

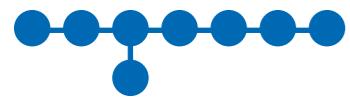
Report 2015/2016

ETH Institute for Theoretical Studies



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The Institute's garden in spring.

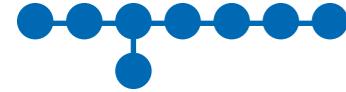
Foreword

The ETH Institute for Theoretical Studies, which started its activities in January 2014, is confirming itself as a unique meeting place for exchanges of ideas in top level research in theoretical sciences. It gathers excellent researchers, who are given the opportunity to dedicate their time to basic research and to interact with the lively ETH research community. With their courses, conferences, seminars, supervision of students, public talks and several research collaborations, the Fellows of the ETH-ITS are having an increasing impact on the theoretical research landscape in Switzerland. The academic year 2015-2016 at the ETH Institute for Theoretical Studies was marked by a substantial increase of the number of Fellows: six new Junior Fellows started their term in September 2015 and we had seven Senior Fellows, some staying part of the year, at the Institute. These Fellows started several activities at the Institute and at ETH and new collaborations were started

that involved several researchers at ETH and in Switzerland. The research of the Fellows obtained several recognitions: Robert Brandenberger was elected Fellow of the Royal Society of Canada, Emily Clader won the SwissMAP Innovator prize, Maria Colombo received the lapichino Prize of the Accademia dei Lincei, Henryk Iwaniec was awarded the Banach Medal, and Walter Schachermayer received the Science Prize of the City of Vienna. Two talks of this autumn's prestigious Séminaire Bourbaki in Paris are dedicated to the work of Junior Fellow Alessandro Carlotto and incoming Senior Fellow Claire Voisin, respectively. I invite you to read about the exciting research of the Fellows in this report and to join the activities of the Institute, in particular the ITS Science Colloquium, a series of accessible talks addressing themes of interest across disciplines.

Giovanni Felder, Institute's director

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





The seminar room of the Institute.

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 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. The Junior 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 Fellows

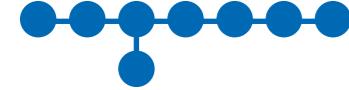
Mid September	Target date for nominations, eligible candidates are invited to apply
Mid October	Deadline for application of nominated candidates
November	Interviews with ETH members of the Advisory Committee
December	Offers are made

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 →

Collaborations

The ETH Institute for Theoretical Studies collaborates with the Departments of ETH and their visitor programmes, such as the Forschungsinstitut für Mathematik (FIM) at the Department of mathematics and the Pauli Centre at the Department of physics. It also nurtures the relationship with other Swiss research institutions through its Fellows and by contributing to scientific activities. For example, the research of Senior Fellow Alexander Balatsky, involves collaborations with the Institute for Theoretical Physics and the Department of Materials at ETH, as well as the Paul-Scherrer Institute; Senior Fellow Riccardo Barbieri organized a regularly meeting journal club, that gathered researchers at ITS, at ETH and at the University of Zurich. The ETH-ITS also hosts part of the activities of the National Centre of Competence in Research «SwissMAP – The Mathematics of Physics» of the Swiss National Science Foundation, based on a collaboration between the University of Geneva and ETH Zurich involving researchers in Switzerland working at the interface between mathematics and physics.





Participants of the workshop «Double Field Theory» that took place at the ETH-ITS in January 2016.



Tanja Stadler talks about evolution in the ITS Science Colloquium.

Activities

Courses, workshops

The ETH-ITS co-sponsored several activities, including a workshop on «Mathematical finance beyond classical» and one on «Double field theory», in collaboration with the Pauli Centre, both taking place in the Institute's building, and a conference «Higher dimensional expanders 2016», a follow-up conference to last year's winter school on the same topic, taking place at les Diablerets, a village in the

Swiss Alps. Senior Fellows Walter Schachermayer and Alex Lubotzky both gave a course in the series ETH Lectures in Mathematics (Nachdiplomvorlesungen) and Junior Fellow Zur Luria gave a semester long course at ETH-ITS. Senior Fellow Alexander Balatsky gave a mini-course on «Dirac materials» with participants from physics and material science at ETH and from the Paul Scherrer Institute.

The ITS Science Colloquium

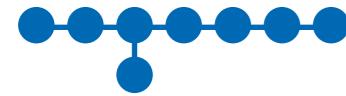
The ITS Science Colloquium aims at exposing students and researchers in mathematics, theoretical computer science and theoretical natural sciences to new questions and research subjects of common interest to different disciplines. This year several talks focused on recent advances in physics, reflecting the interests of Senior Fellows, addressing questions on cosmology, particle physics beyond the standard model and condensed matter physics. Interesting connections emerged such as the occurrence and

experimental observation of the Higgs effect both in particle physics, where it first arose, and in condensed matter physics. These talks were complemented by an exposition by Tanja Stadler of new results in computational biology, leading to novel insights in diverse evolitional questions, ranging from the extinction of dinosaurs to mutations of viruses, and an overview of the results and challenges of mathematical finance by Walter Schachermayer.

Programme 2015/2016

01.10.2015	Robert Brandenberger, ETH-ITS and McGill University	Testing superstring theory with cosmological observations
15.10.2015	Tanja Stadler, ETH Zurich	Genetic sequencing data reveals insight into the extinction of dinosaurs, the speciation of penguins, and the spread of Ebola in last year's epidemic
05.11.2015	Jörg Schmiedmayer, Vienna University of Technology	Does an isolated quantum system relax?
10.12.2015	Eugene Demler, ETH-ITS and Harvard University	Exploring big questions on small scales
10.03.2016	Walter Schachermayer, ETH-ITS and University of Vienna	Mathematics and Finance
07.04.2016	Riccardo Barbieri, ETH-ITS and Scuola Normale Superiore di Pisa	From the electron to the Higgs boson: complete or incomplete?
21.04.2016	Alexander Balatsky, ETH-ITS and NORDITA, Los Alamos	Dirac Materials

Videos of selected talks can be viewed on www.ethz.ch/eth-its/activities →





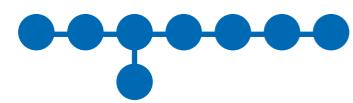
ETH professor Gunther Dissertori participates in the discussion after Barbieri's ITS Science Colloquium talk.

Fellows' seminar

The aim of the Fellows' seminar, organized by Junior Fellows Lavinia Heisenberg and Alessandro Carlotto, 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, that are typically from a different field.

Programme 2015/2016

11.12.2015	Ran Tessler	Waves in shallow water, coconuts and 2 dimensional quantum gravity
20.11.2015	Aline Ramires	SuperSpins to the rescue of heavy fermions
13.11.2015	Titus Lupu	Conformally invariant stochastic processes in the plane: Gaussian Free Field, Conformal Loop Ensembles and Brownian Loop Soups.
23.10.2015	Lavinia Heisenberg	Einstein's unfinished masterpiece
16.10.2015	Alessandro Carlotto	Why should we care about minimal surfaces?
09.10.2015	Zur Luria	Random designs and high dimensional expanders
02.10.2015	Walter Schachermayer	Mathematics and finance
03.05.2016	Adi Shamir	The security and privacy of Bitcoin transactions
19.04.2016	Alexander Lubotzky	Permutations' equations and group theoretic testability
12.04.2016	Riccardo Barbieri	Who ordered the putative resonance hinted by the Large Hadron Collider Data at 750 GeV?
22.03.2016	Robert Brandenberger	The mystery of dark energy
01.03.2016	Emily Clader	Relations in the moduli space of curves





Emily Clader (left) with Zur Luria and his family in the garden of the Institute.



Junior Fellow Maria Colombo.

Awards

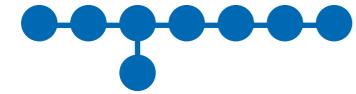
ETH-ITS Senior Fellow Robert Brandenberger was elected Fellow of the Royal Society of Canada. According to the press release, «Robert Brandenberger has made ground-breaking contributions to early universe cosmology. In particular, he contributed prominently to the development of the theory of structure formation in inflationary cosmology. He is largely responsible for the development of the theory of inflationary reheating and is also well known for his pioneering work in the field of superstring cosmology which can explain the earliest moments of the universe.»

ETH-ITS Junior Fellow **Emily Clader** was awarded the Swiss-MAP Innovator Prize «for her outstanding contribution to the study of relations in the cohomology of the moduli space of curves.» The Innovator Prize is a prize awarded once a year to PhD students or postdocs for important scientific achievements in the research areas of the National Competence Centre in Research SwissMAP – The Mathematics of Physics.

Maria Colombo, ETH-ITS Junior Fellow and postdoc at the Institute of mathematics of the University of Zurich, was awarded the Gioacchino Lapichino prize of the Accademia Nazionale dei Lincei for her paper «Counterexamples in multimarginal optimal transport with Coulomb cost and spherically symmetric data», published in *Mathematical Models and Methods for the Applied Sciences*. According to the citation, this work «comes to occupy a prominent place in the considerable mathematical literature on the problem of minimization of atomic energies.»

Henryk Iwaniec, who was Senior Fellow in the academic year 2014-2015 and completed his stay spending two months in 2016, is the 2015 recipient of the Banach medal. The Stefan Banach Medal is awarded by Presidium of the Polish Academy of Sciences «for outstanding achievements in mathematical sciences.»

Walter Schachermayer, ETH-ITS Senior Fellow 2015-2016, is awarded the «Preis der Stadt Wien für Natur- und technische und Wissenschaften,» of 2016, the highest recognition of the city of Vienna in the natural and technical sciences.





Senior Fellows Robert Brandenberger (left) and Riccardo Barbieri (right) discuss with visitor Lawrence Hall of the University of California, Berkeley.



Senior Fellow Robert Brandenberger (right) with collaborator Jürg Fröhlich, Professor emeritus at ETH Zurich.

Fellows' report

Professor **Riccardo Barbieri** joined the Institute for Theoretical Studies as a Senior Fellow in November 2015 for one year. At home in Italy he is professor emeritus of theoretical physics at the Scuola Normale Superiore of Pisa, where he was also educated. His interests are in theoretical particle physics, where he has been particularly influential in the so-called physics beyond the Standard Model of elementary particles. In particular at the beginning of the eighties he formulated, jointly with Sergio Ferrara and Carlos Savoy, the first general realistic model of supersymmetry breaking via supergravity.

His current interests span quite a number of subjects: the existence and the search for possible extra scalar fields other than the Higgs boson, famously found in 2012; the rather mysterious physics of the two replicas of the particles that constitute standard matter (the so-called flavour physics); the search for the still elusive axions, ultra-light scalar particles proposed long ago to understand the absence of CP violation in the strong interactions, which could constitute part of or even the totality of Dark Matter. On some of these subjects he has been and is collaborating with Professors and postdocs at the University of Zurich. On a broader set of subjects he is discussing also with members of the groups at ETH led by Professors Charalampos Anastasiou and Gunther Dissertori. All these issues have been and are being considered in the Journal Club organized on Tuesdays at 5 pm every week at the ITS.

Additionally to the ITS Science Colloquium asking the question «From the electron to the Higgs boson: complete or incomplete?», Riccardo Barbieri has been interacting with the particle physics community at large. Among other talks in Switzerland and abroad, in particular he has given keynote talks at the Users' Meeting of the Paul Scherrer Institute (February 2016) and at the Strategy Workshop on High-Energy Particle Physics in Switzerland (SWHEPPS, June 2016).

Robert Brandenberger, Canada Research Chair and Professor of Physics at McGill University, was Senior Fellow at the ETH Institute for Theoretical Studies from August 2015 to July 2016. He is very grateful for the chance to be able to spend an academic year at the ITS of the ETH. He found the atmosphere very stimulating. During his year in Zurich Prof. Brandenberger started a new collaboration with the group of Prof. Alexandre Refregier of the Institute for Astronomy of ETH. They are studying new statistical tools with which to find signatures of cosmic strings in new observational windows. Prof. Brandenberger co-supervised the «Semesterarbeit» of Mr. Lukas Hergt on this topic. This is developing into a long term collaboration. Prof. Brandenberger also started a new research collaboration with Prof. Jürg Fröhlich, of the ETH Institute for Theoretical Physics. They are working on a unified model of «Dark Matter» and «Dark Energy» in which it is a new

axion field which is responsible for dark energy. The new construction makes use of a Pontryagin term in the action of a new gauge field, and combines ideas which were previously used in Condensed Matter Physics with ideas from cosmology.

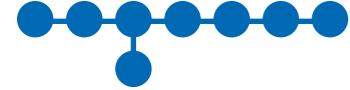
Prof. Brandenberger also started an investigation of the cosmology of «Double Field Theory». Together with Prof. Matthias Gaberdiel, also at the Institute for Theoretical Physics, he organised a small workshop at the ITS which took place in January 2016 and brought together experts in superstring theory and cosmology to discuss the challenges of this proposed program. These ideas will be further discussed during a Banff International Research Center workshop in January 2017.

He hosted visits of senior Japanese theoretical physicists Profs. J. Yokoyama (Univ. of Tokyo), M. Yamaguchi (Tokyo Institute of Technology) and T. Takahashi (Saga University) (who visited the ITS mostly with support from a Japan-McGill collaborative research grant). Prof. Stephon Alexander from Dartmouth College and Brown University visited twice. His first visit was key in getting the collaborative research project with Prof. Fröhlich under way. Prof. Brandenberger's PhD student Jerome Quintin visited him at the ITS for one month, and his students Elisa Ferreira, Disrael Cunha, Evan McDonough, Guilherme Franzmann and Hossein Basrafshan visited each for two weeks. His postdoc Leila Graef visited the ITS

for one week. These visits were funded by McGill travel awards supplemented by a McGill research grant which Prof. Brandenberger holds. Prof. Brandenberger also hosted seminars by Prof. N. Tsamis (Univ. of Crete) and Dr. Subodh Patil (Univ. of Geneva). The local costs of these visits were covered by Prof. Refregier's grant.

Robert Brandenberger wrote a number of papers with various collaborators from different institution, including three preprints based on new collaborations: «Tracking Dark Energy from Axion-Gauge Field Couplings,» arXiv:1601.00057 [hep-th] and Unified Description of Dark Energy and Dark Matter from Axion-Gauge Field Coupling, both with S. Alexander and J. Fröhlich, and «Searching for Cosmic Strings in CMB Anisotropy Maps using Wavelets and Curvelets,» arXiv:1608.00004 [astro-ph.CO], with ETH researchers L. Hergt, A. Amara, T. Kacprzak and A. Refregier.

During his stay at the ETH Prof. Brandenberger gave an ITS Colloquium, an Astrophysics Colloquium, an ITS Fellows' Seminar, and various journal club presentations. He also gave a number of presentations both in Switzerland and abroad, including the public lecture Was war vor dem Urknall? (What was before the Big Bang?) at the Realgymnasium Rämibühl in Zurich.





Junior Fellow Alessandro Carlotto.

Alessandro Carlotto spent the academic year 2015/16 at the Institute for Theoretical Studies as a Junior Fellow. During this time, his research was mostly focused on various global aspects of the theory of minimal submanifolds, both for its own sake and in connection to the study of the large-scale structure of initial data sets for the Einstein equations in general relativity.

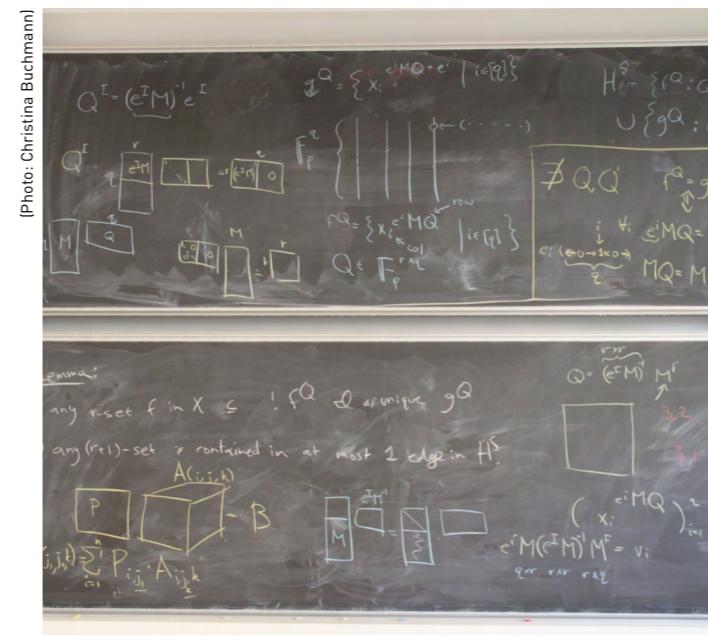
Concerning the first line, he started by investigating the generic finiteness problem for minimal surfaces, proving that indeed positivity of the scalar curvature suffices to ensure that the number of closed minimal surfaces of bounded complexity (measured, for instance, by a uniform bound on the Morse index) contained in a 3-manifold endowed with a generic metric is finite. The proof of this basic fact relies on a variety of tools, including a modification of estimates used in the 70s by Schoen and Yau to prove an existence theorem for black holes due to the condensation of matter in a suitably small region of a spacetime. He then moved to a systematic study of the relations between various sorts of invariants of minimal hypersurfaces and primarily between the Morse index and the (absolute and/or relative) real homology groups of the hypersurface in question.

Together with his collaborators Lucas Ambrozio and Benjamin Sharp, he developed a general method (pioneered, in special cases, by Ros and Savo) to obtain universal and effective index estimates for minimal hypersurfaces inside a Riemannian manifold, given an isometric embedding of the latter in some (possibly high-dimensional) Euclidean space. This approach can be applied to tackle a conjecture by Schoen and Marques-Neves asserting that the Morse index of a closed minimal hypersurface in a manifold of positive Ricci curvature is bounded from below by a linear function

of its first Betti number, which they settled for a large class of ambient spaces. On the other hand, these methods turn out to be very powerful in studying free-boundary minimal hypersurfaces in Euclidean domains: among other things, they provide a lower bound for the index of a free boundary minimal surface which is linear both with respect to the genus and the number of boundary components. This leads to new and surprising applications to compactness criteria, to the explicit analysis of known examples (due to Fraser-Schoen and to Folha-Pacard-Zolotareva) and to novel classification theorems.

Alessandro also delivered a number of talks both at ETH and abroad. He was a visiting scientist at the Institut Henri Poincaré (on invitation by C. Villani), at Harvard University (on invitation by S.-T. Yau) and delivered, among others, invited lectures in Banff (B.I.R.S.), Basel, Boston (M.I.T.), Leipzig (Max-Planck-Institut für Mathematik in den Naturwissenschaften), Montpellier (Institut Montpelliérain Alexander Grothendieck), Münster, Oberwolfach (M.F.O.), Orlando (for the 11th AIMS International Conference) and Potsdam (Albert Einstein Institute). At the same time, he perfectly integrated himself in the Zürich scientific community: apart from serving as organizer (together with Lavinia Heisenberg) of the ITS Fellows' Seminar, he collaborated with the Forschungsinstitut für Mathematik at ETH (which hosted, during the academic year, his collaborators Andrea Malchiodi, Francesca De Marchis and Benjamin Sharp), he was actively involved in the ETH Analysis Seminar and started a long-term collaboration with Camillo De Lellis (University of Zürich).

A Séminaire Bourbaki, to be held in Paris in November 2016 and entitled «Anti-gravité à la Carlotto et Schoen» will be



The blackboard in the seminar room.

devoted to the exposition of the recent construction by Alessandro Carlotto and his former PhD advisor Richard Schoen of localised solutions of the Einstein equations, published in *Inventiones Mathematicae*. The Séminaire Bourbaki is a series public lectures on recent progress in mathematics that has been held in Paris since 1948.

While joining the faculty of the Department of Mathematics of ETH (starting 1 September 2016), Alessandro plans to continue his enthusiastic involvement in the scientific life of the Institute for Theoretical Studies and keep working in connection with Gerhard Huisken, incoming Senior Fellow, with whom special activities in the realm of geometric analysis will be organized in the next academic year.

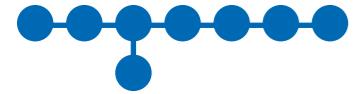
Emily Clader completed her second and final year as a Junior Fellow at the Institute for Theoretical Studies, during which she extended her research program in several directions. With Samuel Grushevsky, Felix Janda, and Dmitry Zakharov, she gave a new proof of one of the fundamental theorems on the cohomology of the moduli space of curves [E. Clader, S. Grushevsky, F. Janda, and D. Zakharov, «Powers of the theta divisor and vanishing in the tautological ring,» arXiv:1605.05425, 2016]; this provides an exciting application of the work she undertook during her first year at the ITS. For her work on this subject, she was awarded the 2016 SwissMAP Innovator Prize. In a rather different direction, she proved a «wall-crossing» theorem for the higher-genus Landau-Ginzburg model as part of joint work-in-progress with Felix Janda and Yongbin Ruan, yielding an important step toward understanding a physical duality known as the Landau-Ginzburg/Calabi-Yau correspondence. A number of her other projects remain ongoing, including work with ETH

postdoc Alexandre Buryak and ITS Junior Fellow Ran Tessler on open r -spin theory, and work with Renzo Cavalieri, ETH professor Rahul Pandharipande, and visiting ETH scholar Dustin Ross on the class of the hyperelliptic locus in the cohomology of the moduli space of curves.

In addition to maintaining her research program, Emily remained active in presenting her work to the scientific community. She delivered talks at the University of California San Diego, the University of Vermont, San Francisco State University, Colorado State University, Columbia University, and the University of Cambridge. She also co-organized a conference at the Chern Institute in Tianjin, China on the subject of global mirror symmetry; bringing together both experts and students from around the world, this conference provided a unique learning experience in a highly-focused environment for all of its fifty participants.

Emily is also passionate about pedagogy, so she made sure to find time for expository work. She wrote an invited contribution to the proceedings of a recent American Mathematical Society conference, giving a rigorous but non-specialized introduction to the topic of Gromov-Witten theory for graduate students in algebraic geometry and related areas. She also participated in a reading seminar with a number of ETH graduate students and postdocs on the theory and applications of stacks, during which she delivered an introductory lecture to her peers. Furthermore, at Peking University in China, she gave a three-hour lecture to a group of graduate students on the basics of the moduli space of curves.

In August 2016, Emily will begin the next stage of her career, as an Assistant Professor in the Department of Mathematics at San Francisco State University.





Senior Fellow Eugene Demler about to speak
at the ITS Science Colloquium.



Junior Fellow Lavinia Heisenberg.

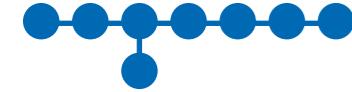
During his stay at the ITS as a Senior Fellow, **Eugene Demler** started several new research directions motivated by experiments done at ETH. This lead to collaborations with the groups of Atac Imamoglu and Tilman Esslinger. His collaboration with Atac Imamoglu's group focused on optical excitations in transition metal dichalcogenides. Their first joint project addressed a question of electron pairing mediated by polariton condensates. The paper has been published in Phys. Rev. B. In their second joint project they suggested a new interpretation of the so-called trion peak that has been observed in experiments by Imamoglu's group. They pointed out that the physical character of this state is not a trion but a Fermi polaron in which exciton plays a role of the impurity particle. The paper which compares theoretical predictions based on this model with experimental results from Imamoglu's group is currently under review. They continue this collaboration on exploring questions of transport of excitons-polarons. Eugene Demler's collaboration with Tilman Esslinger's focused on many-body systems of ultracold atoms. In their first joint project they explored a question of anomalous transport in ultracold atoms. Motivated by experiments in Esslinger's group they analysed theoretically transport properties of a system in which two large reservoirs are connected by a one-dimensional channel. They showed that enhanced pairing inside the 1d channel can explain

anomalous conductance plateaus observed experimentally. Another theoretical project motivated by experiments done in Esslinger's group is a question of super-radiance in a two cavity systems. In particular Eugene Demler started exploring the possibility of a «hidden order» type of symmetry breaking. Work on this project is continuing after Eugene Demler left ITS. Another class of ideas on which Demler and Esslinger continue to collaborate on centres around Shiba type bound states in Fermi superfluids that can be created using spin dependent optical potentials. Such systems can be easily realized in the experimental apparatus in Esslinger's group and open interesting prospects for creating topological states with ultracold atoms.

Since she started her new position as Junior Fellow at the Institute for Theoretical Studies, **Lavinia Heisenberg** initiated a bridge between the theoretical physics and the observational astrophysics groups at ETH. She is very much interested in quantum gravity and general field theories but also very intrigued by the observational signatures of theoretical models. She has been one of the driving forces in understanding the quantum corrections and technical naturalness of massive gravity. She has been very actively involved in extending the standard couplings considered in massive gravity theories, together with their cosmological implications, which received much attention recently. This research line allowed her a new collaboration with Professor Alexandre Refregier at ETH to constrain massive gravity with observational tests, which resulted in two publications. Along an independent research line, Lavinia played the leading role in building consistent generalisations for the Proca field, that presents new and exciting avenues in theoretical cosmology. This has initiated a lot of activities and interests in the community. Alone in the academic year 2016 this resulted in five publications together with her collaborators.

In contrast to these infrared modifications of gravity, she also started collaborations in ultraviolet modifications of gravity in form of generalised Born-Infeld gravity theories and their applications to early universe cosmology.

Besides her research activities, she has been also giving seminars and conference talks in many occasions during the academic year 2015–2016. She has been invited to give seminars at the University of Valencia, University of Geneva, University of Nottingham and the University of Cyprus. She was an invited speaker at the 3rd Korea-Japan workshop on dark energy in Korea and gave also a contributed talk at the 28th Texas Symposium on Relativistic Astrophysics in Geneva. Furthermore, she became a leading member of the management committee of the COST Action CANTATA in Switzerland. Additionally, she has been also involved in two review articles in this academic year within the theory working group of the EUCLID collaboration and the Beyond LCDM document published in Physics of the Dark Universe. Moreover, together with Alessandro Carlotto, she has been the main organiser of the Fellow seminar at Institute for Theoretical Studies since September 2015.





[Photo: Christina Buchmann]

Senior Fellows Alex Lubotzky and Adi Shamir
(front row, middle and right) together with
ETH Professor emeritus Christoph Schmid
(left) and other participants at the ITS Science
Colloquium.



[Photo: Christina Buchmann]

View from the top floor of the ITS building in
the Clausiusstrasse.

Professor **Alex Lubotzky** returned to the ETH-ITS to spend another six months in 2016, after doing so in 2015. He is on a leave of absence from the Hebrew University, Jerusalem, where he holds the Maurice and Clara Weil chair in mathematics. Lubotzky is known especially for being a bridge builder between different areas of mathematics and different communities of mathematicians and computer scientists. In the last few years he is leading the study of «high dimensional expanders» which is a new direction following the very successful study of expanders in math and CS in the last 40 years. He gave a semester long course on this subject at the ETH which has attracted a number of faculty members, postdocs and PhD students from very different groups of the math department. The course touched topics related to combinatorics, computer science, representation theory, Lie groups, number theory and geometry. Various directions of current research were presented as well as many open problems and suggestions for further research.

Last year, while being at the ITS he organized, with Prof. Tatiana Nagnibeda-Smirnov from the University of Geneva, an educational workshop on High Dimensional Expanders. That conference attracted almost 80 participants (mostly postdocs and PhD students) and was supported by the University of Geneva and the ITS. Following that success and the above mentioned course, a second conference was organized by them this year (again supported by ITS and the University of Geneva) this time directed at more advanced level researchers. This conferences brought 35 researchers from around the world of various level: starting with M. Gromov who is one of the greatest mathematicians of our generation, some first class mathematicians and computer

scientists from Europe, the United States, Japan, Taiwan and Israel. But also a number of postdocs and graduate students from ETH, Geneva, MIT and more. This meeting was special by the fact that it brought together people who usually do not meet each other in conferences. Still, they found a common interest and it seems as a starting point for a new community of researchers working on various aspects of high dimensional expanders ranging from group theory, representation theory, random walks, geometry, combinatorics, complexity theory and quantum error correcting codes. The conference made it clear that there is a common interest combining these subjects. The success of the course and the conference pushed Lubotzky to organize a year-long program on this topic at the Israeli Institute of Advanced Study in Jerusalem in the academic year 2017–2018. Many of the participants of the workshop will come also there.

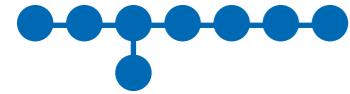
During this period Lubotzky wrote several papers, two of them with ETH people: one with two young postdocs Zur Luria, Junior Fellow at ETH-ITS, and Ron Rosenthal of the Department of mathematics at ETH, and one with Prof. Emmanuel Kowalski, also at the Department of mathematics. In addition, he completed other papers with researchers from France, U.K. and Israel, completing a very fruitful and intensive period of research.

During his PhD at University Paris-Sud, Orsay, under the direction of Yves Le Jan, Junior Fellow **Titus Lupu** studied the random walk loop soup model, in particular the clusters of random walk loops. He showed that on two-dimensional lattices these clusters scale to Conformal Loop Ensembles (CLE). To prove this, he introduced a new object, the cable Gaussian Free Field (cable GFF). A cable system is obtained by replacing the edges of a graph by continuous lines of length equal to the resistance of the edge. A cable GFF is obtained by interpolating the discrete GFF on the graph with independent Brownian bridges on each line-edge. Such an object still satisfies the Markov property as the initial discrete GFF. In his article «From loop clusters and random interlacement to the free field», published in *Annals of Probability*, he establishes a new coupling between some random walk loop soup and the cable GFF, which is essential for the proof of the scaling to CLE.

During the Fall semester 2015 he presented the results of his PhD at the seminar on stochastic processes at ETH, at the seminar of probability and statistics at the University Lyon 1 and at the French-Romanian Colloquium in Probability in Bucharest. At ETH Titus Lupu started to work with Wendelin Werner in continuation of his PhD subject. They observed that the coupling between the random walk loop soup and the cable GFF can be generalised to a coupling between the random current model and the Ising model. Previously relations were only known at the level of partition and correlation functions. This was published in «A note on Ising random currents, Ising-FK, loop-soups and the Gaussian free field» in *Electronic Communications in Probability*. They also started to look at a random metric given by the local time at zero of the cable GFF. Using this metric they

generalize Paul Lévy's theorem for Brownian local time to the cable GFF. They conjecture that this metric scales on two-dimensional lattices to a conformally invariant metric on the loops of a CLE(4) Conformal Loop Ensemble and which is also encoded by the two-dimensional continuum GFF. They believe that using this metric one can translate the results on the cable GFF into new results on the two-dimensional continuum GFF. Their results appeared this June in a preprint «The random pseudo-metric on a graph defined via the zero-set of the Gaussian free field on its metric graph», arXiv:1607.06424 [math.RT]. Titus Lupu also presented these results at the workshop «Recent developments in SLE» at Institut Mittag-Leffler in Stockholm. He started a collaboration with Avelio Sepulveda, PhD student at ETH under the direction of Wendelin Werner, and Juhan Aru, postdoc at ETH, which aims to prove the relations conjectured for the two-dimensional continuum GFF out of the study of cable GFF.

Another direction of Lupu's work was on the Vertex Reinforced Jump Process (VRJP) and the reversed VRJP, in collaboration with Christophe Sabot (University Lyon 1) and Pierre Tarres (CNRS, University Paris-Dauphine). The VRJP is a model of a reinforced random walk where the jump rate to a neighbouring vertex increases proportionally to the time already spent at this vertex. The reversed VRJP is a dual of the VRJP, where the jump rates decrease with the time spent. In fact, there is an alternative description of Lupu's coupling between a random walk loop soup and the cable GFF which involves the reversed VRJP. With Sabot and Tarres they also studied the scaling limits of the VRJP and reversed VRJP in dimension one.





**Junior Fellows Aline Ramires and Titus Lupu
at the ITS tea.**

In both cases in the limit one gets continuous self-interacting stochastic processes, which have the same Hölder continuity properties as the Brownian motion, but are not semi-martingales. Two papers are in preparation with Sabot and Tarres. In January 2016 Titus Lupu gave exercise classes for Wendelin Werner's short lecture Schramm-Loewner Evolution and Gaussian Free Field of the Swiss-MAP master class in planar statistical physics. During the spring 2016 he supervised the Master thesis of a student at ETH, Heidi Pang. The subject of the Master thesis is the Ciesielski-Taylor identity for Bessel processes.

In August 2016 he co-organises a special session on stochastic processes during the 13th French-Romanian Colloquium in Applied Mathematics, in Iasi, Romania.

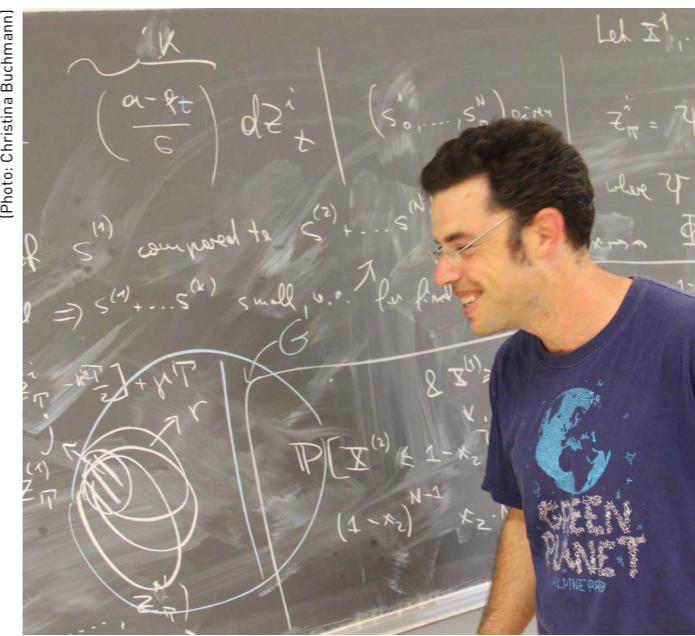
The main focus of Junior Fellow **Zur Luria**'s research this year involved the study of random hypergraphs, simplicial complexes and other «high-dimensional» combinatorial objects.

The most natural generalization of a regular graph to higher dimensions is the notion of designs. An (n, q, r, λ) -design is a collection X of q -element subsets of $\{1, \dots, n\}$ such that every r -element subset of $\{1, \dots, n\}$ is contained in exactly λ elements of X . Very little was known about these objects, until two papers of Peter Keevash established that for every choice of q, r, λ and for every large enough n , there exists an (n, q, r, λ) -design. Keevash was also able to obtain

asymptotic bounds on their number. This has precipitated a revolution in combinatorial design theory and in high dimensional combinatorics, because we can now construct many new combinatorial objects whose existence was not known before.

Zur Luria taught an advanced course presenting Keevash's proof at the ITS. It was aimed at researchers who wished to make use of these new techniques, and the focus was on the applicability of Keevash's methods to new problems. One example of such a problem, which was considered in the course, is the following. An order $N = n^2$ Sudoku square is an $N \times N$ block matrix, consisting of n^2 blocks of dimensions $n \times n$, such that every row, column and block contains the symbols $\{1, \dots, N\}$. Using Keevash's methods, it may be possible to give asymptotic bounds on the number of such objects.

Another area where Keevash's results have had interesting implications is the construction of pseudorandom combinatorial design. This was the topic of Zur's paper with Nati Linial, studying the discrepancy of high dimensional permutations (which are equivalent to Latin cubes and hypercubes). There it is shown that there exist order- n Latin squares with strong pseudorandom properties, and it is conjectured that in fact almost all such objects satisfy a strong version of the expander mixing lemma in high dimensions.



**Junior Fellow Zur Luria discusses
combinatorics at the blackboard.**

In a joint work with Alex Lubotzky and Ron Rosenthal, a beautiful algebraic construction of multicomplexes was studied. It was shown that every connected, regular, $(d+1)$ -partite multicomplex can be so constructed, and this seems to be a promising direction for the construction of high-dimensional expander complexes.

In a joint work with Ran Tessler, the following questions were addressed: What is the higher dimensional analogue of a Hamiltonian cycle? And what is the threshold for the appearance of such an object in a random hypergraph? A Hamiltonian cycle is a spanning set of edges that is topologically equivalent to a circle, and so it is natural to generalize this to higher dimensions as a collection of hyperedges which is topologically equivalent to a sphere.

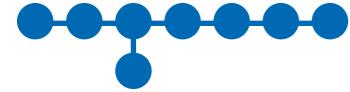
Aline Ramires is a Junior Fellow since September 2015. In her first year at ITS she broadened her research portfolio and started to explore problems related to unconventional superconductivity. In collaboration with Manfred Sigrist at the Institute for Theoretical Physics at ETH, she proposed a new framework to study the stability of a given superconducting state under different symmetry breaking fields, which is now submitted to *Physical Review B*.

The current understanding of the stability of superconducting states under external perturbations rests on symmetry arguments known as Anderson's theorems. Aline and

Manfred show that the generalisation of these arguments to multi-orbital systems cannot be done directly, and introduce a new quantity called superconducting fitness as a measure of the compatibility of a superconducting state under a given perturbation for arbitrarily complex multi-orbital materials. The application of this new scheme to the study of the material Sr_2RuO_4 led to the identification of a new depairing mechanism which goes beyond the standard symmetry arguments. This material is of special interest since it is a putative chiral superconductor which can host exotic quasiparticles called Majorana fermions.

Aline also participated in a number of conferences in the academic year 2015–2016, in Switzerland and abroad. These included the participation in the International Conference on Strongly Correlated Electron Systems, held in Hangzhou, China; and in the meeting Trends in Theory of Correlated Materials hosted at the Paul Scherrer Institute. She was also invited to participate in a workshop on superconductivity at the Aspen Center for Physics over the summer 2016.

During the first part of 2016 she had the opportunity to interact with the Senior Fellow Alexander Balatsky. From their discussions several interesting questions were raised related to odd-frequency superconductivity, which are going to be topic of future work.





«A year as a senior fellow at ITS is the best that can happen to a researcher aiming for an inspiring environment. Here one has the time to go profoundly into one's research problems as well as the possibility to communicate with outstanding colleagues.»

Walter Schachermayer, Senior Fellow 2015–2016

Walter Schachermayer, Professor in Mathematical Finance at University Vienna, spent the period from September 2015 to August 2016 as senior researcher at the ETH-ITS on leave of absence from University Vienna.

During his research visit he mainly focused on two lines of research.

1. Portfolio Optimization under transaction costs. There are empirically interesting models of financial markets which do allow for arbitrage. A prototypical example is fractional Brownian motion, notably advocated by B. Mandelbrot already some 50 years ago. The presence of arbitrage is in sharp contrast to the basic paradigm of mathematical finance that «there is no free lunch». However, these arbitrage opportunities disappear when one faces arbitrarily small proportional transaction costs, such as a Tobin tax. In order to reconcile these models with the main stream of mathematical finance, the problem of portfolio optimization under transaction costs and the related notion of a shadow price process plays a key role. Schachermayer has investigated this theme in a number of papers. He resumed this research in a Nachdiplomvorlesung during the fall semester 2015 at ETH. The lecture notes to this Vorlesung appeared in the series of «Zurich lectures in advanced mathematics», edited by the European Mathematical Society.

2. Martingale transport theory. A problem arising naturally in the mathematical finance is the determination of robust, i.e., model-independent bounds for the value of exotic options. This leads to a surprising connection to the theory of optimal transport. The new ingredient is the martingale property of the resulting price process which is imposed by the «principle of no arbitrage».

There were two conferences organised by Schachermayer on these topics: in September 2015 at ITS and in May 2016 in Oaxaca, Mexico.

Schachermayer had strong relations to the research groups of ETH related to mathematical finance, in particular to Paul Embrechts, Martin Larsson, Johannes Muhle-Karbe, Martin Schweizer, Mete Soner, Josef Teichmann and Mario Wüthrich.

Professor **Adi Shamir** from the Weizmann Institute of Science in Israel spent a 6-month sabbatical at ITS from February 2016 to July 2016. During his visit he worked on a wide variety of topics in cryptography and data security. One of these topics was the general question of how to efficiently find small probability peaks in an otherwise flat distribution. This is a classical search problem with many applications in cryptography and cryptanalysis, since many algorithms for breaking cryptosystems can be reduced to this form. The research led to the discovery of several surprisingly efficient algorithms which require essentially no memory and greatly reduced time complexity compared to the standard algorithms. In fact, the relationship between the probability of the peak and the time complexity of the search algorithm has a complex piecewise linear shape which bends at least four times at particular probability values. The resulting paper, «Memory Efficient Algorithms for Finding Needles in Haystacks» (co-authored with Itai Dinur, Orr Dunkelman, and Nathan Keller) was accepted to CRYPTO 2016, which is the field's most prestigious conference. Other papers published this year deal with side channel attacks such as acoustic key extraction attacks on PCs, and with cyber security topics such as extended functionality attacks on IoT devices.



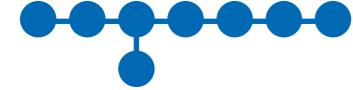
Junior Fellow Ran Tessler (at the blackboard) discusses with ETH postdoc Alexander Buryak.

In addition to his research, Prof. Shamir gave a large number of invited talks at various forums. In February he gave the special anniversary talk at the 20-th meeting of the Financial Cryptography conference, and participated in the cryptographers' panel at the 25-th meeting of the RSA conference (which this year had a record number of about 40'000 participants). In March he gave the keynote talk at the first meeting of the new IEEE symposium on Security and Privacy which was held in Saarbrücken. In April he gave the keynote speech about new connections between randomness hardness and security at the annual meeting of the Swiss Mathematical Society. In May he talked at the ITS Fellows' Seminar about his research findings related to the Bitcoin payment scheme, and later in the month he surveyed the state of the art in the security aspects of autonomous vehicles during a special meeting of the ETH Risk Center with its industrial and financial sponsors. In June he talked at the Nordita research center in Stockholm about alternative payment schemes, and then at the World Minds meeting in Zurich about the security and privacy aspects of Internet of Things (IoT) devices. Finally, in July he gave the special midnight talk at the Arcticrypt conference, which was held in Svalbard Island at a latitude of 80 degrees, near the north pole.

During his stay at the ITS he cooperated in numerous meetings with the cryptography group at ETH headed by Ueli Maurer, had discussions with ETH researchers studying the Bitcoin scheme, and actively participated in many meetings and discussions in both the Mathematics and the Computer Science Departments at ETH.

Ran Tessler is a Junior Fellow since September 2015. His research interests lay in the intersection of geometry, physics and probability. In a recent joint work with Amitai Zernik and Tomer Schlank the authors have found a closed expression for the probability measure that maximizes entropy under constraints, a result which improves the classical linear regression in many cases. Their main tool was Feynman calculus. Ran's main research is in open Gromov-Witten theory. Gromov-Witten theory is the theory of counting holomorphic curves inside manifolds. Open Gromov-Witten theory tries to extend such enumeration problems to the more complicated setting when the Riemann surfaces have boundaries. In a joint work with Alexander Buryak Ran has studied the connection between integrable hierarchies and open GW theories. In an ongoing project with A. Buryak and Emily Clader, another Junior Fellow, open r-spin theory has been constructed for discs and conjectured for higher genera. In another ongoing project with A. Buryak, Rahul Pandharipande and A. Zernik the open GW of the complex projective line has been constructed for discs.

Together with Zur Luria, who is also a Junior Fellow, Ran tries to generalize notions such as Hamiltonian cycles to high dimensional complexes, and to analyse their geometric and probabilistic properties. At the moment Ran's main interest is to understand conformal field theories.





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Outlook 2016/2017

Three Senior Fellows started their activities at the Institute in the summer of 2016:

1 Condensed matter physicist **Alexander Balatsky**, of Nordita (Stockholm) and the Los Alamos National Laboratory, came in July for the second part of his stay at the ETH-ITS that will last until March 2017. He got his PhD from the Landau Institute for Theoretical Physics and is director of the Institute for Material Science at LANL as well as professor of theoretical condensed matter physics at Nordita. His is Fellow of the American Physical Society and American Association for the Advancement of Science Fellow. He is an expert on many aspects of strongly correlated materials, including unconventional superconductivity and biomolecular electronics. One of his main current research interests is Dirac materials, on which he gave a minicourse and an ITS Science Colloquium last spring (photo: Christina Buchmann).

2 Mathematician **Vadim Kaloshin**, who holds the Brin Chair in Mathematics at the University of Maryland, will stay at the ETH-ITS for a year. He is a renowned specialist in dynamical systems and celestial mechanics, who obtained striking results in Hamiltonian mechanics, in particular on the n-body problem and on Arnold diffusion. In the autumn semester 2016, Kaloshin will give a course in the ETH Lectures in Mathematics series (photo: Christina Buchmann).

3 The Institute also welcomes **Eitan Tadmor**, Distinguished University Professor at the University of Maryland, who is a leading applied mathematician with interests in nonlinear partial differential equations, numerical analysis, scientific computing, with applications in fluid dynamics, image processing and more recently in the modelling of social phenomena. He obtained his PhD in 1979 from Tel Aviv University. He is Fellow of the American Mathematical Society and the recipient of the 2015 Peter Henrici prize. He will stay at the ETH-ITS for one year (photo: Eitan Tadmor).

These Senior Fellows join Riccardo Barbieri, who is staying at the ETH-ITS until the end of October and Alexander Balatsky, who will leave in March 2017.

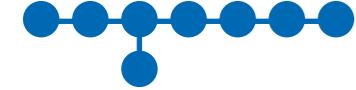
Senior Fellows who will join in 2017 are:

Jean-Michel Coron (Université Pierre et Marie Curie), **Gerhard Huisken** (Mathematisches Forschungsinstitut Oberwolfach), **Claire Voisin** (Collège de France), who will come at the beginning of 2017 and **Leonid Glazman** of Yale University, who will join in May 2017.

Two Junior Fellows are starting their stay at the ETH-ITS in September 2016:

4 **Shoham Letzter** received her PhD in October 2015 from the University of Cambridge under the supervision of Béla Bollobás, after which she spent another year in Cambridge as a Junior Research Fellow. Her main contribution is in Ramsey theory, where she proved several results regarding the existence of sparse monochromatic structures, such as paths, cycles and trees. In addition, together with collaborators, she has also worked in other fields including discrete isoperimetric inequalities, random graphs and extremal combinatorics (photo: V. Gruslys).

5 **Will Sawin** received his PhD in mathematics from Princeton University in May 2016 under the supervision of Nick Katz. His main area of expertise is étale cohomology, especially its use to bound explicit exponential sums for applications to analytic number theory. He also works in combinatorics, proving with collaborators new results on tricolored sum-free sets, sunflower-free sets, and expander graphs, and in other areas of algebraic and arithmetic geometry (photo: C.J. Mossuchi).



People at the ETH-ITS

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Giovanni Felder

Coordinator

Christina Buchmann

Advisory Committee

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Gerhard Huisken (Mathematisches Forschungsinstitut Oberwolfach), Elon Lindenstrauss (Hebrew University, Jerusalem),
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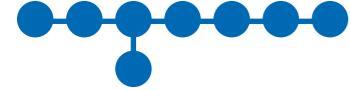
Martin Haefner, Walter Haefner Foundation
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Senior Fellows

Riccardo Barbieri, SNS Pisa	11.2015 – 10.2016
Robert Brandenberger, McGill University	08.2015 – 07.2016
Gilles Brassard, Université de Montréal	06.2014 – 12.2014
Dmitry Chelkak, St. Petersburg	09.2014 – 08.2015
Eugene Demler, Harvard University	05.2015 – 06.2015 and 09.2015 – 12.2015
Henryk Iwaniec, Rutgers University	08.2014 – 05.2015 and 06.2016 – 07.2016
Terry Hwa, UC San Diego	01.2014 – 09.2014 and 04.2015 – 08.2015
Alex Lubotzky, Hebrew University	02.2015 – 08.2015 and 02.2016 – 08.2016
Vadim Kaloshin, University of Maryland	09.2016 – 08.2017
Walter Schachermayer, University of Vienna	09.2015 – 08.2016
Adi Shamir, Weizmann Institute	02.2015 – 07.2015 and 02.2016 – 07.2016
Alexander Balatsky, Nordita and LANL	02.2015 – 05.2015 and 07.2016 – 03.2017
Eitan Tadmor, University of Maryland	08.2016 – 07.2017
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

Junior Fellows

Emily Clader	09.2014 – 07.2016
Zur Luria	09.2014 – 08.2017
Alessandro Carlotto	09.2015 – 08.2016
Maria Colombo (also at Zurich University)	09.2015 – 08.2019
Lavinia Heisenberg	09.2015 – 08.2018
Titus Lupu	09.2015 – 08.2018
Aline Ramires	09.2015 – 08.2018
Ran Tessler	09.2015 – 08.2018
Shoham Letzter	09.2016 – 08.2019
William Sawin	09.2016 – 08.2019



Contact

ETH Zurich
ETH Institute for Theoretical Studies
Clausiusstrasse 47
8092 Zurich

www.ethz.ch/eth-its

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