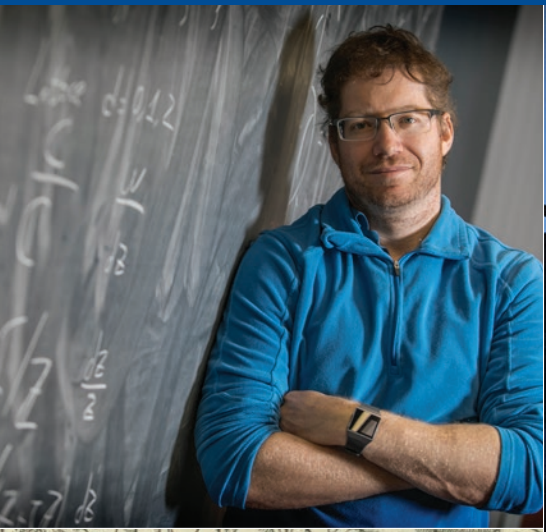
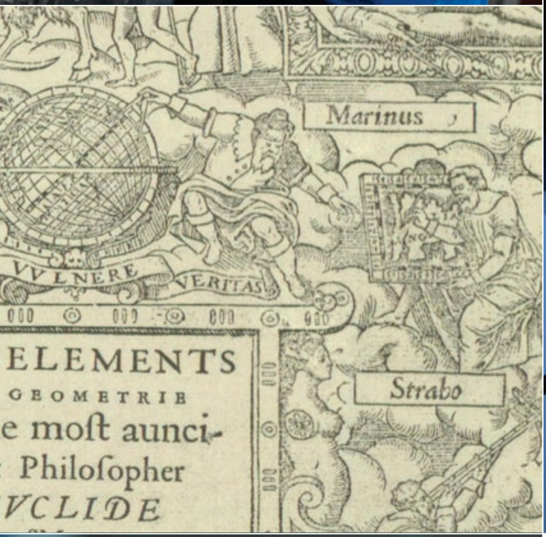
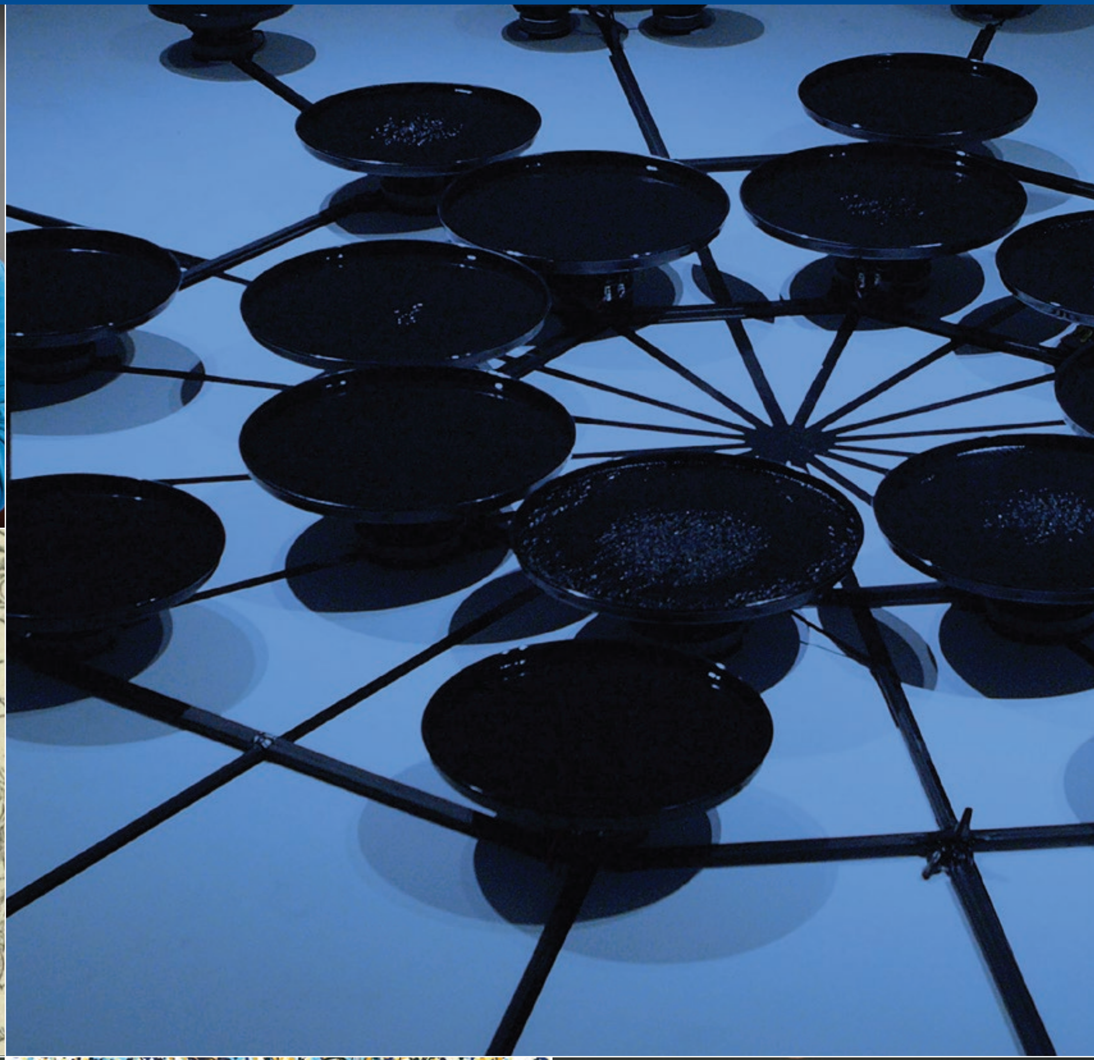
SIMONS CENTER FOR GEOMETRY AND PHYSICS

SCGP news

FALL 2017 | VOL. X







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Front cover, clockwise from top left:

- Zohar Komargodski. Photo: John Griffin

- *Eunoia II,* 2017, by Lisa Park, EEG brainwave sensor installation, dimensions variable, 2017. Image courtesy of the artist.

- Alexander Abanov. Photo: Natalia Ilina

- Young-Kee Kim. Photo: Courtesy Young-Kee Kim

- *Rhythm* Visualizations, 2017, by Lisa Park, heart monitor visualization. Image courtesy of the artist.

- Image: The frontispiece of Sir Henry Billingsley's first English version of Euclid's Elements, 1570, Public Domain.

Back cover:

–Blackboard at the SCGP
Photo: Michael N. Meyer

Stony Brook University

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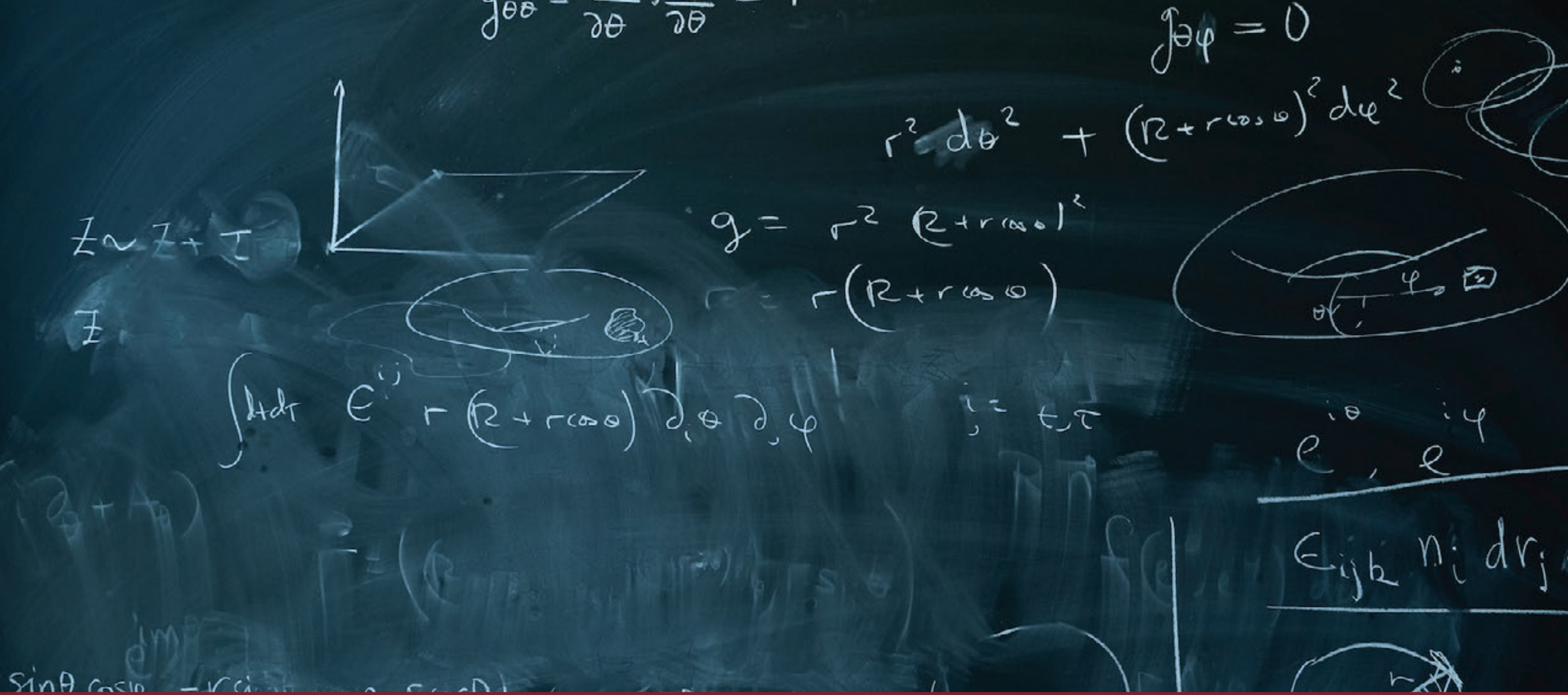
New Logos for the Simons Center

The new SCGP NEWS logo is set in requiem font. Requiem is an old-style serif typeface created by the designer Jonathan Hoefler in 1992. The typeface takes inspiration from a set of inscriptional capitals found in Ludovico Vicentino degli Arrighi's 1523 writing manual *Il Modo de Temperare le Penne* and its italics are based on the chancery calligraphy, or cancelleresca corsiva of the period. Departing from the Renaissance-inspired letter as seen on the cover, the Simons Center Café logo was created via contemporary 3D animation software (see page 32). Yet it still hearkens to time-honored tradition with a classic cursive typeface set inside the Möbius strip.

Logo design revision by Lorraine Walsh; Café logo by Irene Gaumé with Lorraine Walsh - see page 32



Fall 2017 Programs and Workshops

Photo: Michael N. Meyer

PROGRAMS

HYDRODYNAMICS, ERGODICITY, ENTANGLEMENT AND LOCALIZATION IN INTERACTING LATTICE MODELS AND FIELD THEORIES

September 11 - December 15, 2017

Organized by Alexander Abanov, Kristan Jensen and Vadim Oganesyan

This program brought together researchers interested in developing statistical formulations and tools of non-equilibrium many-body physics, broadly interpreted. Several topical efforts were represented, from operator spreading, and quantum chaos to transport, irreversibility, hydrodynamics and application of machine learning techniques to non-equilibrium phases of matter. The program also explored several less well-developed strands of work, from monopole dynamics in frustrated magnets, classical "odd" hydrodynamics, mathematical formulation of subsystem ETH, notions of ETH in conformal field theories, and frustration-free Hamiltonians. A cross-fertilization between condensed matter and high energy fields was attempted through stimulating discussions among visitors of both communities. The program also hosted two workshops, one titled *Wonders of Broken Integrability,* dedicated to the problem of integrability and its weak breaking, and another titled, *Progress in Quantum Collective Phenomena - from MBL to Black Holes*, focused primarily on problems that have recently received attention from diverse communities of workers, such as the relationship between quantum chaos and scrambling of information by black holes.

GEOMETRICAL AND STATISTICAL FLUID DYNAMICS

October 2 - 27, 2017

Organized by Uriel Frisch, Konstantin Khanin and Rahul Pandit

This program sought to explore the solution to some basic questions relating to the Euler and Navier-Stokes equations for the motion of a 3D incompressible fluid. There is a strong belief that answers to these questions cannot be obtained without creative use of geometric/Lagrangian and measure-theoretic/probabilistic tools. As a result of this program, two communities – mathematicians and physicists/numericists – were brought together to establish a common language that allows them to continue to work together on these questions. On the mathematical side, the emphasis was on geometrical and statistical/stochastic methods to tackle both continuous and discrete versions of hydrodynamics. On the physical and computational side, the novelty was, to a large extent, the realization that Lagrangian methods – where one follows fluid particles – give us much more geometric and dynamic insight than, so-called, Eulerian ones. Several lectures to this effect were delivered throughout the duration of the program; talks were given by K. Khanin (Toronto), N. Besse (Nice), U. Frisch (Nice), D. Sullivan (Stony Brook), R. Pandit (Bangalore), W. Smith (Stony Brook), and T. Matsumoto (Kyoto). There are plans to build on what has been achieved in this program and the associated workshop through support of an international team of experts, who can work jointly on the important and outstanding problems, at the interfaces between mathematics and physics.

Simons Center Workshop Participants
Photo: Eddy Orsi

WORKSHOPS

WONDERS OF BROKEN INTEGRABILITY

October 2 - 6, 2017

Organized by Fabian Essler, Giuseppe Mussardo and Alexei Tsvelik

The purpose of this workshop, organized in connection to the program *Hydrodynamics, Ergodicity, Entanglement and Localization in Interacting Lattice Models and Field Theories,* was to further explore the use of the detailed information on the spectrum and matrix elements of local operators available for quantum integrable models, and to investigate the properties of non-integrable perturbations. Techniques that have been employed to this end include the Truncated Conformal Space Approach and its improvements, form-factor perturbation theory, semiclassical approximations, and tensor network methods. The workshop brought together experts in the various techniques in order to discuss the recent theoretical and numerical developments and applications of the various methods to cold atom physics, quantum quenches, quasi one dimensional quantum magnets, relativistic QFT in 1+1 dimensions, and disordered systems. Participants explored many topics of the recent area across breaking integrability, chaos and out of equilibrium quantum physics; a particularly interesting topic was the development of quantum entanglement after a quantum quench, and how it spreads in the system, while another very interesting and timely topic was quantum chaos in many body quantum systems.

GEOMETRICAL AND STATISTICAL FLUID DYNAMICS

October 11 - 17, 2017

Organized by Uriel Frisch, Konstantin Khanin and Rahul Pandit

This workshop was associated with the *Geometrical and Statistical Fluid Dynamics* program, and served as a midway point of concentrated activity for the program participants as well as new conference participants. The goal was to address some of the most basic questions relating to the Euler and Navier-Stokes equations for the motion of a 3D incompressible fluid. The organizers sought to bring together two communities : mathematicians and physicists/numericists in order to establish a common language that allows them to work together on these questions. Talks were given by P. Constantin (Princeton) on *Remarks on High Reynolds Number Hydrodynamics*; J. Bec (Nice) on *Turbulent Mixing and Generalized Flows;* B. Khesin (Toronto) on *Geometry of Motion of Vortex Sheets;* and M. Czubak (Boulder) on *The Effects of Negative Curvature on the Navier Stokes Equations*, among many others. Long discussion sessions were organized at the end of each day allowing participants to discuss the details of important issues raised during the day's lectures. Topics of these discussions included weak and dissipative solutions, Turbulence, Stochastic solutions (including spontaneous stochasticity), and mathematics of Euler and high-Reynolds number flows.

GEOMETRY OF MANIFOLDS

October 23 - 27, 2017

Organized by Xiuxiong Chen, Blaine Lawson, Claude LeBrun and John Morgan

This workshop celebrated Simon Donaldson's diverse contributions to the geometry of manifolds by bringing together a broad group of leading differential geometers and geometric analysts. The speakers at the workshop were J. Morgan, S. Brendle, T. Colding, F. Marques, P. Kronheimer, A. Neves, J. Cheeger, D. McDuff, A. Chang, M. Haskins, G. Szekelyhidi, R. Friedman, B. Wang, X. Chen, R. Thomas, J. Ross, D. Salamon, J. Fine, and P. Gauduchon. Each and every talk discussed important developments in the field, and the scientific level of the conference was exceptionally high. Some of the talks provided a broad overview of certain technical issues of foundational importance, while others announced specific new constructions or classification results. Major new results were announced concerning Kahler geometry, geometric flows, minimal hypersurfaces, and Einstein metrics. This was one of the broadest, most compelling and most interesting conferences recently held concerning differential geometry and related areas. No conference volume is planned, but the conference seems to have stimulated the distinguished group of participants, and may lead to new mathematical collaborations. Simon Donaldson's contributions to the geometry of manifolds have been amazingly broad and influential. The broad participation of this group of leading differential geometers offered clear and compelling testimony that further demonstrated the importance of his influence.

PROGRESS IN QUANTUM COLLECTIVE PHENOMENA - FROM MBL TO BLACK HOLES

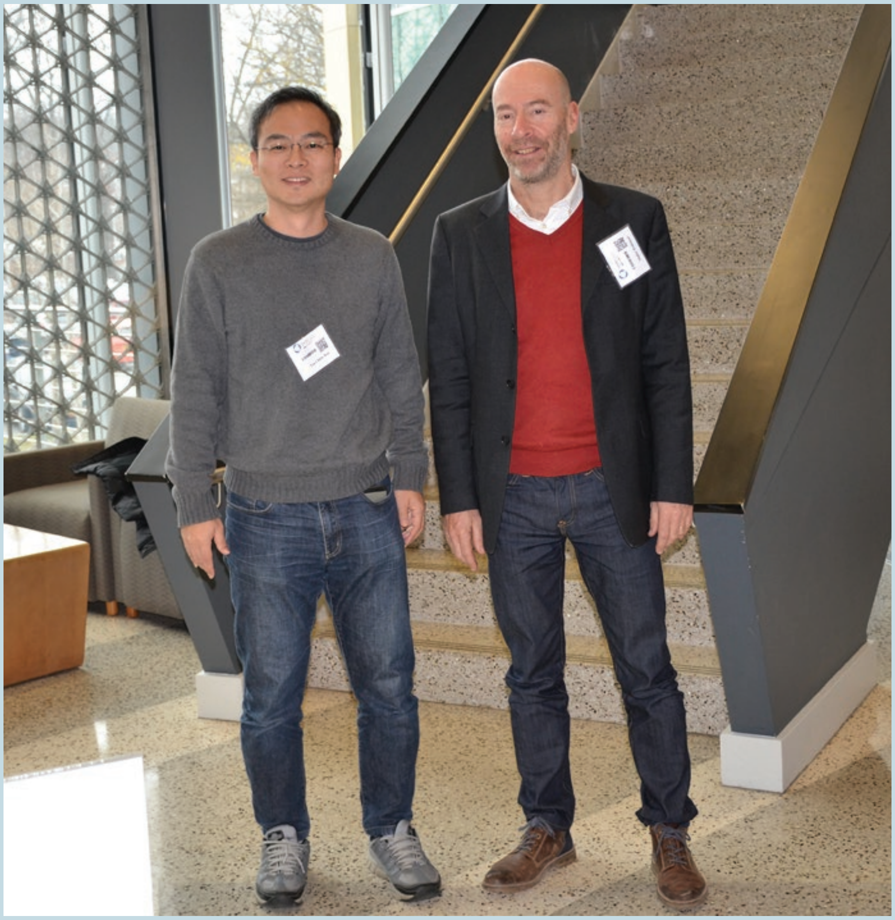
November 13 - 17, 2017

Organized by Alexander Abanov, Sriram Ganeshan, Kristan Jensen and Vadim Oganesyan

The primary objective of this workshop was to bring together leading researchers from high energy physics, condensed matter physics and mathematical

Participants of the workshop on *Tensor Network Methods: Structure, Applications and Holography*
Photo: Eddy Orsi

physics to address recent progress and fundamental challenges in quantum collective phenomena. This workshop succeeded in highlighting the fundamental common ground in quantum collective phenomena (in and out of equilibrium), and brought together researchers who all spoke the language of effective quantum field theories. The question of quantum thermalization and many body quantum chaos was addressed in the context of operator spreading, black hole physics, the Eigenstate Thermalization Hypothesis (ETH), and hydrodynamics. Several solvable models were discussed that straddled different communities such as circuit models in the context of operator spreading hydrodynamics, or the Sachdev-Ye-Kitaev model, which is a soluble strongly correlated model that shares many features with black hole physics in AdS. The workshop also facilitated the sharing of techniques among different communities to address these challenging problems. The colloquium talk during the workshop week was given by H. Verlinde (Princeton). His talk titled *Black Hole Horizons and Many Body Quantum Chaos* perfectly captured the essence of the conference. He discussed the SYK model, scrambling of quantum information in black holes, many-body quantum chaos, and the relations between them.



Tzu-Chieh Wei and Didier Poilblanc
Photo: Eddy Orsi

TENSOR NETWORK METHODS: STRUCTURE, APPLICATIONS AND HOLOGRAPHY

December 11 - 15, 2017

Organized by Glen Evenbly, Roman Orus, David Perez-Garcia and Tzu-Chieh Wei

This interdisciplinary workshop covered research topics from the formal structure of tensor network and condensed matter physics, to AdS/CFT and even machine learning. It began with three days of pre-workshop tutorials followed by five days of conference talks. Some notable talks covered the following subjects: *Tensor Networks for Classifying Topological Phases of Matter, Advances in Simulating 2D Strongly Correlated Systems with PEPS, Chiral Topological Spin Liquids with PEPS, Causal Structure of Emergent Geometries (Wormhole and Tensor Network), Random Tensor Networks and Holography, Machine Learning Relevant Features of Data Using Multi Scale Tensor Networks, Minimally Entangled Purifications: Algorithms, Spins Chains and Holography,* and *Holography and Criticality in Matchgate Tensor Networks.* The pre-workshop pedagogical lectures gave many cross-disciplinary participants a practical introduction to tensor networks while the applied hands-on sessions fostered a useful learning experience. The workshop was well represented and attracted experts and young researchers working on condensed matter physics, quantum information, and high energy (such AdS/CFT & holography), using the emerging framework of tensor networks. The recorded tutorials and workshop talks have become a useful resource for researchers interested in tensor networks and how they are applied in various fields. This workshop provided a unique opportunity for researchers of different fields to interact and collaborate and the variety of talks reflected this interdisciplinary nature. ♦

Simons Summer Workshop

Strings and QFT Without SUSY

July 17 - August 11, 2017

By Maria Shtilmark

David Morrison, Simon Donaldson and Michael Douglas at the Simons Summer Workshop banquet at Avalon Park and Preserve

Photo: Martin Rocek

July 2017 marked the fifteenth anniversary of the Summer Workshop in Mathematics and Physics, known as the Simons Summer Workshop. The legendary event brings the world's best scientists to Stony Brook for four weeks of learning, collaboration and cutting edge research. It is well known among the members of the international scientific community and is a unique and celebrated annual feature of the Simons Center's life.

The Summer Workshop began in the C.N.Yang Institute for Theoretical Physics in Stony Brook in 2003 and has been hosted by the Simons Center for Geometry and Physics since 2008. The Simons Center's mission to develop interaction between geometry, in the broadest sense, and theoretical physics is rooted in a long tradition of engagement between mathematics and physics at Stony Brook, and ultimately in the centuries-long history of these two fields. The Stony Brook tradition is exemplified by the joint ITP-Math seminars initiated by Jim Simons and Frank Yang in the 1970s; these stimulated interest worldwide in the mathematics of gauge theories. In many ways similar to the institutes like IAS, IHES, Perimeter and MSRI, the Simons Center enjoys uniquely close links to Stony Brook University

Departments of Mathematics and Physics, and, of course, the YITP.

Invariably organized by Martin Rocek and Cumrun Vafa, the Summer Workshop runs for four weeks during July and August, bringing over a hundred participants to the Simons Center. Not everybody comes for the entire duration, but at any one time there are 50-60 visiting, as well as 10-20 local workshop participants. (The workshop has doubled in size since its beginning.)

As explained by SCGP Deputy Director Alexander Abanov, "this unique event is like a month-long workshop (or four conferences put together) and it is extremely successful. The general direction of the workshop is string theory, and lots of people attend this extremely popular, intense and in many ways unique event."

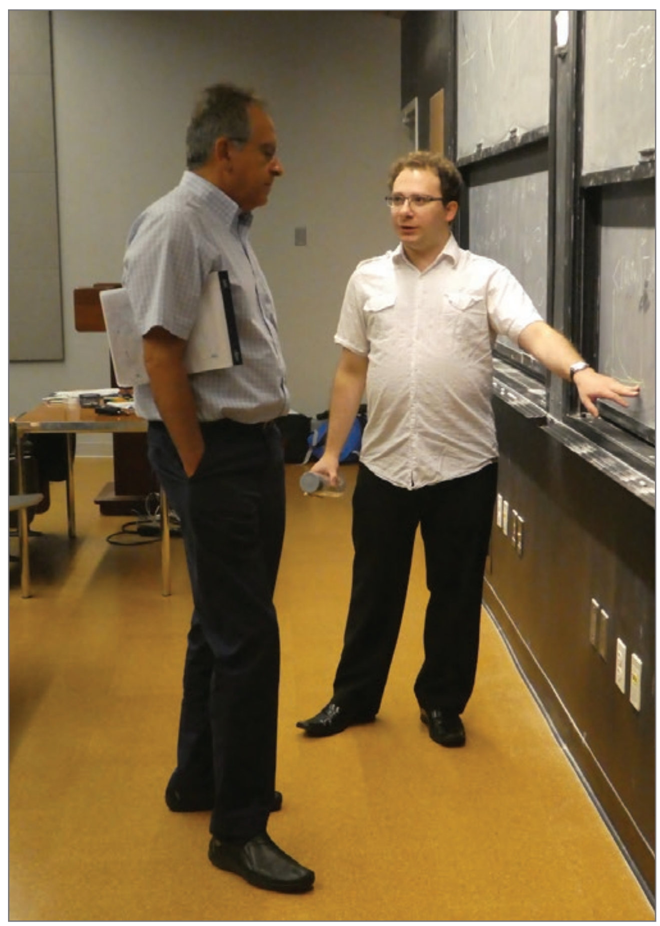
During the first Summer Workshop there was a significant mathematical component, with mathematicians like Andrei Okounkov (Columbia) and Nicolai Reshetikhin (University of California, Berkeley) participating actively. "In fact, Okounkov's work here resulted in a joint paper with Cumrun Vafa and other participants, which was implicitly recognized in his 2006 Fields Medal citation," says Martin Rocek.

String theory continues to be the area that captures the imagination of much of the theoretical community (and increasingly of mathematicians). The workshops welcome people interested in mathematical aspects of string theory, or mathematicians who work with physicists, like David Morrison (UCSB), who has been participating almost every year. Other mathematicians who have participated in multiple workshops include Dan Freed (University of Texas, Austin), Sheldon Katz (University of Illinois, Urbana-Champaign), and, of course, Jim Simons (Stony Brook University). Local mathematicians have also participated. "The workshops' topics have always developed depending on where the most exciting results have been," Martin Rocek says.

Among the past workshops themes (many on more than one occasion) have been Yang-Mills and other gauge theories, topological strings, string cosmology, dark matter, black holes, the swampland program (which was developed at the 2006 workshop to point out the implications of string theory for quantum field theories, and will be revisited during Summer'18), supersymmetry breaking in string theory and string phenomenology, integrable systems and gauge theories, knot invariants and categorification, superconformal theories and the bootstrap program, and theories in spaces with boundaries or defects. Many of these themes spawned programs and more specialized intense SCGP workshops.

Martin Rocek says, "a big advantage of the workshop is that it's not too big and the individual workshops vary. They can be less focused on a specific subject, with some talks more central to it and others being just general interest talks, or pertain to the theme rather directly; there is variation from year to year that way. And both things are very good. The workshop is very responsive to what's going on."

The July 17 - August 11, 2017 Summer Workshop was an anniversary – the tenth one conducted by the Simons Center for Geometry and Physics at Stony Brook and the fifteenth in the series. Titled *Strings with QFT without SUSY*, it focused on strings and QFT without supersymmetry, including non-supersymmetric vacuum constructions in string



Cumrun Vafa and Daniel Jafferis

Photo: Martin Rocek

Leonardo Rastelli lectures at Smith Point Beach, Fire Island

Photo: Martin Rocek

theory, dualities in nonsupersymmetric theories in 3 and other dimensions, issues in connection with deSitter space and its stability, as well as bootstrap techniques, which also apply to nonsupersymmetric contexts.

This past summer, over 130 participants from 50 different institutions came to the Simons Center. The list of speakers included Hirosi Ooguri (Caltech), Eva Silverstein (Stanford), David Lowe (Brown), Domenico Orlando (University of Bern), Sergeu Dubovsky (NYU), Dalimil Mazac (Perimeter), Sergei Gukov (Caltech), Silviu Pufu (Princeton), Adi Armoni (Swansea), Simeon Hellerman (Kavli IPMU), Keith Dienes (Univeristy of Arizona and University of Maryland), Jaume Gomis (Perimeter), Leonardo Rastelli (YITP), Igor Klebanov (Princeton), Shlomo Razamat (Technion), Juan Maldacena (IAS), Clay Cordova (IAS), Davide Gaiotto (Perimeter), Anton Kapustin (Caltech), Daniel Jafferis (Harvard) and Zohar Komargodski of the Simons Center for Geometry and Physics. More on talks given during 2017 workshop can be found in the summary by Yakov Landau (www.scgp.stonybrook.edu/archives/25630).

With the start of the Summer Workshop, halls and blackboard areas of the Simons Center are filled with lively sounds of many languages and accents, as string theory is a very global pursuit. As put by Cumrun Vafa, “we are all from somewhere, we appreciate the diversity of cultures by nature. String theory is a context in which this global aspect comes in a very handy way. It shows that people can do peaceful and exciting things without conflict. Language and culture is not the barrier, all that melts away when you work on subjects like physics or math. A culture can bring a completely different kind of emphasis, and in collaboration this is what you need.”

“For me," Vafa continues, "the goal was to create the environment where people can do good research and learn at the same time. The workshop is both teaching and research, and not just for students, but for faculty and even experts. I learn quite a bit during workshops, and I hope that’s the case for everybody.”

What also matters to the organizers is that it is not just a traditional classroom lecture setup. They aim at the environment that motivates people to do their own research, and they create this environment by limiting the number of lectures to only one a day. Workshop participants are then encouraged to leave their offices and get together, over lunches or Simons Center teas, or by the blackboards, and interact and mingle. “Having top-notch people, experts on the subject giving lectures allows for plenty of first-rate material that they hear, and sometimes the first-rate people aren’t even asked to talk. They are just here, and people can approach them, knock on their door and ask questions. This allows for a very dynamic environment, when participants are able to do good work without experiencing pressure from too many workshops,” Vafa says.

That atmosphere is what drives us forward

Throughout the workshop, every week one talk is held on the beach on Fire Island, which has proved to be one of the most successful ideas of the organizers. Cumrun Vafa remembers, “there always was this dichotomy being on Long Island in this beautiful beach area, but not taking advantage of it. Inviting people to listen to lectures in dark lecture rooms with a lot of blackboards, we felt that at the back of their minds people were thinking of the nice beaches over here. Having talks on the beach is all about trying to stimulate thinking, and it is completely opposite to what one might think. You would think that at a beach lecture one can’t concentrate, but it’s the opposite. It’s the maximum concentration of the subject, and for some reason, which actually I did not anticipate at least, we didn’t think it would be necessarily be more focused, we saw it as just a diversion, but as it turned out change of scenery and fresh air can do magic.”

Beach talks are a highlight of the week in a sense that they are more centrally related to the topic of the workshop. “We usually have a kind of general topic, a theme, and it is reflected in the beach lecture," Rocek says. "And of course we aim at good and clear lectures, specifically trying to make sure things are broad enough for the wider audience to follow. There are just two small white boards at beach talks, so we don’t want too heavy equations. We aim at something that can be easily conveyed."

Another lovely tradition of the Simons Summer Workshop is Tuesday Summer Concert Series, that for many years has been attracting members of the Stony Brook community. Furthermore, there are Thursday social events, of which the first is traditionally held at Martin Rocek’s home, which itself becomes an informal musical soiree. During the second week of the workshop all participants and many members of Stony Brook community are entertained at a fantastic gathering held in the Avalon Park, hosted by the Simons Foundation. The third week is celebrated at the banquet at Victoria and Michael Bershadsky’s residence, rendering the unique atmosphere of warm and welcoming Long Island homes. The closing week’s party is traditionally hosted by the Director of the Simons Center, allowing for informal interactions between members of the Stony Brook community and their families and all the workshop guests.

As Cumrun Vafa says, “with every year the workshop becomes even smoother and more effortless. It is by now well-recognized in our field that at the workshop there is an atmosphere of discussions, collaborations, and top-notch people, as well as eager students and researchers, all gathered in one place. So, not a specific topic, but that atmosphere is what drives us forward, and the Center does an amazing job in making this a friendly environment. Every time I get feedback from the participants, they are always amazed how smoothly things run.” ♦

The 2018 Summer Workshop will be dedicated to the *Recent Developments in the Swampland*. One of the predictions of string theory is that certain apparently consistent quantum field theories cannot be consistently (uniformly) coupled to quantum gravity – they do not arise from consistent string vacua. This gave rise to the notion of the “Swampland.” Recent developments, in particular the weak gravity conjecture, have led to many new and much stronger restrictions which involve physicists working in many fields and give new insights into the structure of string vacua.

It Was a Lucky Choice

Conversation with Zohar Komargodski
Permanent Member, Simons Center for Geometry and Physics

Interview by Luis Álvarez-Gaumé and Maria Shtilmark

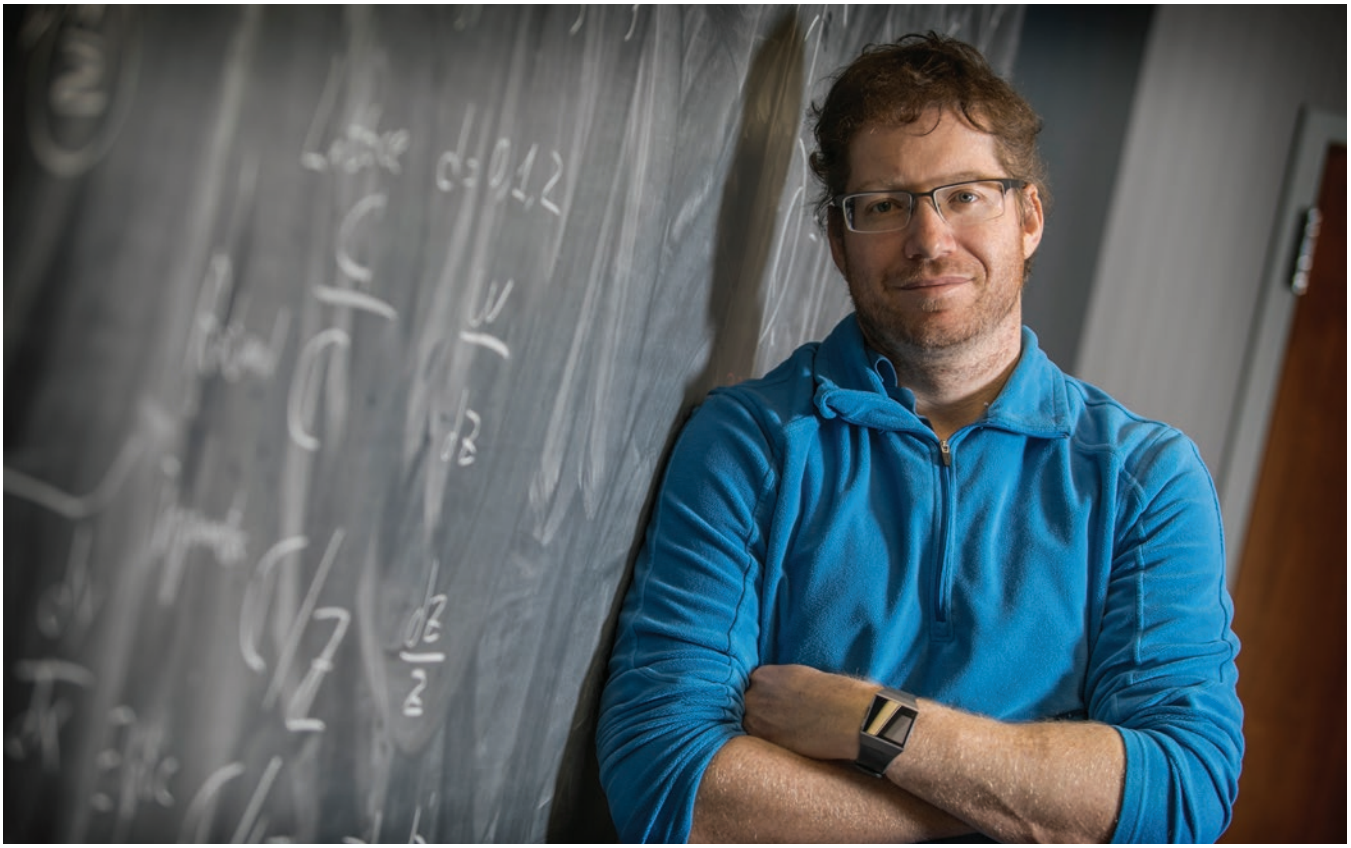


Photo: John Griffin

According to your interview from 2012, your interest in science was awoken by Stephen Hawking's "Brief History of Time" – is that answer still true?

Let's leave it at that, otherwise there will be inconsistencies on the internet.

We can't let that happen. Did your parents contribute to that interest?

My parents taught me extracurricular things, and my father was teaching me mathematics until I was 11 or 12, when he still knew more than me. I was very interested in math, so he taught me stuff beyond elementary school. In school they would study the multiplication table, and at home I would do something more advanced. No physics, just math. My parents were very supportive when I went to university to study science, even though it wasn't the most obvious choice, with unclear future employment opportunities. They contributed a lot, and were happy that I chose a path I like. They would have been happier and less anxious about the future if I had gone into something else, but I never had any real pressure to switch to another area.

Was Tel Aviv University your alma mater?

Yes. When I was still in high school I did a big chunk of my undergraduate studies in the so-called "Open University." I couldn't really attend classes while still in school, and the Open University just sends books so you can study at home and take exams. That way I didn't have to attend university or any meetings, which was much more convenient. And then when I completed about 60% of the undergraduate work there, I finished high school and joined Tel Aviv University. They accepted all the course work I had done, so I didn't have to repeat it and could just start where I had left. I had one more year to complete. In fact, I was at Tel Aviv University full-time for just over a year.

Then I did my PhD at the Weizmann Institute, where my advisors were Professors Ofer Aharony and Micha Berkooz. They were amazing advisors. They gave me a lot of interesting problems in different subjects to work on, so I had exposure to many fields. They were also very supportive and are extremely good scientists, so I learned a lot. They were receptive to questions and discussions, and their doors were always open. It wasn't an educated choice - it was a lucky choice. It wasn't based on some research that I did about who would be the right advisor to pick. I was simply lucky.

How old were you when you defended your PhD?

I was 25. And then I went to the Institute for Advanced Study, Princeton (IAS) to do a postdoc. I worked with postdocs and faculty there, especially Professor Nathan Seiberg. I was already married to Olga at that time. It was an extremely nice and productive period. We really liked the town and had many friends. Then we went back to Israel for four and a half years where I became faculty at the Weizmann Institute. I had a group there that consisted of two students and two postdocs; it wasn't such a big operation.

Now that you are back in the United States again after becoming a father - what changed?

It's completely different – we are experiencing different aspects of the country. We have to familiarize ourselves with all the particularities of the US: the concept of school districts, the rules of daycare, K-12 - all these things are new. So, we are still readjusting. With kids, it's a different life, of course. Life revolves around the kids, their schedule, their schedule becomes our schedule, then our schedule becomes the kids' schedule, etc. It is a fun and intense period. But this year [2017] has been extremely productive. I've had lots of stuff to do.

You are extremely productive: nine papers in 2016, this year [2017] it has already been five?

This year has been much more productive than usual, so there will be more. I have lots of ideas, and many of them are going to come to fruition soon.

You don't seem to have a problem of a block, or how to resist the urge to stop and contemplate?

No, sometimes I take a day off. And sometimes we go on vacation. I just wish I had more time. If I had more time I could have done much more, I guess.

Your field of research is very broad – you work in string theory, in high-energy physics, in condensed matter physics. Is there a field that is the dearest to your heart, and what are you working on now?

No, I don't have any idealistic points of view on this, I just look for opportunities. I go where there are problems I can contribute to. As [Hans] Bethe once said: one should only work on the problems where one has an unfair advantage.

How do you find them?

It's just a matter of style. After some time you know where your strengths and weaknesses are. You know what you are good at and what you are not so good at. So, you stay away from what you are not good at, if you see some developments in fields that you can contribute to then you just dive in. So, I just go where I see interesting stuff happening. I don't tend to have an overarching 10-year plan, as some people do. I like to change my subject of research occasionally.

How do you choose your collaborators?

It is mostly spontaneous interactions. I meet new people, we discuss things, some idea comes up, and we try to fill the gaps. Sometimes I work on something and someone tells me that he or she has been doing a similar thing in parallel, so we join forces. Or somebody tells me about some idea and I can help the ideas converge, and I can join the paper. It can be either of these scenarios.

Was there a figure in the world of science, someone who fascinated and inspired you?

I was very much under the spell of Landau's books when I was younger. I like the style of his school, as well as the style of research and exposition, so there was a period when I was very influenced by that. But that passed, and now I am fascinated by other things.

Over the past few years you have unraveled a large number of interesting dynamical phenomena in 2+1 dimensions - is there an underlying reason for that richness?

Theories in 2+1 dimensions indeed appear to be quite rich and display nontrivial phenomena. For example, there are many cases when anyonic excitations appear dynamically, leading to very nontrivial low-energy physics, including, for instance, quantum entanglement. In addition, fermions can dynamically turn into bosons, and vice versa. This is a peculiar phenomenon (not limited to 2+1 dimensions only).

These various facts are very useful for both high-energy theoretical physics, as well as condensed matter physics. Working in this field nowadays is in fact a very rewarding experience, since both communities are interested and follow closely. Plus, there is constant input from experiments and lattice simulations as well.

The same richness and diversity of dynamical phenomena can be observed in 3+1 dimensional theories with boundaries. Surprisingly, Quantum Chromodynamics has natural excitations, which are 2+1 dimensional walls containing anyons or massless particles of various kinds. Therefore, recent research has also been directed towards understanding the behavior of 3+1 dimensional theories with boundaries or walls. From the more mathematical perspective, the richness of 2+1 dimensional theories is deeply related to the existence of the Chern-Simons invariant.

Do you expect equal richness in higher dimensional theories?

It is hard to say at the moment, but there are definitely some examples of (pure) gauge theories with nontrivial ground state wave functions - for instance, some gauge theories based on non-simply connected groups. From the mathematical perspective there is no immediate analog of the Chern-Simons invariant, but there are many other interesting topological theories. So, I guess we have to wait and see whether surprises are also found in higher dimensions.

This is more of a question about the philosophy of research. Some people think that we have exhausted the paradigm of using symmetries in physics, and that progress will come from a better understanding of dynamics.

Zohar Komargodski lectures at the 2017 Simons Summer Workshop at Smith Point Beach, Fire Island

Photo: Martin Rocek

What is your view?

Yes, I think that over the recent years research into questions of dynamics (i.e. real time processes) has been rather productive, with better understanding of chaos in quantum many body systems (and the connection to Black Holes). In addition, some of the research on the conformal bootstrap and related topics is relying ever more strongly on real time properties of correlation functions and various similar things.

We have many exciting questions to tackle, ranging from understanding the physics of dark matter to figuring out which questions about particle physics are truly foundational and fundamental

Likewise, a lot of current research depends on better understanding of symmetries, their anomalies, etc. In particular, this includes the progress made on 2+1 dimensional theories described briefly above. I believe it is generally true that in the future questions of dynamics will play an increasingly central role. Phenomena far from equilibrium are still very poorly understood, but they play a crucial role in many applications.

So far none of the proposals made for physics beyond the standard model have been verified experimentally. Many of them tried to accommodate naturalness arguments in their formulations. Should we be worried?

I think the existence of (something like) dark matter is incontrovertible. It would be nice to understand why Modified Newtonian dynamics (MOND) works so well. In addition, the neutrino sector is still somewhat poorly constrained. Therefore, there are certainly real opportunities in particle physics even if there are no new actual particles at a currently accessible energy scale.

It is true that the Standard Model appears to be unnatural, i.e. the parameters appear to be fine-tuned. Currently, there is no explanation why these parameters assume their particular values other than that these are the parameters that allow life, as we know it, to exist. This is aesthetically displeasing. An important point is that when one makes measurements of the universe, it is important to distinguish "environmental" parameters from the "fundamental" ones.

As an example of an environmental parameter, we can try to consider the distance between the planet Earth and the Sun. This distance cannot be predicted by our fundamental theories. In fact, there are many solar systems, and many of them include several planets and these planets could be basically anywhere within those solar systems. So, the distance between the Earth and the Sun is not a fundamental property (or constant) of nature, it just happens to be what it is to allow for life as we know it.

As an example of a fundamental parameter, we can ask about the size of a Black Hole with some given mass. Unlike planets, which can come in all the different sizes and masses, the size-mass relation for Black Holes is a fundamental property of nature. Indeed, for spin-less Black Holes, the size of a Black Hole of a given mass is uniquely determined.

There are many parameters for which we do not yet know whether they are environmental or fundamental, for instance, the electron mass. It sounds like the electron mass is some fundamental quantity we should be able to "predict" or "compute," but it may not be so. In fact, no one has ever been able to predict or compute the electron mass yet. The same applies to the mass of the Higgs particle. Ideas of "naturalness" should not necessarily apply to environmental parameters, but only to fundamental ones. One central question in modern physics is to figure out which are fundamental and which are environmental parameters in the Standard Model. In fact, the boundary between environmental and fundamental parameters may not be so sharp. There could also be parameters that are almost fundamental, but their exact value is still not quite predictable from first principles.

In summary, I do not see any reasons to be worried. We have many exciting questions to tackle, ranging from understanding the physics of dark matter to figuring out which questions about particle physics are truly foundational and fundamental. ♦

Milestones and Prizes

The Simons Center is proud to celebrate the accomplishments of our distinguished faculty and visitors. In this inaugural feature we honor two SCGP permanent members, Simon Donaldson and Zohar Komargodski, for their distinctive contributions to mathematics and physics.

Sir Simon Donaldson's 60th Birthday Celebration

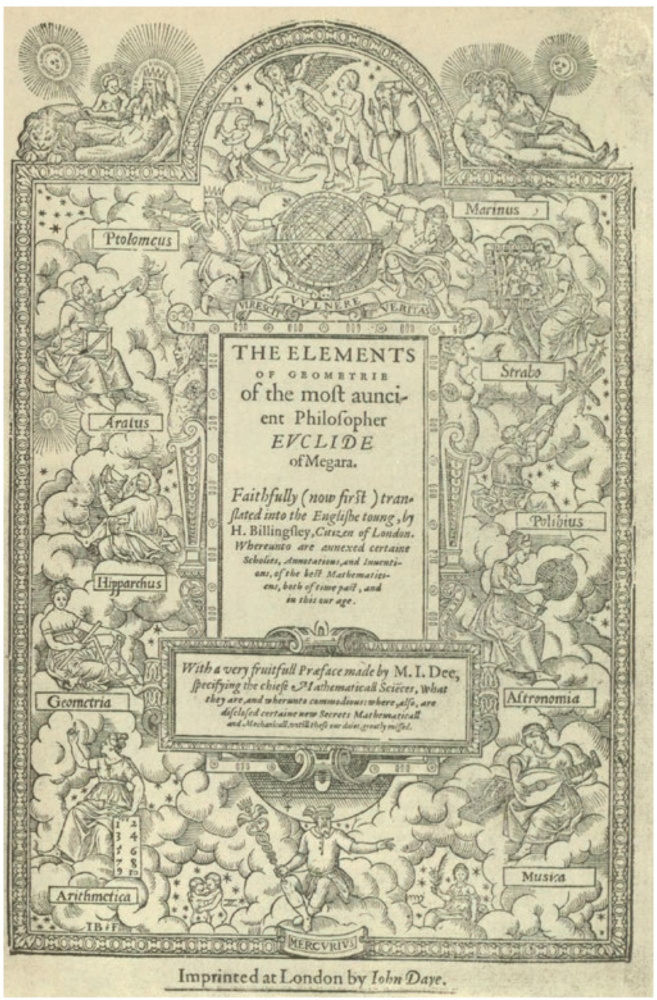


Image: The frontispiece of Sir Henry Billingsley's first English edition of Euclid's *Elements*, 1570 version, Public Domain.

The Simons Center for Geometry and Physics honored Sir Simon Donaldson's 60th birthday last year in recognition of his profound achievements. There was a celebratory banquet at the Center on October 26, 2017, during a special workshop titled *Geometry of Manifolds.* Donaldson was presented with an extraordinary gift for the occasion – a 1566 edition of Euclid's *Elements,* a rare first English version translated from Greek.

Another event marking the important day was a conference on symplectic geometry held at the Isaac Newton Institute (INI), Cambridge, to celebrate Donaldson's significant influence on the subject. The worlds' experts in symplectic geometry and neighboring fields convened at the weeklong meeting from August 14 - 18, 2017. This was a joint INI – CMI (Clay Mathematics Institute) workshop. A characteristic of both his work and the meeting was the influence of (and on) other fields, such as low dimensional topology, algebraic geometry, geometric analysis and theoretical physics.

A recipient of the Fields Medal in 1986 and the Shaw Prize in 2009, Donaldson's recent awards include the "Doctor Honoris Causa" degrees conferred by Université Joseph Fourier, Grenoble (2014) and Universidad Complutense de Madrid (2017), and the Breakthrough Prize in Mathematics (2014) "for the new revolutionary invariants of 4-dimensional manifolds and for the study of the relation between stability in algebraic geometry and in global differential geometry, both for bundles and for Fano varieties." The last result mentioned was a spectacular achievement in 2012: joint work with Xiuxiong Chen (Stony Brook University, Mathematics Department) and Song Sun (Imperial College). ♦

Newton Institute, Cambridge, August 14 – 18, 2017. Simon Donaldson's mathematical family tree. First row from left to right: Sir Michael Atiyah and Nigel Hitchin (Donaldson's PhD advisors). Second row: Simon Donaldson. Also in the photo are some of Donaldson's former PhD students and their students. Pictured on far right is current Stony Brook University PhD student Aleksander Doan.

Photo: Dan Aspel, Isaac Newton Institute's Communications Officer.

Zohar Komargodski Awarded 2018 Sackler Prize in the Physical Sciences

The Raymond and Beverly Sackler International Prize in Physical Sciences was awarded to Zohar Komargodski, professor at the Simons Center for Geometry and Physics, and Weizmann Institute of Science, and Pedro Viera, professor at the Perimeter Institute, Canada and the ICTP-SAIFR, Brazil, "for their outstanding work probing QFT in non-perturbative regimes."

Established through the generosity of Dr. Raymond Sackler and Mrs. Beverly Sackler, and administered by Tel Aviv University through an advisory committee, the Sackler Prizes are awarded every year in the disciplines of Chemistry and Physics. Intended to promote originality and excellence of research in the fields of Biophysics, Chemistry and Physics, the Sackler Prizes recognize researchers under the age of 40.

Professor Komargodski is awarded the prize in the field of "Quantum Field Theory (QFT) – Novel Developments and Applications" for his "broad and deep insights which have shed remarkable light on many aspects of QFT, including renormalization group flows, dualities and phase structure, conformal field theories, and effective field theories for broken supersymmetry and long strings."

According to Komargodski, a theoretical particle physicist working on a variety of topics, including conformal symmetry, supersymmetry, quantum gravity, and particle physics phenomenology, "QFT is a natural framework that describes particle physics, condensed matter systems, and many aspects of statistical physics. The scope of phenomena described by this single unified framework is unprecedented. Understanding QFT in the strongly coupled regime is essential in order to uncover the mysteries of some of the most interesting problems in modern physics."

The significance of Komargodski's work has already been recognized with the New Horizons in Physics Prize (2013), the Gribov Medal (2013), and the Phillipe Meyer Prize in Theoretical Physics (2014).

The Sackler Prize ceremony took place on March 13, 2018 at Tel Aviv University. ♦

Photo: Holly Chen

Mass, Scalar Curvature, and the Geometry of Gravitation

Claude LeBrun

Department of Mathematics

Stony Brook University

In the 1820s, the great mathematician and scientist Carl Friedrich Gauss, tasked with the preparation of accurate maps of the Kingdom of Hanover, instead proved that a perfect solution of such cartographic problems is inherently impossible: any planar depiction of a genuinely curved surface must somehow distort distances. Indeed, if p is a point on a surface $\mathcal{S}$, and if $D_{\mathsf{r}}(p)$ denotes the set of points that can be reached from p along curves in $\mathcal{S}$ of length $\leq \mathsf{r}$, then there is a number $K(p)$, called the Gauss curvature of $\mathcal{S}$ at p, such that

$$\frac{\text{the surface area of } D_{\mathsf{r}}(p)}{\text{the Euclidean answer of } \pi\mathsf{r}^2} = 1 - K(p)\frac{\mathsf{r}^2}{12} + (\text{error term of size } \mathsf{r}^4).$$

For example, the unit-radius 2-sphere in Euclidean 3-space, portrayed in Figure 1, has Gauss curvature $K(p) = +1$ at every point p. But a surface that can be locally depicted in the Euclidean plane, without any distortion of distances, must clearly have Gauss curvature zero everywhere!

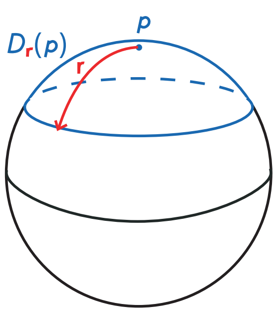


Figure 1: The region $D_{\mathsf{r}}(p)$ of the unit 2-sphere that can be reached from a reference point p by traveling along smooth paths on the surface of length $\leq \mathsf{r} < \pi$. The surface area $2\pi(1 - \cos \mathsf{r})$ of this region is less than the area $\pi\mathsf{r}^2$ of the corresponding disk in the Euclidean plane.

This idea can be generalized to higher-dimensional objects called Riemannian manifolds.

A smooth manifold M of dimension m (or, more briefly, an m-manifold) is a space that can be realized as a subset $M \subset \mathbb{R}^n$ which, near any point, after some permutation of the standard coordinates on Euclidean n-space $\mathbb{R}^n = \mathbb{R}^m \times \mathbb{R}^{n-m}$, becomes the graph of $n - m$ smooth functions of m variables. One often considers two such manifolds to be the same if they are diffeomorphic, meaning there is a smooth one-to-one correspondence between them with smooth inverse. However, a specific embedding $M \hookrightarrow \mathbb{R}^n$ also equips M with an inner product on vectors tangent to M, thereby endowing M with an auxiliary structure called a Riemannian metric g; the pair (M, g) is then called a Riemannian manifold. Two Riemannian manifolds are considered to be the same if they are related by an isometry, meaning a metric-preserving diffeomorphism.

A Riemannian metric g assigns a speed to any parameterized curve in M, and so, by integration, allows us to measure the length of any smooth curve in M. Thus, given some point $p \in M$ and a positive real number r, we may define the disk $D_{\mathsf{r}}(p)$

of radius r, centered at p, to be the set of points $q \in M$ than can be joined to p by smooth curves in M of length $\leq$ r, just as we previously did in the $m = 2$ case of surfaces. However, the metric g also gives rise to a natural assignment of an m-dimensional volume to any region in M. If (M, g) was simply an m-plane $\mathbb{R}^m \subset \mathbb{R}^n$, then the $D_{\mathsf{r}}(p)$ would be a closed Euclidean m-ball of radius r, and its volume would just be $\mathsf{v}_m \mathsf{r}^m$, where $\mathsf{v}_m = \pi^{m/2}/\Gamma(\frac{m}{2}+1)$ is a constant that only depends on the dimension m. The scalar curvature $s(p)$ of (M, g) at p is then characterized by

$$\frac{m\text{-dimensional volume of } D_{\mathsf{r}}(p)}{\text{Euclidean answer of } \mathsf{v}_m \mathsf{r}^m} = 1 - s(p)\ \frac{\mathsf{r}^2}{6(m+2)} + (\text{error term of size } \mathsf{r}^4).$$

For example, the unit m-sphere $S^m \subset \mathbb{R}^{m+1}$, endowed with the metric g induced by the given embedding, has scalar curvature $s = m(m-1)$. Notice, incidentally, that when $m = 2$, the scalar curvature s is exactly twice the Gauss curvature K.

While the scalar curvature provides an interesting higher-dimensional analog of the Gauss curvature, it conveys only a limited amount of information about the intrinsic geometry of a Riemannian m-manifold when $m \geq 3$. This is most easily seen from the incisive point of view first developed by Gauss' brilliant student Bernhard Riemann in the 1850s. From this perspective, the essential feature of an m-dimensional manifold is that such a space can be covered with regions that are faithfully parameterized by $\mathbb{R}^m$-valued coordinate systems $(x^1, \ldots, x^m)$. If M is embedded in $\mathbb{R}^n$ for some $n > m$, some such coordinate systems can be obtained by throwing away all but m of the n standard real-valued Cartesian coordinates on $\mathbb{R}^n$, and then restricting these functions to suitably small regions of M; the general allowed coordinate system on M is then obtained from one of these by composing with a diffeomorphism between regions of $\mathbb{R}^m$. In any allowed coordinate system, a Riemannian metric g then[1] takes the form

$$g = \sum_{j,k=1}^{m} g_{jk}\, dx^j \otimes dx^k$$

where the components $g_{jk} = g_{jk}(x^1, \ldots, x^m)$ are the entries of a positive-definite symmetric matrix that depends smoothly on the coordinates $(x^1, \ldots, x^m)$. Given a point $p \in M$, Riemann asked whether one could choose coordinates $(x^1, \ldots, x^m)$ in which p becomes the origin, and in which the deviation of the metric g from the Euclidean metric δ is as small as possible near p. He discovered that there is a coordinate system in which the components of the metric take the form

$$g_{jk} = \delta_{jk} + \frac{1}{3} R_{ijk\ell} x^i x^\ell + (\text{error terms of size } |\vec{x}|^3)$$

where the numbers $R_{ijk\ell}$ satisfy

$$R_{ijk\ell} = -R_{jik\ell} = -R_{ij\ell k}, \quad R_{ijk\ell} + R_{ik\ell j} + R_{i\ell jk} = 0,$$

and are now understood to be the components of the Riemann curvature tensor of (M, g) at p. Indeed, up to rotations, there is a completely canonical choice of such coordinates, gotten by taking the radial lines through the origin to all represent geodesics through p, meaning curves which are locally as short as possible. Expressions like R_{ijij}, for $i \neq j$, are called sectional curvatures, and represent the Gauss curvatures at p of special embedded surfaces in M obtained by spraying out from p along geodesics tangent to a 2-plane. In these terms, the scalar curvature of M at p is given by

$$s = \sum_{i,j=1}^{m} R_{ijij}$$

and so only gives us average information about the sectional curvatures. It is thus apparent that the scalar curvature only detects a small part of the local geometry of a Riemannian m-manifold when $m \geq 3$.

Despite this, fundamental progress in Riemannian geometry has revealed that positivity of the scalar curvature can have dramatic global implications. For example, there are large classes of compact manifolds that do not admit metrics for which the scalar curvature is everywhere positive. There are also closely related rigidity results concerning open manifolds. For example, suppose that (M, g) is a Riemannian m-manifold in which the complement of some compact subset $C \subset M$ is isometric to the complement of a closed ball in Euclidean space $(\mathbb{R}^m, \delta)$, as depicted in Figure 2. Then either the scalar curvature $s(p)$ of g is negative at some point $p \in M$, or else (M, g) is globally isometric to Euclidean m-space $(\mathbb{R}^m, \delta)$, and so in particular has scalar curvature equal to zero everywhere!

[1]It is not obvious that an arbitrary Riemannian metric g on an m-manifold M, when merely defined to be a consistent collection of smooth local metrics expressed in coordinate charts, necessarily arises from some embedding of M into a high-dimensional Euclidean space $\mathbb{R}^n$. That this is nevertheless true was proved by John Nash in 1956, roughly a century after Riemann's foundational work. However, because these so-called isometric embeddings are highly non-unique, they typically provide little added insight into the intrinsic geometry of Riemannian manifolds.

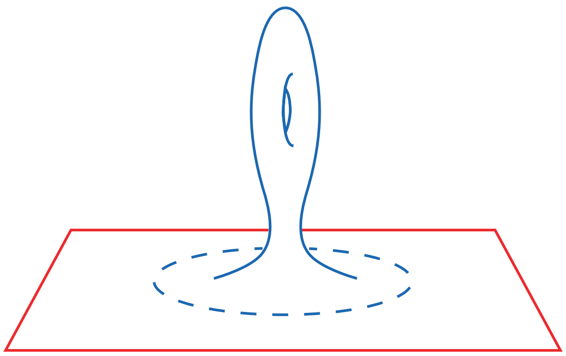


Figure 2: A Riemannian m-manifold that is exactly Euclidean outside of some compact set. Such a manifold can have non-negative scalar curvature only if it is globally isometric to Euclidean m-space.

The above rigidity result is actually a special case of the positive mass theorem, which was originally motivated by work in gravitational physics. In dimension $m \leq 7$, this theorem was proved by Rick Schoen and Shing-Tung Yau in 1979. But an utterly different argument was then published by Edward Witten in 1981 that proves the theorem in all dimensions provided M is also a spin manifold. While Witten's argument only solves the problem for a restrictive class of high-dimensional manifolds, it left many experts convinced that the dimensional constraint in the Schoen-Yau theorem would eventually turn out to be inessential. This hunch now appears to have been on target, because Schoen and Yau have recently released a preprint that subtly modifies their earlier argument in order to provide a proof of the theorem in all dimensions, without any auxiliary topological assumptions concerning M. This exciting development was the centerpiece of a recent Simons Center Workshop, Mass in General Relativity, held during the week of March 26-30, 2018. Workshop participants included Schoen and Yau, along with many other leading experts in the field.

The motivation of the positive mass theorem arose from Albert Einstein's General Theory of Relativity. After carefully studying the work of Levi-Civita and Ricci on Riemannian geometry, Einstein and his friend Marcel Grossman had announced in 1913 that a natural generalization of Riemannian geometry, called pseudo-Riemannian geometry, provides a natural setting for gravitational physics. One key paradigm was provided by Special Relativity, where space-time is represented by Minkowski space, meaning $\mathbb{R}^4 = \{(x, y, z, t)\}$, equipped with the indefinite inner product $dx^2 + dy^2 + dz^2 - dt^2$. General Relativity instead allows space-time to be a more general 4-manifold X, equipped with a pseudo-Riemannian metric h which, as in the Riemannian case, takes the local form

$$h = \sum_{j,k=1}^{4} h_{jk} dx^j \otimes dx^k$$

but now defines point-wise inner products modeled on the Minkowski inner product, rather than the Euclidean one. Vectors v on X with $h(v, v) < 0$ are said to be time-like, and fall into two connected components at each point, called the future-pointing and the past-pointing vectors; smooth paths with future-pointing derivatives are called world-lines, and model the possible trajectories of observers or objects of positive rest-mass. Vectors v with $h(v, v) = 0$ are called null, and represent possible directions for the propagation of light, so the set of all null vectors at a space-time point is therefore called its light-cone. On the other hand, an embedded 3-manifold $M \subset X$ is called a space-like hypersurface if the restriction g of h to M is everywhere positive-definite, as illustrated in Figure 3; notice that (M, g) is then a Riemannian 3-manifold. Space-like hypersurfaces play a central role in the formulation of initial-value problems in relativity, as it is along such submanifolds that initial data are typically specified.

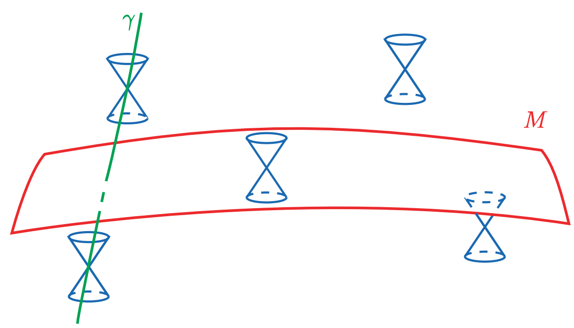


Figure 3: In this portrayal of a 4-dimensional space-time (X, h), one spatial dimension has been suppressed. The light-cones of h are drawn in blue, a world-line γ is indicated in green, and a space-like hypersurface M is shown in red. Note that the restriction of h to the space-like hypersurface M endows it with a Riemannian metric g.

Einstein's gravitational field equations, first published in 1915, equate a divergence-free modification of the Ricci-tensor of (X, h) with a multiple of the stress-energy tensor which represents the distribution of gravitational sources in our space-time. These field equations have a purely Riemannian interpretation, which we will express in units where Newton's constant G and the speed of light c both equal 1. Given a time-like vector v at a point $p \in X$, we can define a small space-like hypersurface M_v by spraying out along geodesics through p in directions perpendicular to v with respect to h. Einstein's equations then just say that the scalar curvature of M_v at p, with respect to the Riemannian metric g induced on M_v by h, is always given by

$$s = 16\pi\rho$$

where ρ is the local mass density at p, as seen by an observer following a world-line tangent to v. Since gravitational sources are generally assumed to locally be attractive rather than repulsive, physically realistic models usually satisfy $\rho \geq 0$ in every possible frame of reference. This hypothesis is usually called the weak energy condition.

Now, if a Riemannian 3-manifold (M, g) were the fixed-point set of a time-reversing isometry of 4-dimensional space-time (X, h), the weak energy condition would force (M, g) to have non-negative scalar curvature. Conversely, Riemannian 3-manifolds of positive scalar curvature can generally be interpreted as time-symmetric initial data for the gravitational field in the presence of physically plausible matter fields. Thus, if the Riemannian manifold depicted in Figure 2 had non-negative scalar curvature, it would be a snapshot of a universe containing an isolated, gravitationally attractive matter source that exerts no gravitation effect whatsoever on objects far from the system! This, of course, is fundamentally unlike anything seen in Newtonian gravity; instead, extrapolating our Newtonian experience into the weak-field regime of Einstein's theory, one expects the spatial metric of an isolated gravitational source to behave like

$$g_{jk} = \left(1 + \frac{\mathsf{A}}{\mathsf{r}}\right)\delta_{jk} + \left(\text{error term} \sim \frac{1}{\mathsf{r}^2}\right) \qquad (1)$$

at infinity, where the constant A is interpreted as twice the "effective total mass" of the isolated system. This motivated the earliest and simplest form of the positive mass theorem: if the complement of a compact set in a Riemannian 3-manifold of scalar curvature $s \geq 0$ is $\mathbb{R}^3$ minus a ball, equipped with a metric of the form (1), then $\mathsf{A} \geq 0$, and $\mathsf{A} = 0$ only if (M, g) is isometric to Euclidean 3-space. In higher dimensions, the corresponding statement is that if the complement of a compact set in a Riemannian m-manifold of non-negative scalar curvature is $\mathbb{R}^m$ minus a ball, equipped with a metric of the form

$$g_{jk} = \left(1 + \frac{\mathsf{A}}{\mathsf{r}^{m-2}}\right)\delta_{jk} + (\text{error term} \sim \frac{1}{\mathsf{r}^{m-1}})$$

then $\mathsf{A} \geq 0$, with equality only if (M, g) is isometric to Euclidean m-space. More sophisticated versions allow for weaker fall-off the metric, permit M to have several "ends," allow M to sit in an $(m+1)$-dimensional space-time (X, h) in a non-time-symmetric manner, permit M to have an interior "black hole" boundary, or consider the total effective energy-momentum vector rather than just the effective total mass.

Nevertheless, much can be learned by simply re-examining the simpler situation depicted in Figure 2. Here, we can reduce the question to one about compact manifolds by gluing either the curved region of M or its oriented double-cover onto a flat torus $\mathbb{T}^m = \mathbb{R}^m/\mathbb{Z}^m$. This results in a compact oriented Riemannian m-manifold N of non-negative scalar curvature that carries m elements of $H^1(N, \mathbb{Z})$ with cup product $1 \in H^m(N, \mathbb{Z}) = \mathbb{Z}$. By a baby version of Ricci-flow, the given metric of non-negative scalar curvature can be perturbed into a metric of positive scalar curvature unless it is Ricci-flat; and in the latter case, a classic theorem of Bochner on harmonic 1-forms would actually force it to be flat. It therefore suffices to obtain a contradiction in the case where N admits a metric of strictly positive scalar curvature.

The original Schoen-Yau method does this by choosing one of the m elements of $H^1(N, \mathbb{Z}) = H_{m-1}(N, \mathbb{Z})$ we have just discussed, and uses geometric measure theory to show that there is a connected hypersurface $N' \subset N$ that minimizes volume among representatives of this homology class. If $m \leq 7$, a regularity result would then force N' to be smooth. Using the second variation for hypersurface volume and the positivity of the ambient scalar curvature one then shows that the lowest eigenvalue of the Yamabe Laplacian of N' must be positive. This implies that a conformal rescaling of the the induced metric of N' also has positive scalar curvature. Moreover, there are $m-1$ elements of $H^1(N', \mathbb{Z})$ with cup-product $1 \in H^{m-1}(N', \mathbb{Z}) = \mathbb{Z}$. We can therefore proceed inductively, by next finding a volume-minimizing hypersurface $N'' \subset N'$. After a finite number of steps, this process gives us a compact oriented surface with positive scalar curvature and $b_1 \neq 0$. But the classical Gauss-Bonnet theorem tells us that this is impossible!

Unfortunately, this argument breaks down if we start in high dimensions, because the stable minimal hypersurfaces arising in the argument can no longer be guaranteed to be smooth. However, Schoen and Yau recently discovered an extrinsic reformulation of their inductive argument, using weighted measures instead of conformal rescalings, that allows them to arrange that the singularities have Hausdorff codimension ≤ 3 at each stage. When we reach the bottom of the ladder, we therefore once again encounter a compact oriented surface with positive scalar curvature and $b_1 \neq 0$, producing exactly the same contradiction as in the earlier argument! ♦

Atlas Flavor Tagging/Higgs to bb

Workshop on Higgs Boson Physics

September 5 - 9, 2017

By Giacinto Piacquadio

Photo: Courtesy Giacinto Piacquadio

More than 60 scientists traveled from all over the world to meet at the Simons Center for Geometry and Physics at Stony Brook University from September 5th through the 9th last year. The group represented a team of physicists within ATLAS, one of the largest science collaborations ever. The aim of the workshop was to discuss how to improve the understanding of the Higgs mechanism by which elementary particles acquire their mass, and to present the latest results and future prospects of using Higgs boson decays to further this exploration. The workshop was complimented by an "Open Day" sponsored by the Simons Center, with public sessions in which the experimentalists discussed these recent results and future prospects with several invited theorists. There was a public lecture titled "Mysteries of the Universe and Everyday Life" given by three influential physicists from the CERN and Fermilab laboratories (Y. Kee Kim, J. Lykken, M. Mangano). This public event offered an opportunity to involve students and teachers from the local community and Long Island schools; many young students attended and their questions gave rise to a lively discussion session. The workshop came at a very special time for the ATLAS team, since they recently reported to the world the first evidence of Higgs boson decays to bottom quarks from collisions of the LHC accelerator. In fact, in 2012, the Higgs boson had been discovered by observing its decay to several other particles, (e.g. photons, Z and W bosons), but these together only represent a mere 30% of the Higgs boson decays. The Higgs boson's favored decay to a pair of bottom quarks, expected in approximately 60% of times, remained elusive. Seeing this decay mode therefore fills one of the largest missing pieces of our knowledge of the Higgs mechanism.

To be chosen to host the workshop, Stony Brook and the Simons Center faced stiff competition with institutes in Paris, Freiburg, and Genova. The support of the Simons Center and of the Physics Department was essential in encouraging the participation of young PhD students and postdocs from Europe, thus making the event a possibility. "The decision to host the workshop at the Simons Center was also a recognition for the role our Stony Brook ATLAS team played in making this first sighting possible," explains Professor Giacinto Piacquadio, one of the workshops local organizers, "and for the many years of work invested in refining the b-quark identification and calibration techniques to the precision level needed for this challenging measurement." Valerio Dao, a former postdoc from the Stony Brook team, has co-led the ATLAS team of 60 scientists during the past crucial year and is now a Research Fellow at CERN. He adds, "this result is an important milestone for the whole team, but we are also looking forward to integrate more LHC data to refine the measurement and challenge theory predictions further." ♦

Young-Kee Kim is an experimental particle physicist, and Louis Block Distinguished Service Professor and Chair of the Department of Physics at the University of Chicago. As Deputy Director of Fermilab between 2006 and 2013, she had broad responsibilities including shaping programs such as the long-baseline neutrino program and the muon experiments. She received the Ho-Am Prize, the Women in Science Leadership Award from the Chicago Council of Science and Technology, South Korea's Science and Education Service Medal, the University of Rochester's Distinguished Scholar Medal, and Korea University's Alumni Award.

Joseph Lykken is Fermilab's Deputy Director. A senior scientist at the laboratory, Lykken was a former head of the Theory Department and is a member of the CMS experiment on the Large Hadron Collider at CERN. Lykken began his tenure at Fermilab in 2005. He is a former member of the High Energy Physics Advisory Panel, which advises both the Department of Energy and the National Science Foundation, and recently served on the Particle Physics Project Prioritization Panel, developing a road map for the next 20 years of U.S. particle physics.

Michelangelo Mangano is a senior theoretical physicist at CERN. His main area of expertise is the dynamics of high-energy particle collisions, and their use for the understanding of elementary particles and for the search and study of the fundamental interactions. As a participant in the CDF experiment at the Fermilab's Tevatron accelerator, he was a member of the team that discovered the top quark in 1994. He has been visiting scholar or lecturer in over 20 Universities and laboratories worldwide, and a member of the Scientific Programme Committee of over 50 International conferences and workshops.

Nuclear Reactions

In addition to experimenting with elementary particles, Young-Kee Kim collaborates with artists. Depicted below is the theatrical production of "Creating Science Art: CP-1 (Chicago Pile-1), and Public Commemoration" at the University of Chicago. This project offered students across campus to contribute an artistic response to the science, history, and impact of CP-1, the world's first nuclear reactor. Working with dance, the project gave students the space and tools to think deeply about how, why, and to what purpose making art in dialogue with science serves. As such, movement played a central role in their investigation. The final performance was directed by choreographer Emily Coates (Yale), and music was composed by Sam Pluta (Chicago) with assistance from Andrew Bearnot (Post-MFA Fellow, Chicago). Young-Kee Kim, co-leader of the workshop, guided the physics knowledge and provided the scientific expertise.

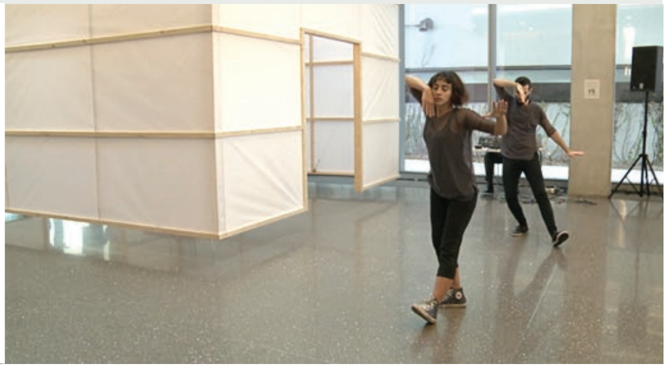


Photo: "Meditation on CP-1". Video still of performance. Led by dance artist Emily Coates and particle physicist Young-Kee Kim for students and staff from the University of Chicago, December 15, 2017. Courtesy Young-Kee Kim.

Puzzle Time

In Volume IX of the SCGP News the puzzle titled **The Not-so-Rigid Hexagon**, conceived by Professor Maxim Kontsevich of the IHÉS, was presented on page 20.

Revealed below is the solution:

The hexagon of the second type has an axis of symmetry. Let us count the number of degrees of freedom for a regular right angle hexagon with a given axis of symmetry (a line in three-dimensional space). The number of coordinates is 3x3, as three consecutive vertices of the hexagon determine by symmetry the other three vertices. The number of constraints is 2x3 (constraints for 3 consecutive edges and 3 consecutive angles). The dimension of the group of motions preserving the given axis is 2, which is one translational and one rotational degree of freedom. Hence, we obtain the expected dimension to be 3x3-2x3-2=1!

Notice that the hexagon of the first type has a central symmetry. If we repeat the previous arguments for a regular right angle hexagon with a given center of symmetry, we obtain 3x3-2x3-3=0 degrees of freedom. In the latter case the dimension of the group of motions preserving the given symmetry point is 3, it is just the group of rotations. We observe that imposing additional symmetry for a system with constraints can lead to the same or even larger expected dimension than in the case of no imposed symmetry. This is a very common, although somewhat counter-intuitive phenomenon.

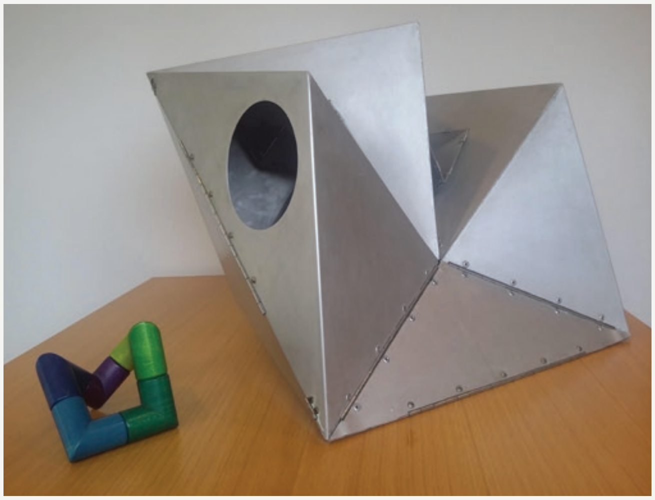


Photo: Courtesy Maxim Kontsevich

Now is the story time:

I learned this example the hard way. In 1994 there was an International Mathematical Congress in Zurich, where I was invited as a plenary speaker. On the way from the hotel to ETH (Eidgenossische Technische Hochschule, the venue of the Congress) I used to pass through a small square. One of the buildings (with the address Spiegelgasse 14) had a commemorative plaque stating that Lenin stayed there in 1916-1917. This was the place where he finished his work "Imperialism as the Highest Stage of Capitalism." There was also a small curiosity shop on the ground floor, with a puzzling object – a half of Lenin's head colored red, with its mirror reflection colored white in the front window, as well as some mathematical-looking structures. Once I went into the shop, and found myself in a paradise of mathematical/mechanical/optical gadgets. The owner was quite an interesting person, and we found a common acquaintance, John Conway. I bought only one object, a wooden Swiss-made model of the regular right angle hexagon, made of six identical rigid angles connected by hidden plastic clips. One can easily disassemble and reconnect the pieces. I bought it at half price, by proposing to the owner an idea about how to make Calabi-Yau varieties from rigid sticks (this is another story). It took me three days to figure out the solution of the puzzle; the only possible excuse was that I was quite busy at the Congress.

In 1995 I moved to IHÉS. It took me several years to recognize that essentially the same object stays at all times on a small table in the IHÉS library. This is the famous flexible polyhedron of Robert

Connelly, discovered during his visit to IHÉS in 1977. The construction of Connelly was a modification of a construction of R. Brickard from 1897, who constructed flexible octahedra in 3-dimensional space. Notice that for a regular hexagon in 3-dimensional space the constraint to have right angles is equivalent to the constraint that the distance between any two vertices that are next to adjacent is the square root of 3 times the length of any side of the hexagon. Connecting 6 pairs of vertices which are next to adjacent, we obtain a graph with 6 vertices and 12 edges combinatorically equivalent to an octahedron.

Brickard's octahedra are self-intersecting, and Connelly's contribution consists of modifying the polytope by adding small crinckles near self-intersection loci, and making the polytope embedded.

IHÉS director Nicolas Kuiper, and Pierre Deligne (IHÉS professor at that time) helped Connelly to simplify the construction. A legend of our institute says that another IHÉS professor, Dennis Sullivan, puffed a lot of cigarette smoke into a model of flexible polytope, and observed that if one flexes the model, no smoke will come in or out. This led to so called volume conjecture, saying that the volume of any flexible polytope stays constant under continuous deformations. This conjecture was spectacularly solved in 1989 by Idzhad Sabitov, using valuation theory, and e.g. p-adic numbers for all primes p!

In early 2000, Sabitov visited IHÉS. I showed him my wooden model. After that he went to Zurich, and bought one of the last remaining copies. He told me afterwards that the owner found the object in the storeroom, not on main display.

The shop still exists, under the name AHA, its web page is www.aha-zurich.ch. ♦

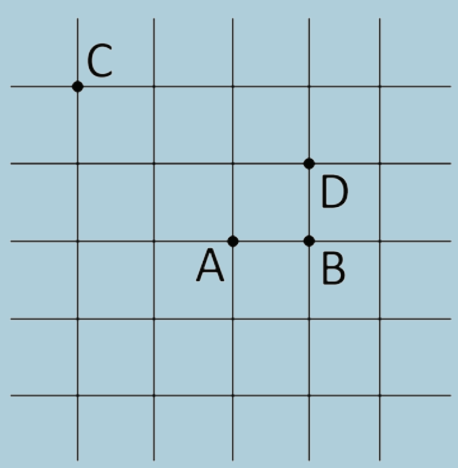
Resistance of the Wire Grid is contributed by **Alexander Abanov, Deputy Director,** SCGP. The solution will be published in the forthcoming SCGP News Volume XI.

Consider the infinite square network built of wire segments of unit electric resistance.

a) Find the resistance between two adjacent nodes A and B of the grid.

b) What is the asymptotic value of the resistance between nodes A and C of the same grid separated by large distance $L \gg 1$?

c)* Can you find the resistance between next to nearest neighbor nodes A and D?



Surprises Are Always Possible

Alexander Abanov, Deputy Director, Simons Center for Geometry and Physics and Professor, Department of Physics, Stony Brook University, on the Simons Center model of scientific life, science summer camps and his fascination with the quantum Hall effect.

Interview by Maria Shtilmark

Photo: Bob Giglione

As this is your sixth year as Deputy Director I would like to start with the major role you have played in establishing the grid of the Simons Center's bustling scientific life. Could you tell us about your vision of the structure behind the plethora of the Center's programs, workshops, seminars, and lecture series?

There are different models of how scientific life can be organized. There is a model practiced in IAS, where visitors come freely, interact, and ideas emerge, or there are places like KITP Santa Barbara, where visits are organized into scientific programs and conferences are an integral part of them. Scientific activities at SCGP can be roughly divided into three categories. First of all, currently there are four permanent faculty members (when I first came to the Center we had one) and a lot of important activity is built around their work and interests. Two other types of activity are concentrated on our visitors. One consists of research programs that run from one month to a semester. We invite about ten visitors at any point in time to come and work on a particular direction in physics or mathematics, or, preferably, at the interface between the two. Anybody can apply to organize a program or to participate in a program that has already been announced. The application procedure is described in detail on our website, and the proposals we request are relatively simple – a list of key speakers and a short summary explaining why the topic proposed is important at this particular time.

The second type of visitor activity is workshops, which are much more concentrated events that last a week, with about 30 participants attending. Workshops can be an integral part of existing programs (typically within a program we have one or two workshops), or independent, selected from outside proposals by the Scientific Advisory Committee. A workshop always has a focused timely topic, and we usually aim at the interaction between mathematics and physics. It is always a plus if a proposal involves the local strengths of Stony Brook University.

Organizing committees, responsible for selecting the participants, always have a goal to bring together mathematicians and physicists who do the most influential and exciting work in their fields from around the world to the Simons Center. Program visitors are expected to come for a period of about one month, and workshop participants usually come for the entire period of the workshop. The Center aims to have 20 programmatic visitors at any time, and the workshops bring an additional 25 to 40 participants to the Center, so the Center can host up to 60 visitors at a time.

How easy is it to organize such an event at the Simons Center?

Organizers enjoy the full support of our excellent staff and the facilities are extremely nice. The word about the Simons Center is out and people know of us as a high-class place to organize activities. We are getting used to the overflow of excellent proposals, and it is becoming difficult to select from them.

Naturally, there are issues organizers face. The standard invitation for program visitors is to come for one month. The reason behind not one or two week visits but longer is to enable visitors to fully participate in program activities and to establish new collaborations. Naturally, almost everybody has teaching obligations and coming for a whole month or longer might present problems at a visitors' home institution. As for program organizers, they look for their sabbatical times, as at least one of them is encouraged to stay here throughout the entire program.

Another issue is certain natural inhomogeneity. If a program involves two workshops most visitors tend to come during them. So, at times we have a slow pace with not many people present, and later we may struggle finding offices for all the visitors.

Often the goal of a program or a workshop is to establish collaborations between researchers from different fields, ideally mathematicians and physicists, and this is not easy. Mathematicians prefer to attend math talks, and physicists are naturally attracted to physics talks. A special effort is often needed to overcome these natural tendencies and have them talk to each other, like scheduling talks in random order, so that we don't have days of physics and days of math, but mixed program days, or having a lot of centralized discussions and making time during scheduled events for people really to get to know each other. Another example of such effort can be KITP Santa Barbara's "blackboard lunches." For longer programs something like that would be very helpful, so people could be introduced in a comfortable environment, and the earlier the better.

A helpful thing we have is that all talks are recorded and posted within hours of the actual talk. This comes in very handy at conferences when talks go back-to-back, and one needs to make hard choices sacrificing attending a talk in order to discuss one's work with a colleague. Being able to listen to talks online with almost no delay is extremely advantageous.

Photo: Courtesy Alexander Abanov

What results to do you strive to achieve?

An ideal outcome of the event would be recognition that the problem has been solved, or sufficient progress towards its solution has been made. This, however, is very hard to achieve, and more operational criterion of success is establishing new collaborations, especially interdisciplinary ones, and this is what the Center's mission is about. If collaborations multiply, additional activities emerge, and papers are published – we consider all of this our success.

How do visitor events correlate to the other Simons Center activities?

An example would be the weekly talk. During a program we have several talks a week, where program participants present the results of their published research and launch discussions. We also have colloquium series "SCGP Weekly Talk," designed for a broader mathematics and physics audience. This is when we ask distinguished scientists who participate in our programs to present an overview of their field of work in a way that is accessible to non-specialist physicists and mathematicians. These are not public talks at all, but physics/math colloquia aimed at a broader audience of people not specialized in that field. We have also started a Physics Seminar, which is run by the Simons Center faculty.

You often mention the focus on intertwining math and physics. As someone who works in theoretical condensed matter physics, would you say it involves interplay with mathematics?

Mathematics is a universal language. Physics is not possible without mathematics, and condensed matter physics is no exception. Question of interplay also involves condensed matter research stimulating the development of mathematics. If we understand condensed matter physics broadly we can think of the early days of physics of fluids resulting in the theory of partial differential equations, or crystallography stimulating developments of the theory of space groups. Many problems of solid state physics can be solved replacing crystals by continuous media and applying classical or quantum field theory methods. The latter methods are very universal, geometrical in nature, and are necessary to understand things like low temperature properties of solids and universal properties of phase transitions.

These days, condensed matter physicists, for the most part, use field theory methods that are already known, and mathematics that already exists. For example, recently developed topological band theory is using topological methods that are well known to mathematicians. However, there are very important exceptions. Studies of exactly solvable spin chains eventually led to new fields of mathematics: quantum groups and integrability theory. The discovery of quantum Hall effect resulted in a much better understanding of emergent symmetries and orders coming from systems of many quantum interacting particles. Condensed matter systems are often discreet (e.g., crystals), and when this discreteness is essential continuum field theory descriptions are not sufficient. Very recently the problem of classification of quantum phases of matter has raised new questions to topologists, caused a rapid development of quantum information theory, and forced physicists to learn mathematical methods that did not belong to the theoretical physics toolbox, such as K-theory.

What aspects of condensed matter physics are you interested in?

I am generally interested in the universal aspects of it, which means the properties of fluids and solids that can be well characterized and are robust, i.e., do not depend on too many microscopic details of a particular system. To understand these properties topological and geometrical methods and methods of quantum field theory are often used. In particular, throughout my scientific life I've been fascinated by quantum Hall effect. I consider it the most important discovery in physics of the second half of the 20th century. In quantum Hall effect we study the properties of interacting electron gas on a surface of semiconductor in strong magnetic field at a very low temperature. It turns out that many properties of this system are the ones of the exotic fluid – quantum fluid. Recently we explored the analogy between deformations of solids studied by elasticity theory and warping of spacetime by gravity studied by general theory of relativity. Placing (theoretically) quantum Hall fluid into nontrivial geometric background we can compute the responses of strongly interacting quantum electrons to external stresses and electromagnetic fields. This idea is illustrated in the Figure 1, made by Gil Cho, one of my collaborators, for the project (Gromov, Cho, You, AA, Fradkin, Phys. Rev. Lett.114, 016805, 2015). It shows a droplet of quantum Hall fluid placed on a curved surface. I have to stress here that in the nearest future we do not plan to put quantum Hall sample near a black hole. However, thinking about stresses inside solids in terms of the warped geometry of space is very convenient computationally, very geometric and gives a lot of new insights.

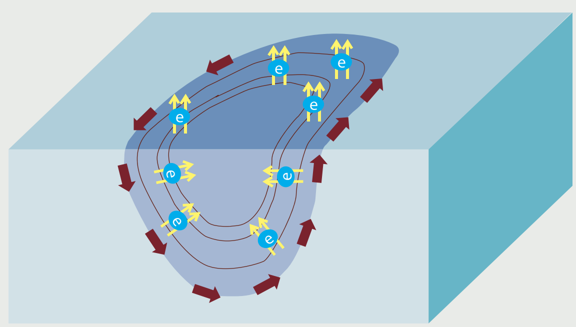


Image: The figure by Gil Cho (Korea Institute for Advanced Studies) illustrates the idea of extracting responses of quantum Hall system to external stresses by putting the system in curved space.

In my recent works I've been trying to use what I've learned from quantum Hall physics to understand properties of classical chiral fluids (fluids that consist of particles rotating in the same direction). I am also using my experience in topological methods in condensed matter physics to study out-of-equilibrium properties of condensed matter systems. There are some recent developments in understanding physics of systems out of equilibrium, role of quantum chaos, and emergence of collective hydrodynamic behavior. I do expect that these developments will lead to some new applications, new tools and new math insights in the nearest future. Condensed matter physics is driven by experiment. Surprises, such as discovery of quantum Hall effect, new questions raised by experiments in cold atom systems, or by discoveries of new quantum materials are always possible and this is the thrilling part of working in condensed matter physics!

I understand your interest in physics began at a young age and was boosted by the Krasnoyarsk Summer School for gifted high school students, and you are still involved with it. Are there things we could learn from each other?

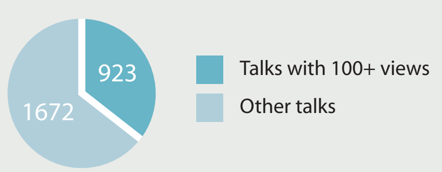
That school was an eye-opening experience for me and I still visit every year to give lectures on physics and math and host physics tournaments. It is a summer school for kids from the Krasnoyarsk region mostly, with some coming from other parts of Russia and even from the US. It is held at various summer camp facilities, in taiga, not far from Krasnoyarsk. There is a tradition of evening clubs when people present their favorite pieces of music, or talk about their favorite paintings. When I first attended I had already been quite motivated in physics and math, but I fell in love with the human aspect of that camp, discovering that people who do amazing research are at the same time extremely diverse and broadly educated, fond of music, poetry and art. The school bears a lot of value for me, as this is also the place where my wife Marina and I first met.

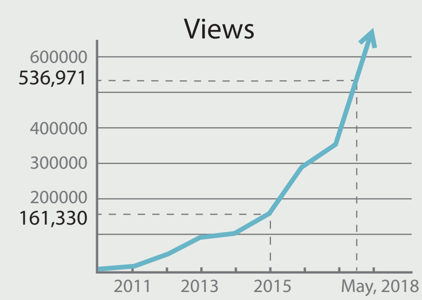
At this point the Simons Center is not directly involved in high school student education, with the exception of the Della Pietra High School Lectures and the Math Kangaroo Competition, an international mathematics contest in which SCGP has provided the building for several years, and everybody is very grateful for that.

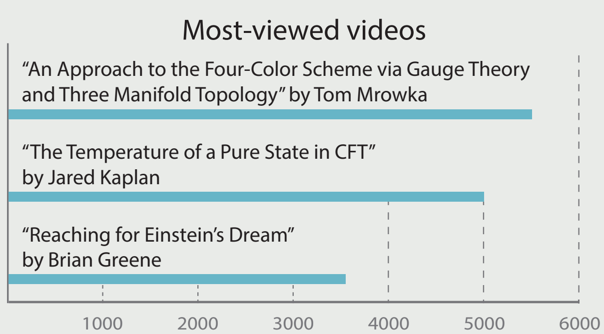
I also participate in a local initiative SchoolNova, Sunday enrichment program for children from 3 to 15 years old, where they have classes in languages, physics and math, held on the P-floor of the Physics building. In Russia, where I am from, there is a long-standing tradition of university faculty participating in various types of math and science circles for school students. As far as I know, this type of outreach is becoming popular in the United States as well, and I hope that the Simons Center will participate more in these activities in future. ♦

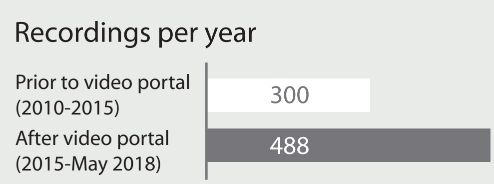
Simons Center Video Portal

The SCGP video portal, launched in the summer of 2015 by Systems Administrator Jason May, allows for all Simons Center-associated talks to be viewed online within minutes of the actual presentation's conclusion. According to May, although the Simons Center has been hosting videos since 2010, the improved video portal "is a searchable database which provides viewers with a centralized location to easily find videos, along with more advanced search options. [This includes] searching by name, title, location, subject matter, scientific event, as well as suggesting related videos from the same event, speaker, and more."









Total recordings (2010-May 2018): 2595 records.

Graphics: Valentina Pogudina

The Simons Center Art and Science Program

By Lorraine Walsh

Art Director and Curator

Simons Center for Geometry and Physics

Eunoia II, 2017, by Lisa Park, EEG brainwave sensor installation, dimensions variable. Pictured with the artist.

Photo: Courtesy Lisa Park

The Simons Center Art and Science Program welcomed multidisciplinary artist **Lisa Park** to exhibit her work in the fall of 2017. Park's solo exhibition, *Manifesting Invisibles*, featured a compelling trilogy of interactive art. The three installations *Eunoia II, Rhythm*, and *Heartmonic,* were on view in the Simons Center Gallery from October 2017 through January 2018.

Park's participatory artwork coupled with programming seeks to explore self-monitored physiological and psychological states via biosensors, albeit with creative play in mind. She cites the 17th century Dutch philosopher Baruch Spinoza as an inspiration for her research. Park refers to the 48 definitions of emotions in Spinoza's book *Ethics* as metaphor specific to her algorithmic installation *Eunoia II*.

In this integration of art and technology, Park makes the invisible visible in visual and sonic environments. Using consumer grade heart rate monitors and brainwave sensors, she repurposes these readily available biofeedback devices with unique proprietary software. Essentially, signals are collected from the intrepid gallery visitor via a heart wrist monitor, and/or their brainwave frequencies are captured from an EEG headset. The data driven heartbeat information triggers digital animations of lines drawn on screens mounted on the gallery wall, much like a painting. And the compiled brainwave algorithms create sound in shallow panned pools of water situated on speakers that produce fluctuating values of amplitude and frequency. Naturally, results vary accordingly with the individual.

As an emerging artist, Park has received many accolades with reviews in numerous publications, including *MIT Press, The New York Times, Wired,* among many others. Awards include a New York Foundation for the Arts (NYFA) Fellowship for Digital and Electronic Arts, and she is an inaugural member of NEW INC, New York City's New Museum's first museum-led incubator program in art, technology, and design. Currently Artist in Residence at Nokia Bell Labs in New Jersey, Park is working with their engineers to devise new forms of human communication.

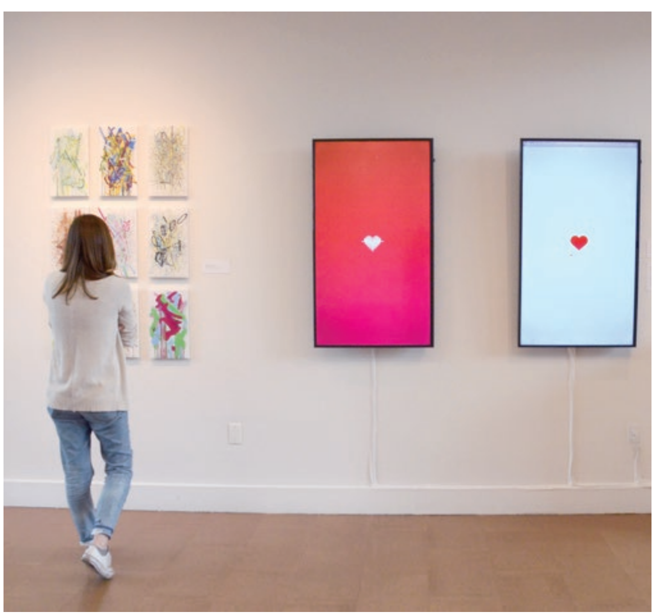
Recognizing scientific creativity in film genre as well as in art exhibitions, the Simons Center was honored to premiere **Galois: Story of a Revolutionary Mathematician** on October 17th in the Della Pietra Family auditorium. The movie is about the brief life of French mathematician Évariste Galois. Although Galois tragically died in a duel at the young age of twenty, his work provided the groundwork for significant developments in mathematics. Best known for polynomial equations and group theory, his manuscripts contributed to an extraordinary mathematical inquiry that lasted for centuries.

Galois: Story of a Revolutionary Mathematician is directed by Diego Cenetiempo and the screenplay is by Giuseppe Mussardo, Professor of Theoretical Physics at SISSA (Trieste). Previous directing and writing collaborative filmmaking by Cenetiempo and Mussardo include *The Dream of Symmetry* and *Maksimovič*, the latter of which was also previously shown at the Center.

The Art and Science Program also screened **Whispers of String Theory** during the 2017 Summer Workshop. The director Ekaterina Eremenko turned an ear toward physics in this movie seeking a unique cinematic viewpoint with sound. Listening closely to the hushed tones of exchanges by physicists at an international meeting, Eremenko beckons the viewer – or in this case the listener – into a private world of whispering correspondence. In a venturesome and original approach, the recorded candid remarks from scientists are the film's protagonist.

Another artistic perspective inspired by physics took the form of verse by poet **Amy Catanzano.** In an integrated artistic practice known as quantum poetics, Catanzano explores the intersection of literature, science and art. As such, she investigates shared principles in poetry and quantum mechanics to reinvent common notions of spacetime, language, and reality.

On October 18th, Catanzano joined us at the Center to talk about her uniquely composed quantum literature. Additionally, she read a poem from her second book *Multiversal,* which received national recognition with the PEN USA Literary Award in Poetry. Catanzano's engaging visit was in anticipation



From top: Art students assisting artist Lisa Park in the Simons Center Gallery.

Photo: Lorraine Walsh

SCGP Postdocs (left to right) Alba Grassi, Francois Greer, and Mazac Dalimil participate in demonstrations of *Eunoia II.*

Photo: Lauren Ruiz

Rhythm by Lisa Park, Simons Center Gallery

Photo: Lorraine Walsh

Cinzia Da Via (center) at Simons Center Summer Concert 2017.
Photo: Lorraine Walsh

of an upcoming stay at the Center as the Inaugural Poet in Residence during National Poetry Month in April 2018. In addition to two other books, Catanzano's work has been published widely in literary journals including *Conjunctions, Denver Quarterly,* and *New American Writing*. She is Associate Professor of Creative Writing and Poet in Residence at Wake Forest University, Winston-Salem, NC.

Drawing of Évariste Galois by Guiseppe Mussardo
Image: Courtesy Guiseppe Mussardo

Celebrating science-inspired writing, the Simons Center for Geometry and Physics and the C.N. Yang Institute for Theoretical Physics were pleased to announce the winners of the fifth annual **Science Playwriting Competition** at Stony Brook University. This competition provides a venue for scientists and playwrights alike for scientifically informed stories told and seen anew with theatre.

Playwrights worldwide submitted entries in 2017. The First Prize was awarded to Richard Lyons Conlon for *The Volitive Effect*, a timely play conveying the perplexing issues surrounding artificial intelligence. Second Prize went to Arthur Lundquist for his play where a meeting of seekers and dreamers find a voice in *The Age of Giants*. And the Third Prize was given to Alan Coyne for *Ducks and Drakes*, the second in a continuing series of adventures involving his characters Keane and Doyle. Previously featured in *Keane and Doyle are Spies*, they now appear as scientists.

In another arena, the Art and Science Program hosted the 2017 **Summer Concert Series**. Now in its fifth year, the series commenced July 18th and ended on August 8th. Musical genres included classical guitar and piano, jazz, Cuban, salsa, and more. The first performance introduced the Early Bird Jazz Band, a New York City-based ensemble led by clarinetist and saxophonist Ricky Alexander.

Thereafter the Center was delighted to welcome Grammy award winner classical guitarist Andrew York. A performer of international stature, York blends his compositions with styles of ancient eras and modern musical directions — creating music at once vital, multi-leveled, and beautiful. On August 1st, a performance led by Jose Conde's Cuban band Ola Fresca brought guests to the dance floor with weaving musical bridges connecting Cuban son, salsa, timba and funk. The final week welcomed the return of Leon Livshin, renowned pianist, soloist and chamber music player. Livshin was joined by Bela Horvath on violin and cellist Marta Bagratuni. The trio focused on Johannes Brahms's unique friendship with Antonin Dvorák in their concert titled *The Friendship of Brahms and Dvorák: Admiration and Emulation.*

Spring 2018 looks forward to a broad range of science-inspired art. They include etching and digital prints created by a theoretical physicist, and mathematical weavings found in Pre-Columbian textiles. Amy Catanzano will join us for a Poet in Residency and will present a poem composed for the Simons Center. Robert P. Crease, Chair of Philosophy at Stony Brook University, whose research includes the history of science, will give a special talk. Crease will share his thoughts and philosophical musing on ten of the most beautiful science experiments of all time. And the harmony of the spheres will once more be found in music during the upcoming Simons Summer Workshop at the Center. ♦

Leon Livshin and Friends. Leon Livshin, Bela Horvath and Marta Bagratuni. Simons Center Summer Concert 2017.

Photo: Lorraine Walsh

Andrew York. Simons Center Summer Concert 2017.

Photo: Annette York

The Equations of Beauty

Though a musician by profession, Andrew York is also a passionate amateur mathematician and physicist. "Like music, I find mathematics to be a universal language, and also timeless," says York. "If Archimedes were here today, we may be able to communicate to a degree musically, though the clarity of our discourse would undoubtedly be affected by the changes in musical meaning over the millennia from cultural transformation; yet we would understand each other instantly and without misunderstanding through basic mathematics." This harmonious blend is most evident in his famous piece, *The Equations of Beauty*. It is a six-movement suite, and each movement is named for a mathematical constant or variable. The names are h, e, π, i, ∞ and c. "These symbols stand for the smallest, the fastest, the infinite, the beautiful and mystical transcendental, irrational and imaginary numbers; all the utmost extremes that inhabit the realm of mathematics. I chose the names to match the spirit of each movement." *Equations* is played entirely with a capo on the fifth fret, and the tuning is D A D F# B D. "Playing a concert at the Simons Center at Stony Brook and looking out at an audience composed primarily of real mathematicians and physicists was truly a career highlight for me," York reminisces. "And sharing with them this composition brought math and music together in the most satisfying way imaginable!"

Announcements

Photo: Bob Giglione

As of January 31, 2018, **Elyce Winters**, Associate Director for Finance and Administration, departed the Simons Center for Geometry and Physics (SCGP) to pursue new opportunities.

Elyce joined the SCGP as Chief Administrative Officer in 2010 and was responsible for the oversight of the Center's operations, including budget planning, grant management, outreach, and recruitment - to name just a few. It was under Elyce's leadership the Centers strong staff was built and evolved. The first port of call for faculty and staff alike, she was the 'go-to' person for all inquiries and requests, while presiding over the increasingly busy financials, liaising with university officials and representing the Center to the public at special events.

We thank Elyce for her contributions to the Center from its very start, and wish her much happiness and success in future endeavors!

Effective January 2, 2018, the Simons Center Café transitioned to new management under the direction of Executive Chef **Eric Werner**, of Lessing's Hospitality Group. The new Simons Center Café features a fresh and modern style, with a focus on organically inspired French, Italian, and American cuisines. Chef Werner credits his career and passions to his roots - Long Island. He studied at the New England Culinary Institute (NECI) where he received professional training to begin building his culinary career. Inspired by the late Chef Gerry Hayden's passion for the farm-to-table concept, he chose to pursue a position at a restaurant that followed suit. "The seasonality and locality of produce and meat, alongside the sustainability of our waters, are all important to me. All impact our lives, directly and indirectly, and is a mindset I adopted while attending the NECI," says Werner.

A Note from the Executive Director of SCGP News

I am delighted to introduce a new organization for the SCGP News. Our editorial team commenced work and redesign in the last issue, and have now formalized the partnership with Maria Guetter, Maria Shtilmark and myself. A special thanks to the producers and editors, including Elyce Winters, who expertly guided the newsletter before my tenure. I am grateful for their invaluable groundwork and editorial direction.

The SCGP News' mission is to provide relevant and substantive scientific news and research. We work to advance and celebrate the accomplishments of the Center, its faculty, and the scientific community at large. As we move forward and build on our success, the editors would appreciate feedback from you, the readers of and contributors to the newsletter. Your input is highly valued for the production of a first-class publication that reflects the Center's excellence. ~ Lorraine Walsh

Email: feedback@scgp.stonybrook.edu

Past issues of the SCGP newsletter: scgp.stonybrook.edu/news/newsletter

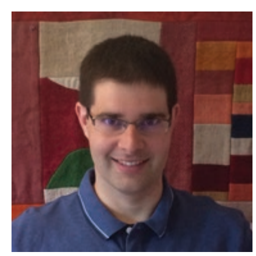
Photo: Paul Guetter

SCGP Welcomes New Research Assistant Professors

Alba Grassi graduated from ETH Zürich in 2012 and completed her PhD in physics in 2015 at the University of Geneva working with Marcos Mariño. In her thesis research she developed a new non-perturbative approach to topological string theory leading to a new family of exactly solvable models in spectral theory. Before joining the Simons Center she spent two years at ICTP in Trieste as a postdoctoral fellow. During that time she worked on supersymmetric gauge theories and (q-) Painlevé equations finding new geometrical solutions of the latter in terms of underlying quantum mirror curves.

François Greer completed his PhD at Stanford University in 2017 under the direction of Jun Li. His research is centered around moduli spaces in algebraic geometry, and their interaction with arithmetic and physics. These spaces parametrize families of polynomial shapes and they are teeming with symmetry. His thesis research titled "Modular Forms in Enumerative Geometry," explored a connection between holomorphic curves on elliptically fibered manifolds and special functions called modular forms, which arise in number theory. François was first exposed to moduli theory as an undergraduate at Harvard University working with Joe Harris. There he learned the philosophy of compactification and degeneration, which continues to permeate his work.

Demetre Kazaras completed his PhD at the University of Oregon in 2017 under the direction of Boris Botvinnik. His primary interest is the study of positive scalar curvature from the perspective of both algebraic topology and general relativity. His thesis work included a gluing theorem for a Yamabe-type problem and some progress on understanding bordism groups of positive scalar curvature metrics. During his postdoctoral program, he hopes to use tools from the study of mass in general relativity to investigate moduli spaces of positive scalar curvature metrics.



Mark Mezei is a high-energy physicist working on strongly coupled field theories and the AdS/CFT correspondence. Most of his research concerns entanglement entropy both in ground states and out of equilibrium. He is also interested in three-dimensional gauge theories and exploring the AdS/CFT duality away from its best understood regimes. He completed his PhD at the Massachusetts Institute of Technology (MIT) in 2014, where his advisor was Hong Liu. His thesis title was "Counting Degrees of Freedom in Quantum Field Theory Using Entanglement Entropy," which earned him the Bershadsky Prize from MIT. Before joining the Simons Center, he was the Sam B. Treiman Postdoctoral Fellow at the Princeton Center for Theoretical Science from 2014 to 2017.

Robert Silversmith began as a postdoc at the Simons Center in Fall 2017, after earning a PhD at the University of Michigan. His thesis, entitled "Gromov-Witten invariants of symmetric products of projective space," was about the enumerative geometry of certain algebraic orbifolds. Rob's primary research interests are the combinatorics of moduli spaces of rational curves, particularly rational curves embedded in certain classical varieties and orbifolds (e.g. the Hilbert scheme of points in the plane). In Fall 2018, Rob will begin as a Zelevinsky Research Instructor at Northeastern University.

2018 - 2019 Academic Year Programs

Exactly Solvable Models of Quantum Field Theory and Statistical Mechanics: ***September 4 - November 30, 2018***, organized by Vladimir Korepin, Sergei Lukyanov, Nikita Nekrasov, Samson Shatashvili and Alexander Zamolodchikov

Geometry and Physics of Hitchin Systems: ***January 22 - June 21, 2019***, organized by Lara Anderson and Laura Schaposnik

Automorphic Structures in String Theory: ***March 4 - April 5, 2019***, organized by Daniel Persson, Terry Gannon, David Ginzburg, Axel Kleinschmidt, Stephen Miller and Boris Pioline

Operator Algebras and Quantum Physics : ***June 3 - 30, 2019***, organized by Stefan Hollands, Vaughan Jones, Gandalf Lechner and Roberto Longo

2018 - 2019 Academic Year Workshops

Geometrical Aspects of Supersymmetry: ***October 22 - 26, 2018***, organized by Manuela Kulaxizi and Maxim Zabzine

Nonequilibrium Physics in Biology: ***December 3 - 7, 2018,*** organized by Jin Wang, Ken Dill, Michael Douglas and Jose Onuchic

Entanglement and Dynamical Systems: ***December 10 - 14, 2018***, organized by Israel Klich, Vladimir Korepin and Bruno Nachtergaele

Vertex Algebras and Gauge Theory: ***December 17 - 21, 2018***, organized by Sergei Gukov, Tomoyuki Arakawa, Boris Feigin, Alba Grassi, Hiraku Nakajima, Nikita Nekrasov and Andrei Okounkov

Holomorphic Differentials in Mathematics and Physics: ***February 4 - 8, 2019,*** organized by Jayadev Athreya, Steve Bradlow, Sergei Gukov, Andy Neitzke, Anna Wienhard and Anton Zorich

Automorphic Structures in String Theory: ***March 4 - 8, 2019***, organized by Daniel Persson, Terry Gannon, David Ginzburg, Axel Kleinschmidt, Stephen D. Miller and Boris Pioline

A Workshop on Challenges at the Interface of Hitchin Systems and String Theory: ***March 18 - 22, 2019***, organized by Lara Anderson and Laura Schaposnik

Convergence and Low Regularity in General Relativity: ***April 29- May 3, 2019***, organized by Philippe LeFloch, Jeff Jauregui, Mike Anderson and Christina Sormani

String field theory, BV quantization, and moduli spaces: ***May 20 - 24, 2019***, organized by Kenji Fukaya, Owen Gwilliam, Stephan Stolz, Peter Teichner and Mahmoud Zeinalian

Graduate Summer School on the Mathematics and Physics of Hitchin Systems: ***May 27 - 31, 2019***, organized by Lara Anderson and Laura Schaposnik

Operator Algebras and Applications: ***June 17 - 21, 2019***, organized by Stefan Hollands, Vaughan Jones, Gandalf Lechner and Roberto Longo

For the most up-to-date schedule, please visit scgp.stonybrook.edu/science

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For possible sabbatical stays, please contact: Alexander Abanov at aabanov@scgp.stonybrook.edu

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