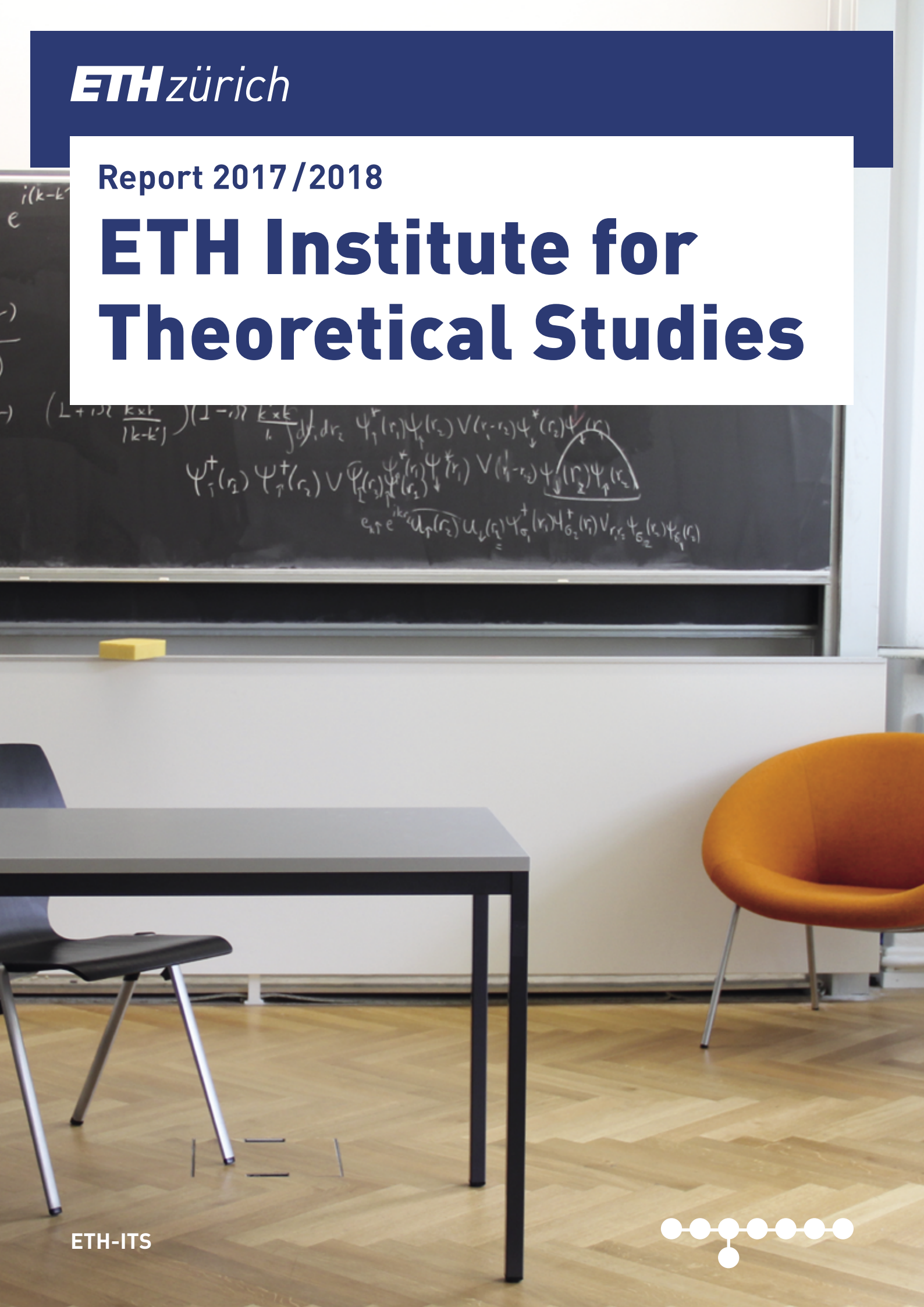
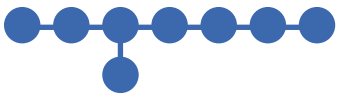
ETH zürich

Report 2017/2018

ETH Institute for Theoretical Studies



ETH-ITS



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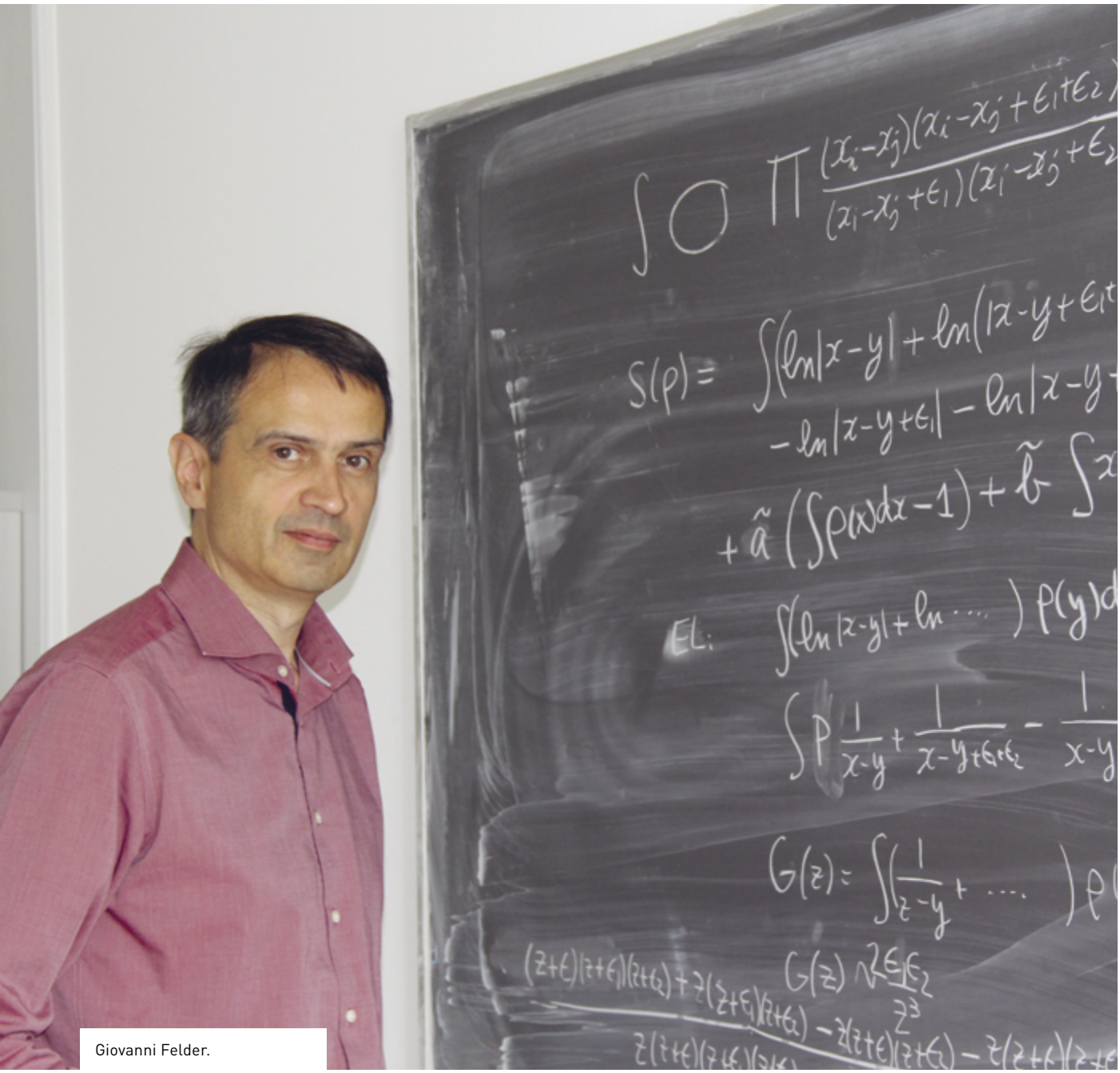


Giovanni Felder.

Foreword

I am glad to present the scientific report of the ETH Institute for Theoretical Studies for the academic year 2017–18, with the description of the activities of Junior and Senior Fellows and the various events that were organized. Last spring, for the first time, the ETH-ITS organized a thematic semester, with two workshops and several visitors. The theme was «New horizons for gravity,» and included hot topics in theoretical cosmology and observational astrophysics. The ITS Science Colloquia were also dedicated to this theme and the programme was a success, thanks to the dedication of Junior Fellows Lavinia Heisenberg and Johannes Noller who organized the activities together with former Senior Fellow Robert Brandenberger and Alexandre Refregier. You will also find several further research activities of high quality in other fields in this report, in particular by Junior Fellows, recognized by prestigious awards. The ETH-ITS aims at offering the best conditions for talented young researchers at the beginning of their career. I am glad that this strategy, made possible by the generous support of the donors, appears to be successful, with four Junior Fellows leaving the ETH-ITS this year to take up tenure track faculty positions and one to join CNRS on a permanent research position. Finally, I would like to mention that the Fields Medal awarded to Alessio Figalli concerns the ETH-ITS in at least two ways: Alessio is a member of the Advisory Committee, which now counts three Fields medalists; Junior Fellow Maria Colombo, a former student of Alessio, was a coauthor of several papers of his.

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 research institute dedicated to investigations in mathematics, theoretical computer science and theoretical natural sciences with a particular emphasis on questions spanning several research areas. The Institute 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. Its mission is to offer top theoretical scientists a stimulating work environment at ETH, fostering interactions with local researchers and establishing 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 who will spend up to three years at ITS working on research topics of their own choice with the support of a mentor, who is an ETH professor.

The Junior Fellows are selected by the director, with the assistance of the scientific Advisory Committee, through a nomination procedure: Candidates are selected from a group of promising young researchers which are nominated by faculty members and senior researchers of universities and research institutions. They are subsequently invited to apply at the ITS.

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 who will spend up to a year at the ITS on a sabbatical leave from their home institutions. They dedicate this time to research and participate in the activities of the ITS and of ETH Zurich, for example by giving a lecture course on research topics. They are invited by the Vice-President for Research and Corporate Relations of ETH Zurich upon recommendation of the Advisory Committee. Candidates are commonly suggested by members of the Advisory Committee or ETH faculty, but they may also apply directly.

www.eth-its.ethz.ch/fellows →

Collaborations
The ITS collaborates with the Departments of ETH and their visitor programmes, such as Forschungsinstitut für Mathematik (FIM) at the Department of mathematics and the Pauli Centre at the Department of physics. It also fosters relationships with other Swiss research institutions through its Fellows by promoting joint research projects as well as contributing to other scientific activities such as workshops and conferences.

The ITS seminar room prepared for a workshop about «New Horizons for Gravity».

Activities

Courses, workshops
In the academic year of 2017/18, the ETH-ITS co-sponsored a variety of activities such as a Congressi Stefano Franscini-conference at the Monte Verità conference center in Ascona on the subject of Hamiltonian Systems, which was organized by former ITS Senior Fellow Vadim Kaloshin from the University of Maryland in collaboration with the Swiss National Science Foundation. Participants were presented with various aspects of Hamiltonian Systems ranging from symplectic geometry, topology, the calculus of variations and partial differential equations as well as applications in celestial mechanics, mathematical billiards and dispersive PDEs. In the autumn semester of 2017, the ITS also hosted a seminar course on «Topology and interactions in solids», organized by Senior Fellow Leonid Glazman, which consisted of ten talks about topics in modern condensed matter physics presented by leaders in the field. Also in the autumn semester, ITS Senior Fellow Claire Voisin delivered a FIM Nachdiplomvorlesung on the subject of «Hyper-Kähler Manifolds» which explored the intricate connections between topology and algebraic geometry exhibited by this class of quaternionic Riemannian manifolds.

In the spring term of 2018, the public activities at ITS were largely dedicated to the thematic semester «New horizons for gravity: from theoretical cosmology to observational astrophysics» combining workshops and colloquium talks about exciting questions of modern-day cosmology (see below for a detailed description of the programme). Senior Fellow Sandu Popescu complemented the emphasis on cosmology with a series of lectures on the topic of «Quantum Paradoxes» which attracted a lot of interest from students and ETH faculty alike.

A big audience pondering the information-theoretic conundrum behind
black hole evaporation as explained by renowned physicist Robert Wald at the ITS Science Colloquium.

The ITS Science Colloquium

The ITS Science Colloquium has the objective of exposing students and researchers in mathematics, theoretical computer science and theoretical natural sciences to new questions and current interdisciplinary research topics. This year's emphasis was on recent advances in cosmology. The topics ranged from the challenges and breakthroughs in gravitational wave observations over effective theories of expansion and large-scale structure formation in the universe to conjectures about the thermodynamic degrees of freedom of spacetime. The theme of cosmology was complemented with a talk about the quantum mechanical foundations of thermodynamics and a presentation of current trends in blockchain technologies.

Leonid Glazman (r) in a lively discussion with Gianni Blatter.

Programme 2017/2018

12.10.2017	Michele Maggiore, University of Geneva	The first detections of gravitational waves
02.11.2017	Christian Cachin, IBM Research Zurich	Blockchain, cryptocurrencies and distributed ledgers – What is new under the sun?
23.11.2017	Sandu Popescu, ETH-ITS and University of Bristol	The smallest possible refrigerator and the foundations of thermodynamics
22.02.2018	Paul J. Steinhardt, Princeton University	Big Bang vs. Big Bounce
29.03.2018	Matthias Bartelmann, Universität Heidelberg	A new theory for old cosmic structures
26.04.2018	Robert Wald, University of Chicago	Black holes, thermodynamics and information loss
17.05.2018	Thanu Padmanabhan IUCAA, Pune, India	Gravity, the information content of spacetime and the cosmological constant

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

Seminar course: Topology and interactions in solids

Senior Fellow Leonid Glazman, together with Manfred Sigrist, of ETH Zurich, Titus Neupert, of the University of Zurich, and Ming Shi, of the Paul Scherrer Institute, organized a seminar course on topological phases in solids in the fall semester 2017. The course consisted of ten lectures, delivered by international specialists in this currently very active subject of condensed matter physics. The lectures introduced the audience to the subtle properties of topological phases, including the interplay between boundary and bulk phenomena and the appearence of Majorana, Dirac and Weyl fermions, and magnetic monopoles, with possible applications to quantum computation.

Programme 2017/2018

21.09.2017	Hae-Young Kee, University of Toronto	Theory of topological semimetals with applications to strongly SO-coupled materials
	Shinsei Ryu, University of Chicago	Bulk-boundary correspondence and topological invariants for topological phases with symmetries
12.10.2017	Felix von Oppen, Freie Universität Berlin	From Majorana bound states to topological quantum computation
02.11.2017	Julia Meyer, Université Grenoble-Alpe	Topological Josephson junctions
	Yong-Baek Kim, University of Toronto	Topological phases in quantum materials with strong spin-orbit coupling
23.11.2017	Nigel Cooper, University of Cambridge	Quantum oscillations in insulators
	Joerg Schmalian, Karlsruhe Institute of Technology	Out of bounds hydrodynamics in anisotropic Dirac systems
14.11.2017	Naoto Nagaosa, University of Tokyo	Physics of Weyl and Dirac fermions in solids
	Masatoshi Sato, Kyoto University	Topological crystalline materials

Fellows' seminar

The objective of the Fellows' seminar is to present the current research of the Fellows of ETH-ITS. It is open to everyone interested and, as a general rule, talks should be accessible to other Fellows that are typically from a different field.

Programme 2017/2018

03.10.2017	Johannes Noller	The universe's toolkit: What gravity is fundamentally made of
17.10.2017	Ulrike Rieß	On apples, irreducible symplectic varieties and Chow rings
24.10.2017	Aline Ramires	Large-*N*: From a theoretical tool to the laboratory
21.11.2017	Sandu Popescu	What is Quantum Nonlocality?
12.12.2017	Leonid Glazman	Quantum liquids in one dimension

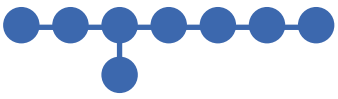
Thematic semester on «New horizons for gravity: From theoretical cosmology to observational astrophysics»

This year's spring semester featured the «New horizons for gravity: from theoretical cosmology to observational astrophysics» programme, running from February–May 2018. The semester was dedicated to several of the tenacious questions of modern cosmology, exploring new horizons in gravity and cosmology, from recently emerged theoretical frameworks and their connection to the underlying fundamental physics to the associated observational signatures. The intense program was bracketed by two workshops and in addition included four colloquia and a number of long-term visitors at the ITS. As such, several of the key pillars of present-day cosmology and astrophysics were presented and critically discussed throughout the workshop, with a key focus on identifying the route going forward and the most promising approaches to tackle several challenges in the field.

The first workshop was dedicated to «Effective field theory approaches to gravity» and took place at ITS during three days 05.–07.03.2018. The goal of this workshop was to provide a venue to compare various recently proposed ways of studying effective field theory approaches to gravity. The key speakers included world leading experts Cliff Burgess, Thibault Damour, John Donoghue, Jürg Fröhlich, Cesar Gomez, Karol Kampf, Subodh Patil, Sergey Sibiryakov, Enrico Trincherini and Christof Wetterich. The workshop covered topics on open effective field theories and gravity as a medium, high energy gravitational scattering and relativistic two-body systems, quantum gravity effects from non-local actions and predictions from the effective field theory of General Relativity, positivity bounds from UV completion on low energy effective field theories and scale symmetries in cosmology as well as the problems of dark matter and dark energy from an effective field theory perspective. The scientific talks were accompanied by long discussion sessions, where the participants could elaborate on remaining concerns. These interactions gave rise to many fruitful collaborations.

The second workshop of the semester, taking place on 28.–30.05.2018, was centred around «Gravitational waves in (modified) gravity». The goal was to extensively exploit the new observational channel of gravitational waves in order to test the validity of General Relativity and put new effects of modified gravity on trial. With the recent rapid developments in the field of gravitational waves, this workshop proved particularly topical and several leading researchers in the field attended, with key speakers including Luc Blanchet, Diego Blas, Philippe Jetzer, David Langlois, Lucas Lombriser, Michele Maggiore, Paolo Pani, Ira Rothstein, Ulrich Sperhake, Leo Stein, Shinji Tsujikawa and Helvi Witek. Over three days the workshop spanned a wide variety of topics such as post-Newtonian expansions to analytically understand the inspiral phase of coalescing black holes, numerical techniques probing the merger phase and how gravitational wave observations can be used to constrain the array of modified gravity theories considered in the literature. Additionally, this workshop also proved to be a key step in the ongoing endeavour to more tightly integrate the numerical relativity and theoretical cosmology communities. Finally, the talks were complemented by extended discussion sessions, which sparked a number of interesting debates and indeed new collaborations, rounding out a very fruitful workshop.

The workshops were complemented by four ITS Science Colloquia on complementary topics of the programme: Paul J. Steinhardt from the Princeton University gave a colloquium on «Big Bang vs. Big Bounce», incepting provocative thoughts into the minds of the attendees on whether it could be possible to replace the Big Bang, the definite beginning of the universe, by a bounce, where the universe undergoes a contracting phase followed by an expanding epoch. In his opinion, the bouncing cosmologies could naturally explain the large-scale properties of the observable universe. He still left echoes in the corridors of the ETH institutes and lively discussions continue to take place among the various astrophysics groups. Interested readers can find more information in arXiv:1803.01961.



Participants of the workshop «Effective field theory approaches to gravity» at the ITS building.

Matthias Bartelmann from the University of Heidelberg gave yet another provocative colloquium on «A new theory for old cosmic structures», where he proposed a new microscopic non-equilibrium field theory, namely kinetic field theory (KFT), for non-linear cosmic structure formation. He definitely amazed the attendees by his analytical non-perturbative non-linear power spectrum of cosmological density fluctuations, even those working on N-body simulations. His interesting talk initiated several new collaborations, where his KFT approach is now directly being applied to alternative theories of gravity. More information can be found in arXiv:1710.07522.

The third ITS Science Colloquium was given by world leading expert on gravity Robert Wald from the University of Chicago on «Black holes, thermodynamics, and information loss». After giving a pedagogical introduction into black hole physics and its relation to thermodynamics, he discussed the challenges arising from the entanglement of quantum fields inside and outside of a black hole and how this gives rise to one of the biggest burdens of modern theoretical physics: information loss. He presented arguments in favour of information loss and analysed some of the counter arguments and alternative possibilities. More details on this tenacious topic can be found in arXiv:1703.02140.

Thanu Padmanabhan from IUCAA Pune gave the fourth ITS Science Colloquium on «Gravity, the information content of space-time and the cosmological constant». In his talk, he aimed at relating classical gravity theory to the quantum micro-structure of space-time and in this way putting on equal footing the gravitational field equations with the equations of fluid mechanics and elasticity. One intriguing outcome was that the cosmological constant can then be directly related to the amount of cosmic information accessible to an eternal observer, hence providing a novel solution to the cosmological constant problem. His talk gave rise to fruitful discussions, some of them even in German and Malayalam. More information on this subject can be acquired from arXiv:1611.03505.

The programme also profited enormously from the expertise of scientific visitors during the semester in form of medium- and long-term visits. Other prominent research topics of the programme were scalar-tensor and vector-tensor theories, massive gravity, analytical non-linear structure formation, affine theories, Born-Infeld inspired cosmology, geometrical interpretations of General Relativity, cosmological parameter constraints and extended symmetries in alternative theories of gravity. These topics were of interest to ITS Junior Fellows currently working in this area as well as to many physicists in Zurich. The programme allowed world leading experts to visit the ITS for extended collaborative visits. Distinguished visitors were Matthias Bartelmann, Jose Beltran, Claudia de Rham, Tomi Koivisto, Scott Melville, Andrew Tolley and Shinji Tsujikawa.

Junior Fellow Lavinia Heisenberg moderating the ITS Science Colloquium.

Awards

ETH-ITS Junior Fellow Lavinia Heisenberg received the Gustav-Hertz-Prize 2018 which is awarded annually by the German Physical Society for outstanding recent work by young scientists. The press release mentions that she was recognized «for her ground-breaking contributions to the development of gravitational theories. With her works, in particular on Proca-type Lagrangian densities for vector fields and their cosmological relevance, she has opened new directions of research on gravity.» Heisenberg has also been awarded the SPS-Prize in General Physics of the Swiss Physical Society for «pioneering and essential contributions to alternative theories of gravity».

Former ITS Senior Fellow Gilles Brassard of the University of Montreal was awarded the 2018 Wolf Prize for Physics «for founding and advancing the fields of Quantum Cryptography and Quantum Teleportation». He shares the prize with Charles H. Bennett, of the IBM Research Center, Yorktown Heights. Professor Brassard will return to ETH-ITS in the spring of 2019 for a second stay.

Senior Fellow Leonid Glazman.

Fellows' report

Senior Fellows

Leonid Glazman spent the academic year 2017/2018 at ITS as a Senior Fellow. He holds a permanent position of the Donner Professor of Physics at Yale University. His research interests include quantum many-body physics of confined and low-dimensional systems, physics of cold atoms and superconductivity. During his stay at the Institute, he organized, jointly with Professors Manfred Sigrist (ETH), Titus Neupert (Zurich University), and Ming Shi (Paul Scherrer Institute), a semester-long seminar course entitled «Topology and interactions in solids». Run in the autumn and winter of 2017, the course presented 10 lectures on one of the most active research areas at the intersection of quantum theory of condensed matter and mathematics. The 90-minutes-long lectures were delivered by the leading researchers in the field, who were coming to ITS on this occasion from countries in Europe, UK, Canada, USA, and Japan. The lectures given at ITS were popular, standing-room-only events. At the invitation of the ITS Junior Fellows' seminar, Leonid Glazman gave an introductory lecture on the theory of non-linear Luttinger liquids in winter of 2017.

During his stay at ITS, Prof. Glazman jointly with Dr. Aris Alexandradinata completed a series of papers devoted to the topological effects in the magnetic oscillations in metals [Phys. Rev. Lett. v.119, 256601 (2017), Phys. Rev. X v. 8, 011027 (2018) and Rev. B v. 97, 144422 (2018)]. This work has led to a renewed collaboration of Prof. Glazman with the ETH experimental Nanophysics group of Prof. Ennslin. The stay at ITS also facilitated many insightful discussions with Prof. Imamoglu leading the Quantum Photonic group at ETH and became the starting point for a new collaboration between Prof. Glazman and the ETH Quantum Optics group of Prof. Esslinger. The goal of this developing collaboration is to elucidate the mechanisms of dissipation occurring in mesoscopic transport of a cold-atoms superfluid.

Sandu Popescu is Professor of Physics at the University of Bristol. He joined ITS as Senior Fellow on a year-long Sabbatical, October 2017–November 2018. He is a theoretical physicist, whose research centres on conceptual and fundamental problems in quantum mechanics. In his view, the fact that so often one discovers seemingly paradoxical new quantum effects is a signature that a deep and intuitive understanding is still missing. Prof. Popescu's main goal is to reach such an understanding. A major focus of his research has been quantum entanglement and non-locality. More recently he became interested in the foundations of statistical mechanics and thermodynamics.

Senior Fellow Sandu Popescu.

The change of environment offered by the fellowship at ITS altered his usual patterns of work and thought, which he describes as a very positive effect. He largely stopped working on his ongoing projects and started thinking in new directions. In particular, he is now interested in the nature of conservation laws in arbitrary non-deterministic theories. Quantum mechanics is our first theory of nature that is non-deterministic at a fundamental level, but is only one of a multitude of non-deterministic theories one could imagine. By comparing what is possible in general to what is specifically quantum, he hopes to get a better understanding of both. Another subject of his present interest is a novel form of non-locality. In addition, Prof. Popescu also completed work on the nature of time flow in non-deterministic theories. One of the most routine observations that we make about our world is that we cannot signal backwards in time. This understanding is so ubiquitous that it is often taken as one of the basic laws of nature. At first glance the remark seems straightforward. However, as Popescu and his co-authors have shown in probabilistic theories such as quantum mechanics, the consequences of such an assertion are far more involved. There is a surprising amount of liberty: some theories even allow the future to affect the past, nevertheless without signalling backward in time, and thus avoiding paradoxical consequences. Finally, he also completed work on quantum frames of reference and their impact on quantum thermodynamics.

During his time at ITS, Prof. Popescu gave an ITS Science Colloquium on «The smallest possible thermal machines and the foundations of thermodynamics», and a seminar on «Quantum non-locality». He also organised a series of lectures entitled «Quantum Paradoxes». The plan is for the series to ultimately consist of about sixteen lectures and it is aimed at advanced undergraduate and graduate students interested in quantum mechanics. ETH has a very strong activity in this area, including a world famous quantum information group, and the first part of the course attracted over 50 students (undergraduates, masters, PhDs, post-docs) as well as staff. The course focuses on topics that are outside the mainstream of present-day research and are generally very little known in the community, despite being, in Prof. Popescu's opinion, essential for understanding quantum mechanics. These include dynamical non-locality (a type of non-locality different from the well-known Bell-type non-locality which derives from entanglement), issues in measurement theory, pre- and post-selection and weak measurements, quantum frames of reference as well as various other effects.

Fellows meeting in the garden behind the ITS building.

Junior Fellows

During her third year at ITS, **Maria Colombo** focussed on some regularity problems for the Navier-Stokes equation. The main problem of the field, which is one of the Millennium problems, consists in showing that given some suitable initial conditions, there exists a smooth solution starting from the initial datum. Even though this problem is still open to this day, several results have been obtained in the last century. In his 1934 fundamental paper Leray proved the existence of weak solutions from any initial datum, satisfying moreover a global energy inequality. Later, Caffarelli, Kohn and Nirenberg described a particular class of Leray solutions, satisfying the so called «local energy inequality», and even though they could not prove that the singular points do not exist in accordance with the Millennium problem, they gave an estimate on the dimension of the (à priori non-excluded) singular set of these solutions.

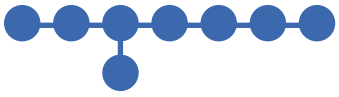
To better understand some supercriticality properties of the Navier-Stokes equation, a one-parameter family of equations has been introduced in the Sixties, where the parameter represents the strength of the dissipation term in the (modified) Navier-Stokes system. The equation is called hypodissipative when the dissipation strength is less than in the classical Navier-Stokes system (and in the limit of no dissipation yields the Euler equation), and hyperdissipative otherwise. If the dissipation is above a certain critical threshold, the equation was known to admit smooth solutions. In a recent paper, Tao showed that this can be slightly improved with a «logarithmically supercritical» operator. In a joint work with De Lellis and Massaccesi, Maria Colombo showed a space-time partial regularity result à la Caffarelli-Kohn-Nirenberg for suitable weak solutions of the hyperdissipative Navier-Stokes equations. As a consequence, the full regularity of solutions does hold not only at the critical threshold in the dissipation strength, but also for an interval of exponents in the supercritical regime, provided that the initial datum is chosen in a bounded set. On another side, very recent results show that the convex integration methods first introduced by De Lellis and Székelyhidi for the Euler equations can be used in presence of a viscous regularization term, as in Navier-Stokes-type systems. This was shown by Maria Colombo in collaboration with De Lellis and De Rosa for the hypodissipative Navier-Stokes system, when the dissipation is less than or equal to 1/5. The result was pushed forward in a breakthrough paper by Buckmaster and Vicol, where they constructed a large class of non-smooth distributional solutions of the classical Navier-Stokes equation, with prescribed kinetic energy.

Among several invited talks, Maria Colombo presented her results on the Navier-Stokes equations at the Courant Institute in New York and at Princeton University, starting a new collaboration on these topics with Buckmaster and Vicol. This broad project has recently involved a PhD and a master student at the University of Zurich, also with the supervision of Maria Colombo. She will continue her academic path by joining in August the mathematics department of EPFL in Lausanne, as a tenure track assistant professor.

In her third year at ITS, **Lavinia Heisenberg** has strengthened her collaborations with the observational astrophysics groups at ETH. After the successful development of a relativistic Boltzmann code implemented in Python with Professor Alexandre Refregier at ETH (with the corresponding results arXiv:1708.05177 being published in MNRAS), she is actively working on extensions of this Boltzmann code to incorporate generalisations of General Relativity with the aim to compare the most promising models to cosmological observations. Within the group of Professor Alexandre Refregier, she has been the main supervisor of the semester project of master student Benjamin Schrittmatter, with whom she has studied the odd-parity perturbations of «hairy» black-hole solutions within the class of vector-tensor theories of gravity. Currently, she is supervising the master student Simon Pekar, whose project deals with the study of different geometrical interpretations of gravity and their particularities. In the group of Professor Phillippe Jetzer at the University of Zurich, she was the main supervisor of Simone Bavera. Together, they studied the role of boundary terms in the computation of the Euclidean action for a black hole in different geometrical representations of gravity. Lavinia Heisenberg has also been the main organiser of the semester programme «New horizons for gravity: From theoretical cosmology to observational astrophysics», held at ITS from February–May 2018. An entire semester was dedicated to the tenacious questions of modern cosmology. The programme aimed at exploring new horizons in gravity and cosmology, from recently emerged theoretical frameworks and their connection to the underlying fundamental physics to the associated observational signatures. This has significantly strengthened the research on gravity and cosmology in Zurich.

Lavinia Heisenberg played a leading role in the construction of vector-tensor theories, the generalised Proca theories, with second order equations of motion. Such theories form a counterpart to alternative theories of gravity, based on an additional scalar field, that have been already documented in the literature for some time under the name Horndeski theories. Recently, she succeeded in unifying these two important classes of modified gravity theories in form of scalar-vector-tensor theories [arXiv:1801.01523], and the corresponding paper has been submitted to PRL. The result constitutes the most general class of scalar-vector-tensor theories with second order equations of motion based on a scalar and a vector field, for both the gauge-invariant and broken-gauge cases. Following this first paper, her research activities within this topic in the academic year 2018 already resulted in four publications together with her collaborators in Tokyo [arXiv:1802.07035, arXiv:1804.00535, arXiv:1805.01066, arXiv:1807.07202].

Along an independent research line, Lavinia Heisenberg played one of the leading roles in constructing the foundations of an alternative geometrical description of gravity based on non-metricity. Einstein's formulation of General Relativity is based on the assumption that gravity is attributed to the curvature of spacetime, a perception we have since grown accustomed to. However, his assumption masks the fact that differential geometry provides much richer classes of objects to represent the geometrical attributes of a given manifold. These are torsion and non-metricity, besides the well known curvature. Einstein's theory is based on vanishing torsion and non-metricity. An equivalent description of General Relativity however arises



The river Limmat as seen from the tower of Liebfrauenkirche next to the ITS building.

in flat spacetimes with a metric, but with an antisymmetric connection, where gravity is entirely assigned to torsion. A third and much simpler representation of General Relativity can be constructed on an equally flat spacetime, this time without torsion, where gravity is purely assigned to non-metricity. In this formulation, the connection completely vanishes by a suitable gauge choice. Hence, it has the advantage of depriving gravity from any inertial character and the resulting theory is purged from a notorious boundary term. These results have been summarised in two papers together with her collaborators Tomi Koivisto in Stockholm and Jose Beltran in Madrid [arXiv:1710.03116, arXiv:1803.10185].

Lavinia Heisenberg has been invited to write an exhaustive review article [arXiv:1807.01725] for Physics Reports on the systematic approach to generalisations of General Relativity, where she reviews the recent progress in constructing consistent field theories of gravity based on additional scalar, vector and tensor fields, and systematically constructs theories with Galileons, with Lagrange densities as constructed by Horndeski and beyond, extended to DHOST interactions, or containing generalized Proca fields and extensions thereof, or several Proca fields, as well as bigravity theories and scalar-vector-tensor theories. She also discusses the different interpretations of gravity both from a geometrical and a field-theory perspective. This review article will be very useful for providing an overview of current open problems and future research opportunities and will facilitate future work on modified gravity theories.

Lavinia Heisenberg has recently been awarded the Gustav-Hertz Prize of the German Physical Society «for her groundbreaking contributions to the development of gravitational theories». She has also been awarded the SPS-Prize in General Physics of the Swiss Physical Society for «pioneering and essential contributions to alternative theories of gravity». Furthermore, she has been awarded an ERC Starting Grant «Modified Gravity on Trial». During the academic year 2017–2018 she has given several plenary talks at conferences and workshops as an invited speaker, and has also been invited to institute seminars and colloquia.

A portrait article about her as a researcher was released at the Swiss magazine «Beobachter»:
www.beobachter.ch/umwelt/wissenschaft-man-liess-mich-spuren-dass-physik-nichts-fur-frauen-sei →
and at «100 Frauen in der Schweiz»:
100frauen.ch/astronautin/ →.

Shoham Letzter (middle row, 3rd from the left) presenting her research at Harvard University.

During her second year as ITS Junior Fellow, **Shoham Letzter** has focused on extremal graph theory, which is an area of graph theory that studies extremal (i.e. maximal or minimal) graphs with certain properties. A classical example is Dirac's theorem (1952), which can be thought of as an answer to the following question: how large does the minimum degree of a graph on n vertices have to be, in order for there to be a cycle that passes through each of the vertices (exactly once)? In a joint work with Vytautas Gruslys from the University of Cambridge, Shoham Letzter investigated possible generalisations of Dirac's theorem to graphs of smaller minimum degree. Of course, as Dirac's theorem tells us that $n/2$ is the lowest minimum degree for which the desired cycle exists, one needs to aim for a weaker condition. One possible way to do this is to allow for more cycles: Instead of looking for one cycle that covers each of the vertices, Letzter and Gruslys allowed for several cycles that together cover each of the vertices exactly once. In addition, to avoid trivial counter examples, they worked with regular graphs (where all the vertices have the same degree). They determined the least number of cycles, that can cover each of the vertices exactly once, among all d-regular graphs on n vertices, whenever d is linear in n. Their proof used existing techniques related to dense regular graphs, as well as new ideas that combined the Max-flow Min-cut and the probabilistic method.

Shoham has worked on other projects as well, including the continuation of last year's research into Ramsey theory, with Matija Bucić, a PhD student from ETH, and Sven Heberle, a Master student that she co-advised together with Prof. Benny Sudakov, who was also involved in this project. In addition, she worked on the Lagrangians of hypergraphs, with Vytautas Gruslys and Natasha Morrison, from the University of Cambridge. Part of the latter project, as well as the project described above, was done while Shoham Letzter was in Cambridge, where she spent several months this year.

Letzter presented her research on several occasions, including the local Mittagseminar, Combinatorics seminars in Tel Aviv University, Bar Ilan University and the University of Warwick, a workshop at Harvard University, and a conference in Denver, where she co-organised a mini-symposium with Alexey Pokrovskiy, an ETH postdoc. Moreover, in July she will attend a conference in Sao Paolo, as an invited speaker.

Johannes Noller arrived at the ITS in September 2017. His recent research has focused on establishing and advancing a comprehensive model-independent framework for exploring, testing and constraining theories of gravity – a so-called effective field theory (EFT) of (modified) gravity.

Johannes Noller welcoming the audience at the Science Colloquium.

This allows for instance to perform precision tests of general relativity. Indeed Johannes' first publication as a member of ITS was a derivation of the constraints on theories of gravity from the neutron star merger GW170817 with Baker-Bellini-Ferreira-Lagos-Sawicki. This merger was the first ever event simultaneously observed with gravitational waves (via the LIGO/VIRGO detectors) and with light (via multiple observations of the ensuing gamma ray burst and other optical counterparts) and, as a result, improved bounds on the speed of propagation for gravitational waves by several orders of magnitude. These novel bounds dramatically constrain possible departures from general relativity, ruling out several popular alternative theories in the process. The research received an Editor's suggestion award in PRL and also generated significant public interest, with Johannes giving follow-up interviews with the NZZ, Tages-Anzeiger and Inside Science among others.

With the same group of co-authors, Johannes Noller further developed the model-independent EFT approach for gravity, showing how stability constraints, required to have a well-behaved evolution in such models, further restrict them. Along another research direction, with Ferreira-Hill-Ross, Noller investigated how early universe models motivated by Weyl or scale symmetry may have seeded the formation of structure in the universe. This is a tantalising approach, potentially resolving old-standing hierarchy problems. With his collaborators, Johannes Noller showed that such models have several attractive features and yield predictions strongly compatible with present-day observational constraints. Within the last year, Johannes Noller has also initiated several new projects with members of ETH, especially in the cosmology group, and also a number of other projects, including collaborations with researchers at Imperial College London and at the University of Groningen.

Together with ITS Junior Fellow Lavinia Heisenberg, Johannes Noller organised the thematic semester «New horizons for gravity: From theoretical cosmology to observational astrophysics». This included two workshops and several colloquia. In bringing together leading researchers from around the world and indeed also from several departments within ETH, this proved to be a very fruitful semester, sparking several discussions and new collaborations. In the past year Johannes has also participated in several other meetings, conferences and workshops and gave a number of seminars, including plenary talks at the «Numerical Relativity beyond General Relativity» conference in Benasque and at the «Swiss Cosmology Days 2018» meeting in Geneva.

During her third year as ITS Junior Fellow, **Aline Ramires** engaged in a new direction: to tailor artificial gauge fields in condensed matter platforms. In collaboration with Jose Lado, a fellow at the Institute for Theoretical Physics at ETH, she identified a new type of artificial gauge field in twisted bilayer graphene systems. Twisted bilayer graphene consists of two graphene layers on top of each other with a relative twist angle. This system has recently attracted a lot of attention for its rich electronic properties and tunability, and for the the discovery of Mott insulating regime and superconductivity in what is called the «magic angle». Ramires was able to show analytically that, for very small twist angles, the application of a perpendicular electric field, or bias, is mathematically equivalent to a new kind of artificial gauge field. This identification opens the door for the generation and detection of pseudo-Landau levels in graphene platforms within robust setups which do not depend on strain engineering and therefore can be realistically harvested for technological applications. Furthermore, the numerical calculations of Lado confirm this scenario and find that this new artificial gauge field leads to the development of highly localized modes associated with bands close to charge neutrality which form an emergent Kagome lattice in real space. These findings indicate that for tiny angles, biased twisted bilayer graphene is a promising platform which can realise frustrated lattices of highly localised states, opening a new direction for the investigation of strongly correlated phases of matter in purely carbon-based systems.

Aline Ramires also continued to explore unconventional superconductivity. Her focus was to provide a framework to engineer materials in order to favour superconducting order parameters with different symmetries and topological properties. In collaboration with Manfred Sigrist from the Physics Department at ETH, and Daniel Agterberg, from the University of Wisconsin in the USA, she developed a non-perturbative framework in which it was possible to identify two superconducting fitness functions, making the previous results obtained by her and Sigrist much more robust and extending their range of applicability. The two superconducting fitness functions have different roles: the first gives a direct measure of the robustness of the weak coupling instability, while the second indicates the presence of detrimental terms in the Hamiltonian. The study of these functions for different materials with distinct symmetry constrains can ultimately allow us to propose new ways to engineer materials in order to enhance the critical temperature of superconductors, which is key for their use in technological applications.

For the 2018 spring semester, Ramires was a lecturer for the course entitled Strongly Correlated Electrons. Electronic correlations are at the core of rich quantum phases of matter like Mott insulators, quantum Hall effect, heavy fermions, superconductivity and magnetism, to name a few. Correlated materials display intriguing quantum phase transitions between competing phases of matter and have widespread applications. The aim of the course was to give Master students an introduction to the complex world of strongly correlated electrons, including the study of their phenomenology and of different methodologies used to study these materials. In this course, the students were introduced to classic topics in the field of correlated systems in condensed matter such as metal-insulator transitions, magnetism and quantum impurity problems. At the same time, they were exposed to state-of-the-art experimental results and theoretical techniques, which gave a modern twist to the course.

Aline Ramires also participated in several meetings in Switzerland and abroad in the academic year of 2017/18. She was invited for a talk at the TTCM 2017 (Trends in Theory of Correlated Materials) workshop in Tsukuba, Japan and contributed talks at the German Physical Society Meeting in Berlin and at the International Conference on

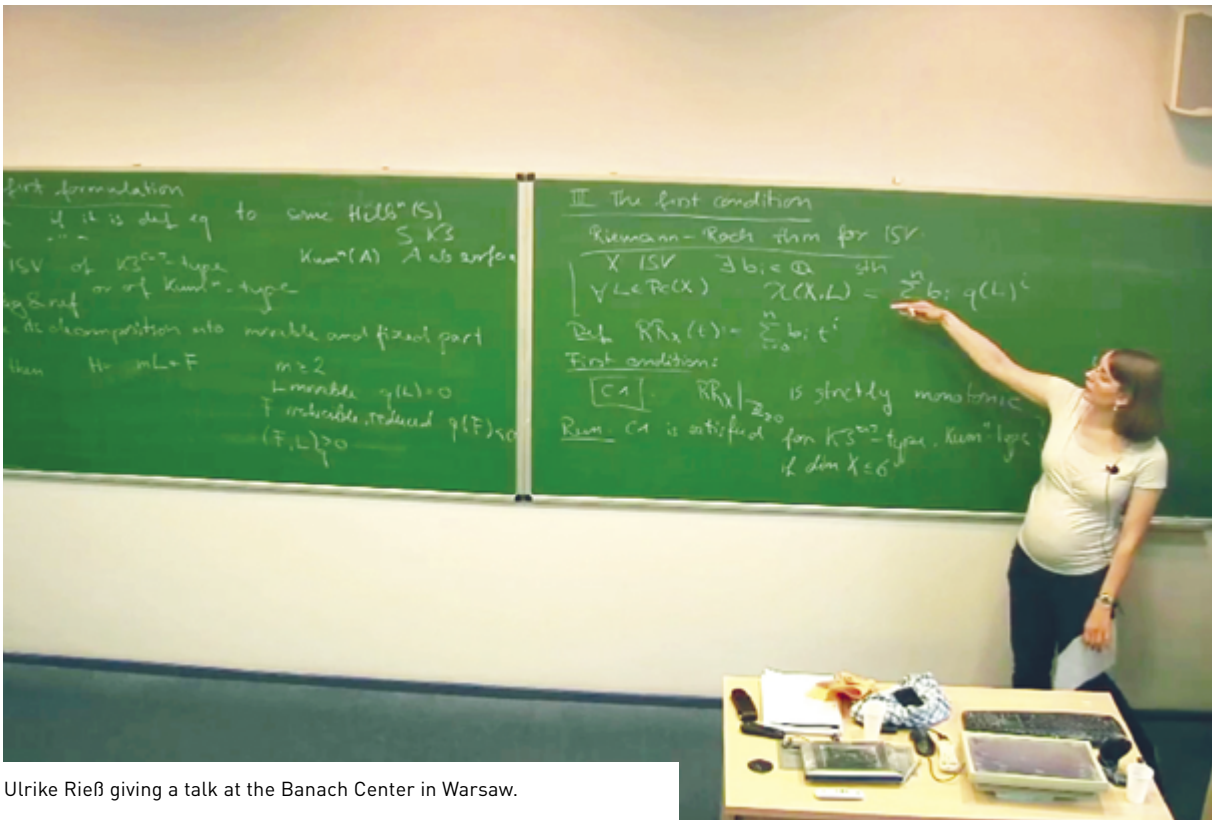
Aline Ramires at the ITS Science Colloquium.

Superconductivity and Magnetism held in Turkey. She was also invited for seminars in several locations such as the Max Planck Institute for Solid State Research in Germany, the Institute of Science and Technology in Austria, and at St. Andrews University, in Scotland. In summer 2018 she is going to participate in the Advanced School and Workshop on Correlations in Electron Systems: from Quantum Criticality to Topology, held at the ICTP in Trieste, Italy. She is also going to be a lecturer for the third edition of the IFT-Perimeter-SAIFR Journeys into Theoretical Physics, an international school organised jointly by the ICTP-SAIFR/IFT-UNESP in Sao Paulo, Brazil with the Perimeter Institute for Theoretical Physics in Waterloo, Canada and the CUNY/Princeton Center for the Physics of Biological Function in Princeton, USA.

In September 2018 she is going to start in a tenure track position at the ICTP-SAIFR (International Centre for Theoretical Physics – South American Institute for Fundamental Research) in Sao Paulo, Brazil. She will also hold a visiting position as a Distinguished Postdoctoral Fellow at the MPI-PKS (Max Planck Institute for the Physics of Complex Systems) in Dresden, Germany, for the year of 2019.

In 2017/18 **Ulrike Rieß** spent her first year as a Junior Fellow at the ITS. She is working in the field of complex algebraic geometry with a focus on irreducible symplectic varieties. This class of varieties occurs naturally in the classification of algebraic varieties and has been subject to vivid research since the 1980's.

As part of her PhD thesis, Rieß started analysing the base loci of ample line bundles on irreducible symplectic varieties. Her present work continues the research on this topic. The two-dimensional irreducible symplectic varieties are exactly K3 surfaces – a class of surfaces with a very rich geometry which has been studied in great detail. For K3 surfaces, the behaviour of base loci of ample line bundles is very special: The occurrence of base divisors for ample line bundles is very well-understood and higher dimensional base loci cannot occur. In her thesis, Ulrike Rieß could find some conditions that ample line bundles on irreducible symplectic varieties necessarily satisfy, if they have a divisorial base locus. Improving this, she could give necessary and sufficient conditions, and use this to describe precisely the behaviour of divisorial base components under deformations.



Ulrike Rieß giving a talk at the Banach Center in Warsaw.

Another interesting subject are base loci of higher codimension for ample line bundles on irreducible symplectic varieties. While this cannot appear for K3 surfaces, Rieß showed in her thesis, that it can in fact occur for higher dimensional irreducible symplectic varieties. Understanding base loci of higher codimension for ample line bundles on irreducible symplectic varieties is still work in progress.

Another project in progress was inspired by a communication with Kamenova and Verbitsky on a recent preprint, where Ulrike Rieß had found an error and helped solving it. In the current form of the article, the natural question occurs whether Lagrangian fibrations on irreducible symplectic varieties can admit multiple fibres. Rieß worked on this question, but it is still an ongoing project.

Irreducible symplectic varieties are also an important area of research of former ITS Senior Fellow Claire Voisin who has vastly influenced the development of the field for many years. During Prof. Voisin's stay at the ITS in 2017, Ulrike Rieß was in regular exchange with her. They discussed various topics around irreducible symplectic varieties, in particular the previously mentioned question of multiple fibres.

Last October, Ulrike Rieß went on maternity leave. Since she has been back to work, she continued her research projects and prepared for collaborations with other international researchers. She started a joint project with Grégoire Menet (Université de Bourgogne) who visited Zurich for a week in May. Together, they generalised some of the theory for irreducible symplectic varieties to singular irreducible symplectic orbifolds, thus extending previous work of Grégoire Menet. Further, Giovanni Mongardi, from Università di Bologna, will be visiting in July for a joint project.

Ulrike Rieß was invited to several international conferences. In particular, she gave a talk about her research at the Banach Center in Warsaw. She is an organiser for the Japanese-European Symposium on Symplectic Varieties and Moduli spaces. This meeting has an emphasis on irreducible symplectic varieties and the related field of moduli spaces. There are many people around the world studying these topics – in particular in Europe and in Japan. However, the exchange between these regions is still rather limited. With the annual meeting, which recurrently brings together young researchers from the different regions, exchange and cooperation is encouraged. The second edition of the symposium took place in Trento (Italy) last September and the third edition will take place end of August 2018 in Tokyo.

Will Sawin.

In the 2017–2018 academic year, **Will Sawin** and collaborators finished and posted arXiv preprints of eight papers from different research projects as explained in the following.

1 Will Sawin proved estimates for exponential sums that Dong Dong and Xiochun Li used to prove new, strong bounds for the size of a subset of a finite field which has no triples of elements satisfying certain translation-invariant polynomial equations, in a generalisation of Roth's theorems. **2** Will Sawin and Emmanuel Kowalski proved new consequences of their previous results on the «Kloosterman paths», graphs constructed from linearly interpolating partial Kloosterman sums. They characterised functions that lie in the support of the limiting distribution of these paths in the large prime limit.

3 Last year, Tim Browning asked Will Sawin whether estimates for the number of finite-field-valued points on the moduli space of rational curves on a smooth projective hypersurface, which Tim Browning had proved together with Pankaj Vishe using the classical circle method in analytic number theory, could be used to calculate the cohomology of this moduli space. This is the reverse direction of the Grothendieck-Lefschetz fixed-point formula, which allows calculating the number of finite-field-valued points of a variety from its cohomology, and can only be applied for certain special classes of varieties, such as smooth projective varieties and complements of hyperplane arrangements, none of which include the moduli space of rational curves. However, Browning and Sawin were able to transform the classical circle method into a geometric argument. Using it, they constructed a spectral sequence which calculates the cohomology of the moduli space of rational curves on a smooth affine hypersurface. It should be possible to handle a projective hypersurface with minor additional technical difficulties.

4 Will Sawin, Emmanuel Kowalski, and Philippe Michel generalized their previous work on bilinear forms in Kloosterman sums in two directions – to the generalized Kloosterman sums defined by Katz, and to sums over much shorter intervals. The minimum length of an interval required to obtain a nontrivial bound now reaches the limit of the method, initiated by Philippe Michel and Etienne Fouvry, which had previously only been reached for dramatically simpler exponential sums.

5 With Mark Shusterman and Michael Stoll, Will wrote a paper giving a simple explicit criterion for a polynomial in one variable over the integers to be irreducible, which applies when the leading few terms of the polynomial are fixed, the trailing few terms are fixed, and there is a long gap in between.

6 Valentin Blomer, Étienne Fouvry, Emmanuel Kowalski, Philippe Michel, Djordje Milićević and Will Sawin wrote a memoir combining results to give a complete description of the mollified second moment of the L-function of a modular form twisted by Dirichlet characters at the critical point. They gave a number of applications of this result, all based on arguments that had appeared in the literature as applications of moment estimates for other families of L-functions and one application that is new, giving a positive proportion of characters where the twisted L-function is non vanishing while an unrelated character sum involving that Dirichlet character is contained in a fixed interval.

7 Sawin wrote a paper on the distribution of L-functions of Galois representations twisted by Dirichlet characters over function fields, generalising a result of Katz. This result is a function field analogue of the second moment problem mentioned previously. However, the methods used are very different. The étale cohomology methods Katz pioneered can be used to study arbitrary statistics of L-functions, rather than the finitely many moments that are possible by the analytic method, but it is restricted to the function field setting and has a very weak error term. It may eventually be possible to combine the strengths of both methods in the function field setting, but currently a more promising direction is trying to obtain «large-q limit» results by the étale cohomology method in the greatest possible generality.

8 Will Sawin and Nicolas Templier proposed a new approach to the Ramanujan conjecture over function fields. Rather than using Shimura varieties, as was done in all cases of the Ramanujan conjecture known over number fields, or the analogous moduli spaces of Shtukas and Drinfeld modules, as were used in almost all cases known over function fields, they used the simpler (though higher-dimensional) geometry of moduli spaces of principal bundles. They proved the Ramunjan conjecture under three conditions: First, the splitness of the underlying group, for reasons of technical simplicity. Second, a geometric local condition at one place which is seemingly stronger than genericity (the Ramanujan conjecture is expected to hold only for generic representations).

Third, a condition on the existence of base change. It should be possible to remove the latter condition through standard techniques, perhaps with some mild additional local hypotheses – they will study this case next.

Will Sawin spoke about his research in Oberwolfach for a workshop on automorphic forms and arithmetic, at Harvard for a workshop on additive combinatorics, and at Bristol for a conference on the Riemann hypothesis. In addition he spoke at research seminars at the Institut Henri Poincaré, University Paris 13, EPFL, and the universities of Bristol, Zurich, Basel, Amsterdam, and Gothenburg.

Sawin received a Clay research fellowship and will be leaving ITS this year for a position as assistant professor at Columbia University.

Ran Tessler has been an ITS Junior Fellow since September 2015. His research interests lay in the intersection of geometry, physics and probability. His main research is in open Gromov-Witten (GW) theory. While Gromov-Witten theory is the theory of counting holomorphic curves inside manifolds, open GW theory tries to extend such enumeration problems to the more complicated setting when the Riemann surfaces have boundaries.

Soon, four rather long works that Tessler took part in are expected to be posted on arXiv:

1 «Open r–spin intersection theory and the Gelfand-Dikii wave function» (with Alexandr Buryak and former ITS Junior Fellow Emily Clader) defines an intersection theory on the moduli of r-spin disks, fully calculates it and gives strong evidence for what should be the high genus generalization.

2 «Open Fermat intersection theory and mirror symmetry, part I» (with Mark Gross and Tyler Kelly) makes the first step, building on the work with Buryak and Clader, towards an open FJRW intersection theory, and its mirror symmetry. During this year an important progress towards the general (concave) case has been made, but it is expected to appear in the second part.

3 «Stationary open CP 1 intersection theory and the open GW/H correspondence» (with Buryak, Amitai Netser-Zernik and Rahul Pandharipande). In this work the stationary open GW theory of the complex projective line is constructed, and the classical GW/Hurwitz correspondence of Okounkov-Pandharipande is being extended to the disk theory (and conjectured in the general case).

Ran Tessler.

4 «Graded spin surfaces and the open Arf invariant» (with Jake Solomon). In this work, the notion of graded spin structures is defined, and a nice invariant is constructed which generalizes the classical Arf invariant of usual spin structures.

In addition to writing these papers, Ran Tessler is involved in two works in progress whose aim is to define open GW invariants twisted by interesting classes, and to calculate them.

In October 2017, Buryak, Pandharipande and Tessler organised, with the support of FIM, a successful workshop on open Gromov Witten Theory and its relations to mirror symmetry and integrable hierarchies. During this academic year Tessler gave lectures on the above subjects in Paris, Israel and Moscow.

Tessler also works in probability and related areas of mathematical physics. Together with Noam Berger (HUJI), he published in «Electronic Journal of Probability» the paper «No percolation in low temperature spin glass,» which proves that in zero and low temperatures there is almost surely no percolation of frustrated edges in the Edwards-Anderson-Ising spin glass model. Together with Netser-Zernik and Tomer Schlank he published in «Journal of Statistical Physics» the paper «Exact maximum-entropy estimation with Feynman diagrams» which gives an explicit formula for the maximiser of entropy using Feynman diagrammatic tools.

Recently, in a joint work in progress with Oren Louidor, a very interesting and surprising generalisation of the classical Random Cluster model has been found, and was applied to natural statistical mechanics models.

During the spring semester, Ran Tessler taught a course on cluster algebras. In addition, he helps in advising Daniel Karyuki, a PhD student from Nairobi university.

In November 2018, Tessler will start a tenure track position at Weizmann Institute.

1

Outlook 2018/2019

1 Gilles Brassard will come to the ETH-ITS next spring for the second part of his Senior Fellowship. Professor Brassard is Canada Research Chair in Quantum Information Science as well as Computer Science Professor at the Université de Montréal. Educated as a theoretical computer scientist, his research combines information theory and cryptography with the foundations of quantum mechanics. A pioneer in Quantum Information Theory, he invented with Charles Bennett quantum teleportation and developed, also with Bennett, the first quantum cryptography protocol. His main current interests are the use of quantum mechanics to enhance our information-processing capabilities and, conversely, the use of a fresh information-theoretic perspective to shed new light on the foundations of quantum mechanics. He was at the ETH-ITS for his first stay in 2014, when he organised a memorable workshop on Foundations of Quantum Mechanics with Renato Renner, of ETH Zurich. *(Photo: Christina Buchmann)*

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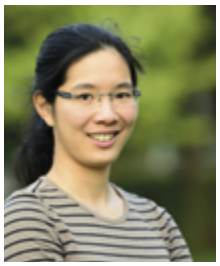

4

Three new Junior Fellows have begun their stay in September 2018:

2 Pierrick Bousseau received his PhD in mathematics from Imperial College London in August 2018 under the supervision of Richard Thomas. He is interested in parts of algebraic geometry having close interactions with theoretical physics. He proved a result connecting tropical and complex curve countings, with applications to a new construction of deformation quantizations in the context of mirror symmetry. *(Photo: Pierrick Bousseau)*

3 Nina Holden received her PhD in mathematics from MIT in June 2018 under the supervision of Scott Sheffield. She does research in probability theory. More specifically, her dissertation was about Schramm-Loewner evolutions, Liouville quantum gravity, and random planar maps. She has also done work on the trace reconstruction problem, allocations and matchings, the Schelling model, and graph limits. *(Photo: Nina Holden)*

4 Fanny Yang defended her PhD thesis in 2018 at the Department of Electrical Engineering and Computer Sciences of the University of California, Berkeley. She analyses algorithms for problems in the intersection between statistics and optimization. She is interested in applications to biomedical problems and machine learning. She also worked as an intern in the Deep Learning group at Amazon Web Services. *(Photo: Fanny Yang)*

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Gilles Brassard, Université de Montréal	06.2014 – 12.2014 and 04.2019 – 06.2019
Dmitry Chelkak, St. Petersburg	09.2014 – 08.2015
Eugene Demler, Harvard University	05.2015 – 06.2015 and 09.2015 – 12.2015
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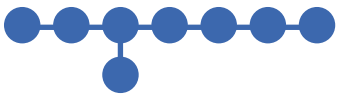
Adi Shamir, Weizmann Institute	02.2015 – 07.2015 and 02.2016 – 07.2016
Alexander Balatsky, Nordita and LANL	02.2015 – 05.2015 and 07.2016 – 03.2017
Eitan Tadmor, University of Maryland	08.2016 – 07.2017
Jean-Michel Coron, Université Pierre et Marie Curie	01.2017 – 12.2017
Claire Voisin, Collège de France	01.2017 – 12.2017
Gerhard Huisken, MFO	02.2017 – 09.2017
Leonid Glazman, Yale University	05.2017 – 12.2017 and 05.2018 – 08.2018
Sandu Popescu, University of Bristol	10.2017 – 09.2018

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
Ulrike Rieß	09.2017 – 08.2020
Johannes Noller	09.2017 – 08.2020
Pierrick Bousseau	09.2018 – 08.2021
Nina Holden	09.2018 – 08.2021
Fanny Yang	09.2018 – 08.2021



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