2016 Annual Meeting

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Simons Fellows
Dear Colleagues,

Welcome to the 2016 Annual Meeting of the Mathematics and Physical Sciences (MPS) Division of the Simons Foundation!

The Foundation continues its rapid growth. The most exciting development of the last year is the Flatiron Institute, a new unit of the Foundation wholly devoted to in-house research and housed across the street from the Foundation. The Flatiron Institute will consist of several centers, each of approximately 50 people and focused on different computationally intensive aspects of science. Two of these have been established: the Center for Computational Astrophysics, headed by David Spergel, and the Center for Computational Biology (formerly SCDA), headed by Leslie Greengard. Other centers are under consideration.

Within MPS, we have added new collaborations: Cracking the Glass Problem (Director Syd Nagel), the Conformal Bootstrap (Director Leonardo Rastelli) and Special Holonomy (Director Robert Bryant). We have recently announced the creation of the Simons Observatory, a large-scale effort in early universe cosmology, which will combine and extend the POLARBEAR/Simons Array and the Atacama Cosmology Telescope to look into the earliest moments of the universe. We are also expanding the range and scope of scientific meetings at the Foundation. But our main focus continues to be you, the extraordinary scientists we support.

Our annual meeting is an occasion for all of us to meet, to discuss the most exciting recent ideas in science and to brainstorm about future directions in our respective fields.

We wish you a productive meeting! Welcome!

Yuri Tschinkel
Director

Andy Millis
Associate Director for Physics
Meeting Information
Meeting Information

Hotel Information

The Roger
131 Madison Avenue, between 30th and 31st Streets
New York, NY 10016
T: (212) 448-7000
www.therogernewyork.com

WiFi is complimentary in each guest room.

Checkout 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 Friday 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. Please be sure you have attached a luggage tag with your name printed clearly.

Contact information

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

Ground transportation questions:
Emily Klein
eklein@simonsfoundation.org
(646) 751-1262
Venue

Gerald D. Fischbach Auditorium
Simons Foundation
160 Fifth Avenue (at 21st Street)
New York, NY 10010
T: (646) 654-0066
www.simonsfoundation.org

WiFi at the Gerald D. Fischbach Auditorium
Network Name 160Guest 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 20

8:30 - 9:30 AM  Check-in & Breakfast
9:30 - 10:30 AM Mina Aganagic  String Duality and Mathematics
10:30 - 11:00 AM Break
11:00 AM - 12:00 PM Lisa Manning  Jamming in Biological Tissues
12:00 - 1:30 PM Lunch
1:30 - 2:30 PM Julia Hartmann  Geometry and Algebra: From Local to Global
2:30 - 3:00 PM Break
3:00 - 4:00 PM Dan Boneh  Recent Developments in Cryptography
4:00 - 4:30 PM Break
4:30 - 5:30 PM Daniel Eisenstein  Dark Energy and Cosmic Sound
6:00 PM Dinner @ Park Avenue Autumn

Friday October 21

8:30 - 9:30 AM  Check-in & Breakfast
9:30 - 10:30 AM Paul Seidel  Symplectic Topology Away from the Large Volume Limit
10:30 - 11:00 AM Break
11:00 AM - 12:00 PM Andrea Alù  Breaking Reciprocity and Time-reversal Symmetry with Metamaterials
12:00 - 1:00 PM Lunch
1:00 Rich Schwartz  Five Points on a Sphere
Dinner will be at Park Avenue Autumn at 6:00 PM on Thursday, October 20.

**Park Avenue Autumn**
360 Park Avenue South
New York, NY 10010
T: (212) 360-0438
www.parkavenuenyc.com

Walking directions from the Simons Foundation to Park Avenue Autumn:

- Head east on 21st Street toward Fifth Avenue.
- Turn left on Fifth Avenue.
- Turn right on 23rd Street.
- Turn left on Park Avenue South.
- Destination will be on the left.
Speaker Profiles
The relationship between mathematics and physics has a long history. Traditionally, mathematics provides the language physicists use to describe nature. In turn, physics brings mathematics to life, by providing inspiration and interpretation. String theory is changing the nature of this relationship. Aganagic will try to explain why and give listeners a flavor of the emerging field.

**Mina Aganagic** applies insights from quantum physics to mathematical problems in geometry and topology. She made deep and influential conjectures in enumerative geometry, knot theory and mirror symmetry using predictions from string theory and M-theory.
Andrea Alù will discuss recent work focused on breaking reciprocity and time-reversal symmetry in metamaterial structures, spanning acoustics, radio waves, nanophotonics and mechanics, without relying on magnetic bias. Alù’s and his collaborators’ approaches are based on using suitably tailored mechanical motion, spatio-temporal modulation and large nonlinearities in coupled resonator systems to realize unusual wave-matter interactions. Alù will discuss the theoretical framework and the modeling, design and implementation of non-reciprocal devices that break Lorentz reciprocity and achieve electromagnetic isolation without using magnetic bias. He will also discuss the impact of these concepts on things ranging from basic science to integrated technology, and how this platform may be at the basis of topological insulators for light, sound and mechanical waves.

Andrea Alù’s work on the manipulation of light in artificial materials and metamaterials has shown how clever designs may surpass what had previously been thought to be limitations on wave propagation in materials. He has developed new concepts for cloaking, one-way propagation of waves in materials, dramatic enhancement of nonlinearities in nanostructures and ultrathin optical devices based on metasurfaces and twisted metamaterials.
Cryptography, the science of secure communication, has advanced considerably in the last fifteen years. With the introduction of tools, such as bilinear maps, multilinear maps and integer lattices, applications that were previously out of reach became possible and sometimes even quite practical. This talk will survey some of these recent developments, giving examples of constructions and proofs techniques, and posing some open problems that are central to further progress.

Dan Boneh is an expert in cryptography and computer security. One of his main achievements is the development of pairing-based cryptography, giving short digital signatures, identity-based encryption and novel encryption systems.
Daniel Eisenstein will discuss how the acoustic oscillations that propagate in the cosmic plasma during the first million years of the universe provide a robust method for measuring the cosmological distance scale. The distance that the sound can travel can be computed to high precision and creates a signature in the late-time clustering of galaxies that serves as a standard ruler. Maps from the Sloan Digital Sky Survey (SDSS) reveal this feature, yielding accurate measurements of the expansion history of the universe. Eisenstein will describe the theory and practice of the acoustic oscillation method and highlight the latest cosmology results from SDSS.

Daniel Eisenstein is a leading figure in modern cosmology. He is known for utilization of the baryon acoustic oscillations standard ruler for measuring the geometry of the universe, which underpins several large, upcoming ground and space missions. Eisenstein blends theory, computation and data analysis seamlessly to push the boundaries of current-day research in cosmology.
Arithmetic geometry views algebraic and arithmetic objects, such as numbers, in a geometric way. This interplay between number theory and algebraic geometry has been a source of inspiration in modern mathematics, as it permits the study of number theoretic problems via geometric methods. Having led to the solution of a number of conjectures, including Fermat’s Last Theorem, it continues to give rise to deep and important problems in algebra.

Local-global principles are a central theme in this interplay of subjects, and many important mathematical problems can be expressed in terms of such principles. Local-global principles in algebra (and other mathematical disciplines) are motivated by analogous geometric principles, by which certain properties of spaces can be determined by considering whether or not they hold locally. The talk will explain these concepts and outline how patching methods can lead to new local-global principles.

Julia Hartmann has been a professor at the University of Pennsylvania since 2014. Prior to that, she was the head of a research group at RWTH Aachen University and a von Neumann Fellow at the Institute for Advanced Study.

Hartmann’s research focuses on problems in algebra with relations to differential algebra and arithmetic geometry. The connecting theme of the questions she works on is the study of symmetries, i.e., of actions of groups on various algebraic objects. In collaboration with David Harbater, she developed the method of field patching. Among the most exciting applications of field patching are local-global principles for numerical invariants associated to fields.
Biological tissues are living materials, with material properties that are important for their function. Recent experiments have shown that many tissues, including some involved in embryonic development, lung function, wound healing, and cancer progression, are close to a liquid-to-solid, or "jamming," transition, similar to the one that occurs when oil and liquid are mixed to make mayonnaise. In mayonnaise and materials like it, a disordered liquid-to-solid transition occurs when the packing density of oil droplets increases past a critical threshold. Over the past 20 years, physicists and mathematicians have made progress in understanding the universal nature of this transition. However, existing theories cannot explain observations of jamming transitions in confluent biological tissues, where there are no gaps between cells and the packing density is always unity. Manning will discuss a theoretical and computational framework for predicting the material properties of such biological tissues, and show that it predicts a novel type of critical rigidity transition, which takes place at constant packing density and depends only on single cell properties, such as cell stiffness. She will show that our a priori theoretical predictions with no fit parameters are precisely realized in cell cultures from human patients with asthma, and she will discuss how we are applying these ideas to understand other processes, such as embryonic development and cancer progression.

Lisa Manning started her research career in the physics of glasses, i.e., how a disordered group of molecules or particles freezes into a rigid solid at a well-defined temperature. She then turned her attention to morphogenesis, the process by which embryos transform from a spherical egg to a shape we recognize as an insect, plant or mammal, showing that aspects of this process could be modeled by surface tension in analogy with the description of immiscible liquids. Her most recent work uses ideas from the physics of glasses to describe the mobility of cells organized in sheets and applies to a broad class of biological tissues, including embryos and cells from asthma patients.
Thomson’s problem, going back to 1904, asks how N points on the sphere are arranged so as to minimize the Coulomb potential, i.e., the sum of the reciprocal distances taken over all pairs of points. A generalization involves using other power law potentials besides the Coulomb potential, i.e., summing other powers of the distances over all pairs of points. The Coulomb potential corresponds to exponent -1. The case N = 5 has been notoriously intractable. Schwartz will sketch his computer-assisted but still rigorous proof that the triangular bi-pyramid is the potential-minimizing configuration with respect to all power laws with exponent in [-1, 0) and the potential-maximizing configuration when the exponent is in (0, 2). As Schwartz will explain, these ranges of exponents are fairly sharp.

Richard Schwartz was born in Los Angeles in 1966. In his youth, he enjoyed video games and sports, especially tennis. He got a B.S. in math from University of California, Los Angeles in 1987 and a Ph.D. in math from Princeton University in 1991. He gave an invited talk at the International Congress of Mathematicians in 2002. He is currently the Chancellor’s Professor of Mathematics at Brown University. He likes to study simply stated problems with a geometric flavor, often with the aid of graphical user interfaces and other computer programs that he writes himself. Aside from his work in math, he has written and illustrated a number of picture books, including You Can Count on Monsters, Really Big Numbers, Gallery of the Infinite and Man Versus Dog.
Symplectic topology is unique within geometry, in that the deeper structure of the spaces under consideration appears only after non-local “instanton corrections” have been taken into account. This is most readily apparent from a string theory motivation, but it also has a direct impact on classical problems from Hamiltonian mechanics. In the theory, the instanton corrections are set up as small perturbations, which corresponds to thinking of the target space as having infinitely large size (the “large volume limit”). Mirror symmetry suggests that it would be interesting to keep the size finite. Attempting to do that has seemingly paradoxical consequences, which one can sometimes get a handle on by changing the space involved. The talk will give an introduction to this problem, based on simple examples, and explain a little of what is known or expected.

Paul Seidel has done major work in symplectic geometry, in particular on questions inspired by mirror symmetry. His work is distinguished by an understanding of abstract algebraic structures, such as derived categories, in sufficiently concrete terms to allow one to derive specific geometric results. On the abstract side, Seidel has made substantial advances toward understanding Kontsevich’s homological mirror symmetry conjecture and has proved several special cases of it. In joint papers with Smith, Abouzaid and Maydanskiy, he has investigated the symplectic geometry of Stein manifolds. In particular, work with Abouzaid constructs infinitely many nonstandard symplectic structures on any Stein manifold of sufficiently high dimension.
Mathematics & the Physical Sciences Division
SCIENTIFIC ADVISORY BOARD

Mathematics

Charles Epstein  
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Margaret Wright  
COURANT INSTITUTE OF MATHEMATICAL SCIENCES

Alfred Aho  
COLUMBIA UNIVERSITY
TARGETED GRANTS

Targeted Grants in MPS

Targeted Grants in the Mathematics and Physical Sciences Division of the Simons Foundation support high-risk projects of exceptional promise and scientific importance. The foundation has funded three major initiatives to date: the Simons Array (a contribution to the POLARBEAR cosmology project), the PTOLEMY Project to detect relic neutrinos, and CASPER, an axion-detection experiment.

Simons Array

The goal of this Simons Foundation–funded project is to deploy and operate a powerful new cosmic microwave background (CMB) polarization experiment called the Simons Array. The Simons Array will feature three multi-frequency cryogenic receivers operating on three separate 3.5m radio telescopes from our high-altitude site in northern Chile. These telescopes will observe for a period of three years. These observations will execute the deepest search for inflationary gravitational waves, and we will use these data to discriminate between the many possible models predicted in modern cosmological theories of the origin of the universe.

In addition to the bold goal of measuring or characterizing inflationary models, the Simons Array will characterize the signal from gravitational lensing on small angular scales to constrain the minimum neutrino mass to 40 meV with 1-sigma significance when combined with Baryon Acoustic Oscillation data, thus addressing the question of neutrino hierarchy.
In the past year, the team has successfully designed, fabricated, deployed and controlled the three Simons Array telescopes at the same observatory that were built up for the successful POLARBEAR experiment (at an altitude of 5,200 meters in the Atacama Desert in northern Chile; see attached photo). Also nearing completion are the POLARBEAR-2 receiver “cameras” that must cool more than 7,000 superconducting detectors to 0.25 Kelvin. Two more receivers are under construction for the second and third telescopes and major progress has already been made.

On the analysis front, the POLARBEAR collaboration continues to analyze data from the first two full observing seasons with the POLARBEAR-1 experiment. POLARBEAR-1 continues to take data using a telescope that will eventually be outfitted with a new POLARBEAR-2 receiver. This past year has seen the publication of the first upper limit of an exotic phenomenon known as “anisotropic cosmic birefringence” from a ground-based CMB polarimeter, in this case POLARBEAR-1. These are not only the first such upper limits, but they also have allowed us to constrain the “seeds” of primordial magnetic fields (PMF).

PTOLEMY Project

The vast production and release of neutrinos into the universe are unequivocal predictions of Big Bang cosmology. However, in the context of these predictions, we face great uncertainties in the nature of dark energy, the origin of early universe non-equilibrium processes generating baryon asymmetry, and in neutrino properties and the origin of their masses. The PTOLEMY project examines the possibility to harness new developments in material science and microcalorimetry to overcome age-old experimental limitations to the present-day direct detection of the primordial relic neutrinos. The highlights of recent achievements are:

(1) Sub-eV molecular energy smearing — Never before have we been closer to achieving large-scale hydrogen storage at the sub-eV level. PTOLEMY has been the first to achieve cold-plasma loading of monolayer graphene surfaces with hydrogen, using techniques developed at the Princeton Plasma Physics Laboratory (PPPL). The heaviest isotope of hydrogen is the key to unlocking direct interactions with the relic neutrinos. PTOLEMY collaborators at Savannah River National Laboratory (SRNL) have produced the world’s first samples of tritiated graphene. The achievements in material processing and analysis of hydrogenated graphene and other substrates, such as TMDs and cryogenic Cu/Au(111), will ascertain whether weakly bound hydrogen will reduce molecular energy smearing to the required sub-eV levels.
MPS PROGRAM SUMMARY

(2) Sub-eV energy measurements — the world’s first ultra-low energy electron microcalorimeter will measure 10eV electrons to a precision approaching the 0.05eV energy scale determined from neutrino-oscillation experiments. Transition-edge sensors (TES) are a driving force behind precision CMB measurements and space-based X-ray astronomy. TES microcalorimetry for electron measurements will break new records in energy resolution, plowing the way for neutrino-mass sensitivity. The PTOLEMY microcalorimetry from StarCryo is under installation, and new designs produced by Argonne National Laboratory (ANL) will be testing in the coming year.

(3) Large-scale electromagnetic filtering and triggering on semi-relativistic electrons — a never before developed electron-filtering method is being studied computationally and incorporates a trigger system based on cyclotron radiation emission. The instrumented surface area of tritiated graphene required to achieve sensitivity to relic neutrinos is many orders of magnitude larger than previous neutrino mass experiments. A reduction of four orders of magnitude in the volume of the filter vacuum comes from a compact, planar filter design with closely stacked graphene layers. Computational studies of this method with a newly equipped fat node have achieved proof-of-principle results.

In summary, the PTOLEMY project, launched in September of 2015 under Simons Foundation funding, is achieving its milestones with breakthrough experimental methods and is on schedule to release publications on these achievements in the coming year. PTOLEMY, made possible by the Simons Foundation, is the center of intellectual leadership and the future of relic-neutrino detection.

Rethinking Relic Neutrino Detection

- Relic Neutrinos → Highest intensity DC neutrino flux in the Universe
- Massive neutrinos → High resolution electron microcalorimetry at 10eV →~0.05eV sensitivity(?)
- RF triggering on single e⁻ → Large-scale tritium target and filtering of endpoint electrons
- Tritiated-Graphene target
- ExB filter ~$10^4$ length of KATRIN for microcalorimeter
- How many?
  (Signal shape and location predicted from mass measurement)


** PROJECT 8 **

SRNL
CASPer

The nature of dark matter is one of the most important mysteries in modern physics. A well-motivated hypothesis consistent with available astrophysical data is that dark matter consists of energy stored in oscillations of a so-called axion field permeating space. The Cosmic Axion Spin Precession Experiment (CASPer) aims to detect the oscillating dark matter field by searching for axion-induced nuclear spin precession using the methods of nuclear magnetic resonance (NMR). The CASPer collaboration is pursuing a multi-pronged approach to develop NMR-based experimental probes targeting different axion dark matter scenarios in a variety of parallel experiments, while simultaneously carrying out research and development of new ideas that will lay the groundwork for an ultimate search targeting a large swath of the QCD axion parameter space that, to date, has been extremely difficult to probe experimentally.

The two first generation direct axion dark matter search experiments are CASPer Electric at Boston University and CASPer Wind at the Helmholtz Institute Mainz. CASPer Electric looks for an oscillating nuclear dipole moment induced by the axion field, while CASPer Wind searches for nuclear spin precession induced by the relative velocity of the axion field with respect to the laboratory frame. Progress in the design and the construction of the experiments in this first year of the project includes design of superconducting magnet systems with the capability of scanning magnetic fields 0–14T and of cryogenic probes to allow precise measurement of nuclear spin precession, as well as construction of the associated detection electronics. A system for hyperpolarization of liquid xenon, the material to be used in CASPer Wind, is presently being experimentally optimized at Mainz. The team at Boston University is beginning tests of the ferroelectric crystals to be used in the CASPer Electric experiment, in order to optimize nuclear spin relaxation rates and other relevant properties. In order to inform the experimental design, the teams has carried out investigations related to the electronic signal detection, sample temperature control, magnetic field inhomogeneities and vibrational noise. The collaboration expects to carry out construction of the complete experimental apparatuses in the next year. In parallel, the team has initiated research into (1) a novel magnetometry technique involving a micron-scale precessing ferromagnetic needle that has the potential to average away quantum noise, (2) new types of samples and NMR techniques that could be used for CASPer, such as parahydrogen-induced polarization of acetonitrile and (3) the use of precision spectroscopy of helium to constrain axion-induced atomic forces. In addition to the above experimental work, support from the Simons Foundation also enabled theoretical work on the axion in relation to the hierarchy problem of the Standard Model, a problem that has been the central focus of research in particle theory for the past 30 years. The hierarchy problem arises from an elementary observation: the gravitational force is orders of magnitude weaker than the other fundamental forces of nature. Previous proposed solutions to this problem, such as supersymmetry, require the existence of new particles that should be, but have not yet been, observed at the Large Hadron Collider. The new axion-based mechanism does not require new physics at the Large Hadron Collider. Instead, it posits that the mass of the Higgs boson could have been very different in the early universe and cosmological evolution then naturally drives the Higgs mass to its presently observed value. The axion is at the heart of this mechanism, and if it is correct experiments such as CASPer will be crucial for experimentally addressing the hierarchy problem.
In addition to the above experimental work, support from the Simons Foundation also enabled theoretical work on the axion. In particular, it was shown that the framework of the axion has a unique ability to address the hierarchy problem of the Standard Model, a problem that has been the central focus of research in particle theory for the past 30 years. The hierarchy problem arises from an elementary observation: the gravitational force is orders of magnitude weaker than the other fundamental forces of nature. This is due to the fact that the mass of the Higgs boson is many orders of magnitude smaller than the fundamental scale of quantum gravity. All previous solutions to this problem, such as supersymmetry, require the existence of new particles that have not been observed at the Large Hadron Collider. These solutions were based on the implicit assumption that the mass of the Higgs was a fundamental constant of nature. In contrast, the new mechanism of dynamical relaxation does not require new physics at the Large Hadron Collider. Instead, it posits that the mass of the Higgs boson could have been very different in the early universe and cosmological evolution then naturally drives the Higgs mass to its presently observed value. The axion is at the heart of this mechanism, and experiments such as CASPER are crucial for experimentally addressing the hierarchy problem.

Targeted Grants to Institutes

Targeted Grants to Institutes 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 29 institutes, including five new awards in 2016 to the Institute for Pure and Applied Mathematics at UCLA, Niels Bohr International Academy at the University of Copenhagen, Institut Mittag-Leffler of the Royal Swedish Academy of Sciences, Hamilton Mathematics Institute at Trinity College Dublin and the International Mathematical Union.

2016 Targeted Grants to Institutes: Awardees

Institute for Pure and Applied Mathematics at UCLA

The Institute for Pure and Applied Mathematics (IPAM) sponsors programs that bring together researchers from different disciplines or from different areas of mathematics with the goal of sparking long-term interdisciplinary collaboration. The Simons Foundation will provide support to enable senior participants to participate in long programs as well as the enhancement of IPAM’s video facility to make lectures more widely accessible.

Niels Bohr International Academy at the University of Copenhagen

The Niels Bohr International Academy (NBIA) is an independent center of excellence hosted by the Niels Bohr Institute. Its mission is to attract the best and brightest to Denmark, to an environment that enables breakthrough research in the physical sciences and mathematics. The Simons Foundation will support a three-year program of Simons Visiting Professorships in theoretical physics at the NBIA, for a total of six four-month professorships.
MPS PROGRAM SUMMARY

Institut Mittag-Leffler of the Royal Swedish Academy of Sciences
Institut Mittag-Leffler (IML) is an international center for research and postdoctoral training in mathematical sciences. The Simons Foundation will support two larger conferences during the major research programs at the IML and enable prominent scientists normally not able to come for longer periods to participate in the IML activities to the benefit of existing research programs.

Hamilton Mathematics Institute at Trinity College Dublin
The Hamilton Mathematics Institute (HMI) aims to foster and support the economic, cultural and societal benefits of mathematics and fundamental science as drivers of progress in Ireland. The Simons Foundation will provide funding for three new appointment types in pure mathematics and theoretical physics: Simons Distinguished Visiting Professor, Simons Postdoctoral Fellow and Simons Visiting Scholar.

International Mathematical Union
International Mathematical Union (IMU) Commission for Developing Countries is a program of cooperation with and in support of mathematical institutions and individual mathematicians in the developing world. The Simons Foundation will provide funds to establish the IMU-Simons African Fellowship Program to support individual research-related travel and living costs for mathematicians from developing countries in Africa to travel to a center of excellence in any part of the world for collaborative research.

AFRICA
Africa Mathematics Project
Université des Sciences et Techniques de Masuku GABON
International University of Science and Technology BOTSWANA
Université Cheikh Anta Diop de Dakar SENEGAL

ASIA
Tsinghua Sanya International Mathematics Forum CHINA
National Centre for Biological Sciences, Tata Institute INDIA
MPS PROGRAM SUMMARY

American University of Beirut
LEBANON

Independent University of Moscow
RUSSIA

International Centre for Theoretical Sciences of Tata Institute of Fundamental Research
INDIA

EUROPE

The Erwin Schrödinger International Institute
AUSTRIA

Institut des Hautes Études Scientifiques
FRANCE

International Mathematical Union
GERMANY

Mathematical Research Institute Oberwolfach
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 at the 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

Centre de Recerca Matemàtica
SPAIN
MPS PROGRAM SUMMARY

NORTH AMERICA

Simons Institute for the Theory of Computing
UNITED STATES

The 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 at UCLA
UNITED STATES

SOUTH AMERICA

ICTP South American Institute for Fundamental Research
BRAZIL
Targeted Grants in Mathematical Modeling of Living Systems

Targeted Grants in MMLS support research in the life sciences. The awards are intended to foster a culture of theory-experiment collaboration similar to that prevailing in the physical sciences by stimulating the development of mathematical models that explain classes of experimental results and suggest new directions for research and experimentation aimed at testing theoretical ideas and expanding their reach.

The foundation currently supports 12 Targeted Grants in MMLS:

- **Adaptive Molecular Sensing in the Olfactory and Immune Systems**
  Vijay Balasubramanian, *University of Pennsylvania*

- **Collective Bacterial Decision-Making**
  Sam Brown, Howard Weiss & William Ratcliff, *Georgia Institute of Technology*

- **Building a Proportional Cell: Design Principles of Biological Size Control**
  Jané Kondev, *Brandeis University*

- **A New Framework for Ecological Kinetics in Natural Environments**
  Simon A. Levin, *Princeton University*

- **What Constrains Microbial Diversity? Deriving New Ecological Principles for the Microbial World**
  Pankaj Mehta, *Boston University*
  Alvaro Sanchez, *Yale University*

- **Coarse-Graining Bacterial Metabolic Network: From Molecules to Growth Physiology**
  Terence Hwa, *University of California, San Diego*

- **Natural Selection in Rapidly Mutating Populations and Mitochondrial Aging**
  Boris Shraiman, *University of California, Santa Barbara*
  Daniel E. Gottschling, *Fred Hutchinson Cancer Research Center*

- **Microscopic Foundations for Macroecological Patterns**
  Christopher Klausmeier & Elena Litchman, *Michigan State University*

- **Models of Collective Cell Migration and Sorting**
  M. Cristina Marchetti, *Syracuse University*
MPS PROGRAM SUMMARY

Learning How Living Systems Navigate Turbulent Environments
Massimo Vergassola, University of California, San Diego

Role of Higher-Order Interactions for Stability of Microbial Communities
Kalin Vetsigian, University of Wisconsin-Madison

Acquisition, Storage and Inheritance of Information in Dynamical Living Matter
Stanislas Leibler, Institute for Advanced Study and the Rockefeller University

Math + X: Encouraging Interactions

Maarten de Hoop joined Rice University in 2015 as the Simons Chair in Computational and Applied Mathematics and Earth Science. His research interests are in inverse problems, microlocal analysis and computation, and applications in exploration and global seismology and geodynamics. In addition to his appointments at Rice and Purdue, de Hoop has been on the faculty of Colorado School of Mines, is a visiting faculty member at Massachusetts Institute of Technology and the Graduate University of Chinese Academy of Sciences in Beijing, and was a senior research scientist and program leader with Schlumberger Gould Research Center. De Hoop has been a scientific advisor with Corporate Science and Technology Projects, Total American Services, Inc., since 2010. He received his Ph.D. in technical sciences from Delft University of Technology in the Netherlands in 1992.

Over the last 15 years, de Hoop has received significant research support from the energy industry. At Purdue, de Hoop founded the Geo-Mathematical Imaging Group, an industry-university consortium project. He is a member of the Society for Industrial and Applied Mathematics, the American Mathematical Society, the American Geophysical Union, the Society of Exploration Geophysicists, from which he received the J. Clarence Karcher Award, and the Institute of Physics, where he has been a fellow since 2001.

As the Simons Chair, he will continue to work to promote interaction between mathematicians and scholars from other disciplines, and collaboration among academia and industry.
Yun S. Song was originally trained in mathematics and theoretical physics, but since receiving his Ph.D. in physics from Stanford University in 2001, he has been carrying out interdisciplinary research at the interface between biology and applied mathematics, computer science and statistics. He is particularly interested in statistical inference problems in population genetics, a branch of evolutionary biology closely related to several areas of mathematics, including probability theory, stochastic processes and combinatorics.

Since 2007, Song has been on the faculty in the Departments of Statistics and Electrical Engineering & Computer Sciences at the University of California, Berkeley. He was the chair/organizer of a semester-long interdisciplinary program on “Evolutionary Biology and the Theory of Computing,” held in Spring 2014 at the Simons Institute for the Theory of Computing. As the Calabi-Simons Chair in Mathematics and Biology at the University of Pennsylvania, he will work to promote the interaction between mathematicians and scholars from other disciplines with research interest in biology.

Song’s honors and awards include an NIH Pathway to Independence Award K99/R00 (2006), an Alfred P. Sloan Research Fellowship (2008), a Packard Fellowship for Science and Engineering (2008), an NSF CAREER Award (2009), Jim and Donna Gray Faculty Award for Excellence in Undergraduate Teaching (2013) and a Miller Research Professorship (2014).
Emmanuel Candès is a professor of mathematics, statistics and electrical engineering, and a member of the Institute of Computational and Mathematical Engineering at Stanford University. Prior to his appointment as a Simons Chair, Candès was the Ronald and Maxine Linde Professor of Applied and Computational Mathematics at the California Institute of Technology. His research interests are in computational harmonic analysis, statistics, information theory, signal processing and mathematical optimization with applications to the imaging sciences, scientific computing and inverse problems. He received his Ph.D. in statistics from Stanford University in 1998.

Candès received numerous awards throughout his career, most notably the 2006 Alan T. Waterman Medal — the highest honor presented by the National Science Foundation — which recognizes the achievements of scientists who are no older than 35, or not more than seven years beyond their doctorate. Other honors include the 2005 James H. Wilkinson Prize in Numerical Analysis and Scientific Computing awarded by the Society of Industrial and Applied Mathematics (SIAM), the 2008 Information Theory Society Paper Award, the 2010 George Polya Prize awarded by SIAM, the 2011 Collatz Prize awarded by the International Council for Industrial and Applied Mathematics, the Lagrange Prize in Continuous Optimization awarded jointly by the Mathematical Optimization Society (MOS) and Society of Industrial and Applied Mathematics (SIAM) in 2012, and the 2013 Dannie Heineman Prize presented by the Academy of Sciences at Göttingen. He has given over 50 plenary lectures at major international conferences, not only in mathematics and statistics, but also in several other areas including biomedical imaging and solid-state physics.

In 2014, Candès was elected to the National Academy of Sciences and to the American Academy of Arts and Sciences. This last summer, he gave an Invited Plenary Lecture at the International Congress of Mathematicians, which took place in Seoul. Additionally, one of his Stanford Math+X collaborators, W.E. Moerner, was one of this year’s Nobel Laureates in Chemistry.
François Baccelli is an expert of stochastic network theory and communication network modeling. His research focuses on the interface of applied mathematics with communications, information theory and network sciences.

Baccelli is co-author of several influential research monographs on: point processes and queues (with P. Brémaud); max plus algebra — algebraic theory for network dynamics (with G. Cohen, G. Olsder and J.P. Quadrat); stationary queuing networks (with P. Brémaud); and stochastic geometry of wireless networks (with B. Blaszczyszyn).

Outside of the academic setting, Baccelli has worked on projects ranging from research on access networks with French telecommunications company Alcatel, investigating network inference with Sprint Corporation in the U.S.

Baccelli received his Doctorat d’Etat from the Université de Paris-Sud in 1983, where he wrote his thesis on probabilistic models for distributed systems. Before joining University of Texas at Austin, Baccelli’s research focused on network theory at Institut National de Recherche en Informatique et Automatique (INRIA) in Paris. He also held an academic appointment in computer science at Ecole Normale Supérieure in Paris.

Prior to that, he served as head of the computer and network performance evaluation research group at INRIA Sophia Antipolis and was professor of applied mathematics at the Ecole Polytechnique. He has held visiting positions at the University of Maryland, Bell Laboratory’s mathematics center, Stanford University, Eindhoven University as a Eurandom Chair, Heriot Watt University as an Honorary Professor, University of California, Berkeley as a Miller Professor, and the Isaac Newton Institute at the University of Cambridge, where he co-organized the 2010 program on Stochastic Processes and Communication Sciences. In 2005, Baccelli was elected as a member of the French Academy of Sciences.

In taking up the Simons Chair in Mathematics and Electrical and Computer Engineering at the University of Texas at Austin, François Baccelli has worked to develop the new, interdisciplinary Simons Center on Communication, Information and Network Mathematics.
GRANTS TO INDIVIDUALS

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 84 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, Nevanlinna Prize and the Dannie Heineman Prize for Astrophysics.

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 their research. Since its launch, the foundation has awarded 207 Fellowships in math and 87 Fellowships in physics.

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 for travel and for hosting collaborators to researchers who do not otherwise have access to funding.

The program began in 2011 and has since supported over 832 mathematicians. Collaboration Grants for Mathematicians is one of MPS’s most popular grants, with 2,795 applications received over five years. Awardees receive support for up to five years.

Deanna Needell terminated her award one year after receiving her grant because she was awarded an Alfred P. Sloan Fellowship and an NSF Career Award. “I strongly feel that the Simons grant has contributed significantly to my success in forming collaborations, publishing work that came out of those collaborations, and eventually securing additional funding.”
MPS PROGRAM SUMMARY

AMS-Simons Travel Grants
The Simons Foundation, in partnership with the American Mathematical Society, provides early-career mathematicians (within four years of receiving the Ph.D.) the opportunity to travel to conferences and to visit current and potential collaborators in their fields. In the three years since the program started, a total of 326 mathematicians have been funded. An additional 66 have been selected for this academic year.

Victor Falgas-Ravry, the 2015 Travel Grant recipient, found the support “hugely beneficial to my professional development, and a wholly positive experience. In addition to the active collaborations, I learned a lot of useful problems and techniques, as well as a host of US-based mathematicians. Even when we did not start a project, I expect many of the connections I made during the conferences and research visits will remain active in the future.”

SIMONS COLLABORATIONS
The aim of the Simons Collaborations in MPS is to stimulate progress on 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 2016, the foundation selected three new Simons Collaboration to join the four currently funded collaborations; Cracking the Glass Problem, The Non-Perturbative Bootstrap and Special Holonomy in Geometry, Analysis and Physics.

Cracking the Glass Problem
Director: Sidney R. Nagel, University of Chicago
Cracking the Glass Problem, headed by Sidney R. Nagel of the University of Chicago, along with a team of 12 principal investigators and six collaborators, ventures to answer a “seemingly simple question: What is a solid?” The collaboration addresses “fundamental issues of disorder, nonlinear response and far-from-equilibrium behavior [to build upon] three powerful approaches: studies of jamming at zero temperature, the mean-field theory of glasses in infinite dimension, and the dynamics in a marginally stable landscape. The convergence of recent breakthroughs in these areas generates a unique opportunity to tackle two outstanding and intimately related challenges: developing a unified theory of structure and excitations in glassy matter and developing a theory for the relaxation dynamics upon approaching the glass transition.” The collaboration will convene at the foundation in the spring for their first annual meeting.
MPS PROGRAM SUMMARY

The Nonperturbative Bootstrap
Director: Leonardo Rastelli, SUNY Stony Brook
Quantum field theory (QFT) is a universal language for theoretical physics, describing the Standard Model of particle physics, early universe inflation, and condensed matter phenomena such as phase transitions, superconductors, and quantum Hall fluids. A triumph of 20th century physics was to understand weakly coupled QFTs. However, weakly interacting systems represent a tiny island in theory space and cannot capture many of the most interesting physical phenomena.

The critical challenge for the 21st century is to map and understand the whole space of QFTs, including strongly coupled models. This is the main goal of the Simons Collaboration on the Non-perturbative Bootstrap. Meeting this challenge requires new physical insight, new mathematics, and new computational tools. Our starting point is the astonishing discovery that the space of QFTs can be determined by using only general principles: symmetries and quantum mechanics. By analyzing the full implications of these general principles, one can make sharp predictions for physical observables without resorting to approximations. This strategy is called the bootstrap.

Special Holonomy in Geometry, Analysis and Physics
Director: Robert Bryant, Duke University
The Simons Collaboration on Special Holonomy in Geometry, Analysis and Physics will advance the theory and applications of spaces with special holonomy and the geometric structures—calibrated submanifolds and instantons—associated with them, particularly in the two exceptional cases: spaces with holonomy G_2 or Spin(7) in 7 or 8 dimensions, respectively.

The best-understood special holonomy spaces are the so-called Calabi–Yauspaces; over the past 30 years the study of these from various viewpoints—geometry, analysis, algebra and physics—has been one of the most active and influential parts of mathematics and its applications to physics. The exceptional cases share some important features with Calabi–Yau spaces, but at the same time they remain the most challenging and the least understood, both mathematically and physically.

Exceptional holonomy spaces are key ingredients in extracting physics from M-theory and F-theory (generalizing the role that Calabi–Yau 3-folds play in string theory), where they provide models for the extra dimensions of space. Progress in understanding the physical applications depends crucially on a better understanding of spaces, especially singular ones, with exceptional holonomy.

Advances in understanding geometric structures associated with exceptional holonomy spaces have often required insights from apparently disparate parts of the field or from outside the field entirely. Our Collaboration therefore brings together the leading mathematics researchers in the various different geometric incarnations of exceptional holonomy with experts on the applications to physics. We will capitalize on several recent mathematical breakthroughs related to the geometric structures associated with exceptional holonomy spaces and also make use of powerful new tools for analyzing singular spaces.
MPS PROGRAM SUMMARY

Homological Mirror Symmetry
Director: Tony Pantev, University of Pennsylvania

Homological Mirror Symmetry held their inaugural conference in November 2015, at the University of Pennsylvania, and featured an intensive program of talks covering various research areas relevant to the collaboration, including symplectic topology, noncommutative geometry, homological algebra, representation theory and quantum field theory, among others. The meeting was attended by over 90 mathematicians and physicists and was preceded by two days of mathematical discussions attended by most of the PIs to explore future joint research as well as organizational plans for the collaboration. The Simons Collaboration on Homological Mirror Symmetry will hold their first annual meeting at the foundation on November 17 and 18.

It from Qubit
Director: Patrick Hayden, Stanford University

The Simons Collaboration on It from Qubit aims to use information theoretic ideas to advance fundamental physics, particularly quantum gravity. The collaboration’s 16 principal investigators collaborate on seven projects, including AdS/CFT and quantum error correction, chaos and the black hole horizon, and circuit complexity and the validity of general relativity at late times. Progress has been rapid and accelerating, despite that fact that the collaboration consists of a mix of quantum field theorists, computer scientists and string theorists who can’t always speak each other’s languages. In July, the collaboration hosted an interdisciplinary summer school at the Perimeter Institute on quantum fields, quantum gravity and quantum information. The Perimeter Institute experiment was simultaneously a school, a conference and a workshop designed to bridge those gaps. It brought together the members of the collaboration plus 110 students and many leading researchers for a total of about 180 participants. Significant contingents of students from California and Germany even participated remotely in the school.

The meeting began with introductory lectures on general relativity for the computer scientists and on quantum information for the field theorists, gradually building to advanced topics like the role of quantum error correction in holographic theories of quantum gravity. Each day included course lectures, problem solving sessions, discussions and research seminars, often with multiple activities scheduled at the same time. Students were sometimes even surprised by well-known researchers joining their ranks in areas new to them for the problem sessions. One of the goals of the It from Qubit collaboration is to train a new generation of scientists fluent in both quantum information science and fundamental physics. Judging by the enthusiasm and engagement of the school’s many and varied participants, that goal is well underway.
Algorithms and Geometry
Director: Assaf Naor, Princeton University
The Simons Collaboration on Algorithms and Geometry addresses fundamental questions at the interface of mathematics and theoretical computer science. It brings together a unique group of researchers from diverse backgrounds in pure and applied mathematics and in theoretical computer science. Investigators focus on questions of computational hardness, on structural foundations of metrics and networks, and on data structures of geometric origin. In addition to investigating the basic structures central to a wide range of algorithmic questions, the Simons Collaboration on Algorithms and Geometry aims to create new mathematics, including the design of advanced algorithms based on new mathematical insights.

During the 2015–2016 academic year, the collaboration held monthly meetings at the Simons Foundation that explored their core research topics and featured an invited speaker. The collaboration also hosted its second annual meeting with 13 principal investigators, along with eight postdoctoral researchers and 30 additional guests, who attended five talks, including a public Simons Foundation lecture, with breaks for casual discussion throughout the day.

The meeting included a two-hour presentation (with a break in the middle) by László Babai on his recent major breakthrough on algorithms for the graph isomorphism problem. The problem itself is natural and famous. It asks if two graphs on n vertices are isomorphic to each other (i.e., if they are just re-labeling the same graph). Babai obtained a fast (but not quite polynomial time) $n^{O(\log n)}$-time algorithm for this task, employing many new and difficult innovations in addition to using various tools from the literature (including the classification of finite simple groups).

Many Electron Problem
Director: Andrew Millis, Simons Foundation & Columbia University
The Simons Collaboration on the Many Electron Problem brings together a group of scientists focused on developing new ways to solve the quantum mechanical behavior of systems comprised of many interacting electrons, with the goal of revolutionizing our ability to calculate and understand the properties of molecules and solids important in chemistry, physics and everyday life.

In June 2016, the collaboration hosted its third annual summer school at the Simons Center for Geometry and Physics with a focus on tensor networks and was organized by the tensor network group leader, Professor Steven White from University of California, Irvine.

The school included a range of both introductory and advanced topics in the field of tensor networks and related numerical methods, as well as hands-on sessions to teach students how to perform their own cutting-edge tensor network calculations. Topics included basic background in numerical tools, such as Lanczos and the singular-value decomposition by Professor White; an introduction to matrix product states and the density matrix renormalization group (DMRG) by Professor Ulrich Schollwöck from Ludwig Maximilian University of Munich; and a review of methods for higher-dimensional tensor networks by Professor Philippe Corboz from the University of Amsterdam. Miles Stoudenmire led some simple, hands-on coding exercises, ranging from performing simple diagonalization to state-of-the-art DMRG calculations using the iTensor library he manages, which is funded by the Many Electron collaboration.
CONFERENCES AND SYMPOSIA

Simons Symposia

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. It is expected that there will be three Simons Symposia in a given subject area held every second year.

MPS leadership works closely with symposia organizers to develop weeklong programs that balance planned talks with time for collaborative interactions. To encourage focused collaborations, symposia take place in an isolated location and participation is limited to 23 individuals. In addition to planning the week’s scientific activities, organizers are also required to provide long-term plans for the continuation of the topics discussed at each symposium. To this end, past symposia organizers have arranged summer schools, published proceedings and maintained webpages.

In 2016, symposia Analysis of Boolean Functions and Geometry Over Non-Closed Fields completed their third and final meetings at Schloss Elmau resort in Krün, Germany, located in the Bavarian Alps. “One of the most tangible outcomes of the symposium series,” writes Ryan O’Donnell, one of three organizers of the Boolean Functions symposium, “is Theory of Computing journal’s special issue on analysis of Boolean functions, which followed the 2012 symposium. Another major outcome of the series was the collection and promotion (on blogs) of the most important problems in analysis of Boolean functions… that the Simons Symposia contributed significantly to the solution of these problems, through promotion of them to the right set of researchers.”

The Simons Symposia on P-adic Hodge Theory, jointly organized by Bhargav Bhatt and Martin Olsson, will hold its first symposium in 2017. Participants will examine the relationship between p-adic Hodge theory, algebraic K-theory, and topological Hochschild homology; discuss recent developments in integral p-adic Hodge theory as well as the connection between p-adic Hodge theory and derived algebraic geometry.

The 2017 symposia will again be held at the Schloss Elmau resort in Bavaria.
MPS PROGRAM SUMMARY

Simons Symposia

Analysis of Boolean Functions / Discrete Analysis Beyond the Boolean Cube
  Organizers: Elchanan Mossel, University of California, Berkeley
               Ryan O’Donnell, Carnegie Mellon University
               Krzysztof Oleszkiewicz, University of Warsaw

Families of Automorphic Forms and the Trace Formula
  Organizers: Werner Müller, Mathematical Institute of the University of Bonn
               Sug Woo Shin, Massachusetts Institute of Technology
               Nicolas Templier, Princeton University

Galactic Superwinds: Beyond Phenomenology
  Organizers: Andrew Benson, Carnegie Observatories
               Juna Kollmeier, Carnegie Observatories

Geometry Over Nonclosed Fields
  Organizers: Fedor Bogomolov, New York University
               Brendan Hassett, Rice University
               Yuri Tschinkel, Simons Foundation

The Kardar–Parisi–Zhang Equation
  Organizers: Alexei Borodin, Massachusetts Institute of Technology
               Jeremy Quastel, University of Toronto
               Herbert Spohn, Technische Universität München
  Symposium Years: 2013
MPS PROGRAM SUMMARY

Knot Homologies and BPS States
Organizers: Davide Gaiotto, Perimeter Institute
Sergei Gukov, California Institute of Technology
Mikhail Khovanov, Columbia University
Jacob Rasmussen, University of Cambridge
Symposium Years: 2012

New Directions in Approximation Algorithms
Organizers: Sanjeev Arora, Princeton University
Michel Goemans, Massachusetts Institute of Technology
Uriel Feige, Weizmann Institute of Science
David Shmoys, Cornell University
Symposium Years: 2013, 2015, 2017

Non-Archimedean and Tropical Geometry
Organizers: Matthew Baker, Georgia Institute of Technology
Sam Payne, Yale University
Symposium Years: 2013, 2015, 2017

P-adic Hodge Theory
Organizers: Bhargav Bhatt, University of Michigan
Martin Olsson, University of California, Berkeley
Symposium Years: 2017

Quantum Entanglement
Organizers: Shamit Kachru, Stanford University
Hirosi Ooguri, California Institute of Technology
Subir Sachdev, Harvard University
Symposium Years: 2013, 2015, 2017

Quantum Physics Beyond Simple Systems
Organizers: Boris Altshuler, Columbia University
Vladimir Falko, Lancaster University
Charles Marcus, Niels Bohr Institute
Symposium Years: 2012, 2014
Lectures, Series and Conferences

Launched in 2013, the Simons Foundation Lecture Series covers topics related to mathematics, physics, computer science, life sciences and autism research. The lectures take place on Wednesdays and are open to scientists and the scientifically literate public from the local research community. During the 2015–2016 academic year, MPS hosted eight such lectures, which included talks from Juna Kollmeier, who spoke on the formation and structure of the cosmos as well as Nobel Prize winner Eric Betzig, who discussed imaging life at high spatiotemporal resolution.

In addition to lectures, the foundation also hosts conferences. All Simons Collaboration groups are required to organize annual meetings, which take place at the Simons Foundation’s Gerald D. Fischbach Auditorium.

In June 2016, the foundation hosted a conference on Shocks and Particle Acceleration in Novae and Supernovae, which brought together 60 researchers working in the fields of novae and supernovae to discuss the physics of shocks and particle acceleration in these transient astrophysical events. The workshop was comprised of pedagogical overview talks meant to bridge the knowledge gap between these fields, interspersed with long open discussion periods aimed at addressing particular aspects of each phenomena. The discussion periods identified a previously neglected discrepancy regarding the low-electron-acceleration efficiency, which is inferred from supernova remnants and PIC simulations, versus the much higher efficiencies inferred from unresolved supernovae. Future methods for analyzing the supernova data were agreed upon to better quantify this discrepancy and its cause.

Starting in 2017, the foundation will host an additional three to five conferences a year on various scientific topics in order to explore new scientific directions and promote interactions and collaborations across disciplines.

INFRASTRUCTURE

arXiv

The arXiv (www.arxiv.org) — a large preprint server and repository that hosts papers in mathematics, physics and computer science — has emerged as one of the most important new means of communicating and accessing new papers in mathematics and physics through the Internet. Papers are freely available to anyone in the world.

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.
MPS PROGRAM SUMMARY

Simons Society of Fellows
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. Fellows are selected by a group of Senior Fellows in collaboration with Simons Foundation senior scientists.

JUNIOR FELLOWS

Ruth Angus
Gilad Asharov
Tobias Bartsch
Sonja Billerbeck
Michal Breker
Timothy Burbridge
Jennifer Bussell
James Dama
Jairo A. Diaz
Logan Grosenick
Benjamin Harrop-Griffiths
Keith Hawkins
J. Colin Hill
Ailsa Keating
Dion Khodagholy
Kohei Inayoshi
Chervin Laporte
Boris Leistedt
Rafael Maia
Aditi Sheshadri
Mijo Simunovic
James Stafford
Yi Sun
Li-Cheng Tsai
Omri Weinstein
Zheng (Herbert) Wu

Columbia University
Cornell University
Rockefeller University
Columbia University
Rockefeller University
New York University
Columbia University
Columbia University
New York University
Columbia University
Columbia University
Columbia University
Columbia University
NYU Langone Medical Center
Columbia University
Columbia University
Columbia University
New York University
Columbia University
Columbia University
New York University
Columbia University
New York University

SENIOR FELLOWS

Gerald D. Fischbach
Boris Altshuler
Moses V. Chao
David Heeger
David I. Hirsh
Thomas Jessell
Daniel Littman
Carol A. Mason
John Morgan
J. Anthony Movshon
Andrei Okounkov
Margaret Wright

Simons Foundation
Columbia University
New York University School of Medicine
New York University
Columbia University
Columbia University
New York University School of Medicine
Columbia University
Simons Center for Geometry and Physics
New York University
Columbia University
Courant Institute of Mathematical Sciences
MPS Budget

- Grants to Individuals
- Grants to Institutes
- Conferences, Symposia & Lectures
- Infrastructure
Vladimir Markovic has made fundamental contributions to the theory of three-dimensional manifolds, resolving several long-standing problems, among them the proof of the Thurston conjecture concerning immersed almost-geodesic surfaces in closed hyperbolic three-manifolds.

James McKernan, in collaboration with Caucher Birkar, Paolo Cascini, and Christopher D. Hacon, has established one of the cornerstones of the Minimal Model Program: the finite generation of canonical rings in all dimensions.

Bjorn Poonen has contributed decisively to many areas revolving broadly around the study of Diophantine equations. Among his achievements are the construction of examples of threefolds without rational points but vanishing local and global obstructions, new heuristics concerning rational points on elliptic curves and results about rational points on curves of higher genus.
THEORETICAL COMPUTER SCIENCE

MADHU SUDAN
HARVARD UNIVERSITY

Madhu Sudan is known for his work in computational complexity theory. He has made fundamental contributions in the areas of probabilistically checkable proofs, nonapproximability of optimization problems and computational aspects of error-correcting codes. More recently, he initiated the study of universal semantic communication.

DAVID ZUCKERMAN
UNIVERSITY OF TEXAS AT AUSTIN

David Zuckerman is a leader in pseudorandomness and randomness extraction, an area that his early work pioneered. He has a number of beautiful and important results in construction and application of extractors, including applications to coding theory, computational complexity and cryptography, as well as his recent breakthrough result with two-source extractors.
2016 Simons Investigators

THEORETICAL PHYSICS

MINA AGANAGIC
UNIVERSITY OF CALIFORNIA, BERKELEY

Mina Aganagic applies insights from quantum physics to mathematical problems in geometry and topology. She made deep and influential conjectures in enumerative geometry, knot theory and mirror symmetry using predictions from string theory and from M-theory.

ANDREA ALÙ
THE UNIVERSITY OF TEXAS AT AUSTIN

Andrea Alù’s work on the manipulation of light in artificial materials and metamaterials has shown how clever designs may surpass what had previously been thought to be limitations on wave propagation in materials. He has developed new concepts for cloaking, one-way propagation of waves in materials, dramatic enhancement of nonlinearities in nanostructures and ultrathin optical devices based on metasurfaces and twisted metamaterials.

ANDREI BELOBORODOV
COLUMBIA UNIVERSITY

Andrei Beloborodov applies first-principles physics to astrophysical systems, and his work provides crucial new insights on how exotic astronomical objects work. He has done important research on compact objects like neutron stars and black holes and is particularly well-known for his studies of gamma-ray bursts, magnetars and pulsars.
2016 Simons Investigators

B. ANDREI BERNEVIG
PRINCETON UNIVERSITY

Andrei Bernevig is a leader in the lively field of topological electronic states in solids. His initial proposal of the quantum spin Hall effect in HgTe quantum wells was soon followed by dramatic experimental confirmation. He has developed a theoretical framework for topological insulators and written a highly regarded book on the subject. His work on topological superconductivity in metal chains on superconducting surfaces, as well as his prediction of two types of Weyl semimetal states in transition metal monophosphides and WTe2, has stimulated considerable theoretical and experimental activity.

GARNET CHAN
CALIFORNIA INSTITUTE OF TECHNOLOGY

Garnet Chan’s research lies at the interface of theoretical chemistry, condensed matter physics and quantum information theory, and is concerned with the phenomena and simulation methods associated with quantum many-particle systems. Some current problems of interest include metalloenzymes and biological catalysts, transition metal oxides and superconductivity, and conjugated organic systems and light harvesting. He has contributed to a wide range of quantum simulation methods, including density matrix renormalization and tensor network algorithms, quantum embedding theories and local correlation approximations.

DANIEL EISENSTEIN
HARVARD UNIVERSITY

Daniel Eisenstein is a leading figure in modern cosmology. He is known for utilization of the baryon acoustic oscillations (BAO) standard ruler for measuring the geometry of the universe, which underpins several large upcoming ground and space missions. Eisenstein blends theory, computation and data analysis seamlessly to push the boundaries of current-day research in cosmology.
ANTON KAPUSTIN
CALIFORNIA INSTITUTE OF TECHNOLOGY
Anton Kapustin’s work lies at the interface of physics and mathematics. He applied ideas from gauge theory to the study of the geometric Langlands program in mathematics and has applied sophisticated mathematics to the classification of exotic quantum states of matter.

SURYA GANGULI
STANFORD UNIVERSITY
Surya Ganguli’s work combines theory with computation, recording, analysis of data, and modeling, contributing to our understanding of how the brain works. He has made fundamental contributions to the mechanisms of short- and long-term memory. His work also addresses difficult problems in machine learning.

KIRILL KOROLEV
BOSTON UNIVERSITY
Kirill Korolev works at the interface of biophysics, statistical physics, soft condensed-matter physics and ecology. He develops elegant theories and combines them with the results of controlled experiments to address topics ranging from spreading of cell populations on a 2-D substrate, cancer progression, and ecology. His work is unified by the theme of how complex interactions determine the dynamics of biological systems.
2016 Simons Investigators

MADHAV MANI
NORTHEASTERN UNIVERSITY
Following thesis work on fluid mechanics and soft matter physics, Madhav Mani transitioned to studying the mechanics of development and gene regulation in organisms. In collaboration with experimentalists, he combined mathematical modeling with quantitative analysis of growing tissues to shed light on how cells collectively develop preferred orientations. Using model-based forced-inference techniques, he also reconstructed the dynamics of networks that drive cellular flows during early embryonic development.

M. LISA MANNING
SYRACUSE UNIVERSITY
Lisa Manning started her research career in the physics of glasses, i.e., how a disordered group of molecules or particles freezes into a rigid solid at a well-defined temperature. She then turned her attention to morphogenesis, the process by which embryos transform from a spherical egg to a shape we recognize as an insect, plant or mammal, showing that aspects of this process could be modeled by surface tension in analogy with the description of immiscible liquids. Her most recent work uses ideas from the physics of glasses to describe the mobility of cells organized in sheets and applies to a broad class of biological tissues, including embryos and cells from asthma patients.

MATH+X

INGRID DAUBECHIES
DUKE UNIVERSITY
Ingrid Daubechies constructed the first example of what mathematicians call “wavelets,” which have had an immense impact on pure and applied mathematics. She has made and continues to make creative applications of wavelets to a large variety of problems in engineering and other fields.
2012-2015 Simons Investigators

MATHEMATICS

Ian Agol
Manjul Bhargava
Ngô Bào Châu
Alex Eskin
Alice Guionnet
Ben Green
Larry Guth
Christopher Derek Hacon
Richard Kenyon
Maryam Mirzakhani
Andrei Okounkov
Raphaël Rouquier
Paul Seidel
Amit Singer
Christopher Skinner
Kannan Soundararajan
Terence Tao
Daniel Tataru
Horng-Tzer Yau

University of California, Berkeley
Princeton University
The University of Chicago
The University of Chicago
Massachusetts Institute of Technology
University of Oxford
Massachusetts Institute of Technology
The University of Utah
Brown University
Stanford University
Columbia University
University of California, Los Angeles
Massachusetts Institute of Technology
Princeton University
Princeton University
Stanford University
University of California, Los Angeles
University of California, Berkeley
Harvard University

COMPUTER SCIENCE

Rajeev Alur
Sanjeev Arora
Dan Boneh
Moses Charikar
Shafi Goldwasser
Russell Impagliazzo
Piotr Indyk
Subhash Khot
Jon Kleinberg
Daniel Spielman
Shang-Hua Teng
Christopher Umans
Salil P. Vadhan

University of Pennsylvania
Princeton University
Stanford University
Princeton University
Massachusetts Institute of Technology
University of California, San Diego
Massachusetts Institute of Technology
New York University
Cornell University
Yale University
University of Southern California
California Institute of Technology
Harvard University
2012-2015 Simons Investigators

THEORETICAL PHYSICS

Igor Aleiner  
Michael Brenner  
Jonathan Feng  
Victor Galitski  
Sharon Glotzer  
Patrick Hayden  
Chris Hirata  
Charles Kane  
Randall Kamien  
Marc Kamionkowski  
Alexei Kitaev  
Andrea Liu  
Joel Moore  
Hirosi Ooguri  
Frans Pretorius  
Eliot Quataert  
Leo Radzihovsky  
Rachel Somerville  
Dam Thanh Son  
Anatoly Spitkovsky  
Iain Stewart  
Senthil Todadri  
Mark Van Raamsdonk  
Ashvin Vishwanath  
Anastasia Volovich  

Columbia University  
Harvard University  
University of California, Irvine  
The University of Maryland  
University of Michigan  
Stanford University  
California Institute of Technology  
University of Pennsylvania  
University of Pennsylvania  
The Johns Hopkins University  
California Institute of Technology  
University of Pennsylvania  
University of California, Berkeley  
California Institute of Technology  
Princeton University  
University of California, Berkeley  
University of Colorado at Boulder  
Rutgers University  
The University of Chicago  
Princeton University  
Massachusetts Institute of Technology  
Massachusetts Institute of Technology  
University of British Columbia  
Harvard University  
Brown University

MATHEMATICAL MODELING OF LIVING SYSTEMS

Michael Desai  
Paul François  
Oskar Hallatschek  
Pankaj Mehta  
Andrew Mugler  
James O’Dwyer  
Olga Zhaxybayeva  

Harvard University  
McGill University  
University of California, Berkeley  
Boston University  
Purdue University  
University of Illinois at Urbana-Champaign  
Dartmouth College

MATH+X

Michael Weinstein  
Columbia University
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**MATHEMATICS**

Jinho Baik  
Fedor Bogomolov  
Lev Borisov  
Alexei Borodin  
Fioralba Cakoni  
Xiu Xiong Chen  
Maria Gordina  
J. Elisenda Grigsby  
Thomas Haines  
Julia Hartmann  
Christopher Hoffman  
Vera Mikyoung Hur  
Michael Hutchings  
Adrian Iovita  
Gautam Iyer  
Vadim Kaloshin  
Vitali Kapovitch  
Kiumars Kaveh  
Sean Keel  
Bryna Kra  
Radu Laza  
Liping Liu  
Dan Margalit  
Andrew Neitzke  
Adam Oberman  
Robert Pego  
Robin Pemantle  
Robert Pollack  
Sorin Popa  
Dinakar Ramakrishnan  
Richard Schwartz  
Avraham Soffer  
Bernd Sturmfels  
Brian White  
Dapeng Zhan  
Shou-Wu Zhang  
Michael Zieve

*University of Michigan*  
*New York University*  
*Rutgers, The State University of New Jersey*  
*Massachusetts Institute of Technology*  
*Rutgers, The State University of New Jersey*  
*Stony Brook University*  
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*University of Washington*  
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*University of Maryland, College Park*  
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*University of California, Los Angeles*  
*California Institute of Technology*  
*Brown University*  
*Rutgers, The State University of New Jersey*  
*University of California, Berkeley*  
*Stanford University*  
*Michigan State University*  
*Princeton University*  
*University of Michigan*
# 2016 Simons Fellows

## THEORETICAL PHYSICS

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>Zoltán Haiman</td>
<td>Columbia University</td>
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<tr>
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<td>Timo Thonhauser</td>
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