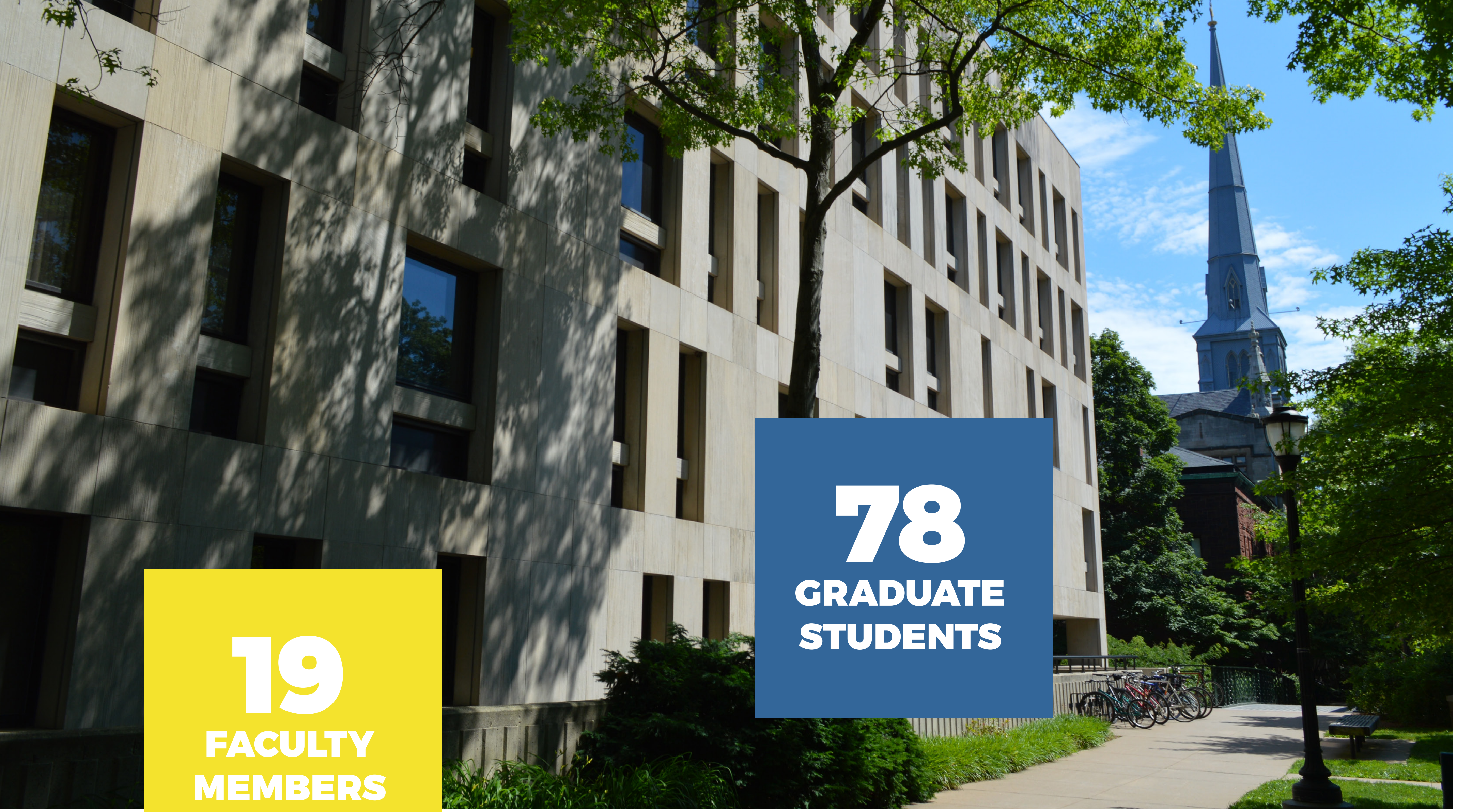
YALE QUANTUM INSTITUTE
ANNUAL REPORT

2018



78
GRADUATE STUDENTS

19
FACULTY MEMBERS

2
STAFF MEMBERS

34
POSTDOCS & ASSISTANTS RESEARCHERS

Contents

Front and Back covers: Quantum Fluctuation 'Brane by Martha W Lewis, photography by Luke Hanscom/Lotta Studios

Director's Word

The Yale Quantum Institute welcomes your interest in our activities and we are pleased to present our second annual report.

In this report, you will find information about the Institute and its mission, as well as some highlights of both our programs and the research performed by YQI members this year. Since the official opening of our renovated offices at 17 Hillhouse in October 2015, the Institute has become a forum and activity hub for scientific interchange and collaboration relating to quantum science. We have hosted a full slate of both short-term and long-term visitors to campus, and a distinguished series of colloquia and seminars by international leading figures across the full spectrum of quantum science (physics, chemistry, nanoscience, optics and photonics, quantum information, computer science, engineering). The Institute also sponsored many other events, from sessions on career-development and professional skills for students and postdocs, to social functions where members from all levels of the YQI community can get to know one another better.

This year YQI recognized its first Distinguished Lecturer in Quantum Science with the selection of Professor Tobias Kippenberg of the EPFL in Switzerland for his seminal contributions to optomechanics and microcavity optics. Prof. Kippenberg visited YQI in early December and delivered two truly inspiring lectures (one for a general audience, and one more technical seminar), kicking off this new tradition with great style (p22). In addition YQI held it first research workshop in October focusing on the topic of Majorana modes (sponsored by the Office of Naval Research). We also welcomed our first artist-in-residence, Martha W. Lewis (p18), whose original artwork, *Quantum Fluctuations*, now graces the wall as visitors enter the Institute meeting space. Trying to understand the quantum world has inspired much imagery, and it is wonderful to have someone of her talent and background here to provide aesthetic insight and a novel perspective on our activities. In addition, YQI has deepened our involvement with the intersection of art, humanities and science by organizing a number of events relating art and science in collaboration with the Franke Program for Science and Humanities and other Yale departments. A highlight of our outreach activities was a unique lecture/performance by Nobel Laureate William Phillips, titled "Time, Einstein, and the coolest stuff in the universe", in which, among many other activities, gallons of liquid nitrogen were poured around the auditorium, creating more spooky "smoke" than a Harry Potter movie.

Now in our fourth year of operation, YQI is humming along, with Institute Manager, Dr. Florian Carle ably organizing our visitor and lecture programs, and Raquel Miller providing efficient administrative support and a friendly smile along the way. We are fortunate to have such a talented team backing up our activities. We would also like to acknowledge the support provided by Yale Office of the Provost and Office of Development which have helped YQI become a world leader in quantum science. This year the institute Director, Rob Schoelkopf, has taken a leave of absence, and I am pleased to be serving as Acting Director in his absence.

Quantum information science and technology are becoming even more widely recognized as critical emerging fields for 21st century research, with immense potential for societal impact. National and International programs in the UK, EU, China, the US and elsewhere are targeting this area for major investments. YQI hosted research in quantum computing and related fields has received attention in major media outlets such as the New York Times, The Economist, and Bloomberg. We are very excited to be at the center of this exciting field and look forward to the developments the coming years will bring.

Please have a look inside this issue to learn more, and we hope to see you soon at YQI.

A. Douglas Stone, Acting Director, YQI

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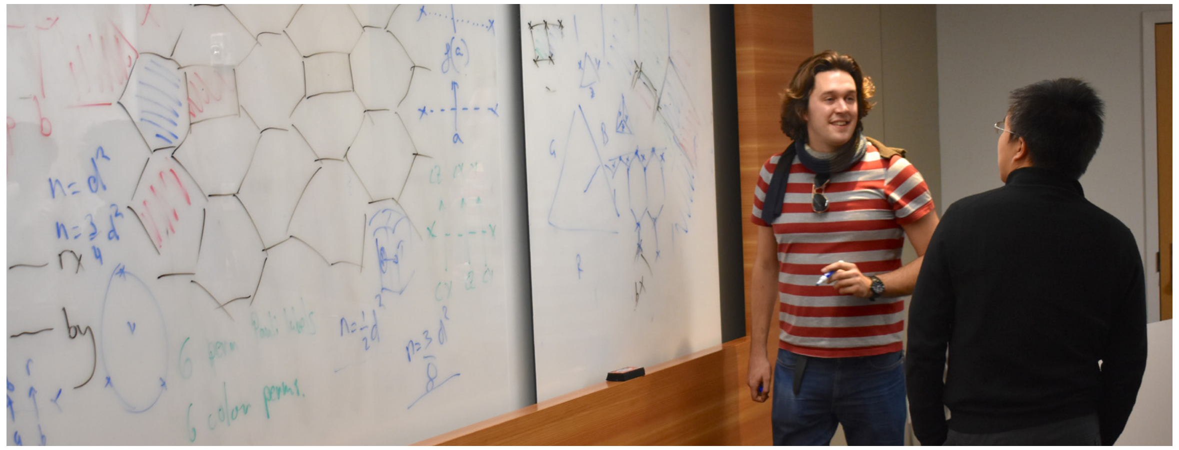
CITATIONS
Data: Scopus

97
PUBLICATIONS

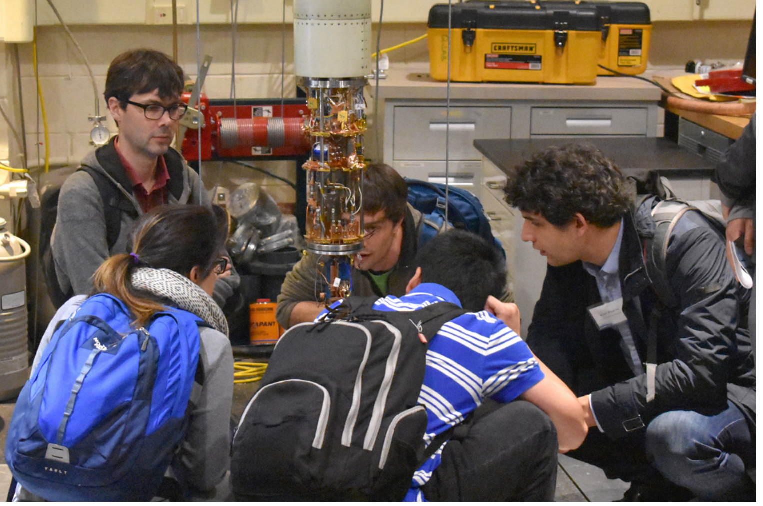


ABOUT THE INSTITUTE

Life as we know it now would not be possible were it not for several profound scientific and technological revolutions over the last century: the Industrial Revolution with electricity, the internal combustion engine, the telephone, and most recently the Digital Revolution which ushered in computers, cellular phones, and the Internet. This transformative period was made possible by the understanding of the fundamental laws of the atom and of light embodied in quantum theory, developed in the first half of the 20th century. At the onset of the 21st century, we are on the brink of a new quantum revolution – and Yale is paving the way.

Our faculty members, spanning the departments of Physics, Applied Physics, Computer Science, and Electrical and Mechanical Engineering, are making scientific breakthroughs that will make new leaps forward that would have been unimaginable only a few decades ago. The Yale Quantum Institute was formed in 2015 to advance the progress in fundamental and applied quantum science at Yale and in the broader community of researchers across the globe. Yale has particular expertise in the theoretical and experimental development of new technologies to store and process quantum information. The goal is to better understand the fundamental quantum laws of our universe, and to harness the unique features of quantum mechanics for novel sensors, secure communications, and eventually the realization of large-scale quantum computers. We now know that by employing a kind of massive parallel processing, quantum computers, based on "quantum bits", can address problems that would otherwise remain forever beyond the reach of our current computers. These problems include basic algorithms underlying secure communication on the internet, as well as quantum simulations of new materials, complex optimization problems, and improved machine learning. As with conventional computers, the true scope of their utility will probably only be discovered once they are built.

Beginning with pioneering work on macroscopic quantum coherence in the 80's to the realization of today's quantum information processors, Yale professors are renowned for their leadership in the Quantum Revolution. In the past fifteen years, under the leadership of Devoret, Schoelkopf and Girvin, the Yale team of more than fifty researchers has been proud to demonstrate several milestones in quantum computing, including the development of the first solid state quantum information processors, based on superconducting electronics. Together, with all of the members of YQI, we are pursuing the collective goal of turning quantum physics into practical technologies and advancing our fundamental understanding of quantum science and engineering. We welcome researchers from around the world to visit and participate in this intellectual adventure.



MISSION AND PROGRAMS

THE INSTITUTE FOSTERS COLLABORATION AND WELCOMES WORLD LEADERS IN THE FIELD TO FOSTER NEW HAVEN'S ROLE AS AN INTELLECTUAL HUB FOR QUANTUM INFORMATION SCIENCE AND ENGINEERING, AND OF QUANTUM SCIENCE MORE GENERALLY.

The Yale Quantum Institute was founded to enhance Yale's leadership in the field of quantum science and technology. It serves as a forum, bringing together experimental and theoretical researchers at Yale in the field of quantum information science and engineering, quantum control, quantum measurement, and quantum many-body physics and chemistry. The Institute also runs an active visitors program to bring quantum information scientists from leading institutions worldwide, and hosts conferences and workshops in sub-fields relating to its core mission.

The past two decades have seen breakthroughs in both the theory and the practice of quantum science. The properties of superposition and entanglement, once thought of as paradoxical and counterintuitive, are now understood instead as unique resources. Progress in the laboratory now allows unprecedented control over individual quantum objects, whether they are naturally-occurring microscopic systems like atoms, or macroscopic, man-made systems with engineered properties.

These advances may soon enable us to perform otherwise intractable computations, ensure privacy in communications, better understand and design novel states of matter, and develop new types of sensors and measurement devices. Today, a new discipline is emerging which combines physics, chemistry, electrical engineering, mathematics, and computer science to further the basic understanding of the quantum world, and to develop novel information processing devices and other quantum-enabled measurement and sensing technologies.

83 EVENTS HELD

44 INVITED SPEAKERS

176 CONFERENCE ATTENDEES

VENUE FOR QUANTUM INFORMATION EVENTS

The Institute hosts many seminars, presentations, group meetings and other events in the field of quantum information science and engineering. YQI is also the organizer of the annual *Yale Science and Engineering Forum*. In 2017, we welcomed the *Majorana Fermions & Beyond* workshop. All interested students, professors and staff from Yale or other academic institutions are welcome to attend our events.

COLLOQUIUM AND SEMINARS SERIES

Every academic year, the institute presents an exciting series of technical seminars and colloquia from experts in the field of quantum information science, quantum control, quantum measurement, and quantum many-body physics. The talks are attended by a diverse cross section of the university ranging from undergraduates to emeritus professors.

VISITORS PROGRAM

The Yale Quantum Institute opens its doors to world leaders in quantum information science for sabbatical visits to Yale. These visiting scientists-in-residence can focus on their research in close proximity to YQI's professors and students at our 17 Hillhouse Avenue location.

NETWORKING AND PROFESSIONAL DEVELOPMENT

We offer a selection of presentations, curated by YQI to help students and postdocs with career development, job search and networking. Speakers in this series includes noted scientists, industry leaders, and legal advisors, all of whom are Yale alumni. These experts return to the university to share their career experiences and offer an opportunity for attendees to build a solid career network and to ask questions.

VISITORS IN 2017

Hughes Pothier
CEA Saclay, France

Stefan Rotter
Vienna University Of Technology, Austria

Saikat Guha
MIT Raytheon, Cambridge, USA

Michael Berry
University of Bristol, UK

Matti Silveri
University of Oulu, Finland

Thorsten Schumm
Tu-Wien, Austria

Michel Metcalfe
Laboratory Physical Sciences, Washington DC, USA

Shingo Kono
University of Tokyo, Japan

Ivan Deutsch
CQUIC, USA

David Schuster
University of Chicago, USA

Michal Lipson
Columbia University, USA

Angel Rivas
Universidad Complutese de Madrid, Spain

Murphy Yuezhen Niu
MIT, USA

Azar Eyvazov
Cornell University, USA

Florentin Reiter
Harvard University, USA

Vijay Jain
Photonics Laboratory, Switzerland

Nicholas Musyoka
CSIR,South Africa

Haidong Yaun
University of Hong Kong, China

Si-Hui Tan
Singapore University Technology and Design

Alan Aspuru-Guzik
Harvard University, USA

David Layden
MIT, USA

Ken Segall
Colgate University, USA

William Phillips
NIST JQI, USA

Zhenghan Wang
University of California, Santa Barbara, USA

Lorenza Viola
Dartmouth College, USA

Chang-Chun Zhong
Purdue University, USA

Benjamin Brown
University of Sydney, Australia

Radim Filip
Palady University of Olomouc, Czech Republic

Jean-Jacques Greffet
Institute d'Optique de Paris, France

Xun Gao
Tsinghua University, China

Manas Kulkarni
Tata Institute of Fundamental research, India

Arno Rauschenbeutel
Vienna Center for Quantum Science and Technology, Austria

Tobias Kippenberg
Ecole Polytechnique Fédérale de Lausanne, Switzerland

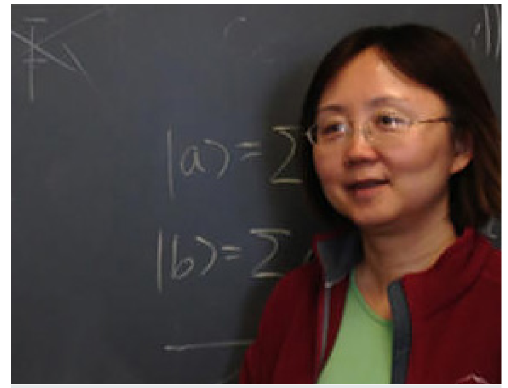
NEWS
FROM THE YQI COMMUNITY

SALOVEY: YALE IS FORGING CONNECTIONS TO SOLVE REAL-WORLD PROBLEMS

An important goal in the sciences at Yale over the next 10 years is having "outsized impact", said Yale President Peter Salovey, pointing as an example the recent news that Yale physicists are seeking to build the world's first quantum computer, which promises to revolutionize the world of computing. "I believe we have the best group in the country working on this," he noted.

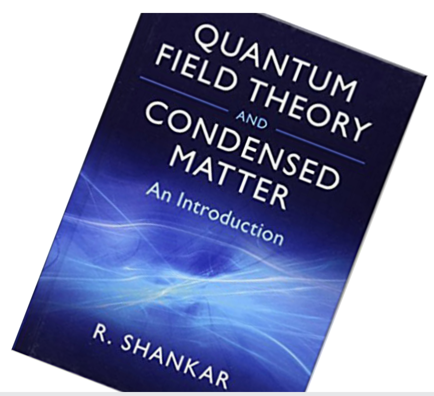
STEVE GIRVIN RECEIVES HONORARY DEGREE FROM CHALMERS UNIVERSITY

Steve Girvin received an honorary degree from Chalmers University, Göteborg, Sweden in recognition of his work on circuit QED. He spent one year as a post-doc at Chalmers during the 1970's in Sweden and established contacts with Swedish researchers, leading to a number of fruitful collaborations. He has frequent contacts with the department of Microtechnology and Nanoscience at Chalmers on the topic of quantum computers. In addition to collaborative research projects, he has also had advisory functions in numerous committees, and has also been a speaker at many local workshops and conferences.



HUI CAO NAMED FELLOW OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Yale scientists Hui Cao, Peter Raymond, and Karen Seto have been named by their peers as fellows of the American Association for the Advancement of Science. They are be among 396 members elevated to the rank of fellow at the Feb. 17 AAAS annual meeting in Austin, Texas. Each honoree was presented with an official certificate and a gold and blue rosette pin.



RAMAMURTI SHANKAR PUBLISHES NEW BOOK

Providing a broad review of many techniques and their application to condensed matter systems, "Quantum Field Theory and Condensed Matter" begins with a review of thermodynamics and statistical mechanics, before moving onto real and imaginary time path integrals and the link between Euclidean quantum mechanics and statistical mechanics. Introducing the reader to a variety of techniques, it opens up vast areas of condensed matter theory for both graduate students and researchers in theoretical, statistical and condensed matter physics.

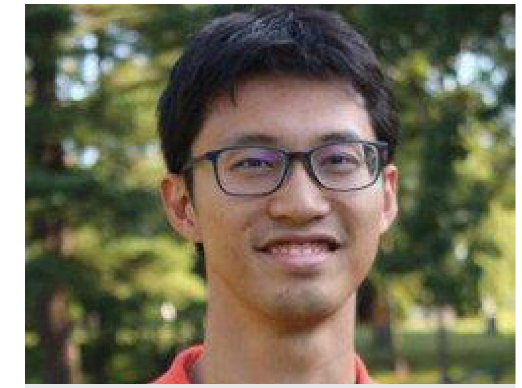
NICHOLAS READ & DANIEL SPIELMAN ELECTED TO NATIONAL ACADEMY OF SCIENCES

Professors Nicholas Read and Daniel Spielman have been elected to the prestigious National Academy of Sciences in recognition of their distinguished and continuing achievements in original research. Election to membership in the academy is considered one of the highest honors that can be afforded to a U.S. scientist or engineer.

"We are thrilled that the achievements of this superb group of Yale faculty have received this singular national recognition," said Steven Girvin, deputy provost for research. "The broad range of their pursuits represents some of the marvelous diversity of the many research directions being advanced at Yale."

THE 2017 CONNECTICUT MEDAL OF SCIENCE GOES TO ROBERT SCHOELKOPF

The Medal of Science is Connecticut's highest honor for scientific achievement in fields crucial to the state's economic competitiveness and social well-being. "The state of Connecticut is proud to award the Connecticut Medal of Science to Robert Schoelkopf, who has made pioneering contributions to the field of quantum science," said Governor Dannel P. Malloy. "I am particularly pleased that Rob, a world leader in this field, is right here in Connecticut."



CHIA WEI HSU SELECTED AS FINALIST FOR 2017 BLAVATNIK REGIONAL AWARD

Chia Wei (Wade) Hui was recognized for his work in controlling light in fundamental and applied optical physics. He uses modern technologies to explore and control light and matter interactions across nano-, micro-, and macro-length scales.

"This award will support my ongoing work in disordered photonics and my pursuit of new ideas," Hsu said. "By leveraging the intricate interactions between light and complex systems, I aim to probe fundamental questions in physics and to develop technologies with positive impacts for society."

YQI 360° VIRTUAL TOUR

While we accommodate frequent laboratory tours, it is impossible for us to welcome everyone in our facilities. However, you now have the chance to wander in our labs and learn more about our research activities thanks to our brand new virtual tour. VR headset owners can enable the VR mode for full immersion. Don't forget to look in each room for sound clips, slide shows, pictures, publications, and videos!

virtualtour.quantuminstitute.yale.edu

NEWS FROM THE YQI COMMUNITY

ADVANCING QUANTUM TECHNOLOGY IN 40 PICOSECONDS

Linran Fan is first author of an article published in Nature Photonics that presents a significant breakthrough in quantum communications and quantum computing.

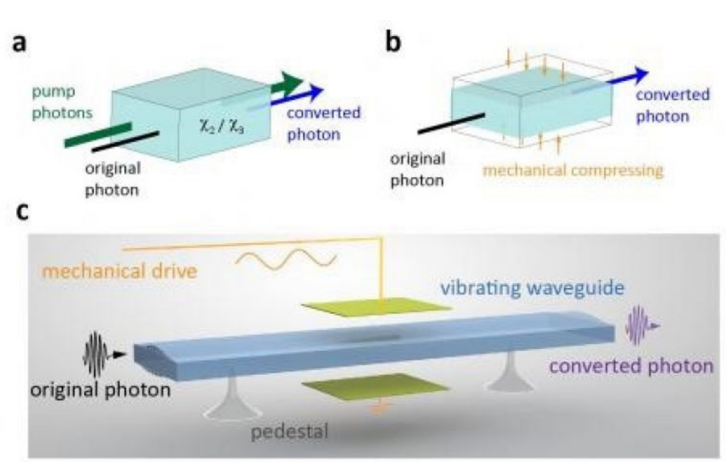
Working in the lab of Hong Tang, the Llewellyn West Jones, Jr. Professor of Electrical Engineering & Physics, Fan and fellow researchers developed a new technique to control the frequency of single photons – a crucial step in realizing the potential of quantum technology.

Established methods for changing photon frequency have significant drawbacks. The most common technique uses "nonlinear optical effects," in which a laser essentially acts as a pump, changing the photon frequency by providing extra photons to mix with the original one. Because the effect is weak and probabilistic, the process requires a very strong laser that creates "noise," which causes some of the quantum properties to be lost.

Using a completely different technique, the Tang lab was able to alter photon frequency by up to 300 GHz without creating any noise. They did this by changing the photon's propagating medium – the material in which the light travels. In standard integrated photonics, silicon, silicon nitride, and silicon di-oxide (SiO2) are commonly used for the "waveguide," the structure that guides the light. Tang's lab introduced the use of aluminum nitride as the propagating medium, and that made all the difference. They were able to stretch or compress the photon and change its frequency while the photon was in the waveguide — a process that takes about 40 picoseconds. A picosecond is one-trillionth of a second, and since the frequency change must happen exactly as the photon enters the waveguide, achieving this was quite a challenge.

"We utilize microwaves and the piezoelectric effect, which turns microwave energy into mechanical stress, to change the waveguide structure," Fan explains. The piezoelectric effect is the ability of certain materials to generate an alternating current (AC) voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both. "We don't need the optical pump, so we don't create any noise photons."

Fan was born and brought up in China, and earned his undergraduate degree from Beijing University. He first became interested in quantum physics in high school, when he participated in a physics knowledge competition. He chose Yale for graduate study because, "Yale's graduate program is focused and outstanding," he says. "It is one of the best in my research area. Also, New Haven is a nice and quiet place for research." When not in the lab, Fan likes to go hiking and camping, play guitar and accordion, and play basketball.



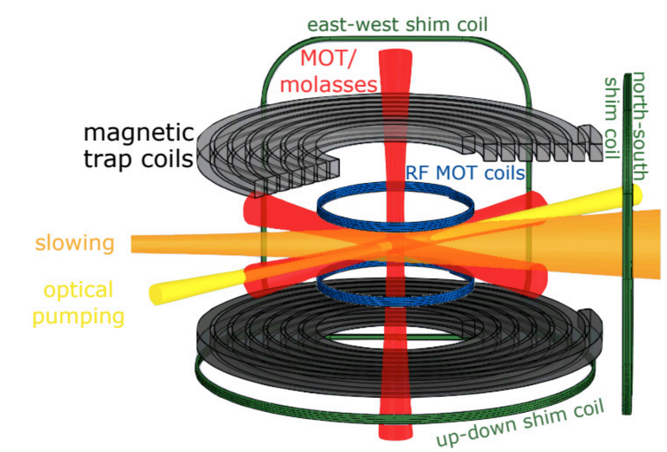
Excerpted from GSAS News

NEWS FROM THE YQI COMMUNITY

COOLING POLAR MOLECULES: A PATHWAY TO QUANTUM DEGENERACY

Magnetic trapping, a technique that uses using magnetic field gradients to trap neutral particles with magnetic moments, has been a key step toward the production of quantum-degenerate atomic gases. The best known example of a quantum gas is a Bose–Einstein condensate, a state of matter consisting of a dilute gas of bosons cooled to temperatures very close to absolute zero, forcing the bosons to occupy the lowest quantum state.

Recently, a team of Yale scientists lead by Professor of Physics David DeMille successfully trapped an ultra-cold gas of polar molecules in a conservative magnetic trap, and their result may open a similar pathway for cooling of polar molecules to quantum degeneracy.



A clever combination of magneto-optical trap and magnetic quadrupole trap is used to cool, accumulate, and trap molecules from a gas beam. This makes it possible to perform measurements for over a second.

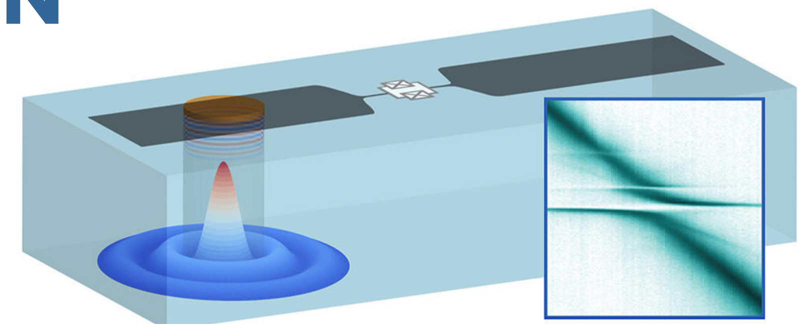
Compared to atoms, polar molecules have extremely large electric polarizability arising from the small energy spacing between rotational states. This property has up to now been largely unexploited for fundamental studies and is at the heart of most of their experiments. The group uses it both as a means of amplifying tiny symmetry-violating effects within the molecules and as a means for manipulating the external properties of the molecules.

DeMille and his team demonstrated a lifetime of over 1 second, limited only by background pressure, making this technique sufficient to begin exploring atom-molecule collisions and the prospects for sympathetic cooling upon the addition of a co-trapped atomic sample. These investigations will naturally lead to studies of controlled ultracold chemistry and attempts to tune elastic and inelastic collision rates. In the longer term, the increasingly high phase-space density accessible in conservatively trapped samples of polar molecules holds enormous promise for future generations of precision measurement experiments.

Co-authors of this study include Daniel McCarron, former postdoctoral associate at Yale who recently became assistant professor of physics at the University of Connecticut, and Matthew Steinecker and Yuqi Zhu, both graduate students in the department of Physics.

Florian Carle - Excerpted from YQI News

QUANTUM DATA TAKES A RIDE ON SOUND WAVES



A schematic drawing of a superconducting qubit coupled to phonons inside a sapphire crystal. Inset shows the energy spectrum of phonons measured using the qubit.

Yale scientists have created a simple-to-produce device that uses sound waves to store quantum information and convert it from one form to another, all inside a single, integrated chip.

The device allows a superconducting artificial atom — a qubit — to exchange energy and quantum information with a high frequency bulk acoustic wave resonator (HBAR). The ability to manipulate and store fragile quantum data in a robust and easy-to-manufacture way is a crucial step in the development of quantum computing technology.

The work is a collaboration at Yale between the labs of Robert Schoelkopf, the Sterling Professor of Applied Physics and Physics, and Peter Rakich, assistant professor of Applied Physics. Yiwen Chu, a postdoctoral associate in Schoelkopf's lab, led the effort and is first author of a study that appeared on Sept. 21 in the online edition of the journal Science.

Chu said the new device features a qubit made from superconducting aluminum and a mechanical resonator made with a sapphire wafer. The wafer has two polished surfaces acting as mirrors for sound waves.

"We found that even a single quantum particle of sound, or a phonon, can live for a very long time when it bounces back and forth between these mirrors," Chu explained. "It can also be coupled to a superconducting qubit made on the surface of the sapphire using a disk of aluminum nitride, which converts acoustic energy into electromagnetic energy and vice versa."

The combination of these properties enables the researchers to transfer quantum states back and forth between the qubit and the mechanical resonator, Chu added. She also noted that the new device is easier to manufacture than other systems that merge superconducting circuits with mechanical motion.

Yale scientists have made a series of quantum superconducting breakthroughs in recent years, directed at creating electronic devices that are the quantum version of the integrated circuit. The ability to combine that knowledge with a mechanical resonator is a valuable step, Chu said.

"For example, mechanical resonators can be used to store quantum information generated by superconducting qubits in a more compact and robust way," she said. They can also be used to interface superconducting circuits to other types of quantum objects, such as visible or infrared light. It would potentially allow us to create quantum information in our circuits and then transmit it over long distances using light."

Co-authors of the new study from the Yale Departments of Applied Physics and Physics include Prashanta Kharel, William Renninger, Luke Burkhart, and Luigi Frunzio.

Jim Shelton -Excerpted from Yale News

QUANTUM METROLOGY ENHANCED BY QUANTUM ERROR CORRECTION

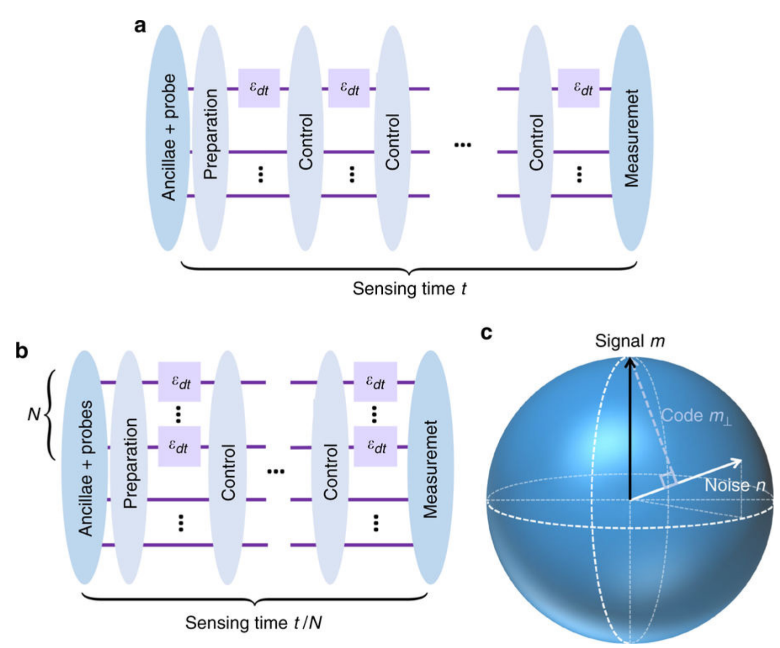
Quantum metrology is of great importance in science and technology, with wide applications including frequency spectroscopy, magnetometry, accelerometry, gravimetry, gravitational wave detection, and other high-precision measurements. To estimate a physical parameter characterizing the Hamiltonian of a quantum system, we can prepare a suitable initial state of the system, allowing it to evolve for a specified time, performing a suitable measurement, and inferring the value of the parameter from the measurement outcome.

The measurement precision is fundamentally limited by quantum mechanics. This limit, called the Heisenberg limit, constrains how the precision of parameter estimation scales as the total probing time and the total number of probes used in the experiment. The Heisenberg limit can be achieved for ideal noiseless quantum systems, but is not achievable in general for systems subject to noise. In practice, however, physical systems are always subject to noise, due to unavoidable couplings with the environment. Hence, it is important to study the fundamental limit of quantum metrology of physical systems subject to noise and develop protocols to achieve the sensing limit.

A team of theoretical researchers, led by Liang Jiang, investigated how measurement precision can be enhanced through quantum error correction, a general method for protecting a quantum system from the damaging effects of noise. They found a necessary and sufficient condition for achieving the Heisenberg limit using quantum probes subject to Markovian noise, assuming that noiseless ancilla systems are available, and that fast, accurate quantum processing can be performed. When the sufficient condition is satisfied, a quantum error-correcting code can be constructed that suppresses the noise without obscuring the signal; the optimal code, achieving the best possible precision, can be found by solving a semidefinite program.

This work, a collaboration between Sisi Zhou, Mengzhen Zhang and Jiang Liang from the Yale Quantum Institute and John Preskill from Caltech, is published in Nature Communications in 2018.

Florian Carle - Excerpted from YQI News



The sequential (a) or parallel (b) metrology schemes used to achieve the Heisenberg limit. The sphere represents the relation between the signal Hamiltonian, the noise, and the QEC code for a qubit probe.

NEWS FROM THE YQI COMMUNITY

BASKERVILLES HOUND MEETS SCHRÖDINGER CAT

Sir Arthur Conan Doyle, the famous creator of the Sherlock Holmes detective stories, endowed his famous sleuth with master powers in the science of logical deductions. Sherlock Holmes is perhaps at the pinnacle of his career when he solves the case known as the *Adventure of Silver Blaze*, a story written in 1892:

> *Gregory (Scotland Yard detective): "Is there any other point to which you would wish to draw my attention?"*
>
> *Holmes: "To the curious incident of the dog in the night-time."*
>
> *Gregory: "The dog did nothing in the night-time."*
>
> *Holmes: "That was the curious incident."*

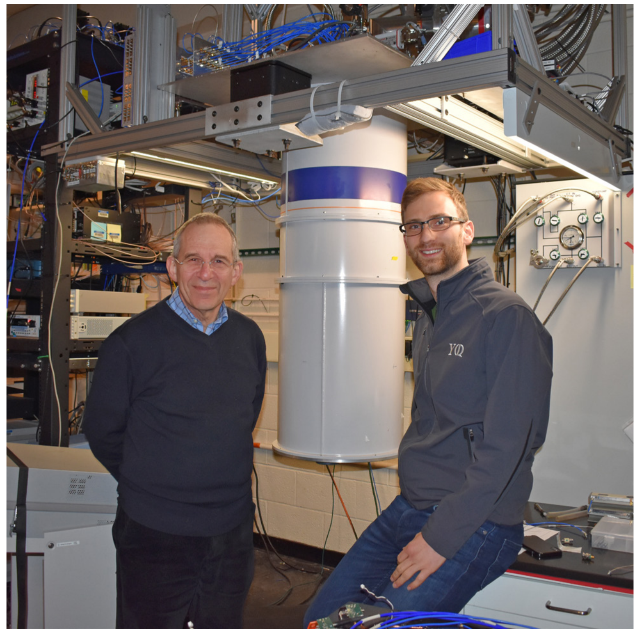
In that story, it is the clue that the dog had <u>not</u> barked during the night of the murder that resolves the crime mystery. In other words, the logical deduction that solves the case is based on the *absence* of an event. This plot twist has become synonymous with the logical

The Hound of the Baskervilles cover, illustrated by Sidney Paget for the book first edition published in 1902

inference property that the non-observation of an event can bring as much information as the observation of the same event. Interestingly, many people believe that the name of the unnamed dog in that story is the Baskervilles Hound, another famous dog in another Sherlock Holmes story, and for the title of this piece, we have played along with the doubtful identity of the dog that did not bark.

In 1935, wanting to convince the public at large that the state superpositions of quantum mechanics deeply violated our intuition about the physical world, Erwin Schroedinger, one of the founders of quantum mechanics, imagined a cat which would be in a superposition of being both alive and dead. While an extreme case, it is permissible in quantum mechanics to place a very complex system in a superposition of two states that are incompatible according to the rules of classical logic. The paradox arises from the fact that in our everyday world, two events that are mutually exclusive, like being alive or dead, are never realized at the same time. However, in the world of quantum computers, machines that follow Nature's own logic, which is quantum, a quantum bit (aka a 'qubit') can be in a superposition of the states of 0 and 1. In plain language, that means that the bit is both zero AND one *at once*. But a basic law of quantum mechanics stipulates that this quality can be true only as long as one does not make a measurement of the bit. In such observations, what is known as state collapse takes place: the observation of the value of the bit forces it to adopt one of its two states, destroying the superposition.

Yet, the subtle nature of quantum mechanics allows for the coexistence of observation and superposition in the case of indirect measurements, which exploit the "dog that did not bark" effect. One can construct measurement schemes in which, instead of directly measuring the qubit to see if it is zero or one, one sets

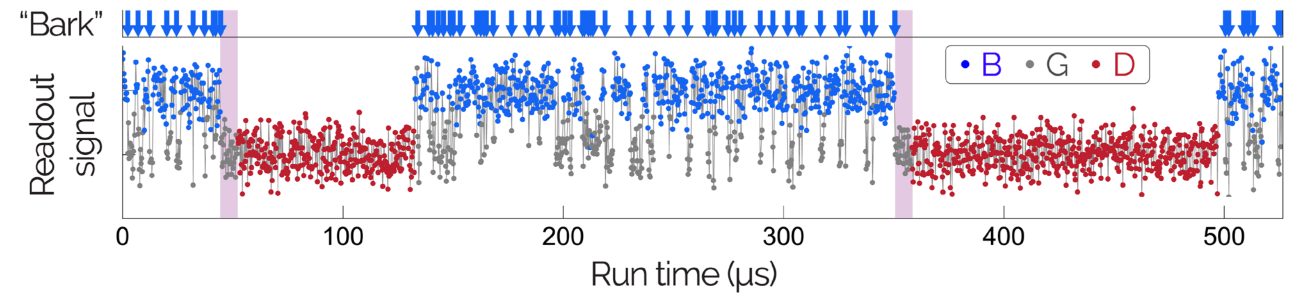


up an external force that brings the system, if it is in the zero state, into an auxiliary state B (for bark). Then, one continuously monitors the system and watches if it is in state B or not, making sure that this monitoring does not acquire any direct knowledge as to whether the system is in 0 or 1. Thus, while this continuous monitoring does not disturb any superposition of 0 and 1, it still does allows one to acquire some knowledge on the qubit. The way this works is as follows: contingent on the non-observation of B, our apparatus acquires the knowledge that the qubit must not be in 0, otherwise it would be brought up to B by the external force and our apparatus would be alerted.

An experiment performed by our group has recently employed this type of indirect measurement to demonstrate the continuous and coherent nature of quantum jumps. The experiment is based on a 3-level artificial atom created using a superconducting electrical circuit. The ground level G and an excited level D which is not coupled to the readout channel (dark level) forms a protected qubit which *cannot be measured directly*. The indirect qubit measurement involves the auxiliary 3rd level B whose population is monitored by the readout channel while a microwave drive tone continuously induces transitions from the ground to the B level. During the quantum jump, the atom can be captured in the superposition of being both 0 and 1, hence in a Schroedinger cat state, by conditioning the measurement on the non-observation of the system in the continuously monitored level B, an event which here plays the role of the dog that did not bark.

The article reporting this experiment, entitled "Catching and reversing a quantum jump mid-flight", co-authored by Zlatko Minev, Shantanu Mundhada, Shyam Shankar, Philip Reinhold, Ricardo Gutierrez-Jauregui, Rob Schoelkopf, Mazyar Mirrahimi, Howard Carmichael, and Michel Devoret, can be found at arXiv:1803.00545.

Zlatko Minev and Michel Devoret
Excerpted from YQI News



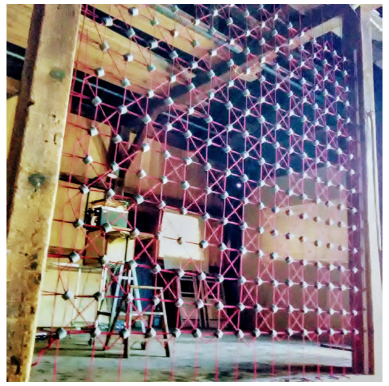
Quantum jumps displayed by experiment on a superconducting three-level atom. The downward blue arrows correspond to a change in the measurement record from B to not-B (either G or D), analogous to the "Bark!" of the Baskervilles hound. When the hound doesn't bark for a certain period of time (pink region), then the atom must be in the D level; otherwise, it would should have been brought from the G to the B level by the strong microwave drive applied to the atom. The color of the dots results from a real-time quantum-logic assignment. Data not shown demonstrate that the atom is in a coherent superposition of G and D in the pink region—a Schrodinger cat being both dead and alive.

Martha W Lewis
Artist-in-Residence

Thanks to the great intersection between Martha's work on history of science and the human knowledge and the institute mandate to explain Quantum Information across disciplines and in particular across the humanities-science divide, we have decided to welcome her for a year long residency.

When I arrived to YQI this past September, I felt excited but also awkward and a bit shy. As their first artist-in-residence I had a tabula rasa for approaching the citizens of the institute and the intellectual material they produce. It's difficult placing oneself in a position of near-constant ignorance, and every time I felt I understood something the carpet would quickly ripple out from under my feet sending me tumbling again. So far, I have been simultaneously floating in a dazzled state of Aporia*, (which literally means simultaneous: 'perplexity', 'impasse' 'puzzlement') and happily working through visual ideas for various quantum concepts that also invoke the unique working culture of the place itself, which I find compelling.

As a traveler visiting a strange land the people here were kind, hospitable but also a bit wary. The question: "Do we NEED an artist is residence?" hung invisibly in the air, and because most scientists are themselves artists in so many ways, it was hard to succinctly encapsulate the WHY. I have stopped trying to answer it in this way, focusing on the HOW instead, using an array of possible approaches in as un-programmatic a manner as possible. If an initiative doesn't seem effective, I chalk it up as an interesting detour, and try another route.



My scattershot approach ranges from the very direct - attending weekly seminars, visiting labs and offices, to the more remote - curating the Institute's glass display cabinets with mixtures of scientific objects and my artworks, offering up a rotating collection of curiosities to look at. My goal when I leave is for the shelves to survive as an active museum for the institute, occupied with various instruments and artifacts marking the historic life of the institution.

Initially, this residency was to be purely for research- to generate ideas and models without the pressure of making something- yet the response I have as an artist is, of course, visual and tactile. The richness of the mind-bending stories I am told here are irresistible to me, thus I have been making what I consider to be crude prototypes from the beginning, testing the waters. This has most publicly materialized as Remembering Memory, a large-scale installation I put together at the historic Ely Whitney Barn as a part of the City-Wide-Open Studios Festival in October. Rough around the edges, it offered a glimpse of what I was up to at YQI and gave me the perfect test site for a multi-facetted work that involved- in addition to the object and its technology- the history of women's hand-labor, a meditation on the interrelationship between our own minds and the "memory" functions of the devices we make, science fiction, cinema and the metaphor of mind as a location – palace, garden or library and the impermanent state of our own brains. YQI generously gave me support in terms of equipment, and to my delight many students, researchers and faculty alike made the trek out to the barn over the weekend to visit. Remembering Memory acted like a Zen garden as a place to contemplate and offered the public a chance to see first-hand into the delicate architecture of the discarded machine's consciousness.

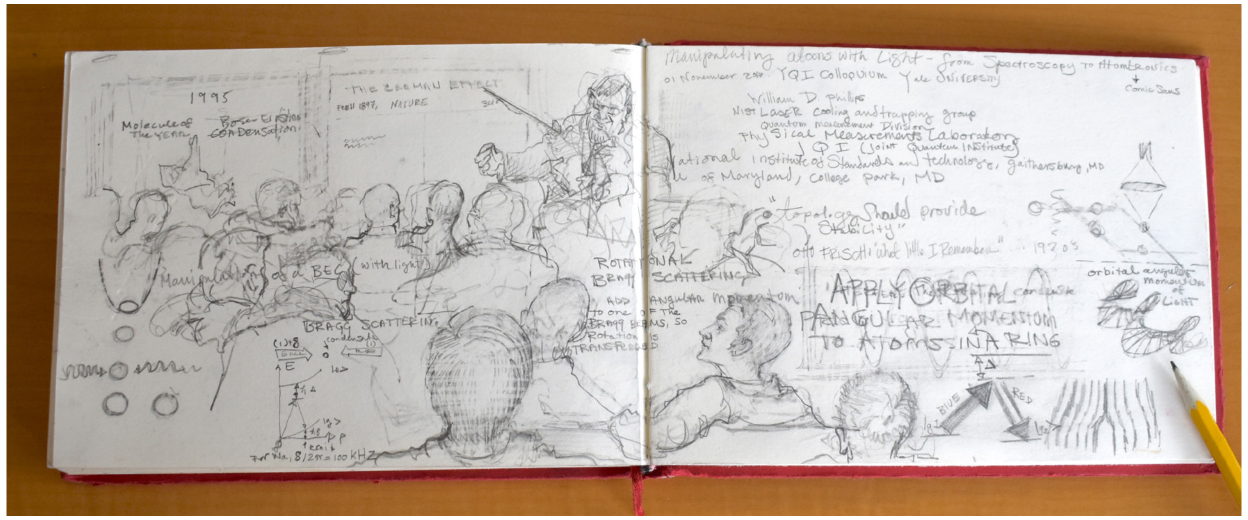
I also have created a permanent artwork for the lobby. How it manifested only came into being after having interacted with those at YQI. The mural is far more collaborative in nature than what I habitually produce, offering a sea-change from my usual solitary studio practice, much more in keeping with the collective methodology in operation at the institute. I had input as to the ramifications of the visual elements in process, I had skilled technical support, I had remote fabrication of the final work, all new experiences. I was -unusual for me- uneasy up until the installer finished his last burnishing stroke and we saw it in situ, shining in the light of the lobby, a reflected glow shimmering along the floor. I had selected four possible outcomes and posted the mock-ups in the YQI kitchen. Members were invited to tick off their choice, as they sipped coffee or picked up a sandwich before a talk. Without risk nothing creatively special really ever happens, and I wanted to give the institute something special.

Over the course of these 4 months my artwork has become entangled as insignia for the institute on multiple levels; images of my work grace YQI's banners, logos, screens and podiums.

The Spring Semester offers up more challenges and excitement. We are memorializing the end of the residency with a panel talk and new artwork for the International Festival of Arts and Ideas. From the beginning I have been fielding expressions of curiosity from the general public about YQI, about my projects. One of my functions is as a kind of visual translator, hopefully making what goes on at the institute a bit more tangible. The irony is that with things quantum "tangible" is a tall order, but this is what I do, I take ideas and model them into layered, nuanced, palpable things....

Martha W. Lewis

**Aporia is described by Valiur Rahaman, in his book Interpretations: Essays in Literary Theory (2011), as a creative force in both the artist and their art; it is, for the artist, "an edgeless edge of the text or a work of art".*



5
SPECIAL EVENTS

399
ATTENDEES

QUANTUM PHYSICS & MUSIC

Micheal Berry kick-started the series by explaining how quantum physics democratized music thanks to the development of lasers and Compact Disks.

SCIENCE & ART

Martha Willette Lewis creates multi-dimensional artworks inspired by the history of science and human knowledge.

PHYSICS & DANCE

Adele Myers and Emily Coates took the stage to discuss the intersectionality of dance and physics in their choreographies and performances.

MATHEMATICS & CROCHET

Daina Taimina taught us how hyperbolic crochet can make us visually understand mathematics and showcased her 2013 World Guinness Record largest hyperbolic crochet.

DEMYSTIFYING SCIENCE AND INSPIRING NEW GENERATIONS

These nontechnical events, accessible to a large audience composed of the Yale and the Greater New Haven communities, invite us to reflect on the contribution science makes in our daily lives.

When I meet new people, I usually get asked what I do for a living. "I manage the Yale Quantum Institute and I work with quantum physicists". Almost every time, regardless of the level of education, I am met with blank stares and awkward silences. Quantum physics seems so abstract and foreign that it paralyzes my interlocutors, forcing them away from this fascinating subject. This is unfortunate. When I think about quantum physics, I get excited about cats being dead and alive at the same time, spooky actions at a distance, entanglements...

The lack of exposure to quantum physics and the cultural assumption that it is one of the most complex subjects in physics might be the reasons why people are so reluctant to discuss this topic.

One of the missions this year at the institute was to create outreach programs to engage the general audience, to combat quantum physics phobia, and, in a more general way, science phobia.

Leveraging the Intersectionality of science and the humanities, we launched in Spring 2017 a new series of non-technical talks, co-sponsored by The Franke Program in Science and the Humanities.

We wanted these talks to bring a fresh approach to quantum physics and science by having experts cast new light on often-overlooked aspects of scientific work. Using various conduits of music, visual art, dance and crochet, we engaged the audience to talk about quantum physics, science, physics and mathematics in an accessible, creative way.

Additionally, YQI hosts public science lectures aimed at middle and high school students, as well as interested adults. Last fall, 1997 Physics Nobel Prize Laureate William Daniel Phillips (pictured on the left throwing frozen balloons into the audience), gave a lively, multimedia presentation, which included exciting experimental demonstrations and down-to-earth explanations of some of today's hottest (and coolest) science.

Curating these events is my favorite part of my job at YQI. It is truly rewarding to see people from different backgrounds engaged in a common topic. These interactions often lead to new ideas I would not have thought of if it were not for these stimulating discussions. I also hope these events will leave a lasting impression on young attendees, and encourage them to consider a career in STEM.

Florian Carle

THE FRANKE PROGRAM

The Nontechnical Talk Series is co-sponsored by The Franke Program for Science and the Humanities, a program at Yale that aim to foster communication, mutual understanding, collaborative research and teaching among diverse scientific and humanistic disciplines.

TOBIAS KIPPENBERG
2017 YQI DISTINGUISHED LECTURER

This year, YQI launched a brand new series featuring a preeminent international speaker

Tobias Kippenberg of the École Polytechnique Fédérale de Lausanne was presented in December with the inaugural *Yale Quantum Institute Distinguished Lecturer Award* by Deputy Director Douglas Stone.

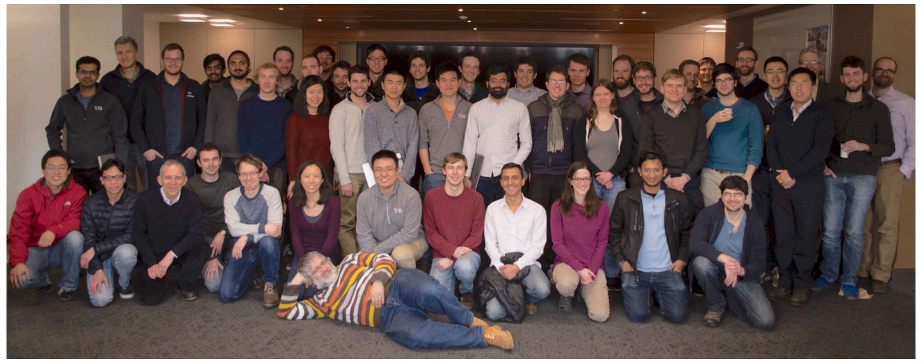
This title recognizes a researcher whose work significantly advances quantum science, with emphasis on the areas of mesoscopic physics, nanoscience, quantum information, quantum computing and related theoretical and mathematical topics.

Annually, a *Distinguished Lecturer* will be invited to visit the Yale Quantum Institute to deliver a lecture about a valuable research result or body of important work which has advanced our understanding in one or several sub-fields of quantum science. Eligible candidates for the title of *YQI Distinguished Lecturer* must be within 12 years of receiving their PhD.

Tobias was recognized for his groundbreaking work in quantum opto- and electro-mechanics. He delivered an acceptance lecture about the physics and applications of high-Q microresonators from quantum optomechanics to chipscale frequency combs. Tobias gave a second more technical seminar on reservoir engineering of mechanical oscillators for quantum limited amplification, masing and non-reciprocal devices the next day.

During his stay, numerous students and faculty members met with him to discuss the intersections of their work and establish possible new collaborations. We appreciate Tobias' intellectual generosity with us during this brief and intensive visit.

BECOME A YQI FELLOW



In keeping with the mission of the institute, we are pleased to invite applicants for the YQI postdoctoral fellowships. These Fellowships will support research in the field of quantum science for recent Ph.D. recipients to work in the research group of any of the YQI faculty members.

Candidates should have demonstrated excellent research ability in their prior work and exceptional promise for future leadership in their field of interest. A selection committee will review each application and evaluate the candidates based on the quality of their previous work (thesis and publications) and their potential for original research, within their proposed research group.

New YQI Fellows will be appointed every year, for a 2-year period. You are encouraged to learn more about the YQI Fellowship and to apply by visiting our website.

EXECUTIVE TEAM

A. DOUGLAS STONE

Former chair of the Department of Applied Physics at Yale and author of "Einstein and the Quantum", Doug serves as Acting Director for 2018.

ROBERT SCHOELKOPF

Internationally recognized for his experimental work in quantum circuits, Rob is the founding Institute Director since 2015.

FLORIAN CARLE

After earning a PhD in France, Florian joined Yale as a postdoctoral associate in Mechanical Engineering before becoming YQI Manager.

RACQUEL MILLER

A native of Pasadena, CA, Racquel has worked at Yale for more than 10 years and joined the YQI executive team as an Administrator Assistant in 2016

Engage with us on Twitter @Yale_QI

The Quantum Institute facilitates the research and teaching of quantum science on the Yale campus. YQI performs outreach in the form of seminars, workshops, and by hosting leading scientists from around the world.

QUANTUMINSTITUTE.YALE.EDU