ESI
Erwin Schrödinger International Institute
for Mathematics and Physics

universität
wien

Scientific Report for 2015

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Preface

The Institute and its Mission

The Erwin Schrödinger International Institute for Mathematics and Physics (ESI), founded in 1993 and part of the University of Vienna since 2011, is committed to the promotion of scholarly research in mathematics and physics. In the beginning its focus was on mathematical physics and mathematics and it has gained an international reputation in these fields of research. Over the years, the thematic spectrum of its scientific activities has been carefully extended, while maintaining high scientific standards. Recently, the ESI has enlarged its fields of competence to include theoretical, computational and experimental aspects of mathematics and physics.

It is the Institute's foremost objective to advance scientific knowledge over broad ranges of fields and themes in mathematics and physics, with an emphasis on the interface between them. Since January 1, 2016, reflecting this long-run extension of scope, the Institute carries the name *Erwin Schrödinger International Institute for Mathematics and Physics.*[1]

Creating an environment where scientists can exchange ideas, and where fruitful collaborations can unfold is imperative to the mission of the ESI. The best way of achieving this goal is to ensure that the ESI continues to interweave leading international scholars, both in mathematics and physics, and the local scientific community. In particular, the research and the interactions that take place at the Institute are meant to have a lasting impact on those who pursue their scientific education in Vienna.

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

The Institute currently pursues its mission in a number of ways

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

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

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

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

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

(e) by a programme of *Junior Research Fellows* (JRF), which supports graduate students or recent postdocs to work on a project of their own that is either connected to a research direction carried out at the University of Vienna or to an ESI thematic programme; this JRF programme was restarted in January 2016;

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

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

Scientific Activities in 2015

The list of research areas in mathematics and physics covered by the scientific activities of the Erwin Schrödinger Institute in 2015 shows a remarkable variety: the following thematic programmes were in place

– *Infinite-dimensional Riemannian Geometry with Applications to Image Matching and Shape Analysis*
January 7 – February 27, 2015
(org.: Martin Bauer (U Vienna), Martins Bruveris (EPF Lausanne), Peter W. Michor (U Vienna))

– *Arithmetic Geometry and Automorphic Representations*
April 7 – May 29, 2015
(org.: Stephen S. Kudla (U Toronto), Michael Rapoport (U Bonn), Joachim Schwermer (U Vienna))

– *Quantum Many-body Systems, Random Matrices, and Disorder*
June 1 – July 31, 2015
(org.: Laszlo Erdös (IST Austria), Robert Seiringer (IST Austria), Simone Warzel (TU Munich))

– *Modern Theory of Wave Equations*
July 6 – September 30, 2015
(org.: Colin Guillarmou (ENS Paris), Werner Müller (U Bonn), Alexander Strohmaier (Loughborough U), András Vasy (Stanford U))

– *Higher Structures in String Theory and Quantum Field Theory*
November 16 – December 18, 2015 (org.: Harald Grosse (U Vienna), Danny Stevenson (U of Adelaide), Richard J. Szabo (Heriot-Watt U, Edinburgh))

The pages of this report provide ample evidence that the quality of the thematic programmes in 2015 was high. These scientific 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 and conferences 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. Here is a list of these activities:

- *The Interrelation between Mathematical Physics, Number Theory and Noncommutative Geometry*
  March 2 – 13, 2015
  (org.: Harald Grosse (U Vienna), Ryszard Nest (U Copenhagen), Walter Van Suijlekom (Radboud U Nijmegen), Stefan Weinzierl (U Mainz))
- *ESI - CECAM Workshop: From Trajectories to Reaction Coordinates: Making Sense of Molecular Simulation Data*
  September 16 – 18, 2015
  (org.: organized by Peter G. Bolhuis (U Amsterdam), Christoph Dellago (U Vienna), Gerhard Hummer (MPI Biophysics, Frankfurt))
- *Ergodic Theory and Holomorphic Dynamics*
  September 28 – October 2, 2015
  (org.: Anna Miriam Benini (U of Rome II, Tor Vergata), Henk Bruin (U Vienna), Dierk Schleicher (Jacobs U Bremen) Sebastian van Strien (Imperial College, London))
- *Higher Topological Quantum Field Theory and Categorical Quantum Mechanics*
  October 19 – 23, 2015
  (org.: Nils Carqueville (U Vienna), Daniel Murfet (U Melbourne), Ingo Runkel (Hamburg U))
- *Several Complex Variables and CR Geometry*,
  November 3 – 13, 2015
  (org.: Siqi Fu (Rutgers U, Camden), Friedrich Haslinger (U Vienna), Bernhard Lamel (U Vienna))

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

In March - June 2015, Primoz Ziherl (U of Ljubljana) gave a course and exercise class on *Soft Matter Physics*. Also in the summer term Sławomir Kołodziej (Jagiellonian University (Krakow)) gave a course on *Nonlinear Elliptic Equations in Geometry*.

By January 1, 2012, the Erwin Schrödinger Institute had established the *Research in Teams Programme* as a new component in its spectrum of scientific activities. The programme provides an opportunity to work at the Institute in Vienna in order to concentrate on new collaborative research in mathematics and physics. The interaction between the team members is a central component of this programme. The number of proposals, on themes of topical interest, was high. However, due to limited resources, the Kollegium could only accept one of these applications for the year 2015, namely:

- F. Kupka and H. Muthsam (U Vienna), A. Petrosyan (Russian Academy of Sciences), O. Pomazan (Nat. Research Nuclear U MEPhI, Moscow), *Multiscale Models of Magneto-hydrodynamic (MHD) Turbulence in Solar Convection, Follow-up from September 2014*, March 19 – April 18, 2015.

Other teams are already accepted for the year 2016. More applications for 2016 resp. 2017 are currently evaluated.

The Institute's Management

Kollegium and Scientific Advisory Board

The ESI is governed at the organizational and scientific level by a board ('Kollegium') of six scholars, necessarily faculty members of the University of Vienna. Their term of office is three years. These members of the board are appointed by the President (Rektor) of the University after consultations with the Deans of the Faculties of Physics and Mathematics. In the period January 1, 2014 - December, 2015, the Kollegium consisted of G. Arzhantseva (Mathematics), P. Chrusciel (Physics), A. Constantin (Mathematics), Ch. Dellago (Physics), A. Hoang (Physics), J. Schwermer (Mathematics). All members of the Kollegium still act as Professors at the University.

In addition, the Scientific Advisory Board (SAB) of the ESI plays the crucial role of a scientific supervision; it also reflects the international ties which are essential for the ESI. In 2015 the composition of the SAB was as follows: Denis Bernard (ENS Paris), Isabelle Gallagher (U Paris-Diderot), Helge Holden (U Trondheim), Daniel Huybrechts (U Bonn), Horst Knörrer [chair] (ETH Zürich), Christian Lubich (U Tübingen), Vincent Rivasseau (U Paris-Sud, Orsay), and Catharina Stroppel (U Bonn).

The composition of the SAB of the ESI changed by the end of the year 2015. After two terms of office, Horst Knörrer and Vincent Rivasseau left the Board. The Institute is extremely thankful to both of them for many years of valuable advice and support. Stefano Ruffo (SISSA, Trieste) and Martin Zirnbauer (U Cologne) joined the Board on January 1, 2016, as new members.

Administration

The composition of the administrative staff of the ESI changed within the year 2015. Alexandra Katzer left the Institute, and Sophie Kurzmann joined the team whose members continued to work with their customary efficiency towards our visitors, research fellows and scientific staff.

Joachim Schwermer May 15, 2016

Director

Erwin Schrödinger International Institute for Mathematics and Physics

The ESI in 2015

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

Kollegium of the Research Centre ESI at the University of Vienna: Joachim Schwermer (ESI Director), Goulnara Arzhantseva (ESI Deputy Director), Christoph Dellago (ESI Deputy Director), Piotr T. Chruściel, Adrian Constantin, Andre Hoang.

Administration of the Research Centre ESI at the University of Vienna: Sophie Kurzmann, Maria Marouschek, Beatrix Wolf (Head of Administration).

Computing and networking support of the Research Centre ESI at the University of Vienna: Sascha Biberhofer, Thomas Leitner.

International Scientific Advisory Board in 2015:

Denis Bernard (ENS Paris)	Horst Knörrer (ETH Zürich) [chair]
Isabelle Gallagher (U Paris-Diderot)	Christian Lubich (U Tübingen)
Helge Holden (U Trondheim)	Vincent Rivasseau (U Paris-Sud, Orsay)
Daniel Huybrechts (U Bonn)	Catharina Stroppel (U Bonn)

Budget and visitors: In 2015 the support of ESI from the Austrian Federal Ministry of Science, Research and Economy received via the University of Vienna was € 812 000. The total spending on scientific activities in the year 2015 was € 299 775 (ESI) plus € 165 793 (third party funds), in total € 465 568 and on administration, infrastructure, and reconstruction work € 420 138.

The number of scientists visiting the Erwin Schrödinger Institute in 2015 was 591, see pages 81–92.

ESI research documentation: Starting from January 2013, the ESI research outcome is tracked using the published articles and the arXiv database. The ESI website provides web links to these arXiv preprints resp. to the local ESI preprints collected until December 2013. It also contains the bibliographical data of the already published articles. Moreover, publications which appeared in 2015 but are related to past ESI activities, starting from 2011, have been tracked as well in order to provide a long-term evidence of the ESI research outcome success.

The total number of preprints and publications contributed to the ESI research documentation database in 2015 is 98 [related to the activities in 2015: 75, related to the activities in previous years: 23], see pages 74–80 for details.

The Foundation ESI
President: Klaus Schmidt

Scientific Reports

Main Research Programmes

Infinite-dimensional Riemannian Geometry with Applications to Image Matching and Shape Analysis

Organizers: Martin Bauer (U Vienna), Martins Bruveris (Brunel), Peter W. Michor (U Vienna)

Dates: January 7 – February 27, 2015

Budget: ESI € 44 240

Report on the programme

The aim of this programme was to bring together researchers in pure and applied mathematics in order to expand and deepen our understanding of infinite-dimensional manifolds and their Riemannian geometry, with special emphasis on those manifolds, which are used in shape analysis, image matching and computational anatomy.

Among the manifolds of interest are the spaces of plane and space curves, the space of immersed surfaces and more generally spaces of mappings between finite-dimensional manifolds. A special case, that is interesting in its own right, is the diffeomorphism group, that is the space of invertible maps of a manifold to itself, as well as its subgroups: the group of volume preserving diffeomorphisms, the symplectomorphism group, and the contactomorphism group. Also related are manifolds of tensor fields on a finite-dimensional manifold, including the manifold of Riemannian metrics and the space of probability densities.

The interest in the diffeomorphism group is motivated by its relation to hydrodynamics. Arnold noted in 1966 that Euler's equations, which govern the motion of ideal, incompressible fluids, can be interpreted as geodesic equations on the group of volume preserving diffeomorphisms with respect to a suitable Riemannian metric. Since then other PDEs arising in physics have been interpreted as geodesic equations on the diffeomorphism group or related spaces. Examples include Burgers' equation in fluid mechanics, the KdV and Camassa–Holm equations in hydrodynamics, the Hunter–Saxton equation in the theory of nematic liquid crystals and the governing equations of ideal magnetohydrodynamics. The geometric approach has led to a proof of local well-posedness for some of these PDEs, including Euler's equations, as well as to results on stability of solutions.

In a similar spirit, distances on the space of probability densities, that are used in optimal transport and information geometry can be interpreted from the point of view of Riemannian geometry. The Wasserstein distance as well as the Fisher–Rao information metric are geodesic distance functions for suitable Riemannian metrics on the space of probability densities. Furthermore, since the diffeomorphism group acts on the space of densities by push-forward, these

Riemannian metrics arise as projections of metrics on the diffeomorphism group. This connection between the diffeomorphism group and the space of densities is still an active area of investigation.

Activities

During the programme we hosted two week-long workshops on Riemannian geometry in infinite-dimensions. The first workshop concentrated on theoretical aspects as well as connections with physics, while the second workshop was focused on applications to image matching, shape analysis and computational anatomy. Furthermore we organized three series of introductory "master lectures", each of them consisting of four talks.

- Peter W. Michor: *Overview of convenient calculus and differential geometry in infinite dimensions, with applications to diffeomorphism groups and shape spaces.*

  Abstract: This series of talks presented an overview of various notions of shape spaces, including the space of parametrized and unparametrized curves, the space of immersions, the diffeomorphism group and the space of Riemannian metrics. The Riemannian metrics that can be defined thereon were discussed. Particular emphasis was put on the induced geodesic distance, the geodesic equation and its well-posedness, geodesic and metric completeness and properties of the curvature.

- Gerard Misiołek: *Geometry and analysis of the incompressible Euler equations.*

  Abstract: In the first part of the lecture series the geometric approach to the Euler equations of hydrodynamics initiated by V. Arnold was discussed. Present results on the structure of singularities of the L^2-Riemannian exponential map on the group of volume-preserving diffeomorphisms were discussed. In the second part recent progress on ill-posedness of the Cauchy problem for the Euler equations in the various function spaces including the borderline spaces $C^1, B^1_{\infty,1}$ were presented.

- Xavier Pennec: *Geometric structures for statistics on shapes and deformations in computational anatomy.*

  Abstract: Computational anatomy is an emerging discipline at the interface of geometry, statistics, image analysis and medicine that aims at analysing and modelling the biological variability of the organs shapes at the population level. The goal is to model the mean anatomy and its normal variation among a population and to discover morphological differences between normal and pathological populations. For instance, the analysis of population-wise structural brain changes with ageing in Alzheimer's disease requires first the analysis of longitudinal morphological changes for a specific subject. This can be evaluated through the non-rigid registration. Second, to perform a longitudinal group-wise analysis, the subject-specific longitudinal trajectories need to be transported in a common reference (using some parallel transport). To reach this goal, one needs to design a consistent statistical framework on manifolds and Lie groups.

In the remaining weeks of the programme we organized various seminar talks, including two lectures at the colloquium of the faculty for mathematics of the university of Vienna:

- David G. Ebin: *Constraining forces and a problem in fluid motion.*
- Adrian Nachmann: *Reconstruction method for the Calderón problem with partial data.*

The activities at the programme resulted in a total of ∼80 talks. In conjunction with the programme, there will be a special issue on Infinite-Dimensional Riemannian Geometry in the Journal of Geometric Mechanics. The articles for the special issue are currently under review amd we expect publication by end of 2016.

In the following we will describe the topics of the two workshops in more detail.

Workshop 1

During the first workshop we had 24 presentations, that were mainly concerned with the theoretical aspects of the field. In the following we want to describe some of the questions, that were treated in this week: manifolds of mappings and the diffeomorphism group are infinite-dimensional Riemannian manifolds carrying a weak Riemannian metric. This is a metric, which is not an isomorphism between the tangent bundle and its dual. As a consequence several results that are standard for finite-dimensional manifolds may fail in the infinite-dimensional case.

The geodesic equation on spaces of mappings is usually a nonlinear combination of PDEs and ΨDEs and therefore existence of geodesics is not obvious. Metrics, for which the well-posedness of the geodesic equation is still an open question include Sobolev-type metrics of fractional order on the diffeomorphism group and the so-called "almost-local" metrics on the space of immersions.

A Riemannian metric defines the geodesic distance function and thus the manifold becomes a metric space. In finite dimensions the topology of this metric space coincides with the manifold topology. For infinite-dimensional manifolds with weak Riemannian metrics the behaviour of the geodesic distance is more complicated. The distance function can vanish identically as it does on the space of immersions with respect to the L^2-type metric. On several Riemannian manifolds it is still unknown, whether the geodesic distance vanishes or not. Even when the distance doesn't vanish, describing the topology of the resulting metric space and the metric completion are challenging questions. Another problem, which is open for many manifolds, is to find bounds on the geodesic distance, using quantities that can be computed more explicitly.

While the reasons for the vanishing of the geodesic distance are not completely clear, there seems to be a relation with locally unbounded positive sectional curvature. It is possible to compute a formula for the curvature tensor for various families of metrics on the diffeomorphism group, on the space of immersions as well as for other spaces. Apart from some special cases the curvature tensor is indefinite and explicit bounds on the positive and negative parts are rarely known. A better understanding of the curvature tensor would lead to more reliable statistical models in shape analysis and other applications.

Workshop 2

The diffeomorphism group and other mapping spaces play a central role in the field of computational anatomy. The space of medical images is acted upon by the diffeomorphism group and differences between images are encoded by diffeomorphisms in the spirit of Grenander's pattern theory. The study of anatomical shapes is thus reduced to the study of the diffeomorphism group. Several problems of interest to computational anatomy whose solution requires new geometrical tools or raises interesting mathematical questions relating to infinite-dimensional spaces.

This relation between infinte dimensional geometry and applications to medical imaging were the topic of the second workshop. We will now sketch some of the topics that were discussed: Pairwise image registration is the problem of finding an invertible map giving the point-to-point correspondences between two images. A variety of mathematical methods have been developed during the last decades to address this problem. Group-wise registration, i.e. finding consistent

correspondences across a collection of images, on the other hand still remains a challenge. This is due to the non commutativity of the diffeomorphism group, lack of bi-invariant metrics and the presence of noise in the images.

The deformations between anatomical shapes exhaust only a small part of the diffeomorphism group. The mathematical task is to find methods that allow us to describe or approximate this set of anatomically meaningful deformations. Possible approaches include statistical methods to learn submanifolds, estimating probability densities on the diffeomorphism group and finding ways to adapt the Riemannian metric on the diffeomorphism group to a given data set.

Riemannian geometry provides a very comfortable setting for statistics on manifolds. A Riemannian metric equips the manifold with the global structure of a metric space, which can be used to define means of data sets and to measure closeness of points. It provides the notion of geodesics, which enable us to generalize linear regression from Euclidean space to shape space. Furthermore it allows us to approximate the space locally with a linear space using the exponential map with second order corrections given by curvature. Finally parallel transport enables us to identify tangent spaces at different points and thus to transfer information between them.

However given the lack of bi-invariant and the scarcity of flat Riemannian metrics on the diffeomorphism group, Riemannian metrics might result in a too restrictive statistical framework. In order to obtain bi-invariant means or a curvature-free notion of parallel transport one has to look for statistical frameworks based on less structure. Possible candidates are connections, that are not necessarily induced by a Riemannian metric or Finsler metrics. The challenge is to study properties of these structures and their relation to shape analysis.

Outcomes and achievements

In the course of the programme a variety of new collaborations and projects has been started. In the following we want to mention only a few examples:

- M. Bauer, B. Kolev, S. Preston: Conjugate points for the $H^{1/2}$-metric on the diffeomorphism group.
- M. Bauer, M. Bruveris, E. Cismas, J. Escher, B. Kolev: Local and Global Well-posedness of the fractional order EPDiff equation on a compact manifold M.
- M. Bauer, M. Bruveris, P. Harms: Soliton-like solutions on the manifold of plane curves.
- M. Bauer, M. Bruveris, P. Harms, Jakob Møller-Andersen: Numerics for higher-order Sobolev-type metrics.
- M. Bauer, K. Modin and S. Joshi: Optimal information density matching with applications to lung imaging.

Some of these collaborations have already resulted in the following

Preprints and publications

P. Balseiro, T. J. Stuchi, A. Cabrera, J. Koiller, *About simple variational splines from the Hamiltonian viewpoint*, 2016.

E. Bardelli, A. C. G. Mennucci. *Probability measures on infinite dimensional Stiefel manifolds*, 2016.

Martin Bauer, Peter W. Michor, Olaf Müller, *Riemannian geometry of the space of volume preserving immersions*.

Martin Bauer, Martins Bruveris, Philipp Harms, Jakob Møller-Andersen, *A numerical framework for Sobolev metrics on the space of curves*, arXiv:1603.03480, Code available on https://github.com/h2metrics/h2metrics.

Martin Bauer, Martins Bruveris, Philipp Harms, Jakob Møller-Andersen, *Second order elastic metrics on the shape space of curves*, 1st International Workshop on Differential Geometry in Computer Vision for Analysis of Shapes, Images and Trajectories, 2015, arXiv:1507.08816.

Martin Bauer, Martins Bruveris, Philipp Harms, Jakob Møller-Andersen, *Curve Matching with Applications in Medical Imaging*, 5th MICCAI Workshop on Mathematical Foundations of Computational Anatomy, 2015, arXiv:1506.08840.

M. Bauer, B. Kolev and S. Preston, *Geometric investigations of a vorticity model equation*, Journal of Differential Equations (1), 260 (2016), Pages 478516.

M. Bruveris, *Optimal reparametrizations in the square root velocity framework*, 2015. Preprint available at arXiv:1507.02728.

S. Calamai, D. Petrecca, K. Zheng, *The Geodesic Problem for the Dirichlet Metric and the Ebin Metric on the Space of Sasakian Metrics*.

B. Chhay, *Contactomorphism Group with the L^2 Metric on Stream Functions*.

F. Gay-Balmaz, *Well-posedness of higher dimensional Camassa-Holm equations on manifolds with boundary*, 2016.

N. Konovenko, V. Lychagin, *Lobachevskian geometry in image recognition*, Lobachevskii Journal of Mathematics.

V. Lychagin, V. Yumaguzhin, *Invariants in Relativity Theory*, Lobachevskii Journal of Mathematics.

C. Rottman , M. Bauer, S. Joshi and K. Modin, Weighted Diffeomorphic Density Matching with Applications to Thoracic Image Registration, 5th MICCAI workshop on Mathematical Foundations of Computational Anatomy, 2015.

Stefan Sommer, *Evolution Equations with Anisotropic Distributions and diffusion PCA*, accepted for the GSI15 conference.

S. Sommer, A. M. Svane, *Modelling anisotropic covariance using stochastic development and sub-Riemannian frame bundle geometry*, 2016.

A. B. Tumpach, S. C. Preston, *Quotient elastic metrics on the manifold of arc-length parametrized plane loops*, 2016.

A. B. Tumpach, H. Drira, M. Daoudi, A. Srivastava, *Gauge Invariant Framework for Shape Analysis of Surfaces*, Transactions on Pattern Analysis and Machine Intelligence.

We expect that other publications and preprints will be written in the coming months. Another outcome of this programme is a special issue in the Journal of Geometric mechanics that is currently being prepared.

List of talks

First Workshop: Infinite-dimensional Riemannian geometry, January 12 – 16, 2015

Boris Kolev	Local and global well-posedness of the fractional order EPDiff equation on $\mathbb{R}^d$
Peter W. Michor	Uniqueness of the Fisher–Rao metric on the space of smooth densities
Thomas Kappeler	On the convexity of the KdV Hamiltonian
Valentin Lychagin	Lobachevsky geometry and image recognition
Valentin Lychagin	Invariants of diffeomorphism group actions
Yuri Neretin	The group of diffeomorphisms of the circle and its completions
Armin Rainer	On Lie groups of diffeomorphisms generated by time-dependent vector fields
Stephen Preston	The exponential map on the area-preserving diffeomorphism group for a bounded surface
Pearce Washabaugh	On the geometry of axisymmetric fluid flows with swirl
Boramey Chhay	Conjugate points on the group of contactomorphisms
James Benn	L^2-geometry of the symplectomorphism group
David G. Ebin	The initial value problem for fluids with free boundary and surface tension
Klas Modin	Diffeomorphic density matching using Fisher–Rao geodesics
Christian Becker	String connections via the caloron correspondence
Sylvain Arguillère	Infinite-dimensional sub-Riemannian geometry
Emmanuel Trélat	Sub-Riemannian structures on the group of diffeomorphisms
Jakob Møller-Andersen	An example of a shape space modelled on Hilbert space
Jean-Paul Gauthier	Reconstruction and pattern recognition via the Petitot model of the primary visual cortex
Andrea Mennucci	Probabilities and manifolds
Mario Micheli	Matrix-valued kernels for shape deformation analysis
Sergey Kushnarev	PCA on manifolds: applications to spaces of landmarks
Kai Zheng	The gradient and the weighted metrics for the space of Kähler metrics
Ugo Boscain	The intrinsic hypoelliptic Laplacian on sub-Riemannian manifolds
François Gay-Balmaz	Infinite-dimensional manifold structures on spaces of submanifolds with boundary

Second Workshop: Riemannian geometry in shape analysis and computational anatomy, February 16 – 20, 2015

Michael Miller	Bayesian models in computational anatomy, neurodegenerative illnesses and Brain Clouds
Helmut Pottmann	Freeform architecture and differential geometry
Henry Jacobs	Approximation of diffeomorphisms with $U(n)$ and the Hilbert–Schmidt group
Volker Schulz	On the usage of the Riemannian geometry framework for PDE constrained shape optimization
Jair Koiller	On the comparison of short processes
Laurent Risser	Designing and learning Riemannian metrics in medical imaging (part I)
François-Xavier Vialard	Designing and learning Riemannian metrics in medical imaging (part II)
Stephanie Allassonnière	Bayesian mixed effect atlas estimation with a LDDMM deformation model
Stanley Durrleman	Morphometry in neuroimaging
Irène Kaltenmark	A growth model in computational anatomy based on diffeomorphic matching
Barbara Gris	Shape statistics with modular multi-scale diffeomorphic deformations
Anuj Srivastava	Rate-invariant analysis of covariance trajectories with applications to video-based action recognition
Eric Klassen	Precise matching of piecewise linear curves using the square root velocity function (part I)
Ganesh Sundaramoorthi	Deformable shape tracking and a new region-based Sobolev metric
Xavier Pennec	On an extension of PCA on manifolds

Stephen Marsland	Shape and image invariants under Lie group actions
Nicole Sanderson	Simplicial multivalued maps and the witness complex
Fred Bookstein	Scaling dimension: a promising new parameter for morphometrics of organisms
Marc Arnaudon	A stochastic algorithm finding generalized means on compact manifolds
Giacomo Nardi	Matching of geometric-functional structures via a BV-energy
Stefan Sommer	Diffusion processes and dimensionality reduction on manifolds with affine connection
François Demoures	Stochastic multisymplectic variational integrators for SE(3)-strand
José Iglesias	A level set method for the matching of implicit surfaces

Individual talks

Martins Bruveris	Optimal reparametrizations in the square root velocity framework
David G. Ebin	Constraining forces and problems of fluid motion
Boris Khesin	Steady Euler flows on hyperbolic plane
Boris Khesin	Symplectic fluids and point vortices
Eric Klassen	Precise matching of piecewise linear curves using the square root velocity function (part II)
Leandro Lichtenfelz	Nonuniqueness of solutions of the Navier–Stokes equations on negatively curved manifolds
Sarang Joshi	Analyzing the changing anatomy
Stephen Marsland	Shape statistics in Weitzenböck space
Facundo Mémoli	The shape space defined by the Gromov–Wasserstein distance
Peter W. Michor	Overview on convenient calculus and differential geometry in infinite dimensions, with applications to diffeomorphism groups and shape spaces I-V
Nina Miolane	Statistics on Lie groups: can we obtain a consistent framework with pseudo-Riemannian metrics?
Gerard Misiołek	Geometry and analysis of the incompressible Euler equations I-IV
Adrian Nachman	Reconstruction method for the Calderon problem
Karl-Hermann Neeb	Realization of reducible positive energy representations of the Virasoro group in spaces of holomorphic section
Yuri Neretin	The space of holomorphic functionals on the space of univalent functions and actions of the group of diffeomorphisms of the circle
Xavier Pennec	Geometric structures for statistics on shapes and deformations in computational anatomy I-IV
Gabriel Peyré	A review of Wasserstein barycenter algorithms, with a new one
Stephen Preston	The geometry of whips and chains
Tudor Ratiu	Representations of continuum mechanics models
Bernhard Schmitzer	Contour manifolds and optimal transport in variational image segmentation
Karsten Tabelow	msPOAS - an adaptive densoising procedure for dMRI data
Cornelia Vizman	Coadjoint orbits of diffeomorphism groups via dual pairs
Kathrin Welker	A Riemannian view on PDE constrained shape optimization

Invited scientists

Stephanie Allassonniere, Sylvain Arguillére, Marc Arnaudon, Martin Bauer, Christian Becker, James Benn, Fred Bookstein, Ugo Boscain, Martins Bruveris, Benjamin Charlier, Boramey Chhay, Piotr Chrusciel, Emanuel Cismas, Francois Demoures, Stanley Durrleman, David Ebin, Markus Eslitzbichler, Jean-Paul Gauthier, Francois Gay-Balmaz Joan Alexis Glaunès, Barbara Gris, Philipp Harms, Julian Hodgson, José A. Iglesias, Henry Jacobs, Sarang Joshi, Irene Kaltenmark, Thomas Kappeler, Boris Khesin, Eric Klassen, Jair Koiller, Boris Kolev, Nadiia Konovenko, Sergej Kushnarev, Alice Le Brigant, Jae Min Lee, Leandro Lichtenfelz, Valentin Lychagin, Tony Lyons, Stephen Marsland, Facundo Mémoli, Andrea C. Mennucci, Mario Micheli, Peter Michor, Michael Miller, Washington Mio, Nina

Miolane, Gerard Misiolek, Klas Modin, Jakob Møller-Andersen, Adrian Nachman, Akil Narayan, Giacomo Nardi, Karl Hermann Neeb, Yuri Neretin, Marc Niethammer, Susovan Pal, Xavier Pennec, Gabriel Peyré, Helmut Pottmann, Stephan Carl Preston, Armin Rainer, Tudor Ratiu, Laurent Risser, Pierre Rousillon, Nikki Sanderson, Bernhard Schmitzer, Otmar Scherzer, Volker Schulz, Stefan Sommer, Anuj Srivastava, Ganesh Sundaramoorthi, Karsten Tabelow, Émmanuel Trélat, Alain Trouvé, Barbara Tumpach, Alexander Vasiliev, Francois-Xavier Vialard, Cornelia Vizman, Pearce Washabaugh, Enxin Wu, Kathrin Welker, Shihui Ying, Sirong Zhang, Kai Zheng.

Arithmetic geometry and automorphic representations

Organizers: Stephen S. Kudla (U Toronto), Michael Rapoport (U Bonn), Joachim Schwermer (U Vienna)

Dates: April 7 - May 29, 2015

Budget: ESI € 34 800

Report on the programme

Summary: This programme dealt with new research directions involving automorphic representations and their interplay with geometry, specifically, the arithmetic geometry of Shimura varieties and the cohomology of arithmetic groups. The main overarching themes have been:

(1) progress on establishing the Gross-Prasad conjectures about certain branching laws for automorphic representations with applications to the arithmetic intersection theory of special algebraic cycles on products of orthogonal and unitary Shimura varieties,

(2) new results on the geometry of integral models and local models of Shimura varieties, including those which are not moduli spaces for abelian varieties,

(3) mixed Hodge structures, residues of Eisenstein series and cohomology of Shimura varieties, and

The programme brought together the leading experts involved in these developments, among which there are many important interconnections, to survey the present state of our knowledge and to foster new collaborative efforts.

Background: The interconnections between arithmetic geometry and the theory of automorphic representations are profound and have deep historical roots. Already in the work of Gauss one can see the interplay of geometry and arithmetic. For example in his study of the problem of dissecting the circle (constructibility of the regular 17-gon) and the analogous problem of dissecting the leminscate, one sees the roots of theories which would preoccupy mathematicians for the following two centuries, the construction of class fields, elliptic curves and the theory of complex multiplication. Although the language has shifted over time, the deep vein uncovered in the early 19th century remains a rich source of beautiful and surprising mathematics.

In the middle of the 20th century, Hasse and Weil introduced L-series that encode the number of solutions of polynomial equations mod p as the prime p varies and the quest to establish their analytic properties (which remain mostly conjectural even now) has driven many fundamental developments in arithmetic geometry, e.g., étale cohomology, ℓ-adic cohomology, and the theory of motives. Hasse, Weil, Deuring, Eichler and Shimura realized that in the case of

elliptic curves with complex multiplication and modular curves, the L-functions arising from geometry can be expressed in terms of the L-functions for modular forms. Such a relation allows one to establish their analytic properties (analytic continuation, functional equations, etc.) Moreover, the analytic expressions for the L-functions provide the basis for the investigation of their special values at critical points.

One of the main achievements in the arithmetic theory of automorphic forms is a generalization of these automorphic expressions for Hasse-Weil L-functions to a large class of Shimura varieties, thanks to work of Langlands, Kottwitz, and many others. Here many open problems remain, particularly concerning the geometry of the Shimura varieties at primes of bad reduction and the expression of the corresponding Euler factors in terms of automorphic forms. This motives the introduction and study of local models of Shimura varieties. Indeed, such problems were one of the main topics of the programme.

Fundamental relationships between special values of L-functions of smooth projective varieties over number fields (or of motives) and arithmetic invariants of such varieties are encoded in the conjectures of Deligne and of Bloch-Kato. For example, the most interesting ingredient in their conjectural expression for the leading term of such an L-function at the central critical point is (a determinant of) the height pairing(s) of suitable algebraic cycles. Of course, these conjectures assume the conjectural analytic properties of the L-functions in question, so, as a more feasible problem, one can try to establish cases of these conjectures for the L-functions of Shimura varieties. Already in the simplest example of modular curves or elliptic curves, this amounts to the Birch–Swinnerton-Dyer conjecture, a Clay Math prize problem. But if one further restricts to the case in which a supply of explicitly constructed cycles exists – in this case Heegner points – then the celebrated Gross-Zagier formula provides an explicit formula for the central derivative in terms of a height pairing of such points. Here, of course, the root number (sign of the functional equation of the L-function) is assumed to be -1.

The Gross-Prasad conjectures have their origin in Gross's search for examples of Shimura varieties of odd dimension $2n-1$ with explicitly constructed algebraic cycles of codimension n for which a Bloch-Beilinson height pairing is thus defined. More importantly, one needs to establish (or conjecture) a link between local root numbers and the existence of invariant linear forms on the relevant automorphic representations. This link provides a systematic supply of automorphic L-functions with odd functional equation and hence with vanishing central value. Two sets of conjectures result, one set providing very delicate predictions about the branching behavior of the automorphic representation of orthogonal and unitary groups based on local root numbers and a second set predicting relations between height pairings of Hecke eigencomponents of the algebraic cycles and the central derivative of a corresponding automorphic L-function. Important recent developments concerning aspects of both parts of these conjectures have been dealt within this programme.

Of course, many of the most interesting Shimura varieties are only quasi-projective, and, while much is known about their compactifications, for example, toroidal compactifications and their arithmetic analogues, many important questions remain. The Betti cohomology of such varieties carries both a mixed Hodge structure and in particular a weight filtration, encoding information about the boundary of their compactification, and an automorphic filtration arising from the expression of this cohomology in terms of automorphic forms. The relation between these structures and, most importantly, the role played by the residues of Eisenstein series and special values of automorphic L-functions and their derivatives were the third main focus of the programme.

Finally, in all of these developments in geometry and arithmetic, the theory of automorphic representations as formulated in the Langlands program plays an absolutely essential role.

Recently, through the work of Arthur, Ngo and many others, fundamental progress has been achieved on the structure of the automorphic representations of classical groups and the theory of endoscopy. But the Langlands functoriality principle predicts relations among automorphic representations beyond those covered by endoscopy, and Langlands has proposed a method of attacking the formidable problem of proving the existence of such relations using the trace formula.

Activities

There was a tremendous amount of mathematical energy and interaction during the program. The list of topics and lecture activity [see below] is very substantial and impressive and the organizers certainly achieved what they had proposed, namely to bring together leading experts in an ideal environment for mathematical interaction.

Two Workshops were at the core of the programme:

Workshop 1: April 20 - 24, 2015
"Local Models of Shimura Varieties and related Topics".

Workshop 2: May 6 - 22, 2015
"Automorphic Forms - Geometry and Arithmetic".

Specific information on the programme

Workshop 1:

The first week of this activity had a distinct algebro-geometric flavor. At the center of this first week was the workshop on the geometry of Shimura varieties and other related varieties, and its relation to the fundamental problems in the theory of automorphic forms. To underline the coherence of this activity, we describe below in a structured way the main currents represented during the first week and its workshop.

Structure of local models of Shimura varieties. Here the concern is the singularities occurring in the reduction of Shimura varieties with parahoric level structure. By the *local model diagram*, this comes down to studying the functorial description, the singularities, and the stratifications of local models. T. Haines gave a new simplified combinatorial description of the *admissible set* which describes the set of strata of a local model, thus confirming a conjecture of Pappas/Rapoport/Smithling. B. Smithling gave a moduli-theoretical description of the local model in the case of a unitary Shimura variety of signature $(n-1,1)$ with *special* parahoric level structure. U. Görtz gave an elementary geometric description of some local models, by relating them to quiver Grassmannians in the sense of Zelevinsky.

Reduction of Shimura varieties. Under this heading fall the investigations of T. Haines and B. Stroh of arithmetic models of Shimura varieties with $\Gamma_1(p)$-structure. What is remarkable about this work is that it goes beyond the much-studied case of a parahoric level structure. The first study of this kind of a level structure is due to T. Haines and M. Rapoport and concerns the reduction in the case of a unitary Shimura variety at a prime which splits. The general case considered by T. Haines and B. Stroh, for which the Siegel moduli space is a representative

example, displays quite different features and leads to very interesting questions. One question addressed in the inter-coordinated talks of T. Haines and B. Stroh was whether the theory of local models, so successful in the cases of parahoric level structure, can be extended to these cases.

In this relation, one can also mention the investigations of U. Görtz and X. He, presented at the workshop by U. Görtz. They give an essentially complete list of Shimura varieties with parahoric level structure such that their *basic locus* can be described explicitly in terms of Deligne-Lusztig varieties. They actually address in their work the equal-characteristic analogue, but there is little doubt that their list should transpose to the context of this heading.

Tools in the study of reductions. Under this heading falls the work of A. Langer and T. Zink, presented by T. Zink at the workshop. This work extends to higher degree cohomology the Dieudonné theory for p-divisible groups that is given by *display theory*. In particular, Langer and Zink explained their version of the Grothendieck-Messing deformation theory in the context of K3-surfaces and varieties with similar higher degree cohomology (like hypersurfaces of degree 4 in projective space of dimension 5).

The arithmetic Gan-Gross-Prasad conjecture. M. Rapoport explained a version of the *Arithmetic Fundamental Lemma*-conjecture of W. Zhang in the presence of bad reduction of the underlying Shimura variety (joint work of Rapoport/Smithling/Zhang). The original conjecture of Zhang is closely related to the arithmetic Gan-Gross-Prasad conjecture. The version for bad reduction leads to a series of conjectures on local models, which were discussed by the participants of the workshop.

Cohomology of Shimura varieties. A. Scholl discussed in his talk his joint work with J. Nekovar on the cohomology of Shimura varieties, where the underlying Shimura data come from an algebraic group arising by restriction of scalars (like the Hilbert-Blumenthal Shimura varieties). This situation leads to a new conjectural cohomology theory called the *plectic cohomology*.

Families of trianguline Galois representations. The talk by E. Hellmann was not about Shimura varieties, but rather about certain adic spaces parametrizing trianguline Galois representations. However, the methods to study these parameter spaces have their origin in the theory of Shimura varieties. Furthermore, the results of this theory, conjectural or actually proved, are of relevance in the theory of p-adic deformations of automorphic forms.

Workshop 2:

The second workshop of the programme had a somewhat unusual format. It extended over three weeks, with 2 or 3 lectures most days and several days with no scheduled lectures. This format was due, in part, to fact that the visits of the participants were spread out over the period of the programme. But it was also intended to provide more time for mathematical discussions, collaborations, and concentrated work than is normally available with a more compressed workshop format. Based on feedback from the participants and our own experience, the result of this format was an open and very fruitful working environment.

The lectures of the second workshop covered a broad range of topics, reflecting the rich interplay of mathematical ideas which is one of the most attractive aspects of this area of research. Topics included representation theory, automorphic representations, automorphic forms, in particular, their classical, spectral and p-adic aspects, cohomology of arithmetic groups, connections with motives and L-values, and arithmetic geometry. Here is a summary with a few more details.

Representation theory. Much work in this area is ultimately motivated by the role it plays in the Langlands programme, the trace formula, and the study of L-functions. All of these themes were touched upon in the lectures of the workshop. Cogdell and Shahidi discussed the behavior of ε-factors in the local Langlands correspondence. In particular, Cogdell gave an exposition of his proof, joint with Shahidi and Tsai, of the preservation of exterior and symmetric square ε-factors and Shahidi outlined an axiomatic approach for proving the coincidence of the set of Artin factors with a set of analytically defined factors in more general cases, including, for example, exterior cubes. Moeglin described progress on the determination of the structure of the archimedean A-packets, in particular, the computation of local multiplicities. Shin explained joint work with Kim and Tempier on limit formulas and upper bounds on formal degrees of supercuspidal representations of p-adic groups. Their results are expected to have applications to problems in the low-lying statistics of certain families of automorphic L-functions. Waldspurger described joint work with Lemaire and Moeglin in which they give a local proof of the fact that the fundamental lemma for the whole Hecke algebra follows from the fundamental lemma for the unit element. Their proof applies to the important case of twisted endoscopy and provides relations essential to the global applications of the trace formula. Lapid discussed joint work with Minguez which provides combinatorial conditions the the irreducibility of certain induced representations in the non-archimedean case. Such irreducibility is a crucial ingredient in, for example, Minguez proof of the local Howe duality conjecture in the case of dual pairs of type II. Finally, Gan explained progress on the extension of Langlands 'reciprocity' relations, or local Langlands conjectures, to the case of non-linear groups both local and global. This is a very intriguing development which is still in its early stages.

Automorphic representations and automorphic forms. This is a highly developed and very vibrant area of research and the lectures of the workshop covered several of its many aspects. One of these is the study of the automorphic forms constructed from Eisenstein series and their residues. Hanzler described joint work with Múic on the automorphic representations generated by degenerate Eisenstein series for the groups Sp_n and GL_n. Jing Feng Lau discussed the residual spectrum for quasi-split groups of type D_4. The work of Arthur on classification of automorphic representations of classical groups leads to many interesting questions. For example, Dihua Jiang described progress on the problem of determining which global Arthur packets consist entirely of cuspidal automorphic representations and which contain only non-cuspidal constituents. Miatello explained his results on the equidistribution of Hecke eigenvalues of cuspidal automorphic forms on Hilbert modular groups, where the methods involving the Kuznetsov sum formula have an analytic number theory aspect. Other lectures in the workshop involved p-adic modular forms and automorphic forms for function fields. Mahnkopf described results about a higher rank Gouvea-Mazur conjecture obtained via a comparison of trace formulas approach. Morel introduced a 'pseudo-representation' functor inspired by recent results of V. Lafforgue on the global Langlands correspondence for function fields.

Cohomology of arithmetic groups. Automorphic representations provide an important tool for studying questions in the geometry of locally symmetric manifolds and of Shimura varieties. For example, the cohomology of arithmetic groups can be studied by means of relative Lie algebra cohomology of the space of automorphic forms and here the theory of Eisenstein series plays a key role. Some recent developments were described by Grbac who discussed his joint work with Schwermer on the Eisenstein cohomology in the case of unitary groups. Such cohomology has deep connections with questions in arithmetic, for example with extensions of motives. Such connections were the subject of two talks at the workshop. Nair explained how certain extensions of mixed Tate motives can be realized in the cohomology of the group $\mathrm{Sp}(2g,\mathbb{Z})$. Harder proposed a hypothesis asserting the relation of Betti-deRham and ℓ-adic

Galois cohomology extension classes and showed how to obtain information about denominators of Eisenstein classes from it. Other types of cohomology can also be studied by means of automorphic forms, and two lectures in the workshop touched on this. Kai-Wen Lan reported on vanishing theorems for coherent cohomology of toroidal compactifications of locally symmetric varieties. Klingler explained how connections between symmetric differentials and automorphic forms can be used to obtain new rigidity results for congruence complex hyperbolic lattices. Millson provided an overview of the applications of the theta correspondence to the study of special cycles in locally symmetric spaces with much valuable information concerning the underlying geometric insights. Funke discussed his joint work with Millson which gives an explanation of the old results of Cogdell on Picard modular surfaces and their possible extensions to the case of higher dimensional ball quotients. These lectures show in a very striking way the wide applicability of the theory of automorphic representations to cohomological questions.

Arithmetic geometry. Several lectures at the workshop highlighted other arithmetic aspects, in particular connections between automorphic forms and arithmetic geometry. Bruinier explained how older results of Gross-Kohnen-Zagier on modular generating series for Heegner points and recent results of Zagier on modular generating series for traces can be obtained in a unified way by means of generalized Jacobians of modular curves. Howard discussed his joint work with Andreatta, Goren and Madapusi in which they prove an average version of the Colmez conjecture on Faltings heights of CM abelian varieties as a consequence of results on the arithmetic intersection theory on integral models of Shimura varieties of orthogonal type. Berger showed how to construct Asai type elements in certain Selmer groups by using suitable congruences between automorphic forms over CM fields. Also in this area, two talks in the second workshop continued themes from the first workshop. Wedhorn explained how to construct Hasse invariants for Shimura varieties of Hodge type at primes of good reduction. Viehmann introduced a new stratification of the reduced subscheme of a Rapoport-Zink space and the related affine Deligne-Lusztig varieties.

List of talks

Workshop 1 on "Local Models of Shimura Varieties and related Topics", April 20 - 24, 2015

Ulrich Görtz	Basic loci of Coxeter type in Shimura varieties
Thomas Zink	Displays for varieties of K3-type
Brian Smithling	On the moduli descriptions of some local models
Thomas Haines	The strongly admissible set and the Pappas-Rapoport-Smithling conjecture
Eugen Hellmann	Degenerations of families of trianguline Galois representations
Ulrich Görtz	Local models and quiver Grassmannians
Thomas Haines	Local models for $\Gamma_1(p)$-level structure, I
Michael Rapoport	Arithmetic Transfer and local models
Benoit Stroh	Local models for $\Gamma_1(p)$-level structure, II
Anthony Scholl	Plectic cohomology of Shimura varieties

Workshop 2 on "Automorphic Forms - Geometry and Arithmetic", May 6 - 22, 2015

Marcela Hanzer	Degenerate Eisenstein series for symplectic groups
Joachim Mahnkopf	On local constancy of dimension of slope subspaces of automorphic forms
Roberto Miatello	The Kuznetsov formula and Hecke eigenvalues on Hilbert modular groups
John Millson	The geometric theta lift for compact quotients of orthogonal and unitary symmetric spaces
Jens Funke	The geometric theta lift for non-compact quotients of the complex n-ball
Jing-Feng Lau	On the residual spectrum of a quasi-split simply-connected group of type D_4
Tobias Berger	Bloch-Kato conjecture for Asai representations
Jan Hendrik Bruinier	Classes of Heegner divisors and traces of singular moduli
Torsten Wedhorn	Generalized Hasse invariants
Colette Moeglin	Around archimedean Arthur's packets
Dihua Jiang	Cuspidality of Certain Global Arthur Packets for Classical Groups
Eva Viehmann	Affine Deligne-Lusztig varieties and the building of J
Wee Teck Gan	The Langlands-Weissman Program for Brylinski-Deligne extensions
Jean-Loup Waldspurger	The fundamental lemma for the Hecke algebra in the twisted case
James W. Cogdell	The local Langlands correspondence for GL(n) and the exterior and symmetric square epsilon factors
Sug Woo Shin	Asymptotic behavior of supercuspidal characters
Günter Harder	Mixed motives and denominators of Eisenstein cohomology classes
Bruno Klingler	Symmetric differentials and ball quotients
Neven Grbac	Eisenstein series for unitary groups in view of cohomological applications
Arvind Nair	Mixed motives in Shimura varieties and automorphic forms
Ben Howard	Orthogonal Shimura varieties and Faltings heights of CM abelian varieties
Kai-Wen Lan	Vanishing theorems for coherent automorphic cohomology
Sophie Morel	Pseudo-representations for general groups
Erez Lapid	Irreducibility criteria for induced representations
Freydoon Shahidi	On equality of local factors for a general representation of $GL(n,\mathbb{C})$

Individual talks

Jan Nekovar	Plectic Cohomology
Goran Muic	On the Existence of Cusp Forms for Congruence Subgroups of an Almost Simple Algebraic Group over some Number Field
Steve Kudla	Some degenerate Whittaker functions for $Sp_n(\mathbb{R})$

Publications and preprints contributed

[BFK] J.-H. Bruinier, J. Funke, S. Kudla, Degenerate Whittaker functions for $Sp_n(\mathbb{R})$, submitted.

[G-S 1] N. Grbac, J. Schwermer, A non-vanishing result for the residual Eisenstein cohomology of arithmetic groups of low rank, to be submitted

[G-S 2] N. Grbac, J. Schwermer, Eisenstein series for unitary groups in view of cohomological applications, in preparation

[M-R] C. Moeglin, D. Renard, Paquets d'Arthur des groupes classiques complexes, submitted

[M] C. Moeglin, Paquets dArthur spéciaux unipotents aux places archimédiennes et correspondance de Howe

[Mu] G. Muic, Fourier coefficients of automorphic forms and integrable discrete series; arXiv:1505.02263

Invited scientists

Tobias Berger, Sascha Biberhofer, Don Blasius, Jan-Hendrik Bruinier, Igor Ciganovic, James W. Cogdell, Jens Funke, Wee Teck Gan, Ulrich Görtz, Neven Grbac, Harald Grobner, Thomas Haines, Marcela Hanzer, Guenter Harder, Eugen Hellmann, Fritz Hörmann, Benjamin Howard, Dihua Jiang, Steffen Kionke, Karen Klein, Bruno Klingler, Lapkova Kostakinka, Stephen Kudla, Jean-Pierre Labesse, Kai-Wen Lan, Erez Lapid, Jing Feng Lau, Joachim Mahnkopf, Ivan Matić, Roberto Miatello, John Millson, Sophie Morel, Colette Moeglin, Goran Muic, Jan Nekovar, Arvind Nair, Takayuki Oda, Yiannis Petridis, Michael Rapoport, Anthony Scholl, Joachim Schwermer, Freydoon Shahidi, Sug Woo Shin, Brian Smithling, Benoit Stroh, Marko Tadic, Eva Viehmann, Jean-Loup Waldspurger, Torsten Wedhorn, Haifeng Wu, Jeanine Van Order, Shunsuke Yamana, Thomas Zink.

Quantum Many-body Systems, Random Matrices, and Disorder

Organizers: Laszlo Erdös (IST Austria), Robert Seiringer (IST Austria), Simone Warzel (TU Munich)

Dates: June 1 – July 31, 2015

Budget: ESI € 39 200,
AIP € 1 659, IST Austria € 8 000 (to support the special days of the workshops taking place at IST Austria)

Report on the programme

Within the past decade, investigating the combined effects of disorder and interactions in many-body quantum systems has become an enormously popular topic in the physics community. The interesting questions here concern, e.g., the effects of disorder on interacting Bose-Einstein condensates or the effects of interactions on the Anderson metal-insulator transition. On the theory side, new phenomena, such as the existence of an intermediate phase of bad metallic behavior, have been proposed. Experimentally, systems such as ultra-cold gases for which model parameters are tunable serve as a testing ground for the interplay of disorder and interaction.

In contrast to the vast amount of physics literature, the mathematical understanding of such systems is much more limited. Some rigorous results on mostly one-dimensional disordered quantum spin systems have been obtained already in the early 1990s. More recently, the question of localization in the N-body Anderson model with a fixed particle number has been resolved, albeit with spectral methods which are not yet able to properly deal with the many-body limit. Despite all these recent efforts, fundamental questions such as a mathematically suitable definition and the characterizing features of many-body localization remain unsolved.

The goal of this program was to bring together leading experts in the mathematical analysis of many-body quantum systems and random operators/matrices and generate a stimulating atmosphere in which new mathematical tools for dealing with these complex systems can be developed.

Activities

During the programme, two one-week long workshops took place, with a busy schedule of 20 talks per workshop:

Workshop 1, June 8 – 12, 2015 and
Workshop 2, July 13 – 17, 2015.

One day of each workshop was organized at IST Austria, with the goal of encouraging future exchange and collaboration between the two institutions. IST Austria provided the funds for all associated costs, including transport of the participants as well as a social program in the evening, with a guided tour at the Klosterneuburg monastery and a subsequent dinner.

During the remaining part of the program, there were only a few talks per week, leaving ample time for individual research as well as discussions in small groups.

Specific information on the programme

Aside from senior scientists (see below) totally 11 PhD students and 11 postdoctoral researchers participated in the various activities of the program; many of them were given the opportunity to present their work:

PhD students: Alt, Carollo, Karczmarczyk, Krüger, Landon, Mayer, Moser, Nemish, Rademacher, Reuvers, Schröder

Postdocs: Ajanki, Bao, Bauerschmidt, Gebert, Greenblatt, Nam, Napiorkowski, Petrat, Sadel, Schnelli, Shcherbina

Outcomes and achievements

Disordered many-body systems form the interface for the two main topics of the program. The recent rigorous results have been partially obtained by researchers whose expertise has been mainly in either the field of random operators or the field of many-particle quantum mechanics. In view of the emerging interesting results on this interface, a combination of forces seemed due. The program offered an ideal opportunity to stimulate the exchange of ideas and initiate cooperations among these two communities.

In the sequel, we list some results presented during the program, grouping thematically related contributions.

Random Matrices. The recent developments leading to the proof of the Wigner-Dyson-Mehta conjecture on the universality of the local statistics for random matrices opened up new avenues to attack the fundamental conjecture for disordered quantum models in the delocalized regime. Several visitors of our program worked on various aspects of this idea.

Roland Bauerschmidt and Antti Knowles gave talks on their recent results to extend the local semicircle law and bulk spectral universality for the adjacency matrix of very sparse Erdos-Renyi graphs, i.e. where the average degree of any vertex is only a $(\log N)$-power, where N is the size of the matrix. New techniques were necessary to access this regime of sparsity that was not accessible before. They also continued their collaboration in Vienna; especially useful since they are based on different sides of the Atlantic. In addition, Bauerschmidt had an opportunity to meet the random matrix group of Laszlo Erdos in Vienna and Benjamin Schlein in Zurich. Knowles also worked with Erdos on their project on mesoscopic eigenvalue statistics.

Benjamin Landon gave a talk on a general approach to prove universality of the Dyson Brownian motion; a very similar parallel work was recently done independently by Schnelli and Erdos; the meeting was an opportunity to discuss the relation between these approaches.

Guilio Biroli and Marco Tarzia have completed a paper on heavy tailed random matrices. This paper and their corresponding talk stressed the physical aspects and conjectures of the problem and it was very motivating for the random matrix group in Vienna, especially for Zhigang Bao and Laszlo Erdos who plan to pursue this direction from a mathematical rigorous aspect.

Yuriy Nemish investigated local laws of products of non-hermitian matrices; here the key idea is to use Girko's trick to reduce it to a hermitian problem. This direction nicely complements the existing results on the hermitian theory.

Margherita Disertori is a key expert in the rigorous applications of supersymmetric techniques in random matrices. This time she presented how to apply this method for transfer matrices that are used in one-dimensional systems. She plans to start a project with Christian Sadel based in Vienna. Another key participant in supersymmetric techniques was Tatyana Shcherbina who had several long discussions with Bao and Erdos since her previous work was one of the inspirations for their recent work on optimal local semicircle law for band matrices.

Eman Hamza, partly motivated by the popularity of random matrices, started a paper on non-unitary random operators. She will be invited again to Vienna in November to establish further contacts.

On the physics side, many participants benefited from the lively overview talk of Yan Fyodorov who presented a special application of random matrix theory for wave scattering. As a genuine physicists, he is a constant source of interesting problems and some of the models he explained may well be mathematically tractable.

Leonid Pastur, one of the founders of rigorous random matrix theory, has chosen to talk about a different topic at the workshop, but discussions with him gave a unique opportunity of younger researchers to meet an iconic figure of the topic.

Many-body quantum systems. One of the key challenges in (mathematical) quantum statistical mechanics is to derive effective (and typically nonlinear models) from the fundamental, linear Schrödinger equation involving a macroscopic number of particles, and to estimate the range of validity of various approximative models. Despite substantial progress in recent years, many important questions remain to be understood. Some of the key researchers in this field participated in this program, and presented an overview of the state-of-the-art as well as the challenges for the future. This includes Jan Philip Solovej (on the Bose gas and the Bogoliubov method), Elliott Lieb (on exchange energies and density functional theory), Benjamin Schlein (on the time-evolution in BCS theory), Alessandro Giuliani (on the Quantum Hall effect), Bruno Nachtergaele (on quantum spin systems), and Vojkan Jaksic (on the relation between conductance and spectra of Schrödinger operators). On the physics side, Wilhelm Zwerger presented on overview on research on attractive Fermi gases in the unitary limit (which he termed a "new paradigm in many-body physics"), and Jörg Schmiedmayer showed his latest results of his experiments with cold atomic gases taking place at the TU Vienna.

Disordered many-body systems. Investigating the combined effects of disorder and interactions in many-body quantum systems is a current topics of great interest in condensed matter theory. Over the last years, much understanding developed on the level of theoretical physics, but many controversies still remain. The program aimed to stimulate exchange among theoretical physicists and mathematicians who are experts in the field of random operators. Some participants praised it as one of the first serious and fruitful attempts to compare different approaches to the problem of localization in presence of interaction, and to clarify what has been really proved

and what is conjectural in this field, which is a necessary prerequisite for further research and progress.

To stimulate the interaction, Markus Müller and Michael Knap, both young eminent theoretical physicists in the field, gave overview talks on their predictions concerning the existence or non-existence of a mobility edge in disordered many-particle systems. Denis Basko, one of the authors of the early key paper in condensed matter physics, presented his recent results on chaos versus Anderson localization in classical disordered nonlinear chains. These talks triggered various discussions with experts working on the subject on the mathematical side such as Michael Aizenman, Tom Spencer, John Imbrie, Leonid Pastur and Vieri Mastropietro.

John Imbrie, who is the author of the first mathematical approach to localization in a disordered (non-integrable) spin chain, chose to talk about results on a key technical issue concerning eigenvalue spacing. This is of interest in any analysis of disordered systems – irrespective of whether one deals with interacting or non-interacting systems.

Vieri Mastropietro presented his recent result on localization in an interacting quasi-periodic fermionic chain. This paper contains the first proof of the existence of a many-body localized phase in a quasi-periodic system.

Michael Aizenman presented his results on resonant delocalization, a mechanism which explains the absence of localization in tree graphs, which is potentially also of relevance in the case of configuration spaces of many particles with disorder.

The workshops also offered the possibility to reach out to colleagues working mostly in the area of quantum information theory, for whom many-body localization and the absence of information transport is also of interest. Jens Eisert gave a overview on his views on how to unify various facets of many-body localization. Robert König presented his work on disorder-assisted error correction in Majorana chains. He also used and praised his stay for learning about rigorous works which he hasn't been exposed to before. In particular, he benefited from interactions with Valentin Zagrebnov, who presented a work on semigroups, and Vojkan Jaksic, who informed him about rigorous works on central limit theorems in quantum systems.

The stimulating atmosphere at the ESI has led to several collaborations, some of which have already resulted in joint papers that have either been submitted to the arXiv and the ESI preprint list, or will be submitted in the near future.

- Alessandro Giuliani and Robert Seiringer completed a project on the formation of striped ordering in Ising models with competing interactions (arXiv:1509.00057).
- Vojkan Jaksic completed the paper "Entropic fluctuations in Gaussian dynamical systems", jointly with A. Shirikyan and C-A. Pillet (arXiv:1509.03244).
- Jan Philip Solovej and Elliott Lieb completed the paper "Proof of the Wehrl-type Entropy Conjecture for Symmmetric SU(N) Coherent States" (arXiv:1506.07633).
- Phan Thanh Nam, Marcin Napiorkowski, and Jan Philip Solovej completed their paper "Diagonalization of bosonic quadratic Hamiltonians by Bogoliubov transformations" (arXiv:1508.07321).
- Markus Müller and Wojciech de Roeck completed a joint paper on the existence (resp. non-existence) of mobility edges in disordered many-particle systems.
- Wojciech de Roeck completed a paper with D. Abanin, F. Huveneers and W.W. Ho on slow heating and bounds on linear response coefficients (arXiv:1509.05386).

- Robert Seiringer and Simone Warzel started and completed research on the absence of superfluidity in the Tonks-Girardeau gas with disorder.
- Robert König completed a paper on entropy power inequalities for quantum systems (arXiv:1509.07414).
- Guilio Biroli and Marco Tarzia have completed a paper on heavy tailed random matrices, with title "Level statistics and localization transition for Levy matrices" (arXiv:1507.00296).

Many participants started discussions in smaller groups. We briefly list some of the discussions that were started and of which we are aware:

- Sasha Sodin and Michael Aizenman collaborated on a joint paper on the invertibility of certain deformed Gaussian ensembles; this is a specific Wegner type estimate for a large class of random matrices, including certain band matrices.
- Jakob Yngvason and Elliott Lieb continued a project on quantum thermodynamics.
- Sven Bachmann and Wojciech de Roeck conducted research on a joint project on adiabatic evolution for Bogoliubov Hamiltonians.
- David Hasler and Jan Derezinski advanced a research project on spectral analysis of Liouvilleans.
- Federico Carollo had the opportunity to carry on an open collaboration with Heide Narnhofer, on collective observables in many-body systems undergoing to a particular class of dissipative dynamics.
- Vojkan Jaksic and Benjamin Landon conducted research on a joint project "Charge transport and Kotani theory".
- Nicolas Rougerie conducted research on the Laughlin phase with Jakob Yngvason, and on non-linear Gibbs measures with Phan Thanh Nam.
- Jan Philip Solovej conducted research on a joint project on "Fermionic Bogolubov diagonalization" with Phan Thanh Nam and Marcin Napiorkowski. He also worked on "Bogolubov Theory for Bose gases" with Marcin Napiorkowski and Robin Reuvers, and on "Entanglement Entropy" with Robert Seiringer.
- Robert Seiringer and Rupert Frank discussed various aspects of the Fröhlich Hamiltonian of a polaron.
- Wilhelm Zwerger had discussions with Robert Seiringer on "Density-functional theory in momentum space".

List of talks

First Workshop, June 8 – 12, 2015

Jan Philip Solovej	The Bogolubov Variational Model for Bose gases
Jeff Schenker	Dissipative transport in the localized regime
Hermann Schulz-Baldes	An index walk in the periodic table
Wojciech De Roeck	(Energy) localization in driven systems

Nicolas Rougerie	Incompressibility estimates for the Laughlin phase
Wolfgang Spitzer	Area law for the entanglement entropy of the free Fermi gas at nonzero temperature
Jörg Schmiedmayer	'Solving' a Quantum Many Body Problem by Experiment
Jakob Yngvason	Superfluidity and BEC in a model of interacting Bosons in a Random Potential
Elliott Lieb	Indirect Coulomb Energy with Gradient Correction
Simone Warzel	From adiabatic computing to the phase transition in the QREM
Giulio Biroli	Ergodicity, Level Statistics and Localization Transitions on the Bethe lattice and for Levy random matrices
Benjamin Schlein	Time-evolution of quantum systems in the BCS approximation
Sven Bachmann	Scattering theory for gapped quantum spin systems
Benjamin Landon	Convergence of local statistics of Dyson Brownian motion
Yuriy Nemish	About some local properties of the products of independent square non-hermitian random matrices with independent entries
Martin Gebert	On the asymptotics of eigenfunction-correlation determinants
Margherita Disertori	Transfer matrix approach in the supersymmetric context
Marco Tarzia	Level statistics, ergodicity, and localization transition of Lévy Matrices
Eman Hamza	Product Vacua and Boundary State Models in d-Dimensions
Roland Bauerschmidt	Eigenvalues of random regular graphs

Second Workshop, July 13 – 17, 2015

Abel Klein	An eigensystem approach to Anderson localization
Frederic Klopp	Interacting one dimensional particles in a random background.
Janek Wehr	Low lying eigenvalues of the one-dimensional Schrödinger operator with a Bernoulli random potential
Sasha Sodin	Invertibility in deformed Gaussian ensembles and some applications
Jens Eisert	Unifying various facets of many-body localization
Michael Knap	Dynamics of disordered many-body systems: from thermal transport to many-body localization
John Imbrie	Iterated Schur complementation and the level-spacing problem
Denis Basko	Chaos vs Anderson localization in classical disordered nonlinear chains
Michael Aizenman	Resonant Delocalization in Quantum Dynamics under Disorder
Yan Fyodorov	Random matrix theory for resonances in chaotic wave scattering: A short overview
Markus Müller	Many-body localization: A route to retaining quantum memory in interacting systems
Wilhelm Zwerger	Attractive Fermi gases at infinite coupling: a new paradigm in many-body physics
Leonid Pastur	Large Block Dehavior of the Entanglement Entropy of Disordered Fermions
Vojkan Jaksic	Conductance and AC spectrum of 1D samples
Vieri Mastropietro	Localization in an interacting quasi-periodic fermionic chain
Tatyana Shcherbina	Universality of the local regime for some types of random band matrices
Heinz Siedentop	Accumulation Rate of Bound States of Dipoles in Graphene
David Hasler	Asymptotic expansions in quantum field theory
Robert König	Disorder-assisted error correction in Majorana chains
Valentin Zagrebnov	Dynamical Semigroups for Unbounded Repeated Perturbation

Individual talks

Jan Derezinski	My observations on how physicists use QED
Antti Knowles	Local law for random regular graphs
Alessandro Giuliani	Quantum Hall effect in the Haldane model
Bruno Nachtergaele	Frustration-Free Quantum Spin Systems
Daniel Ueltschi	Spin 1 system with SU(2)-invariant interactions
Igor Aleiner	The internal structure of a vortex in a two-dimensional superfluid with long healing length
Rupert Frank	Derivation of an effective evolution equation for a strongly coupled polaron

Publications and preprints contributed

R. Seiringer, S. Warzel, *Decay of correlations and absence of superfluidity in the disordered Tonks-Girardeau gas*, arXiv:1512.05282.

M. Napiórkowski, R. Reuvers, J. P. Solovej, *The Bogoliubov free energy functional II. The dilute limit*, arXiv:1511.05953.

M. Napiórkowski, R. Reuvers, J. P. Solovej, *The Bogoliubov free energy functional I. Existence of minimizers and phase diagram*, arXiv:1511.05935.

J. Huang, B. Landon, *Spectral statistics of sparse Erd/os-Rnyi graph Laplacians*, arXiv:1510.06390.

C. Benassi, B. Lees, D. Ueltschi, *Correlation inequalities for the quantum XY model*, arXiv:1510.03215.

H. Abdul-Rahman, B. Nachtergaele, R. Sims, G. Stolz, *Entanglement Dynamics of Disordered Quantum XY Chains*, arXiv:1510.00262.

M. Bishop, B. Nachtergaele, A. Young, *Spectral Gap and Edge Excitations of d-dimensional PVBS models on half-spaces*, arXiv:1509.07550.

V. Jaksic, C.-A. Pillet, A. Shirikyan, *Entropic fluctuations in Gaussian dynamical systems*, arXiv:1509.03244.

M. Aizenman, R. Peled, J. Schenker, M. Shamis, S. Sodin, *Matrix regularizing effects of Gaussian perturbations*, arXiv:1509.01799.

A. Giuliani, R. Seiringer, *Periodic striped ground states in Ising models with competing interactions*, arXiv:1509.00057.

P. T. Nam, M. Napiórkowski, J. P. Solovej, *Diagonalization of bosonic quadratic Hamiltonians by Bogoliubov transformations*, arXiv:1508.07321.

E. Tarquini, G. Biroli, M. Tarzia, *Level statistics and localization transitions of Lévy matrices*, arXiv:1507.00296.

E. H. Lieb, J. P. Solovej, *Proof of the Wehrl-type Entropy Conjecture for Symmmetric SU(N) Coherent States*, arXiv:1506.07633.

Invited scientists

Michael Aizenman, Igor L. Aleiner, Oskari Ajanki, Sven Bachmann, Denis M. Basko, Roland Bauerschmidt, Giulio Biroli, Federico Carollo, Wojciech De Roeck, Jan Derezinski, Margherita Disertori, Jens Eisert, Laszlo Erdös, Rupert L. Frank, Yan V. Fyodorov, Martin Gebert, Alessandro Giuliani, Rafael Greenblatt, Eman Hamza, David Hasler, John Imbrie, Vojkan Jaksic, Maciej Karczmarczyk, Abel Klein, Frédéric Klopp, Michael Knap, Antti Knowles, Robert Koenig, Benjamin Landon, Elliott

Lieb, Vieri Mastropietro, Simon Mayer, Markus Müller, Bruno Nachtergaele, Taro Nagao, Marcin Napiorkowski, Heide Narnhofer, Yuriy Nemish, Leonid Pastur, Simone Rademacher, Robin Reuvers, Nicolas Rougerie, Christian Sadel, Jeffrey Schenker, Benjamin Schlein, Jörg Schmiedmayer, Kevin Schnelli, Dominik Schröder, Hermann Schulz-Baldes, Robert Seiringer, Tatyana Shcherbina, Heinz Siedentop, Sasha Sodin, Jan Philip Solovej, Thomas Spencer, Wolfgang Spitzer, Marco Tarzia, Daniel Ueltschi, Simone Warzel, Janek Wehr, Valentin A. Zagrebnov, Wilhelm Zwerger.

Modern Theory of Wave Equations

Organizers: Colin Guillarmou (ENS Paris), Werner Müller (U Bonn), Alexander Strohmaier (Loughborough U), András Vasy (Stanford U)

Dates: July 6 – September 30, 2015

Budget: ESI € 51 440,
National Science Foundation (NSF) € 17 852

Report on the programme

Wave equations are hyperbolic differential equations that describe the propagation of waves in space-time. Apart from the huge significance in physics the properties of wave equations on manifolds provide very elegant and fruitful paths towards the understanding of various areas in mathematics. The programme focused on the following selection of topics with the common theme being microlocal and pseudodifferential methods.

- Asymptotic behavior of waves on Lorentzian spacetimes and related resolvent esimates
- Scattering Theory, Resonances and Semi-classical Analysis
- Distinguished parametrices and Hadamard states and the relation to Quantum Field Theory

Activities

The programme started with several introductory lectures ranging from Hawking radiation to index theory. Some talks were organized as joint seminars with the relativity group in Vienna. Two workshops around the above mentioned topics were organized to bring together experts in several of the above mentioned focus areas:

Workshop 1 on "Semi-classical Analysis: Spectral Theory and Resonances",
August 24 – 28, 2015 and

Workshop 2 on "Hyperbolic Equations on Spacetimes: Stability, microlocal Analysis and Quantum Field Theory" , September 7 – 11, 2015.

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

Specific information on the programme

Of the total of 73 invited scientists there were 17 PostDocs and 7 PhD students. The participants ranged from junior colleagues to the most senior figures in the relevant fields.

Scientific content

Semi-classical methods are tools which allow to describe high-frequency (oscillatory) behaviour of families of distributions. Typically, solutions of certain linear PDEs with high oscillatory behavior are related to the dynamics of the Hamilton vector field of the principal symbol of the equation. One important aspect of what was discussed during the program is to quantify this relation. More concretely, questions about distributions of nodal lines (and nodal domains) and lower/upper bounds of restrictions to submanifolds of high-frequency eigenfunctions of Laplacian on compact Riemannian manifolds were studied and very interesting new results were shown by Christianson, Nguyen Viet, Toth, Zelditch.

For non self-adjoint problems, there were some collaborations on both classical resonances (eigenvalues for vector fields generating a hyperbolic flow) and quantum resonances (eigenvalues of Laplace type operators with certain radiation condition at infinity). The main problems which were described and discussed are the localisation of the resonances in the complex plane and the classical/quantum correspondence: for instance, Datchev, Hora and Sa Barreto gave high-frequency resolvent estimates, which are the main tools to prove the absence of long living quantum resonances, Dyatlov explained his recent result on the existence of a strip with no resonances for certain non-compact hyperbolic surfaces, Zworski discussed inverse problems for resonances. More generally, scattering theory was also a topic of discussion, for instance by Isosaki and Nakamura.

On the side of wave equations for Lorentzian background, some very interesting new approaches introduced by Vasy were the basis of many discussions, in particular by Baskin, Gell-Redman, Hintz and Vasy. These problems are closely related to Quantum Field Theory via the description of the Feynman propagator and Hadamard states, and also wave-front analysis in order to define properly renormalisation. Dappiaggi, Fewster, Gerard, and Wrochna have also described their recent works on the Hadamard states in Quantum Field Theory, showing that microlocal technics are powerful and appropriate for studying QFT. This was explained by Wald in an introductory lecture about Quantum Field Theory in curved spacetimes. Fredenhagen and Rejzner gave lectures on how these techniques propagate into the perturbative description of QFT and the description of gauge theories. More classical problems of relativity, like solutions of Einstein equations, were the subject of discussions and talks, for instance by Andersson, Chrusciel, Dafermos, Hintz, Shlapentokh-Rothman. They explained the recent advances on the topic, including existence and regularity questions, as well as scattering theory or inverse problems for these models. The classical theory of scattering theory on non-trivial geometries then feeds back into the theory of Hawking radiation, as this was explained in the talk by Häfner. The mix of geometric, microlocal and pure PDE technics was reflected in the list of speakers and invited mathematicians and, we hope, was an important aspect of the program. In the setting of Lorentzian geometry, Bär and Strohmaier proved a new index theorem which opens to new possible developments.

Outcomes and achievements

We believe that programme will have a long term impact on the specific disciplines but also on the level of interaction between scientists working in microlocal and semiclassical Analysis and mathemtical physicists. At the time of writing the report we are aware of the following collaborations and outcomes.

- Baskin, Wunsch and Vasy continued work on the paper "Asymptotics of scalar waves on long-range asymptotically Minkowski spaces".
- Chrusciel started a collaboration with Luc Nguyen on the mass of asymptotically hyperbolic manifold. This is still work in progress.
- Drago and Murro continued their project on: "A new class of Fermionic Projectors: Möller operators and mass oscillation properties".
- Li completed a paper with Strohmaier (arXiv:1509.00198).
- Li started working on another project with Strohmaier on "Heat kernel bounds and finite propagation speed estimates."
- Bär and Strohmaier wrote a paper on the Gravitational Chiral Anomaly during their stay at the ESI (arXiv:1508.05345).
- Macia started a collaboration with Shu Nakamura on "Semiclassical measures and observability for Schrödinger flows on the Euclidean space".
- Macia started a collaboration with Hans Christianson on "Decay rates for discrete damped wave equations".
- Dappiaggi, Pinamonti and Drago started working on a project aimed at constructing the modular data for a massive real scalar field theory living on a future/past light cone in Minkowski spacetime.
- Fewster, Pinamonti, Hack, Dappiaggi and Nosari started a project on the Casimir effect and so-called torque anomaly.
- Fewster did further work on properties of SJ (and related) states with Verch.
- Marzuola continued a collaboration with Baskin and Gell-Redman regarding wave equations on conic manifolds and continued a collaboration with Daniel Tataru and Jason Metcalfe on quasilinear Schrödinger equations.
- Rejzner started a collaboration with Fredenhagen and Pinamonti on applications of perturbative AQFT to cosmology.
- Vassiliev and Strohmaier continued discussions on Fourier integral operators techniques for operators acting on vector bundles and will continue this as a project.
- Hintz and Vasy continued their project on "Analysis of linear waves near the Cauchy horizon of cosmological black holes" and Hintz on "Boundedness and decay of scalar waves at the Cauchy horizon of the Kerr spacetime".
- Galkowski worked on "The Quantum Sabine Law for Resonances in Transmission Problems" which resulted in arXiv:1511.05091.
- Strohmaier, Faure and Guillarmou have started a collaboration on Ruelle resonances for hyperbolic surfaces, in order to recover (and refine) the result of Dyatlov-Faure-Guillarmou using representation theory.
- Dyatlov and Guillarmou discussed the definition of Ruelle resonances for exterior domains with convex obstacles on $\mathbb{R}^n$ and are collaborating at the moment to prove that their previous result extends to these cases.

- Dyatlov and Zworski worked on Chapter 5 on their joint book in progress (available on their websites), relating to Vasy's method.
- Helffer and T. Hoffmann-Ostenhof started work on Pleijel's theorem for the Schrödinger operator. This may lead to a common paper with P. Charron, whose previous work the method is based on.
- Vasy and Wrochna continued work on a project on global propagators in QFT.
- Gell-Redman and Vasy worked on revising their paper with Haber on Feynman propagators.

List of talks

First Workshop: Semi-classical Analysis: Spectral Theory and Resonances, August 24 – 28, 2015

Steve Zelditch	Counting boundary zeros and nodal domains of eigenfunctions
Semyon Dyatlov	Spectral gaps via additive combinatorics
Jesse Gell-Redman	The Feynman Propagator on perturbations of Minkowski space
Hans Christianson	Uniform lower bounds for restrictions of quantum ergodic eigenfunctions
Fabricio Macia	Delocalization of solutions to the Schrödinger equation
Shu Nakamura	High energy asymptotics of the scattering matrix for Schrödinger and Dirac operators
Stephane Nonnenmacher	Logarithmic quasimodes along a hyperbolic orbit
Nicolas Burq	Second microlocalization and stabilization of damped wave equations on tori
Antonio Sa Barreto	Semiclassical Resolvent Estimates on Conformally Compact Manifolds with Variable Curvature at Infinity
Maciej Zworski	Heat traces and inverse problems for scattering resonances
John Toth	Nodal Lengths of Steklov-Eigenfunctions on real-analytic Riemannian Surfaces
Dmitri Vassiliev	Analysis of first order systems of PDEs on manifolds without boundary
Xuwen Zhu	Nodal degeneration of hyperbolic metrics and asymptotics of the Weil-Petersson metric on the moduli space
Dean Baskin	Asymptotics of scalar waves on asymptotically Minkowski spaces
Hiroshi Isozaki	Inverse scattering on non-compact manifolds with general metric
Raphael Falcao da Hora	Resolvent Estimates on Asymptotically Hyperbolic Manifolds
Martin Vogel	Eigenvalue statistics for a class of non-self-adjoint semiclassical differential operators under small random perturbations
Jared Wunsch	Semiclassical asymptotics for exterior Helmholtz problems

Second Workshop: Hyperbolic Equations on Spacetimes: Stability, microlocal Analysis and Quantum Field Theory, September 7 – 11, 2015

Robert Wald	Introduction to Quantum Field Theory in Curved Spacetime
Chris Fewster	On preferred states for QFT in curved spacetimes
Peter Hintz	Quasilinear waves on Kerr-de Sitter spacetimes
Lars Andersson	Symmetries and conservation laws
Mihalis Dafermos	The inside story of black hole stability
Dietrich Häfner	Scattering theory for Dirac and Klein-Gordon fields on the (De Sitter) Kerr metric and the Hawking effect
Yakov Shlapentokh-Rothman	Scattering for the wave equation on Kerr black hole exterior spacetimes
Rainer Verch	KMS-like properties of local thermal equilibrium states in quantum field theory

Gunther Uhlmann	Seeing Through Space Time
Christian Gerard	Hadamard states on spacetimes of bounded geometry
Igor Khavkine	Graviton propagator on Schwarzschild spacetime
Michal Wrochna	From global propagators to quantum fields: the case of asymptotically Minkowski and extended de Sitter space
Klaus Fredenhagen	From quantum field theory on Lorentzian manifolds to perturbative quantum gravity I
Kasia Rejszner	From quantum field theory on Lorentzian manifolds to perturbative quantum gravity II
Claudio Dappiaggi	Constructing Isometry Invariant Hadamard States via a Novel Deformation Argument
Dang Nguyen-Viet	Equidistribution of the conormal cycle of random nodal sets
Stefan Hollands	Perturbative quantum field theory from the viewpoint of Fedosov quantization
Jan Sbierski	A dezornification of the proof of the existence of a maximal Cauchy development for the Einstein equations
Piotr Chrusciel	Singularities in General Relativity

Individual talks

Valter Moretti	Local Hawking Radiation
Christian Bär	Index Theory for Lorentzian manifolds
Jeremy Marzuola	Waves on surfaces with conical singularities
Alexander Strohmaier	The Dirac operator on curved spaces: Index Theorems, Spectral Theory & Gravity
Kiril Datchev	Exponential Resolvent Estimates and Applications
Luc Nguyen	Maximal (hyper)surfaces in low dimensions
Steve Zelditch	Heat kernel random Kaehler metrics
Vesselin Petkov	Location and Weyl formula for the eigenvalues of some non self-adjoint operators
Leondid Parnovski	Local Density of States and the spectral function of almost-periodic operators
Bernard Helffer	Semiclassical Analysis for Schrödinger Operators with Magnetic Fields

Invited scientists

Susama Agarwala, Ben Albert, Francesca Arici, Pangiotis Batakidis, Gabriel Baditoiu, Spencer Bloch, Jacob Bourjaily, David Broadhurst, Alan Carey, Özgür Ceyhan, Alain Connes, Ludwik Dabrowski, Dmitry Doryn, Kurusch Ebrahimi-Fard, Victor Gayral, Hualong Gervais, Jonathan Gleason, Harald Grosse, Lars Hesselholt, Tajron Juric, Thomas Krajewski, Dirk Kreimer, Giovanni Landi, Andres Larrain-Hubach, Osmar Maldonado, Pedro Morales, Ryszard Nest, Pranav Pandit, Sylvie Paycha, Erik Panzer, Loukas Papadogiannis, Carlos Ignacio Perez-Sanchez, Valerio Proietti, Aldo Rampioni, Ettore Remiddi, Kasia Rejzner, Vincent Rivasseau, Steve Rosenberg, Paolo Solis, Chen Sun, Ruben Stienstra, Adrian Tanăsa, Juraj Tekel, Pierre Vanhove, Walter van Suijlekom, Stefan Weinzierl, Daping Weng, Jörg Wildeshaus, Harold Williams, Raimar Wulkenhaar, Yunyun Yang, Karen Yeats, Shoji Yokura.

Higher Structures in String Theory and Quantum Field Theory

Organizers: Harald Grosse (U Vienna), Danny Stevenson (U of Adelaide), Richard J. Szabo (Heriot-Watt U)

Dates: November 16 – December 18, 2015

Budget: ESI € 21.040,
European Cooperation in Science and Technology (COST) € 9 300, Australian National University € 1 300, Institute for Geometry and its Applications (IGA), University of Adelaide € 3 300

Report on the programme

String theory over the years has provided a plethora of physical predictions in various branches of mathematics, most notably in geometry. This has been and continues to be a source of fruitful exchange, inspiration and interaction between physicists and mathematicians. The focus of this programme was in using recent developing ideas from string theory and quantum field theory, in particular T-duality, non-geometry and M-brane models, with the aim of understanding their constructions in terms of higher geometric structures, topological field theories, and Kasparov theory. This very exciting field involves many different branches of mathematics: Topology, differential geometry, category theory and noncommutative geometry. Compared to other areas of string theory and quantum field theory, notably AdS/CFT and field theory amplitudes, the attention and impact of homotopical and higher structures in the mathematics of string theory has received considerably less attention, and the goal of the programme was to provide an intensive focus on these topics.

Activities

Formal activity started on November 23 with a 2 week introductory workshop geared at postdoctoral fellows and PhD students. This began in week 1 with introductory lecture series and was followed in week 2 by some advanced instructional lectures. Week 3 was a research workshop aimed at bringing together researchers from string theory and mathematics: the range of topics covered in the workshop was very broad, including topics in double and exceptional field theory, T-duality, higher structures and equivariant cohomology. In the final week of December 14–18 a smaller, more focussed research workshop was held covering topics on KK-theory, twists and applications.

In week one the participants were overwhelmingly students and the flavour of the interactions was primarily at the level of discussions on topics arising from the lectures. Ralph Blumenhagen gave a series of three lectures on 'Non-geometric strings and non-commutative geometry'; Christian Sämann gave a series of three lectures on various aspects of higher gauge theory, while Peter Bouwknegt gave three lectures covering the basics of T-duality. These introductory lectures attracted an audience of about 20 people over the week. A feature of the week were the discussion sessions in the afternoons where there was considerable interaction between the lecturers and the audience.

In the second week the activity intensified with some more advanced instructional lectures. Mathai Varghese gave a mini-course on T-duality via non-commutative geometry and its applications. Urs Schreiber delivered a 4 lecture series on his work on higher gauge theory, entitled 'Pre-quantum field theory and Green-Schwarz WZW terms'. Schreiber supplemented his lectures with an extensive set of notes derived from his writings on the well-known 'n-lab'. Peter

Schupp gave a series of three lectures aimed at uncovering structures one step up from non-commutative geometry and describing quantization of these structures. In the afternoons Shahn Majid gave a series of lectures on various topics in non-commutative geometry and quantum spacetime describing some of his recent work in this area.

Week three was devoted to the main workshop of the program with the audience increasing significantly in numbers at this point. Jonathan Rosenberg opened the workshop with a talk describing work on classifying D-brane charges in orientifold string theories in terms of twisted KR-theory. This talk was representative of the theme of the workshop based around the interaction of string theory with mathematics, especially the relationship with higher structures. This talk was followed by an introduction to double and exceptional field theory by David Berman, with a particular emphasis on isolating directions for further research on mathematical aspects of the theory. In the afternoon there were talks by Jouko Mickelsson on central extensions of Lie groups and their relations to 3-cocycles characterising gerbes, and by Patricia Ritter on the categorification of Poisson algebras of local observables in terms of strong homotopy Lie algebras.

Maxime Zabzine described relationships between one-dimensional integrals, matrix models and deformations of the Virasoro algebra; Chris Rogers gave a report on his work on categorifying the correspondence between moment maps and equivariant cohomology using strong homotopy Lie algebras. There was also a series of talks on aspects of double field theory and T-duality by Dieter Lüst and Eric Plauschinn with a focus on connections to non-geometry and noncommutative/nonassociative geometry, and a talk by Andreas Deser on deformations of the C-brackets of Courant algebroids which remarkably match string theory calculations. Christoph Schweigert gave a lecture on recent work of his on the construction of surface defects in extended three-dimensional topological field theories. Keith Hannabuss lectured about his work on understanding T-duality and non-geometry as a progression from geometry to C^*-algebras and ultimately to tensor categories, while Guo-Chuan Thiang reported on aspects of their work on the applications of T-duality to the classification of topological phases in condensed matter physics. The workshop concluded with lectures by Urs Schreiber on his recent understanding of the cohomological structure of M2/M5-brane charges in M-theory in terms of an ADE-equivariant cohomotopy theory in degree four, by Konrad Waldorf on the cancellation of global anomalies in supersymmetric sigma models using higher-categorical structures, and a talk by Peter Presjnadjer on his novel perspective on noncommutative quantum field theory as a particular deformation of noncommutative quantum mechanics. Fewer students stayed on in week 3, partly because the lectures in the third week were a step up in level of difficulty for novices.

In week four a mini-workshop was held on KK-theory, twists and applications. This workshop was more focussed than the previous, larger workshop. Jens Kaad described his work on Morita equivalence for spectral triples, and Alan Carey reported on work on the spectral flow for skew-adjoint Fredholm operators on a real Hilbert space. Jonathan Rosenberg gave a talk on the intriguing but mysterious connection between T-duality and the Baum–Connes conjecture, Bram Mesland spoke on understanding the K-homology of certain noncompact hyperbolic 3-manifolds in terms of the non-commutative geometry of Bianchi groups, while Mahmoud Zeinalian described his work on Wilson line observables on the derived moduli stack of perfect complexes. Paolo Aschieri gave a talk on the construction of noncommutative principal bundles using Drinfeld twist deformation theory, and Hisham Sati finished the program with a report on his recent work on iterated algebraic theory of the connective K-theory spectrum ku.

The program of week three also featured the distinguished Erwin Schrödinger Lecture ‘Symmetries and K3 Surfaces’ by Daniel Huybrechts (Bonn).

Specific information on the programme

This programme assembled groups of prominent string theorists and mathematicians in the pertinent areas for a concentrated period of research activity. It began at a somewhat pedagogical level with introductory mini-courses geared at young researchers, and evolved into more advanced themes concentrated into two specialised workshops. A feature of both workshops was the large number of new and unpublished results that were announced. A commonly expressed view by the participants was the very productive time spent at the ESI.

We received many thanks for organising the meeting and there was a common view that the ESI provided excellent hospitality and a forum where interesting interactions can take place.

Outcomes and achievements

Keith Hannabuss, Mathai Varghese and Guo-Chuan Thiang had the opportunity to work on some ideas which they had formulated earlier in the year, involving an application of T-duality to condensed matter physics and string theory. They managed to clarify certain C^*-algebraic constructions, made several significant generalisations, and are now working on a joint paper together. This paper will appear on the arXiv in February 2016, acknowledging the ESI.

Christoph Schweigert profited from discussions with Konrad Waldorf on how to investigate surface defects between Chern–Simons theories using Chern–Simons 2-gerbes and with Keith Hannabuss on non-trivial associators in the context of T-duality of torus fibrations involving higher-dimensional tori.

Satoshi Watamura had many interesting discussions, including discussions with Urs Schreiber on FDA approach and graded manifolds. He was also able to exchange ideas especially with Andreas Deser, Peter Schupp and Patricia Ritter about the relation between the algebra in generalized geometry and double field theory, and also higher gauge theory.

Jonathan Rosenberg had useful conversations with Mahmoud Zenalian about differential K-theory and with David Berman about double field theory.

During the mini-workshop, Jens Kaad and Bram Mesland intensively worked on their ongoing project 'Trace class operators on Hilbert modules'. The expertise of Alan Carey on related subjects led to useful discussions that were beneficial to the project as well.

Urs Schreiber had the opportunity to further develop his research programme regarding the cohomological structure of M2/M5-branes in M-theory thanks to interactions with colleagues during his stay at ESI. He particularly profited from discussions with Danny Stevenson, and with Mathai Varghese who had reported on generalization of T-duality on circle fibrations to a new kind of duality on S^3-fibrations which finds a curious analogy to the pivotal role played by the quaternionic Hopf fibration in ADE-equivariant cohomotopy in Schreiber's work. Other interactions also led him to realise similarities between the topic of 'exceptional geometry' in some of the workshop talks and his work on globalization of M2-brane sigma-models using moduli of higher gerbe connections, which are naturally parameterized by the 56-dimensional representation of the exceptional Lie group E_7.

Patricia Ritter had lengthy discussions with Christian Sämann and Lennart Schmidt, which led to a paper that was published shortly after the end of the programme; she also had intensive discussions with Andreas Deser and Satoshi Watamura, which she anticipates will follow up into future collaborations. She also took the opportunity to learn about double and exceptional field theory from Kyle Wright.

Severin Bunk, Christian Sämann and Richard Szabo were able to advance their joint work

on higher-geometric quantization with bundle gerbes during the instructional workshop. During the last week of the programme, Paolo Aschieri and Richard Szabo initiated new work together exploring the metric aspects of the nonassociative differential geometry in connection with non-geometric string backgrounds. Progress in understanding the geometrization of non-geometric flux compactifications was also achieved through joint discussions on Courant sigma-models between Andreas Deser, Larisa Jonke, Branislav Jurço, Peter Schupp, Richard Szabo and Satoshi Watamura.

Richard Szabo was able to tap into various expertise at the programme in connection with his ongoing work on twisted *KR*-theory: With Alan Carey he discussed how a suitable bundle gerbe formalism could be exploited in the description of Kane–Mele type invariants for topological insulators as a concrete application, and with Jonathan Rosenberg he discussed Real cohomology and twistings for *KR*-theory.

A commonly expressed view was that all in all, this was a very important meeting for the unique mix of mathematicians and mathematical physicists.

List of talks

Workshop 1: Instructional workshop for students and junior researchers, November 23 – December 4, 2015

Ralph Blumenhagen	Non-geometric Strings and Noncommutative Geometry (I - III)
Peter Bouwknegt	A First Introduction to T-duality (I - III)
Shahn Majid	Quantum Spacetime and Noncommutative Geometry
Shahn Majid	Reconstruction and quantisation of Riemannian manifolds
Shahn Majid	Cosmological constant from quantum spacetime
Shahn Majid	Hodge operator in noncommutative geometry as a braided Fourier transform
Christian Sämann	Basics of Higher Gauge Theory
Christian Sämann	Twistor Descriptions of Higher Gauge Theories
Christian Sämann	Quantized Multisymplectic Manifolds and Categorified Matrix Models
Peter Schupp	Beyond noncommutative geometry (I - IV)
Urs Schreiber	Prequantum field theory and Green-Schwarz WZW terms (I - IV)
Mathai Varghese	T-duality via noncommutative geometry and applications

Workshop 2: Main workshop, December 7 – 11, 2015

David Berman	Aspects of Double and Exceptional Field Theory
Andreas Deser	Star products on graded manifolds and deformations to Courant algebroids from string theory
Keith Hannabuss	T-duality: geometry, C^*-algebras, and tensor categories
Dieter Lüst	Some worldsheet aspects of double field theory and closed string noncommutativity
Jouko Mickelsson	Locally smooth group cohomology, gerbes and central extensions
Eric Plauschinn	Collective T-duality transformations
Peter Prešnajder	From Noncommutative Quantum Mechanics towards Noncommutative QFT
Patricia Ritter	Strong homotopy algebras of local observables (shlalos) and Vinogradov algebroids
Chris Rogers	Equivariant cohomology and homotopy moment maps
Jonathan Rosenberg	Duality of twisted orientifolds
Urs Schreiber	Generalized cohomology of M2/M5-branes
Christoph Schweigert	State sum constructions of extended topological field theories and defects

Guo-Chuan Thiang	T-duality, K-theory, and bulk-boundary correspondence for topological phases
Konrad Waldorf	String structures and supersymmetric sigma models
Maxim Zabzine	Integrals, matrix models and deformed Virasoro algebra

Workshop 3: Mini Workshop on KK-theory, twists and applications, December 14 – 16, 2015

Paolo Aschieri	Deformation quantization of Noncommutative Principal Bundles
Alan Carey	Spectral flow in the skew adjoint Fredholm operators on a real Hilbert space
Jens Kaad	Morita equivalences of spectral triples
Bram Mesland	The noncommutative geometry of Bianchi groups
Jonathan Rosenberg	T-duality and the Baum–Connes conjecture
Hisham Sati	Higher twisted spectra and applications
Mahmoud Zeinalian	Poisson geometry of moduli stack of twists

Publications and preprints contributed

J. A. Lind, H. Sati and C. Westerland, *A higher categorical analogue of topological T-duality for sphere bundles*, arXiv:1601.06285 [math.AT].

U. Schreiber, *Equivariant cohomology of M2/M5-branes*, https://ncatlab.org/schreiber/show/Equivariant+cohomology+of+M2/M5-branes

D. S. Berman, C. D. A. Blair, E. Malek and F. J. Rudolph, *An Action for F-theory:* $\mathrm{SL}(2) \times \mathbb{R}^+$ *Exceptional Field Theory*, arXiv:1512.06115 [hep-th].

G. A. Demessie and C. Sämann, *Higher Gauge Theory with String 2-Groups*, arXiv:1602.03441 [math-ph].

P. Ritter, C. Sämann and L. Schmidt, *Generalized Higher Gauge Theory*, arXiv:1512.07554 [hep-th].

Invited scientists

Paolo Aschieri, Klaus Bering, David Berman, Ralph Blumenhagen, Lars Borutzky, Peter Bouwk-negt, Severin Bunk, Alan Carey, Harald Grosse, Keith Hannabuss, Larisa Jonke, Branislav Jurčo, Jens Kaad, Yukio Kaneko, Gerald Kelnhofer, Samuel Kovacik, Dieter Lüst, Yoshiaki Maeda, Shahn Majid, Osmar Maldonado, Bram Mesland, Jouko Mickelsson, Ossi Niemimäki, Lada Peksova, Peter Presnajder, Jan Pulmann, Patricia Ritter, Chris Rogers, Jonathan Rosenberg, Christian Sämann, Hisham Sati, Gregor Schaumann, Lennart Schmidt, Urs Schreiber, Peter Schupp, Christoph Schweigert, Harold Steinacker, Danny Stevenson, Richard Szabo, Juraj Tekel, Guo-Chuan Thiang, Mathai Varghese, Konrad Waldorf, Satoshi Watamura, Kyle Wright, Maxime Zabzine, Mahmoud Zeinalian, Roberto Zucchini.

Workshops organized independently of the Main Programmes

The Interrelation between Mathematical Physics, Number Theory and Noncommutative Geometry

Organizers: Harald Grosse (U Vienna), Ryszard Nest (U Copenhagen), Walter Van Suijlekom (U Nijmegen), Stefan Weinzierl (U Mainz)

Dates: March 2 – 13, 2015

Budget: ESI € 19 600,
National Science Foundation (NSF) € 13 525

Report on the workshop

The newly discovered relation between Feynman integrals in quantum field theory and Grothendieck's theory of motives of algebraic varieties has become a topic of growing importance in the panorama of theoretical and mathematical physics. In particular, the field has developed along different parallel lines, and one of the pressing needs is to create more interaction between researchers involved in the various different aspects of this area of research.This ESI programme was aimed at four different directions:

1. Motives and periods in perturbative quantum field theory
2. Amplitudes and super Yang–Mills theory
3. Algebraic structures in renormalization
4. Quantum field theory on noncommutative spacetimes

Activities

The full schedule of the workshop is available at the workshop's home page:
`http://www.noncommutativegeometry.nl/esi2015`.

The first week of the programme consisted of a series of lectures forming a master class aimed at junior researchers.

Speakers and topics were:
Stefan Weinzierl, *Feynman integrals and the functions associated to them*;
Karen Yeats, *Graph theory and QFT periods*;
Raimar Wulkenhaar, *Quantum field theory on noncommutative spacetimes*;
Jacob Bourjaily, *Scattering Amplitudes and Grassmannian Geometry*.

Due to cooperation between the Erwin Schrödinger Institute and the Collège de France, Alain Connes delivered a series of three lectures as part of the overall programme. The overall title of the series was "The Arithmetic Site", and in the first week he gave lecture 1: Noncommutative Geometry.

In addition, Pierre Vanhove delivered an Erwin Schrödinger Lecture entitled: *Modular invariance and duality symmetries in Quantum Field Theory and String Theory*.

In the second week there was a research workshop with some of the leading researchers on both the Physics and Number Theory side.

Alain Connes delivered the second and third talks in his series entitled: *Quanta of Geometry and the Arithmetic Site respectively*.

In addition Nils Carqueville gave a talk suitable for a general audience entitled: *Topological quantum field theory: symmetries and defects*.

Some Specific information on the workshop

There was an excellent group of junior researchers present in week one especially due to the NSF funding, which supported ten graduate students and postdocs from the US, and the fact that the organisers kept some 7.000 Euro in reserve from the overall budget in order to fund Europeans.

The special lectures by Alain Connes, Pierre Vanhove and Nils Carqueville were especially appreciated by the attendees who included a very large number of people from outside the workshop.

Outcomes and achievements

The organisers received very positive feedback from the participants on the extent of collaborative activity initiated by those present.

Groups formed around particular interests such as perturbative QFT (Argawala, Broadhurst, Kreimer and Yeats) and NCG (Arici, Dabrowski, Carey, Gayral, Krajewski, Landi, Nest). Ongoing collaborations such as that of Baditiou and Rosenberg and that of Grosse and Wulkenaar were stimulated and there was a lively interaction between Hesselholt and Connes on cyclic homology. There was also considerable interaction between the different specialities represented at the workshop.

Slides from many of the talks are available at
`http://www.noncommutativegeometry.nl/esi2015/slides/`.
This means that the workshop content is available to the mathematical and physics community generally.

List of talks

Master Class, March 2 – 6, 2015

Stefan Weinzierl	Feynman integrals and the functions associated to them (Lecture Series I - III)
Raimar Wulkenhaar	Quantum field theory on noncommutative spacetimes (Lecture Series I - IV)
Jacob Bourjaily	Scattering Amplitudes and Grassmannian Geometry (Lecture Series I - V)
Karen Yeats	Introduction to a combinatorial perspective on QFT
Karen Yeats	Graph theory and QFT periods
Karen Yeats	Recursive and algebraic structure via DSEs
Pierre Vanhove	Erwin Schrödinger Lecture: Modular invariance and duality symmetries in Quantum Field Theory and String Theory
Alain Connes	The Arithmetic Site, Lecture Series, part 1 of 3: Noncommutative Geometry

Research Meeting, March 9 – 13, 2015

Katarzyna Rejzner	BV algebras in perturbative AQFT and effective quantum gravity
Sylvie Paycha	The residue of meromorphic functions with linear poles and the geometry of cones
Jacob Bourjaily	Scattering Amplitudes and Grassmannian Geometry
Susama Agarwala	A Tale of two renormalizations: BPHZ and Epstein Glaser
Adrian Tanasa	Tensor models
Lars Hesselholt	Topological Hochschild homology and periodicity
Alain Connes	The Arithmetic Site, Lecture Series, part 2 of 3: Quanta of Geometry
Vincent Rivasseau	Tensor Models, from branched polymers to Brownian spheres
Alain Connes	The Arithmetic Site, Lecture Series, part 3 of 3: Arithmetic Site
Nils Carqueville	Topological quantum field theory: symmetries and defects
David Broadhurst	Polylogs of roots of unity: the good, the bad and the ugly
Dirk Kreimer	Organizing QFT by next to leading logs
Victor Gayral	From equivariant quantization to locally compact quantum group
Giovanni Landi	The geometry of quantum lens spaces
Thomas Krajewski	Some applications of the loop vertex expansion
Spencer Bloch	Cutkosky rules and vanishing cycles
Dmitry Dorin	Counting rational points on graph hypersurfaces

Publications and preprints contributed

E. Remiddi, L. Tancredi, *Differential equations and dispersion relations for Feynman amplitudes.The two-loop massive sunrise and the kite integral.* arXiv:1602.01481 [hep-ph] , Nuclear Physics B (tbp).

P. Morales-Alazan, K. Kirsten, *Casimir effect for smooth potentials on spherically symmetric pistons*, 2015, J. Phys. A: Math. Theor. 48 495201 http://dx.doi.org/10.1088/1751-8113/48/49/495201.

E. Panzer, *The parity theorem for multiple polylogarithms*, by Erik Panzer, arXiv:1512.04482.

J.Tekel, *Matrix model approximations of fuzzy scalar field theories and their phase diagrams*, JHEP 12 (2015) 176 arXiv:1510.07496.

L. Dabrowski, G. Landi, Franz Luef *Sigma-model solitons on noncommutative spaces* Lett. Math. Phys. 105 (2015) 1663–1688.

L. Hesselholt, *Periodic topological cyclic homology and the Hasse-Weil zeta function* arXiv:1602.01980.

Invited scientists

Susama Agarwala, Ben Albert, Francesca Arici, Pangiotis Batakidis, Gabriel Baditoiu, Spencer Bloch, Jacob Bourjaily, David Broadhurst, Alan Carey, Özgür Ceyhan, Alain Connes, Ludwik Dabrowski, Dmitry Doryn, Kurusch Ebrahimi-Fard, Victor Gayral, Hualong Gervais, Jonathan Gleason, Harald Grosse, Lars Hesselholt, Tajron Juric, Thomas Krajewski, Dirk Kreimer, Giovanni Landi, Andres Larrain-Hubach, Osmar Maldonado, Pedro Morales, Ryszard Nest, Pranav Pandit, Sylvie Paycha, Erik Panzer, Loukas Papadogiannis, Carlos Ignacio Perez-Sanchez, Valerio Proietti, Aldo Rampioni, Ettore Remiddi, Kasia Rejzner, Vincent Rivasseau, Steve Rosenberg, Paolo Solis, Chen Sun, Ruben Stienstra, Adrian Tanăsa, Juraj Tekel, Pierre Vanhove, Walter van Suijlekom, Stefan Weinzierl, Daping Weng, Jörg Wildeshaus, Harold Williams, Raimar Wulkenhaar, Yunyun Yang, Karen Yeats, Shoji Yokura.

ESI - CECAM Workshop: From Trajectories to Reaction Coordinates: Making Sense of Molecular Simulation Data

Organizers: Peter G. Bolhuis (U Amsterdam), Christoph Dellago (U Vienna), Gerhard Hummer (MPI Biophysics, Frankfurt)

Dates: September 16 – 18, 2015

Budget: ESI € 4 960,
Centre Européen de Calcul Atomique et Moléculaire (CECAM) € 11 949

Report on the workshop

As computational science is playing an increasingly important role in all fields of science and engineering and even the social sciences and the humanities, enormous amounts of data are produced each day by computer simulations running on computers around the world. In many areas, the challenge no longer is to create data, but to make sense of them. Molecular simulation has been dealing with such problems for some time, for instance when studying rare transitions between long-lived states such as the folding of a protein or the freezing of a liquid. Given detailed observations from computer simulations or from experiment, how does one extract a reliable description of the mechanism of the process? Such mechanistic understanding is expressed in terms of low-dimensional models that capture the essential features of the process under study.

The problem of constructing dynamical models from trajectory data is tied to two classic sampling problems in statistical mechanics, i.e., the calculation of the populations of metastable states, expressed in terms of free energies, and the sampling of the rare events associated with transitions between the metastable states. For these purposes, a broad range of methods have been developed that allow us to explore conformation space and to reach time scales much more efficiently than with direct unbiased simulation. These enhanced sampling methods typically rely on advance knowledge of relevant coordinates. Order parameters, for instance, are used to delineate the boundaries of the metastable states. Reaction coordinates measure also the progress of the transition in a dynamically relevant way.

With reaction coordinates occupying such a central role in both the sampling and of simulation of trajectories and their mechanistic interpretation, it is no surprise that finding them has attracted much attention. Formally, the progress of a reaction can be measured using the so-called committor. However, this quantity is both hard to determine and difficult to make sense of. In practice, therefore, one often seeks simple functions in terms of physically meaningful quantities that approximate the committor. Over the last couple of years, a number of methods have been developed to find good reaction coordinates. These methods are based on a variety of approaches including neural networks, maximum likelihood, transition path theory, path reweighting, Markov state models as well as dimensionality reduction.

The central goal of this workshop was to define and advance the state of the art in constructing reliable and meaningful models from data obtained from molecular simulations, and in using such models to gain mechanistic insight as a guide for applications and further study. Furthermore, the workshop aimed at pooling the cumulative knowledge of diverse but related fields. Applied mathematicians interested in transition path theory, computer scientists interested in machine learning, physicists interested in phase transitions, chemists working on reaction mechanisms, and biologists elucidating the function of molecules s are representative

of the many fields benefiting from an improved understanding of reaction coordinates. A main goal of the meeting therefore was to enhance communication in this diverse community, with the hope of developing new ideas and computational approaches.

Activities

Due to the rather large number of participants, which resulted from the strong interest generated in the community following the announcement of the workshop, the program was rather dense. There were a total of 30 invited talks of 25 minutes and 6 contributed talks of 15 minutes.

A poster session on the first day of the workshop provided young participants with the opportunity to present their research work to the community. Essentially all participants, who did not give a talk, presented a poster. For the organizers it was gratifying to see that there were intense discussions in front of all posters which went on from 17:00 until the poster session was closed at 21:00.

On the second day of the workshop, a round table discussion moderated by the organizers took place. The discussion was very productive and some of its outcomes are summarized below in Section ”Outcomes and achievements”.

Despite the dense program, there was sufficient time for informal discussions in small groups during coffee and lunch breaks and, in particular, at the social dinner, which was attended by almost all participants.

Specific information on the workshop

The workshop was organized jointly by the Erwin-Schrödinger-Institute for Mathematics and Physics and DaCAM, the Austrian node of CECAM (European Center for Atomic and Molecular Computation). CECAM is a European organisation for the promotion of particle based simulations with headquarters in Lausanne and nodes in several European cities including Vienna. The main activities of CECAM (www.cecam.org) are the organisation of workshops, conferences, school and tutorials in fields ranging from physics, chemistry and molecular biology to materials science and engineering. The theme of the workshop belongs to the focal points of DaCAM and is central to research carried out at the Univeristy of Vienna (Group of Profs. C: Dellago and C. Likos), at the Technical University of Vienna (Group of Prof. G. Kahl) and the Vienna University for Life Sciences and Natural Ressources (Group of Prof. C. Oostenbrink).

The announcement of the workshop in early 2015 generated much interest in the community. In fact, the organizers received many more requests for workshop participation than they could accommodate. Including local participants (mainly students and postdocs from the simulation groups at the University of Vienna and the Technical University of Vienna) the workshop was attended by about 70 people, which is probably too large but this number is due of the overwhelming interest in the workshop. About 50 applications for participation had to be turned down.

In response to the great interest in the topic of the workshop, the organizers have applied for a Lorentz Center/CECAM workshop on “Reaction coordinates from molecular trajectories”. The workshop has already been granted and it will take place from 9 August to 2 September 2016 at the Lorentz Center in Leiden, The Netherlands (http://www.lorentzcenter.nl). This workshop is intended to focus on the central issues that emerged from the Vienna workshop.

As was noted by many participants, the average age of the workshop participants was particularly low. The following early stage researchers took part in the workshop and presented a poster (title in parenthesis):

Bianco Valentino, University of Vienna, Austria, “Proteins and Bio-polymer Design in explicit water: a Coarse-Grained Approach”

Brotzakis Phaedon, University van Amsterdam, The Netherlands, “Transition path sampling of self-assembly of anti-freeze peptide nanotubes”

Cardelli Chiara, University of Vienna, Austria, “Interplay between geometrical constrains and alphabet size in the design of patchy polymers”

Chaimovich Aviel, Max-Planck-Institut fr Polymerforschung, Germany, “Relative Resolution: A Hybrid Formalism for Fluid Mixtures”

Dahlen Oda, Norwegian University of science and technology (NTNU), Norway, “Mesoscopic modeling of DNA denaturation rates”

Delemotte Lucie, Swiss Federal Institute of Technology Lausanne EPFL , Switzerland, “In Silico Electrophysiology: Molecular Dynamics of a Voltage Gated Ion Channel Gating Charge”

Goldsmith Bryan, University of California, Santa Barbara, USA, “Rate-Enhancing Roles of Water Molecules in Methyltrioxorhenium-Catalyzed Olefin Epoxidation by Hydrogen Peroxide”

Granata Daniele, Temple University, USA, “Characterizing structure and free energy landscape of proteins by NMR-guided metadynamics”

Kukharenko Oleksandra, University of Konstanz, Germany, “Use of the dimensionality reduction to systematically expand configuration sampling of IDPs”

Leitold Christian, University of Vienna, Austria, “Construction of string reaction coordinates using RapidMiner”

Lervik Anders, Norwegian University of Science and Technology (NTNU), Norway, “Gluing potential energy surfaces with rare event simulations”

Meloni Roberto, University of Milan, Italy, “Numerical Recovery of Drift and Diffusion Coefficients via the Kramers-Moyal Formalism”

Menzl Georg, University of Vienna, Austria, “Bubbles in water under tension”

Moqadam Mahmoud, Norwegian University of Science and Technology (NTNU), Norway, “Reactive Born-Oppenheimer Molecular Dynamic via Rare Event Method”

Morawietz Tobias, University of Vienna, Austria, “Simulating Proton Transfer Reactions in Liquid Water by Artificial Neural Networks”

Moritz Clemens, University of Vienna, Austria, “Investigating the Disk- to Slab-Geometry Phase Transition”

Nerattini Francesca, University of Vienna, Austria, “Designing highly specific probes with tunable affinity”

Newton Arthur, University of Amsterdam, The Netherlands, “Self-assembly kinetics of anisotropic particles by path sampling”

Nguyen Minh Khoa, Grenoble University, France, "As-Rigid-As-Possible shape interpolation for molecular modeling"

Oprzeska-Zingrebe Ewa Anna, University of Stuttgart, Germany, "Uncovering the free energy landscape and the unfolding motion of a 7-bp DNA hairpin in the presence of urea by molecular dynamics simulations and metadynamics"

Pérez Villa Andrea, SISSA-Scuola Internazionale di Studi Superiori Avanzati, Trieste, Italy, "Modeling of NS3 Helicase Interactions with ssRNA"

Poon Geoffrey, University of California, Santa Barbara, USA, "Accelerated nucleation due to trace additives"

Rene Espinosa Jorge, University Complutense of Madrid, Spain, "The crystal-fluid interfacial free energy and nucleation rate of NaCl from different simulation methods"

Riccardi Enrico, Norwegian University of Science and Technology (NTNU), Norway, "New Monte Carlo moves for path sampling: 'stone skipping' and 'web throwing'"

Rosa Marta, SISSA-Scuola Internazionale di Studi Superiori Avanzati, Trieste, Italy, "Sampling the conformational free-energy landscape of complex molecules in solution: achieving QM-level accuracy at a nearly MM-level computational cost"

Singraber Andreas, University of Vienna, Austria, "Investigating phase transitions of copper sulfide using a neural network potential"

Söderhjelm Pär, Lund University, Sweden, "A hunt for good collective variables to enhance flap dynamics in proteases"

Tapia Rojo Rafael, Universidad de Zaragoza, Spain, "Mechanical and Thermal Unfolding of a Simple Protein Goes Beyond the Reach of One-Dimensional Descriptions"

Outcomes and achievements

The following topics emerged as central from the presentations and the Q&A sessions of the workshop. These issues were also at the focus of a round table discussion, which took place within the meeting.

One-dimensional models, committor as reaction coordinate

As the committor can in principle serve as the perfect reaction coordinate, the question arises, whether the dynamics in this coordinate (or in any coordinate that can be simply mapped into the committor) is Markovian such that the kinetics of the process can be easily analyzed in terms of the free energy landscape. Beyond this issue of principle, from a practical point of view the question arises if it always feasible to adopt a one-dimensional description of the dynamics based on a single (but possibly complicated) reaction coordinate or whether it is preferable to construct higher dimensional models such as Markov-State-Models. In this context an important recent publication was pointed out (A.M. Berezhovski and A. Szabo, J. Phys. Chem. B 117, 13115, 2013) and its significance was discussed at the workshop. In this paper, the authors demonstrated that if a multidimensional dynamics is projected onto the committor, the resulting diffusion equation yields the correct flux even if it does not correctly describe the dynamics. The question of the validity of one-dimensional models is of particular importance because, as pointed out by the experimentalists participating in the workshop, such models are very popular for the interpretation of experimental data.

Machine learning methods for finding reaction coordinates

One topic intensely discussed at the workshop was the use of machine learning tools to identify relevant variables necessary to describe the dynamics of the system. Given the rapid increase in computing power, such tools and related dimensionality reduction approaches (for instance diffusion and sketch maps) will be of crucial importance in the future. The hope is that on this point one will be able to learn from other fields in which machine learning methods are used in big data applications.

Trajectory sampling

A recurring issue in the discussions at the workshop concerned the possibility of understanding the dynamics of the system in the relevant variables in terms of free energies alone. In other words, when do we need to sample trajectories and when can we get away sampling solely configuration space and then adding the stochastic dynamics on top of the free energy surface? Furthermore, particular complications both for the sampling but also for the construction of simplified models arise if a reaction can proceed via several different pathways.

Resolving these issues is a major current challenge for the simulation and modeling of molecular processes.

List of talks

Ron Elber	Milestoning Networks in Search for Reaction Pathways
Michele Ceriotti	Automatically recognizing molecular patterns in atomistic simulations
Carla Molteni	Exploring the Effects of Mutations on the Neurotransmitter Binding Free Energy Landscape of Ligand-Gated Ion Channels
Srabani Taraphder	Determination of the Reaction Coordinate for a Key-Conformational Fluctuation in Human Carbonic Anhydrase II
William A. Eaton	Protein Folding Transition Paths: Single Molecule Experiments, Theory and All-Atom MD Simulations
Michael Woodside	Direct observation of transition paths during the folding of proteins and nucleic acids
Robert Best	Reduction of all-atom folding dynamics to one-dimensional diffusion
Swetlana Jungblut	Caveats of mean first-passage time methods applied to crystallization
Francesco Gervasio	Investigating Allosteric Regulation Through Enhanced Sampling Simulations.
Jordi Marti	Computer Simulation Study of DMPC-Cholesterol Biomembranes in Aqueous Solution: Diffusion, Spectroscopy and Free Energy Surfaces
Aaron Dinner	Understanding Error in Umbrella Sampling
Chris Oostenbrink	Protein-Ligand Binding from Distancefield Distances and Hamiltonian Replica Exchange Simulations
Carsten Hartmann	Cross entropy minimization for rare events based on optimal control of reaction coordinates
Frank Noe	pyEMMA: Estimation and analysis of Markov models from molecular dynamics and thermodynamic simulations
Jan-Hendrik Prinz	OpenPathSampling (OPS): An open Python framework for path sampling simulations
Omar Valsson	Variationally-Enhanced Sampling
Richard Sear	Crystallisation via an intermediate that is neither liquid nor crystalline
Ivan Coluzza	Transferable Coarse-grained potential model for quantitative protein folding and design

Eduardo Sanz	A seeding approach to the crystal nucleation problem
Titus van Erp	Analyzing complex reaction mechanisms using path sampling
Baron Peters	From path sampling to mechanistic hypothesis testing
Pietro Faccioli	Using the Renormalisation Group theory to rigorously construct Markov State Models of adjustable time-resolution from atomistic trajectories
Modesto Orozco	Towards and integrative approach to the exploration of the conformational landscape
Christine Peter	Making Sense of a Mess: Conformational Equilibria of (Partially) Disordered Systems
Yannis Kevrekidis	Some twists in the use of diffusion maps for data mining of atomistic simulations
Daniel Munoz-Santiburcio	Simulating Prebiotic Peptide Synthesis with ab initio Metadynamics
Marco Saitta	Miller Experiments in Atomistic Computer Simulations
Pratyush Tiwary	Towards predictive pharmacokinetics simulations with recent developments in enhanced sampling
Cristian Micheletti	Self-assembling knots of controlled topology by designing the geometry of patchy templates
Sergei Krivov	Optimal Reaction Coordinates
Giovanni Bussi	RNA dynamics in stop motion: from crystal structures to trajectories
Christof Schütte	A complete theory of how to select the optimal reaction coordinates
Edina Rosta	Asymmetric activation of RAF Kinase Dimers
Fabio Pietrucci	Exploiting Topological Coordinates to Explore Reactive Pathways in Gas Phase and Solution in a Unified Way
Bernd Ensing	Describing the Environment Reorganization that Governs Charge Transfer Reactions

Invited scientists

Albert Ardevol, Robert Best, Valentino Bianco, P.G. Bolhuis, Phaedon Brotzakis, Giovanni Bussi, Chiara Cardelli, Michele Ceriotti, Aviel Chaimovich, Eliodoro Chiavazzo, John Chodera, Ivan Coluzza, Roberto Covino, Oda Dahlen, Janos Daru, Lucie Delemotte, Christoph Dellago, Aaron Dinner, William A. Eaton, Ron Elber, Bernd Ensing, Pietro Faccioli, Francesco Gervasio, Bryan Goldsmith, Daniele Granata, Gyorgy Hantal, Carsten Hartmann, Jaffar Hasnain, Mathias Hld, Gerhard Hummer, Zuzana Jandova, Swetlana Jungblut, Yannis Kevrekidis, Minh Khoa Nguyen, Sergey Krivov, Oleksandra Kukharenko, Christian Leitold, Anders Lervik, Jordi Marti Rabassa, Manuela Maurer, Roberto Meloni, Georg Menzl, Cristian Micheletti, Carla Molteni, Mahmoud Moqadam, Tobias Morawietz, Clemens Moritz, Daniel Munoz Santiburcio, Arthur Newton, Francesca Nerattini, Frank Noe, Chris Oostenbrink, Modesto Orozco, Andrea Perez-Villa, Ugo Perricone, Francesca Pescati, Christine Peter-Tittelbach, Baron Gabriel Peters, Fabio Pietrucci, Geoffrey Poon, Harald Posch, Jan-Hendrik Prinz, Jorge Rene Espinosa, Enrico Riccardi, Marta Rosa, Edina Rosta, Marco Saitta, Eduardo Sanz Garcia, Christof Schütte, Richard Sear, Marcello Sega, Martina Setz, Andreas Singraber, PŁr Sderhjelm, Rafael Tapia Rojo, Srabani Taraphder, Pratyush Tiwary, Luca Tubiana, Ayzegvri Tunpcu, Omar Valsson, Titus van Erp, Michael Woodside.

Ergodic Theory and Holomorphic Dynamics

Organizers: Anna Miriam Benini (Rome II - Tor Vergata), Henk Bruin (U Vienna), Dierk Schleicher (Jacobs University Bremen), Sebastian van Strien (Imperial College)

Dates: September 28 – October 2, 2015

Budget: ESI € 13 680

Report on the workshop

The theory of complex dynamics branches out in many directions, and makes connections with complex analysis, chaotic dynamics, symbolic languages, algebra and continuum theory. The main goal of this workshop was to foster the interaction between the theory of complex dynamics and ergodic theory, with special attention to ergodic theory and transcendental dynamics. As the knowledge about the dynamics of rational functions progresses, investigating transcendental functions are a natural next step. For this class of maps, the measures of interest are frequently infinite, thus bordering the area of infinite ergodic theory, but several other aspects on the crossing between complex dynamics and ergodic theory have been addressed.

Titles and abstracts of all talks, as well as slides of several presentations, can be found on the conference webpage http://www.mat.univie.ac.at/∼bruin/Workshops/WS2015.html.

Activities

The workshop was structured with mini-courses and survey talks in the morning and research talks in the afternoon.

As one of the border topics between ergodic theory and complex dynamics, we had two survey talks and one research talk on Kleinian Groups, Patterson-Sullivan theory and Dynamics on hyperbolic manifolds by Falk, Peigné and Sambusetti.

We also had a mini-course on thermodynamic formalism for transcendental maps by Zdunik and Karpińska.

We naturally had several research talks in order to present recent developments in both complex dynamics and ergodic theory. We also had several shorter talks in order to give younger researchers the opportunity of presenting their work (and more senior researchers the opportunity to get in touch with it).

Specific information on the workshop

Among the participants there were 5 PhD students (Marten Fels, Khudoyor Mamayusupov, David Marti-Pete, Leticia Pardo Simon, Vasiliki Evdoridou) and 5 Postdoctoral fellows (Anna Miriam Benini, Trevor Clark, Alexandre Dezotti, Neil Dobbs, Dima Dudko). Out of the 33 participants in the workshop, 9 were females (27%).

The main themes of the conference have been:
• Thermodynamical formalism and transcendental functions (A. Zdunik, B. Karpińska, K. Barański);
• Kleinian groups, Patterson-Sullivan theory and negatively curved manifolds (K. Falk, M. Peigné, A. Sambusetti);
• Ergodicity and the conjecture that the Mandelbrot set is locally connected (G. Levin, T. Clark and D. Dudko);
• Measure-Theoretical properties of rational and transcendental dynamics (M. Todd, N. Dobbs, J. Hawkins, F. Przytycki);
• Fatou components in transcendental dynamics (N. Fagella, X. Jarque, D. Marti-Pete, G. Stallard).

The Friday afternoon of the conference was reserved to the Budapest-Vienna Ergodic Theory Workshop (see http://www.mat.univie.ac.at/∼zweimueller/BudWiSer/Budwiser.html).
Given the close connection in topic, this was a natural choice: two speakers (Przytycki and Urbański) came from conference, one fresh input (Selley) came from Budapest, and it had

the additional advantage of preventing the conference to peter out because a fair number of participants have to leave early on Friday.

Outcomes and achievements

- Anna Miriam Benini, Phil Rippon and Gwyneth Stallard have collaborated on a joint project on the classification of simply connected wandering domains for entire transcendental functions.
- Kurt Falk and Marc Peigné have started a collaboration which will be followed up during subsequent visits in spring 2016.
- Bruin and Schleicher worked on an extensive revision of a paper on the Hausdorff dimension of biaccessible eternal angles for quadratic Julia sets and the Mandelbrot set.
- Bruin, Fels and Schleicher discussed the Ph.D. work of Marten Fels which turned out to be related to (partly unpublished) work of the other two.
- Genadi Levin and Sebastian van Strien had discussions on a joint project together with Weixiao Shen.

We believe that there will be short-term and long-term benefits of this workshop to the scientific community, by the publication of related papers in the next 2-3 years and by the increased awareness of ergodic theoretical aspects and the dynamics of Kleinian groups by participants whose main field of research is holomorphic dynamics (and vice versa for researchers whose main research is in the dynamics on negatively curved manifolds).

List of talks

Anna Zdunik	Thermodynamic formalism for transcendental maps I
Marc Peigné	Counting for negatively curved manifolds : an introduction I
Marc Peigné	Counting for negatively curved manifolds : an introduction II
Mariusz Urbański	Random dynamics of transcendental meromorphic functions
Dmitry Dudko	Self-similarity of the Mandelbrot set around Siegel parameters of periodic type
Andrea Sambusetti	Volume growth and rigidity of negatively curved manifolds of finite volume
Trevor Clark	Rigidity for one-dimensional maps
Trevor Clark	Quasi-symmetric rigidity for one-dimensional maps II
Fanni Selley	Mean field coupling of identical expanding circle maps
Sebastian van Strien	Fictitious games: a class of piecewise smooth dynamical system with very interesting properties
Xavier Jarque	Wandering domains for composition of entire functions
Bogusia Karpińska	Thermodynamic formalism for transcendental maps II
Phil Rippon	Connectedness properties of the set where the iterates of an entire function are unbounded
Gwyneth Stallard	Commuting functions and multiply connected wandering domains.
Neil Dobbs	Typical behaviour in the exponential family
Carsten Petersen	On quasi-conformal (in-) compatibility of satellite copies of the Mandelbrot set

Genadi Levin	The Lyapunov exponent of holomorphic maps
Núria Fagella	Escaping points in the boundary of Baker domains
Mike Todd	Continuity of measures
Feliks Przytycki	Geometric pressure in real and complex 1D dynamics via trees of pre-images and via spanning sets
David Marti-Pete	Escaping Fatou components of transcendental self-maps of the, punctured plane
Alexandre Dezotti	The eventual hyperbolic dimension of entire functions
Kurt Falk	An introduction to dynamics on hyperbolic manifolds
Kurt Falk	Conformal ending measures
Vasiliki Evdoridou	Fatou's web and non-escaping endpoints
Jane Hawkins	Lebesgue measure dynamics of rational maps
Kryzstof Barański	Ergodic aspects of transcendental dynamic

Feedback from participants

Jane Hawkins *The recent holomorphic dynamics and ergodic theory workshop held at ESI provided many interesting talks on a wide variety of topics of current research in all aspects of the field. I was able to hear about the latest results in many aspects of the focus areas and to connect with researchers who have overlap with my own work. The feedback on my talk was also valuable, and I exchanged ideas with some mathematicians about ways to extend my results. I returned to my home university with new connections and ideas. The organizers provided a welcoming and friendly atmosphere, and I was impressed that the participants and speakers spanned several generations of mathematicians and included a diverse group of speakers.*

Kurt Falk *I thought the meeting in Vienna was very well organised and the location as always very visitor-friendly. In terms of mathematics, I was very happy to finally get to meet Marc Peigné and Andrea Sambusetti, who work in Kleinian groups and whose work I (partially) knew before. In fact, Marc was interested in what I had to say in my research talk and we agreed that I will visit him in Tours in spring of 2016 to discuss matters further. However, interacting with the Holomorphic Dynamics crowd was also interesting, as one gets to see what kind of questions they are looking at nowadays. In this respect the meeting was for me personally (and possibly also for some of the participants like Gwyneth, Phil and students, who were in Bremen too) a bit of a follow up to the winter school I had organised here in Bremen in 2014: http://wisdict.math.uni-bremen.de*

Gwyneth Stallard: *The conference on "Ergodic Theory and holomorphic dynamics" was an excellent event. The mix of survey talks and research talks was just right. The survey talks were very helpful in reinforcing key ideas and it was interesting to have survey talks from different areas as these highlighted some of the similarities between results in the different areas. The number of talks each day was also just right with enough time between talks to allow useful discussions which may lead to new research ideas. The administrative support of the ESI was excellent and the staff were all very helpful and friendly. The facilities were also excellent - and the high quality blackboards were much appreciated!*

Genadi Levin *The conference schedule was divided between survey talks in complex dynamics and in hyperbolic manifolds and more specialized talks mainly in complex dynamics. As my area of specialization is complex dynamics, some survey talks about hyperbolic manifolds were fresh and very interesting to hear. Alltogether, there were many interesting talks and perhaps I liked especially the ones given by Zdunik, Peigné, Petersen, Dezotti, Dobbs, Clark (I was absent on Friday though). The conference was well organized, was definitely successful and left a good feeling.*

Publications and preprints contributed

Anna Miriam Benini, *A note on repelling periodic points for meromorphic functions with bounded set of singular values*, http://arxiv.org/abs/1411.6796

Henk Bruin and Dierk Schleicher, *Hausdorff dimension of biaccessible angles for quadratic polynomials,* submitted to Fund. Math.

Invited scientists

Krzysztof Barański (Univ. of Warsaw), Anna Miriam Benini (Univ. of Roma II), Henk Bruin (Univ. of Vienna), Carlo Carminati (Univ. Pisa), Jernej Činč (Univ. of Vienna) Trevor Clark (Imperial College, London), Alexandre Dezotti (Univ. of Liverpool), Neil Dobbs (Univ. of Geneva), Dmitry Dudko (Univ. of Göttingen), Vasiliki Evdoridou (OPen University, UK), Nuria Fagella (Univ. Auton. Barcelona), Kurt Falk (Univ. of Bremen), Marten Fels (CUNY), Jane Hawkins (North Carolina, Chapel Hill), Xavier Jarque i Ribera (Univ. Auton. Barcelona), Boguslawa Karpińska (Univ. of Warsaw), Genadi Levin (Hebrew Univ. Jerusalem), Khudoyor Mamayusupov (Jacobs Univ. Bremen), David Marti-Pete (Open University, UK), Paul Müller (Univ. of Linz), Leticia Pardo Simon (University of Bristol), Marc Peigné (Univ. of Orléans-Tours), Carsten Lunde Petersen (Roskilde Univ.), Feliks Przytycki (IMPAN, Warsaw), Hesameddin Rajabzadehestahlbanati (Sharif University of Technology, Tehran), Phil Rippon (Open University, UK), Andrea Sambusetti (Univ. Roma I), Dierk Schleicher (Jacobs Univ. Bremen), Fanni Selley (BME, Budapest), Gwyneth Stallard (Open University, UK), Aminosadat Talebi (Sharif University of Technology, Tehran), Niclas Technau (TU Graz), Mike Todd (Univ. St. Andrews), Mariusz Urbański (Univ. of Texas, Denton), Sebastian Van Strien (Imperial College, London), Stephen Worsley (Univ. of Liverpool), Anna Zdunik (Univ. of Warsaw).

Higher Topological Quantum Field Theory and Categorical Quantum Mechanics

Organizers: Nils Carqueville (U Vienna), Daniel Murfet (U Melbourne), Ingo Runkel (Hamburg U)

Dates: October 19 – October 23, 2015

Budget: ESI € 14 640,
Murfet's grant € 1 224

Report on the workshop

The overall purpose of this workshop was to bring together two communities, which share a common language but heretofore have not interacted very strongly: one community consists of those investigating the role of higher categories in topological quantum field theory (TQFT), while the other community is made up of researchers studying new categorical foundations for quantum mechanics and quantum computation. Higher categories are coming to play a central role in TQFT and related fields including algebra, geometry, topology, condensened matter physics, supersymmetric gauge theory, and string theory. On the other hand, researchers in categorical quantum mechanics have made rapid progress on clarifying the conceptual problems of quantum information. Recently many parallels between the foundations of quantum mechanics, quantum computation and topological quantum field theory have begun to take shape, centered around the common mathematical language of symmetric monoidal categories (both ordinary categories and higher categories) with duals at various levels.

These two communities met for a week of scientific discussions and a long list of talks covering many of the important overlaps. As a result of the workshop the fundamental ideas and recent progress in each area has been advertised to the other, and a series of obstacles to direct collaboration have been removed.

Activities

The workshop was held from October 19 to October 23, 2015. During the whole week we planned 23 talks, 5 talks per day with the exception of Wednesday when we had 3 talks in the morning followed by a free afternoon for discussion and a colloquium talk by Constantin Teleman at the Vienna mathematics department. The speakers included both senior scientists, post-docs and PhD students.

At the beginning of the week there were two introductory lectures on categorical quantum mechanics by Chris Heunen and two introductory lectures on topological quantum field theory and higher categories by Gregor Schaumann.

Specific information on the workshop

As we have already indicated, the goal of the programme was to create an opportunity for researchers in both communities to explain their work to the other community, in the hope that some of the obvious questions about the connections could be resolved and further investigation begun on deeper questions. In addition to the speakers on TQFT and categorical quantum mechanics, there were speakers from mathematical logic (Paul-André Mellies and Richard Blute) and computer science (Simon Perdrix).

One of the highlights of the workshop was the lively questioning during and after talks, which we took as a strong indication of interest by both camps in understanding each other, and a confirmation of our hunch that the time was ripe for a workshop of this kind (this was further confirmed by the replies we received from our email survey of the participants after the workshop had concluded).

The themes of the workshop included:

- The strongest unifying theme between TQFT and categorical quantum mechanics is the important role in both subjects of Frobenius algebras. These algebras (and various generalisations, such as Calabi-Yau categories) appear naturally in TQFT as a consequence of basic symmetries of cobordism categories. In categorical quantum mechanics Frobenius algebras encode orthonormal bases, which are interpreted as a choice of measurement set-up made by a "classical observer". For the TQFT participants understanding the role of Frobenius algebras in categorical quantum mechanics was one of the primary motivations of the workshop. This was explained in the introductory lectures by Chris Heunen, and recent results in this direction were presented by Ross Duncan. There was a clear interest by the participants of the workshop in a further investigation of the "meaning" of the Frobenius condition, and the fundamental reason why it appears in such a prominent role in both subjects.
- One of the most significant practical applications of categorical quantum mechanics is to provide a diagrammatic language for specifying algorithms for quantum computers - these diagrams denote unitary maps on Hilbert space. This raises a basic question: if two diagrams denote the same unitary map, can this equality be "explained" by a series of diagrammatic transformations that are specified as "allowed" in advance? This property is referred to as *completeness* of the diagrammatic language and Simon Perdrix spoke on his disproof of an important conjecture in this area.
- In topological quantum field theory there are various approaches to incorporating cobordisms of multiple dimensions into the field theory. One is the extended topological field

theories, often defined using ∞-categories, and these were discussed in the workshop by Gregor Schaumann. Another approach is topological field theories with defects. Several speakers reported on progress in this area, including the noteworthy advances made by Catherine Meusburger and collaborators on making 3D TQFTs with defects computable in terms of piece-wise linear cobordism diagrams.

Outcomes and achievements

Overall the workshop met its original goal, namely it has introduced the TQFT and categorical quantum mechanics communities to each other, and we believe the workshop will serve as an excellent starting point for future meetings. Furthermore, the interaction between between experts in TQFT and mathematical logic has sparked strongly increased interest in each others' field, which we see as a very promising development.

List of talks

Chris Heunen	Introduction to Categorical Quantum Mechanics
Gregor Schaumann	Introduction to Topological Quantum Field Theory
Ross Duncan	Interacting Frobenius Algebras Are Hopf
Manuel Bärenz	Dichromatic state sum models and four-dimensional topological quantum field theories from pivotal functors
Nick Gurski	2-categorical methods in abstract homotopy theory
Paul-Andre Mellies	Dialogue categories and Frobenius algebras
Claudia Scheimbauer	(Op)lax natural transformations for higher categories and relative field theories
Alessandro Valentino	Boundary conditions for 3d TQFTs and module categories
Constantin Teleman	Matrix Factorizations and Lie group representations
Bob Coecke	From quantum foundations to natural language meaning via string diagrams
John Barrett	The non-commutative geometry of defects
Christoph Schweigert	Traces for bimodule categories, generalized Wilson lines and generalized conformal blocks
Catherine Meusburger	Gray categories with duals and their diagrammatical description
Domenico Fiorenza	Group actions on boundary structures in Dijkgraaf-Witten theory
Dorette Pronk	Orbifold Atlases Revisited
Simon Perdrix	Supplementary of Interacting Frobenius Algebras
Sergei Gukov	LG interfaces and categorification of interesting algebras
Richard Blute	Towards a Theory of Integral Linear Logic via Rota-Baxter algebras
Bruce Bartlett	The centre of a fusion category, the adjoint representation, and the tube algebroid
Alexei Davydov	Higher Witt categories of modular categories
Jamie Vicary	Higher categories and quantum computation

Invited scientists

Christos Aravanis, Bruce Bartlett, Manuel Bärenz, John Barrett, Klaus Bering, Richard Blute, Nils Carqueville, Bob Coecke, Alexei Davydov, Domenico Fiorenza, Ross Duncan, Jürgen Fuchs, Stefano Gogioso, Sergei Gukov, Nick Gurski, Amar Hadzihasanovic, Christiaan Heunen, Andrey Lazarev, Calin Lazaroiu, Paul-Andre Mellies, Catherine Meusburger, Flavio Montiel Montoya, Stepan Moskaliuk, Daniel Murfet, Simon Perdrix, Dorette Pronk, David Reutter, Francisco Rios, Ingo Runkel, Niccolo Salvatori, Gregor Schaumann, Claudia Scheimbauer, Urs Schreiber, Christoph Schweigert, Matteo Tammasini, Constantin Teleman, Alessandro Valentino, Dominic Verdon, Jamie Vicary, Linde Wester.

Several complex variables and CR geometry

Organizers: Siqi Fu (Rutgers U, Camden), Friedrich Haslinger (U Vienna), Bernhard Lamel (U Vienna), Emil Straube (Texas A & M U)

Dates: November 03 – November 13, 2015

Budget: ESI € 11 040,
Qatar National Research Fund € 960, Fonds zur Förderung der wissenschaftlichen Forschung (Austrian Science Fonds FWF, Internationale Programme) € 960

Report on the workshop

The topic of this workshop was the interaction between several complex variables and CR geometry and the connections to problems in mathematical physics. CR analysis refers to the study of the Cauchy-Riemann (or $\overline{\partial}$) equations on open subsets of $\mathbb{C}^n$, or to the equations they induce on real submanifolds of $\mathbb{C}^n$ (the tangential Cauchy-Riemann or $\overline{\partial}_b$ equations). This includes the study of functions in the kernels of these operators, that is, holomorphic functions and CR-functions respectively.

It was the goal to bring together researchers from complex analysis with expertise on the Cauchy-Riemann equations and their tangential variants (CR analysis) and experts in CR-geometry, in order to initiate a transfer of current ideas and methods between the two fields. CR analysis is also intimately related to diamagnetism, paramagnetism, and semiclassical analysis in quantum mechanics. The purpose of this workshop was to rejuvenate and deepen the investigation of these connections.

Activities

In the first part (Nov. 3 - Nov 6, 2015) the focus was on more geometric aspects, in the second part (Nov. 9 - Nov.13, 2015) on more analytic aspects.

There were over 35 invitees coming mostly from Europe, but also from Japan, the USA, Brazil and Africa. The participants were roughly divided in half between senior staff members and younger scientists, such as PhD students and post-doc fellows. During the whole period we planned 26 talks, mostly 3 per days so that enough free time was left for discussions. The speakers included both senior scientists, post-docs and PhD students. The planning of the talks was organized in such a way that each day covered one of the main thematic areas.

Specific information on the workshop

The first day was devoted to abstract CR geometry, its connections to algebraic geometry, and to umbilical and singular points of CR manifolds. In the following $\overline{\partial}$-homotopy formulas on complex varieties with mild singularities were discussed using appropriate integral operators. It was explained how to use results on unique continuation of holomorphic maps of one complex variable at the boundary for extensions of solutions of planar, complex vector fields. The analyticity of pseudoconvex graphs and their possible generalizations to the q-pseudoconvex case was presented as one of the research topics of the complex analysis group in Wuppertal.

The next day was devoted to the presentation of seminal progress on proper holomorphic embeddings and non-orientable minimal surfaces by the research group of the University of Ljubljana.

The last talks of the first week were given by young researchers (post-doc and PhD students) on Schwarzian derivatives and regularity of infinitesimal CR automorphisms.

The second week started with an interesting review talk by Takeo Ohsawa (recently awarded by the Bergman Prize) on applications of L^2-methods to extension problems of holomorphic functions mentioning connections to algebraic geometry and potential theory and some open problems. The Bergman kernel for generalized Hartogs triangles and singular integral techniques in complex analysis were the themes of the next talks. As the following day was devoted to more geometric aspects, the last talk on higher order symmetries of real hypersurfaces in $\mathbb{C}^3$ served as a preparation for automorphic groups of Levi degenerate hypersurfaces in $\mathbb{C}^3$ and stationary discs and singular Riemann-Hilbert problems. Interesting phenomena appear if one tries to get results for the L^2-theory on the intersection of pseudoconvex domains from the L^2-theory on the single original domains. The connection between the weighted box-operator and matrix valued Schrdinger operators with magnetic field opens a wide door for interesting pointwise estimates of the Bergman kernel using methods inspired by mathematical physics. Parameter dependence of Bergman kernels, its Hölder continuity, were extensively discussed. Interesting new estimates for the Szegö kernel on unbounded convex domains were derived with the help of classical convexity tools. In addition important new results concerning compactness and Sobolev estimates for $\overline{\partial}_M$ were presented. Here M is a compact pseudoconvex orientable CR-manifold without boundary, of hypersurface type. In addition, integral formulae for the solution of the $\overline{\partial}$-equation for domains with non-smooth boundaries were developed.

With the help of general methods from spectral theory the essential spectrum of the complex Laplacian on product domains was determined with applications to questions about compactness of the $\overline{\partial}$-Neumann operator. An improvement of the celebrated Hörmander theorem on semi-global solvability for linear partial differential operators statisfying condition (P) was presented. Finally recent results on the multidimensional Suita conjecture were discussed at least for convex domains and global L^q-Gevrey spaces were intorduced to estimate the $\Box_b$-heat kernel on polynomial models.

In both weeks there were talks by PhD students (Stefan Fürdös and Franz Berger) and also by Post-docs (Son Ngoc Duong, Soledad Benguria and Gian-Maria Dall'Ara).

Outcomes and achievements

During the workshop Gian-Maria Dall'Ara (Scuola Normale Superiore, Pisa) agreed to join the complex analysis group in Vienna for a Post-doc position supported by a FWF-grant beginning Januray 2016.

We believe that the event was a success, allowing young and senior researchers to exchange ideas in the studious atmosphere of the Schrdinger Institute. The next activity ("Symposium in Complex Analysis and Geometry ") with a similar scope is planned to take place at Tsinghua Sanya International Mathematics Forum in Sanya, Hainan Province in southern China on January 16-20, 2016.

List of talks

Soledad Benguria	An application of John ellipsoids to the Szegö kernel on unbounded convex domains
Franz Berger	The essential spectrum of the complex Laplacian on product manifolds
Shiferaw Berhanu	Some remarks on the weak Hopf lemma
Mehmet Celik	Analysis on the intersection of pseudoconvex domains
Bo-Yong Chen	Parameter dependence of the Bergman kernels: Hölder continuity
Paulo Cordaro	Semi-global solvability with loss of one derivative for linear partial differential operators in dimension 2
Gian Maria Dall'Ara	The weighted $\overline{\partial}$-problem in $\mathbb{C}^n$: solvability, compactness, and pointwise bounds for the Bergman kernel
Giuseppe Della Sala	Stationary discs and singular Riemann-Hilbert problems
Barbara Drinovec Drnovšek	Complete proper holomorphic embeddings of strictly pseudoconvex domains into balls
Son Ngoc Duong	On Schwarzian derivative and CR mappings
Peter Ebenfelt	Umbilical points on compact, three dimensional CR manifolds
Franc Forstnerič	Non-orientable minimal surfaces in $\mathbb{R}^n$
Stefan Fürdös	Regularity of infinitesimal CR Automorphisms
Martin Kolar	Automorphism groups of Levi degenerate hypersurfaces in $\mathbb{C}^3$
Loredana Lanzani	Singular Integral techniques in Several complex variables
Ingo Lieb	Formulae and estimates for the Cauchy-Riemann equations
Jeffery McNeal	The Bergman projection on generalized Hartogs triangles
Francine Meylan	Higher order symmetries of real hypersurfaces in $\mathbb{C}^3$
Nordine Mir	Artin approximation and CR geometry
Takeo Ohsawa	Backgrounds and updates of L^2 extension theorems
Andrew Seth Raich	Global L^q-Gevrey Function Spaces
Jean Ruppenthal	$\overline{\partial}$-homotopy formulas on singular varieties
Nikolay Shcherbina	Some remarks on analyticity of q-pseudoconcave graphs
Laurent Stolovitch	Real submanifolds of maximum complex tangent space at a CR singular point
Emil Straube	L^2-Sobolev and compactness estimates for $\overline{\partial}_M$: a (very) brief survey
Wlodzimierz Zwonek	Multidimensional Suita conjecture

Publications and preprints contributed

Duong Ngoc Son, *The Schwarzian derivative and Mbius equation on strictly pseudo-convex CR manifolds*, arXiv:1512.01663.

Bo-Yong Chen, *Parameter dependence of the Bergman kernels*, arXiv : 1506.01146v2.

Invited scientists

Franz Berger (University of Vienna), Shiferaw S. Berhanu (Temple University), Soledad Benguria (University of Wisconsin-Madison), Mehmet Celik (Texas A&M University Commerce), Boyong Chen (Fudan University), Paulo Domingos Cordaro (University of So Paulo), Gian Maria Dall'Ara (Scuola Normale Superiore, Pisa), Giuseppe Della Sala (Beirut University), Son Ngoc Duong (Texas A&M University at Qatar), Barbara Drinovec-Drnovšek (University of Ljubljana), Peter Ebenfelt (University of California, San Diego), Armen Edigarian (Jagiellonian University in Krakow), Damir Ferizovic (University of Vienna), Franc Forstnerič (University of Ljubljana), Gabor Francsics (Michigan State University), Siqi Fu (Rutgers University, Camden), Stefan Fürdös (University of Vienna), Abraham Hailu (Addis Abeba University), Friedrich Haslinger (University of Vienna), Martin Kolar (Masaryk University, Brno), Lukasz Kosinski (Jagiellonian University in Krakow), Ilya Kossovskiy (university of Vienna),

Bernhard Lamel (university of Vienna), Loredana Lanzani (Syracuse University), Ingo Lieb (UniversitŁt Bonn), Jeffrey McNeal (Ohio State University), Francine Meylan (University of Fribourg), Nordine Mir (Texas A&M University at Qatar), Stephanie Nivoche (Universit Nice Sophia Antipolis), Takeo Ohsawa (Nagoya University), Andy Seth Raich (University of Arkansas), Michael Reiter (U Vienna), Jean Ruppenthal (Bergische UniversitŁt Wuppertal), Filippo Salis University of Cagliari), Nikolay Shcherbina (Bergische UniversitŁt Wuppertal), Laurent Stolovitch (Universit Nice Sophia Antipolis), Emil Straube (Texas A&M University), Sebastian Woblistin (University of Vienna), Wlodzimierz Zwonek (Jagiellonian University in Krakow).

Research in Teams

Herbert Muthsam et al: Multi-scale Models of Magnetohydrodynamic (MHD) Turbulence in Solar Convection, Follow-up from September 2014

Collaborators: Friedrich Kupka (U Vienna), Herbert Muthsam (U Vienna), Arakel Petrosyan (Russian Academy of Sciences, Moscow), Oleh Pomazan (National Research Nuclear University MEPhI, Moscow)

Dates: March 19 – April 18, 2015

Budget: ESI € 4 800

Scientific Background

Turbulence represents one of the most important phenomena, both in astrophysical and in laboratory plasmas. There is increasing evidence of the key role played by turbulence within different physical processes taking place in magnetofluids, like transport phenomena or the nonlinear dynamics of such complex systems. The presence of velocity and magnetic field fluctuations in a wide range of spatial and time scales has been directly detected in the solar interior with helioseismology. A "complete" direct numerical solution (DNS) resolving *all* length scales, including the small ones, is out of the question for many astrophysical and other systems. It would require computer power tremendously above any realizability. Thus, new computational methods need to be developed to tackle solar convection flows with its huge Reynolds number (which characterizes, to an extent, the number of degrees of freedom of the system). Instead, one tries to *explicitly calculate* the *large scales* only and to *model turbulence* on the smaller, *subgrid scales* (subgrid scale modelling or Large Eddy Simulation, LES).

Project aims and scope

Our aim in this project has been to develop subgrid scale models with solar and stellar convection in mind and to implement it to the package ANTARES (A Numerical Tool for Astrophysical RESearch; see [Muthsam et al. (2010)], [Mundprecht et al.(2013)]). ANTARES has been developed primarily at the Institute of Mathematics, University of Vienna for simulations of solar granulation and other astrophysical flows. After critically reviewing the state of the art in LES for MHD flows we intended to develop subgrid-scale models for statistical properties of MHD turbulence. MHD problems differ from those of the (non-magnetic) hydrodynamics, HD, (where subgrid modelling is implemented in ANTARES): MHD equations contain two vector fields, leading to considerably more freedom into the dynamics. Many self-organization processes in MHD have no counterpart in ordinary hydrodynamics. This necessitates to carefully validate one's MHD subgrid model.

Outcomes and achievements

Two periods were scheduled for our research. In the *first period* (one month, September 2014) we jointly performed test computations with ANTARES code with the already implemented HD subgrid model of the Smagorinsky type. We commenced development and implementation of an MHD subgrid model for MHD based on Smagorinsky type methods based on the work

of [Chernyshov et al.(2008)]. It turned out that the relevant subgrid parametrization could be implemented in ANTARES code in a way that could make use of much of the program structure already present in ANTARES, which amounted to an advantage.

In the *second period* (one month again, April/May 2015) we performed three-dimensional numerical simulations of compressible MHD turbulence. To separate large and small eddy components of the turbulent flow, a Gaussian filter of fourth order accuracy is applied. We adopt periodic boundary conditions for all three coordinate directions. A uniform mesh with 64^3 grid cells is used for obtaining LES results. The simulation domain is a cube of side length π. An initial isotropic turbulent spectrum close to k^{-2} with random amplitudes and phases in all three directions was chosen for kinetic and magnetic energies in Fourier space. The choice of such a spectrum as initial conditions is due to velocity perturbations with an initial power spectrum in Fourier space similar to that of developed turbulence. This k^{-2} spectrum corresponds to spectrum of Burgers turbulence. Initial conditions in physical space for velocity and magnetic field have been obtained using the inverse Fourier transform. In these cases the validation of the LES method requires proving the possibility of reproducing of the scale-similarity Kolmogorov and Iroshnikov-Kraichnan spectra in natural conditions.

Initially, we consider a polytropic electrically conductive fluid. For the first case similarity numbers are: $Re = 1500$, $Re_M = 800$, $M_s = 0.89$, $\gamma = 1.7$ and $E_k \gg E_M$, that is, the value of kinetic energy is initially much higher than that of magnetic energy. The temporal evolution of kinetic and magnetic energy is analysed. It is visible from the numerical results that statistically stationary turbulence arises after an initial time interval when large fluctuations are observed. Later on, the values of E_K and E_M practically do not vary with time so that the balance between dissipation and energy injected in the system has been achieved. It is interesting to note that E_K reaches a stationary regime slightly faster than E_M. The time dynamics of mean density is modelled. The density fluctuations decrease after an initial time interval when strong fluctuations are observed. In the steady-state stationary regime the density weakly fluctuates around the mean value.

Inertial range properties are defined as time averages over periods of stationary turbulence conditions. A Kolmogorov-like spectrum $-5/3$ is observed when MHD turbulence is examined and magnetic energy is much less than kinetic energy, that is, nonlinear interactions are much more considerable than magnetic ones and the fluid is practically a neutrally hydrodynamic one. In Fig.1, the spectra of the kinetic and the magnetic energies are shown (the solid line is the kinetic energy spectrum and the dashed line is the magnetic energy spectrum). The spectra are normalized by factor $k^{5/3}$. The dotted line represents Kolmogorov scaling. The spectra of the kinetic and magnetic energy are obtained after time averaging in the statistically stationary regime and therefore they clearly mark an inertial turbulent range with the Kolmogorov-like spectrum $k^{-5/3}$ for both kinetic energy and magnetic energy as follows from Fig.1. The normalized total energy (that is, the product $E_T^k k^{5/3}$ where E_T^k is the total energy in Fourier space and k is the wave vector) and the smoothed spectrum of the total energy $E_T = E_M + E_K$ are shown in Fig.2. It follows from Fig.2 that in the first case a Kolmogorov-like spectrum has occurred. This result supports the theoretical expectations. The residual energy spectrum ($E_R^K = |E_M^K - E_K^K|$) is shown for the first case. This spectrum is interesting because it gives an insight into the spectral interplay of kinetic and magnetic energies and exhibits self-similar scaling. Fig.3 demonstrates the normalized smoothed spectrum of residual energy and $E_R^K \sim k^{-7/3}$ in inertial range of turbulence, spectrum which was theoretically obtained and was numerically confirmed for incompressible MHD turbulence.

The results obtained have been compared with DNS data, with LES without any SGS models, and with LES without using SGS parametrizations in the total energy equation, but only us-

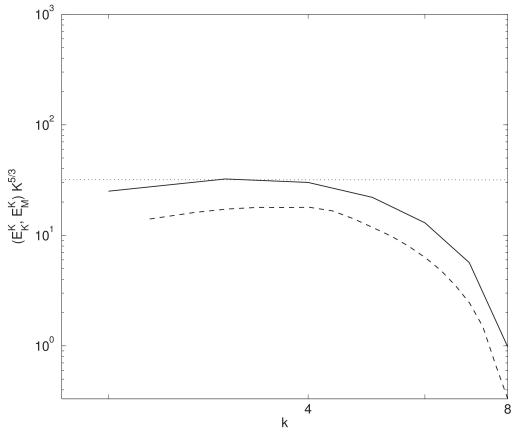

Figure 1: Normalized (multiplied by $k^{5/3}$), time-averaged spectra of kinetic energy (solid line) and magnetic energy (dashed line) for the first case.

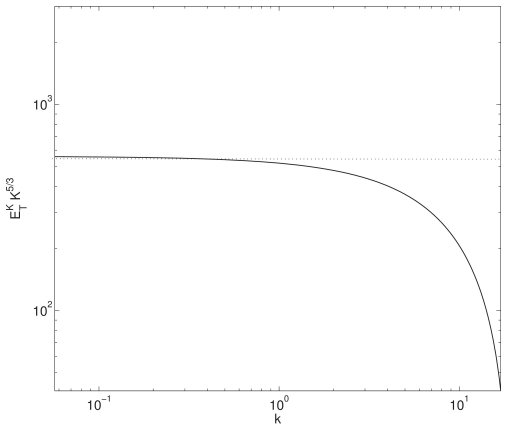

Figure 2: Normalized, time-averaged and smoothed spectrum of the total energy, multiplied by $k^{5/3}$, for the first case.

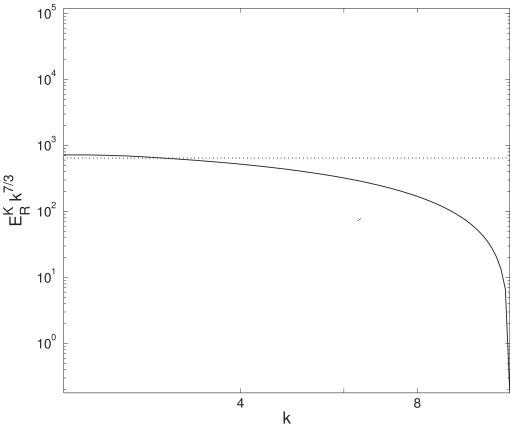

Figure 3: Normalized, time-averaged and smoothed spectrum of the residual energy, multiplied by $k^{7/3}$, for the first case.

ing the ones in the momentum and magnetic induction equations. Consideration of the SGS terms in the energy equation scarcely affects the kinetic and magnetic energies even at high Mach numbers, while for temperature and for internal energy the presence of SGS models in the energy equation is an important condition for improvement of accuracy of the thermodynamic quantities. The work undertaken substantially improved the capabilities of ANTARES code to model compressible Solar convection for realistic Prandtl numbers and to model for the first time Solar oscillations in presence of magnetic fields and to understand Solar surface dynamo for Prandtl numbers smaller than one. It should be noted that all computations mentioned above need to be done for time intervals far exceeding characteristic times of turbulent flows in ANTARES model as well as those we use for validation of Smagorinsky parametrisation in Large Eddy Simulations. Moreover, computations need to be done for very small meshes. Such computations showed that we obtain non-realistic temperature fields in isolated spots. This inevitably lead us to perform two very important and time-consuming complimentary

work packages, namely to understand mathematical reasons for such numerical instability in temperature fields predictions, and to develop ways forward to improve predictions. Comprehensive ANTARES code runs proved that this is due to error accumulation in radiative transfer block of code. We developed and implemented in ANTARES code special limiters to avoid non-realistic temperature predictions. This produced some delays in presentation of publications of obtained scientific outcomes.

Publications and preprints contributed:

Oleh Pomazan, Friedrich Kupka, Herbert Muthsam and Arakel Petrosyan, *Studies of Solar surface dynamo for small Prandtl numbers with Large Eddy Simulations*, in preparation

Oleh Pomazan, Friedrich Kupka, Herbert Muthsam and Arakel Petrosyan, *Modelling of Solar granulation in presence of magnetic fields at extreme resolution*, in preparation

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[Muthsam et al. (2010)]muth10 Muthsam, H. J., Kupka, F., Löw-Baselli, B., et al. 2010, *New Astronomy* **15**, 460

[Mundprecht et al.(2013)]mun13 Mundprecht, E., Muthsam, H. J., & Kupka, F. 2013, *Monthly Notices of the Royal Astronomical Society* **435**, 3191

Senior Research Fellows Programme

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

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

Primoz Ziherl (U of Ljubljana), Summer 2015:
Soft matter physics
Lectures and Exercise Classes (260129 VO): March 2 – June 23, 2015
Monday 10:30 – 12:00 (lecture) and 12:15 – 13:00 (tutorial)

Sławomir Kołodziej (Jagiellonian U), Summer 2015:
Nonlinear elliptic equations in geometry
Lectures (260130 VO): March 11 – May 8, 2015
Wednesday and Friday 14:00 – 15:30

Visitors associated with Senior Research Fellowships:

Ahmed Zeriahi (Université Paul Sabatier, Toulouse), April 13 – April 19, 2015
Matej Krajnc (Jožef Stefan Institute Ljubljana), May 24 - May 29, 2015
Antonio Šiber (U of Zagreb), May 11 - May 15, 2015

Primoz Ziherl: Soft Matter Physics

Course:

The one-semester course in theoretical physics of soft condensed matter physics aimed to provide a broad review the phenomena and the concepts characteristic of soft matter, covering selected topics in the theory of liquid state, liquid crystals, polymers, colloids, and amphiphile assemblies. The course built on the equilibrium thermodynamics and statistical mechanics as well as on classical elasticity. The theoretical topics introduced were illustrated by problems discussed in the tutorials, giving the students some hands-on experience.

Research

During his stay at ESI, P. Ziherl worked on several projects in the theoretical physics of soft condensed matter and in theoretical biophysics, some of them initiated earlier and some started in Vienna.

In collaboration with C. N. Likos (Vienna), he continued to work on the coarse-grained continuum model of the **elasticity of a spherical polymer brush** as a prototype nanocolloidal particle. To interpret the results of numerical simulations carried out by J. Riest (Forschungszentrum Jülich), they proposed two effective continuum models, the so-called soft-ball model and liquid-drop model. During his stay at ESI, Likos and Ziherl established the connection between the elasticity of these brushes and the Egelstaff-Widom length, a concept from the theory of

classical molecular liquids. They used the scaling theory to explain the observed universal response of the brushes upon diametral compression between parallel walls.They wrote the final version of the manuscript "Elasticity of polymeric nanocolloidal particles" co-authored by J. Riest (Jülich), L. Athanasopoulou (Ljubljana), and S. A. Egorov (Charlottesville), which was submitted for publication.

G. Kahl (Vienna) and P. Ziherl started a joint project on the orientational order in suspension of **dendrimer particles**. In their past work done in collaboration with G. Georgiou (Vienna), we showed that the neighboring dendrimers orient preferentially such that their long axes are perpendicular, which is referred to as the antinematic order. In his MS thesis, G. Kahl's student B. Pezendorfer (Vienna) examined this behavior across a broad range of temperatures and other parameters. The interpretation of the raw results is still missing, and Kahl and Ziherl started working on this. They also wrote a proposal for a CECAM workshop on "Structure formation in soft colloids" to be held in Vienna in 2016 provided that the proposal is approved.

With T. Dotera (Osaka), Ziherl started to theoretically study a new type of **two-lenthgscale quasicrystals** with a novel type of symmetry. This project is a continuation of their past collaboration, and they expect to finalize it in Fall 2015. Ziherl Dotera also wrote the first draft of the manuscript "A geometric view of structure formation in soft colloids" to be published in the proceedings of the summer school "Soft Matter Self-Assembly" held in Varenna, Italy, from June 28 to July 7 2015.

In collaboration with T. Jimbo, Y. Sakuma, M. Imai (Sendai), and N. Urakami (Yamaguchi), Ziherl completed a joint project on **self-reproduction of lipid vesicles** where they experimentally and theoretically analyze the transformation of a single spherical vesicle into a budded dumbbell-like shape which then divides into two spherical daughter vesicles, which can then be repeated to produce several generations of vesicles. This process is driven by the intra-membrane phase transition on heating. The manuscript "Temperature-controlled self-reproduction cycle of binary vesicles" was submitted for publication.

Ziherl also wrote the final version of the manuscript "Quantitative morphology of epithelial folds" coauthored by N. Štorgel, M. Krajnc, P. Mrak, and J. Štrus (Ljubljana). In this manuscript, the authors propose a **theoretical model of folded epithelial tissues** found in many animals, e.g., in the mouse bronchiole or in the stomach of the stalked sea squirt. Their model differs from the existing theories in that it associates the deformed folded shape with the apico-basal intra-epithelial tension rather than with, e.g., buckling due to the mismatch of areas of the epithelium and of the supporting stroma. The authors' main finding is that in the folded states, epithelial thickness is modulated rather than uniform. They were able to identify four distinct types of epithelial folds. This division is supported by experimental observations. This manuscript has been submitted for publication. With M. Krajnc, Ziherl also worked on the revised version of the manuscript "Embryo-scale tissue mechanics coordinates gastrulation movements" co-authored by M. Rauzi, T. Saunders, U. Kržič, L. Hufnagel, and M. Leptin (European Molecular Biology Laboratory Heidelberg).

Another project started and completed while Ziherl was at ESI deals with a microscopic model of **spontaneous curvature of binary lipid mixtures**. He showed that the existing theories predicting that the spontaneous curvature of the mixture is a lever-rule weighted average of the curvatures of the component may be insufficient and that the relative size of the molecules may matter too. Using a simple hard-particle packing model, Ziher proposed a more general formula and analyzed the possible consequences of the unequal molecular size of the components in typical experimental situations where the accessible range of concentrations is limited. An in-depth experimental study is needed to either prove or disprove the theory, and Ziherl is planning a collaboration with G. Pabst (Graz) on this topic.

Finally, Ziherl also worked on a book project with A. Šiber (Zagreb); Šiber also gave a seminar "Conformations of circular DNA bundles in viruses" for researchers and students in Vienna. They completed the draft of a chapter and sketched the contents of another two chapters. During his stay at ESI, Ziherl visited the University of Graz where he served on the PhD thesis committee of Dr. B. Kollmitzer and gave a seminar entitled "Mosaic two-lengthscale quasicrystals", and he visited IST Austria where he met with several researches and gave a talk on "Quantitative morphology of epithelial folds".

Lecture Notes

The draft version of the lecture notes for the course *Soft matter physics* is available at `http://www-f1.ijs.si/ ziherl/smt.pdf`.

Publications and preprints contributed

1. J. Riest, L. Athanasopoulou, S. A. Egorov, C. N. Likos, and P. Ziherl, "Elasticity of polymeric nanocolloidal particles", Nature, DOI: 10.1038/srep15854, (2015).
2. M. Rauzi, U. Krzic, T. E. Saunders, M. Krajnc, P. Ziherl, L. Hufnagel, M. Leptin, "Embryo-scale tissue mechanics during Drosophila gastrulation movements", Nature, DOI: 10.1038/ncomms9677, (2015).
3. N. Štorgel, M. Krajnc, P. Mrak, J. Štrus, and P. Ziherl, "Quantitative morphology of epithelial folds", Biophyscial Journal, http://dx.doi.org/10.1016/j.bpj.2015.11.024, (2016).
4. T. Jimbo, Y. Sakuma, N. Urakami, P. Ziherl, and M. Imai, "Temperature-controlled self-reproduction cycle of binary vesicles", submitted.
5. P. Ziherl and T. Dotera, "A geometric view of structure formation in soft colloids", in preparation.
6. P. Ziherl, "Spontaneous curvature of binary lipid mixtures", in preparation.

Sławomir Kołodziej: Nonlinear Elliptic Equations in Geometry

Course

I gave a course titled Nonlinear elliptic equations in geometry. The goal of this course was to show the role of weak solutions of the complex Monge-Ampère equation in describing the limits of the Kähler-Ricci flow and finding singular canonical metrics in Kähler geometry. The topic required short introductions to: complex analysis (plurisubharmonic functions and positive differential forms); elliptic and parabolic PDE's (maximum principles, Schauder estimates, Evans-Krylov theorem); and Kähler geometry. In the second part the proof of Calabi-Yau on the solution of the complex Monge-Ampre equation theorem was given. The continuity method of Yau was simplified by making use of Evans-Krylov theory. To study the weak solutions of the equation I introduced some elements of pluripotential theory like positive currents and capacities. Then the existence of solutions to the complex Monge-Ampre equation when the right hand side belongs to L^p (with $p > 1$) was established as well as the stability of those solutions. The last part of the course dealt with the Kähler-Ricci flow on compact Kähler manifolds. Using recent, excellent lecture notes of Song and Weinkove I sketched proofs of some results on the evolution of geometric quantities along the flow, long time existence, the convergence of

the flow for definite Chern classes, and Tian-Zhang theorem on the singular Kähler-Einstein metrics.

Research

During my stay at the ESI I worked on the paper Weak solutions of complex Hessian equations on compact Hermitian manifolds, written in collaboration with Cuong Ngoc Nguyen, and posted on arXiv:1507.06755. The institute invited my other collaborator Ahmed Zeriahi for one week in April. We discussed some open problems which may lead to new projects. I also had many interesting discussions with Piotr Chruściel and the members of the Seminar Complex Analysis at Vienna University. I am very grateful to the ESI Director and to Piotr Chruściel for organizing this stay and the staff of the ESI for creating the perfect working conditions.

Publications and preprints contributed:

S. Kołodziej, N. Cuong Nguyen, *Weak solutions of complex Hessian equations on compact Hermitian manifolds*, `arXiv:1507.06755` [math.CV], SRF.

Erwin Schrödinger Lectures 2015

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

Speaker: Pierre Vanhove (Institut des Hautes Études Scientifiques, Bures-sur-Yvette)

Date: March 4, 2015

Pierre Vanhove: Modular invariance and duality symmetries in Quantum Field Theory and String Theory

Abstract
An apocryphal quote (sometime attributed to Martin Eichler) says that "There are five elementary arithmetical operations: addition, subtraction, multiplication, division, and . . . modular forms." Modular and automorphic forms play prominent role in the understanding of the fundamental properties of quantum field theory and string theory. They are consequences of fundamental duality symmetries connecting weakly coupled and strongly coupled regimes of the theory. In this talk we will describe the appearance of modular and automorphic forms in string theory in connection to fundamental properties of black hole. We will explain how physically motivated questions connect to deep properties of automorphic representation. We will as well report on the recent progress in perturbative computations in QCD and quantum gravity, and the role of modular forms in the evaluation of Feynman integrals.

Speaker: Daniel Huybrechts (University Bonn, Mathematical Institute)

Date: December 10, 2015

Daniel Huybrechts: Symmetries and K3 surfaces

Abstract
Since Kodaira and Weil in the fifties, K3 surfaces have attracted a great deal of attention and it seems they will continue to do so for many years to come. Many mathematical concepts can be tested in their realm, from geometry, arithmetic, and more recently conformal field theory.

There is, however, one aspect that remains completely mysterious. Why is it that K3 surfaces have symmetries that can only be explained in terms of sporadic simple groups like the Conway group, related to the famous Leech lattice, or the slightly smaller Mathieu groups? This intriguing link has been observed in many instances but it has not yet been explained.

This talk will introduce into this fascinating area, starting with Mukai's result on finite groups of automorphisms of K3 surfaces, its modern version using derived algebraic geometry and to a phenomenon called 'K3 moonshine' in superconformal field theory.

Simons Junior Professor Nils Carqueville

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

Teaching

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

Summer Term 2015:

Introduction to category theory
Lecture Course, 2h, 250093 VO: March 5 – June 30, 2015 Thursday 11:15 - 12:45

Course description: This course is an introduction to category theory, a theory of structures and powerful organising principles with many applications. We start with an extended discussion of the basic definitions and properties of categories and functors, with many illustrating and motivating examples from various areas of mathematics.

Important milestones of later parts of the lecture course will be the study of universal properties in the following guises: (i) adjoint functors; (ii) representability and the Yoneda lemma; (iii) limits (special cases of which are products, equalisers, or pullbacks) and colimits (e.g. sums, coequalisers, or pushouts).

The last part of the course will depend on the audience's taste; possible topics include (a) (co)ends (generalising (co)limits) and Kan extensions; (b) the relation to logic and computer science (lambda calculus and Curry-Howard correspondence), monoidal categories with additional structures (relevant e.g. for topological and conformal field theories), or (d) aspects of "categorification" (e.g. of representations of Lie algebras or of polynomial knot invariants).

Bachelorseminar
Seminar, 2h, 250037 VO: March 6 – June 30, 2015 Friday 10:15 - 16:45

Course description: Forum for Bachelor students to present their projects; supervision of two projects on bordism categories and quantum logic.

Winter Term 2015/16:

Topological Quantum Field Theory
Lecture Course, 2h, 250104 VO: October 1, 2015 – January 31, 2016 Thursday 11:15 - 12:45

Course description: The functorial approach to topological quantum field theory goes back to Atiyah and Segal. After a motivational discussion of the Feynman path integral and a brief, self-contained introduction to monoidal categories, the lecture is roughly divided into three parts. (1) We will first study general properties of "closed d-dimensional TQFTs", and work out specific details for d=1,2,3. Interesting examples in the two-dimensional case are topological Yang-Mills theory, sigma models and Landau-Ginzburg models. (2) We then move to "open/closed 2d TQFT" a la Moore-Segal and Lazaroiu, which "live" on surfaces that may have non-trivial boundary conditions. We will see that such TQFTs are equivalently described by an interplay of commutative Frobenius algebras and Calabi-Yau categories. (3) Finally we add further structure to the surfaces by embedding certain one-dimensional submanifolds. This leads to "2d TQFT with defects". A minimal generators-and-relations description analogous to (1)

and (2) is not known in this case, but we will explain that 2-categories are the natural language here. This lecture course may be continued in the summer term 2016.

Higher category theory seminar
Seminar, 2h, 250111 VO: October 2, 2015 – January 31, 2016 Friday 11:15 - 12:45

Course description: Fusion categories, ribbon categories, module categories, graphical calculus, 2d state sum models, Turaev-Viro theory.

Cryptography
Seminar, 2h, 250095 VO: October 7, 2015 – January 31, 2016 Wednesday 14:15 - 15:45

Course description: Elementary topics in cryptography and their modern relevance, including: discrete logarithms; Diffie-Hellman key exchange; integer factorisation; RSA encryption; elliptic curve cryptography; Logjam attack; NIST backdoor; fully homomorphic encryption.

Linear Algebra
Tutorial, 2h, 250009 VO: October 1, 2015 – January 31, 2016 Thursday 16:45 - 18:15

Course description: Tutorial for lecture course on Linear Algebra.

Research

In 2015 the research of Nils Carqueville focused on (i) 3-dimensional TQFT and associated tricategories, (ii) Calabi-Yau completions of dg-categories and their orbifold completion, (iii) homological knot invariants, (iv) quiver representations, and (v) group actions on higher categories.

Further activities

In March and April 2015, Nils Carqueville was an invited participant of the programme on "Knot homologies, BPS states, and SUSY gauge theories" at the Simons Center for Geometry and Physics. In October 2015, he organised the ESI workshop "Higher TQFT and categorical quantum mechanics" ($\sim$ 50 participants), and in December 2015 the "Advanced school on Topological Quantum Field Theory" ($\sim$ 50 participants) in Warsaw together with Piotr Sulkowski and Rafal Suszek. He also welcomed into his group Daniel Scherl as a Master student and Omid Hurson as a PhD student (co-supervised with Domenico Fiorenza (U Rome 1)).

Visits from: Catherine Meusburger (U Erlangen), Simon Lentner (U Hamburg), Domenico Fiorenza (U Rome 1), Paige North (U Cambridge), Florian Schätz (U Aarhus), Daniel Tubbenhauer (U Louvain), Ingo Runkel (U Hamburg), Junya Yagi (SISSA), Daniel Murfet (U Melbourne), Christoph Schweigert (U Hamburg).

Visits to: Simons Center for Geometry and Physics, CUNY, LMU München, MPI for Mathematics, Bonn, U Erlangen, U Münster.

List of talks given by guest scientists:

Wolfgang Wieland (Penn State University)	Covariant loop quantum gravity
Alessandro Valentino (MPI Bonn)	Boundary conditions for extended TQFTs and anomalies
Domenico Fiorenza (U Rome 1)	Central extensions of mapping class groups from characteristic classes
Gregor Schaumann (MPI Bonn)	Algebraic operations from topological field theory
Simon Lentner (U Hamburg)	BiGalois objects and the Brauer Picard group
Daniel Tubbenhauer (U Louvain)	From Dualities to Diagrams
Florian SchäŁtz (U Aarhus)	Represention of the based loop space
Paige North (U Cambridge)	Weak factorization systems for intensional type theory
Junya Yagi (SISSA, Trieste)	Quiver gauge theories and integrable lattice models
Constantin Teleman (U Berkeley)	Introduction to quadratic topology
Daniel Murfet (U Melbourne)	Two odd things about computation
Christoph Schweigert (U Hamburg)	An isomorphism in representation theory and its interpretation in topological field theory

Publications and preprints contributed

N. Carqueville, A. Quintero Vélez, *Calabi-Yau completions and orbifold equivalence*, arXiv:1509.00880 [math.RT].

EPDI: European Post-Doctoral Institute Scholars

The European Post-Doctoral Institute for Mathematical Sciences was founded in October 1995 by the The Institut des Hautes Études Scientifiques (Bures-sur-Yvette, France), The Isaac Newton Institute for Mathematical Sciences (Cambridge, United Kingdom) and The Max-Planck-Institut für Mathematik (Bonn, Germany) with the common goal to encourage the mobility of young scientists on a European scale. In 1999 the membership has been enlarged to include among others the Erwin Schrödinger International Institute for Mathematical Physics (Vienna, Austria). At this time the number of institutes engaged in the pursuit of excellence is eleven.

Each year five laureates are awarded a grant-in-aid which allows them extended research visits at member institutions. In 2015 the following EPDI scholar visited the ESI:

Felix Günther (TU Berlin): July 6 – December 30, 2015:

Report

The three main objectives of my six-month stay at the ESI were to continue my research on discrete complex analysis, in particular considering discrete Riemann surfaces and discussing discrete holomorphic spinors, to start a new project on smooth polyhedral surfaces together with Helmut Pottmann (TU Wien), and to advertise discrete differential geometry to the general public, but especially to high school and undergraduate students.

In my doctoral thesis [G14], I discussed a linear theory of discrete complex analysis on general quad-graphs, continuing and extending previous work of Duffin, Kenyon, Mercat, Skopenkov, Chelkak and Smirnov. The medial graph of the quad-graph plays a crucial role in this theory. It provides the connection between the notions of discrete derivatives of Chelkak and Smirnov [CS11], extended from rhombic to general quad-graphs, and discrete differential forms and discrete exterior calculus as suggested by Mercat in [M01]. The medial graph approach turns out to be quite useful for integration theory. For example, the key lemma stating that the discrete exterior derivative is a derivation of the discrete wedge-product can only be formulated and proven using the medial graph decomposition. Many further results rely on this lemma and discrete Stokes' theorem. In the plane, this concerns discrete Green's identities and discrete Cauchy's integral formulae for discrete holomorphic functions, and on discrete Riemann surfaces, the discrete Riemann bilinear identity and the discrete Riemann-Roch theorem rely on these two lemmas.

A small part of my stay at the ESI was devoted to the final revisions on the joint papers on discrete complex analysis in the plane [BG16], which is going to appear in the Springer book *Advances in Discrete Differential Geometry* in early 2016, and on discrete Riemann surfaces [BG15] that Bobenko and I submitted in November 2015. In addition, visiting the ESI workshops *Ergodic theory and holomorphic dynamics* and *Several complex variables and CR geometry* gave me inspiration for further possible discretizations of classical theorems. However, my major focus was the development of a theory of discrete holomorphic spinors on discrete Riemann surfaces. Discrete spinors on a double cover of the medial graph were just sketched by Mercat in [M01] for the case of rhombic quad-graphs. Shortly before I arrived in Vienna, I identified Mercat's Dotsenko equation of spinors as a discrete holomorphicity condition on the medial graph and then continued investigating this notion of discrete holomorphicity as well as the corresponding discrete Laplacians. For weighted surface graphs that differently generalize the setup of rhombic quad-graphs, this was discussed by Cimasoni in [C15].

Quite surprisingly, much of the discrete theory of complex analysis can be recovered for this

slightly different way of defining discrete holomorphic functions. For example, a new discrete exterior derivative can be defined that is again a derivation of the discrete wedge-product, and discrete Green's identities hold true for the new discrete derivatives. These discrete derivatives depend on the choice of one of two specific decompositions of the parallelograms of the medial graph into triangles, resulting in a more complicated discrete Laplacian. In October 2015, I presented a report on the relation between discrete spinors and discrete holomorphicity at the *International Conference on Discretization in Geometry and Dynamics* in Herrsching am Ammersee. In the near future, I am planning to investigate the relations between my approach using the medial graph and the formalism of Kac-Ward matrices Cimasoni used in [C15] and to discuss the impacts of these results on statistical physics. One of my long-term goals is to understand Atiyah's famous theorem that the dimension of holomorphic spinors on an even or odd spin structure is even or odd, respectively, already in the discrete setup. In August 2015, I had the particular opportunity to discuss spinors in the smooth and the discrete setup with Atiyah himself at the *Heidelberg Laureate Forum*.

I began my stay in Austria by visiting the *Geometry Workshop* in Seggau 2015. The topics of this meeting included polyhedral surfaces and discrete differential geometry in general, so it was not a coincidence that I met Helmut Pottmann there. He invited me to the symposium of the center of *Geometry and Computational Design* and we met several times in his office at TU Wien to discuss the geometry of polyhedral surfaces. In his joint paper [JTVWP15], where he studied the design and optimization of polyhedral patterns, which are patterns of planar polygonal faces on freeform surfaces, he discovered that some patterns adapt their shape according to the sign of the Gaussian curvatures and others do not. Polyhedral patterns of the first type look smoother than patterns of the other type. The aim of our project is now to find suitable assessments of smoothness of polyhedral surfaces without a smooth reference surface. The property we started with is that the Gaussian image of the star of a vertex of either positive or negative discrete Gaussian curvature shall have no self-intersections. Already this property limits the possible shapes of Gaussian images to convex spherical polygons in the case of positive discrete Gaussian curvature and to spherical pseudo-digons, -triangles and -quadrilaterals in the case of negative discrete Gaussian curvature.

In the smooth theory, planes parallel and close to the tangent plane at a point of positive or negative curvature intersect the surface in curves that resemble ellipses and hyperbolas, respectively. To get a similar behavior in the discrete setup, one has to require in addition that the Gaussian image of negatively curved vertex stars is star-shaped. This condition can also be easier implemented into an algorithm. As a result, the asymptotic directions can be identified with the faces of inflection at the vertex star and might lead to better initializations. Furthermore, the change of sign of discrete Gaussian curvature and isolated points of vanishing curvature inside a polyhedral face can be described with the help of the Gaussian image. In the next months, we are planning to discuss the properties of the projective dual surface and possible further conditions that are necessary to ensure smoothness of the projective dual. Also, the consequences for optimization algorithms shall be investigated.

Finally, I was engaged in several public outreach activities during my stay at the ESI. In August 2015, Lara Skuppin (TU Berlin) and I organized a two-week seminar on discrete differential geometry in the framework of the summer academy of the *German National Academic Foundation* in Leysin. With an interdisciplinary group of eleven undergraduate students we discussed in particular the geometry of discrete curves and polyhedral surfaces, discrete minimal surfaces, discrete complex analysis and discrete conformal maps. Moreover, I gave a plenary lecture on discrete differential geometry and discrete complex analysis in front of all 160 participants. In November 2015, I was a lecturer at a seminar of the program *Youth trains Mathematics* in Ulm,

where the best German high-school students in mathematics are prepared for the participation in math competitions. On this occasion, I repeated the plenary lecture I gave in Leysin and in a four-hour course I described the importance of conformal maps in navigation and in mathematics. In Berlin, I volunteered for the project *Physics for Refugees* and showed on the day before Christmas a physical experiment and mathematical tricks to young children in their first accommodation in Germany.

The highlight of my promotion of discrete differential geometry was the participation in the *Science Slam Vienna* on 19th November 2015. In just slightly more than six minutes I used an atlas, charts, a cucumber, a knife, a cube and a picture illustrating Cauchy's integral formula to explain my research to a general audience. A recording of my performance can be found on `https://www.youtube.com/watch?v=Xhx75YnNvkY`. The audience chose me as the winner of this competition, such that I will represent Vienna in the Austrian championship on 22nd April 2016. I am looking forward to coming back to Vienna since thanks to the excellent working conditions, the friendly atmosphere and the supportive staff at the ESI I have wonderful memories of the six months I stayed there.

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[C15] D. Cimasoni, *Kac-Ward operators, Kasteleyn operators, and s-holomorphicity on arbitrary surface graphs*. *Annales de l'Institut Henri Poincaré D* 2(2), pages 113–168, 2015.

[G14] F. Günther, *Discrete Riemann Surfaces and Integrable Systems*. *PhD thesis*, Technische Universität Berlin, Faculty II – Mathematics and Natural Sciences, 194 pages, September 2014. `http://opus4.kobv.de/opus4-tuberlin/files/5659/guenther_felix.pdf`

[JTVWP15] C. Jiang, C. Tang, A. Vaxman, P. Wonka, H. Pottmann, *Polyhedral patterns*. *ACM Transactions on Graphics (Proceedings of SIGGRAPH Asia)* 34(6), 12 pages, 2015

[M01] C. Mercat, *Discrete Riemann surfaces and the Ising model*. *Communications in Mathematical Physics* 218(1), pages 177–216, 2001.

Publications and preprints contributed

[BG15] A.I. Bobenko, F. Günther, *Discrete Riemann surfaces based on quadrilateral cellular decompositions*. Preprint `arXiv:1511.00652` [math.CV], 36 pages, 2015.

[BG16] A.I. Bobenko, F. Günther, *Discrete complex analysis on planar quad-graphs*. To appear in *Advances in Discrete Differential Geometry*, Editor: A.I. Bobenko, Springer, 74 pages, 2016. Preprint `arXiv:1505.05673` [math.CV], 2015.

Seminars and colloquia outside main programmes and workshops

398 seminar and colloquia talks have taken place at the ESI in 2015.

2015 01 09, W. Wieland: “Covariant loop quantum gravity”
2015 02 18, A. Valentino: “Boundary conditions for extended TQFTs and anomalies”
2015 02 18, D. Fiorenza: “Central extensions of mapping class groups from characteristic classes”
2015 03 04, P. Vanhove: “Modular invariance and duality symmetries in Quantum Field Theory and String Theory” [Erwin Schrödinger Lecture]
2015 03 05, A. Connes: “Noncommutative Geometry”
2015 03 10, A. Connes: “Quanta of Geometry”
2015 03 11, A. Connes: “Arithmetic Site”
2015 03 17, G. Schaumann: “Algebraic operations from topological field theory”
2015 05 07, S. Lentner: “BiGalois objects and the Brauer Picard group”
2015 05 11, A. Šiber: “Conformations of circular DNA bundles in viruses”
2015 05 13, D. Tubbenhauer: “From Dualities to Diagrams”
2015 05 15, F. Schätz: “Represention of the based loop space”
2015 05 20, P. North: “Weak factorization systems for intensional type theory”
2015 06 17, J. Yagi: “Quiver gauge theories and integrable lattice models”
2015 12 10, D. Huybrechts: “Symmetries and K3 surfaces” [Erwin Schrödinger Lecture]

ESI Research Documentation

ESI research in 2015: publications and arXiv preprints

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

BBS = Ergodic Theory and Holomorphic Dynamics
BMB = Infinite-dimensional Riemannian Geometry with Applications to Image Matching and Shape Analysis
EPDI = European Post-Doctoral Fellow
EWS = Quantum Many-body Systems, Random Matrices, and Disorder
FHL = Several Complex Variables and CR Geometry
GMS = Modern Theory of Wave Equations
GNV = The Interrelation between Mathematical Physics, Number Theory and Noncommutative Geometry
KRS = Arithmetic Geometry and Automorphic Representations
RIT = Research in Teams
SGS = Higher Structures in String Theory and Quantum Field Theory
SRF = Senior Research Fellows

THEMATIC PROGRAMMES

Infinite-dimensional Riemannian Geometry with Applications to Image Matching and Shape Analysis (BMB)

P. Balseiro, T. J. Stuchi, A. Cabrera, J. Koiller, *About simple variational splines from the Hamiltonian viewpoint*, 2016, BMB.

E. Bardelli, A. C. G. Mennucci. *Probability measures on infinite dimensional Stiefel manifolds*, 2016, BMB.

Martin Bauer, Peter W. Michor, Olaf Müller, *Riemannian geometry of the space of volume preserving immersions*, BMB.

Martin Bauer, Martins Bruveris, Philipp Harms, Jakob Møller-Andersen, *A numerical framework for Sobolev metrics on the space of curves*, arXiv:1603.03480, Code available on https://github.com/h2metrics/h2metrics, BMB.

Martin Bauer, Martins Bruveris, Philipp Harms, Jakob Møller-Andersen, *Second order elastic metrics on the shape space of curves*, 1st International Workshop on Differential Geometry in

Computer Vision for Analysis of Shapes, Images and Trajectories, 2015, arXiv:1507.08816, BMB.

Martin Bauer, Martins Bruveris, Philipp Harms, Jakob Møller-Andersen, *Curve Matching with Applications in Medical Imaging*, 5th MICCAI Workshop on Mathematical Foundations of Computational Anatomy, 2015, arXiv:1506.08840, BMB.

M. Bauer, B. Kolev and S. Preston, *Geometric investigations of a vorticity model equation*, Journal of Differential Equations (1), 260 (2016), Pages 478516, BMB.

M. Bruveris, *Optimal reparametrizations in the square root velocity framework*, 2015. Preprint available at arXiv:1507.02728, BMB.

S. Calamai, D. Petrecca, K. Zheng, *The Geodesic Problem for the Dirichlet Metric and the Ebin Metric on the Space of Sasakian Metrics*, BMB.

B. Chhay, *Contactomorphism Group with the L^2 Metric on Stream Functions*, BMB.

F. Gay-Balmaz, *Well-posedness of higher dimensional Camassa-Holm equations on manifolds with boundary*, 2016, BMB.

N. Konovenko, V. Lychagin, *Lobachevskian geometry in image recognition*, Lobachevskii Journal of Mathematics, BMB.

V. Lychagin, V. Yumaguzhin, *Invariants in Relativity Theory*, Lobachevskii Journal of Mathematics, BMB.

C. Rottman , M. Bauer, S. Joshi and K. Modin, Weighted Diffeomorphic Density Matching with Applications to Thoracic Image Registration, 5th MICCAI workshop on Mathematical Foundations of Computational Anatomy, 2015, BMB.

S. Sommer, A. M. Svane, *Modelling anisotropic covariance using stochastic development and sub-Riemannian frame bundle geometry*, 2016.

A. B. Tumpach, S. C. Preston, *Quotient elastic metrics on the manifold of arc-length parametrized plane loops*, 2016, BMB.

A. B. Tumpach, H. Drira, M. Daoudi, A. Srivastava, *Gauge Invariant Framework for Shape Analysis of Surfaces*, Transactions on Pattern Analysis and Machine Intelligence, BMB.

Arithmetic Geometry and Automorphic Representations (KRS)

J. Bruinier, S. Kudla, J. Funke, *Degenerate Whittaker functions for $Sp_n(R)$*, submitted, KRS.

N. Grbac, J. Schwermer, *A non-vanishing result for the residual Eisenstein cohomology of arithmetic groups of low rank*, to be submitted, KRS.

N. Grbac, J. Schwermer, *Eisenstein series for unitary groups in view of cohomological applications* in preparation, KRS.

C. Moeglin, D. Renard, *Paquets d'Arthur des groups classiques complexes*, submitted, KRS.

C. Moeglin, *Paquets d'Arthur spéciaux unipotents aux places archimédiennes et correspondence de Howe*, KRS.

G. Muić, *Fourier coefficients of automorphic forms and integrable discrete series*, arXiv:1505.02263, KRS.

Quantum Many-body Systems, Random Matrices, and Disorder (EWS)

R. Seiringer, S. Warzel, *Decay of correlations and absence of superfluidity in the disordered Tonks-Girardeau gas*, arXiv:1512.05282, EWS.

M. Napiórkowski, R. Reuvers, J. P. Solovej, *The Bogoliubov free energy functional II. The dilute limit*, arXiv:1511.05953, EWS.

M. Napiórkowski, R. Reuvers, J. P. Solovej, *The Bogoliubov free energy functional I. Existence of minimizers and phase diagram*, arXiv:1511.05935, EWS.

J. Huang, B. Landon, *Spectral statistics of sparse Erdös-Rényi graph Laplacians*, arXiv:1510.06390, EWS.

C. Benassi, B. Lees, D. Ueltschi, *Correlation inequalities for the quantum XY model*, arXiv:1510.03215, EWS.

H. Abdul-Rahman, B. Nachtergaele, R. Sims, G. Stolz, *Entanglement Dynamics of Disordered Quantum XY Chains*, arXiv:1510.00262, EWS.

M. Bishop, B. Nachtergaele, A. Young, *Spectral Gap and Edge Excitations of d-dimensional PVBS models on half-spaces*, arXiv:1509.07550, EWS.

V. Jaksic, C.-A. Pillet, A. Shirikyan, *Entropic fluctuations in Gaussian dynamical systems*, arXiv:1509.03244, EWS.

M. Aizenman, R. Peled, J. Schenker, M. Shamis, S. Sodin, *Matrix regularizing effects of Gaussian perturbations*, arXiv:1509.01799, EWS.

A. Giuliani, R. Seiringer, *Periodic striped ground states in Ising models with competing interactions*, arXiv:1509.00057, EWS.

P. T. Nam, M. Napiórkowski, J. P. Solovej, *Diagonalization of bosonic quadratic Hamiltonians by Bogoliubov transformations*, arXiv:1508.07321, EWS. E. Tarquini, G. Biroli, M. Tarzia, *Level statistics and localization transitions of Lévy matrices*, arXiv:1507.00296, EWS.

E. H. Lieb, J. P. Solovej, *Proof of the Wehrl-type Entropy Conjecture for Symmmetric SU(N) Coherent States*, arXiv:1506.07633, EWS.

Modern Theory of Wave Equations (GMS)

C. Bär, A. Strohmaier, *A rigorous geometric derivation of the chiral anomaly in curved backgrounds*, arXiv:1508.05345 [math-ph], GMS.

R. Brunetti, K. Fredenhagen, T.-P. Hack, N. Pinamonti, K. Rejzner, *Cosmological perturbation theory and quantum gravity*, arXiv:1605.02573 [gr-qc], GMS.

C. Dappiaggi, H. Gimperlein, S. Murro, A. Schenkel, *Wavefront sets and polarizations on supermanifolds*, arXiv:1512.07823 [math-ph], GMS.

J. Galkowski, *The Quantum Sabine Law for Resonances in Transmission Problems*, arXiv:1511.05091, GMS.

L. Li, A. Strohmaier, *The local counting function of operators of Dirac and Laplace type*, arXiv:1509.00198 [math.SP], GMS.

J. L. Marzuola, D. E. Pelinovsky, *Ground state on the dumbbell graph*, arXiv:1509.04721 [math.AP], GMS.

D. Prandi, L. Rizzi, M. Seri, *A sub-Riemannian Santaló formula with applications to isoperimetric inequalities and Dirichlet spectral gap of hypoelliptic operators*, arXiv:1509.05415 [math.DG], GMS.

Higher Structures in String Theory and Quantum Field Theory (SGS)

D. S. Berman, C. D. A. Blair, E. Malek, F. J. Rudolph, *An Action for F-theory:* $\mathrm{SL}(2) \times \mathbb{R}^+$ *Exceptional Field Theory*, arXiv:1512.06115 [hep-th], SGS.

G. A. Demessie, C. Sämann, *Higher Gauge Theory with String 2-Groups*, arXiv:1602.03441 [math-ph], SGS.

J. A. Lind, H. Sati and C. Westerland, *A higher categorical analogue of topological T-duality for sphere bundles*, arXiv:1601.06285 [math.AT]. SGS.

P. Ritter, C. Sämann, L. Schmidt, *Generalized Higher Gauge Theory*, arXiv:1512.07554 [hep-th], SGS.

P. Ritter, C. Sämann, L_∞*-Algebra Models and Higher Chern-Simons Theories*, arXiv:1511.08201 [hep-th], SGS.

U. Schreiber, *Equivariant cohomology of M2/M5-branes*, `https://ncatlab.org/schreiber/show/Equivariant+cohomology+of+M2/M5-branes`, SGS.

R. Zucchini, *A Lie based 4-dimensional higher Chern-Simons theory*, arXiv:1512.05977 [hep-th], SGS.

WORKSHOPS

The Interrelation between Mathematical Physics, Number Theory and Noncommutative Geometry (GNV)

E. Remiddi, L. Tancredi, *Differential equations and dispersion relations for Feynman amplitudes.The two-loop massive sunrise and the kite integral.* arXiv:1602.01481 [hep-ph] , Nuclear Physics B (tbp).

P. Morales-Alazan, K. Kirsten, *Casimir effect for smooth potentials on spherically symmetric pistons*, 2015, J. Phys. A: Math. Theor. 48 495201 `http://dx.doi.org/10.1088/1751-8113/48/49/495201`.

E. Panzer, *The parity theorem for multiple polylogarithms*, by Erik Panzer, arXiv:1512.04482.

J.Tekel, *Matrix model approximations of fuzzy scalar field theories and their phase diagrams*, JHEP 12 (2015) 176 arXiv:1510.07496.

L. Dabrowski, G. Landi, Franz Luef *Sigma-model solitons on noncommutative spaces* Lett. Math. Phys. 105 (2015) 1663–1688.

L. Hesselholt, *Periodic topological cyclic homology and the Hasse-Weil zeta function* arXiv:1602.01980.

Ergodic Theory and Holomorphic Dynamics (BBS)

A. M. Benini, *A note on repelling periodic points for meromorphic functions with bounded set of singular values*, arXiv:1411.6796 [math.DS], BBS.

H. Bruin, D. Schleicher, *Hausdorff dimension of biaccessible angles for quadratic polynomials*, submitted to Fund. Math., BBS.

Several Complex Variables and CR Geometry (FHL)

L. B. Thaler, F. Forstnerič, *A long $\mathbb{C}^2$ without holomorphic functions*, Preprint, FHL.

D. N. Son, *The Schwarzian derivative and Möbius equation on strictly pseudo-convex CR manifolds*, arXiv:1512.01663 [math.CV], FHL.

B.-Y. Chen, *Parameter dependence of the Bergman kernels*, arXiv:1506.01146v2, FHL.

M. Çelik, Y. E. Zeytuncu, *Analysis on the Intersection of Pseudoconvex Domains*, arXiv:1601.08072 FHL.

RESEARCH IN TEAMS PROGRAMME (RIT)

O. Pomazan, F. Kupka, H. Muthsam, A. Petrosyan, *Studies of Solar surface dynamo for small Prandtl numbers with Large Eddy Simulations*, in preparation, RIT.

O. Pomazan, F. Kupka, H. Muthsam, A. Petrosyan, *Modelling of Solar granulation in presence of magnetic fields at extreme resolution*, in preparation, RIT.

SENIOR RESEARCH FELLOWS PROGRAMME (SRF)

S. Kołodziej, N. Cuong Nguyen, *Weak solutions of complex Hessian equations on compact Hermitian manifolds*, arXiv:1507.06755 [math.CV], SRF.

J. Riest, L. Athanasopoulou, S. A. Egorov, C. N. Likos, P. Ziherl, *Elasticity of polymeric nanocolloidal particles*, Nature, `http://dx.doi.org/10.1038/srep15854`, (2015), SRF.

M. Rauzi, U. Krzic, T. E. Saunders, M. Krajnc, P. Ziherl, L. Hufnagel, M. Leptin, *Embryo-scale tissue mechanics during Drosophila gastrulation movements*, Nature, `http://dx.doi.org/10.1038/ncomms9677`, (2015), SRF.

N. Štorgel, M. Krajnc, P. Mrak, J. Štrus, P. Ziherl, *Quantitative morphology of epithelial folds*, Biophyscial Journal, `http://dx.doi.org/10.1016/j.bpj.2015.11.024`, (2016), SRF.

T. Jimbo, Y. Sakuma, N. Urakami, P. Ziherl, M. Imai, *Temperature-controlled self-reproduction cycle of binary vesicles*, submitted, SRF.

P. Ziherl, T. Dotera, *A geometric view of structure formation in soft colloids*, in preparation, SRF.

P. Ziherl, *Spontaneous curvature of binary lipid mixtures*, in preparation, SRF.

SIMONS JUNIOR PROFESSOR NILS CARQUEVILLE

N. Carqueville, A. Quintero Vélez, *Calabi-Yau completions and orbifold equivalence*, arXiv:1509.00880 [math.RT].

EPDI SCHOLARS (EPDI)

A.I. Bobenko, F. Günther, *Discrete Riemann surfaces based on quadrilateral cellular decompositions*, Preprint arXiv:1511.00652 [math.CV], 36 pages, 2015, EPDI.

A.I. Bobenko, F. Günther, *Discrete complex analysis on planar quad-graphs*. To appear in *Advances in Discrete Differential Geometry*, Editor: A.I. Bobenko, Springer, 74 pages, 2016. Preprint arXiv:1505.05673 [math.CV], 2015, EPDI.

ESI research in previous years: additional prints and arXiv preprints

The following papers complement the ESI preprints already taken into account in 2014.

ABCF = 4th Central european Relativity Seminar
ATV = Combinatorics, geometry, and physics
BDF = Algebraic quantum field theory: Its status and its future
BGS = Minimal energy points, lattices, and designs
FRS = Modern trends in topological quantum field theory
RIT= Research in Teams
RYZ = Topological phases of quantum matter
JF2009 = Junior Research Fellow in 2009

S. Burciu, *On an analogue of a Brauer Theorem for fusion categories*, arXiv:1503.04601 [math.QA], FRS.

S. Burciu, *Categorical Green functors arising from group actions on categories*, arXiv:1407.3994 [math.CT], FRS.

T. Johnson-Freyd, C. Scheimbauer, *(Op)lax natural transformations, relative field theories, and the "even higher*, arXiv:1502.06526 [math.CT], FRS.

P. T. Chruściel, J. Jezierski, J. Kijowski, *Hamiltonian dynamics in the space of asymptotically Kerr-de Sitter spacetimes*, arXiv:1507.03868 [gr-gc], DOI: 10.1103/PhysRevD.92.084030, ABCF.

P. T. Chruściel, P. Klinger, *Vacuum spacetimes with controlled singularities and without symmetries*, arXiv:1507.00158 [gr-gc], DOI: 10.1103/PhysRevD.92.041501 ABCF.

P. T. Chruściel, R. Gicquaud, *Bifurcating solutions of the Lichnerowicz equation*, arXiv:1506.00101 [gr-gc], ABCF.

P. T. Chruściel, L. Ifsits, *The cosmological constant and the energy of gravitational radiation*, arXiv:1603.07018 [gr-gc], ABCF.

M. Duetsch, *Massive vector bosons: is the geometrical interpretation as a spontaneously broken gauge theory possible at all scales?*, Rev. Math. Phys. **27 (10)** (2015) 1550024 `http://dx.doi.org/10.1142/S0129055X15500245`, BDF.

M. Duetsch, *Higgs mechanism and renormalization group flow: are they compatible?*, Quantum Mathematical Physics - A Bridge between Mathematics and Physics', ed. F. Finster et al., Birkhäuser Verlag (2016), http://arxiv.org/abs/1502.00099arXiv:1502.00099, BDF.

O. Bernardi, M. Bousquet-Mélou, *Counting coloured planar maps: differential equations*, arXiv:1507.02391 [math.CO], ATV.

C. Boutillier, J. Bouttier, G. Chapuy, S. Corteel, S. Ramassamy, *Dimers on Rail Yard Graphs*, arXiv:1504.05176 [math-ph], ATV.

G. Graziani, A. Makhlouf, C. Menini, F. Panaite, *BiHom-Associative Algebras, BiHom-Lie Algebras and BiHom-bialgebras*, arXiv:1505.00469 [math.RA], ATV.

T. Krajewski, I. Moffatt, A. Tanasa, *Combinatorial Hopf algebras and topological Tutte polynomials*, arXiv:1508.00814 [math.CO], ATV.

F. Vides, *Dynamical Deformation of Toroidal Matrix Varieties*, arXiv:1506.07470 [math.OA], RYZ.

J. S. Brauchart, *Explicit formulas for the Riesz energy of the Nth roots of unity*, arXiv:1105.5530v2 [math-ph], accepted by Contemporary Mathematics (Proceedings of Constructive Functions 2014), BGS.

J. S. Brauchart, E. B. Saff, I. H. Sloan, Y. G. Wang, R. S. Womersley, *Random Point Sets on the Sphere — Hole Radii, Covering, and Separation*, arXiv:1512.07470 [math.PR], submitted to Experimental Mathematics, BGS.

P. D. Dragnev, D. P. Hardin, E. B. Saff, N. Zorii, *Minimum Riesz energy problems for a condenser with "touching plates"*, arXiv:1504.03805 [math.CA], http://dx.doi.org/10.1007/s11118-015-9519-9, (2015), BGS.

L. Fukshansky, *Height bounds on zeros of quadratic forms over Q-bar*, arXiv:1508.00830 [math.NT], BGS.

Y. Kallus and W. Kusner, *The local optimality of the double lattice packing*, arXiv:1509.02241 [math.MG], BGS.

N. Zorii, *Constrained Gauss variational problem for condensers with touching plates*, arXiv: 1505.02596 [math.CA], BGS.

A. Carey, F. Gesztesy, G. Levitina, D. Potapov, F. Sukochev, D. Zanin, *On Index Theory for Non-Fredholm Operators: A* $(1+1)$*-Dimensional Example*, arXiv: 1509.01356 [math-ph], RIT.

A. Carey, F. Gesztesy, G. Levitina, F. Sukochev, *On the Index of a Non-Fredholm Model Operator*, arXiv: 1509.01580 [math.SP], RIT.

W. A. Moens, *Arithmetically-free group-gradings of Lie algebras*, arXiv:1604.03459 [math.RA], JF2009.

List of all visitors in 2015

591 scientists have visited the ESI in 2015.

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

BBS = Ergodic Theory and Holomorphic Dynamics
BDH = ESI - CECAM Workshop: From Trajectories to Reaction Coordinates: Making Sense of Molecular Simulation Data
BMB = Infinite-dimensional Riemannian Geometry with Applications to Image Matching and Shape Analysis
CMR = Higher Topological Quantum Field Theory and Categorical Quantum Mechanics
EPDI = European Post-Doctoral Fellow
EWS = Quantum Many-body Systems, Random Matrices, and Disorder
FHL = Several Complex Variables and CR Geometry
GMS = Modern Theory of Wave Equations
GNV = The Interrelation between Mathematical Physics, Number Theory and Noncommutative Geometry
IS = Individual Scientist
KRS = Arithmetic Geometry and Automorphic Representations
RIT = Research in Teams
SGS = Higher Structures in String Theory and Quantum Field Theory
SRF = Senior Research Fellows

Agarwaea Susama, Oxford U; 05.03.2015 - 13.03.2015, GNV;
Aizenmann Michael, Princeton University; 06.07.2015 - 16.07.2015, EWS;
Ajanki Oskari, IST Autria; 13.07.2015 - 14.07.2015, EWS; 25.06.2015 - 25.07.2015, EWS;
Albert Benjamin, U of Pennsylvania, Philadelphia; 01.03.2015 - 12.03.2015, GNV;
Aldana Dominguez Clara Lucia, U of Luxembourg ; 05.07.2015 - 12.07.2015, GMS;
Aleiner Igor, Columbia U, New York; 19.07.2015 - 31.07.2015, EWS;
Allasonniere Stephanie, Ecole Polytechnique, Palaiseau; 13.02.2015 - 20.02.2015, BMB;
Alt Johannes, IST Austria; 08.06.2015 - 12.06.2015, EWS;
Andersson Lars, Albert Einstein Institut, Postdam; 02.09.2015 - 10.09.2015, GMS;
Arici Francesca, SISSA, Trieste; 01.03.2015 - 06.03.2015, GNV;
Aravanis Christos, U Sheffield; 18.10.2015 - 24.10.2015, CMR;
Ardevol Albert, MPI, Frankfurt am Main; 15.09.2015 - 20.09.2015, BDH;
Arguillere Sylvain, Johns Hopkins U, Baltimore; 11.01.2015 - 24.01.2015, BMB;
Arnaudon Marcs, U de Bordeaux; 15.02.2015 - 20.02.2015, BMB;
Aschieri Paolo, U del Piemonte Orientale, Alessandria; 13.12.2015 - 20.12.2015, SGS;
Bachmann Sven, LMU Munich; 02.06.2015 - 12.06.2015, EWS;
Baditoiu Gabriel, Simion Stoilow Institute of Mathematics, Bucharest; 01.03.2015 - 14.03.2015, GNV;
Bär Christian, U Potsdam; 06.07.2015 - 17.07.2015, GMS;
Baransky Krzysztof, U Warsaw; 27.09.2015 - 02.10.2015, BBS;

Bärenz Manuel, U Bamberg; 18.10.2015 - 24.10.2015, CMR;
Barrett John, U Nottingham; 18.10.2015 - 24.10.2015, CMR;
Bartlett Bruce, U Oxford; 20.10.2015 - 24.10.2015, CMR;
Baskin Dean, Texas A&M U, Collage Station; 24.08.2015 - 29.08.2015, GMS;
Basko Denis, CNRS Paris; 11.07.2015 - 25.07.2015, EWS;
Batakidis Panagiotis, Penn State U, University Park; 09.03.2015 - 15.03.2015, GNV;
Bauer Martin, U Vienna; 07.01.2015 - 27.02.2015, BMB;
Bauerschmidt Roland, Harvard U, Cambridge; 11.06.2015 - 25.06.2015, EWS;
Becker Christian, U Potsdam; 07.01.2015 - 15.01.2015, BMB;
Benatti Fabio, U of Trieste; 25.11.2015 - 26.11.2015, IS;
Benguria Soledad, U of Wisconsin-Madison; 08.11.2015 - 14.11.2015, FHL;
Benini Anna Miriam, U Roma 2 Tor Vergata ; 26.09.2015 - 04.10.2015, BBS;
Benn James, U of Notre Dame, Indiana; 09.01.2015 - 19.01.2015, BMB;
Berger Franz, U Vienna; 03.11.2015 - 13.11.2015, FHL;
Berger Tobias, U Sheffield; 10.05.2015 - 16.05.2015, KRS;
Berhanu Shiferaw, Temple U, Philadelphia; 01.11.2015 - 07.11.2015, FHL;
Bering Klaus, U Masaryk, Brno; 19.10.2015 - 20.10.2015, CMR; 09.12.2015 - 11.12.2015, SGS;
Berman David, U Queen Mary, London; 06.10.2015 - 12.12.2015, SGS;
Bernard Denis, ENS, Paris; 29.05.2015 - 31.05.2015, SAB;
Best Robert, NIH Bethesda; 13.09.2015 - 22.09.2015, BDH;
Bianco Valentino, U Vienna; 16.09.2015 - 16.09.2015, BDH;
Biroli Giulio, CEA SACLAY, Gif-sur-Yvette; 08.06.2015 - 12.06.2015, EWS;
Blasius Don, UC Los Angeles ; 02.05.2015 - 31.05.2015, KRS;
Bloch Spencer, U of Chicago; 08.03.2015 - 14.03.2015, GNV;
Blumenhagen Ralph, MPI Munich; 22.11.2015 - 27.11.2015, SGS;
Blute Richard, U Ottawa; 18.10.2015 - 24.10.2015, CMR;
Bolhuis Peter, U Amsterdam; 15.09.2015 - 19.09.2015, BDH;
Bookstein Fred, U of Washington; 07.02.2015 - 21.02.2015, BMB;
Borutzky Lars, U Ernst-Moritz-Arndt, Greifswald; 07.12.2015 - 11.12.2015, SGS;
Boscain Ugo, CNRS, CMAP Ecole Polytechnique; 11.01.2015 - 16.01.2015, BMB;
Bourjaily Jacob, Niels Bohr Institute, Kopenhagen; 01.03.2015 - 11.03.2015, GNV;
Bouwknegt Pier Gerard (Peter), ANU Canberra; 24.11.2015 - 04.12.2015, SGS;
Boyong Chen, U Fudan; 08.11.2015 - 14.11.2015, FHL;
Broadhurst David, Open U, Milton Keynes; 02.03.2015 - 13.03.2015, GNV;
Brotzakis Phaedon, U Amsterdam; 15.09.2015 - 18.09.2015, BDH;
Bruin Henk, U Vienna; 28.09.2015 - 02.10.2015, BBS;
Bruinier Jan Hendrik, U Heidelberg; 04.05.2015 - 14.05.2015, KRS;
Bruveris Martins, Brunel University London; 07.01.2015 - 27.02.2015, BMB;
Bunk Severin, U Heriot-Watt, Edinburgh; 22.11.2015 - 05.12.2015, SGS;
Burq Nicolas, U Paris-Sud Orsay; 24.08.2015 - 28.08.2015, GMS;
Bussi Giovanni, SISSA Trieste; 15.09.2015 - 19.09.2015, BDH;
Cardelli Chiara, U Vienna; 16.09.2015 - 18.09.2015, BDH;
Carey Alan L., ANU Canberra; 21.02.2015 - 17.03.2015, GNV; 24.06.2015 - 29.06.2015, IS; 16.09.2015 - 26.09.2015, IS; 19.11.2015 - 17.12.2015, SGS;
Carminati Carlo, U Pisa; 28.09.2015 - 02.10.2015, BBS;
Carollo Federico, INFN, Trieste; 07.06.2015 - 20.06.2015, EWS; 25.11.2015 - 26.11.2015, IS;
Celik Mehmet, U Texas A&M; 07.11.2015 - 14.11.2015, FHL;
Ceriotti Michele, Ecole Polytechnique Federale Lausanne; 15.09.2015 - 16.09.2015, BDH;
Ceyhan Özgür, U Luxembourg; 02.03.2015 - 13.03.2015, GNV;
Chaimovich Aviel, MPI, Mainz; 15.09.2015 - 25.09.2015, BDH;
Charlier Benjamin, U de Montpellier; 15.02.2015 - 21.02.2015, BMB;
Chhay Boramey, U of Colorado, Boulder; 11.01.2015 - 18.01.2015, BMB;
Chiavazzo Eliodoro, Politecnico di Torino; 15.09.2015 - 19.09.2015, BDH;
Chodera John D., Memorial Sloan Kering Cancer Center, New York; 15.09.2015 - 18.09.2015, BDH;
Christianson Hans, U of North Carolina, Chapel Hill; 12.08.2015 - 26.08.2015, GMS;

Stephan Christoph, U Potsdam; 02.08.2015 - 12.08.2015, GMS;
Chrusciel Piotr, U Vienna; 28.07.2015 - 14.09.2015, GMS;
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