# TABLE OF CONTENTS

- **WELCOME** 3
- **MEETING INFORMATION** 4
  - Hotel Information 5
  - Venue Information 6
  - Meeting Agenda 7
  - Annual Meeting Dinner 8
- **SPEAKER PROFILES** 9
- **2019 SIMONS INVESTIGATORS** 18
- **2019 SIMONS FELLOWS** 32
- **ABOUT MPS** 35
  - Scientific Advisory Board 36
  - Staff 37
  - Program Summary 38
Dear Colleagues and Friends,

We are thrilled to welcome you to the seventh Annual Meeting of the Mathematics and Physical Sciences Division.

This year is a very special year for us: the Simons foundation celebrates its 25th anniversary, and the MPS division its 10th!

The foundation is rapidly growing, expanding its in-house research and adding new funding initiatives. It now comprises the Autism Research Initiative, MPS, Life Sciences, as well as the Education and Outreach Division. The range of activities is broad, from clinical trials for promising drugs to treat autism, to the study of the origins of life and the origins of the universe, to the production of science documentaries, Quanta magazine, and Math for America, supporting math and science teachers in NYC.

In the last ten years, the number of employees increased from 20 to 400, including 200 researchers.

Most of our in-house research takes place at the Flatiron Institute across the street. Its mission is to advance scientific research through cutting-edge computational methods. Currently, the Institute houses the five units: Center for Computational Astrophysics (CCA), Center for Computational Biology (CCB), Center for Computational Mathematics (CCM), Center for Computational Quantum Materials (CCQ), in addition to the Scientific Computing Core, which develops and maintains the computational infrastructure. These units have active postdoctoral programs; they host sabbatical visitors and organize conferences. We encourage you to explore potential collaborations with scientists there.

In MPS, our priority is to support fundamental research in mathematics, physics and theoretical computer science. Most of our funding proceeds via open annual calls, in the framework of our established programs: Grants to Individuals, Grants to Institutions, and Infrastructure. We have an ongoing call for Targeted Grants in MPS, supporting very few, high-risk and high-impact efforts.

We organize Simons Symposia and conferences at the foundation. We regularly review our programs with our Scientific Advisory Board and make adjustments as necessary.

Last year, we have made two new awards in the Simons Collaborations in MPS program: Ultra-Quantum Matter (Director Ashvin Vishwanath) and Wave Turbulence (Director Jalal Shatah). We have established four centers in Mathematical Biology, jointly with the NSF at Harvard, Northwestern, UC Irvine and Georgia Tech. Work continues at the Simons Array and Simons Observatory in Chile.

We look forward to celebrating your accomplishments and to hearing more about your vision, ideas and plans for the future.

Sincerely,

YURI TSCHINKEL
Director of Mathematics and Physical Sciences

GREG GABADADZE
Associate Director for Physics
HOTEL INFORMATION

W UNION SQUARE
201 Park Avenue South
New York, NY 10003
T: (212) 253-9119
www.wnewyorkunionsquare.com

Wi-Fi is complimentary in each guest room.

Checkout is at noon. You will be automatically checked out and a final bill for any incidentals will be placed under your door on the morning of your day of departure.

Service and facilities
Business and fitness centers are open 24 hours a day.

Transportation
A written reminder of your departure itinerary as well as ground transportation information will be delivered to your room shortly after check-in.

MPS staff will be available at the Gerald D. Fischbach Auditorium on Thursday morning for any questions regarding your travel arrangements.

Luggage
Those departing from the Gerald D. Fischbach Auditorium after the conclusion of the annual meeting should bring their luggage to the meeting.

Contact information
Meeting questions:
Meghan Fazzi
(646) 706-1007
mfazzi@simonsfoundation.org

Ground transportation questions:
Emily Klein
eklein@simonsfoundation.org
(646) 751-1262
Wi-Fi at the Gerald D. Fischbach Auditorium:
Network Name: SimonsGuests
Password: simonsnyc

Auditorium
A microphone and AC power connection are located at each seat. Food and beverages are not allowed in the auditorium.
### MEETING AGENDA

#### Thursday, October 17, 2019

<table>
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<tr>
<th>Time</th>
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<tr>
<td>8:30 AM</td>
<td>Check-in &amp; Breakfast</td>
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| 9:30 AM | **YANBEI CHEN**  
Gravitational Wave Science: from Black Hole Physics to Macroscopic Quantum Mechanics |
| 10:30 AM | Break |
| 11:00 AM | **AMIT SINGER**  
Mathematics of Cryo-Electron Microscopy |
| 12:00 PM | Lunch |
| 1:30 PM | **NIGEL COOPER**  
Topology and Dynamics in Quantum Matter |
| 2:30 PM | Break |
| 3:00 PM | **MICHAEL WOLF**  
Limits of Geometric Structures on Surfaces |
| 4:00 PM | Break |
| 4:30 PM | **RACHEL ROSEN**  
Black Holes for Massive Gravitons |
| 6:00 PM | Cocktails and Dinner @ Union Park |

#### Friday, October 18, 2019

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<tr>
<td>8:30 AM</td>
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| 9:30 AM | **LUCY COLWELL**  
Using Evolutionary Sequence Variation to Build Predictive Models of Protein Structure and Function |
| 10:30 AM | Break |
| 11:00 AM | **SCOTT AARONSON**  
Gentle Measurement of Quantum States and Differential Privacy |
| 12:00 PM | Lunch |
| 1:00 PM | **MICHAEL BRENNER**  
Machine Learning for PDE’s |
| 2:00 PM | Meeting Concludes |
ANNUAL MEETING DINNER
Union Park Restaurant

Thursday, October 17 at 6:00 p.m.

Union Park
5-7 East 17th Street, New York, NY 10003
T: 347.913.5581
https://www.unionparkevents.com/

Walking directions from the Simons Foundation to Union Park:
1. Head east on 21st Street toward Fifth Avenue.
2. Turn right on Fifth Avenue toward 20th Street.
3. Turn left on East 17th Street.
4. Union Park will be on your left.
Gentle Measurement of Quantum States and Differential Privacy

Aaronson will discuss a recent connection between two seemingly unrelated problems: how to measure a collection of quantum states without damaging them too much ('gentle measurement') and how to provide statistical data without leaking too much about individuals ('differential privacy,' an area of classical CS). This connection leads to, among other things, a new protocol for 'shadow tomography' of quantum states (i.e., answering a large number of questions about a quantum state given few copies of it).

Scott Aaronson has established fundamental theorems in quantum computational complexity and inspired new research directions at the interface of theoretical computer science and the study of physical systems.
Michael Brenner will discuss several ways in which machine learning can be used for solving and understanding the solutions of nonlinear partial differential equations.

Michael Brenner is the Michael T. Cronin Professor of Applied Mathematics and Applied Physics at the Harvard School of Engineering and Applied Sciences. His research uses mathematics to examine a wide variety of problems in science and engineering, ranging from understanding the shapes of whale flippers, bird beaks and fungal spores, to answering ordinary questions about daily life, such as why a droplet of fluid splashes when it collides with a solid surface.
Since the Advanced Laser Interferometer Gravitational-wave Observatory (LIGO) started operation in September 2015, gravitational waves from more than 12 pairs of merging binary black holes have been observed. In August 2017, the neutron-star binary merger GW170817 was observed by both gravitational-wave and electromagnetic telescopes. Since April 2019, compact binaries are being detected at a rate of around once per week. From these initial events, we have tested basic properties of gravitational waves and black holes and have made the connection between neutron star mergers and gamma-ray bursts. Next, we will not only gather more population statics and make better measurements, but will also be testing more subtle predictions of general relativity, detecting events from the more distant/earlier universe, and search for deviations from general relativity and exotic phenomena. These ambitious goals will be achieved by new generations of ground-based detectors, as well as space-based detectors. Gravitational-wave detectors are at the frontier of precision measurement physics. Macroscopic test masses in Advanced LIGO are already being monitored continuously at a level of only several times the Heisenberg uncertainty. Improving detector sensitivity requires considering measurement-induced back action, as well as the quantum coherence between the test masses and the measuring devices. This provides us with the opportunity to study the quantum mechanical behaviors of macroscopic objects.

Yanbei Chen made major contributions to understanding the noise of laser-interferometer gravitational-wave detectors that arise from quantum fluctuations of light and matter. He proposed conceptual interferometer designs that can achieve better sensitivity, also formulating a vision for experimentally testing quantum mechanics and quantum measurement theory on macroscopic objects. Chen made important contributions to gravitational-wave data-analysis strategies and works on using gravitational-wave observations to test the predictions of general relativity in strong gravity and to study the structures of black holes.
NIGEL COOPER
University of Cambridge

Topology and Dynamics in Quantum Matter

Quantum many-body systems arise in a wide range of physical settings from quark-gluon plasmas to electrons in semiconductor devices. They are known to give rise to very rich and complex forms of collective behavior, such as superconductivity and the quantum Hall effect. Much progress has been made in understanding equilibrium phases of quantum matter, through concepts of symmetry breaking and, more recently, via topological classifications. However, recent developments of experimental platforms are allowing the far-from-equilibrium dynamics of quantum many-body systems to be explored in detail. Cooper will describe some of the new theoretical issues that arise, focusing on the constraints imposed by topology on dynamical evolution.

Nigel Cooper has shown how to design optical lattices for cold atoms that provide controllable laboratories for exploring the physics of interacting particles in the presence of gauge fields. He is also known for foundational works on the topological Kondo effect and on quantum oscillations in topological insulators.
The evolutionary trajectory of a protein through sequence space is constrained by its function. A central challenge across the biological sciences is to predict the functional properties of a protein from its sequence and thus (i) discover new proteins with specific required functionality and (ii) better understand the functional effect of changes within protein-coding genes. The explosive growth in the number of available protein sequences raises the possibility of using the natural variation present in homologous protein sequences to infer these constraints and thus identify residues that control different protein phenotypes. Because in many cases phenotypic changes are controlled by more than one amino acid, the mutations that separate one phenotype from another may not be independent, requiring us to build models that take into account the correlation structure of the data. Models that have this feature are capable of (i) inference of residue pair interactions accurate enough to predict all atom 3-D structural models and predictions of (ii) binding interactions between different proteins and (iii) accurate annotation of sequence domains with as low as 20 percent identity to the training set.

Lucy Colwell has demonstrated that the 3-D structure of proteins can be determined from large sequence alignments. Her current research develops methods for relating phenotype to genotype, using large data sets from high-throughput biological experiments, focusing mainly on proteins, small molecules and nucleic acids.
Single particle cryo-EM is becoming an increasingly popular technique for determining 3-D molecular structures at high resolution. We will discuss the mathematical principles for reconstruction using cryo-EM and then focus on computational challenges, in particular, reconstruction of small molecules and heterogeneity analysis.

Amit Singer is one of the leaders in the mathematical analysis of noisy data provided by cryo-EM.
What would happen to a black hole if the graviton had a mass? In this talk, Rosen will review the status of black hole solutions for theories in which the gravitational force is mediated by a massive spin-2 particle. She will present the arguments that such black holes must necessarily be time dependent and will discuss the implications for black hole mechanics and for observations.

Rachel A. Rosen’s research focuses on quantum field theory and its applications to particle physics, gravitational physics and condensed matter systems. She is best known for her contributions to massive gravity, a theory in which the graviton — the spin-2 particle that transmits the gravitational force — has a mass. She has also helped to develop new techniques for studying various states of matter, from ordinary fluids to an exotic quantum liquid that could exist in the cores of certain very dense stars.
The study of surfaces lies at the crossroads of many subjects, and this reflects in there being a variety of geometries — hyperbolic, complex projective and affine spherical, among others — that a surface can admit. We discuss how these moduli spaces of geometric structures may by parametrized by holomorphic objects associated to variational problems and then focus on describing the singular objects that emerge when we allow the geometric surfaces to degenerate. Along the way, we meet a number of constructions central to this subject.

Michael Wolf’s research focuses on deformations of geometric structures on surfaces, typically with applications to and from conformal optimization problems. The work often blends complex analytic quantities with synthetic constructions that reflect the qualitative features of the solutions to the extremal problems. A recent principal interest is in higher rank Teichmüller theory, which applies gauge theory to the study of representations of surface groups in Lie groups. He has past contributions to complex projective geometry as well as to classical minimal surface theory, where he and collaborators found the first embedded complete minimal surface in space with infinite total curvature but finite topology since the eighteenth-century helicoid.
BHARGAV BHATT
University of Michigan

Bhargav Bhatt works in arithmetic algebraic geometry, with an emphasis on questions in positive and mixed characteristic. His research, which often draws on ideas from derived algebraic geometry, has also contributed to the solution of long-standing problems in commutative algebra and algebraic topology.

XIUXIONG CHEN
Stony Brook University

Xiuxiong Chen is a leading figure in complex geometry with fundamental contributions to the field. He and his collaborators have made major breakthroughs and finally settled several long-standing problems. With S.K. Donaldson and S. Sun, Chen proved the stability conjecture (which goes back to Yau) on Fano Kähler manifolds. With B. Wang, Chen confirmed the Hamilton-Tian conjecture on the Kähler-Ricci flow on Fano manifolds. With J.R. Cheng, Chen found a groundbreaking a priori estimate for Kähler metrics, under assumptions on the scalar curvature, which involved a fourth-order differential equation and verified the fundamental Donaldson geodesic stability conjecture and the properness conjecture.

NETS KATZ
California Institute of Technology

Nets Katz is a harmonic analyst. Much of his work has been focused on the Kakeya problem. Because that problem has such broad connections with different parts of mathematics, it has led him to work in other areas, such as incidence geometry and additive combinatorics. Jointly with Larry Guth, he solved (up to logarithmic factors) the Erdős distinct distances problem, in the process introducing polynomial partitioning, which is now having an impact on Kakeya.
Elchanan Mossel’s primary research fields are probability theory, combinatorics, theoretical computer science and statistical inference. Mossel is broad and collaborative in his research. Much of his work spans different areas of mathematics or bridges mathematics and other sciences. With collaborators, he made fundamental contributions to discrete Fourier analysis and its applications to computational complexity and voting theory. In the area he named ‘combinatorial statistics,’ his collaborative work includes important discoveries on tree broadcast models and associated reconstruction problems, detection of block models, the inference of evolutionary histories and, more recently, deep inference.
Rouven Essig is a theoretical particle physicist whose research focuses on the search for dark matter and other new particles beyond the standard model. He has helped pioneer several novel direct-detection concepts to probe dark matter below the proton mass and has been a leader in establishing this as a new research direction, attracting significant theoretical and experimental efforts. He has also been a leader in conceiving of fixed-target experiments to search for new forces, helping to spawn several new efforts. Although a theorist, he is co-leading or participating in several experiments searching for dark matter and new forces.

Sean Hartnoll’s recent work has aimed to understand the flow of charge and heat in strongly quantum many-body systems without well-defined ‘quasiparticle’ excitations. His research has mobilized fundamental principles of statistical quantum mechanics to constrain this flow, and he has also studied solvable models that can reveal organizing principles behind non-quasiparticle physics. He is known for results on holographic models that translate the dissipative dynamics of black hole event horizons into phenomena of interest in condensed matter systems and has co-authored a book on the resulting holographic quantum matter.

Gil Refael is best known for his works on realizing Majorana fermions in solid state systems and on quantum dynamics and control. Refael’s group has introduced the concepts of Floquet topological insulators and topological polaritons, and additionally worked on disordered magnets, superconductors and superfluids. Currently, he focuses on implementing concepts from topological physics to quantum control, as well as the microscopic origins of many-body localization.
Neal Weiner works on physics beyond the standard model, with an emphasis on understanding dark matter. He was active in developing the cosmology and signals of dark matter with interactions and contributed many ideas that helped shape our current thinking on theories of dark matter. Of late, he has focused on understanding the range of dark structures that may populate the Milky Way and how to detect them with gravitational lensing.

Cenke Xu’s research has contributed to several different topics in theoretical condensed matter physics, such as quantum spin liquid states, interacting topological insulators and, more generally, symmetry protected topological phases, duality of unconventional 2+1 dimensional quantum critical points and new understanding of non-Fermi liquid phenomena constructed based on the Sachdev-Ye-Kitaev model and related models. Most recently Xu’s group is also interested in understanding the strongly correlated phenomena observed in graphene-based systems with Moiré superlattice.
Daniel Kasen studies energetic astrophysical phenomena such as supernovae and compact object mergers and their applicability as probes of physics and cosmology. His models of electromagnetic signals have guided observational efforts and played an important role in interpreting the first neutron star merger jointly detected in light and gravitational waves. His work has helped illuminate the diverse ways in which stars die and how the heavy elements in the universe formed from their ashes.

Rachel Mandelbaum is an observational cosmologist who uses data from large sky surveys to measure gravitational lensing (the deflection of light from distant objects by more nearby mass). She works at all stages of the measurement process, including data analysis methodology, production of theoretical predictions and development of statistical methodology. She uses gravitational lensing measurements to reveal the connection between the visible components of galaxies and invisible dark matter, which can answer basic questions about galaxy evolution and to reveal how cosmic structure has grown and evolved, which relates to the accelerated expansion rate of the universe and dark energy.
THEORETICAL COMPUTER SCIENCE
2019 Simons Investigators

DAVID BLEI
Columbia University

David Blei studies probabilistic machine learning, including its theory, algorithms and application. He has made contributions to unsupervised machine learning for text analysis, approximate Bayesian inference with variational methods, flexible modeling with Bayesian nonparametrics and many applications to the sciences and humanities.

ODED REGEV
New York University

Oded Regev works on mathematical and computational aspects of point lattices. A main focus of his research is in the area of lattice-based cryptography, where he introduced the learning with errors (LWE) problem. This problem is used as the basis for a wide variety of cryptographic protocols, including some of the leading candidates for post-quantum secure cryptographic standards. He is also interested in quantum computation, theoretical computer science and, more recently, molecular biology.

BRENT WATERS
University of Texas at Austin

Brent Waters is a leader in the field of cryptography. His pioneering work introduced the concepts of attribute-based encryption and functional encryption. He is known for developing novel proof techniques including lossy trapdoor functions, dual-system encryption and punctured programming analysis in cryptographic code obfuscation.
Ben Machta examines how physical laws constrain the design principles of biological systems. His research uses statistical physics, information theory and Riemannian geometry to understand how the need to coordinate and process information constrains function. He has worked to understand how simple models emerge from complex molecular details and to bound the energetic needs of small thermodynamic systems. He has also sought to understand how cells exploits the subtle physics near critical points to sense and respond to their environment.

Caroline Uhler has made major contributions to the development of methods in statistics and machine learning for applications in genomics. Her work to date has broken new ground on providing a systematic approach to studying graphical models. In particular, she uncovered statistical and computational limitations for causal inference and developed a novel framework for causal structure discovery from a mix of observational and interventional data. This led to new models and algorithms for inferring gene regulatory networks and for disease diagnostics by integrating gene expression data with the 3-D organization of the genome.
MATHEMATICS

IAN AGOL
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University of Chicago

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Columbia University

MANJUL BHARGAVA
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DAVID SCHWAB
CUNY Graduate Center

ARYEH WARMFLASH
Rice University

DANIEL WEISSMAN
Emory University

DANIELA WITTEN
University of Washington

OLGA ZHAXYBAYEVA
Dartmouth College
# MATH+X

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>Andrea Bertozzi</td>
<td>University of California, Los Angeles</td>
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<td>Ingrid Daubechies</td>
<td>Duke University</td>
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<td>Amit Singer</td>
<td>Princeton University</td>
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<td>Michael Weinstein</td>
<td>Columbia University</td>
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# MATH+X CHAIRS

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>François Bachel</td>
<td>University of Texas at Austin</td>
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<td>Emmanuel Candès</td>
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<td>Maarten de Hoop</td>
<td>Rice University</td>
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<td>Yoichiro Mori</td>
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# Mathematics

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<tr>
<td>Federico Ardila</td>
<td>San Francisco State University</td>
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<td>Sergey Bobkov</td>
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<td>Ivan Cherednik</td>
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<td>Gheorghe Craciun</td>
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<td>William Duke</td>
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<td>Matthew Kahle</td>
<td>Ohio State University</td>
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<td>Nets Katz</td>
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<td>Rinat Kedem</td>
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<td>Temple University</td>
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<td>Toan Nguyen</td>
<td>Pennsylvania State University</td>
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<td>Denis Osin</td>
<td>Vanderbilt University</td>
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<td>Dmitriy Panchenko</td>
<td>University of Toronto</td>
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<td>Irena Peeva</td>
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<td>Malabika Pramanik</td>
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<td>Eric Rowell</td>
<td>Texas A&amp;M University</td>
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<td>Andreas Seeger</td>
<td>University of Wisconsin-Madison</td>
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<td>Evgeni Tevelev</td>
<td>University of Massachusetts Amherst</td>
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<td>Tatiana Toro</td>
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<td>Jared Weinstein</td>
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<td>Michael Wolf</td>
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<td>Paul Yang</td>
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<td>Guoliang Yu</td>
<td>Texas A&amp;M University</td>
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<td>BORIS ALTSHULER</td>
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<td>TONY GHERGHETTA</td>
<td>University of Minnesota</td>
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<td>DAVID HUSE</td>
<td>Princeton University</td>
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<td>RENATA KALLOSH</td>
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<td>ANDREI LINDE</td>
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<td>BRIAN METZGER</td>
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<td>ELENA PIERPAOLI</td>
<td>University of Southern California</td>
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<tr>
<td>MARK ROBBINS</td>
<td>Johns Hopkins University</td>
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<td>DI XIAO</td>
<td>Carnegie Mellon University</td>
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SCIENTIFIC ADVISORY BOARD

Mathematics

SHMUEL WEINBERGER
University of Chicago

NICK KATZ
Princeton University

JILL PIPHER
Brown University

HORNG-TZER YAU
Harvard University

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Columbia University

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MEGHAN FAZZI
Manager, Events and Administration

LIZ ROY
Senior Manager, Programs and Administration
Targeted Grants support high-risk projects of exceptional promise and scientific importance for up to five years. The foundation currently supports the following projects:

**Cosmic Axion Spin Precession Experiment (CASPER)**

The CASPER team, which searches for the coupling of dark matter consisting of axions, axion-like particles (ALPs) such as the relaxion, and dark photons to nuclear spins and the gluon field, has made progress in their first-generation experiments. The CASPER-Electric experiment targets the coupling of the oscillating dark matter field to the gluon field within the nucleus, which generates an oscillating electric dipole moment. Using thermally polarized Pb-207 nuclear spins in ferroelectric PMN-PT crystals, the first-generation experimental apparatus has been constructed and tested, including the superconducting magnet, control and probe electronics, data processing and a vibration isolation system to reduce one of the more important systematic effects in a dark-matter search.

The CASPER-Wind experiment targets the direct coupling of the oscillating dark matter field to nuclear spins. The experiment uses hyper-polarized liquid Xe as the sample, where the nuclear spin polarization exceeds that of the thermally polarized Pb nuclei used in CASPER-Electric by many orders of magnitude. The Xe polarizer has been constructed and optimized and preliminary data on the experiment is expected this year. It also pioneered the development in zero-and-ultralow-field (ZULF) NMR to carry out an experiment using a sample of C-13 enhanced formic acid to search for oscillating dark-matter fields at ultralow frequencies (from about 20 Hz to 50 mHz), which recently completed its first stage experiments.

The CASPER grant also supports the theory work of Professor Surjeet Rajendran at UC Berkeley. In the past year, Rajendran worked on four main topics. First, Rajendran identified experimental technologies such as torsion pendulums, atomic magnetometers and atom interferometry to search for axions in the frequency range 100 nHz–100 Hz, a range that could not be probed by other established experimental techniques. With this work (arXiv: 1709.07852), it has now become possible to probe axions all the way to the lowest frequency where they could still be the dark matter of universe. Rajendran also continued his earlier efforts to make use of the instability of carbon white dwarfs to runaway nuclear fusion to probe ultra heavy dark matter candidates such as Q balls. Rajendran worked on detecting ultra-heavy dark matter candidates in laboratory based terrestrial experiments. In this work, he showed that ultra-heavy dark matter can cause transient signals in experiments such as CASPER and LIGO, lead to heat deposition as phonons in calorimeter experiments and produce acoustic waves in hydrophone networks. Rajendran also invented and developed a new experimental protocol to search for particles in the mass range ~ MeV through missing energy events in nuclear gamma cascades. The idea is to place a radioactive source such as Co-60 or Na-24 that triggers gamma cascades in the middle of a large, hermetically sealed scintillation detector, enabling photon identification with high accuracy.

**FASER: Forward Search Experiment at the LHC**

FASER, the Forward Search Experiment, is the first experiment dedicated to searching for new light weakly interacting particles at CERN’s Large Hadron Collider (LHC) in Geneva. The LHC accelerates counter-rotating beams of protons to the largest energies ever achieved in the lab. These beams collide at a few interaction points along the circular ring, and these points are surrounded by enormous detectors that are designed to look for evidence of new particles. If new light and weakly interacting particles exist,
however, they are typically produced parallel to the beam line. The existing detectors at the LHC have holes along the beam line to let the proton beams in and are therefore blind to such particles. From its position just off the beam line and 480 meters downstream from one of these interaction points, FASER will cover this blind spot and provide world-leading sensitivity to these particles.

To achieve this sensitivity affordably and quickly, FASER will employ silicon strip detectors and electromagnetic calorimeter modules generously loaned by the ATLAS and LHCb collaborations, respectively. With three powerful permanent magnets to bend the trajectories of charged particles and a scintillator-based veto system to exclude more mundane processes, FASER will be able to unambiguously identify dark photons and other proposed long-lived particles that decay inside it. The discovery of such particles will have revolutionary implications for particle physics and cosmology, providing evidence for new forms of matter or new fundamental forces, and possibly a breakthrough in identifying the particle nature of dark matter.

MathJax: Universally Enhancing Math on the Web

In MathJax's second year, progress was made in several areas. Improvements were made in the speech-rule engine (SRE) that underlies the semantic interpretation of formulas in MathJax. This is responsible for aural rendering of formulas to provide audio descriptions in MathJax's accessibility module. Other second-year goals for the project included leveraging input formats to enhance semantic understanding of the expressions being rendered, improved heuristics for handling complex layout structures like tables, and experiments with content mining to use contextual information from elsewhere on the page to augment semantic knowledge applied to the expressions.

In addition, the MathJax team continued work on extending output options and on contributing to standards development for assistive technologies in support of mathematics. Important steps in this direction were made during a weeklong conference at the American Institute of Mathematics (AIM) in May 2018, which brought together content authors, assistive support staff, math software developers and screen reader developers to address barriers to creation and adoption of accessible web content for mathematics.

Origins of the Universe

The Origins of the Universe project is designed to advance our understanding of the universe by stimulating theoretical research into mechanisms of cosmogenesis. The project includes three groups: Cosmology Beyond Einstein's Theory group, Research in Modern Inflationary Cosmology group and Cosmological Bounces and Bouncing Cosmologies group.

Progress highlights in the Cosmology Beyond Einstein's Theory group include a proposal to embed massive gravity and bigravity in a five-dimensional brane-world theory to address the strong coupling issue of these theories. Greg Gabadadze, New York University, presented an embedding that raises the strong scale by many orders of magnitude and also proposed a theory in which the strong scale could be raised all the way up to the 5D Planck scale. Gabadadze outlined how this theory can be used for geodesically complete cosmology in the early universe, as well as for the description of the late time accelerated expansion of the universe. Once this work is finished, the theory can be straightforwardly applied to both cosmology of the early universe with the goal to produce
noninflationary scenario, and can also be applied to cosmology of late time universe, with the goal to accelerate expansion of the universe described as an effect of modified gravity.

Over the next decade, the Research in Modern Inflationary Cosmology will use measurements of the development of the large-scale structure of the universe to provide us with new cosmological information about the composition of the universe and the properties of the primordial seeds created during inflation.

The work of Matias Zaldarriaga, Institute for Advanced Study, in his paper “Beyond the Traditional Line-of-Sight Approach of Cosmological Angular Statistics” centers around developing new tools to compute theoretical predictions and compare those with the data. In particular, an important part of the effort was devoted to developing tools to infer the properties of the initial seeds in a given region of the universe based on the late time distribution of matter and galaxies. These techniques could help mitigate some of the contamination that degrades measurements of the statistical properties (Gaussianity) of the primordial seeds and their scale dependence.

The principal focus of the Cosmological Bounces and Bouncing Cosmologies group over the past year has been on determining whether stable classical bounces are theoretically possible in which the universe reverses from contraction to expansion at a time when the energy density is well below the Planck scale and quantum gravity effects are highly suppressed. Earlier work by Anna Ijjas, Max Planck Institute for Gravitational Physics, and Paul Steinhardt, Princeton University, had pointed to gravitational braiding as being a promising mechanism to achieve the bounce, also known as NCC (null convergence condition) violation. Braiding means there are derivative couplings between a scalar field and gravity (a generalization of Brans-Dicke theory) that only apply near the bounce where scalar-tensor interactions might naturally be expected but are insignificant at the current energy density of the universe. Papers by the group provided the first proof that violation of the NCC and a classically smooth (nonsingular) bounce can be achieved without generating any pathologies and embedded the bounce in a full geodesically complete cosmology in which the braiding turns off and gravity converges to Einstein gravity in the post-bounce universe, ensuring the theory is in accordance with observations. However, based on the methods conventionally used by cosmologists, there appeared to be the restriction that braiding had to persist throughout the contracting phase so that Einstein gravity is never reached in the pre-bounce past. The puzzling condition imposed a constraint on viable bouncing scenarios; for example, it appeared that cyclic models were not possible.

**PTOLEMY project: Princeton Tritium Observatory for Light, Early-Universe, Massive-Neutrino Yield**

After over two years of intense study, a landmark result was achieved with the submission of a publication that will have an historical impact on the study of the universe at one second after the Big Bang. The paper, titled “A Design for an Electromagnetic Filter for Precision Energy Measurements at the Tritium Endpoint,” demonstrates two orders of magnitude more sensitivity than previously achieved after over half a century of development in electrostatic filters.

Additionally, the first landmark output of the PTOLEMY has been achieved with the new filter design and the several other outcomes have already begun to appear. The original target of the paper was to impact the Division of Particles and Fields (DPF) community planning discussion organized in Snowmass. That progress is in its early phase. However, as the R&D phase project has moved to the Gran Sasso National Laboratory (LNGS) in Italy to evaluate low backgrounds from the target substrate and filter and
calorimeter materials, it is natural that the current focus is with the European Strategy of Particle Physics. To this end, a location is being sought in Italy for the first deployment of new filter design — the first Cosmic Neutrino Telescope.

Simons Observatory

The Simons Observatory (SO) is an ambitious project to study the Cosmic Microwave Background (CMB) to address questions such as: How did the universe begin? What are the properties of its contents? How do the formation of structures evolve under the influence of gravity? And what is the nature of dark energy? The Simons Observatory will be located at 5,200 meters elevation in the Atacama Desert in northern Chile, at a site that currently hosts some of the world’s most advanced telescopes, including the Atacama Cosmology Telescope (ACT) and the Simons Array (SA). The Simons Observatory unites the ACT and SA teams to construct several new telescopes and detector camera receivers with state-of-the-art sensor arrays. The new instrumentation will give SO an unmatched combination of resolution, sensitivity, frequency range and sky coverage. The multifaceted project has made progress in many areas including the Large Aperture Telescope (LAT) having recently passed a major milestone of the Critical Design Review or CDR. The development of the Large Aperture Telescope Receiver (LATR) has been dominated by fine-tuning the design and making changes based on recommendations, including the review of hundreds of machine drawings to check for errors. The Small Aperture Telescope (SAT) team had a series of design reviews to finalize the basic design of the SAT and its interface with the platform. All the designs are now final.
TARGETED GRANTS TO INSTITUTES

This program supports centers of excellence in their effort to extend and enhance their mission. Funding is provided to help establish and strengthen contacts with the international scientific community. Currently, the foundation supports 34 institutes, including six new awards in 2019 to the Institute of Mathematical Sciences of the Americas at the University of Miami, Isaac Newton Institute for Mathematical Sciences at the University of Cambridge, Instituto de Matemáticas at the Universidad Nacional Autónoma de México (UNAM), Hamilton Mathematics Institute at Trinity College Dublin, Steklov Mathematical Institute of the Russian Academy of Sciences and The Abdus Salam International Centre for Theoretical Sciences.

2019 Targeted Grants to Institutes: Awardees

**Institute of Mathematical Sciences of the Americas at the University of Miami**
The University of Miami Department of Mathematics will create and manage the Institute of Mathematical Sciences of the Americas (IMSA), with the goal of building a cohesive mathematical community for the Americas. Intensive, two-year-long research working groups, semester emphasis programs and hot-topic workshops will be key components of IMSA’s work.

**Isaac Newton Institute for Mathematical Sciences at the University of Cambridge**
The Simons Foundation will continue to provide funding to the Isaac Newton Institute for Mathematical Sciences to expand upon the Simons Fellowship Program to support more fellows, provide per diem and travel support, and allow fellows to be appointed to short programs, with the condition that they must stay for the full duration (four to six weeks).

**Instituto de Matemáticas at the Universidad Nacional Autónoma de México (UNAM)**
Funding will go to support Casa Matemática Oaxaca (CMO), a recently created center developed by a partnership between Banff International Research Station (BIRS), UNAM and the Centro de Investigación en Matemáticas. Activities include CMO/BIRS meetings and workshops, research groups, schools and conferences, contributing to the training of U.S.-based mathematical scientists, mostly young researchers, and encouraging interactions with the Mexican, Canadian and Latin American mathematical communities.

**Hamilton Mathematics Institute at Trinity College Dublin**
The Simons Foundation will continue to provide funding to the Hamilton Mathematics Institute to extend the Simons Visiting Professors, the Simons Postdoctoral Fellows and Simons Visiting Scholars programs. Additionally, funding will support an annual Simons Graduate School focusing on mathematics and theoretical physics in alternating years, offering lectures suitable for graduate students and early-career researchers to benefit Irish and international students. The funds will also support the organization of a Simons Symposia during the final two years of the grant, bringing Irish and international mathematicians and physicists together.
TARGETED GRANTS TO INSTITUTES

Steklov Mathematical Institute of the Russian Academy of Sciences
Steklov Mathematical Institute of the Russian Academy of Sciences is a leading institute in Russia covering all significant areas of mathematics and mathematical physics. Simons Foundation support will be used toward conference and research visits, a distinguished lecture series and thematic months, combining several events into one series focused on a particular topic.

The Abdus Salam International Centre for Theoretical Sciences
The Simons Foundation will continue to support the Simons Associates Program, designed to allow scientists from developing countries to spend extended periods at the ICTP. The grant will also enable Simons Ph.D. students to attend the Ph.D. program at the International School for Advanced Studies (SISSA) in Trieste, Italy.
TARGETED GRANTS TO INSTITUTES

AFRICA

Université des Sciences et Techniques de Masuku
Gabon

University of Botswana
Botswana

Université Cheikh Anta Diop de Dakar
Senegal

Mandelstam Institute for Theoretical Physics, University of the Witwatersrand
South Africa

ASIA

Tsinghua Sanya International Mathematics Forum
China

Center for the Study of Living Things
National Center for Biological Sciences
India

International Centre for Theoretical Sciences
Tata Institute of Fundamental Research
India

Institute of Mathematics
Vietnam Academy of Science and Technology
Vietnam

EUROPE

Erwin Schrödinger International Institute for Mathematics and Physics
Austria

Institut des Hautes Études Scientifiques
France

Oberwolfach Research Institute for Mathematics
Germany

International Centre for Theoretical Physics
Italy

Isaac Newton Institute for Mathematical Sciences
United Kingdom

Galileo Galilei Institute at the Istituto Nazionale di Fisica Nucleare
Italy

Institute of Mathematics of the Polish Academy of Sciences
Poland

Niels Bohr International Academy, University of Copenhagen
Denmark

Institut Mittag-Leffler of the Royal Swedish Academy of Sciences
Sweden

Hamilton Mathematics Institute at Trinity College, Dublin
Ireland

International Mathematical Union, Commission for Developing Countries
Germany

Independent University of Moscow
Russia

Saint Petersburg Department of V.A. Steklov Institute of Mathematics of the Russian Academy of Sciences
Russia

Steklov Mathematical Institute of the Russian Academy of Sciences
Russia
TARGETED GRANTS TO INSTITUTES

NORTH AMERICA

Simons Institute for the Theory of Computing
United States

Aspen Center for Physics
United States

Kavli Institute for Theoretical Physics
United States

Mathematical Sciences Research Institute
United States

Institute for Pure and Applied Mathematics, University of California, Los Angeles
United States

Institute for Computational and Experimental Research in Mathematics, Brown University
United States

American Institute of Mathematics
United States

Institute for Nuclear Theory, University of Washington
United States

Institute of Mathematical Sciences of the Americas at the University of Miami
United States

Centre de Recherches Mathématiques, Université de Montréal
Canada

Perimeter Institute
Canada

Instituto de Matemáticas at the Universidad Nacional Autónoma de México
México

SOUTH AMERICA

ICTP South American Institute for Fundamental Research
Brazil

Centre de Recerca Matemàtica
Brazil
Simons Investigators

The Simons Investigators program supports leading scientists in the fields of mathematics, physics, theoretical computer science and mathematical modeling of living systems by providing generous and flexible funding for five to ten years.

Funding received by Investigators is used to support their work during the most active time in their careers, allowing them the freedom to focus on their current research or initiate new research directions as well as cultivate collaborative connections with junior scientists and colleagues by hiring postdocs, hosting visitors and coordinating workshops. The foundation now supports 124 investigators.

Since their appointments, several Simons Investigators have been elected to membership of the American Academy of Sciences and National Academy of Sciences and won such prestigious awards as the Fields Medal, the Rolf Nevanlinna Prize and the Dannie Heineman Prize for Astrophysics.

2019 Academy Elections
National Academy of Sciences
Marc Kamionkowski, Johns Hopkins University
American Academy of Arts and Sciences
Sylvia Serfaty, New York University

Simons Fellows

Simons Fellowships in Mathematics and Simons Fellowships in Theoretical Physics enable the extension of sabbatical leaves from a semester or quarter to a full year, allowing awardees to spend a substantial time away from teaching and administrative duties, focusing only on their research. Since its launch, the foundation has awarded 330 fellowships in math and 121 fellowships in physics. Fellows have been appointed to the National Academy of Sciences, American Academy of Arts and Sciences and won prestigious awards such as the Nobel Prize and Henri Poincaré Prize, among others.

Collaboration Grants for Mathematicians

The ability to work with colleagues both near and far is an essential ingredient for the advancement of ideas and research in mathematics. The Collaboration Grants for Mathematicians program provides support to researchers for travel and hosting collaborators who do not otherwise have access to funding.

The program began in 2011 and has since supported over 1,400 mathematicians. Collaboration Grants for Mathematicians is one of
GRANTS TO INDIVIDUALS

MPS's most popular grants, with over 4,500 applications received since 2011. Awardees receive support for up to five years.

Louis Billera of Cornell University writes, “For me, this Collaboration Grant has been an invaluable asset during my final years as an active faculty member. I formally retired from Cornell in July 2018 after 50 years on the faculty, continuously supported by (mostly NSF) research grants during this period. Not wanting the summer salary of an NSF grant during the last five or so years, this Collaboration Grant enabled me to travel and invite visitors nonetheless, maintaining an active research program as I wound down my teaching responsibilities through a phased retirement program. For this, I am very grateful to the Simons Foundation.”

AMS-Simons Travel Grants

The Simons Foundation, in partnership with the American Mathematical Society, provides early-career mathematicians (within four years of receiving their Ph.D.) the opportunity to travel to conferences and visit current and potential collaborators in their fields. Since 2011, the AMS-Simons Travel Grants have funded almost 2,000 trips by more than 500 recent Ph.D.s.
The aim of the Simons Collaborations in MPS program is to stimulate progress on the fundamental scientific questions of major importance in the broad areas of mathematics, theoretical physics and theoretical computer science. Supported collaborations address questions both concrete and conceptual, with the hope that with answers come major scientific milestones. Among research activities of these collaborations are small workshops and annual meetings held at the foundation. Collaborations are supported initially for four years.

In 2019, the foundation awarded two new collaborations:

**Ultra-Quantum Matter**

Quantum mechanics is well established as the correct and successful theory of the dynamics of electrons, atoms and photons. Yet since its inception, its nonintuitive features — superposition, entanglement and measurement-induced collapse — have perplexed and fascinated physicists. Usually quantum phenomena are associated with atomic scales, but recent revolutionary developments demonstrate that, in the right circumstances, these essential quantum aspects can extend to macroscopic matter. This is ultra-quantum matter (UQM), possessing robust nonlocal quantum entanglement, a key property and a resource. It allows for novel quantum effects impossible at the scale of individual atoms, like the distributed storage of information and electrical charges that are a fraction of the electron’s charge.

The goal of the Simons Collaboration on Ultra-Quantum Matter, directed by Ashvin Vishwanath of Harvard University, is to fully develop the theory of UQM from fundamental characterization and classification to the design for realization and testing of UQM in the lab. To achieve this, the collaboration will bring together experts in condensed matter physics, high energy physics, quantum information and atomic physics. The ramifications range from the discovery of new phases of matter to revolutionary quantum technologies to tabletop models for elementary particles and potentially even quantum gravity.

**Wave Turbulence**

Waves are ubiquitous in nature. They are central in describing fundamental physical phenomena at all scales, from quantum mechanics to general relativity. When in a given physical system a large number of interacting waves are present, the description of an individual wave is neither possible nor relevant. What becomes of physical importance and practical use is the density and statistics of the interacting waves. This is wave turbulence theory, which has the remarkable feature of universally predicting the evolution of the wave action spectral density of interacting wave systems.

Under the leadership of Jalal Shatah of New York University, the Simons Collaboration on Wave Turbulence is the first attempt for a systematic coordinated study of wave turbulence theory in a large-scale project, bringing together state-of-the-art skills in the areas of mathematics and physics, with theoretical, experimental and numerical expertise. It is a joint effort of several groups of researchers who are ready to collectively collaborate, question all assumptions and approximations, and coordinate the progress on an interdisciplinary set of problems.
SIMONS COLLABORATIONS IN MPS

**ALGORITHMS AND GEOMETRY**
Director: Assaf Naor, Princeton University

**ARITHMETIC GEOMETRY, NUMBER THEORY, AND COMPUTATION**
Director: Brendan Hassett, Brown University

**CRACKING THE GLASS PROBLEM**
Director: Sidney R. Nagel, University of Chicago

**HIDDEN SYMMETRIES AND FUSION ENERGY**
Director: Amitava Bhattacharjee, Princeton University

**HOMOLOGICAL MIRROR SYMMETRY**
Director: Tony Pantev, University of Pennsylvania

**IT FROM QUBIT**
Director: Patrick Hayden, Stanford University

**LOCALIZATION OF WAVES**
Director: Svitlana Mayboroda, University of Minnesota

**MANY ELECTRON PROBLEM**
Director: Andrew Millis, Flatiron Institute & Columbia University

**NONPERTURBATIVE BOOTSTRAP**
Director: Leonardo Rastelli, Yang Institute for Theoretical Physics, Stony Brook University

**SPECIAL HOLONOMY IN GEOMETRY, ANALYSIS AND PHYSICS**
Director: Robert Bryant, Duke University

**ULTRA QUANTUM MATTER**
Director: Ashvin Vishwanath, Harvard University

**WAVE TURBULENCE**
Director: Jalal Shatah, New York University
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<tr>
<th>Date</th>
<th>Event</th>
<th>Organizer(s)</th>
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<tbody>
<tr>
<td>January 10–11, 2019</td>
<td>SIMONS COLLABORATION ON ARITHMETIC GEOMETRY, NUMBER THEORY AND COMPUTATION ANNUAL MEETING</td>
<td>Brendan Hassett, Brown University</td>
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<td>February 14–15, 2019</td>
<td>SIMONS COLLABORATION ON THE MANY ELECTRON PROBLEM ANNUAL MEETING</td>
<td>Andy Millis, Simons Foundation</td>
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<tr>
<td>February 27–March 1, 2019</td>
<td>MPS CONFERENCE ON NUMBER THEORY, GEOMETRY, MOONSHINE AND STRINGS III</td>
<td>Jeffery Harvey, University of Chicago</td>
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</tbody>
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| March 7–8, 2019    | SIMONS COLLABORATION ON THE CRACKING THE GLASS PROBLEM ANNUAL MEETING | Giulio Biroi, Institut de Physique Théorique  
                           Jorge Kurchan, LPENS, Paris  
                           Sidney Nagel, University of Chicago  
                           David Reichman, Columbia University |
| March 28–29, 2019  | SIMONS COLLABORATION ON HIDDEN SYMMETRIES AND FUSION ENERGY ANNUAL MEETING | Amitava Bhattacharjee, Flatiron Institute & Princeton University             |
| April 11–12, 2019  | THEORY AND BIOLOGY ANNUAL MEETING                                   | Gregory Gabadadze, Simons Foundation                                         |
| May 17, 2019       | SIMONS COLLABORATION ON ALGORITHMS AND GEOMETRY ANNUAL MEETING      | Assaf Naor, Princeton University                                             |
| June 6–14, 2019    | SIMONS COLLABORATION ON THE MANY ELECTRON PROBLEM SUMMER SCHOOL    | Andrew Millis, Flatiron Institute                                             |
| September 12–13, 2019 | SIMONS COLLABORATION ON SPECIAL HOLONOMY IN GEOMETRY, ANALYSIS AND PHYSICS ANNUAL MEETING | Robert Bryant, Duke University                                               |
## SIMONS CONFERENCES IN MPS

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<th>Date</th>
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<tr>
<td>September 26–27, 2019</td>
<td>ORIGINS OF THE UNIVERSE ANNUAL MEETING</td>
<td>Gregory Gabadadze, Simons Foundation</td>
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<td>Eva Silverstein, Stanford University</td>
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<td>Paul Steinhardt, Stanford University</td>
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<td>October 23–25, 2019</td>
<td>MPS CONFERENCE ON HIGH-DIMENSIONAL EXPANDERS</td>
<td>Alexander Lubotzky, Hebrew University</td>
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<td>November 7–8, 2019</td>
<td>SIMONS COLLABORATION ON THE NONPERTURBATIVE BOOTSTRAP ANNUAL MEETING</td>
<td>Leonardo Rastelli, Yang Institute for Theoretical Physics</td>
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<tr>
<td>November 14–15, 2019</td>
<td>SIMONS COLLABORATION ON HOMOLOGICAL MIRROR SYMMETRY ANNUAL MEETING</td>
<td>Tony Pantev, University of Pennsylvania</td>
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<td>December 5–6, 2019</td>
<td>SIMONS COLLABORATION ON IT FROM QUBIT ANNUAL MEETING</td>
<td>Patrick Hayden, Stanford University</td>
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<td>Matthew Headrick, Brandeis University</td>
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Simons Symposia are meetings on exciting developments in mathematics, theoretical physics and theoretical computer science. For one week, top researchers are brought together for discussions and collaborations in a relaxed yet scientifically stimulating atmosphere. Symposia are normally a series of three meetings held every second year. The foundation awarded two new symposia: Multiscale Physics and Geometry of Arithmetic Statistics, the first meetings of which will take place in spring 2020.

In 2019, the symposium on New Directions in Theoretical Machine Learning held its first meeting. Organized by Sanjeev Arora, Princeton University; Nina Balcan, Carnegie Mellon University; Sanjoy Dasgupta, University of California, San Diego; and Sham Kakade, University of Washington, the gathering brought together a select group of experts with different backgrounds to discuss the next set of theoretical challenges for advancing machine learning and artificial intelligence. A central question in robotics and interactive learning is how to make use of models of the environment (such as physical simulators). While much of machine learning does not utilize models of the world (ML is largely prediction based), the area of robotics is one where it is increasingly clear that models of the environment are important. Drew Bagnell is one of the world’s leading experts in self-driving cars, along with being a leading robotics theorist, and he discussed the interplay of human demonstration with physical models; the focus was on how to obtain provably better planning algorithms (say for self-driving cars) utilizing models of the world along with human examples. Emo Todorov is a robotics theorist and has also developed one of the most widely used physics simulators in robotics; he spoke about how ML methods for robotics are unlikely to succeed without incorporating physical models. Emma Brunskill discussed the fundamental limits of how accurately we need to learn a model in order to utilize it for planning purposes.

Sham Kakade writes, “This was a wonderful event where I think everyone started rethinking their research questions in order to think about the role of deep learning in tackling more ambitious questions. Many people actively started new collaborations. Personally, I have a number of new questions to follow up on.”

The next gathering of the Simons Symposia will be in 2020 at Schloss Elmau resort in Bavaria, Germany.
<table>
<thead>
<tr>
<th>Symposium Years</th>
<th>Organizers</th>
<th>Title</th>
<th>Speakers</th>
</tr>
</thead>
</table>
| 2019            | Laura DeMarco, Northwestern University  
                    Mattias Jonsson, University of Michigan | ALGEBRAIC, COMPLEX AND ARITHMETIC DYNAMICS                      |          |
| 2019            | Nima Arkani-Hamed, Institute for Advanced Study  
                    Daniel Baumann, University of Amsterdam  
                    John Joseph Carrasco, Northwestern University and the Institute for Theoretical Physics (IPhT, CEA-Saclay)  
                    Daniel Green, University of California, San Diego | AMPLITUDES MEET COSMOLOGY                                   |          |
| 2012, 2014, 2016 | Elchanan Mossel, University of California, Berkeley  
                    Ryan O'Donnell, Carnegie Mellon University  
                    Krzysztof Oleszkiewicz, University of Warsaw | ANALYSIS OF BOOLEAN FUNCTIONS/DISCRETE ANALYSIS BEYOND THE BOOLEAN CUBE |          |
| 2014, 2016, 2018 | Werner Müller, Mathematical Institute of the University of Bonn  
                    Sug Woo Shin, University of California, Berkeley  
                    Nicolas Templier, Cornell University | FAMILIES OF AUTOMORPHIC FORMS AND THE TRACE FORMULA |          |
| 2014, 2016, 2018 | Andrew Benson, Carnegie Observatories  
                    Juna Kollmeier, Carnegie Observatories | GALACTIC SUPERWINDS: BEYOND PHENOMENOLOGY |          |
| 2020            | Aline Bucur, University of California, San Diego  
                    Jordan Ellenberg, University of Wisconsin, Madison  
                    Ila Varma, University of California, San Diego  
                    David Zureick-Brown, Emory University | GEOMETRY OF ARITHMETIC STATISTICS |          |
| 2012, 2015, 2016 | Fedor Bogomolov, New York University  
                    Brendan Hassett, Rice University  
                    Yuri Tschinkel, Simons Foundation | GEOMETRY OVER NONCLOSED FIELDS |          |
| 2013            | Alexei Borodin, Massachusetts Institute of Technology  
                    Jeremy Quastel, University of Toronto  
                    Herbert Spohn, Technische Universität München | THE KARDAR–PARISI–ZHANG EQUATION |          |
## SIMONS SYMPOSIA

### Symposium Years: 2012
Organizers

**KNOT HOMOLOGIES AND BPS STATES**

- **Davide Gaiotto**, Perimeter Institute
- **Sergei Gukov**, California Institute of Technology
- **Mikhail Khovanov**, Columbia University
- **Jacob Rasmussen**, University of Cambridge

### Symposium Years: 2018, 2020
Organizers

**ILLUMINATING DARK MATTER**

- **Rouven Essig**, Stony Brook University
- **Jonathan Feng**, University of California, Irvine
- **Kathryn Zurek**, Lawrence Berkeley National Laboratory

### Symposium Years: 2020
Organizers

**MULTI-SCALE PHYSICS**

- **Alexander Schekochihin**, Oxford University
- **Eliot Quataert**, University of California, Berkeley
- **Laure Zanna**, New York University

### Symposium Years: 2013, 2015, 2017
Organizers

**NEW DIRECTIONS IN APPROXIMATION ALGORITHMS**

- **Sanjeev Arora**, Princeton University
- **Michel Goemans**, Massachusetts Institute of Technology
- **Uriel Feige**, Weizmann Institute of Science
- **David Shmoys**, Cornell University

### Symposium Years: 2019
Organizers

**NEW DIRECTIONS IN THEORETICAL MACHINE LEARNING**

- **Sanjeev Arora**, Princeton University
- **Maria-Florina Balcan**, Carnegie Mellon University
- **Sanjoy Dasgupta**, University of California, San Diego
- **Sham Kakade**, University of Washington

### Symposium Years: 2013, 2015, 2017
Organizers

**NON-ARCHIMEDEAN AND TROPICAL GEOMETRY**

- **Matthew Baker**, Georgia Institute of Technology
- **Sam Payne**, Yale University

### Symposium Years: 2017, 2019
Organizers

**P-ADIC HODGE THEORY**

- **Bhargav Bhatt**, University of Michigan
- **Martin Olsson**, University of California, Berkeley

### Symposium Years: 2018, 2020
Organizers

**PERIODS AND L-VALUES OF MOTIVES**

- **Jean-Benoit Bost**, University of Paris
- **Gisbert Wüstholz**, ETH and University of Zurich
- **Shou-Wu Zhang**, Princeton University
## SIMONS SYMPOSIA

<table>
<thead>
<tr>
<th>Symposium Years: 2013, 2015, 2017</th>
<th>QUANTUM ENTANGLEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizers</td>
<td>Shamit Kachru, Stanford University</td>
</tr>
<tr>
<td></td>
<td>Hirosi Ooguri, California Institute of Technology</td>
</tr>
<tr>
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<td>Subir Sachdev, Harvard University</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symposium Years: 2012, 2014</th>
<th>QUANTUM PHYSICS BEYOND SIMPLE SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizers</td>
<td>Boris Altshuler, Columbia University</td>
</tr>
<tr>
<td></td>
<td>Vladimir Falko, Lancaster University</td>
</tr>
<tr>
<td></td>
<td>Charles Marcus, Niels Bohr Institute</td>
</tr>
</tbody>
</table>
arXiv

Since its inception in 1991, with a focus on the high-energy physics community, arXiv has significantly expanded both its subject coverage and user base. It provides open access to about 1.5 million e-prints in physics, mathematics, computer science, quantitative biology, quantitative finance, statistics, electrical engineering and systems science, and economics. In 2018, the repository received 140,616 new submissions, a 14 percent increase from 2017. The subject distribution is evolving as computer science represented about 26 percent of overall submissions, and math 24 percent. In July 2018 the subject areas of theoretical economics and general economics were added. There were about 228 million downloads from all over the world proving that arXiv is truly a global resource.

In 2019, the arXiv development team improved the platform with updates to various search, browse and account features with new software components being developed in public repositories and released under permissive open source licenses wherever possible.

Magma

Magma is a large, well-supported software package designed for computations in algebra, number theory, algebraic geometry and algebraic combinatorics. The Simons Foundation bought a site license that covers all academic and nonprofit research users in the United States.

In 2019, there were 211 participating entities (sites) in the Simons-Magma scheme, which includes the following:

- 171 mathematics departments
- Eight combined mathematics and computer science departments
- Eight computer science departments
- Seven university HPC centers
- Three physics departments
- Three engineering departments/laboratories
- One chemistry department
- One U.S. service academy
- Six independent research institutes:
  - American Institute of Mathematics (San Jose)
  - Institute for Advanced Study (Princeton)
  - Institute for Computational and Experimental Research in Mathematics (Providence, RI)
  - Mathematics Sciences Research Institute (Berkeley)
  - On-Line Encyclopedia of Integer Sequences
  - Santa Fe Institute (Santa Fe)
- Two university-based medical research institutes:
  - Canary Center at Stanford for Cancer Early Detection (Stanford)
  - Neuroscience Institute (Princeton)
Initiated in 2013, the Society of Fellows strives to create a community of scholars and to encourage intellectual interactions across disciplines and across research centers in the New York City area. Junior Fellows are selected by a group of Senior Fellows in collaboration with Simons Foundation senior scientists. Since its inception, the Society of Fellows has appointed 62 Junior Fellows and has seen three classes of Junior Fellows graduate.

In the spring of 2019, the Fellows attended a retreat in Palmetto Bluff, SC, featuring talks by Junior and Senior Fellows.

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New York University

JAROSŁAW BŁASIOK
Columbia University

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Columbia University

SYLVAIN CARPENTIER
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New York University

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New York University School of Medicine

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Courant Institute of Mathematical Sciences

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New York University

KEITH HAWKINS
Columbia University

AILSA KEATING
Columbia University

KOHEI INAYOSHI
Columbia University

BORIS LEISTEDT
New York University

RAFAEL MAIA
Columbia University

ANTIGONI POLYCHRONIADOU
Cornell University

ILYA RAZENSHTEYN
Columbia University

ADITI SHESHADRI
Columbia University

MIJO SIMUNOVIC
Rockefeller University

YI SUN
Columbia University

LI-CHENG TSAI
Columbia University

OMRI WEINSTEIN
New York University

ZHENG (HERBERT) WU
Columbia University
MPS BUDGET

Grants to Individuals

Grants to Institutes

Conferences, Symposia & Lectures

Infrastructure