked out. Progress was made on reconciling the two.

Finally Zeinalian also joined the discussions with Urs Schreiber on non-abelian bundle gerbes from infinitesimal connection data and the likelihood of extending work on abelian gerbes on a manifold M. By restricting the equivariant holonomy to the thin tori in M, one obtains the Chern character of the line bundle on the free loop space LM, associated to the gerbe on M. This suggests a way of getting at the topological invariants of non-abelian gerbes on M as classes obtained similarly by restricting the torus equivariant holonomy, on the mapping space of the standard torus into M, to the loop space thought of as the subspace of all thin tori in M.

July participants. The second workshop was more more focussed with fewer topics being investigated. The interaction of researchers with a background in physics and those whose primary interests were mathematical was a feature of this period of the programme. The focus on noncommutative geometry produced some lively discussions and led to some joint research being initiated.

For example, Snigdhayan Mahanta initiated discussions on a project with Michael Joachim. He also joined the NCG group in discussions especially with Bram Mesland.

The recent discovery of an extension of the notion of gerbe by Murray and collaborators was a focus of interest for Raymond Vozzo, Pedram Hekmati and Jouko Mickelsson. They explored the idea as an approach to differential K-theory for infinite-dimensional vector bundles using these recent results. Their plan was to use differential characters for loop group bundles. In particular they proved the existence of a universal N-classifying loop group bundle with universal connection and Higgs field. They also computed explicit Chern-Simons forms for such bundles and outlined a strategy for constructing an associated differential K-theory, following the model by Simons-Sullivan.

Another topic of interest was the construction of the index bundle gerbe associated to a family

of Dirac type operators. There is a geometric construction of this gerbe in one dimension which uses the so called caloron transform and the basic positive energy representation of the loop group. In higher dimensions, one must work with bundle gerbes with non-constant structure group bundle and "homotopy" group cocycles. Thanks to the ESI meeting important progress has been made.

G. Landi and others had discussions about BRST quantization of non-abelian two-dimensional BF-theory. This theory appears to be intimately related to Chern-Simons theory on product 3-manifolds and has been applied to topological insulators. The partition function for Chern-Simons is given explicitly by the Verlinde formula, while the former is related to analytic torsion. It would be interesting to make this connection more precise.

Courant sigma models were discussed with Richard Szabo and this could lead to further research. There was also interest in Richard Szabo's recent work on Poisson geometry and potential applications of techniques from the theory of gerbes.

Carey and Nest continued previous discussions on index theorems for families of Fredholm operators. Progress was made on both sides in existing projects. Also the idea of studying geometric cycles to probe the K-homology of loop spaces was discussed extending earlier research with Baum and Wang.

The project on solvable four dimensional quantum field theories by Harald Grosse and Raimar Wulkenhaar received a boost through lengthy interactions with several participants.

Invited scientists:
Matt Ando, Eitan Angel, Gabriel Baditoiu, Paul Baum, Liu Bei, Peter Bouwknegt, Branimir Cacic, Alan Carey, Christopher Douglas, David Evans, Marzeih Forough, John Francis, Dan Freed, Aaron-Mazel Gee, David Gepner, Ezra Getzler, Harald Grosse, Piotr Hajac, Antti Harju, Pedram Hekmati, Nigel Higson, Rohit Dilip Holkar, Michael Joachim, Pierre Julg, Svatopluk Krysl, Alan Lai, Giovanni Landi, Matthias Lesch, Henri Lipponen, Snigdhayan Mahanta, Bram Mesland, Jouko Mickelsson, Ryszard Nest, Thomas Nikolaus, Sylvie Paycha, Eric Peterson, Frederic Rochon, Steve Rosenberg, Jenny Santoso, Martin Schlichenmaier, Urs Schreiber, Christoph Schweigert, Daniel Stevenson, Richard Szabo, Constantin Teleman, Ryan Thorngren, Raymond Vozzo, Bai-Ling Wang, Jesse Wolfson, Raimar Wulkenhaar, Mahmoud Zeinalian.

The Interaction of Geometry and Representation Theory. Exploring new frontiers.

Organizers: A. Čap (U Vienna), A. Carey (Australian National U), A.R. Gover (U Auckland), C.R. Graham (U Washington), J. Slovák (Masaryk U, Brno).

Dates: September 3 – 14, 2012

Budget: ESI € 26.000,–
plus additional funding of
approximately € 8.800,– by the Australian National University,
approximately € 2.000,– by the Union of Czech Mathematicians and Physicists, and
approximately € 1.800,– by Elsevier scientific publishing.

Preprints contributed: [2393],]2388], [2373], [2353], [2348]

Report on the programme

Introduction

The main topics of the programme were the various types of interactions between (differential) geometry, representation theory of semisimple Lie groups and Lie algebras, and the theory of differential equations. During recent years, ideas from conformal geometry, complex analysis (in particular the theory of CR structures), and the geometric theory of differential equations, have led to the development of a general theory of *parabolic geometries* which is an important source of such interactions. These are differential geometric structures which can be equivalently described as those Cartan geometries which have as their homogeneous model the quotient of a semisimple Lie group by a parabolic subgroup. Tools from semisimple representation theory play an important role in most aspects of the theory of parabolic geometries.

The theory of Bernstein–Gelfand–Gelfand (BGG) sequences provides a systematic construction of differential operators which are intrinsic to a parabolic geometry as well as tools for the study of these operators. The first operator in any such sequence defines a (geometric) overdetermined system of PDEs, and a large number of well known examples of such systems arises in this way. These "first BGG operators" in turn can be used in the study of parabolic geometries by, for example, their solutions providing holonomy reductions.

There are many analogs and generalizations of this picture, which also provide further interactions of the type described above. In particular, Cartan geometries play an important role in the *geometric theory of differential equations*. While these usually are not parabolic geometries, some ideas from the parabolic theory can be used in this way. On the other hand, the machinery of BGG sequences has inspired techniques for the study of other overdetermined systems than the first BGG equations.

Activities

The programme extended only over two weeks, with the first and second week being of very different character. The first week was of much smaller scale (about 20 participants) with only seven organized talks and lots of time for discussions and collaboration in small groups. Most of the talks in the first week were delivered by junior participants. The relaxed and quiet atmosphere of the ESI was a perfect surrounding for interactions ranging from the loose exchange of ideas, and the identification of questions of joint interest, to focussed and intense collaboration between the participants.

The second week of the programme was comprised of a conference with a (more or less) full day schedule of talks. We decided to avoid too many talks and instead to schedule all talks with a duration of 50 minutes. Also longer breaks were placed in the schedule to give the participants time for discussions. There was a total of 28 talks in that week (we avoided talks on Friday afternoon, since several participants had planned to be already gone by the Friday). In order to give also young people the opportunity to present their results, we organized a poster session, with posters being displayed in the main corridor of the ESI for most of the second week. The posters were received with interest by the participants and stimulated several discussions.

An important inspiration during the organization of this programme was the scientific work of Micheal Eastwood, who celebrated his 60th birthday in 2012. His broad interests and large number of collaborations have strongly influenced many of the topics discussed during the conference and initiated many of the interactions contributing to these topics. Having many of Mike's collaborators in Vienna for the conference in week two, we used the opportunity of celebrating his birthday as a highlight of the social side of the programme. The main event in this direction was a joint evening at a "Heurigen" which was financed by Elsevier scientific publishers.

With a two week programme, one cannot hope for too much "formal" output at this stage, just four months after the activities, but we believe that the programme was very successful. The range of topics was perfect in the sense that it was small enough to allow for easy interactions between large groups of participants while at the same time being wide enough for everybody to pick up new information and to have the possibility of establishing new contacts. These opportunities were eagerly exploited by the participants; the nice facilities and atmosphere of the ESI certainly contributed a lot to this process.

In connection with our programme, there will be a special issue of the journal "Differential geometry and its applications" for which the organizers of the programme serve as guest editors. This will not be a proceedings volume, but a thematic issue, with all submissions being refereed according to the usual standards of the journal.

Specific topics of the programme

As stated above, the main topic of the programme involved the interactions between different fields, so the separation into different fields below is not completely appropriate. Indeed many talks and discussions in the programme addressed aspects from two or more of the fields discussed below.

Geometric structures. As mentioned already, much of the activity in the programme was related to parabolic geometries. Apart from several talks on the general theory of (subclasses of) parabolic geometries, there were also many talks devoted to particular geometries. Here in particular, conformal structures, projective and h–projective structures, and CR structures have to be mentioned. There also were talks on more general geometric structures with applications to the geometry of curves, the geometric theory of differential equations and the geometry of Levi–degenerate CR structures. In fact, almost all of the talks had a substantial amount of geometric content.

Differential operators and differential equations. Most of the differential operators studied during the programme are of geometric origin or have some geometric relevance. Here one should certainly mention the GJMS–operators (conformally invariant powers of the Laplacian) which, mainly via their relation to Q–curvature and the renormalized volume, play a deep role in conformal geometry. A strong link between parabolic geometries and differential operators is provided by the machinery of BGG sequences, which occurred in several talks. During the conference also a relative version of the BGG construction and a version of BGG sequences depending just on filtrations of the tangent bundle of a manifold (for example a contact structure) were presented. Invariant differential operators also play an important role in representation theory.

Apart from differential operators of geometric origin, there were also some talks on the geometric theory of general differential equations, in particular, on normal forms for Pfaffian systems, higher order contact geometry, and a global version of the Lie–Tresse theorem.

Complex analysis and complex geometry. There are two important links between complex analysis and complex geometry and the other topics of the programme. On the one hand, CR structures form a natural point of contact. The second important connection comes from twistor theory, which connects to all the other topics and which played an important role in several talks.

Representation theory. The relation of representation theory to the other topics of the programme mainly is through applications of invariant differential operators and of twistor theory to representation theory. An important topic that came up recently is branching laws for Verma modules. The relation to (families of) invariant differential operators for parabolic geometries is an important motivation for these developments.

Appendix. List of talks

First week, September 3–7

B. Doubrov	Cone structures: definitions, local equivalence, examples
K. Neusser	Some complexes of differential operators
P. Nurowski	Split signature 4–dimensional metrics, real totally null planes and $(2,3,5)$–distributions
J. Šilhan	Invariant bilinear operators on AHS structures
P. Somberg	The branching problem for generalized Verma modules, with application to the pair $(SO(7), G_2)$
D. The	The gap phenomenon in parabolic geometries
T. Willse	Generic plane fields and special holonomy

Conference week, September 10–14

P. Baird	On functions with a conjugate
R.L. Bryant	On normal forms for Pfaffian systems and their application
N. Buchdahl	Spheres and symmetry
D.M.J. Calderbank	Projective parabolic geometries
A. Čap	Relative BGG sequences
A. D'Agnolo	On the Laplace transform for temperate holomorphic functions
M. Dunajski	$SU(2)$ solutions to self-duality equations in eight dimensions
V. Ejov	Classification of spherical rigid hypersurfaces in $\mathbb{C}^2$
A. Isaev	Reduction of five-dimensional uniformly Levi degenerate CR structures to absolute parallelisms
A. Juhl	On the structure of GJMS-operators and Q-curvatures
S. Gindikin	Twistors and representations. 25 years after
A.R. Gover	Riemannian geometry in the parabolic playground
C.R. Graham	New proof of Juhl's formulae for GJMS operators and Q-curvatures
K. Hirachi	Invariant theory for the Szegö kernel and CR Q-curvature
T. Kobayashi	Natural differential operators in parabolic geometry and branching laws
B. Kruglikov	Global Lie-Tresse theorem
J.M. Landsberg	Geometry, representation theory, and the complexity of matrix multiplication
C. LeBrun	Instantons, quotient singularities, and the geometrization of 4–manifolds
T. Leistner	Conformal holonomy, symmetric spaces, and skew symmetric torsion
L. Mason	Einstein gravity from rational curves in twistor space
V. Matveev	Degree of mobility of metrics with respect to projective and h–projective equivalence
B. Ørsted	Natural differential operators in parabolic geometry and branching laws II
J. Sawon	Twistor theory for generalized complex manifolds
V. Souček	On the BGG complexes in a singular infinitesimal character
P. Tod	The behaviour of conformal geodesics
R.O. Wells	Manifolds and Euclidean space
J.A. Wolf	Principal series representations for some infinite dimensional Lie groups
K. Yamaguchi	B_3–geometry in contact geometry of second order

Invited scientists:

Spyros Alexakis, Jesse Alt, Paul Baird, Helga Baum, John Bland, Robert Bryant, Nick Buchdahl, David Calderbank, Andreas Čap, Alan Carey, Stephen Casey, Kevin Coulembier, Andrea D'Agnolo, Boris Doubrov, Maciej Dunajski, Mike Eastwood, Vladimir Ejov, Aleksandra Fedorova, Simon Gindikin, Rod Gover, Robin Graham, Jan Gregorović, Matthias Hammerl, Kengo Hirachi, Alexander Isaev, Andreas Juhl, Hironao Kato, Toshiyuki Kobayashi, Boris Kruglikov, Svatopluk Krýsl, Joseph M. Landsberg, Claude LeBrun, Thomas Leistner, Gianni Manno, Lionel J. Mason, Vladimir Matveev, Alexander Medvedev, Thomas Mettler, Tohru Morimoto, Katharina Neusser, Pawel Nurowski, Bent Orsted, Matthew Randall, Stefan Rosemann, Katja Sagerschnig, Tomáš Salač, Justin Sawon, Gerd Schmalz, Ravi Shroff, Josef Silhan, Jan Slovak, Petr Somberg, Vladimir Soucek, Arman Taghavi-Chabert, Dennis The, Paul Tod, Vit Tuček, Peter Vassiliou, Zuzana Vlasakova, Ronny Wells, Travis Willse, Joseph A. Wolf, Keizo Yamaguchi, Vojtech Zadnik, Lenka Zalabova.

Modern Methods of Time-Frequency Analysis II

Organizers: Hans G. Feichtinger (U Vienna), Karlheinz Gröchenig (U Vienna).
The workshops were organized with international co-organizers.

Dates: September 10 – December 15, 2012

Budget: € 63.840,–
plus additional funding of approx. € 5.300,– DFG, and € 4.000,– WWTF.

Preprints contributed: [2410], [2408]

Thirteen participants of the workshop "Wavelets in Scientific Computing" were supported by the priority program "Extraction of Quantifiable Information from Complex Systems" SPP 1324 of the German Research Foundation DFG (this program is coordinated by the workshop organizer Stephan Dahlke). The total contribution was 5.300 Euros.

The workshop "Time-frequency methods for the applied sciences" was supported by the project "Audio-Miner" of Monika Dörfler. The contribution of ca. 4.000 Euros was used to cover per diems and travel expenses of several participants.

Several long-term visitors spent part of their sabbatical semester at ESI. Although they received some support through per diems, the major part of their stay was funded by their own means.

The social events for each workshop were partially supported by the Numerical Harmonic Analysis Group of the University of Vienna. The social event of the last workshop was hosted at and supported by the Acoustical Research Institute (of the Austrian Academy of Sciences).

Report on the program

Introduction

The goal of the special semester was to survey the state-of-the-art and to explore new directions of time-frequency analysis. Since the first special semester on time-frequency analysis at the Erwin Schrödinger Institute held in the spring of 2005 the field has expanded, deepened, and matured significantly. The many excellent talks during this semester bear witness to this remarkable development.

Contemporary time-frequency analysis covers many different directions in mathematics, with topics as diverse as operator theory and the signal processing of music signals. To cover a range

as large as possible, the program of the special semester was organized in six workshops of one week.

The *first* workshop was devoted to coorbit theory and its applications. This field has many connections to group and representation theory, but also to important decomposition methods in applied analysis.

The *second* workshop focused on a single problem, namely the problem of phase retrieval. This is a fundamental problem in physics and signal processing and has recently become a hot topic again.

The *third* workshop covered a large spectrum of time-frequency methods for pseudo-differential operators and partial differential equations.

The *fourth* workshop studied numerical and computational issues of time-frequency analysis. The focus was mainly on wavelet methods.

The *fifth* workshop explored the connections between abstract time-frequency analysis, Gabor frames, and operator theory.

Finally, the *sixth* workshop covered real world applications of time-frequency analysis to signal processing and to the description of music signals.

Although the overall coordination of the semester was in the hands of the local organizers Hans G. Feichtinger and Karlheinz Gröchenig, the organization of the workshops was carried out by a larger group of international and local scientists. The co-organizers of the workshops were S. Dahlke, Phillips University of Marburg; M. Fornasier, Technical University Munich; M. de-Hoop, Purdue University; Michael Ruzhansky, Imperial College London; B. Torresani, Université de Provence. The local co-organizers were highly successful former students of H.G. Feichtinger, namely Monika Dörfler, University of Vienna; Peter Balacz, Acoustics Research Institute, Vienna; and Franz Luef, currently University of California at Berkeley.

Whereas the main scientific activities took place during the workshop, the Institute was well populated in the weeks between the workshops. In fact, many long-term visitors commented that these were their most productive times at ESI.

During the special semester the program hosted roughly 110 scientists, an impressive number of 123 talks was given during the special semester.

The overall quality was excellent. In general the organizers scheduled only few talks per day and made sure that long "coffee breaks" provide a good opportunity for mathematical discussions. Most participants were asked to deliver a talk, though the time constraints made it impossible to have a talk by all participants.

The workshops were frequently attended by local mathematicians from the University of Vienna, in particular by the Numerical Harmonic Analysis Group. Local young scientist had the chance to learn from these talks (ca. 25 people worked at NuHAG during this period, and most of them attended many of these talks, but also master and PhD students) and see what the current research topics are in the field. On the other hand some of the local PostDocs got an opportunity to present their result to an international audience of experts.

The special semester was definitely a very successful event. Many participants are among the leaders of the field and have shaped time-frequency analysis to its current status. The collection of all talks represents an impressive panorama of contemporary time-frequency analysis. The semester has helped to facilitate new collaborations and to continue established collaborations.

Activities

The core activities of the ESI program consisted of **six workshops**, each of one week duration, with different workshop organizers. For the schedule see the appendix or the website

http://www.nuhag.eu/esi12. The following sections contain the reports of the workshop organizers on the activities and contributions of their workshops.

Workshop 1: Applied Coorbit Theory

Organizers: Hans Feichtinger (UVienna), Stephan Dahlke (Philipps-University, Marburg).

Coorbit theory is a well-established tool in applied harmonic analysis. Based on group representations, this theory provides a unified approach to many different transforms in analysis and signal processing, such as the wavelet- and the Gabor-transform. Furthermore, the coorbit approach provides canonical smoothness spaces, the coorbit spaces. The concrete analysis of such spaces depends on the chosen group representation (but not so much on the explicit choice of the atom, or coherent frame family), as one might expect from the situation of analytic functions which are invariant under the Möbius transform, or the theory of coherent states, using the Gauss function and the analyticity of the elements of the corresponding Fock space.

Coorbit theory also provides atomic decompositions for the coorbit spaces by means of stable (Banach) frame decompositions. In many cases coorbit spaces coincide with classical smoothness spaces such as Besov and modulation spaces. For these spaces, many different atomic and molecular decompositions exist. Therefore, an additional aim of this workshop was to clarify the relations of these different decomposition techniques as far as possible, and see how specific techniques developed in one area (e.g. motivated by facts in complex analysis) could possibly be transferred to the general setting and hence to other concrete cases.

To this workshop, leading experts from coorbit theory, function space theory and group representations were invited. The overall topics were discussed from different points of views, and a lot of interactions between experts from the different areas have been initiated during the workshop. Some the highlights of the workshop were the following:

a) In an overview talk, Morten Nielsen presented a very general strategy to design smoothness spaces and frames which, e.g., contains the Besov and modulation spaces as special cases. The construction starts with a splitting of the frequency space which is compatible with the class of functions one wants to analyze. Then, one creates an associated partition on unity and defines smoothness spaces by means of this partition. Finally, an associated discrete system (frame) is designed that can be used to characterize smoothness.

b) Philip Grohs discussed atomic decompositions in the context of directional systems such as curvelets or shearlets. By means of localization arguments, it turned out that all frame systems based on parabolic scalings possess exactly the same approximation properties.

c) In a series of three talks, G. Kerkyacharian, P. Petruchev and G. Kyriazis presented a universal approach to design frames and atomic decompositions for smoothness spaces on quite general manifolds. The approach is based on two properties, the doubling property and a Poincaré inequality. Therefore, the approach applies to compact Riemannian manifold, nilpotent Lie groups, to Riemannian manifolds with positive Ricci curvature and many others.

d) In recent years, it has turned out that there is a deep relation between directional systems such as shearlets and coorbit space theory that has not been fully exploited yet. The state of the art concerning constructions, traces, embeddings etc. was presented by G. Steidl. In the same session, G. Teschke explained the relationships of alpha-modulation spaces with coorbit theory via representations modulo quotients. Moreover, he presented applications of the resulting alpha-modulation frames in prenatal diagnostics.

e) The relations of coorbit space theory with group representations was the topic of the talks of E. De Vito and F. De Mari. They have been able to derive a complete classification of all square-integrable group representation stemming from the metaplectic representation in 2D.

f) Coorbit space theory usually relies on a certain integrability condition which is quite re-

strictive. J.G. Christensen presented first ideas to weaken this condition. The organizers are convinced that this approach will have a significant impact on further researches.

g) H. Führ presented a quite general approach to coorbit space theory. He stated universal conditions under which coorbit theory is applicable; his approach contains the affine group, the Weyl-Heisenberg group, and the shearlet group as special cases.

h) On Thursday afternoon, a round table discussion, chaired by Hans G. Feichtinger, was organized. The aim was to exchange ideas and to identify fruitful directions for further research. It was suggested to study representations of groups involving different models for dilations. The power of localization theory should also be studied. Furthermore, the construction of coorbit spaces on domains and manifolds is still open and presents challenging problems. Moreover, the relations between coorbit space constructions and operator equations should be further investigated.

Workshop 2: Phase Retrieval

Organizers: Karlheinz Gröchenig (U Vienna), Thomas Strohmer (U C Davis).

This workshop was devoted to a single problem, the so-called phase retrieval problem. This refers to the question whether and how a function can be reconstructed from *magnitude measurements* taken in some transform domain. In crystallography, typically a function should be reconstructed from the magnitude of the Fourier transform. This is a classical problem that has confounded mathematicians, physicists and engineers for a century. New imaging modalities make this problem more important than ever. This workshop saw some exciting new developments in phase retrieval, addressing theory as well as numerics and applications. Stefano Marchesini, a world expert in this area, opened the workshop with a brief overview of the problem and recent developments, such as ptychography.

One line of research that attracted considerable attention in recent years, is based on formulating phase retrieval as a trace minimization problem, and utilizing convex optimization combined with major advances in the area of compressive sensing and matrix completion. This approach, developed by Emmanuel Candes, Vlad Voroninski and Thomas Strohmer, is known as PhaseLift and was featured in several talks. For instance, Irene Waldspurger and her coauthor Stephane Mallat reported on exciting connections between PhaseLift and the famous MaxCut problem in combinatorial graph theory. Radu Balan analyzed the phase retrieval problem in presence of stochastic noise, using tools from convex optimization. He showed results in terms of Cramer-Rao lower bounds, along with some numerical simulations that illustrate convergence of his algorithm. Martin Ehler presented a powerful generalization of the central theorem of PhaseLift to the case where intensity measurements are taken with respect to higher-dimensional subspaces instead of simply inner products between vectors.

Another research direction is concerned with the minimal number of measurements needed to ensure uniqueness of the phase retrieval problem. This question, which already engaged Wolfgang Pauli, was the topic of several talks, and some great progress has been reported in independent developments by Philippe Jaming, Yang Wang, as well as Bernhard Bodmann. Among others, it seems clear now that the minimum number of measurements to recover a complex signal of dimension n from magnitude measurements is in the order of $4n$. Some of the reported results on this topic did arise from direct interactions at the workshop itself!

In a series of talks, Dustin Mixon, Matthew Fickus, and Alfonso Bandeira presented a compelling new approach to phase retrieval via polarization. Their framework, which exploits certain properties of expander graphs, opens up deep connections to other problems, such as the angular synchronization problem, which consists of estimating a set of unknown angles (or higher dimensional rotations) from noisy measurements.

Several exciting developments on the numerical front of phase retrieval were presented, such as in the talks by Albert Fannjiang and Gregory Beylkin. Fannjiang made great strives using alternating projections, a classical approach to phase retrieval, which for the last 30 years or so suffered from lack of convincing theory. Fannjiang was able to prove several interesting convergence results. Beyklin's talk demonstrated impressively how the classical tools from prolate spheroidal wave functions can solve some delicate numerical issues surrounding the phase retrieval problem. Overall, the workshop provided a wide range of interesting developments in this rather challenging and important problem at the intersection of pure and applied mathematics.

Workshop 3: Phase Space Methods for Pseudodifferential Operators

Organizers: Karlheinz Gröchenig (U Vienna), Maarten deHoop (Purdue U), Michael Ruzhansky (Imperial College, London).

This workshop was devoted to modern phase space methods for the investigation of pseudodifferential operators. It united leading experts from several sub-disciplines of analysis. The group of participants covered specialists from several different communities. As a consequence the range of topics covered was very broad and gave the participants an excellent view of the state-of-the-art.

(a) Pseudodifferential operators in mathematical physics: A good number of talks represented the "spirit" of ESI and was devoted to problems in mathematical physics.

A. Parmeggiani studied the spectrum of coupled harmonic oscillators in quantum mechanics, M. Mantoiu tried to develop an axiomatic theory of quantization and relate it to recent results in coorbit theory (which was the topic of the first workshop). E. Cordero's talk presented promising results on the phase-space representation of evolution equations, in particular Schrödinger evolutions. M. deHoop, motivated by geophysical problems, studied scattering problems by means of parabolic phase-space decompositions.

(b) S. Jaffard began to study the application of wavelet decompositions for the analysis of stochastic processes, in particular, he was able to characterize the local Besov smoothness of sample paths.

(c) The talks of Cordero, Pfander, and Toft pursued general principles of phase-space (- time-frequency) analysis for the investigation of pseudodifferential operators and their composition, they also studied some applications to problems in PDE and wireless communications.

(d) An whole day of the workshop was devoted to the analysis of pseudodifferential operators on Lie groups, in particular on nilpotent groups. This topic represents a completely new direction represented by M. Ruzhansky and his collaborators V. Turunnen, J. Wirth, and J. Delgado. The goal is to develop a global pseudodifferential operator calculus on Lie groups that does not require the localization by means of charts.

(e) The methods of "hard analysis" in the style of Fefferman and Stein were pursued by Benyi, Boulkhemair, Parmeggiani, Sugimoto, and Torres in their quest to understand multlinear Calderon-Zygmund operators or pseudodifferential operators with rough symbols.

Several visitors, mainly long terms visitors, spent time at the Institute outside the workshop. They gave lectures either at ESI or at the Numerical Harmonic Analysis Group. Notably, N. Lerner gave a lecture on the Wick calculus and composition formulas, and E. Malinnikova lectured on uncertainty principles in time-frequency analysis.

Workshop 4: Wavelet Methods in Scientific Computing

Organizers: Stephan Dahlke (Philipps-University, Marburg) Massimo Fornasier (TU Munich).

Wavelets are a well-established tool in scientific computing, in particular for the numerical treatment of operator equations. Compared to other methods, wavelets provide the following

advantages. The strong analytical properties of wavelets, in particular their ability to characterize function spaces such as Sobolev or Besov spaces, can be used to design adaptive numerical schemes that are guaranteed to converge for a huge class of problems including operators of negative order. Moreover, the vanishing moments of wavelets give rise to compression strategies for densely populated matrices. Quite recently, it has also turned out that variants of the classical wavelet algorithms (tensor wavelets, orthogonal multiwavelets) have some potential to treat high-dimensional problems. Therefore, the aim of this workshop was to discuss the state of the art and the further perspectives of wavelet methods in scientific computing.

During the workshop emerged four main directions of current research activity.

(a) *Adaptive wavelet methods for high-dimensional problems.* At the beginning of the meeting, Rob Stevenson presented an overview talk concerning the general setting of adaptive wavelet schemes for operator equations. In particular, he described his rather exciting joint results with Christoph Schwab on problems defined on tensor product spaces with applications on adaptive wavelet space-time discretizations of parabolic problems. Angela Kunoth also addressed tensor product problems and showed new applications of the machinery proposed by Schwab and Stevenson to optimal control problems. Closely related to these contributions was the talk of Ulrich Friedrich on a new construction of tensor product wavelets on more general domains beyond the unit cube such as polygonal and polyhedral domains. The talk of Helmut Harbrecht also fits into this category. He presented a tensor product wavelet version of optimized sparse grids. Optimal approximations are achieved by equilibrating the degrees of freedom.

(b) *Generalization of adaptive wavelet methods. Beyond linear elliptic problems and towards new wavelet-type discretizations.* Dominik Lellek presented new results on adaptive wavelet methods based on domain decompositions for nonlinear equations. Thorsten Raasch presented extensions of basis discretizations towards adaptive computations, by considering so-called quarkonial frames of wavelet type. Claudio Canuto and Silvia Bertoluzza were concerned with nonstandard adaptive and collocation methods for high-order equations. Sebastian Kestler presented new adaptive wavelet methods for equations on unbounded domains, where the discretization adapts itself also with respect to the domain. Stefan Kinzel's talk was concerned with adaptive wavelet methods for time-dependent problems such as parabolic PDEs. He presented a rigorous convergence and complexity analysis for spatially adaptive wavelet Rothe methods. The results also apply to SPDEs.

(c) *Tensor product approximations.* Tensor product approximations of high-dimensional functions are used in many applications such as high-dimensional and stochastic PDEs. Therefore, this technique have been an important topic of the workshops with the outstanding contributions of Wolfgang Hackbusch and Reinhold Schneider who presented the state of the art of the development of these very important tools.

(d) *Adaptive wavelet methods for stochastic PDEs.* Stig Larsson presented an overview of the state of the art on the treatment of stochastic PDEs by adaptive wavelet methods, with emphasis on the theoretical background of the analytic formulation of stochastic problems.

A number of participants of this workshop (which was an official event within the DFG priority program DFG 1324 'Extraction of Quantifiable Information from Complex Systems', coordinated by S. Dahlke) received funding through the DFG program.

Workshop 5: Operator Algebras and Time-frequency Methods

Organizer: Franz Luef (U Vienna, currently at UC Berkeley)

Methods and results from Banach algebras and operator algebras have turned out to be essential tools in recent breakthroughs in time-frequency analysis. The goals of the activities around Workshop 5 were (1) the creation of awareness of the relevance of operator algebras for problems

in time-frequency analysis and wavelets, and (2) to demonstrate to researchers in time-frequency analysis some of the modern developments in the field of operator algebras and of their links to time-frequency analysis. The field of Gabor analysis has many real-world applications, most notably audio mining, music and wireless communication. Gröchenig and Leinert demonstrated that one of the central problems of signal analysis is equivalent to the construction of inverse-closed Banach algebras, e.g. in the case of time-frequency analysis they showed that these Banach algebras are subalgebras of non-commutative tori. These results have led to the localization theory for frames and non-commutative approximation theory. A central feature of Gabor analysis is the so-called duality theory. In his PhD thesis Luef showed that the duality theory of Gabor analysis is a consequence of the construction of Morita-Rieffel equivalent non-commutative tori due to Connes and Rieffel. Connes' interest is rooted in his theory of non-commutative geometry, where these results amount to the construction of vector bundles over non-commutative tori. There has been another point of contact between time-frequency analysis and operator algebras: the work of Casazza on the Feichtinger conjecture for Gabor frames and his generalization to general frames in Hilbert spaces. Most notably, Casazza and his collaborators have established the equivalence of Feichtinger's conjecture with the Kadison-Singer conjecture, one of the long-standing problems of operator algebras. Over the last six decades many excellent mathematicians have attacked this problem, such as Anderson, Bourgain and Tzafiri, but Casazza's contribution has triggered renewed interest in the Kadison-Singer conjecture, and it has attracted researchers in operator algebras to exploit the consequences of this deep result. Most notably, Paulsen has proved many interesting implications of the equivalence of Feichtinger's conjecture and the Kadison-Singer conjecture.

Several participants visited the ESI for an extended period (2-3 weeks), which allowed for various fruitful discussions between the participants. Overall there were 15 presentations on a variety of topics. In addition to leading experts a few graduate students and postdocs, Guillemard, Klotz and Purkis, were invited to present their work. Unfortunately, some of the invited speakers had to cancel their visit, among them Han, Kadison, Larson, Marcolli and Rieffel.

A strong focus was put on the relevance of non-commutative geometry around non-commutative tori, in particular the ones around quantum physics such as the Quantum Integer Hall effect, quantum field theory and KMS states. More specifically, Carey provided a survey on spectral triples, Gibilisco on uncertainty principles and the use of operator monotone functions in this topic, Grosse presented new results on quantum field theory that led to a construction of deformations of non-commutative tori that interpolate between spheres and tori, Landi discussed recent progress in the understanding of the Quantum Integer Hall effect that are based on non-commutative geometry over rational non-commutative tori and Raeburn reviewed some of his research on KMS states on operator-algebraic dynamical systems.

Research on certain aspects of time-frequency analysis and quantum physics were discussed in Feichtinger's talk on Gabor analysis via MATLAB, the presentation of Digernes on the approximation of continuous Weyl systems via finite-dimensional Weyl systems. Links between time-frequency analysis, wavelets and operator algebras were discussed by Luef who reviewed the main results of his work about Gabor analysis and non-commutative geometry, by Guillemard who announced a new approach to the separation of signals in music using groupoids and AF-algebras, Packer talked about a new class of non-commutative manifolds, the so-called non-commutative solenoids and their relation to the construction of wavelets and Purkis discussed a generalization of projective multiresolution analysis, which was originally introduced by Packer and Rieffel.

There were also a series of talks on mathematical aspects of the aforementioned topics. Frank presented a survey of his groundbreaking work with Larson on frames for Hilbert C^*-modules, which is crucial for the applications of operator algebras to non-commutative geometry and time-frequency analysis. As mentioned above, the construction of inverse-closed algebra is an important problem. Leinert discussed some new results about inverse-closed subalgebras of non-

commutative tori, and Klotz presented aspects of non-commutative approximation that deal with norm-controlled inversion in smooth subalgebras of operator algebras. Finally, Paulsen surveyed the state of the art of the Kadison-Singer and Feichtinger conjecture.
Potential collaborations have emerged from the discussions between the participants. We just mention a few projects that the activities at ESI have initiated: Luef has started a collaboration with Landi on Gabor frames and the implication of Landi's work on non-commutative geometry over rational non-commutative tori, which also led to an invitation to SISSA in Trieste for a month. Luef and Leinert are currently working out the relevance of continuous fields of C^*-algebras for the problem, when one is varying Gabor frames. Furthermore, Luef and Paulsen have made some progress on the Feichtinger conjecture for Gabor frames and finally Luef and Raeburn have a project on Hilbert C^*-modules and their relevance in understanding the Zak transform and its vector-valued variants.

Workshop 6: Time-frequency Methods for the Applied Sciences

Organizers: Monika Dörfler (U Vienna), Peter Balazs (Acoustics Research Institute, Austrian Academy of Sciences) and Bruno Torrésani (Aix-Marseille Université)

The last workshop of the program was dedicated to the interaction between recent theoretical developments in time-frequency analysis and applied sciences. Since the audience and the participating researchers in this workshop came from a diverse range of specializations, we decided to organize a mix of tutorial talks and shorter, specialized contributions.

Time-frequency methods are present in various highly active applied research fields, the connections to the following fields were presented in various talks during the workshop: multi-sensor data fusion, manifold learning and recovery, speech recognition, audio processing, image processing, acoustics, psycho-acoustics, analysis of time-series in medicine, economics, astronomy, music information retrieval (MIR).

The theoretical perspectives important to the applied sciences mentioned above comprise topics such as the following:

1. **Adaptive representations, reassignment.** Adaptive representations have received increasing attention over the past years. In many applications standard (regular) representations are replaced by adaptive approaches. Two tutorials (P. Flandrin: Uncertainty and spectrogram geometry; H.-T. Wu: Tutorial and Introduction to Synchrosqueezing transform) were given as an introduction to both classical as well as recently developed methods in adaptive time-frequency analysis.

2. **Sparsity.** Sparsity has recently been one of the most successful ideas in signal modeling and processing, partly due to its close connection to compressed sensing. In our workshop, the newly introduced concept of co-sparsity was treated in a tutorial (Sangnam, Nam: Co-Sparsity) and complemented by several specialized talks on sparse and structured sparse representations.

3. **Statistical modeling in time-frequency.** Statistical modelling is a perspective that is often under-represented in mathematical time-frequency analysis. In this workshop, the important method of non-negative matrix factorization was discussed in a tutorial by C. Fevotte. This introduction was complemented by contributions on estimation problems, classification, Wiener filtering and compressive sampling.

4. **Audio and Music Applications.** The last two days (Friday, Saturday) were dedicated to time-frequency analysis for music processing, in particular in MIR. These days were co-funded by the WWTF-project Audio-Miner and the results achieved in this project (it ends in 2013) were also presented. The presentation of AudioMiner was rounded off by

an artistic performance (Thomas Grill) using the time-frequency methods developed in AudioMiner. An introductory tutorial on the classical music-visualization software developed at IRCAM (Paris), (Depalle, Philippe: Audiosculpt, and of the structuring role of the phase in time-frequency representation) was followed by several specialized talks on applications in classification, sound quality judgement, real-time implementation of adaptive transforms and texture recognition.

Outcomes and achievements

(a) The special semester helped to strenghten and enlarge the mathematical community of time-frequency analysts. Time-frequency analysis is a "young" field with many junior scientists. Whereas the large majority of the participants are well established researchers, about 15% of the participants were Postdocs. The program helped junior researchers to present their work and make a name.

(b) The special semester helped several groups to continue and intensify their scientific collaborations. A number of new collaborations was established. We are aware of the new collaboration between Balazs, Dahlke, and Harbrecht; of the intensive collaboration between Ruzhansky, Turunnen, Tychonov, Delgado, and Wirth; of the ongoing work between the time-frequency groups in Vienna and Trondheim (Malinnikova, Lyubarskii). During the workshop on phase retrieval Bodmann and Jaming connected and started a new project.

At the workshop "Wavelets in Scientific Computing" a cooperation between the Marburg group (Dahlke/Lellek) and Rob Stevenson (Amsterdam) concerning constructions and applications of divergence-free wavelet bases has been initiated. Moreover, there are plans for a cooperation of the Marburg group (Dahlke/Kinzel) with Stig Larsen concerning the adaptive numerical treatment of SPDEs.

At the workshop "Applied Coorbit Theory" a cooperation between Dahlke (Marburg), Steidl (Kaiserslautern) and Teschke (Neubrandenburg) concerning the relations of coorbit theory with representations of the metaplectic group has been initiated. A first paper is in preparation. Another new cooperation was started by M. de Hoop, K. Gröchenig and J.L. Romero (NuHAG), and a joint paper in preparation.

(c) Although the Erwin Schrödinger Institute is an important spot on map of "pure" mathematics and mathematical physics, it is less known in other communities. Many participants of the workshops on scientific computing and on applied time-frequency analysis were not aware of the importance and stature of ESI. The inclusion of non-standard topics in the program has helped to increase the visibility of ESI in those "nearby" communities.

Invited scientists: Luis Daniel Abreu, Joakim Anden, Radu Balan, Peter Balazs, Afonso Bandeira, Sebastiano Barbieri, Dominik Bayer, Arpad Benyi, Silvia Bertoluzza, Gregory Beylkin, Bernhard Bodmann, Abdesslam Boulkhemair, Jameson Cahill, Claudio Canuto, Alan Carey, Gilles Chardon, Donal Connolly, Wojciech Czaja, Jens G. Christensen, Elena Cordero, Stephan Dahlke, Marie Dankova, Laurent Daudet, Maurice de Gosson, Maarten de Hoop, Filippo De Mari, Philippe Depalle, Ernesto De Vito, Trond Digernes, Simon Dixon, Monika Dörfler, Martin Ehler, Gianpaolo Evangelista Albert C. Fannjiang, Hans-Georg Feichtinger, Gero Fendler, Cedric Fevotte, Matt Fickus, Patrick Flandrin, Arthur Flexer, Massimo Fornasier, Ulrich Friedrich, Hartmut Führ, Michael Frank, Arash Ghaani Farashahi, Paolo Gibilisco, Martina Glogawatz, Thomas Grill, Karlheinz Gröchenig, Philipp Grohs, Harald Grosse, Anna Grybos, Mijail Guillemard, Wolfgang Hackbusch, Helmut Harbrecht, Jonathan Harrington, Christopher Heil, Sigrid Bettina Heineken, Jeff Hogan, Volker Hohmann, Nicki Holighaus, Andre Holzapfel, Radek Hrbacek, Stephane Jaffard, Philippe Jaming, Christian Kasess, Gerard Kerkyacharian, Sebastian Kestler, Nicholas Kevlahan, Stephane Kinzel, Andreas Klotz, Matthieu Kowalski, Wolfgang Kreuzer, Angela Kunoth, George Kyriazis, Giovanni Landi, Stig Larsson, Michael Leinert, Dominik Lellek, Nicolas Lerner, Hanfeng Li,

Franz Luef, Vaclav Mach, Wolodymyr Madych, Piotr Majdak, Eugenia Malinnikova, Marius Mantoiu, Stephano Marchesini, Ewa Matusiak, Hrushikesh Mhaskar, Dustin G. Mixon, Mozhgan Mohammadpour, Saso Musevic, Sangnam Nam, Thibaud Necciari, Markus Neuhauser, Morten Nielsen, Krzysztof Nowak, James Oldfield, Anaik Olivero, Harold Omer, Darian M. Onchis, Roman Ozdobinski, Judith Packer Jesudason, Margit Pap, Alberto Parmeggiani, Vern Paulsen, Pencho Petrushev, Götz Pfander, Mark Plumbley, Benjamin Purkis, Thorsten Raasch, Iain Raeburn, Pavel Rajmic, Luigi Rodino, Jose Luis Romero, David Rottensteiner, Michael Ruzhansky, Yoshihiro Sawano, Benjamin Scharf, Jiri Schimmel, Catherine Schnackers, Reinhold Schneider, Kai Siedenburg, Peter Søndergaard, Filip Sroubek, Gabriele Steidl, Thomas Strohmer, Rob Stevenson, Diana Todorova Stoeva, Mitsuru Sugimoto, Anita Tabacco, Gerd Teschke, Serge Tikhonov, Joachim Toft, Rodolfo Torres, Bruno Torresani, Gantumur Tsogtgerel, Ville Turunen, Tino Ullrich, Bjorn Ursin, Gino A. Velasco, Emmanuel Vincent, Stefano Vigogna, Jan Vybiral, Irene Waldspurger, Baoxiang Wang, Yang Wang, Timothy Wertz, Christoph Wiesmeyr, Jens Wirth, Ingo Witt, Hau-Tieng Wu, Wen Yuan, Harald Ziegelwanger.

Workshops Organized Outside the Main Programmes

Operator Related Function Theory

Organizers: Alexandru Aleman (U Lund), Kristian Seip (Norwegian U of Science and Technology, Trondheim)

Dates: March 26 – 31, 2012

Budget: ESI €14.000,–

Report on the workshop

Introduction

Reproducing kernel Hilbert spaces have been studied for decades, but remain an expanding and vivid area of research. Recent developments reveal strong links between the algebraic structure of the kernel and the properties of the space in question. This general idea is certainly not completely understood, but it has led to important progress related to interpolation, invariant subspaces, and also in multivariate operator theory, which combines complex analysis in several variables and the study of commuting tuples of operators.

A more special related topic of recent interest are the Hardy spaces of Dirichlet series. It began with a paper of Hedenmalm, Lindqvist, and Seip in 1997. An interesting theory is now evolving, modeled on the classical theory of Hardy spaces but also interacting profoundly with several complex variables and analytic number theory. One of the most difficult research objectives in the development of this theory is to achieve a deeper understanding of the mapping properties of Riesz projections and similar operators on the infinite-dimensional torus.

The spectral theory of symmetric operators (for example, Schrödinger operators) developed by Krein has found analogues in de Branges's seminal work on spaces of entire functions. It has been recognized that de Branges's structure theorems for these spaces have valuable applications in this field, and in recent years, Makarov and Poltoratski have introduced more general model spaces to translate important spectral problems into questions about kernels of Toeplitz operators, or other specific objects from operator related function theory. Their work opened a wide circle of interesting new problems. In addition, scattering theory combines methods of mathematical physics, operator related function theory, partial differential equations, and harmonic analysis. This field originated in the study of basic physical phenomena and finds direct applications in modern technology, with uninvasive control and nanotechnology taken as examples. Classical tools from operator related function theory, such as Hilbert transforms, spaces of analytic functions, and techniques for Riemann–Hilbert problems are widely used, and in many cases the inverse scattering problem serves to motivate new questions.

The aim of the workshop was to present, discuss, and pursue recent advances in these directions. The idea was to bring together researchers, chosen carefully and selectively, that could promote productive interaction and communication within and across these lines of research.

Activities

There were 40 minute talks by the following 28 speakers:
Lacey, Vasiliev, Kozma, Girela, Belov, Hedenmalm, Olsen, Saksman, Reguera, Malinnikova, Montes-Rodriguez, Borichev, Ross, Badea, Baranov, Grivaux, Poltoratski, Conway, Sundberg, Queffélec, Richter, Bayart, Vukotic, Arcozzi, Pott, Englis, Putinar, and Nikolski.

Among the participants in the workshop, there was a fine mixture of leading senior researchers and promising young workers in the field, representing some of the most exciting recent achievements. There was considerable scientific breadth in the programme, ranging from hard core harmonic analysis, Fourier series, spectral problems, operator theory and functions spaces to interpolation problems, and time-frequency analysis. We want to emphasize the high quality of the workshop talks. We had a clear impression that most of the speakers were able to communicate their results and problems across the fairly broad spectrum of subareas represented by the workshop participants.

The very lively discussions at the blackboards in the halls of ESI were a genuine testimony of the success of the workshop.

Outcomes and achievements

In general, it is not easy to estimate the concrete outcome of the many faceted scientific interaction that took place during the workshop. However, we are indeed able to point at a specific result, namely the paper

Anton Baranov, Yurii Belov, Alexander Borichev, *A restricted shift completeness problem*, arXiv:1204.4648, 2012.

This paper was written as a direct response to question posed by Marcus Carlsson and Carl Sundberg in Sundberg's talk given during the workshop.

In addition, one of us, after initial discussions with Eero Saksman during the workshop, solved a basic problem in the theory of Hardy spaces of Dirichlet series in the following paper:

Kristian Seip, *Zeros of functions in Hilbert spaces of Dirichlet series*, Math. Z., to appear; arXiv:1206.2815, 2012.

Most likely, there are many more examples of similar nature of interaction during the workshop leading to new results, collaborations, and directions of research.

Appendix. List of talks

N. Arcozzi	About interpolating sequences for the Dirichlet space
C. Badea	K-spectral sets
A. Baranov	Completeness of rank one perturbations of selfadjoint operators
F. Bayart	Composition operators on the polydisk induced by affine maps
Yu. Belov	There is no linear summation method for arbitrary formal Fourier series from exponentials
A. Borichev	Small polyharmonic functions
J. Conway	Powers and direct sums of operators
M. Englis	Analytic continuation of weighted Bergman kernels
D. Girela	Mean Lipschitz spaces and generalized Hilbert operators
S. Grivaux	Non-recurrence sets for weakly mixing linear dynamical systems
H. Hedenmalm	Heisenberg's uncertainty principle in the sense of Beurling
G. Kozma	Menshov and Privalov
M. Lacey	On the two weight inequality for the Hilbert transform
E. Malinnikova	Boundary behavior of harmonic functions in growth spaces
A. Montes-Rodriguez	Fourier uniqueness sets and the Klein–Gordon equation
N. Nikolski	Spectrum and invisible spectrum of Fourier–Muckenhoupt multipliers
J-F. Olsen	Decay estimates for the Balian–Low theorem
A. Poltoratski	Bernsteins problem on weighted polynomial approximation
S. Pott	On Toeplitz products on Bergman space
M. Putinar	Reducing subspaces for analytic multipliers of the Bergman space
H. Queffélec	Lens maps and composition operators

M. C. Reguera	Sharp Békollé estimates for the Bergman projection
S. Richter	Cyclic vectors in the Drury-Arveson space
W. Ross	Reverse Carleson embeddings for model spaces
E. Saksman	Interpolation of L^p-spaces with complex exponents p, and rotation of quasiconformal maps
C. Sundberg	Approximation by shifts on finite intervals
A. Vailiev	Loewner evolution and integrable systems
D. Vukotic	An overview of certain extremal problems in classical spaces of analytic functions

Invited scientists:
Alexandru Aleman, Nicola Arcozzi, Catalin Badea, Anton Baranov, Frederic Bayart, Yury Belov, Alexander Borichev, Marcus Carlsson, Olivia Constantin, John Conway, Miroslav Englis, Hans-Georg Feichtinger, Gero Fendler, Sophie Grivaux, Daniel Girela Alvarez, Antti Haimi, Håakan Hedenmalm, Joshua Isralowitz, Gady Kozma, Michael Lacey, Eugenia Malinnikova, Alfonso Montes Rodriguez, Artur Nicolau, Nikolai Nikolski, Jan-Fredrik Olsen, Alexei Poltoratski, Sandra Pott, Mihai Putinar, Hervé Queffélec, Martine Queffélec, Maria Reguera, Stefan Richter, William Ross, Eero Saksman, Kristian Seip, Joachim Stöckler, Carl Sundberg, Alexander Vasiliev, Dragan Vukotic.

Higher Spin Gravity

Organizers: Matthias Gaberdiel (ETH Zurich), Daniel Grumiller (Vienna U of Technology), Per Kraus (UCLA), Radoslav Rashkov (Sofia U & Vienna U of Technology),

Dates: April 10 – April 20, 2012

Budget: ESI €18.960,–

Preprints contributed: [2363], [2368], [2372], [2375], [2378], [2380], [2382]
Preprints on the arXiv not necessarily contained in the ESI database: 1204.1793, 1204.2341, 1204.3288, 1205.2472, 1205.3339, 1205.4117, 1206.1048, 1206.2052, 1207.1079, 1207.2844, 1207.3439, 1207.4751, 1208.1307, 1208.1851, 1208.4371, 1209.2860, 1209.5396, 1211.3113

Report on the workshop

Introduction

Higher spin gravity was pioneered by M. Vasiliev more than two decades ago. It circumvents various no-go theorems (Coleman–Mandula, Haag–Lopuszanski–Sohnius, Weinberg–Witten,...) about the non-existence of interacting higher spin theories by introducing a cosmological constant. In its simplest incarnation it is an extension of Einstein gravity that includes massless fields of arbitrary integer spins. For this reason it is believed that higher spin theories could be an unbroken phase of string theory, which in turn has massive spin excitations of arbitrarily high spin.

Moreover, the fact that higher spin gravity typically arises in (Anti-)deSitter space makes it potentially relevant for the AdS/CFT correspondence. Some interesting conjectures by Klebanov–Polyakov and Sezgin–Sundell made this relation more concrete.

In the past few years several striking developments — among others by Giombi–Yin, Henneaux–Rey, Campoleoni–Fredenhagen–Pfenninger–Theisen, Gaberdiel–Gopakumar — led to a burst of activities in higher spin gravity in various dimensions. Our workshop was devoted mostly to these recent developments, but included also a handful of overview talks.

Specific information on the workshop

The aim of the workshop at the ESI was twofold. It brought together leading experts and pioneers of higher spin theories, and it provided a series of introductory and advanced lectures for the benefit of local students and faculty members. The workshop was of interest for experts in the fields of higher spin field theories, gravity, conformal field theory, AdS/CFT, string theory and integrable systems;

We had about 2 + 2 talks a day, with sufficient time for discussions and collaborations in between.

In total there were 31 talks at ESI, one colloquium at Vienna University of Technology, and one seminar talk at University of Vienna.

The full workshop programme, as well as links to the slides of most talks, are available at the conference webpage `http://quark.itp.tuwien.ac.at/~grumil/ESI2012`.

Outcomes and achievements

The scientific discussions led to numerous new collaborations and projects in higher spin gravity in various dimensions, many of which have already progressed to scientific publications. At the time of writing this workshop summary, there are 18 pre-prints on the arXiv whose work was initiated or performed at our ESI workshop (see the list above). The intense discussions between different groups led also to various invitations at future activities (workshops, conferences, scientific visits) and new opportunities for local PhD students and postdocs (particularly Hamid Afshar, Mike Gary and Max Riegler).

As a spin-off of the workshop, a research project on higher spin gravity between Seoul (S.-J. Rey) and Vienna (D. Grumiller and R. Rashkov) was recently granted (about half a million Euro).

Invited Scientists:
Kostya Alkalaev, Martin Ammon, Glenn Barnich, Xavier Bekaert, Eric Bergshoeff, Nicolas Boulanger, Josef Buchbinder, Andrea Campoleoni, Constantin Candu, Alejandra Castro, Slava Didenko, Stefan Fredenhagen, Matthias Gaberdiel, Michael Gary, Simone Giombi, Rajesh Gopakumar, Maxim Grigoriev (Vasiliev), Daniel Grumiller, Marc Henneaux, Olaf Hohm, Carlo Iazeolla, Antal Jevicki, Kewang Jin, Euihun Joung, Maximilian Kelm, Per Kraus, Cristian Martinez, Alfredo Perez, Eric Perlmutter, Stefan Pfenninger, Dimitri Polyakov, Massimo Porrati, Joris Raeymaekers, Rakibur Rahman, Radoslav Rashkov, Soo-Jong Rey, Jan Rosseel, Augusto Sagnotti, Oliver Schlotterer, Per Sundell, David Tempo, Ricardo Troncoso, Mauricio Valenzuela, Misha Vasiliev, Carl Vollenweider, Andrew Waldron, Thomas Zojer.

Computational Inverse Problems

Organizers: Peter Maass (U Bremen), Otmar Scherzer (U Vienna)

Dates: April 23 – 27, 2012

Budget: ESI € 18.560,–

Report on the workshop

Inverse problems appear in a wide range of applications, such as for instance

- *Computerized Tomography*, which is tied to the fundamental work of the Viennese mathematicians Johann Radon and Paul Funk. Recent developments in Medicine make use of sophisticated mathematical developments and stable numerical algorithms, which support novel experimental setups for safer and less harmful imaging,

- *Adaptive Optics* in Astronomy, which aims for computational cleaning of atmospherical blur in astronomical data,
- Calibration in *Financial Mathematics*,
- *Computer vision*, shape recovery, pattern recognition

Addressing a particular inverse problem requires dealing with three topics:

1. *Solvability*: Existence of a solution of the Inverse Problem;
2. *Identifiability*: That is, uniqueness of the solution;
3. *Stable solution*: Inverse problems are inherently unstable (ill-posed) and require appropriate computational methods for stable and efficient solution processes.

The workshop focused on the third topic, stable solution of inverse problems. Recently, driven by applications, the field has progressed rapidly: Novel trends have been *sparsity promoting methods, sampling methods, shape optimization* and *level set techniques*. Moreover, vice versa, stimulated by Inverse Problems applications novel mathematical developments in *Convex Analysis, Functional Analysis* and *Banach space* theory appeared. This workshop aimed at bringing together researchers working in abstract and computational Inverse Problems. Both theoretical foundations, computational aspects, and mathematical modeling of Inverse Problems were considered in this workshop.

Workshop programme

Mario Bertero	Efficient optimization methods for imaging problems with Poisson data
Ronny Ramlau	Inverse Problems in Adaptive Optics
Barbara Kaltenbacher	Adaptive discretization of parameter identification problems in PDE's for variational and iterative regularization
Ming Jiang	2D Phase Unwrapping Problem
Habib Ammari	Resolution and cloaking enhancements
Pierre Marechal	A digression about ill-posed problems, intertwining relationships and spectral functions
Simon Arridge	Quantitative PhotoAcoustic Tomography
Alfred Louis	Feature Reconstruction in Inverse Problems
Elena Beretta	On the stability issue for some inverse boundary value problems
Samuli Siltanen	Electrical impedance imaging using nonlinear Fourier transform
Gerd Teschke	On sampling and sparse recovery
M. Zuhair Nashed	Conductivity Imaging from Interior Data and Related Nonsmooth Optimization Problems
Sung Ha Kang	Unsupervised multiphase applications and infinite parameter model
Peter Elbau	Modelling Photoacoustic Sectional Imaging
Thorsten Hohage	Nonlinear inverse problem with Poisson data
Martin Hanke	One shot inverse scattering methods
Armin Lechleiter	Inverse Medium Scattering and Sparsity Reconstruction
Bernd Hofmann	Smoothness concepts in regularization and the autoconvolution problem revisited
Mourad Sini	Reconstruction of interfaces using elastic waves
Anne Vanhems, Markus Grasmair	Non-parametric Instrumental Regression with Non-convex Constraints an Illustration of Consumer Demand Theory
Kristian Bredies	Inverse problems with measure-based regularization functionals
Andreas Kirsch	An Inverse Acoustic-Elastic Scattering Problem

Young Researcher's Talks:

Robin Strehlow	Norm sensitivity of sparsity regularization with respect to p
Bernadette Hahn	Reconstruction of dynamic objects
Valeriya Naumova	Numerical differentiation by means of Legendre polynomials
Sivananthan Sampath	Multi-parameter regularization in Learning Theory
Roland Griesmaier	Source reconstruction using windowed Fourier transforms and the filtered backprojection
Patrick Dülk	Parameter identification problems for differential equations: analytic properties for sparsity reconstructions
Benjamin Tremoulhéac	Decomposition into low-rank and sparse components in dynamic MR images
Karl Kunisch	Parameter learning as bilevel optimization problem (or: how to choose the regularization parameters)
Arnd Rösch	Regularization in Sobolev spaces with fractional order
Maitine Bergounioux	Tomographic reconstruction with few views
Zakaria Belhachmi	Control of the regularization for some ill-posed problems in computer vision
Laurent Seppecher	An acousto-optic imaging model for the reconstruction of the optical absorption parameter
Jürgen Frikel	Sparse regularization in limited angle tomography
Thanh Nguyen	Inverse obstacle scattering problems using multifrequency measurements
Manas Kar	Reconstruction of interfaces using CGO solutions for the Maxwell equations
Alessandro Benfenati	Image restoration for Poisson data with iterative Bregman regularization procedure

Invited scientists: Habib Ammari, Simon Arridge, Zakaria Belhachmi, Alessandro Benfenati, Elena Beretta, Maitine Bergounioux, Mario Bertero, Kristian Bredies, Durga Prasad Challa, Patrick Dïlk, Peter Elbau, Hans Georg Feichtinger, Jürgen Frikel, Daniel Gerth, Markus Grasmair, Roland Griesmaier, Bernadette Hahn, Martin Hanke-Bourgeois, Bernd Hofmann, Thorsten Hohage, Dmitri Ivanizki, Ming Jiang, Konstantinos Kalimeris, Barbara Kaltenbacher, Sung Ha Kang, Manas Kar, Andreas Kirsch, Karl Kunisch, Armin Lechleiter, Alfred Louis, Peter Maass, Pierre Marechal, M. Zuhair Nashed, Valeriya Naumova, Trung Thanh Nguyen, Sergei Pereverzyev, Ronny Ramlau, Arnd Rösch, Sivananthan Sampath, Laurent Seppecher, Samuli Siltanen, Mourad Sini, Otmar Scherzer Robin Strehlow, Gerd Teschke, Benjamin Tremoulheac, Anne Vanhems.

Periodic Orbits in Dynamical Systems

Organizers: Michael Baake (Bielefeld U), Klaus Schmidt (U Vienna), Tom Ward (U East Anglia)

Dates: May 21 – 25, 2012

Budget: ESI €8.640,–
plus additional funding from FWF €3.220,–

Report on the workshop

The plan for this meeting grew out of discussions between the organisers about a year ago, when one of us (M.B.) spent three months as a Senior Research Fellow at the ESI. We realised that, in recent years, the study of periodic orbits had made unexpected progress in, and contributions to, different aspects of dynamical systems theory, and that a timely meeting on this topic could unravel interesting connections between these developments. Let us briefly mention some of them.

1. Dynamical systems with free translation action on tiling and related spaces are important examples for the understanding of the structure of aperiodically ordered systems used to model quasicrystals. These were discovered by Shechtman in 1982, for which he was awarded the 2011 Nobel Prize in Chemistry. Important classes of them admit an additional $\mathbb{Z}$-action by inflation, whose periodic orbits and zeta functions are extremely helpful in understanding spectral and topological properties of these systems.

2. For automorphisms of finite-dimensional tori or solenoids, it is well known that the logarithmic growth rate of the number of points of period n coincides with the entropy of the automorphism. If the automorphism is nonexpansive, this fact depends on a nontrivial Diophantine estimate due to Gelfond. For $\mathbb{Z}^d$-actions by automorphisms of compact Abelian groups, the analogous statement is conjectured also to be true, but has so far only been proved under additional conditions concerning the 'degree' of nonexpansiveness of the action. Another very active line of investigation with strong connections to Diophantine number theory concerns the equidistribution of periodic orbits of algebraic actions and of flows on homogeneous spaces as the size of the periods of these orbits increases.

3. Concrete non-linear dynamical systems, for instance on the torus, are studied in detail, aiming at a better understanding of the distribution of periodic orbits on rational lattices. There is some universal behaviour that essentially only depends on the symmetry of the mappings, and on their reversibility. Some of these features, as well as the existence of invariants, can effectively be tested by restricting the dynamics to finite fields or local rings, which is one concrete example of recent activities in algebraic and arithmetic dynamics.

4. The spectral theory of Schrödinger operators, in particular in one dimension and with aperiodic potentials of low complexity, has always relied deeply on special dynamical systems known as trace maps. Viewing them as dynamical systems on $\mathbb{C}^3$ and studying the hyperbolic behaviour near their periodic orbits has now led to a better understanding not only of the spectral but also of the transport properties of such systems. Likewise, the detailed analysis of potentials with a Toeplitz structure has led to a better understanding of the range of possible spectra, the latter including singular continuous spectra in the form of Cantor sets of positive measure.

Although the meeting had a wider scope than usual, the interaction between the speakers and the various groups worked well, and several unexpected connections emerged. The friendly atmosphere of the ESI, with its good infrastructure and friendly staff, contributed very positively to the outcome.

List of speakers:

Alexander Felshtyn	Dynamical zeta functions, topological entropy and Reidemeister torsion
Franz Gähler	The dynamical zeta function: A powerful tool to understand the topology of a tiling space
Uwe Grimm	Squiral Diffraction
Anton Gorodetski	Periodic points of the Fibonacci Trace Map
Manfred Einsiedler	Effective equidistribution of closed orbits on homogeneous spaces
Douglas Lind	Periodic points and entropy for algebraic actions
C. Robinson Edward Raja	Strong relative property and spectral gap for actions on solenoids
Peter Stollmann	Spectral properties of quasicrystal Laplacians

John Roberts	Periodic orbits for the Casati–Prosen map and the gamma distribution
Natascha Neumärker	The structure of preperiodic orbits of toral endomorphisms on the rational lattices
Franco Vivaldi	Near-integrable behaviour in a system with discrete phase space
Robert Moody	Model sets and dynamical systems
E. Arthur Robinson	The core of the Kari–Culik shift
David Damanik	The subshift conjecture
John Hunton	The shape of an attractor
Shigeki Akiyama	On shift radix systems
Jörg Thuswaldner	S-adic Rauzy fractals
Richard Sharp	Pair correlations and length spectra

Invited Scientists: Shigeki Akiyama, Michael Baake, Christopher Cedzich, David Damanik, Manfred Einsiedler, Alexander Felshtyn, Franz Gähler, Swiatoslaw Gal, Martin Göll, Anton Gorodetski, Uwe Grimm, John Hunton, Douglas Lind, Robert Moody, Natascha Neumärker, Johan Nilsson, Mark Pollicott, C. R. E. Raja, Christoph Richard, John Roberts, Arthur Robinson, Klaus Schmidt, Richard Sharp, Peter Stollmann, Jörg Thuswaldner, Evgeny Verbitzkiy, Franco Vivaldi, Tom Ward.

EMS-IAMP Summer School on Quantum Chaos

jointly with the European Mathematical Society (EMS) and the International Association of Mathematical Physics (IAMP)

Organizers: Nalini Anantharaman (Orsay U), Stéphane Nonnenmacher (U Paris-Saclay), Zeév Rudnick (Tel Aviv U) and Steve Zelditch (Northwestern U).

Dates: July 30 – August 3, 2012

Budget: ESI €13.454,–
co-funded by
the National Science Foundation US (NSF) US$ 12.707,–,
EMS €4.000,–, and
IAMP €2.960,–

Report on the summer school

Introduction

This summer school presented the research field of "quantum chaos" to an audience of graduate students, postdocs and young researchers. The aim of this field is to understand the dynamics of quantum (or wave) systems admitting a chaotic classical counterpart. One is especially interested in a precise description of the eigenvalues and eigenmodes of the quantum Hamiltonian of such a system. A paradigmatic example is the wave (or Schrödinger) equation on a compact Riemannian manifold of negative curvature, for which the quantum Hamiltonian is the Laplace Beltrami operator.

The school consisted of several basic courses (elementary dynamical systems theory, semiclassical analysis, random matrices and random waves) which introduced the subject and the basic methods and concepts to the students and other participants. They were followed by more advanced talks presenting some recent progresses.

The school was supported by the European Mathematical Society, the International Association of Mathematical Physics and the Erwin Schrödinger Institute, where it was held. It also benefited from some funding from the U.S. National Science Foundation in favour of the US and Canadian participants.

Specific information on the summer school

This summer school, initiated jointly by the EMS and the IAMP, is planned to be the first one of a series of schools devoted to various topics in mathematical physics.

Apart from the lectures, the school also included a poster session on Tuesday evening, where several students, postdocs or other participants presented their work. This poster session, which was organized in order to help some participants to get travel funding, turned out to be very successful and lively. It also showed that the participants had rather diverse research interests and backgrounds.

In spite of the dense programme the lectures were well-attended by the students, up to the very last one. We had a very positive feed-back from many of them.

Appendix. List of talks

Introductory Lectures:

- Stéphane Nonnenmacher + Gabriel Rivière - Introduction to Dynamical systems (4h)
- Stéphane Nonnenmacher + Steve Zelditch (replacing Andrew Hassell) - Semiclassical Analysis and Quantum Ergodicity (4h)
- Jonathan Keating - Random Matrix Theory and Quantum Chaos (2h)
- Mikhail Sodin - Nodal portraits of random waves (2h)

Advanced talks

- Sebastian Müller - Spectral vs. periodic orbit correlations
- Jens Marklof - Spectral correlations for integrable systems
- Manfred Einsiedler - Arithmetic Quantum Unique Ergodicity (2h)
- Steve Zelditch - Ergodicity and nodal sets of eigenfunctions
- John Toth - L^p bounds for eigenfunctions
- Gabriel Rivière - Entropic bounds for eigenfunctions
- Zeév Rudnick - Pseudo-integrable systems
- Stéphane Nonnenmacher - Quantum chaos with open systems

Invited scientists / graduate students:
Tayeb Aissiou, Julio Cesar Andrade, Janine Bachrachas, Ram Band, Michael Barbosu, Brice Camus, Yaiza Canzani, Xie Chen, David Damanik, Tien-Cuong Dinh, Remy Dubertrand, Manfred Einsiedler, Layan El Hajj, Suresh Eswarathasan, Jeffrey Galkowski, Oran Gannot, Jesse Gell-Redman, Xiaolong

Han, Boris Hanin, Lysianne Hari, Peter Humphries, Chris Joyner, Olena Karpel, Jonathan Keating, Thomas Leble, Etienne Le Masson, Fabricio Macia, Jens Marklof, Mykola Matviichuk, Zahra Mortezaie, Sebastian Müller, Patrick Munroe, Alon Nishry, Stephane Nonnenmacher, Anke Pohl, Guillaume Poliquin, Eric Potash, Julie Rowlett, Gabriel Riviere, Guillaume Roy-Fortin, Zeev Rudnick, Mikhail Sodin, Anton Solomko, Cesar Escalante Terrero, John Toth, Jan-Hendrik Treude, Nikolai Tropin, Henrik Ueberschär, Martin Vogel, Tobias Weich, Nadav Yesha, Steve Zelditch.

Golod-Shafarevich Groups and Algebras, and the Rank Gradient

Organizers: Mikhail V. Ershov (U Virginia) and Nikolay Nikolov (Oxford U)

Dates: August 20 – 24, 2012

Budget: ESI €20.160,–
plus external funding from the Sloan Research Fellowship grant of M. Ershov (grant BR 2011-105).

Preprints contributed: [2407], [2405], [2384]

Report on the workshop

Introduction

Golod-Shafarevich algebras and groups were discovered in 1964 and were immediately applied to construct number fields with infinite class field towers and infinite finitely generated torsion groups, thereby solving the famous class field tower problem and the general Burnside problem. They attract a lot of interest even today from group-theorists and number-theorists alike and have stimulated a lot of research in ring theory. On the other hand the rank gradient was defined relatively recently to study hyperbolic 3-manifolds and turned out to have connections with classical combinatorial group theory and measurable group actions. Techniques from one area have been applied to others. For example study of the rank gradient is often paralleled by similar results on L^2-Betti numbers. In turn L^2-cohomology has been applied to the study of group rings and the zero divisor conjecture. Constructions of nonamenable torsion groups of positive rank gradient touch on ideas similar in spirit to Golod and Shafarevich algebras.

The workshop aimed to present an overview of these subjects for the experts who might be unaware of connections between them and at the same time provide an introduction to them for the young mathematicians - postdocs and graduate students.

Activities

The workshop was held from August 20 to 24, 2012. There were 55 participants from Europe, USA and South America, of which 22 were postdocs and graduate students. The programme was based on 3 mini-courses:

- *Rank gradient and where it leads* by M. Abert
- *Rank gradient and property tau* by M. Lackenby
- *Golod Shafarevich groups and algebras* by E. Zelmanov and M. Ershov.

There were also 13 research talks covering recent progress on related topics in number theory, ring theory and group theory. There were 2 problem sessions and in addition opportunities for PhD students to give short presentations on their research.

Specific information on the workshop

Rank gradient. The rank gradient was probably the most popular topic at the workshop and was featured in two mini-courses, two talks and one short presentation.

The first mini-course was taught by M. Abert who gave a very clear and entertaining introduction to the rank gradient and its connections with L^2-Betti numbers, cost and many other topics in the rapidly expanding field of measurable group theory. Although many recent developments were presented, all four lectures were completely accessible to non-experts, including graduate students.

The other mini-course dealing with rank gradient was given by M. Lackenby. The notion of rank gradient was introduced by Lackenby eight years ago as a tool for studying 3-manifold groups. The rank gradient and its variations such as mod p-homology gradient played an important role in his impressive series of papers which solved many important open problems not only in 3-manifold topology, but also in group theory, and many of these results were presented in Lackenby's mini-course. The main theme of the mini-course was relationship between rank gradient and property (τ), and more generally, relationship between algebraic properties of a finitely generated group and geometric properties of its finite quotients, but connections with completely different areas, e.g. coding theory, were also discussed.

Both mini-courses were beautifully delivered. Perhaps even more importantly, while the two speakers discussed the rank gradient from different points of view, they did an excellent job of emphasizing connections between problems in different areas. Thus, we feel that these two mini-courses provided a unified and comprehensive picture on recent developments involving the rank gradient.

J.-C. Schlage-Puchta talked about his work on constructing p-groups with positive rank gradient (which, in particular, yields a very simple solution to the general Burnside problem) and a follow-up paper with Y. Barnea. At the end of his talk, several interesting questions involving subgroup growth were formulated. R. Grigorchuk discussed, among other things, the notion of a rank gradient function (which is a finer invariant than rank gradient) and presented several results on possible behavior of such functions in lamplighter group.

Finally, N. Pappas, one of the graduate students participating in the workshop, gave a 10 minute presentation on his paper about constructing groups with arbitrary p-gradient. Several people in the audience were interested in details of his work, so this short presentation was followed by another (informal) talk where the main idea of the proof and possible extensions of the result were discussed.

L^2-Betti numbers. L^2-Betti numbers were initially defined by M. Atiyah to study the topology of manifolds. They have found numerous applications to group theory. There is the *Lück Approximation Theorem* which says that the normalized Betti numbers of a chain of normal subgroups of a group G converges to the L^2-Betti number of G. Another (much more basic) fact is that the first L^2-Betti number of G, denoted $b_1^{(2)}(G)$, is a lower bound for its rank gradient and in particular for its rank.

This was exploited in the talk by A. Thom to prove the existence of a simple group S with rank $d(S)$ equal to an arbitrary given integer $n > 1$. He also discussed the conjecture that $b_1^{(2)}(G) + 1$ is at most the number of normal generators for G and gave some evidence for its validity in special classes of groups.

Another application of L^2-Betti numbers is to the Zero Divisor Conjecture. This was elaborated in the talk by L. Grabowski who studied the question of decidability of the spectral measure of a group ring operator on $L^2(G)$. One application of his methods is the following Theorem: The question whether an element of the group ring $\mathbb{Z}[(\mathbb{Z} \wr \mathbb{Z})^4]$ is a zero divisor or not is undecidable.

This theme was continued by G. Elek who introduced the Linnell and Schick ring $R(G) \subset \mathcal{U}(G)$ and discussed conjectural structural Lück approximation for $R(G)$ and its generalizations.

The talk by N. Nikolov presented new results concerning the asymptotic behavior of the Betti numbers of sequences of locally symmetric spaces. There is a uniform version of the Lück Approximation Theorem in the higher rank case. The basic idea is to adapt the theory of local convergence, originally introduced for sequences of graphs of bounded degree by Benjamimi and Schramm, to sequences of Riemannian manifolds.

Golod-Shafarevich groups and algebras. A comprehensive introduction to Golod-Shafarevich groups and algebras was given in a four lecture mini-course, co-taught by E. Zelmanov and M. Ershov. Zelmanov, who delivered the first two lectures, defined Golod-Shafarevich algebras and groups, gave a complete proof of the Golod-Shafarevich inequality and discussed its basic applications – solutions to the general Burnside problem and Kurosh-Levitzki problem. Ershov discussed more recent developments in the subject, including interpretation of Golod-Shafarevich groups as groups of positive weighted deficiency and outlined a construction of residually finite analogues of Tarski monsters using Golod-Shafarevich groups.

Golod-Shafarevich groups and algebras and most importantly Golod-Shafarevich inequality were also featured in several of ring-theoretic and number-theoretic talks, covering a broad range of topics. One of the most important consequences of the Golod-Shafarevich inequality is a lower bound for the number of relators needed to present a graded associative algebra or a finite p-group. N. Iyudu talked about her recent work with Shkarin where the best possible bounds of this kind were obtained in some cases. D. Piontkovski talked about Golod-Shafarevich theorem for operads illustrating the general phenomenon that analogues of Golod-Shafarevich inequality can be established for very different kinds of algebraic structures.

Golod-Shafarevich inequality remains one of the main tools for analyzing Galois groups of pro-p extensions of number fields with restricted ramifications and, in particular, finding sufficient conditions for such groups to be infinite. N. Boston and M. Bush discussed a number of results and open questions on the structure of these groups and formulated purely group-theoretic conjectures about Golod-Shafarevich groups which would solve some of these questions. The latter theme was continued by F. Hajir, who talked about asymptotically good families and discussed possible analogies between the Galois groups of the above form and pro-p completions of 3-manifold groups.

There were two more ring-theoretic talks which did not deal with Golod-Shafarevich algebras and groups directly, but touched on closely related developments in ring theory. J. Bell gave a very intuitively clear introduction to the so called bottleneck principle, introduced A. Smoktunowicz, which is a key tool in many recent constructions of graded associative algebras with exotic finiteness properties, including the first examples of finitely generated graded nil algebras of finite positive Gelfand-Kirillov dimension by Smoktunowicz and Lenagan. Bell also talked about his recent work with A. Young on constructing graded nil algebras of subexponential growth over uncountable base fields. Many related problems were discussed by T. Lenagan who gave an excellent survey on the structure of algebras with restricted growth.

Outcomes and achievements

Overall the workshop stimulated an exchange of ideas and promoted collaboration between mathematicians working in different areas. In particular, there were fruitful conversations between ring-theorists and group-theorists on possible connections between Smoktunowicz-type monsters and Golod-Shafarevich algebras, while number-theorists and group-theorists discussed how recent advances in the study of rank gradient and Golod-Shafarevich groups could be applied to problems about pro-p Galois groups with restricted ramification. The group-theorists discussed

the conjectures put forward in the talks, for example on the structure of the finitely presented groups with positive rank gradient. A collaboration between A. Kar and N. Nikolov resulted in the preprint 'Rank gradient for Artin groups and their relatives' arxiv.org/abs/1210.2873

Appendix. List of talks

J. Bell	On the Kurosh problem with growth restrictions
N. Boston	Pro-p Galois groups with restricted ramification
M. Bush	Computing pro-p Galois groups
G. Elek	Structural Lück approximation
L. Grabowski	Decidability aspects of computing spectral measures
R. Grigorchuk	The subgroup structure of certain amenable groups and the relative gradient rank
F. Hajir	Asymptotically good families
N. Iyudu	The Anick conjecture on the minimal Hilbert series of quadratic algebras
T. Lenagan	Algebras with restricted growth
N. Nikolov	Growth of Betti numbers of lattices in semisimple Lie groups
D. Piontkovskii	Golod-Shafarevich theorem for operads
J.-C. Schlage-Puchta	On the p-deficiency of groups
A. Thom	Normal generation of subgroups and ℓ^2-invariants

Invited scientists: Miklos Abert, Florian Aigner, Theofanis Alexoudas, Yago Antolin-Pichel, Yiftach Barnea, Laurent Bartholdi, Jason Bell, Nigel Boston, Henry Bradford, Michael Bush, Jack Button, Pierre-Emmanuel Caprace, Christopher Cashen, Nhan-Phu Chung, Gabor Elek, Mikhail Ershov, Elisabeth Fink, Alejandra Garrido, Darlan Girao, Jon Gonzalez-Sanchez, Lukasz Grabowski, Rostislav Grigorchuk, Dominik Gruber, Farshid Hajir, Wolfgang Herfort, Natalia Iyudu, Andrei Jaikin-Zapirain, Aditi Kar, Steffen Kionke, Benjamin Klopsch, Dessislava Kochloukova, Marc Lackenby, Tom Lenagan, Matthew Levy, Paunescu Liviu, Szabolcs Meszaros, Wolfgang A. Moens, Nikolay Nikolov, Damian Osajda, Nathaniel Pappas, Dmitri Piontkovski, Ashley Rall, Susanne Schimpf, Jan-Christoph Schlage-Puchta, Dan Segal, Ilir Snopce, Jan Spakula, Markus Steenbock, Nora Gabriella Szöke, Anitha Thillaisundaram, Andreas Thom, John S. Wilson, Alexander Young, Pavel Zalesskii, Efim Zelmanov, Rudolf Zeidler, Zezhou Zhang, Amaia Zugadi-Reizabal.

Recent Developments in the Mathematical Analysis of Large Systems

Organizers: Christian Hainzl (U Tübingen), Robert Seiringer (McGill U), Stefan Teufel (U Tübingen).

Dates: October 1 – 6, 2012

Budget: ESI €17.360,–
plus external funding of US$ 1.000,– from the American Institute of Physics (AIP) for a reception

Preprints contributed: [2364], [2365]

Report on the workshop

Introduction

The rigorous derivation of effective models for complex physical systems starting from microscopic theories was always one of the driving topics in mathematical physics. This general question generated new mathematical developments in a variety of different fields and over several generations of researchers.

The goal of this workshop was to bring together some of the leading figures from the different communities and allow a broad exchange on the latest developments. The workshop presented also a unique opportunity for young researchers to learn about the different fields and their interconnections.

Specific examples of recent progress that among others were the central topics of the conference are kinetic equations, the BCS model, the polaron model and quantum diffusion. The main tools analytical tools that were discussed are scaling limits like e.g. mean field, low density or adiabatic limits.

Activities

The workshop consisted of 32 talks, spread over five and a half days, each 45 minutes long. These talks covered a broad range of topics from the following research areas: Nonequilibrium Statistical Physics (Lebowitz, De Roeck, Olla, Lukkarinen, Ferrari, Grosskinsky, Loss, Pickl, Joye, Jaksic, Baumgartner), Quantum Many Body systems, including random interactions (Lewin, Derezinski, Warzel, Nachtergaele, Sasamoto, Schlein, Teschl, Ueltschi), Radiation and Matter (Hagedorn, Lein, Betz, De Bievre, Matte, Panati, Sigal, Deckert, Pizzo), Thermodynamics (Yngvason), Interpretation of Quantum Mechanics (Dürr), Entropy of Quantum States (Solovej), and the Bessis-Moussa-Villani Coonjecture (Lieb).

In addition, on Wednesday afternoon Joel Lebowitz presented a report on Human Rights issues for scientists around the world.

The speakers and the titles of their talks were as follows:

Joel Lebowitz	Stationary non-equilibrium states: Some of the things I learned from Herbert Spohn
Wojciech De Roeck	Can thermal fluctuations cause many-body localization
Stefano Olla	Macroscopic fluctuations of energy in chains of oscillators
Jani Lukkarinen	Kinetic theory of the Hubbard model: a Boltzmann equation with a twist
Patrik Ferrari	Free energy fluctuations for directed polymers in $1+1$ dimension
Stefan Grosskinsky	Equilibration dynamics and metastability in inclusion processes
Jakob Yngvason	Second thoughts on entropy and the second law of thermodynamics
George Hagedorn	a simple model for molecular raman scattering
Mathieu Lewin	The excitation spectrum of interacting Bose gases
Jan Derezinski	General properties of Bogoliubov transformations
Simone Warzel	The Anderson model on the Hemming cube
Max Lein	Effective dynamics for electromagnetic waves traveling in slowly modulated photonic crystals
Michael Loss	The Kac master equation; a review
Alain Joye	Spectral transition for tandom quantum walks on trees
Volker Betz	Effective density of states of a quantum oscillator coupled to a radiation field
Peter Pickl	Effective dynamics of a heavy particle in an ideal Bose gas in the thermodynamic limit
Detlef Dürr	Quantum physics not understandable? Surely you're joking, Mr. Feynman!
Bruno Nachtergaele	Quantum harmonic oscillator systems with disorder
Stephan De Bievre	Scattering induced diffusion and current in a tight binding band
Gianluca Panati	Localization of electrons charge in insulators and minimizers of the Marzari-Vanderbilt functional

Oliver Matte	On enhanced binding due to the quantized radiation field
Vojkan Jaksic	Non-equilibrium statistical mechanics of the spin-boson model
Jan Philip Solovej	Solution to a conjecture on the classical entropy of quantum states
Tomohiro Sasamoto	Replica analysis of surface growth models using quantum many-body systems in one-dimension
Benjamin Schlein	Dynamics of BEC of fermion pairs in the low density limit of BCS theory
Gerald Teschl	Lieb-Robinson bounds for the Toda lattice
Michael Sigal	Bounds on photon speed and asymptotic completeness of Rayleigh scattering
Dirk Deckert	Ultraviolet properties of the spinless, one-particle Yukawa model
Alessandro Pizzo	Coulomb scattering in the massless Nelson model I: Foundations of two-electron scattering and regularity of groun states
Bernhard Baumgartner	Quantum dynamical processes, semigroups and structures of Hilbert space
Daniel Ueltschi	Random loop representations for quantum Heisenberg models
Elliott Lieb	The 36 year old saga of the BMV conjecture

Invited scientists

Bernhard Baumgartner, Volker Betz, Stephan de Bievre, Gerhard Bräunlich, Wojciech De Roeck, Dirk Deckert, Jan Derezinski, Andreas Deuchert, Detlef Dürr, Patrick Ferrari, Stefan Grosskinsky, Stefan Haag, George Hagedorn, Christian Hainzl, Vojkan Jaksic, Alain Joye, Johannes von Keler, Jonas Lampart, Joel Lebowitz, Max Lein, Mathieu Lewin, Elliott Lieb, Michael Loss, Jani Lukkarinen, Oliver Matte, Bruno Nachtergaele, Stefano Olla, Gianluca Panati, Peter Pickl, Alessandro Pizzo, Tomohiro Sasamoto, Benjamin Schlein, Robert Seiringer, Israel Michael Sigal, Sergio Simonella, Jan Philip Solovej, Herbert Spohn, Stefan Teufel, Daniel Ueltschi, Stefan Walter, Simone Warzel, Jakob Yngvason, Mirolsav Znojil.

9th Vienna Central European Seminar on Particle Physics and Quantum Field Theory: Dark Matter, Dark Energy, Black Holes and Quantum Aspects of the Universe

Organizer: Helmuth Hüffel (U Vienna)

Dates: November 30 – December 2, 2012

Budget: ESI €1.520,–
of co-funding with:
The Austrian Federal Ministry of Science and Research,
The Faculty of Physics, University of Vienna,
FWF Doctoral Program: Complex Quantum Systems (CoQuS),
COST Action MP1006, Fundamental Problems in Quantum Theory,
The Vienna University of Technology,
The Institute of High Energy Physics of the Austrian Academy of Sciences,
The Vienna Convention Bureau.

Report on the seminar

The seminar series "Vienna Central European Seminar on Particle Physics and Quantum Field Theory" was created 2004 and is intended to provide stimulating interactions between leading

researchers and promising junior physicists. As in previous years the lectures took place at the Faculty of Physics of the University of Vienna.

List of plenary speakers

Hartmut Abele (Vienna)	Spectroscopy of gravity
Abhay Ashtekar (Penn State)	Quantum gravity and the very early universe
Andrea Campoleoni (Brussels)	Higher-spin gravity
Timothy Clifton (London)	Does dark energy exist?
Antonio Di Domenico (Rome)	Hunting for CPT symmetry and quantum mechanics violations in neutral meson systems
Ivete Fuentes (Nottingham)	Moving cavities and detectors for relativistic quantum information processing
Beatrix C. Hiesmayr (Brno)	Testing foundational issues of quantum mechanics at accelerator facilities
Seth Lloyd (MIT)	The quantum geometric limit
Nick E. Mavromatos (London)	CPT in the early universe and the observed baryon asymmetry
Paolo Natoli (Ferrara)	Cosmology with Planck
Roger Penrose (Oxford)	Dark energy, dark matter, and black holes, as essential ingredients of a new cyclic theory of the universe
Josef Pradler (Johns Hopkins)	Rare events underground: dark matter interpretation and new physics opportunities
Margaret Reid (Melbourne)	Quantum mechanics versus local reality: fields and atoms
Jochen Weller (Munich)	Constraining cosmic acceleration

Sir Roger Penrose gave a Public Lecture on "Dark Energy, Dark Matter, and Black Holes, as Essential Ingredients of a New Cyclic Theory of the Universe" on the evening of November 30. See `www.univie.ac.at/vienna.seminar/2012/publiclecture12.html`.

Invited scientists: Abhay Ashtekar, Harmut Abele, Andrea Campoleoni, Adriano Cantillo, Timothy Clifton, Brian Dolan, Silvije Domazet, Antonio Di Domenico, Nicolai Friis, Ivete Fuentes, Michael Gary, Beatrix C. Hiesmayr, Helmuth Hüffel, Alfredo Iorio, Tim Langen, Renate Loll, Seth Lloyd, Katarina Markovic, Nick E. Mavromatos, Paolo Natoli, Roger Penrose, Andra Puhm, Josef Pradler, Enikö Regös, Margaret Reid, Dominik Schwarz, Jochen Weller.

Dynamics of General Relativity: Black Holes and Asymptotics

Organizers: Lars Andersson (MPI Potsdam), Robert Beig (U Vienna), Mark Heinzle (U Vienna), Sascha Husa (U Balearic Islands)

Dates: December 10 – 21, 2012

Budget: ESI €25.600,–

Preprints contributed: [2406]

Report on the programme

The programme "Dynamics of General Relativity" was devoted to numerical and analytical aspects of General Relativity and their interaction. It was a follow-up to a workshop of the same

held from July 4 to September 3 in 2011. Not including local participants, the programme was attended by 47 scientists, out of whom roughly one fourth had not attended the previous workshop. Of the participants 17 gave formal talks. In accordance with our original aims participants were numerical relativists, mathematical relativists or relativists doing numerics-based mathematical relativity (Bizon and collaborators). The format was that, except for the first and last day of the workshop, there were two talks per day, at fixed day-time - with the purpose of facilitating the transition between informal discussions among participants and attendance of talks. This kind of schedule met with great approval except for one participant who complained there were too many talks. The quality of talks was generally considered to be very good. Perhaps even more importantly, talks given by mathematical relativists were generally well attended by numerical relativists and vice versa.

Talk highlights. The choice here is highly subjective, based in part on what seemed to best trigger future interactions among participants. There were closely related talks given by S. Dain and P. Bizon, the latter based on recent joint work with Friedrich. These concerned recent claims (Aretakis) in the literature of an 'instability' of the extremal Reissner-Nordström black hole. A talk by Zenginoglu concerned the rich phenomenology of wave propagation on black hole spacetimes, in particular the effect of 'caustic echos'. These results are potentially important amongst other things to self-force computations for small compact objects moving in the field of a supermassive black hole. Although, as amply demonstrated by our workshop, there is great interest on the part numerical relativists to learn from mathematical relativists and vice versa, direct collaboration is still rare. Moncrief, in his talk, reported on such a collaboration (with Rinne) on numerical implementations of a fully constrained system for integrating the vacuum Einstein equations out to null infinity.

Collaborations. In feedback emails sent to the organizers after the end of the workshop several participants reported on very useful interactions and progress in ongoing collaborations. In addition some collaborations initiated at the present workshop came to the notice of the organizers. These included: projected work on big bang singularities in Bianchi cosmologies of Uggla and Hell, joint numerical work of Schäfer and Racz, projects of Zenginoglu and Donninger concerning using hyperboloidal foliations of spacetime in analyzing nonlinear wave equations. Furthermore Valiente-Kroon and Zenginoglu plan to collaborate using the general conformal field equations in the study of the global structure of extreme Reissner-Nordström spacetimes. There are plans of Anderssen, Calogero and LeFloch to extend previous work by Calogero (with Leonori) on equilibrium configurations of static, self-gravitating elastic bodies from the Newtonian to the relativistic regime.

Invited scientists:

Peter Aichelburg, Steffen Aksteiner, Lars Andersson, Hakan Andreasson, Thomas Bäckdahl, Robert Beig, Piotr Bizon, Pieter Blue, Simone Calogero, Piotr Chrusciel, Joao Costa, Sergio Dain, Roland Donninger, Michal Eckstein, David Fajman, Albert Fathi, Helmut Friedrich, Greg Galloway, James Grant, Nishanth Abu Gudapati, Dietrich Häfner, Mark Heinzle, Juliette Hell, David Hilditch, Sascha Husa, Joanna Jalmuzna, Jacek Jezierski, Jeremie Joudioux, Jerzy Kijowski, Mikolaj Korzyński, Stephen Lau, Philippe LeFloch, Maciej Maliborski, Ettore Minguzzi, Vincent Moncrief, Luc Nguyen, Niall OMurchadha, Harald Pfeiffer, Denis Pollney, Michael Pürrer, István Rácz, Gerhard Rein, Moritz Reintjes, Christian Reisswig, Hans Ringström, Andrzej Rostworowski, Olivier Sarbach, Gerhard Schäfer, Bernd Schmidt, Walter Simon, Sebastian Jan Szybka, Gabor Toth, Claes Uggla, Juan Valiente Kroon, Anil Zenginoglu.

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 activties. 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. The number of proposals, on themes of topical interest, was high. However, due to limited resources, the Kollegium could only accept four of these applications for the year 2012. The first scholars within this programme were at the ESI in June 2012. Other teams are already accepted for the year 2013.

Bruno Nachtergaele et al: Disordered Oscillator Systems

Collaborators: Bruno Nachtergaele (UC Davis), Robert Sims (U Arizona), Günter Stolz (U Alabama, Birmingham)

Dates: June 18 – August 5, 2012

Budget: ESI EUR 9.760,–
partly co-supported by NSF grants DMS-1009502 (B.N.), DMS-0757424 and DMS-1101345 (R.S.), and DMS-1069320 (G.S.).

Preprints contributed: [2383]

Scientific Background

Our overall goal was to better understand the effects of disorder on many-body quantum systems. While such effects have been frequently studied in physics (where they play an important role in a number of intriguing phenomena like Bose-Einstein condensation, superconductivity, and the quantum Hall effect), their mathematical understanding is much more limited. We attribute this to the multiple challenges one encounters in the study of interacting quantum many-body systems (ground states, thermal equilibrium states and phase transitions, dynamics) on the one hand, and random Schrödinger operators on the other hand. Almost inevitably, when one tries to understand the effect of disorder on many-body quantum systems, one is faced with a combination of difficulties already present in these two major areas of mathematical physics separately. In both areas, however, there has been significant progress in the past decade. For example, recent progress on quantum spin systems, which are simple models of many-body physics, is contained in works by Bravyi, Hastings, Matsui, Nachtergaele, Sims, Yarotsky and similarly, Aizenman, Bourgain, Germinet, Klein, Stolz, Warzel have contributed to modern advances in the theory of localization for random Schrödinger operators. As can be seen from the recent works by Chulaevsky and Suhov [2,3] as well as Aizenman and Warzel [1], we now have reached the point where we can start to answer interesting questions about many-body systems with randomness.

Project aims and scope

As a team of mathematical physicists we brought together our expertise in the areas of random operator theory (Anderson localization, R.S. and G.S.) and quantum many-body theory (quantum lattice systems, B.N. and R.S.). We decided, as a first step, to study some fundamental properties of disordered harmonic oscillator systems. Specifically, we were interested in

understanding how a number of basic consequences of the existence of a spectral gap above the ground states in such systems fare if the spectral gap assumption is replaced by the assumption of a mobility gap. It is typical for disordered systems for there *not* to be a gap in the spectrum above the ground state. Instead, the gap is filled with localized states. Hence, the part of the spectrum consisting only of those states that contribute to transport (mobility) in the system is still gapped, but the spectrum as a whole is not. This situation is referred to as the existence of a *mobility gap*. Two general and important consequences of a spectral gap are the exponential decay of correlations and the validity of an area law bound for the entanglement entropy of finite regions. Our goal was to prove that similar properties hold under the assumption of a mobility gap, as predicted by Hastings [4].

Outcomes and achievements

Our collaboration resulted in a number of new results on disordered oscillator systems, including a general proof that a mobility gap implies exponential decay of static and dynamic correlation functions in the ground state and temperature states of these systems, published in [5]. An article with the derivation of an upper bound of the expected area law behavior for the entanglement entropy has been posted on the arXiv [6].

To prove these results we had to first obtain some interesting extensions of existing theorems in the theory of Anderson localization, namely estimates for singular eigenfunction correlators. We believe these results are interesting in their own right and are contained in an appendix of [5]. The results in [6] also rely on this appendix. In addition, we provide in [6] a self-contained treatment of partial transposes of states and the diagonalization of quasi-free functionals on the Weyl algebra.

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Alexander Fel'shtyn et al: Twisted Conjugacy Classes in Discrete Groups

Collaborators: Alexander Fel'shtyn (Szczecin U, Poland), Evgenij Troitsky (Moscow State U)

Dates: July 23 – August 23, 2012

Budget: ESI € 4.720,–

Preprints contributed: [2396]

Scientific Background

The interest in twisted conjugacy relations has its origins, in particular, in the Nielsen-Reidemeister fixed point theory (see, e.g. [15, 2]), in Selberg theory (see, eg. [17, 1]), and Algebraic Geometry (see, e.g. [14]). In representation theory twisted conjugacy probably occurs first in Gantmacher's paper[13] (see, e.g [18, 16]).

The following two interrelated problems are the main ones in the theory of twisted conjugacy (Reidemeister) classes in infinite discrete groups. The first one is the 20-years-old conjecture on existence of an appropriate twisted Burnside-Frobenius theory (TBFT), i.e. identification of the number $R(\phi)$ of Reidemeister classes and the number of fixed points of the induced homeomorphism $\widehat{\phi}$ on an appropriate dual object (supposing $R(\phi) < \infty$). The second one is the problem to outline the class of R_∞ groups (that is $R(\phi) = \infty$ for any ϕ).

Recently in our joint paper [12] important advances in both problems were obtained. Namely, first, it is proved that TBFT holds for finitely generated residually finite groups (we take the finite-dimensional part of the unitary dual as the dual space) (Theorem A). Secondly, it is discovered that finitely generated residually finite non-amenable groups are R_∞-groups (Theorem B). tThis progress was based on our previous research [2-9, 11, 19].

Project aims and scope

Our research project (as it was stated in the application) supposes a development of these results in the following directions in contact with colleagues from the ESI.

1. We plan to obtain new classes of R_∞ groups weakening the condition of residually finiteness in Theorem B and making more restrictive the condition of non-amenability (namely, to Kazhdan's property (T), uniform non-amenability or C^*-simplicity).

2. The problems from the first item are closely related to the study of groups "with extreme properties", like Osin's group, which has only two ordinary conjugacy classes, i.e. $R(\mathrm{Id}) = 2 < \infty$, but has only one finite-dimensional representation (the trivial one). On the other hand a detailed study of the harmonic analysis on those groups should suggest a variant of Theorem A for "very non-residually finite" groups.

3. The (weakly) branch groups form an important class of residually finite amenable groups, hence, they are not covered by Theorem B. Nevertheless, for some of them (including Grigorchuk and Gupta-Sidki groups) in [6] the R_∞ property was proved. We intend to extend this subclass.

4. In 2006, C. Deninger started a programme to compute the entropy of principal algebraic actions of a countable discrete amenable group in terms of the Fuglede-Kadison determinant. Let f be a non-zero-divisor in the integral group ring $\mathbb{Z}\Gamma$ of Γ and denote by $\mathbb{Z}\Gamma f$ the left ideal in $\mathbb{Z}\Gamma$ generated by f. Classical results by Yuzvinski for $\Gamma = \mathbb{Z}$ and by Lind-Schmidt-Ward for $\Gamma = \mathbb{Z}^d$ (1990) showed that the entropy $h(X_f)$ of the Γ-action on X_f, the Pontryagin dual of $\mathbb{Z}\Gamma/\mathbb{Z}\Gamma f$, is equal to the logarithm of the Fuglede-Kadison determinant $\log\det(N\Gamma f)$, which can be identified with the logarithm of the Mahler measure of f. C. Deninger conjectured that this equality extends to all amenable groups.

Later C. Deninger and K. Schmidt (Erg. Th. Dyn. Sys., 2007) proved this equality for certain expansive actions of a countable discrete residually finite amenable group Γ by automorphisms of compact abelian groups. Recently, H. Li and A. Thom (arXiv:1202.1213) established the equality of the entropy of the action of discrete amenable group Γ on M and the L^2-torsion of M, for any $\mathbb{Z}\Gamma$-module M of type FL with $\chi(M) = 0$.

H. Li and A. Thom have proved the conjectured equality of the entropy of a principal algebraic action and the logarithm of the Fuglede-Kadison determinant as a special case of this result. Recently, the entropy theory has been extended to actions of countable sofic groups which include

all countable amenable groups and countable residually finite groups. The analogue of the later result of H. Li and A. Thom for countable residually finite groups has been established for some special cases (Bowen, Erg. Th. Dyn. Sys. 2011; Bowen, H. Li, preprint 2011), though the general case is still open.

5. The twisted inner representation and twisted inner amenability are the new notions which naturally generalize the inner (conjugate) representation and inner amenability. We have already used the twisted inner representation (in a some similar way with the usage of the inner representation in (Kaniuth-Markfort, 1992)) to prove theorem B.

Outcomes and achievements

Our main progress obtained is related to item 5 above. Our results are contained in a preprint of the ESI, submitted to J. K-Theory [10].

We prove under supposition of finiteness of stabilizers of ϕ-twisted action, that the twisted inner representation γ_G^ϕ is weakly contained in the regular representation λ_G. Then we obtain a more strong version of this statement: $\gamma_G^\phi \prec \lambda_G$ if and only if the twisted stabilizer $C_\phi(a)$ is amenable for all $a \in G$. Also, we prove that $\lambda_G \prec \gamma_G^\phi$ for any ICC group G. Then we consider an automorphism ϕ of a finitely generated residually finite group G with a finite Reidemeister number. We prove that G is ϕ-inner amenable in an evident sense if and only if it is amenable. This differs from the case of inner amenability (i.e. Id-inner amenability).

Besides our joint research we had very useful discussions of problems in our project with some of the participants of the workshop "Golod-Shafarevich Groups and Algebras and Rank Gradient".

We have started some discussions with K. Schmidt around the problems formulated in item 4 above.

We would like to express our sincere gratitude to the ESI for the kind hospitality, financial support, and the use of facilities

Since our joint stay in the ESI was relatively short, we have not managed to have a significant progress in the directions of the other items above.

We hope make a progress in the remaining directions of our project at later visits to ESI. In particular, we are very interested in a discussion of problems of item 1 with *G.Arzhantseva* in relation with her work on uniform non-amenability (Arzhantseva et al., Adv. Math., 2005) and on C*-simplicity (Arzhantseva, Minasyan, JFA, 2007). A development of results of [12] for lattices could be supported by possible discussions with *J.Schwermer*. The problems in 3 are related to (Arzhantseva, Sunic, arXiv:math/0607778). While working on item 4 we hope to have fruitful discussions with *K.Schmidt*, who is one of the initiators of this field.

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Erez Lapid et al: Whittaker Periods of Automorphic Forms

Collaborators: Erez Lapid (Hebrew U), Zhengyu Mao (Rutgers U Newark)

Dates: July 1 – July 31, 2012

Budget: ESI €4.800,–

Preprints contributed: [2404], [2403]

Scientific Background

This RIT project continues our current collaboration on the Ichino-Ikeda conjecture, an explicated version of the Gross-Prasad conjecture.

The Ichino-Ikeda conjecture is pertaining to period integrals of automorphic forms. Let F be a number field, $\mathcal{A}$ its ring of adeles. Let G be a reductive group and H a spherical subgroup, both defined over F. Let φ be a cusp form on $G(F)\backslash G(\mathcal{A})$. The period integral

$$\mathbb{P}_H(\varphi) = \int_{H(F)\backslash H(\mathcal{A})} \varphi(h)\, dh \tag{1}$$

is of fundamental importance in the analysis, topology and arithmetic of the space $G(F)\backslash G(\mathcal{A})$. Many such periods are known or expected to be related to special values of L-functions.

In [1] and [2], Gross-Prasad formulated several conjectures about the period (1) when $G = O(n+1)\times O(n)$ and $H = O(n)$ embedded diagonally in G. These conjectures were subsequently

refined by Ichino-Ikeda [4]. Roughly speaking, the conjecture expresses the square of the period in terms of a special point of an L-function, namely for any φ in the space of an irreducible cuspidal automorphic representation π of G we have (up to normalization of measures)

$$|\mathbb{P}_H(\varphi)|^2 = 2^{-k} L^S(\tfrac{1}{2}, \pi) \int_{H(F_S)} \langle \varphi(\cdot h), \varphi \rangle \, dh \tag{2}$$

where k is an integer determined by π and $\langle \cdot, \cdot \rangle$ is the Petersson inner product. Here $L(s, \pi)$ is a certain L-function which is expected to have analytic continuation. One can extend this conjecture to Bessel periods of G (where the reductive part of H is a smaller orthogonal group). In this case the local integrals have to be suitably interpreted. There are also versions for unitary groups and symplectic/metaplectic groups where Bessel periods are replaced by Fourier-Jacobi coefficients. An extreme case of the general conjectures is the case of Whittaker coefficients.

Some low rank cases of the above conjecture have been established by Waldspurger in the 1980's ($n = 2$) and more recently by Ichino ($n = 3$) using the theta correspondence. However, this method is not applicable for bigger n. Another approach for this conjecture is by the relative trace formula of Jacquet-Rallis. Important progress in this direction has been made by Z. Yun and W. Zhang.

Project aims and scope

We plan to attack the Ichino-Ikeda conjecture for generic π using the automorphic descent method due to Ginzburg-Rallis-Soudry [3]), which (roughly) associates to an automorphic form on the general linear group Φ an automorphic form φ on the classical group. Both the Bessel period and the Petersson inner product can in principle be expressed in terms of the Whittaker function of Φ. The conjectural identity should then be reduced to local integral identities of Whittaker functions of the local components of the representation generated by Φ.

So far we treated (for general n) the case of Whittaker coefficients for the metaplectic group. In this case the global identity is indeed reduced to an identity of local Whittaker functions induced from the general linear group. This local identity is highly nontrivial. We proved it so far in the supercuspidal case and it already revealed some new functional equations in the context of Whittaker functions on GL_n.

Outcomes and achievements

During the RIT project we finished and submitted the preprint [5].

The main results in the paper include: reduction of the conjectured identity (2) in the case of Whittaker coefficients of metaplectic group to a conjectured local identity; the proof of the conjectured local identity in the case when the local representation is supercuspidal.

We take this opportunity to thank the ESI staff for a wonderful and productive period in Vienna over the summer.

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Dale Cutkosky et al: Resolution of Surface Singularities in Positive Characteristic

Collaborators: Dale Cutkosky (U Missouri), Herwig Hauser (U Vienna), Hiraku Kawanoue (Kyoto U), Stefan Perlega (U Vienna), Bernd Schober (U Regensburg).

Dates: November 5 – December 21, 2012

Budget: ESI EUR 8.400,–

Scientific Background

The non-embedded resolution of surface singularities has been established by Abhyankar in his thesis [1]. The much more difficult case of embedded resolution was also achieved by Abhyankar in the sixties in a series of papers summing up to more than 500 pages [2,3]. This complicated proof has recently been substantially simplified by Cutkosky to some 40 pages, exhibiting clearly the main arguments and the necessary resolution invariant [7]. In the seventies, Hironaka proposed a quite elementary proof for surfaces which are hypersurfaces – the only defect of this proof is that it seems to have no chance to be extended to higher dimensions [9]. Cossart-Jannsen-Saito extended in a long paper Hironaka's proof to surfaces of arbitrary codimension [5]. As for threefolds, non-embedded resolution has been proven by Abhyankar [2] and Cossart-Piltant [6], and the embedded case is still open.

A recent sub auspiciis thesis student of Hauser, Dominique Wagner, proposed an alternative proof for surfaces based on the analysis of the so called kangaroo phenomenon where the characteristic zero invariant increases under blowup in positive characteristic [8]. This destroys, in a first instance, the induction. Wagner has shown how to overcome this difficulty in the purely inseparable case of order p by considering a suitably defined correction term. This modification makes the induction work again.

Aside of these approaches, Villamayor and his collaborators as well as Kawanoue-Matsuki have recently proposed a different argument based on projections, respectively singular hypersurfaces, instead of restrictions to smooth hypersurfaces [4, 10]. Their method is based on a detailed investigation of the exceptional divisor.

Project aims and scope

While all of the existing proposals for resolution in positive characteristic add some insight to the problem, none of them seems to be the definite one. The aim of the Research in Teams programme was to compare the different methods in order to improve our understanding and to develop a more systematic proof for the surface case. Getting a good understanding of the surface case is an important prerequisite for attacking the still unsolved three-dimensional case of embedded resolution.

Outcomes and achievements

In the project, the existing approaches were analyzed thoroughly, evaluating flaws and strengths. A serious gap was discovered in Moh's proof of the stability theorem for local uniformization in positive characteristic [11]. Despite serious efforts, neither a counterexample nor a working proof

could be found. This indicates that the situation is more intricate than it was initially expected. Proving or disproving the stability theorem is a joint research interest of the collaborators of this RiT programme.

Further, Abhyankar's proof for the resolution of surfaces was examined very closely and compared to Wagner's approach. We found that many parts of these proofs can be made more conceptual, which makes the argument more accessible and may lay the foundation for understanding the higher dimensional case. In particular, an alternative invariant for the resolution of surfaces could be found that builds both on Abhyankar's invariant and the one used in Wagner's thesis. While some good properties of this invariant even hold in higher dimension, others fail. Why this happens and how it possibly can be prevented will be the subject of future research.

We would like to emphasize that our RiT-programme was extremely valuable for us. All participants felt that we could really advance in the subject in a systematic way. We would like to thank the Schrödinger Institute and its members for the hospitality and the opportunity to carry out this cooperation in such an ideal atmosphere.

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Invited guest scientists:

Takuro Abe (Kyoto University), December 7 - 13, 2012

Heisuke Hironaka (Japan Assoc. for Jap. Math. Sciences), November 25 - December 3, 2012

Hema Srinivasan (University of Missouri), November 11 - 17, 2012.

Senior Research Fellows Programme

To stimulate the interaction with the local scientific community the ESI offers 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 University of Vienna. In exceptional cases this programme also includes long-term research stays of small groups or individual distinguished researchers.

This year's programme was focused on the following lecture courses:

James Cogdell (Ohio State U, Columbus), Winter 2011-12: *L-Functions and Functoriality.*

Detlev Buchholz (Georg-August-Universität Göttingen), Summer 2012: *Fundamentals and Highlights of Algebraic Quantum Field Theory*

Eduard Feireisl (Academy of Sciences of the Czech Republic), Summer 2012: *Mathematics and Complete Fluid Systems*

Visitors and Guest Speakers within the Senior Research Fellowship framework:

Henning Bostelmann (U York), June 15 – 22, 2012

Gerardo Morsella (U Rome), June 26 – 30, 2012

James Cogdell: L-functions and Functoriality

Course. The principle of functoriality is one of the central tenets of the Langlands program; it is a purely automorphic avatar of Langlands vision of a non-abelian class field theory. There are two main approaches to functoriality. The one envisioned by Langlands is through the Arthur-Selberg trace formula, and with the recent work of Ngô, Arthur, and others this is now becoming available. The second method is that of L-functions as envisioned by Piatetski-Shapiro and is based on the converse theorem for $GL(n)$. The overall purpose of the series of lectures was to develop and explain the L-function approach to functoriality. The course consisted of 12 lectures of 90 minutes each together with the accompanying question periods of 45 minutes each.

The first lecture covered the theory of modular forms and their L-functions, the classical $GL(2)$ theory, as developed by Hecke in the 1930's. This includes his original Converse Theorem. The modern theory of L-functions for $GL(n)$ builds on this work of Hecke, combined with interaction of local and global harmonic analysis as was initiated in Tate's thesis, where he recast Hecke's work on $GL(1)$ in terms of an adelic theory.

The second lecture began the adelic theory of automorphic representations for $GL(n)$, covering the basic definitions of cuspidal automorphic representations and their decomposition into local representations. This decomposition is eventually responsible for the Euler product expansion of the L-functions. We then discussed the Fourier expansion for cusp forms on $GL(n)$, the role the existence and uniqueness of Whittaker models play in the $GL(n)$ theory, and finally the Multiplicity One Theorem on the multiplicity of a cuspidal automorphic representation in the automorphic spectrum of $GL(n)$.

Lectures 3 through 10 were spent on the theory of L-functions for $GL(n)$ and the twisted L-functions for $GL(n) \times GL(m)$. One begins with cuspidal automorphic representations π and π' on $GL(n)$ and $GL(m)$ respectively. First one writes down two families of Eulerian integrals, one for the cases $m < n$ and one when $m = n$, which have nice analytic properties: convergence, entire (meromorphic in the case $m = n$) continuation to the complex plane, bounded in vertical

strips, and satisfying a functional equation as $s \mapsto 1 - s$. These integrals were modeled on those of Hecke ($m < n$) or Rankin and Selberg ($m = n$). One next shows that these families factor into a product of local integrals, as in Tate's thesis, and then analyses the local families. At the non-archimedean places, these integrals form a fractional ideal in the space of rational functions in q^{-s} and the generator of this ideal is the local L-function. At a place where the local representation is unramified, one can explicitly compute the local Euler factor using classical invariant theory for $GL(n, \mathbb{C})$. At the archimedean places, the theory is more complicated, but there is an analogous theory. Finally one combines the properties of the global integrals plus the analysis at the local places to to define $L(s, \pi \times \pi')$ as an Euler product and prove that it has "nice" analytic properties: convergence in a half plane, entire continuation (again meromorphic if $m = n$), is bounded in vertical strips and again satisfies a $s \mapsto 1 - s$ functional equation. As a consequence of the analysis of the poles in the $m = n$ case, one obtains an analytic proof of the Multiplicity One Theorem for $GL(n)$.

The tenth lecture was devoted to the Converse Theorem for $GL(n)$. This is roughly the statement that if one has a degree n-Euler product that is "nice" in that it and its twists have the same analytic properties that the L-function of a cuspidal representation of $GL(n)$ has, then in fact the Euler product is that of a cuspidal automorphic representation of $GL(n)$. The proof of this was given in the basic case, and, following Hecke's classical proof for $GL(2)$ given in the first lecture, it was obtained by inverting the process developed in lectures 3–9. Morally, this theorem says that any degree n Euler product that one expects to be nice must come from a automorphic representation, i.e., must be "modular".

The eleventh lecture was devoted to describing an arithmetic family of Euler products that are conjecturally nice, the Artin L-functions attached to an n-dimensional representation of a Galois group. In this lecture we surveyed the results of class field theory and then the contents of Artin's three papers on his non-abelian L-functions from 1923, 1930, and 1931.

In the final lecture we applied the "moral theorem" coming from the Converse Theorem to the conjecturally "nice" L-functions of Artin to motivate the global and local Langlands correspondences, which roughly state that n-dimensional local or global Galois representations should be locally or globally modular, i.e., attached to appropriate representations of $GL(n)$ in such a way that preserves their L-functions. This is Langlands' formulation of a "non-abelian class field theory". Next, we discussed how one would formulate such a Langlands correspondence for groups G other than $GL(n)$. Finally, putting all this together, we formulated the Langlands Functoriality Conjecture as a process of transferring local and automorphic representations of G to $GL(n)$ mediated by the local and global Langlands correspondences, that is, by L-functions. Finally we discussed how one would then use the Converse Theorem on $GL(n)$ as a tool for establishing cases of this Functoriality Cojecture; this is the aforementioned "L-function approach" to functoriality.

Research. During my stay at the ESI I worked on two projects. The first project was with F. Shahidi (Purdue University) and T-L. Tsai (MPIM Bonn). While at the ESI, I worked on our paper *Local Langlands correspondence for GL_n and the exterior and symmetric square ε–factors.* This project was begun before my residence at ESI, but the final work and the writing were done at ESI. Both Shahidi and Tsai were in residence at the ESI in the month of January 2012 as part of the "Automorphic Forms: Arithmetic and Geometry" programme. In this work, we show that the local Langlands correspondence for $GL(n)$ preserves both the exterior square and symmetric square L– and ε–factors. This is a measure of robustness of the local Langlands correspondence and hopefully will help us understand the local Artin ε–factors better. As part of this work, we established the local analytic stability of the exterior square γ-factor for supercuspidal representations $GL(n)$, a result of independent interest in the local theory of automorphic forms. Given the central location of the ESI within Europe, I took the opportunity of my ESI residence

to travel and talk on this work at the ETH in Zurich, the EPFL in Lausanne, and the Rényi Institute in Budapest.

The second project was related to the history of mathematics. This projects dates from my participation in the meeting "Emil Artin – His Work and His Life" held at the ESI in January of 2006. For the accompanying volume on Artin I had prepared a paper *On Artin L-functions* based on my 2006 lecture. I have taken this time at ESI to revise this article. In particular I have now included much of the material that I discussed in the lecture on Artin L-functions in my SRF course.

Programme and Workshop Organization. My tenure as a SRF overlapped with the ESI Programme on Automorphic Forms: Arithmetic and Geometry Jan.3–Feb. 29, 2012. I was a co-organizer of this programme with C. Mœglin (Paris), G. Muić (Zagreb) and J. Schwermer (Vienna). The programme itself will be covered in a separate report for the year 2012. As this relates to my SRF tenure, since the SRF began before the programme I was an "on site" organizer, along with Schwermer, and was involved with decisions about cancellations, late invitations, and offices, etc. As mentioned above, during the first half of the programme my collaborators Shahidi and Tsai were in residence and we worked on our paper *Local Langlands correspondence for GL_n and the exterior and symmetric square ε–factors*. In particular, both Shahidi and Tsai gave talks on this work during the first Workshop (9–20 January 2012). Finally, I am happy to report that the students in my SRF course were regular attendees at the two Workshops associated with the Programme.

Detlev Buchholz: Fundamentals and Highlights of Algebraic Quantum Field Theory

Course. During my visit of the ESI from mid–April until the end of June 2012 I gave twelve lectures on the algebraic approach to relativistic quantum physics. After a brief introduction into the basic physical concepts and mathematical methods a survey was given on recent applications of the formalism to problems of physical interest; in particular, a novel approach to the analysis of states in theories with long range forces was presented. Some topics covered were

- manifestations of long range forces (SSB, Gauss' law, Huygens principle)
- charge classes as a generalization of the concept of superselection sectors (equivalence classes of partial states on lightcones)
- statistics and conjugates of charge classes
- covariance and spectral properties of charge classes

In the accompanying seminar further topics of current interest were presented by participants of the course and by invited speakers. The course was regularly attended by graduate students and also by senior colleagues.

Research. During my stay at ESI I worked on several topics, particularly on

- the structure of theories with long range forces (collaborations with S. Doplicher and J.E. Roberts). I was able to establish substantial improvements of results pertaining to the statistics of charge classes. They were subsequently presented in my lectures.
- resolvent algebras, a new approach to the treatment of canonical quantum systems (collaboration with H. Grundling). Here I profitted from an exchange with another ESI guest,

B. Nachtergaele, on Lieb–Robinson bounds. I also presented recent results on the algebraic sturcture of the resolvent algebra in a talk at ESI.

- a project aiming at the understanding of local properties of thermal states in algebraic QFT which was initiated by H. Narnhofer. We have isolated some pertinent phase space properties which are encoded in a new typ of nuclearity condition. Moreover, we could show that this condition is satisfied in free field theory. We are continuing this research and expect that it will be possible to establish within this framework quite generally local normality properties of thermal states and the exixtence of an entropy density.

During my stay I had numerous fruitful exchanges with senior members, postdocs and students of the Mathematical Physics group of the University and with other guests of ESI. I would like to thank the scientific governing board and the staff of ESI for giving me this opportunity to spend a stimulating, productive and enjoyable time at the University of Vienna.

Eduard Feireisl: Mathematics and Complete Fluid Systems

Course. The course was a concise introduction to the modern theory of partial differential equations modeling the motion of general compressible viscous and heat conducting fluids. Basic knowledge of the theory of partial differential equations including the theory of weak solutions and the associated function spaces framework (Sobolev spaces and related topics) were necessary.

In the first part of the course, we derived the basic equations starting from fundamental physical principles and formulated them in the language of the theory of generalized derivatives. Then the problem of *existence* of global and "large" solutions was discussed in detail. To this end, the modern methods of functional analysis, compensated and concentrated compactness, weak solutions and their possible singularities were discussed at length. The final part of the course was devoted to possible applications, an outline of future research directions, and to open problems.

The specific topics discussed in the course included:

1. Mathematical theory of *balance (concervation) laws*, differential form, weak form, the theory of constitutive relations.

2. Field equations of continuum fluid mechanics, basic notions of thermostatics, bulk velocity, equation of continuity. momentum balance, energy balance and its different forms, entropy, boundary conditions.

3. Weak formulation, equivalent statements of the energy balance, entropy inequality.

4. Weak vs. strong solutions, vacuum problem, weak-strong compatibility.

5. A priori bounds, total mass conservation, energy estimates, dissipation and entropy estimates, thermodynamic stability, ballistic free energy, total dissipation balance, Korn's inequality.

6. Weak sequential stability, weak continuity of the convective terms, Div-Curl lemma, weak continuity of the effective viscous pressure, commutator estimates, density oscillations, oscillation defect measure.

Lecture Notes. The lecture notes for the course *Mathematics of complete fluid systems* are available at my personal webpage at `www.math.cas.cz`.

Research. I continued my previous research in collaboration with A.Novotný (Toulon) on the applications of the method of relative entropies in the mathematical theory of the full Navier-Stokes-Fourier system. We obtained a rigorous justification of the inviscid, incompressible limit for ill prepared data. The results were published in the ESI preprint series:

E. Feireisl, A. Novotný: *Inviscid incompressible limits of the full Navier-Stokes-Fourier system*, ESI preprint 2366

The corresponding manuscript is accepted for publication in Communications in Mathematical Physics and will appear 2013.

Seminars and colloquia

2012 01 10, D. Jiang: Construction of automorphic forms for classical groups
2012 01 10, J. Arthur: Endoscopic Classification of Representations: Statement of Theorems
2012 01 10, T. Scholl: De Rham realizations of modular forms motives
2012 01 10, T. Yang: Period integrals of automorphic Green functions and derivatives of Rankin-Selberg L-functions (after Luanli Zhao)
2012 01 12, C. Nien: Twisted Gamma factor for cuspidal representations of general linear groups over a finite field
2012 01 12, F. Shahidi: Local Langlands conjecture for GL(n) and the symmetric and exterior square ε-factors
2012 01 12, J. Arthur: Endoscopic Classification of Representations: On Applications and Proofs
2012 01 12, J. Labesse: The Friday Morning Seminar on the Trace Formula revisted
2012 01 17, F. Hörmann: The arithmetic volume of orthogonal Shimura varieties
2012 01 17, K. Klosin: Congruences among automorphic forms on symplectic and unitary groups and the Bloch-Kato conjecture
2012 01 17, S. Kionke: Lefschetz numbers of involutions on the special linear group over quaternion algebras
2012 01 17, S. Morel: How to work with perverse sheaves
2012 01 19, D. File: Bessel coefficients of induced representations of some classical groups
2012 01 19, G. Muić: Cuspidal automorphic representations with many unramified components fully induced
2012 01 19, S. Morel: Mixed ℓ-adic complexes on varieties over $\mathbb{Q}$
2012 01 19, T. Tsai: Stability of exterior square γ–factors for $GL(n)$
2012 02 03, S. Hollands: Black Holes and Extra Dimensions
2012 02 13, D. Soudry: On CAP-representations of orthogonal groups
2012 02 14, M. Adrian: The local Langlands correspondence : from real to p-adic groups
2012 02 14, M. Rapoport: On the Arithmetic Fundamental Lemma of Wei Zhang
2012 02 14, U. Terstiege: Computation of Arithmetic Intersection Numbers for the Arithmetic Fundamental Lemma
2012 02 15, J. Lau: Reducibility of certain induced representations of E_6 and E_7
2012 02 15, S. Schimpf: Geometric construction of cohomology classes for cocompact arithmetically defined subgroups of $SL_n(\mathbb{C})$
2012 02 16, H. Hida: Finiteness of potentially p-ordinary Q-simple abelian varieties of $GL(2)$-type
2012 02 16, H. Kim: Logarithmic derivatives of Artin L-functions at $s = 1$
2012 02 17, M. Hanzer: An explicit construction of a certain class of automorphic representations with given Arthur parameter
2012 02 17, W. Gan: Theta correspondence and the local Gross-Prasad conjecture

2012 02 20, G. Savin: Finite Galois groups attached to automorphic representations
2012 02 20, M. Tadić: On tempered and square integrable representations of classical p-adic groups
2012 02 21, N. Gurevich: A new way
integral for the standard L-function on G_2
2012 02 21, U. Goertz: Affine Deligne–Lusztig varieties in the Iwahori case
2012 02 22, E. Lapid: A class of representations of GL_n over a p-adic field
2012 02 23, H. Grobner: Rationality for critical L-values for GL_{2n}
2012 02 23, S. Shin: Fields of rationality for automorphic representations
2012 02 24, G. Henniart: On mod p representations of reductive p-adic groups

2012 02 24, I. Matić: Conservation relation for discrete series of metaplectic groups
2012 03 20, E. Lieb: Applications of Reflection Positivity: Graphene and Other Examples
2012 03 22, T. Weidl: From the colour of the sun to the stability of matter
2012 03 26, A. Montes-Rodríguez: Fourier uniqueness sets and the Klein-Gordon equation
2012 03 26, G. Kozma: Menshov and Privalov
2012 03 26, J. Olsen: Decay estimates for the Balian-Low theorem
2012 03 26, M. Lacey: On the two weight inequality for the Hilbert transform
2012 03 26, M. Reguera Rodriguez: Sharp Békollé estimates for the Bergman projection
2012 03 26, Y. Belov: There is no linear summation method for arbitrary formal Fourier series from exponentials
2012 03 27, A. Borichev: Small polyharmonic functions
2012 03 27, A. Vasiliev: Loewner evolution and integrable systems
2012 03 27, D. Girela: Mean Lipschitz spaces and generalized Hilbert operators
2012 03 27, E. Malinnikova: Boundary behavior of harmonic functions in growth spaces
2012 03 27, E. Saksman: Interpolation of L^p-spaces with complex exponents p, and rotation of quasiconformal maps
2012 03 27, H. Hedenmalm: The random normal matrix ensemble and its polyanalytic generalization
2012 03 28, A. Baranov: Completeness of rank one perturbations of selfadjoint operators
2012 03 28, A. Poltoratski: Bernstein's Problem on Weighted Polynomial Approximation
2012 03 28, C. Sundberg: Approximation by Shifts on Finite Intervals
2012 03 28, D. Vukotic: An overview of certain extremal problems in classical spaces of analytic functions
2012 03 28, S. Richter: Cyclic vectors in the Drury-Arveson space
2012 03 28, W. Ross: Reverse Carleson embeddings for model spaces
2012 03 29, C. Badea: K-spectral sets
2012 03 29, F. Bayart: Composition operators on the polydisk induced by affine maps
2012 03 29, H. Queffélec: Lens maps and composition operators
2012 03 29, J. Conway: Powers and Direct Sums of Operators
2012 03 29, N. Arcozzi: About interpolating sequences for the Dirichlet space
2012 03 29, S. Griveaux: Non-recurrence sets for weakly mixing linear dynamical systems
2012 03 30, M. Englis: Analytic continuation of weighted Bergman kernels
2012 03 30, M. Putinar: Reducing subspaces for analytic multipliers of the Bergman space
2012 03 30, N. Nikolski: Spectrum and Invisible Spectrum of Fourier-Muckenhoupt Multipliers
2012 03 30, S. Pott: On Toeplitz products on Bergman space
2012 04 10, A. Sagnotti: On String theory and Higher Spins
2012 04 10, E. Perlmutter: Black holes in 3D higher spin gravity, part III
2012 04 10, M. Ammon: Black holes in 3D higher spin gravity, part II
2012 04 10, P. Kraus: Black holes in 3D higher spin gravity, part I
2012 04 11, M. Grigoriev: Parent BRST approach to higher spin gauge fields
2012 04 11, N. Boulanger: Off-shell Formulation of Higher-Spin Gravity Part I: Classical Action
2012 04 11, P. Sundell: Off-shell Formulation of Higher-Spin Gravity Part II: BRST-BV Action
2012 04 12, A. Perez Donoso: Regularized action for higher spin gravity in 3D: black holes, global charges and thermodynamics
2012 04 12, A. Waldron: Bulk Conformal Geometry and Solutions to Proca Systems
2012 04 12, J. Buchbinder: Review of BRST Approach to Lagrangian Formulation for Higher Spin Field Theories
2012 04 12, S. Giombi: Higher spin theories, holography and Chern-Simons vector models
2012 04 13, E. Joung: Cubic interactions of massive and massless higher spins in (A)dS
2012 04 13, G. Barnich: Topics in asymptotically flat gravity in 3 and 4 dimensions
2012 04 13, K. Alkalaev: Generating formulation for higher spin gauge fields
2012 04 13, M. Porrati: On the Unitarity of Critical Gravity and Other Higher-Derivative Theories
2012 04 15, A. Rösch: Regularization in Sobolev spaces with fractional order
2012 04 16, A. Campoleoni: Towards a metric-like formulation of three-dimensional higher-spin gauge theories
2012 04 16, D. Polyakov: String Theory and Frame-Like Formalism for Higher Spins
2012 04 16, E. Bergshoeff: Massive Higher-Derivative Gravity
2012 04 16, M. Henneaux: Colloquium: Three-dimensional gravity: a superb theoretical laboratory
2012 04 17, A. Jevicki: On the S-matrices in Vector Model/Higher Spin Correspondence

2012 04 17, H. Afshar: Conformal Chern-Simons gravity
2012 04 17, M. Gary: Beyond AdS holography in 3d higher spin gravity
2012 04 17, M. Vasiliev: Holography, Unfolding and Higher-Spin Theory
2012 04 18, C. Candu: Supersymmetric holography on AdS3
2012 04 18, K. Jin: Higher Spin Black Holes from CFT
2012 04 18, R. Gopakumar: On level-rank duality and the symmetries of minimal model holography
2012 04 18, R. Rahman: Higher-Spin Fermionic Gauge Fields and their Electromagnetic Coupling
2012 04 19, A. Castro: Finite N phenomena in AdS_3 higher spin theories
2012 04 19, C. Iazeolla: Families of exact solutions of 4D higher-spin gravity with spherical, cylindrical and axial symmetry
2012 04 19, S. Didenko: Black holes: from general relativity to higher spins
2012 04 19, X. Bekaert: Towards a bulk dual of the unitary Fermi gas
2012 04 20, M. Henneaux: Higher Spin AdS Supergravity in 2+1 Dimensions and Super W(infinity) algebras
2012 04 23, B. Kaltenbacher: Adaptive discretization of parameter identification problems in PDE's for variational and iterative regularization
2012 04 23, H. Ammari: Resolution and cloaking enhancements
2012 04 23, M. Bertero: Efficient optimization methods for imaging problems with Poisson data
2012 04 23, M. Jiang: 2D Phase Unwrapping Problem
2012 04 23, P. Marechal: A digression about ill-posed problems, intertwining relationships and spectral functions
2012 04 23, R. Ramlau: Inverse Problems in Adaptive Optics
2012 04 23, S. Arridge: Quantitative PhotoAcoustic Tomography
2012 04 24, A. Louis: Feature Reconstruction in Inverse Problems
2012 04 24, B. Hahn: Reconstruction of dynamic objects
2012 04 24, B. Tremoulhéac: Decomposition into low-rank and sparse components in dynamic MR images
2012 04 24, E. Beretta: On the stability issue for some inverse boundary value problems
2012 04 24, G. Teschke: On sampling and sparse recovery
2012 04 24, P. Dülk: Parameter identification problems for differential equations: analytic properties for sparsity reconstructions
2012 04 24, R. Griesmaier: Source reconstruction using windowed Fourier transforms and the filtered backprojection
2012 04 24, R. Strehlow: Norm sensitivity of sparsity regularization with respect to p
2012 04 24, S. Sampath: Multi-parameter regularization in Learning Theory
2012 04 24, S. Siltanen: Electrical impedance imaging using nonlinear Fourier transform
2012 04 24, V. Naumova: Numerical differentiation by means of Legendre polynomials
2012 04 25, K. Kunisch: Parameter Learning as bilevel Optimization Problem (or: how to choose the regularization parameters
2012 04 25, M. Bergounioux: Tomographic reconstruction with few views
2012 04 25, M. Nashed: Conductivity Imaging from Interior Data and Related Nonsmooth Optimization Problems
2012 04 25, S. Kang: Unsupervised multiphase applications and infinite parameter model
2012 04 25, Z. Belhachmi: Control of the regularization for some ill-posed problems in computer vision
2012 04 26, A. Lechleiter: Inverse Medium Scattering and Sparsity Reconstruction
2012 04 26, B. Hofmann: Smoothness concepts in regularization and the autoconvolution problem revisited
2012 04 26, M. Hanke-Bourgeois: One shot inverse scattering methods
2012 04 26, M. Sini: Reconstruction of interfaces using elastic waves
2012 04 26, P. Elbau: Modelling Photoacoustic Sectional Imaging
2012 04 26, T. Hohage: Nonlinear inverse problem with Poisson data
2012 04 27, A. and Markus Grasmair: Non-parametric Instrumental Regression with Non-convex Constraints: an Illustration of Consumer Demand Theory
2012 04 27, A. Benfenati: Image restoration for Poisson data with iterative Bregman regularization procedure
2012 04 27, A. Kirsch: An Inverse Acoustic-Elastic Scattering Problem
2012 04 27, J. Frikel: Sparse regularization in limited angle tomography
2012 04 27, K. Bredies: Inverse problems with measure-based regularization functionals

2012 04 27, L. Seppecher: An acousto-optic imaging model for the reconstruction of the optical absorption parameter
2012 04 27, M. Kar: Reconstruction of interfaces using CGO solutions for the Maxwell equations
2012 04 27, T. Nguyen: Inverse obstacle scattering problems using multifrequency measurements
2012 05 21, A. Felshtyn: Dynamical zeta functions, topological entropy and Reidemeister torsion
2012 05 21, A. Gorodetski: Periodic points of the Fibonacci Trace Map
2012 05 21, F. Gähler: The dynamical zeta function: A powerful tool to understand the topology of a tiling space
2012 05 21, U. Grimm: Squiral Diffraction
2012 05 22, C. Raja: Strong relative property and spectral gap for actions on solenoids
2012 05 22, D. Lind: Periodic points and entropy for algebraic actions
2012 05 22, M. Einsiedler: Effective Equidistribution of closed orbits on homogeneous spaces
2012 05 22, P. Stollmann: Spectral properties of quasicrystal Laplacians
2012 05 23, F. Vivaldi: Near-integrable behaviour in a systems with discrete phase space
2012 05 23, J. Roberts: Periodic orbits for the Casati-Prosen map and the gamma distribution
2012 05 23, N. Neumärker: The structure of preperiodic orbits of toral endomorphisms on the rational lattices
2012 05 24, D. Damanik: The Subshift Conjecture
2012 05 24, E. Robinson Jr.: The core of the Kari-Culik shift
2012 05 24, J. Hunton: The shape of an attractor
2012 05 24, R. Moody: Model sets and dynamical systems
2012 05 25, J. Thuswaldner: S-adic Rauzy fractals
2012 05 25, R. Sharp: Pair correlations and length spectra
2012 05 25, S. Akiyama: On shift radix systems
2012 05 29, D. Stevenson: An introduction to twisted K-theory and higher structures I
2012 05 29, F. Rochon: K-duality on stratified spaces I
2012 05 29, U. Schreiber: Twisted differential structures in string theory I
2012 05 30, D. Stevenson: An introduction to twisted K-theory and higher structures II
2012 05 30, J. Francis: Factorisation algebras and homology I
2012 05 30, U. Schreiber: Twisted differential structures in string theory II
2012 05 31, F. Rochon: K-duality on stratified spaces II
2012 05 31, J. Francis: Factorisation algebras and homology II
2012 05 31, M. Lesch: A gluing formula for the analytic torsion on singular spaces
2012 05 31, U. Schreiber: Twisted differential structures in string theory III
2012 06 01, A. Carey: ∼Analytic K-homology
2012 06 01, A. Degasperis: Integrable nonlinear equations, nonlocal interaction and spectral methods
2012 06 01, M. Lesch: Regular operators in Hilbert C^*-modules
2012 06 01, U. Schreiber: Twisted differential structures in string theory IV
2012 06 04, B. Wang: Thom isomorphism in twisted K-theory
2012 06 04, B. Wang: Twisted geometric cycles and twisted K-homology I
2012 06 04, H. Lipponen: On noncommutative BRST-complex and superconnection character forms
2012 06 04, S. Paycha: The Gauss-Bonnet theorem for the non-commutative torus in the light of pseudodifferential calculus
2012 06 05, B. Wang: Twisted geometric cycles and twisted K-homology II
2012 06 05, F. Rochon: Pseudo differential operators and stratified spaces
2012 06 05, P. Baum: Atiyah-Singer Revisited
2012 06 05, U. Schreiber: Anomalies
2012 06 06, B. Wang: Twisted geometric cycles and twisted K-homology III
2012 06 06, E. Getzler: n - stacks as categories of fibrant objects
2012 06 06, P. Baum: Beyond Ellipticity
2012 06 07, D. Freed: Twisted K-theory and superstrings I
2012 06 07, D. Freed: Twisted K-theory and superstrings II
2012 06 08, D. Freed: Twisted K-theory and superstrings III
2012 06 08, D. Freed: Twisted K-theory and superstrings IV
2012 06 11, C. Schweigert: Bicategories for boundary conditions and for surface defects in 3-d TFT
2012 06 11, D. Freed: Topological phases of matter and K-theory
2012 06 12, C. Teleman: Gauge theory, mirror symmetry, and Langlands duality

2012 06 12, M. Zeinalian: Equivariant holonomy and idfferential K-theory
2012 06 13, D. Gepner: The relative Brauer group of real K-theory
2012 06 13, U. Schreiber: Twisted geometric infinity-bundles
2012 06 14, D. Buchholz: Resolvent Algebras. A New Algebraic Framework For Quantum Physics
2012 06 14, J. Wolfson: A Coherent Framework for the Study of Lie n-Groupoids and their Extensions
2012 06 14, S. Rosenberg: Residue Chern classes and Chern-Simons classes
2012 06 15, E. Getzler: Higher analytic stacks
2012 06 15, T. Nikolaus: Smooth models for the String group
2012 06 19, P. Pandit: Moduli of objects in linear infinity categories
2012 06 20, A. Harju: Twisted K-theory of product manifolds
2012 06 22, J. Santoso: Differential K-Theory
2012 07 12, P. Hajac: The K-Theory of Heegaard Quantum Lens Spaces
2012 07 12, P. Hajac: The K-Theory of the Triple-Toeplitz Deformation of the Real Projective Plane
2012 07 16, M. Joachim: Classification of twists in equivariant K-theory for proper and discrete actions
2012 07 16, P. Jülg: The Baum-Connes conjecture with coefficients for simple Lie groups of rank one
2012 07 17, R. Szabo: String orbifolds and differential equivariant K-theory
2012 07 17, S. Mahanta: Twisted K-theory and K-homology in a bivariant setting
2012 07 18, A. Lai: Spectral action for 1-parameter family of Dirac-type operators on SU(2)
2012 07 18, B. Ćaćić: A reconstruction theorem for (real) almost commutative spectral triples
2012 07 18, G. Landi: Gauge and Higgs fields over noncommutative spaces
2012 07 18, R. Wulkenhaar: Self dual noncommutative ϕ^4 - theory in four dimensions is a nonperturbatively solvable and non-trivial quantum field theory
2012 07 19, B. Mesland: Gauge theory via correspondences in KK-theory
2012 07 19, M. Schlichenmaier: Toeplitz operators and TQFT
2012 07 20, P. Hekmati: Loop group bundles and secondary invariants
2012 07 20, R. Vozzo: Bundles gerbes and abelian lifting problems
2012 07 23, D. Evans: Subfactors, Conformal Field theory and
Twisted Equivarient K-theory
2012 07 23, R. Nest: Index theorems for Fredholm tuples
2012 07 30, G. Rimière: Introduction to Dynamical systems III
2012 07 30, S. Nonnenmacher: Introduction to Dynamical systems I
2012 07 30, S. Nonnenmacher: Introduction to Dynamical systems II
2012 07 30, S. Nonnenmacher: Semiclassical Analysis and Quantum Ergodicity I
2012 07 30, S. Nonnenmacher: Semiclassical Analysis and Quantum Ergodicity II
2012 07 30, Z. Rudnick: Introduction to Quantum Chaos
2012 07 31, G. Rivière: Introduction to Dynamical systems IV
2012 07 31, J. Keating: Random Matrix Theory and Quantum Chaos I
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List of all visitors in 2012

The following codes indicate the association of visitors with particular programmes:

ACG = K-Theory and Quantum Fields
AS12 = Operator Related Function Theory
BSW = Periodic Orbits in Dynamical Systems
CMS = Automorphic Forms: Arithmetic and Geometry
EN = Golod-Shafarevich Groups and Algebras and Rank Gradient
FG = Modern Methods of Time-Frequency Analysis II
GKR = Higher Spin Gravity
HBA-FU: Dynamics of General Relativity: Black Holes and Asymptotics
HST = Recent Developments in the Mathematical Analysis of Large Systems
MSCH = Computational Inverse Problems
NON = EMS/IAMP Summer School on Quantum Chaos
RIT = Research in Teams
SAB = Scientific Advisory Board
SCHW = Individual Scientists
SGC = The interaction of Geometry and RepresentationTheory. Exploring new frontiers
SRF = Senior Research Fellows
VS9 = 9th Vienna Central European Seminar on Particle Physics and Quantum Field Theory: Dark matter, dark energy, black holes and quantum aspects of the universe

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Rodino Luigi, Universita di Torino; 15.10.2012 - 19.10.2012, FG;
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Sawon Justin, University of North Carolina, Chapel Hill; 07.09.2012 - 16.09.2012, SGC;
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Toft Joachim, Linnaeus University, Vaxjoe; 09.10.2012 - 26.10.2012, FG;
Tolic Dijana, Inst. Ruder Boskovic, Zagreb; 29.11.2012 - 02.12.2012, VS9;
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Waldspurger Jean-Loup, CNRS, Paris; 12.02.2012 - 28.02.2012, CMS;
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Warzel Simone, TU München; 01.10.2012 - 05.10.2012, HST;
Weich Tobias, Universität Marburg; 28.07.2012 - 03.08.2012, NON;
Weidl Timo, Universität Stuttgart; 21.03.2012 - 25.03.2012, SCHW;
Wells Raymond, Jacobs University; 09.09.2012 - 16.09.2012, SGC;
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Young Alexander, University of Washington, Seattle; 19.08.2012 - 25.08.2012, EN;
Yuan Wen, Beijing Normal University; 16.09.2012 - 22.09.2012, FG;
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