ETH zürich

Institute for Theoretical Studies

Report 2021/2022

ETH-ITS

Coverphoto: ITS group hike from Quinten to Weesen in Spring 2022; photo by Dominik Schröder

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Dominik Schröder

Albrecht Klemm (Senior Fellow) and Rahul Pandharipande on the Flumserberg in Fall 2021.

Foreword

The academic year 2021 – 2022, especially in the Spring term, marked a return, after two years of Covid regulations, to a fully active institute. We had five Senior Fellows over the year: Mikhail Lyubich (Stony Brook) and Albrecht Klemm (Bonn) in the Fall and Winter and Viviane Baladi (CNRS, Paris), Yakov Eliashberg (Stanford), and Daniel Huybrechts (Bonn) in the Spring. In addition, there were four Advanced Fellows and seven Junior Fellows. The ITS was essentially at maximum capacity for the whole period with weekly teas, Fellows seminars, and scientific guests. The enormous breadth of the research conducted can be seen in the reports of the Fellows.

Our ITS colloquium was also back in person with lectures on enumerative geometry, renormalization in dynamics, and symplectic and hyperkähler geometry by our Senior Fellows. In the upcoming year, the ITS colloquium will include more external speakers as travel returns (hopefully) to normal.

As usual, we had time for a few institute outings including an ascent of the Flumserberg in the Fall and a walk around the Walensee in the Spring (see the cover photo).

Rahul Pandharipande, Director

The ETH Institute for Theoretical Studies is supported by Dr. Max Rössler, the Walter Haefner Foundation and the ETH Foundation.

The ETH Institute for Theoretical Studies

History and aims

The ETH Institute for Theoretical Studies (ETH-ITS) is an interdisciplinary Institute dedicated to research in mathematics, theoretical computer science and theoretical natural sciences. It was founded on 1 June 2013 on the initiative of former ETH president Ralph Eichler, with a generous donation of Dr. Max Rössler and the Walter Haefner Foundation. The aim of the Institute is to enable top theoretical scientists to be active for an extended period of time at ETH, interact with local researchers, and establish lasting scientific collaborations in an interdisciplinary context.

Fellows at the ITS

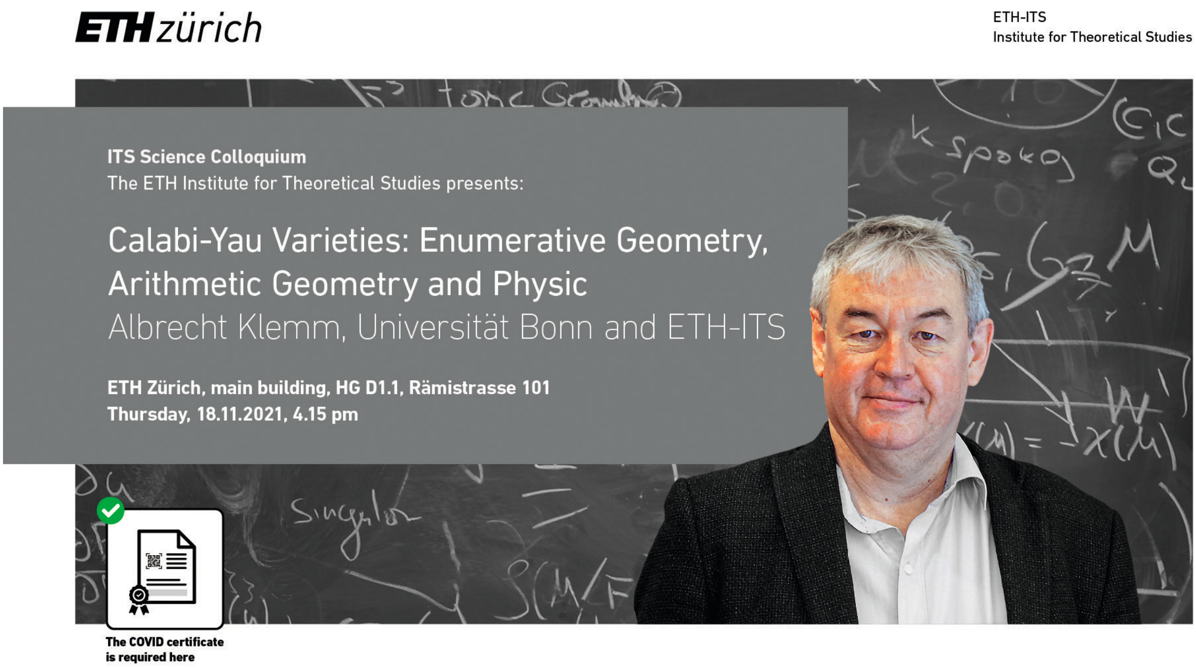
The Institute hosts up to six Senior Fellows and up to twelve Junior and Advanced Fellows. Junior Fellows are talented young independent postdocs spending up to three years at ETH Zurich to work on research subjects of their choice. They are supported by a mentor, who is an ETH professor. Advanced Fellows are young researchers with some experience after their PhD, who have established themselves as leaders in their disciplines. The Junior and Advanced Fellows are selected by the director, with the assistance of the scientific Advisory Committee, by a nomination procedure: candidates are selected from a group of young researchers that are nominated by faculty members and senior researchers of universities and research institutions and are invited to apply.

Schedule for the selection of Junior and Advanced Fellows

Mid-September	Target date for nominations, eligible candidates are invited to apply
Mid-October	Deadline for application of nominated candidates
November	Interviews with ETH members of the Advisory Committee
December	Offers are made

Senior Fellows are leading international researchers in mathematics, theoretical computer science and theoretical natural sciences, spending up to a year at the Institute on a sabbatical leave from their home institutions. They dedicate their time to research and participate in the activities of the Institute and of ETH Zurich, for example by giving a course on research topics. They are invited by the Vice-President for Research and Corporate Relations of ETH Zurich on the recommendation of the Advisory Committee. Candidates are often suggested by members of the Advisory Committee or ETH faculty, but they can also apply directly.

www.ethz.ch/eth-its/fellows.html



Announcement of Albrecht Klemm's talk in November 2021.

Activities

The ITS Science Colloquium

The ITS Science Colloquium aims at exposing students and researchers in mathematics, theoretical computer science and theoretical natural sciences to new questions and research subjects of common interest to different disciplines.

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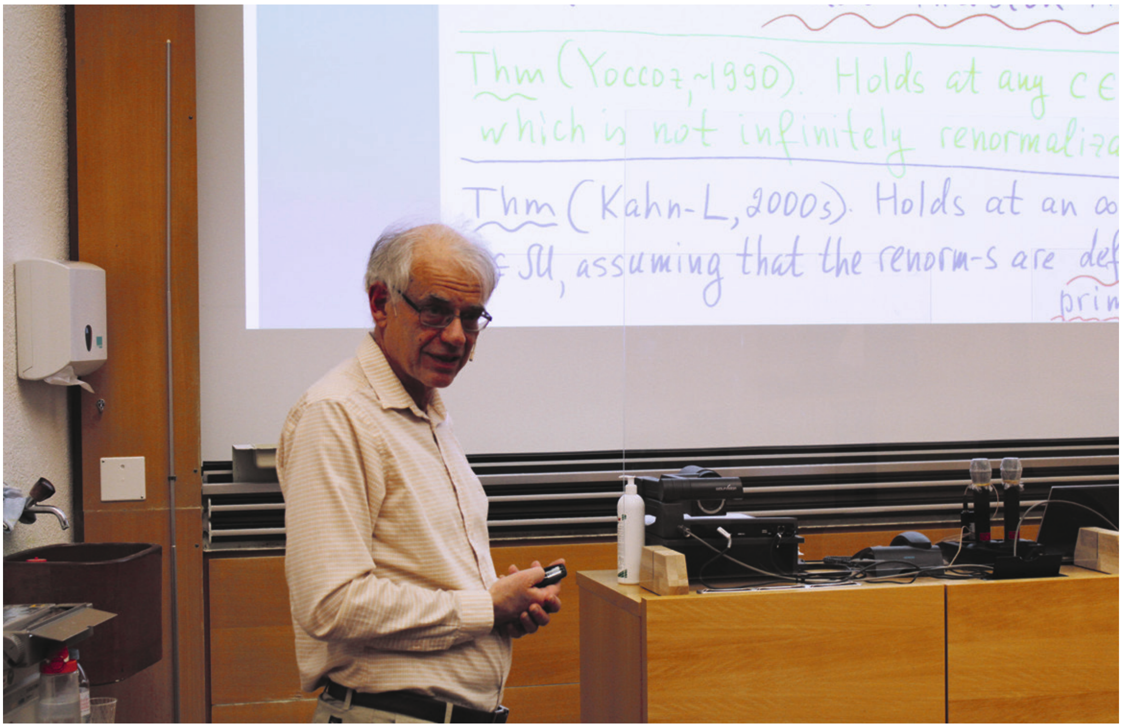

Picture of Mikhail Lyubich at his colloquium in December 2021.

The ITS colloquium in 2021 – 2022 took a special form. In order to have in-person lectures and avoid Covid travel restrictions, the speakers were all Senior Fellows in residence. The colloquium gave an opportunity for them to present their field of research to the ETH community. For the upcoming year, the ITS colloquium will return to the usual format consisting also of invited external speakers.

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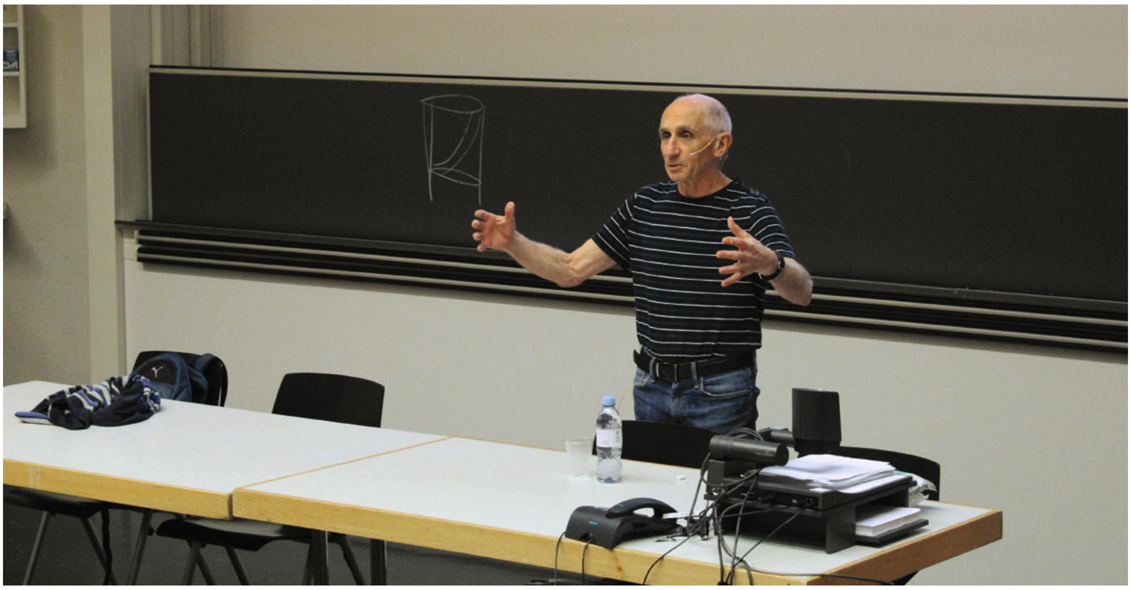

Yakov Eliashberg during his talk in Spring 2022.

Mandatory check of Covid certificates before the talks in Fall 2021.

Programme 2021 – 2022

18.11.2021	Albrecht Klemm, University of Bonn and ETH-ITS	Calabi-Yau Varieties: Enumerative Geometry, Arithmetic Geometry and Physics
16.12.2021	Mikhail Lyubich, Stony Brook University and ETH-ITS	Renormalization ideas in Dynamics
05.05.2022	Yakov Eliashberg, Stanford University and ETH-ITS	Symplectic and contact convexity in interaction
30.05.2022	Daniel Huybrechts, University of Bonn and ETH-ITS	Computational analysis of viral sequencing data

Videos of selected talks can be viewed on https://eth-its.ethz.ch/activities/videos.html

Fellows’ seminar

The aim of the Fellows’ seminar, organized by Junior Fellows François Bienvenu, Alexandru Gheorghiu, Stefan Glock and Dominik Schröder, is to present the research of the Fellows of the ETH-ITS. It is open to all interested and the rule is that talks should be accessible to other Fellows, which are typically from a different field.

Programme 2021 – 2022

28.09.2021	Albrecht Klemm	Feynman Integrals in Dimensional Regularization and Extensions of Calabi-Yau Motives
05.10.2021	Marvin Künnemann	Towards a Structural Complexity Theory in P
19.10.2021	Sándor Kisfaludi-Bak	On geometric variants of the traveling salesman problem
09.11.2021	Michael Borinsky	Strange numbers at the heart of physics
16.11.2021	Rhea Palak Bakshi	A Survey of Skein Modules
08.03.2022	Yunan Yang	Optimal Transport for Learning Chaotic Dynamics via Invariant Measures
29.03.2022	François Bienvenu	Random Graphs in Evolution
05.04.2022	Johannes Knörzer	Feynman’s Dream: Quantum Simulation in the NISQ era
24.05.2022	Sylvain Lacroix	Symmetries, conserved quantities and integrable systems

Ruelle resonances in parabolic dynamics

Senior Fellow Viviane Baladi and Corinna Ulcigrai (UZH) organized a workshop on «Ruelle resonances in parabolic dynamics» (27 – 29 June 2022) jointly supported by the ITS and the math department of UZH.

Ruelle resonances, related to singularities of the Ruelle zeta function, play an important role in the study of dynamical systems. In the hyperbolic case there are well developed tools to understand them (transfer operators, anisotropic Banach spaces, microlocal analysis). In recent years, it was discovered that Ruelle resonances also play a role in understanding parabolic dynamical systems which can be ‹renormalized› via a hyperbolic operator. The Ruelle resonances of the latter can then be used to explain parabolic phenomena such as the power spectrum of deviations of ergodic averages or obstructions to solve cohomological equations. This focussed research workshop brought together specialists from anisotropic Banach spaces and microlocal analysis on one side and parabolic dynamical systems on the other, to discuss and explore this interaction.

Awards

Pierrick Bousseau, former ETH-ITS Junior Fellow, received the Cours et Prix Claude-Antoine Peccot 2021 – 2022.

Dominik Schröder

Viviane Baladi in the ITS garden in June 2022.

Fellows' report

Senior Fellows

Viviane Baladi is interested in statistical properties of smooth chaotic (hyperbolic) dynamical systems with singularities. These properties are often obtained via the spectral properties of transfer operators, acting on suitable Banach or Hilbert spaces of functions or anisotropic distributions. Such spaces must be taylor-made. With Liverani, Gouëzel, Tsujii, and others, Baladi has been one of the pioneers in this topic which has emerged in the beginning of the present century and has received widespread recognition within the dynamics and semi-classical communities in the past decade.

One dynamical system that Baladi has studied extensively in recent years is the Sinai billiard, both in discrete time (the map) and continuous time (the flow). Sinai billiards are simple mechanical models, originating from statistical mechanics, which are surprisingly difficult to study rigorously and numerically, due to the singularities arising from those orbits which are tangential to the scatterers. With Demers and Liverani, Baladi proved exponential mixing of the physical measure of the billiard flow in 2018 (the corresponding result for the map had been published in 1998 by Lai-Sang Young). More recently, Baladi studied other natural invariant measures of the billiard map with Demers, showing first existence and uniqueness of the measure of maximal entropy (MME) under a condition of sparse recurrence to singularities, and then existence, uniqueness, and exponential mixing of the equilibrium measures for natural geometric potentials interpolating between the MME and the physical measure (2020, 2022). Baladi's Zurich Colloquium in Mathematics in April 2022 was a survey talk entitled «Statistical properties of Sinai billiards obtained via anisotropic spaces,» in which she outlined the above set of results.

Baladi's PhD student Jérôme Carrand visited ITS in May 2022. The goal of Carrand's PhD topic is to construct the MME for the Sinai billiard flow. At the time of his visit to Zurich, Carrand had already succeeded in constructing equilibrium states for some elements in a one-parameter family of natural potentials. For a special parameter in this family, Carrand also showed that the equilibrium state, if it exists, would give the flow MME. Unfortunately, Carrand's construction is limited to a subset of parameters which does not include this special parameter value. The discussions of Baladi and Carrand in ITS were instrumental to overcome this difficulty, by revisiting the bootstrap argument in Baladi and Demer's 2022 paper.

This work in progress of Baladi, Carrand, and Demers is expected to lead to a complete proof of the existence, uniqueness and Bernoullicity of the Sinai billiard flow MME under a sparse recurrence to singularities condition, satisfied by most billiards.

A dream project of Baladi is to study the dynamical zeta functions of Sinai billiards, a totally unexplored research area. A work in progress of Baladi and Castorrini (University of Pisa) aims at first considering a toy model of piecewise hyperbolic systems, applying to this model the Milnor-Thurston regularisation which turned out to be very powerful for Anosov diffeomorphism. Castorrini's planned visit of ITS in the Spring of 2022 was cancelled due to Covid, and this has (temporarily) slowed down this project.

Baladi is also interested in linear response and the violation thereof. Linear response describes the first order response to perturbations of the physical measure of a dynamical system. (This topic has obvious applications to climate change.) With Daniel Smania, Baladi has been particularly interested in understanding how linear response breaks down in the famous quadratic family of interval maps. Existing results of Baladi, Smania, and others indicate that this family enjoys fractional response with exponent exactly one half. In order to sharpen these results, it is necessary to understand better the statistical features of the quadratic family. In particular, in view of the work of de Lima and Smania for a piecewise expanding toy model, it is desirable to establish a parameter-almost sure invariance principle on a suitable set of parameters. Baladi is pursuing this goal with Magnus Aspenberg and Tomas Persson (both from the University of Lund). Their visit to ITS in April and May 2022 allowed the trio to explore thoroughly the strategy laid out by Schnellmann in 2015 in the toy model of piecewise expanding dynamics. Work on this project is still ongoing, but promising progress has been accomplished.

Last but not least, Baladi co-organised with Corinna Ulcigrai, Professor at the University of Zurich, a Workshop on Ruelle resonances in parabolic dynamics, which took place in Zurich on 27 – 29 June 2022. Ulcigrai's main research area is centered around various algebraic instances of parabolic dynamics. Since the 1970s, it has been known how to exploit knowledge on hyperbolic systems in order to study the (more mysterious) parabolic systems, via a tool called «renormalisation». (For example, renormalisation intertwines geodesic and horocycle flows

Yakov Eliashberg on a sightseeing trip to Winterthur in Spring 2022.

in negative curvature.) Renormalisation has been especially powerful in algebraic settings (constant curvature), but the new analytical tools for transfer operators (in particular anisotropic spaces) developed in the past 20 years have opened the way to study less rigid objects. Together with Baladi (who presented her 2022 work with Adam on horocycle flows in suitably bunched variable negative curvature surfaces), other experts (Liverani, Forni, Guillarmou ...) gave long lectures presenting the state of the art to the Zurich dynamics community during this small focused workshop. The event was held partly in University of Zurich (Irchel) and partly at ITS.

Baladi also gave a lecture on the work with Adam on horocycle flows at the workshop on Limit Theorems for Slowly Mixing Systems at the International Centre for Mathematical Sciences (ICMS) in Edinburgh.

Professor **Yakov Eliashberg** spent the second part of his appointment as a Senior Fellow at the ETH-ITS in April – June 2022. For the first half of his appointment he stayed at the ITS in March – June 2019. His return was delayed due to Covid-19 pandemic. In between the visits Eliashberg was awarded, jointly with S. Donaldson, the 2020 Wolf Prize in Mathematics for their contribution to differential topology and geometry. Yakov Eliashberg holds a permanent position of Herald L. and Caroline L. Ritch Professor of Mathematics at Stanford University. His research interests include symplectic and contact topology, several complex variables and low-dimensional topology.

The earlier work of Yakov Eliashberg in the 1970s was devoted to topological problem in singularity theory of smooth mappings. In one of his earlier papers, he developed a new method for constructing maps with only simplest singularities of the so-called fold type. One of striking corollaries of his result was existence of a map of any orientable 3-manifold into to the Euclidean 3-space with the fold along any dividing surface.

In the 1980s Eliashberg's work was at the origin of a new subject of symplectic topology, along with the work of

M. Gromov, A. Floer, H. Hofer, C. Conley and E. Zehnder. One of his main lines of research in this area continues to be the interaction between flexible and rigid phenomena in symplectic topology. Until a few years ago, the most exciting development was on the rigidity side of the subject, beginning with the development of Gromov-Witten invariants, various flavors of Floer homology theory, and more recently Fukaya categorical methodsrelated Kontsevich's homological mirror symmetry conjecture. However, several unexpected flexibility results were proven in the last 10 years. Highlights here include Murphy's theory of loose Legendrian knots, Cieliebak-Eliashberg's theory of flexible Weinstein manifolds (with more recent advances by Lazarev), Borman-Eliashberg-Murphy's classification of overtwisted contact structures on manifolds of all dimension, and most recently Honda-Huang's theory of contact convexity.

During his second stay at the ITS Yakov Eliashberg interacted with several senior and junior faculty members, postdocs and students at the ETH, as well as a number of ITS visitors, including Grigory Mikhalkin and Gleb Smirnov from the University of Geneva. At the ITS Eliashberg gave a series of lectures devoted to the theory of contact convexity. He also gave talks at seminars at Universities of Neuchâtel and Geneva, as well as Université Libre de Bruxelles. Eliashberg also gave a talk at the conference «Convexity in contact and symplectic topology» at the IHP, Paris.

While at the ITS, Yakov Eliashberg worked on several research projects. Jointly with D. Pancholi, he wrote a paper devoted to new development in the theory of contact convexity. Eliashberg was also working with K. Cieliebak and N. Mishachev on preparation of the second extended edition of the book «Introduction to the h-principle». The book is scheduled to go to the print in the early Fall 2022.

Several other research projects are still ongoing. A joint work with Thomas Kragh is devoted to new connections between topology of spaces of Legendrian submanifolds and Algebraic K-theory.

Jointly with D. Nadler and D. Alvarez-Gavela, Eliashberg is involved in a fundamental project of the so-called arborealization program, with the goal is reformulation of symplectic topology as differential topology of the so-called arboreal spaces which generalize the classical notion of a smooth manifold. Three papers towards along the line of this project already appeared, and currently the authors work on the final 4th paper devoted to the classification of Reidemeister moves of 1-parametric families of arboreal spaces.

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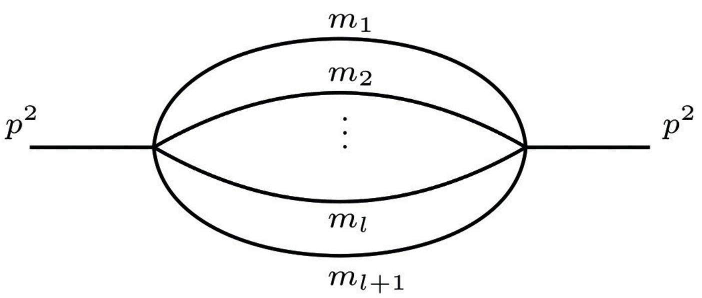
Daniel Huybrechts answering questions at the colloquium in May 2022.

Daniel Huybrechts pursued his work on various aspects of hyperkähler geometry and the geometry of cubic hypersurfaces. In an ITS colloquium he introduced a wider audience to various classical aspects of hyperkähler geometry and presented his recent work with Debarre, Macrì, and Voisin on a topological classification of four-dimensional hyperkähler manifolds. A simple topological assumption expressed in terms of its second cohomology implies that a hyperkähler fourfold is deformation equivalent to a Hilbert scheme of a K3 surface. An analogous result is expected for the second known example in dimension four, but a preliminary numerical consideration does not exclude the existence of yet another class of hyperkähler fourfold, which would be exiting news. Huybrechts also used his stay at the ITS to work on his new monograph entitled ‹The geometry of cubic hypersurfaces› to be published by Cambridge University Press in 2023. The subject is so rich that in the course of the preparation new and interesting questions concerning these very classical objects came up which are now intensively studied. For example, the Fano variety of lines on a cubic fourfold, itself a hyperkähler fourfold of the type above, determines a cubic uniquely. Is the same true for the Fano surface of lines of the second type? This question makes sense even for cubic threefolds and leads to intriguing questions concerning algebraic curves. Also, the Fano surface of lines meeting a given line shows intriguing similarities to abelian and Kummer surfaces, which needs further investigation.

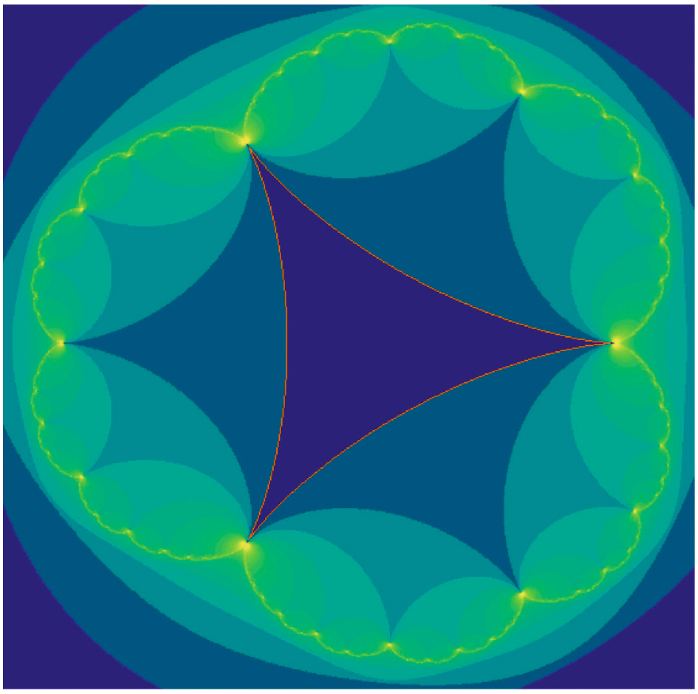
During his stay at the ITS, he also looked into the possibility of connecting two classical results which display a similar numerical behavior: Mazur's theorem on the order of torsion points on elliptic curves over the rationals and Mukai's theorem about curves being contained in families of K3 surfaces. The problem involves mirror symmetry and stability condition, but whether the observation is a pure numerical coincidence or hides something deeper remains a mystery.

It has been recently realized that higher loop Feynman integrals that occur in perturbative approximations to quantum field theories or gravitational wave solutions are related to period integrals over middle dimensional cycles in higher dimensional Calabi-Yau varieties. This leads to exciting confluence of techniques from algebraic geometry, arithmetic geometry and automorphic functions with physical methods of computation. Michael Borinsky (ITS), Johannes Brödel (ETH Physics Department) and **Albrecht Klemm (ITS)** organized an ETH workshop in the Fall of 2021 to trigger deeper exploration of these connections. Klemm and collaborators finished a paper in which the maximal cut integrals of the l-loop Banana Feynman graph are identified as period integrals on complete intersection



Albrecht Klemm

The l-loop banana graph.



Mikhail Lyubich

The cauliflower generated by three Schwarz reflections with respect to the sides of the deltoid (from a paper by Lee, Lyubich, Makarov and Mukherjee).

Calabi-Yau (l-1)-folds defined by the vanishing locus of two degree (1, ...,1) constraints in the homogeneous coordinates of a product of projective spaces. The ratios of the mass squares of the propagating particles and the external momentum, define an (l+1)– dimensional sub-family in the complex structure moduli space of these complete intersections singled out geometrically by mirror symmetry. The homogeneous Picard-Fuchs differential equations together with boundary conditions, imposed at the point of maximal unipotent monodromy, specify the maximal cut Feynman integrals and its analytic properties in these physical parameters.

While at the ITS, Klemm has worked on further topics related to Feynman integrals, Yangian symmetries, and Picard-Fuchs equations with Claude Duhr, Florian Loebbert, Christoph Nega, Franziska Porkert, and Lorenzo Tancredi. He profited greatly from discussions with Advanced Fellow Michael Borinsky.

With Kilian Böhnisch, Emanuel Scheidegger and Don Zagier, Klemm finished a long-term study of arithmetic properties of periods of the fourteen hypergeometric one parameter families of Calabi-Yau 3-folds. Visits of Böhnisch and Zagier to the ITS was particular helpful for this purpose.

During his visit to the ITS, **Mikhail Lyubich** was working on the variety of problems of Low-Dimensional Dynamics, real and complex. Together with Artur Avila, a faculty member of the University of Zurich at Irchel, he was exploring the measurable dynamics of infinitely renormalizable Henon maps, real and complex. Henon maps are quadratic automorphisms of the 2D space (real or complex), which are the simplest non-linear invertible dynamical systems. Still, they produce notoriously complicated dynamics phenomena. The outcome of Avila and Lyubich discussions was a construction of a complex Henon map whose forward Julia set has positive measure, and a real Henon-like map that has a wild attractor.

A number of visitors came to Zurich in the Fall 2021 to collaborate with Lyubich. With Romain Dujardin from Paris Jussieu, he discussed the structure of hyperbolic Henon maps, with Bac Dang from Paris Orsay he worked on the renormalization of self-similar groups. With Sabya Mukherjee from the Tata Institute in Mumbai and with Jacob Mazor from Stony Brook, he discussed the dynamics of systems generated by Schwarz reflections, and with Dima Dudko from Stony Brook, he worked on the problem of local connectivity of the Mandelbrot set (the MLC Conjecture). Inspiring atmosphere of the ITS, numerous cafes around, and beautiful Zurich hills provided a perfect environment for these discussions.

To seed ideas of Holomorphic Dynamics in the local soil, Lyubich gave a mini-course in the Irchel University on the basic theory (with a number of faculty, postdocs and students attending it), gave there a seminar talk on the current status of the MLC Conjecture, and a Colloquium talk at the ETH on the Renormalization Ideas in Dynamics. He also took advantage of a renewed opportunity to travel, to pay visits to several European scientific centers: to Luminy (holding one of the first post-pandemic workshops in person), to Geneva, and to Orsay.

Advanced Fellows

Michael Borinsky joined the ITS as an Advanced Fellow in September 2021. His research is situated at the interface between mathematics and physics. On the mathematical side, he uses tools from quantum field and string theory to tackle problems in enumerative geometry. On the physical side he applies algebraic geometric tools to improve the understanding of physics at the fundamental level and to facilitate quantum mechanical computations that are needed, for instance, at experiments such as the LHC at CERN.

In a collaboration with Karen Vogtmann, Borinsky continued his study of the outer automorphism group of the free group using quantum field theory methods. They were able to prove that the topology of this group is quite intricate: It has huge amounts of rational cohomology in odd degrees in the limit of many generators. In February, Borinsky and Vogtmann published an expository paper of their previous and an update of their upcoming work. This upcoming work will appear in the next months.

A similar result has been obtained by Harer and Zagier for the moduli space of curves in the 1980s. Very recently,

Dominik Schröder

Rahul Pandharipande and Michael Borinsky during the Fall group hike 2021 to Flumserberg.

Borinsky was able to prove a refinement of this classic statement that implies the existence of large amounts of top-weight graded cohomology in the moduli space of curves. He is very excited about these results which will be the subject of an upcoming publication.

Borinsky also supervised a Bachelor thesis project in algebraic topology. The student studied the forested graph complex that computes the rational cohomology of the outer automorphism group of the free group. In his thesis the student gave a new proof for the existence of the Morita cycles in this complex.

Together with Johannes Brödel (ETH) and Albrecht Klemm (ETH-ITS), Borinsky set up the lecture course ‹From Feynman Integrals to Calabi-Yau Manifolds› at the ETH. In his lectures, Borinsky gave a pedagogical introduction into the (tropical) geometric structure of Feynman integrals. The evaluation of such integrals, which is a necessary ingredient for any concrete computation in particle physics and other advanced quantum mechanical systems, can be greatly facilitated using tools from tropical geometry.

In a joint work with David Broadhurst, Borinsky published a study of a renormalon in six-dimensional phi3 quantum field theory. Such renormalons are rather mysterious objects and it is unclear whether they are merely mathematical artefacts or if they can be endowed with concrete physical meaning. Borinsky and Broadhurst used resurgence, a new mathematical theory still in development, to highlight and clarify aspects of these objects.

Borinsky also continued his study of the tropical geometry of Feynman and related algebraic integrals. He was able to win Anna-Laura Sattelberger, Bernd Sturmfels and Simon Telen (Max-Planck Institute Leipzig) as new collaborators for this endeavor. Together, they successfully extend previous results by Borinsky on integration over positive projective space to integration over general toric varieties. Borinsky, Sattelberger, Sturmfels and Telen were also able to establish a novel application of these tropical geometric methods in Bayesian statistics. Their results were published as a preprint in April.

Since September, Borinsky was invited to present his research in various venues. He spoke at the Copenhagen Centre for Geometry and Topology, the Niels Bohr Institute in Copenhagen, the Max-Planck-Institute for applied Mathematics in the Sciences in Leipzig, the conference ‹Graph Complexes and Quantum Field Theory› in Berlin, the ‹Talks in Mathematical Physics› series at the ETH and the theory department of CERN in Geneva. He also gave virtual talks, at the Kolleg Mathematics and Physics Berlin and the mathematical physics group at Humboldt-University Berlin.

Marvin Künnemann joined the ITS as Advanced Fellow in April 2021. His main research interests lie in theoretical computer science, particularly fine-grained complexity theory.

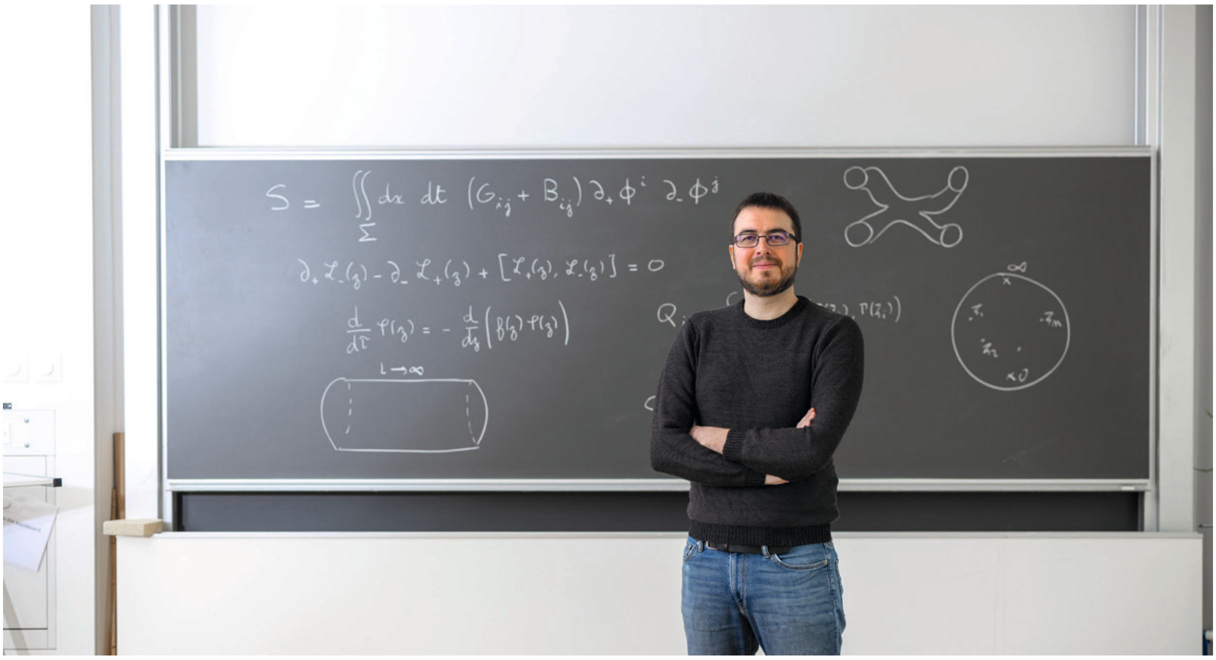
A major focus of his research at ITS was to investigate und uncover structures inside the polynomial-time regime by studying the complexity of large classes of first-order properties. This includes a study of first-order properties with ordering relations together with Haozhe An, Mohit Gurumukhani, Russell Impagliazzo, Michael Jaber, and Maria Paula Parga Nina. This work was accepted to the 16th International Symposium on Parameterized and Exact Computation (IPEC 2021) and has been invited to the IPEC 2021 special issue of Algorithmica. Turning towards the study of approximation hardness in P, Künnemann and his collaborators Karl Bringmann, Alejandro Cassis, and Nick Fischer define and analyze a class MaxSP of polynomial-time optimization problems, which provides an analogue of the well-studied class MaxSNP for NP optimization problems.

Two resulting works give completeness as well as classification theorems for this class of problems and have been accepted to the 2021 International Conference on Approximation Algorithms for Combinatorial Optimization Problems (APPROX 2021) and the 49th International Colloquium on Automata, Languages, and Programming (ICALP 2022).

A second focus during his time at ITS targets algorithms and conditional lower bounds for geometric problems. Together with collaborators within ITS (Sándor Kisfaludi-Bak) as well as outside ITS (Karl Bringmann, Dániel Marx, André Nusser, Zahra Parsaeian), Künnemann developed approximation algorithms for dynamic time-warping under translation, gave conditional lower bounds for the diameter problem in geometric intersection graphs, and revisited the classic polygon containment problem under translations and rotations. The first two topics led to two works accepted at the 38th International Symposium on Computational Geometry (SoCG 2022), the third topic led to a work accepted at the 33rd ACM-SIAM Symposium on Discrete Algorithms (SODA 2022).

Besides these works, Künnemann initiated research projects in parallel algorithmics as well as Klee's measure problem, with corresponding manuscripts currently in

Nicola Pitaro



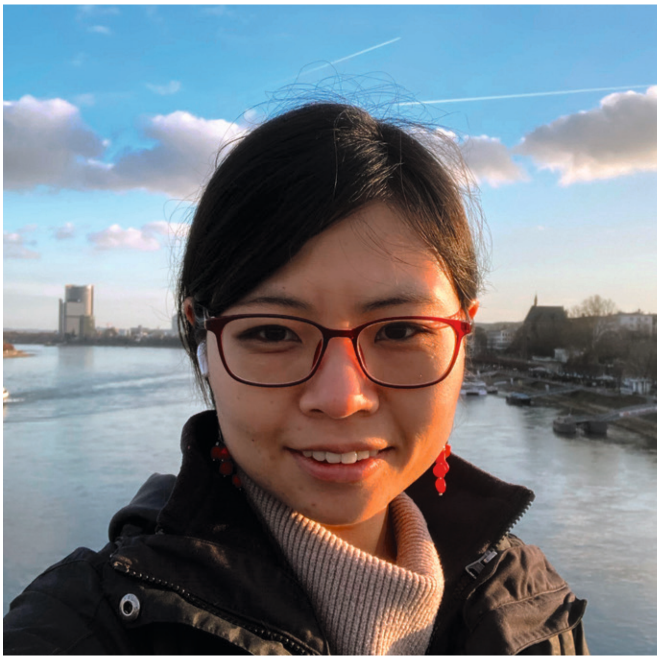
Advanced Fellow Sylvain Lacroix in front of some of the fundamental equations describing integrable sigma models.

preparation. He served as a member of the program committees for the 47th International Workshop on Graph-Theoretic Concepts in Computer Science (WG 2021), the 29th Annual European Symposium on Algorithms (ESA 2021), and the 37th Computational Complexity Conference (CCC 2022). After a very productive year at ITS, Marvin Künnemann left the institute for a professorship at TU Kaiserslautern, Germany.

Sylvain Lacroix started his Advanced Fellowship at the ITS in September 2021. His research interests are at the boundary between physics and mathematics and concern the development of exact methods for the study of field theories, which play an important role in modern physics. His works use the mathematical languages of integrable systems and conformal field theories, and rely on various algebraic and geometric structures. During his first year at the ITS, Lacroix conducted research projects in two different main axes.

The first one concerns the study of integrable sigma-models, which are particular two-dimensional field theories with applications in high energy physics, string theory and condensed matter physics. The approach followed by Lacroix to study these theories is based on the formalism of so-called affine Gaudin models, which takes its roots in the mathematical theory of infinite dimensional Kac-Moody algebras. In particular, his recent works focused on the applications of this formalism to the problem of quantisation of integrable sigma-models. Together with his collaborators, Lacroix studied examples of such models at their conformal locus, i.e. the points in parameter space where they define a quantum scale invariant theory, which in particular can be described using the powerful formalism of Vertex Operator Algebras. In this context, one of the key goal of quantum integrability is to construct and diagonalise an infinite family of commuting operators in the Vertex Operator Algebra of the theory. The recent results of Lacroix make some first steps towards such a goal, using the language of affine Gaudin models. Moreover, these results exhibit connections to various other aspects in the study of integrable systems, such as quantum groups, Yang-Baxter algebras and the so-called ODE / IQFT correspondence. They open some natural future perspectives, which Lacroix is currently exploring with his collaborators.

The second main research axis explored by Lacroix in his first year at the ITS is the study of mathematical objects called multipoint conformal blocks. The latter naturally appear in the description of conformal field theories in any dimension. More precisely, conformal blocks are



Yunan Yang visiting University of Bonn in February 2022.

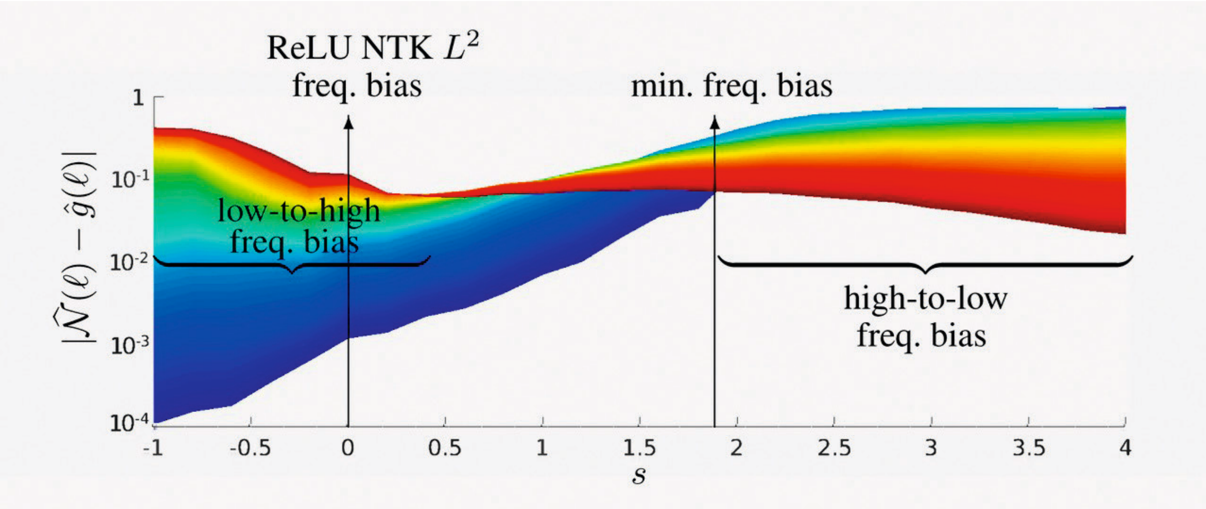
model-independent building bricks from which the correlation functions of conformal theories are built and thus provide fundamental tools for the study of these theories. Although these conformal blocks and their applications are now quite well understood in the simplest case of four-point correlation functions, the multipoint case, i.e. for a higher number of points in the correlation functions, is not yet fully understood and forms an active subject of research. Some of the research works of Lacroix and his collaborators are devoted to this subject. The approach they follow consists of characterising the multipoint conformal blocks as solutions of several compatible partial differential equations forming an integrable system, generalising to the multipoint case a celebrated result on four-point blocks. In his recent work, Lacroix and his collaborators showed that these differential equations can be considerably simplified in certain specific limits, in which their solutions take a simple factorised form as a product of lower-points blocks.

In addition to developing his research projects, Lacroix presented his work in several seminars and workshops, both in-person and virtually, and participated in various activities at ETH. He is looking forward to future opportunities to develop his research and scientific activities, including the supervision of a Master's student next year.

Yunan Yang joined ITS in January 2022 as an Advanced Fellow. Her research interests include inverse problems, optimization, optimal transport, and machine learning.

The excellent research conditions of ITS allow Yang to finish several papers initiated before. Two projects focus on weighted optimization algorithms for machine learning. A generalized weighted least-squares optimization method for computational learning with noisy data can improve the generalization capacity of various machine learning models. In particular, the intrinsic spectral properties of Sobolev norms can counterbalance the low-frequency biasing of the Neural Tangent Kernel, which is formulated to describe the evolution of deep artificial neural networks (NN) during their training by gradient descent. Another work of Yang is to design a stochastic gradient descent (SGD) method for global optimization. Many optimization problems from inverse problems and machine learning are highly nonconvex, leaving the deterministic gradient-based methods only to find local minimizers. SGD can tackle this difficulty with a gradually decaying randomness. Yang's new SGD algorithm has an algebraic convergence compared to the logarithmic rate of the conventional method. Yang also finished a paper on natural gradient descent, an optimization method motivated from the perspective of information geometry. She designed

Yunan Yang



Frequency-biasing during neural network training.

efficient numerical schemes so that the method could apply to large-scale optimization problems in solving computational inverse problems.

Yang has been interacting with faculty at different departments of ETH. She has given presentations at Prof. Andreas Fichtner's group at the Department of Earth Sciences and Prof. Andreas Krause's group at the Institute for Machine Learning at ETH. Yang has been invited to several workshops and seminars at other institutions in Europe, including the University of Bonn, the University of Bath, and the Isaac Newton Institute for Mathematical Sciences, where Yang set up future research collaborations. Additionally, she has given many online seminars at the University of Hong Kong, UC Berkeley, and other places. Yang also virtually presented her work at the Tenth International Conference on Learning Representations (ICLR).

In Spring 2022, Yang mentored two female students at African Institute for Mathematical Sciences (AIMS) Cameroon for their master thesis projects. Besides, she is currently mentoring an undergraduate student at MIT, a Master's student at the University of Bonn, and a PhD student at Cornell University. She has been active in the Women-in-Math activities at ETH.

Junior Fellows

Rhea Palak Bakshi started her Junior Fellowship at the Institute for Theoretical Studies in Fall 2021 after obtaining her PhD in Mathematics at the George Washington University in the Spring of the same year. Her research interests lie at the confluence of low-dimensional topology, quantum topology, and knot theory. In particular, she focusses primarily on the study of skein modules and skein algebras of 3-manifolds and the Topological Quantum Field Theoretic description of the Witten-Reshetikhin-Turaev 3-manifold invariant.

Skein modules are invariants of 3-manifolds and generalize the skein theory of the various polynomial link invariants in the 3-sphere to arbitrary 3-manifolds. Over time, skein modules have evolved into one of the most important objects in knot theory and quantum topology having strong ties with many fields of mathematics, a few of which are algebraic geometry, hyperbolic geometry, quantum cluster algebras and representation theory. Moreover, skein modules are used in the combinatorial construction of the Witten-Reshetikhin-Turaev Topological Quantum Field Theories. At ITS, Bakshi undertook research which revolved around understanding the structure of the Kauffman bracket skein module (KBSM) of

Rhea Palak Bakshi

Rhea Palak Bakshi at the Albert Einstein Memorial while attending Knots in Washington DC in April 2022.

a 3-manifold over various commutative rings and determining whether they reflect the geometry or topology of the manifold, for example, whether the module detects the presence of incompressible or non-separating surfaces in the manifold.

In collaboration with Thang Lê and Józef Przytycki, Bakshi undertook research to compute the KBSM of the connect sum of two solid tori and gave their exact structure. Moreover, Bakshi and her coauthors found that the handle sliding relations present in the KBSM have a succinct presentation given by Chebyshev polynomials of the second kind. Furthermore, they concluded that the handle sliding relations present in the KBSM of any non-prime oriented 3-manifold always have a nice Chebyshev representation. Bakshi also worked on writing and polishing six chapters devoted to the study of 3-manifold topology and skein modules in a scholarly book on knot theory aimed at advanced undergraduate and graduate students. The first draft of the manuscript was received well by reviewers and the book will soon be published by Springer, Universitext. This is the first instance of an academic book that gives an in-depth treatment of topics such as skein modules, which are at the forefront of research in quantum topology.

Bakshi was invited to present her research at and participate in several seminars and conferences including the Oberwolfach Seminar on Combinatorial and Geometric Knot Theory, the Seminar on Knots and Representation Theory, the Claremont Topology Seminar, Knots in Washington, the workshop on Braids and Low-Dimensional Topolgy at ICERM, the Spring Topological School on Witten's Finiteness Conjecture for Skein Modules, and a Special Session at the AMS-SMF-EMS Joint International Meeting (upcoming). Bakshi was also invited to deliver a lecture series on skein modules at Jilin University in Spring 2022. Bakshi looks forward to continue contributing to the scholarly activities at ITS and the endless possibilities that the coming academic year presents.

Dominik Schröder

François Bienvenu (front) is having lunch with other ITS members after a group hike to Flumserberg.

François Bienvenu started as a Junior Fellow in September 2021. His research is at the interface between mathematics and biology: in mathematics, he is mostly interested in combinatorial stochastic processes, in particular in relation to random graphs; in biology, he works on problems from ecology (notably structured population dynamics) and evolution (phylogenetics and modelization of speciation).

Since arriving at ITS, Bienvenu's main focus has been phylogenetic networks. Although the evolutionary relationships between species are traditionally represented using trees, these cannot be used to model phenomena such as hybrid speciation or horizontal gene transfers. As a result, in the past decades there have been growing calls by biologists to replace trees by networks – but the mathematical tools to do this are still lacking. Together with his collaborator Jean-Jil Duchamps, Bienvenu has introduced and studied a biologically relevant yet mathematically tractable model of random phylogenetic network. One of the main features of this model is that closely related species are more likely to hybridize than phylogenetically distant ones, which results in networks having a lot of shorts cycles but a tree-like structure on the large scale (more specifically, the rescaled network, seen as a metric space, converges to the continuum random tree). Bienvenu is also co-supervising (with Céline Scornavacca) a Master's student working on the simulation of random phylogenetic networks.

Besides this, Bienvenu has worked on questions related to population ecology with Guilhem Doulcier and Alexandra Băcoianu. They have developped a method to quantify the imprecision resulting from intraclass heterogeneities of the vital rates in matrix population models – that is, the numerical error that is introduced in demographic statistics (e.g, the net reproductive rate or the generation time) when we fail to take into account some steps in the life-cycle (something that is inevitable in practice). They wrote MatPopMod, a Python library providing biologists with a complete toolkit for studying matrix population models, and they are currently using their method to assess the overall impact of intraclass heterogeneities of the vital rates on the conclusions of the published literature.

Bienvenu has also worked with a team of population geneticists lead by Jérémy Guez and his PhD advisors to understand the impact of the cultural transmission of reproductive success on demographic inferences. Current methods to infer the past demography of a population from genomic data rely on Kingman's coalescent, which produces very balanced genealogies. However, in many

Dominik Schröder

Alexandru Gheorghiu (6th right) attending a group hike in Spring 2022 with a spectacular view over Walensee.

human populations there is often a positive correlation of non-genetic origin between the number of children of the parents and that of their children. This tends to produce imbalanced genealogies, and it was not clear how this impacts demographic inferences. Using computer simulations and machine learning techniques, this work has showed that the cultural transmission of reproductive success can have an effect similar to that of a population contraction, thereby biasing demographic inferences.

Finally, Bienvenu is co-supervising a Master's student with Amaury Lambert. In a fledgling project with Félix Foutel-Rodier and Veronica Miró Pina, they are studying an interactiong particle system that aim at improving our understanding of how ecological parameters such as the migration rate and the geometry of the habitat influence speciation.

Alexandru Gheorghiu has been a Junior Fellow at the ITS since September 2020. His work is mainly focused on verification of quantum computation and quantum complexity theory. Throughout his second year at the ITS, he continued to work on these topics.

Quantum computing promises to offer tremendous speed-ups in solving certain problems when compared to non-quantum (classical) computers. Such speed-ups have already been demonstrated with quantum devices of Google and the University of Science and Technology of China, and termed «quantum advantage demonstrations». However, one problem with these demonstrations of quantum advantage is that verifying the results produced by the quantum devices requires exponential time for classical computers and is thus intractable. Gheorghiu's work has focused on coming up with protocols for efficiently certifying quantum advantage. These are known as «proof of quantumness» protocols. Unfortunately, proof of quantumness protocols demonstrating quantum advantage have not yet been implemented with existing quantum devices due to the large overhead in the resources required to implement them. One of Gheorghiu's projects in 2021, with ETH student Zhenning Liu, directly addressed this challenge. They showed that proof of quantumness protocols can be made to work with short depth quantum circuits, thus making them more amenable to implementation with near-term devices. The work was presented at the conference Quantum Information Processing (QIP) 2022, the premiere conference for quantum computing research.

Along the same line of work, Gheorghiu worked with ETH student Tony Metger and Caltech student Alexander

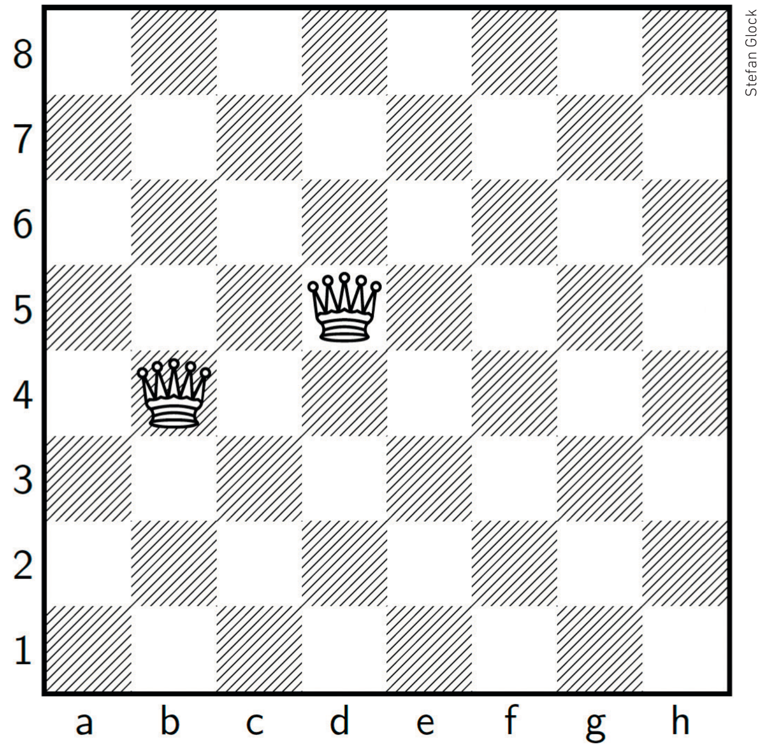
Dominik Schröder

Stefan Glock (right) and François Bienvenu enjoying the ITS group hike to Flumserberg in 2021.

Poremba in developing protocols for efficiently certifying the preparation of certain quantum states on a quantum computer. They showed that this protocol then allows for the implementation of multiple quantum cryptographic protocols using only classical communication (i.e., the parties involved in the protocol would exchange only classical bits, rather than having to exchange quantum states). This was an important theoretical development, as for some of these protocols (unclonable encryption, quantum copy-protection) it was believed that any implementation would require quantum communication. This also makes these protocol more suitable for implementation with near-term devices (by only requiring a classical communication infrastructure, rather than a quantum one). The work was accepted at the conference Theory of Quantum Computation (TQC) 2022.

Lastly, in the area of quantum complexity theory, an important research direction is concerned with understanding the strengths and limitations of so-called hybrid quantum-classical algorithms. These are algorithms that combine both classical and quantum computation. Crucially, the quantum computation involves only circuits of short depth and so the hybrid models are representative for the types of problems that could be performed with near-term quantum devices. Gheorghiu, together with Atul Singh Arora from Caltech and Uttam Singh from the Polish Academy of Sciences, studied two types of hybrid models: one where a classical computer interrogates a short depth quantum computer many times and one where a short depth quantum computer can perform classical pre- and post-processing throughout its computation. The former is representative of various quantum machine learning algorithms, while the latter is representative of so-called measurement-based quantum computation. In their work, Gheorghiu, Arora and Singh showed that the two models are incomparable: there are problems that one model can solve but not the other and viceversa. This illustrated that the advantage one can gain from short-depth quantum computation is highly dependent on how quantum and classical computation are combined. The work was presented at an IBM research seminar.

Gheorghiu presented his results at several venues, including invited talks at the Institute for Advanced Study in Princeton, the Simons Institute for the Theory of Computing in Berkeley and the Symposium on the Theory of Computing (STOC) 2022, in Rome.



In 1850, Nauck posed the first instance of the n-queens completion problem: with two queens on b4 and d5 already given, is it possible to add six more queens to obtain an 8-queens configuration?

In his third and final year at ITS, **Stefan Glock** continued his research in Combinatorics.

In one project, together with his mentor Benny Sudakov, and David Munha Correia, who is a PhD student at ETH, he investigated the n-queens completion problem, the first instance of which was introduced by Nauck in 1850. The problem can be easily described. An n-queens configuration is a placement of n mutually non-attacking queens on an n-by-n chessboard. Now, given a partial configuration, the question is whether it can be completed to a full n-queens configuration. Since the n-queens completion problem has been used for decades in Artificial Intelligence papers as a benchmark problem, it is important to understand how difficult it actually is. Perhaps surprisingly, Glock and his co-authors were able to show that a constant proportion of queens can be placed arbitrarily (as long as mutually non-attacking) on the chessboard, and it is always possible to complete it to a full configuration.

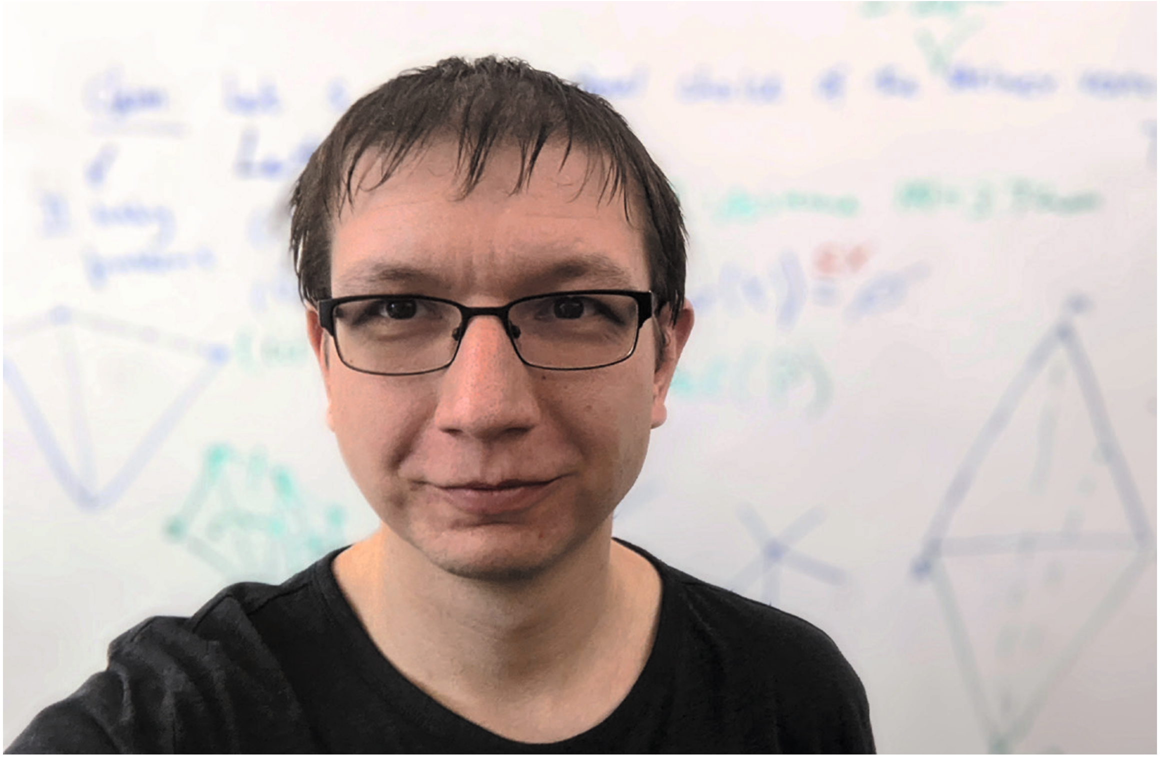
In an international collaboration with Felix Joos, Marcus Kühn (both Heidelberg), Jaehoon Kim (Daejeon), and Lyuben Lichev (Saint-Etienne), Glock obtained a general result on hypergraph matchings. By developing a novel concept of «conflict-free» matchings, they were able to show that several well-known theorems in Combinatorics, with no obvious connections to each other, are in fact just special instances of one general phenomenon. More than that, the introduced machinery also yields several new results, most importantly concerning so-called high-girth Steiner systems.

Glock was invited to present his research on several occasions, including a number of seminars (Princeton, Harvard, Graz, Ilmenau) and a plenary talk at the Third Southwestern German Workshop on Graph Theory (upcoming).

After three productive and enjoyable years at ITS, Stefan Glock will take up a tenure-track professorship at the University of Passau in Germany.

Sándor Kisfaludi-Bak spent 4 months at ITS as a Junior Fellow from September to December 2021, and since January 2022 he is an Assistant Professor at Aalto University in Finland. His research focuses on computational geometry, and more narrowly on creating geometric algorithms whose running time can be (conditionally) proven optimal. During his time at ITS, the pandemic was still impeding international in-person events, and collaborations were mostly online. But in October Kisfaludi-Bak was invited to give a mini-course consisting of 4 lectures about techniques in geometric approximation

Sándor Kisfaludi-Bak



Sándor Kisfaludi-Bak while working on a question about Euclidean Steiner trees.

algorithms in a Training Week of the Networks program in the Netherlands.

Kisfaludi-Bak typically works on exact and approximation algorithms for NP-complete problems on geometric intersection graphs as well as geometric variants of the famous travelling salesman and Steiner tree problems. Given a set of objects (i.e., subsets) in some ambient metric space, one can define their intersection graph as the graph whose vertices are the objects, and whose edges correspond to object pairs that have a non-empty intersection. One often considers unit radius disks in the Euclidean plane: the resulting unit disk graphs are also motivated as a model for wireless networks, but it is also natural to consider other geometric objects.

One of Kisfaludi-Bak's projects (with several collaborators) was about diameter computation in geometric intersection graphs. The diameter of a graph is the maximum length shortest path. Current algorithms have near-quadratic $O(n^2)$ running times in case of unit disks and other ‹simple› objects, while a recent breakthrough led to an $O(n^{5/3})$ algorithm is possible (ignoring polynomials of log n in both running times) in the simpler case of planar graphs. In this project the goal was to find sub-quadratic algorithms also for geometric intersection graphs, or prove that those do not exist (under complexity-theoretic hypotheses). The outcome was that for many natural objects sub-quadratic algorithms cannot exist under widely accepted complexity-theoretic hypotheses, but the key question of sub-quadratic diameter computation on unit disk graphs remained open. The paper was accepted to the International Symposium on Computational Geometry (SoCG 2022).

In a different (still ongoing) project Kisfaludi-Bak has been working with Dániel Marx on approximation algorithms for variants of the travelling salesman and the Steiner tree problem in geometric intersection graphs. Preliminary results show that polynomial time approximation schemes are possible for these problems if the objects are unit disks or other simple shapes, that is, one can obtain approximations where the size of the obtained solution is arbitrarily close to the optimum in, albeit the running time depends on the desired approximation quality.

Johannes Knörzer started at the ITS as a Junior Fellow in February 2022. His research interests lie at the intersection of quantum information science, condensed-matter physics and quantum optics. More specifically, he investigates quantum optical and solid-state implementations of quantum information processing. In the past year, he

Dominik Schröder

Johannes Knörzer (on the right) enjoying a boat trip on Walensee in Spring 2022.

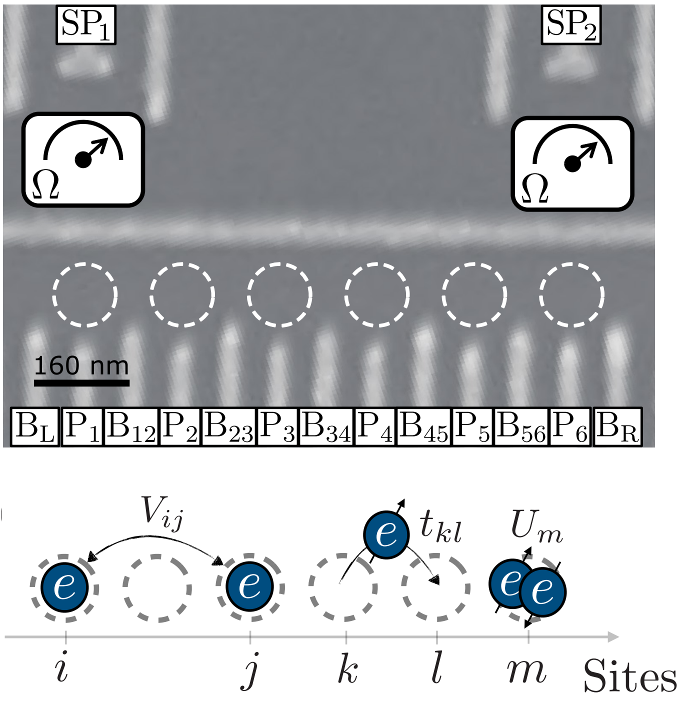
has been working on several projects related to quantum simulation and quantum many-body physics.

Many phenomena in nature are governed by quantum physics. Yet their quantitative description is often notoriously hard, and our classical computers are doomed to fail at computing many properties of quantum systems that involve even only a moderate number of particles. Forty years ago, Nobel Laureate Richard Feynman suggested that this may be overcome by using and measuring controllable quantum systems, in order to compute properties of other complex quantum systems that are described by the same underlying mathematical model as the system in the laboratory. Nowadays quantum simulators provide a promising route towards solving complex quantum many-body problems in regimes where other methods fail. Many physical platforms are being developed for this task, including trapped ions, superconducting qubits, quantum dots, and cold atoms.

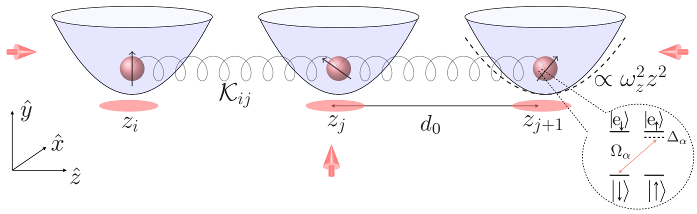
Recently, together with his colleagues Knörzer has investigated how trapped-ion quantum systems can be used to study models that are considered relevant for an improved understanding of electron-phonon interactions, and benchmark expensive numerical calculations. The international collaboration of researchers from ETH Zurich, the Max Planck Institute of Quantum Optics and the Chinese Academy of Sciences focused on a particular spin-Holstein model that can be implemented with arrays of ions confined by individual microtraps, and that is closely related to the Holstein model of condensed matter physics, used to describe electron-phonon interactions. In a numerical study, they employed a combination of complementary approaches, based on non-Gaussian variational ansatz states and matrix product states, respectively. Crucially, they could demonstrate that this novel hybrid approach outperforms standard density-matrix renormalization group calculations. As a tantalizing prospect, trapped-ion quantum simulators may help to gain new insights into the underlying physical mechanisms of phenomena related to electron-phonon interactions. Their work has recently been published in Physical Review Letters [PRL 128, 120404 (2022)].

In another research project on exploring best use cases for quantum simulators, Knörzer and his collaborators from theory and experiment investigated long-range interactions between electrons in quantum-dot systems. Long-range interactions play a key role in several phenomena of quantum physics and chemistry. To study these phenomena, analogue quantum simulators provide an appealing alternative to classical numerical methods.

Johannes Knörzer



Quantum-dot system studied in the preprint arXiv:2202.06756 and a schematic illustration of electron hopping and interactions.



Schematic depiction of trapped-ion setup investigated in PRL 128, 120404 (2022).

Gate-defined quantum dots have been established as a platform for quantum simulation, but for those experiments the effect of long-range interactions between the electrons did not play a crucial role. In a recent study, Knörzer and colleagues have presented the first detailed theoretical and experimental characterization of long-range electron-electron interactions in an array of gate-defined semiconductor quantum dots. They demonstrated significant interaction strength among electrons that are separated by up to four sites and showed that their theoretical prediction of the screening effects matched well their experimental results. Based on these findings, they also investigated how long-range interactions in quantum-dot arrays may be utilized for analogue simulations of artificial quantum matter. Numerically they could show that about ten quantum dots are sufficient to observe binding for a one-dimensional hydrogen-like molecule. These combined experimental and theoretical results pave the way for future quantum simulations with quantum dot arrays and benchmarks of numerical methods in quantum chemistry. The work is accessible as a preprint on arXiv (2202.06756) and will be published in Physical Review Research.

Together with his colleagues from the Max Planck Institute of Quantum Optics, Knörzer recently investigated strong sound-matter and light-matter interactions in systems of artificial giant atoms. Quantum optical theory provides a solid framework for the study of light-matter interaction. Yet paradigmatic models are based on several approximations, such as the rotating-wave, electric dipole and Born-Markov approximations. While the underlying assumptions are typically well justified, recent experimental advances have paved the way for investigations of yet unexplored parameter and physical regimes. Superconducting circuits offer a versatile platform for such studies in which artificial atoms may be efficiently and strongly coupled to electromagnetic and sound waves. In particular giant artificial atoms permit the investigation of systems in which the electric dipole approximation breaks down and pronounced non-Markovian effects become important. While previous studies of giant atoms focused on the realm of the rotating-wave approximation, Knörzer and his colleagues recently extended these previous studies and performed a numerically exact analysis of giant atoms strongly coupled to their environment, in regimes where counterrotating terms cannot be neglected. To achieve this, they used a Lanczos transformation to cast the field Hamiltonian into the form of a one-dimensional chain and employ matrix-product state simulations. This approach yields access to a wide range of system-bath observables and to previously unexplored

Dominik Schröder on a carbon-neutral conference travel to Oberwolfach.

parameter regimes. Based on the relatively low computational costs of these simulations, their study paves the way for further numerical investigations of waveguide quantum electrodynamics with multiple giant atoms in all coupling regimes. The work is accessible as a preprint on arXiv (2201.11544) and will be published in Physical Review A.

Dominik Schröder spent his third and final year at the ITS. In past year he worked on three projects on the interface of random matrix theory and theoretical physics.

In a first line of works, Schröder and his collaborators proved the physics prediction on spectral form factors (SFF) up to an intermediate time scale for a large class of random matrices. The spectral form factor is the squared Fourier transform of the empirical eigenvalue density and is a popular tool to test universality of disordered quantum systems. Beyond Wigner matrices the result also covers the monoparametric ensemble and establishes that the universality of the SFF remarkably can already be triggered by a single random parameter.

In a second line of work, Schröder proved Quantum Unique Ergodicity (QUE) for Wigner matrices and deterministic observables of any intermediate rank, unifying several previous results. QUE is fundemantal conjectured property of disordered or chaotic quantum systems and states that eigenstates are uniformly distributed in the phase space. For general physical systems, a proof of this phenomenon remains an important open problem.

Finally, Schröder worked on extremal statistics of non-symmetric random matrices and proved, together with collaborators, that the right-most eigenvalue converges to a Gumbel distribution. Since ground-breaking work of May non-symmetric random matrices have been extensively used to describe the evolution of complex systems both in theoretical neuroscience and in mathematical ecology. In such systems, the maximal growth rate is determined by the maximal real part of the spectrum of the coefficient matrix, making the right-most eigenvalue an interesting object for applications.

Schröder supervised two theses of ETH students on the «BBP phase transition» and the «double descent phenomenon» and was delighted to participate again in in-person workshops, conferences and seminars in Geneva, Vienna, Oberwolfach & Trieste after a two-year hiatus due to Covid19.


1 2

Outlook

We are delighted to welcome Sanjeev Arora as Senior Fellow at the ETH-ITS in Fall 2022.

1 **Sanjeev Arora** is the Fitzmorris Professor of Computer Science at Princeton University. He is well-known for his work on probabilistically checkable proofs and has more recently proven foundational theoretical results in the area of machine learning. He has won many prizes for his work (the Goedel Prize in 2001 and 2010, the Fulkerson Prize in 2012). He is a member of the US National Academy of Sciences.

One new Advanced Fellow is joining the ETH-ITS in September 2022.

2 **Gramoz Goranci** received his PhD in Computer Science from the University of Vienna in 2019 under the supervision of Monika Henzinger. He was a postdoc at the University of Toronto and then held a permanent lectureship at the University of Glasgow. He is broadly interested in the design and analysis of fast graph algorithms with a focus on dynamic algorithms and compression techniques. His research draws connections between different areas such as combinatorial data structures, graph partitioning, numerical linear algebra, metric embeddings, and machine learning.

3

4

5

The ETH-ITS is delighted to welcome one new Junior Fellow in September 2022. Christoph Kehle is returning to the institute to finish his remaining term of two years as Junior Fellow. Deeksha Adil will join the ETH-ITS in January 2023.

3 Deeksha Adil is about to receive her PhD in Computer Science from the University of Toronto in August 2022 under the supervision of Sushant Sachdeva. Her research is centered around the design of fast algorithms for problems in optimization, machine learning, and theoretical computer science. Her dissertation focussed on finding fast algorithms and new methods for regression problems, specifically p-norm regression via tools from optimization theory and continuous analysis.

4 André Guerra received his PhD in Mathematics from the University of Oxford in 2021 and, before joining the ITS, he spent a year at the Institute for Advanced Study in Princeton. He is broadly interested in the calculus of variations and partial differential equations. He has worked on problems arising in complex analysis, elliptic PDEs and geometry.

5 Christoph Kehle received his PhD from the University of Cambridge in 2020 before he joined the ITS during 2020 – 2021. In the academic year 2021 – 2022, he has been a member of the School of Mathematics at the Institute for Advanced Study in Princeton. He is interested in analysis, geometry, and partial differential equations, specifically in the context of general relativity. His works show a novel connection of Diophantine approximation arising from small divisors to the Strong Cosmic Censorship conjecture in general relativity. Recently, he has also been working on a proof of a turbulent nonlinear instability for AdS black holes.

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Melanie Borer

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Martin Haefner, Walter Haefner Foundation
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Advisory Committee

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Gianni Blatter, Matthias Gaberdiel, Rahul Pandharipande, Tristan Rivière, Angelika Steger, Nicola Spalding*
External members
Noga Alon (Tel Aviv and Princeton), Luis Alvarez-Gaumé (CERN), Artur Ekert (Oxford), Shafira Goldwasser (MIT and Weizmann Institute), Gerhard Huisken (MFO), Elon Lindenstrauss (Hebrew University), Martin Hairer (Warwick)
*replaced by Ueli Maurer in 2015

2017 – 2019
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External members
Noga Alon (Tel Aviv and Princeton), Robert Brandenberger (McGill), Artur Ekert (Oxford), Gerhard Huisken (MFO), Elon Lindenstrauss (Hebrew University), Martin Hairer (Imperial College), Claire Voisin (Collège de France)

2019 – 2022
ETH members
Alessio Figalli, Renato Renner, Manfred Sigrist, Olga Sorkine-Hornung, David Steurer, Tanja Stadler
External members
Robert Brandenberger (McGill), Ben Green (Oxford University), Albrecht Klemm (University of Bonn), Nathan Linial (Hebrew University of Jerusalem), Madhu Sudan (Harvard University), Corinna Ulcigrai (University of Zurich), Claire Voisin (Collège de France)

Fellows 2014–2022

Senior Fellows

Terry Hwa, UC San Diego	02.2014 – 09.2014 and 04.2015 – 08.2015
Gilles Brassard, Université de Montréal	06.2014 – 12.2014 and 04.2019 – 06.2019
Henryk Iwaniec, Rutgers University	08.2014 – 05.2015 and 06.2016 – 07.2016
Dmitry Chelkak, St. Petersburg	09.2014 – 08.2015
Alex Lubotzky, Hebrew University	02.2015 – 07.2015 and 02.2016 – 08.2016
Adi Shamir, Weizmann Institute	02.2015 – 07.2015 and 02.2016 – 07.2016
Eugene Demler, Harvard University	05.2015 – 06.2015 and 09.2015 – 12.2015
Robert Brandenberger, McGill University	08.2015 – 07.2016
Walter Schachermayer, University of Vienna	08.2015 – 08.2016
Riccardo Barbieri, SNS Pisa	11.2015 – 10.2016
Alexander Balatsky, Nordita and LANL	02.2016 – 04.2016 and 07.2016 – 03.2017
Eitan Tadmor, University of Maryland	08.2016 – 07.2017
Vadim Kaloshin, University of Maryland	09.2016 – 08.2017
Jean-Michel Coron, Université Pierre et Marie Curie	01.2017 – 12.2017
Claire Voisin, Collège de France	01.2017 – 12.2017
Gerhard Huisken, MFO	02.2017 – 09.2017
Leonid Glazman, Yale University	05.2017 – 12.2017 and 05.2018 – 08.2018
Sandu Popescu, University of Bristol	10.2017 – 12.2017 and 03.2018 – 12.2018
Yakov Eliashberg, Stanford University	06.2019 – 09.2019 and 04.2022 – 06.2022
Ivan Cherednik, University of North Carolina at Chapel Hill	07.2019 – 06.2020
Nicolai Reshetikhin, UC Berkeley	07.2019 – 07.2020
Ming Yuan, Columbia University	09.2019 – 08.2020
Kannan Soundararajan, Stanford University	09.2019 – 03.2020
Albrecht Klemm, University of Bonn	08.2021 – 03.2022
Mikhail Lyubich, Stony Brook University	08.2021 – 01.2022
Viviane Baladi, CNRS	04.2022 – 06.2022
Daniel Huybrechts, University of Bonn	04.2022 – 06.2022
Sanjeev Arora, Princeton University	09.2022 – 10.2022

Junior Fellows (with current affiliation of former Junior Fellows)

Emily Clader, University of San Francisco	09.2014 – 07.2016
Zur Luria, Azrieli College of Engineering	09.2014 – 09.2017
Alessandro Carlotto, ETH Zurich	09.2015 – 08.2016
Maria Colombo, EPF Lausanne	09.2015 – 08.2018
Lavinia Heisenberg, University of Heidelberg	09.2015 – 09.2018
Titus Lupu, CNRS	09.2015 – 12.2017
Aline Ramires, Paul Scherrer Institut	09.2015 – 08.2018
Ran Tessler, Weizmann Institute	09.2015 – 10.2018
Shoham Letzter, University College London	09.2016 – 12.2019
William Sawin, Columbia University	09.2016 – 07.2018
Ulrike Rieß	09.2017 – 09.2021
Johannes Noller, ICG Portsmouth	09.2017 – 03.2020
Pierrick Bousseau, CNRS and ETH Zurich	09.2018 – 09.2020
Nina Holden, New York University	09.2018 – 12.2020
Fanny Yang, ETH Zurich	09.2018 – 09.2019
Yi-Jun Chang, University of Singapore	07.2019 – 08.2021
Stefan Glock, University of Passau	09.2019 – 08.2022
Dominik Schröder, ETH Zurich	09.2019 – 08.2022
Christoph Kehle	09.2020 – 08.2021 and 08.2022 – 07.2024
Alexandru Gheorghiu, Chalmers University	09.2020 – 09.2022
Rhea Palak Bakshi	09.2021 – 08.2024
François Bienvenu	09.2021 – 08.2024
Sándor Kisfaludi-Bak, Aalto University	09.2021 – 12.2021
Johannes Knörzer	02.2022 – 01.2025
André Guerra	09.2022 – 08.2025
Deeksha Adil	01.2023 – 01.2026

Advanced Fellows (with current affiliation of former Advanced Fellows)

Marvin Künnemann, TU Kaiserslautern	04.2021 – 03.2022
Michael Borinsky	09.2021 – 08.2026
Sylvain Lacroix	09.2021 – 08.2026
Yunan Yang, Cornell University	01.2022 – 06.2023
Gramoz Goranci	09.2022 – 08.2027

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