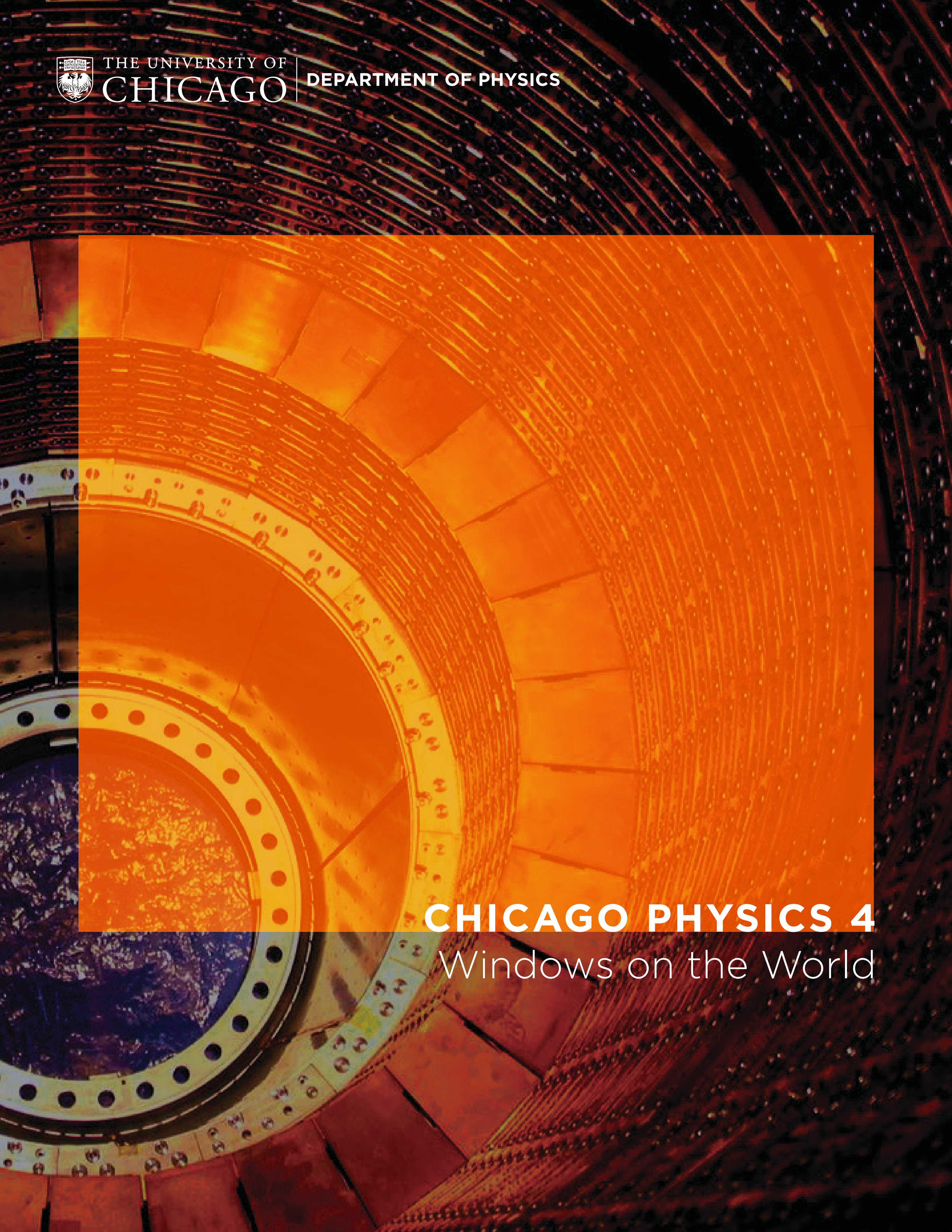
THE UNIVERSITY OF CHICAGO | DEPARTMENT OF PHYSICS



CHICAGO PHYSICS 4

Windows on the World

Welcome to the fourth issue of Chicago Physics! In our last issue, we took you on a journey to the quantum world. In the current issue, we will guide you to explore the frontiers of our Universe.

This year has been an extremely challenging year forcing all of us to adapt to new realities. Despite unprecedented times, we have achieved much, thanks to the collective efforts of everyone in our department including undergraduate and graduate students, postdocs, the staff and the faculty. Special thanks should go to our staff and in the current issue our staff shares some of their experiences in adapting their work with students and faculty during these extraordinary circumstances. We also celebrate new members of the Department in this issue.

The 4th Maria Goeppert-Mayer Lecture featured Andrea Ghez who was awarded the 2020 Nobel Prize in Physics for discovering the supermassive black hole that lurks at the center of the Milky Way. Her work is nicely connected to the theme of the current issue. The virtual lecture by Ghez, a 1983 graduate of the University of Chicago Laboratory Schools, attracted a diverse audience of about 2,500 people from around the world, including Maria Goeppert-Mayer's grand-daughter Tania DeBeau, the 1st, 2nd, and 3rd Maria Goeppert-Mayer lecturers (Melissa Franklin, Helen Quinn, and 2018 Nobel Laureate Donna Strickland), Program Director of the Heising- Simons Foundation Cyndi Atherton, Ghez's mother Susanne Ghez, Ghez's high school chemistry teacher from the University of Chicago Lab Schools Judy Keane, and Interim Director of the Lab Schools Dave Magill.

We hope that the stories we share will inspire you to become more involved and engaged in the Department. Please keep in touch and let us know what you think.

Yours sincerely,

YOUNG-KEE KIM

Louis Block Distinguished Service Professor
Chair, the Department of Physics

Editor's Note

A century ago to observe the universe was to point an optical telescope at the stars, and to imagine that visible light interacting with ordinary matter are the sum contents of our world. Expanding the observable spectrum into radio frequencies allowed us to trace our universe back to the earliest available times and understand that it is not in stasis. Hence traditional astronomy gave us the geometry and some of the history of the universe (though there is much more to do), but we now know it missed out most of the content – so called "dark matter" and "dark energy".

Meanwhile, in quite separately motivated experiments on earth, we have dissected matter in particle colliders to confirm the "standard model", which is a triumph of unification of three of the four known forces of nature, yet annoyingly incomplete (no gravity) and perfused with parameters whose values we cannot predict.

As physicists, we would like matters to be more tidy, and the solution is more data. But not just more data in the traditional probes but qualitatively new "windows on the universe." In this edition of Chicago Physics, three of our colleagues talk about the new tools we have to observe the fabric of the universe. The particle collider at CERN recreates conditions from the early universe and while the standard model is now confirmed in all of its ingredients, David Miller explains how increasing the resolving power and flux of this instrument gives us an opportunity both for precision measurements and searching for candidates for dark matter. Neutrinos – the elusive particle named by Fermi – are streaming past us in high flux, but are so difficult to capture that only very recently have we been able to build the first neutrino telescopes. Abby Vieregg explains how rapidly we are moving from detection of astrophysical neutrinos to discovering their correlations. The other recent "jolt" as Abby describes it is the remarkable discovery of gravitational waves arising from the merger of massive black holes and neutron stars – events that appear to be common enough that gravitational wave astronomy is now a burgeoning field. (Daniel Holz reported on the initial discovery in Chicago Physics' inaugural issue.) Black holes represent singularities in the solutions of general relativity which remain mysterious, and Bob Wald presents us with the latest thinking on how lifting the veil on cosmic censorship might enable the construction of a quantum theory of gravity. For a special colloquium upcoming this spring, we are delighted to welcome back Walter Massey, who is one of our most distinguished former faculty. He is a theoretical physicist whose roles have included being Director of Argonne National Laboratory, Director of the National Science Foundation, Provost of the University of California, President of Morehouse College, and President of the School of the Art Institute of Chicago.

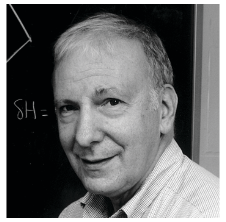
For us, as for all of you, COVID has made this a challenging year for education, and for our students. Our staff has risen to this challenge and tell you here about the efforts put in place to mitigate the pandemics impacts, and sometimes how rethinking what we do can deliver unexpected improvements. Nonetheless, we are looking forward to putting the pandemic behind us, and consolidating lessons learned.

PETER LITTLEWOOD

Contents

Spacetime Singularities and Predictability

ROBERT M. WALD



Roger Penrose was awarded the 2020 Nobel Prize in Physics (shared with Andrea Ghez and Reinhard Genzel) for his groundbreaking work proving that, according to general relativity, singularities must arise in a wide variety of circumstances relevant to gravitational collapse and to cosmology. However, although the singularity theorems of Penrose and Hawking establish that “something must go wrong,” they say very little about the nature of the singularities. This has remained a major, open issue in general relativity for the past 50 years.

One very important open issue regarding singularities is whether any singularity arising from the complete gravitational collapse of a body must always be hidden within a black hole. By definition, a black hole is a region of spacetime from which it is impossible to escape. If the singularity is contained within a black hole, then—unless we, ourselves, go into the black hole—we don’t have to worry about it because anything inside a black hole cannot have any causal effect on anything outside of the black hole. By contrast, if a singularity arising from gravitational collapse were not contained in a black hole, it would be a called a “naked singularity” and, in principle, a distant observer could “see” its effects. The belief that all singularities of gravitational collapse are contained within black holes is known as the cosmic censorship conjecture. The overwhelming belief in the general relativity community is that this conjecture is true, and there are many indirect arguments that support it. However, there is nothing close to a complete proof of this conjecture yet, and, indeed, many mathematicians are continuing to build up tools that might help tackle this question.

There is a related question about singularities that is also of considerable interest. Suppose that cosmic censorship is true and that singularities of gravitational collapse are always contained within a black hole. But now suppose that one goes into a black hole. Could one then “see” the singularity? Alternatively, would one necessarily fall into the singularity before one could “see” it? This question might seem rather esoteric, but it contains fundamental implications with regard to the issue of predictability. There are no (known) laws of physics governing what can emerge from a singularity, so if one can “see” a singularity from a nonsingular region of spacetime, there should be an accompanying breakdown of predictability. In other words, if it is possible for an observer to “see” a singularity, then even if one is given the complete initial conditions of the universe prior to the gravitational collapse, one would not be able to predict what will happen to observers who go sufficiently far inside of a black hole. The strong cosmic censorship conjecture asserts that, generically, all singularities that result from nonsingular initial data must be of the type that one would fall into them before they can be seen. If true, this would mean that there would be no breakdown of predictability in any nonsingular regions of spacetime. It should be noted that, despite its name, “strong cosmic censorship” does not imply “cosmic censorship,” since strong cosmic censorship would not preclude a singularity created from gravitational collapse from extending out to distant observers and thus not be confined to a black hole.

The singularity inside of a Schwarzschild black hole (corresponding to a black hole with no angular momentum or electric charge) is of the type compatible with strong cosmic censorship. However, the singularities inside of a Reissner-Nordstrom black hole (corresponding to a black hole with electric charge) and inside of a Kerr black hole (corresponding to a black hole with angular momentum) would be visible to observers who enter sufficiently far into the black hole. In other words, for a Reissner-Nordstrom or Kerr black hole, only a portion of the spacetime would be predictable. (This portion includes the entire exterior of the black hole and a portion of its interior.) These examples do not disprove strong cosmic censorship because of the word “generically” in the conjecture. These solutions are very special, and arbitrarily small perturbations will drastically alter the nature of the singularity.

The first image of a black hole, obtained using Event Horizon Telescope observations of the center of the galaxy M87. Credit: Event Horizon Telescope Collaboration

This can be formulated as follows. The boundary of the predictable region of the spacetime is called the Cauchy horizon. The Reissner-Nordstrom and Kerr solutions have a nonsingular Cauchy horizon. However, arbitrarily small initial perturbations of these solutions will become singular on the Cauchy horizon.

Thus, the behavior found in perturbations of the Reissner-Nordstrom and Kerr solutions is in support of strong cosmic censorship. However, a few years ago, an apparent counterexample was found. Consider a Reissner-Nordstrom black hole that is put in an expanding universe with accelerating expansion (as we observe in our own universe). The resulting solution—known as a Reissner-Nordstrom-deSitter (RNdS) black hole—has the property that perturbations decay more rapidly in time due to the expansion of the universe. It turns out that this makes the singularity on the Cauchy horizon milder, and, for certain choices of parameters of the black hole, it makes the singularity on the Cauchy horizon so mild that it shouldn’t be considered a singularity at all. Thus, it would appear that a generically perturbed RNdS black hole can be extended beyond its Cauchy horizon, in violation of strong cosmic censorship and predictability.

However, for RNdS black holes, quantum effects come to the rescue of strong cosmic censorship. During the past year, Stefan Hollands, Jochen Zahn, and I showed that, within the context of quantum field theory in curved spacetime, the behavior of quantum fields near the Cauchy horizon of RNdS black holes is far more singular than that of classical fields. Even for choices of parameters that lead to only very mildly singular behavior classically, the quantum field behavior is sufficiently singular that solutions cannot be extended beyond the Cauchy horizon. I believe that it may be possible to extend this argument to completely general spacetimes. If so, this would establish a general version of strong cosmic censorship in the context of quantum field theory in curved spacetime.

Ultimately, of course, one would like to have a description of the singularities themselves in a full, quantum theory of gravity. We are very far from that goal at present. However, as I have described above, progress is being made towards understanding the nature of singularities in classical general relativity and quantum field theory in curved spacetime.

Opening New Windows on the Universe

ABIGAIL VIEREGG

Ten years ago, multi-messenger astrophysics including neutrinos and gravitational waves seemed far-fetched, at least to me. After all, the only sources that had ever been seen in the light of neutrinos were the Sun and Supernova 1987, and gravitational waves had not been directly detected.

Yet I am amazed at how science progresses. Sometimes it moves with a jolt, like an earthquake under your feet. You wake up one day and all of a sudden your understanding has shifted markedly. This happened for me in February 2016, when I watched the press conference where LIGO announced the first detection of gravitational waves. Rather than being with my colleagues at Chicago (which I was sad to miss) I was at UBC, where I was giving a colloquium that day. I had to rewrite the first 5 slides of my colloquium right there, on the spot. Enough had changed that morning to render my usual "science motivation" slides obsolete.

Sometimes science moves slowly, incrementally, and then one day you look up and you realize just how much the landscape has changed. This is what has happened with neutrino astronomy over the last decade. IceCube, a large neutrino detector at the South Pole, made the first observation of astrophysical neutrinos in 2013 – a signal just poking up above the background. IceCube continues to invent new analysis techniques and acquire more data, and the significance of this detection has grown. In addition, IceCube has started seeing hints of correlations (both in time and in space) of neutrino events with specific sources. The landscape has changed significantly over the last decade. No longer are we hoping to discover astrophysical neutrinos; instead, we are characterizing them and using them to learn about the astrophysical processes that drive their acceleration.

We sit now in this exciting new era of multi-messenger astrophysics, where gravitational wave astronomy and neutrino astronomy are no longer fiction. One in which we can credibly talk about using information from electromagnetic observations across the entire spectrum as well as observations of gravitational waves, neutrinos, and cosmic rays to learn about fundamental physical laws, the evolution of the universe, and the nature of the most energetic accelerators in the universe.

NSF's Summit Station in Greenland, where the Radio Neutrino Observatory in Greenland (RNO-G) is being built.

History has shown that when you build a new, powerful detector, even if you aren't really sure what you'll find just below the surface where no one has looked before, that if you build the right instrument, you'll surely find something interesting. I took a bet and decided to place it on developing technology to detect the highest energy neutrinos, above the energies that IceCube can reach, to learn about the nature and evolution of the highest energy accelerators in the universe, and maybe even learn something about neutrino interactions in the mean time. Along with colleagues from many institutions in Europe and the US, we've been building and integrating a new experiment (the Radio Neutrino Observatory in Greenland) over the last two years, which is a radio detector that aims to discover signatures of the highest energy neutrinos as they interact in the Greenland Ice Sheet. After a year delay due to the ongoing pandemic, we are planning to deploy the first set of detectors to NSF's Summit Station Greenland this summer. We have our fingers crossed for no more deployment delays (getting new things to the field during a pandemic is challenging to say the least!)

It is a simple idea: each time you find a new way of looking at the universe, you learn new things that were previously unknowable, and linking together observations using multiple messengers leads to new discoveries. I can only imagine what the next decade holds.

Frontiers of Particle Physics

DAVID W. MILLER

Exploring the frontiers of our Universe has always been a critical human endeavor. But what if humans could not only peer backwards into the history of the Universe—as we do with the celestial observatories that are used to study astronomy, astrophysics, and cosmology—but also to directly interact with the basic elements that constitute the fabric of the Universe itself?

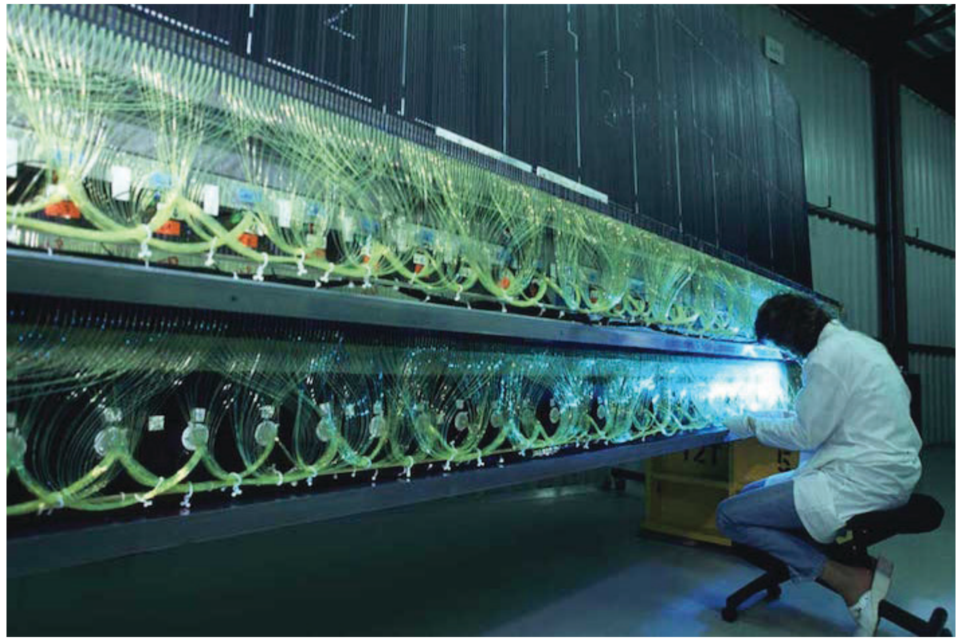
In many ways, this seemingly impossible task is the daily business of particle physics. In the case of high energy collider physics, this is achieved by colliding particles such as hydrogen nuclei—protons—at nearly the speed of light in a laboratory. This enables us to study the processes that dominated the Universe when it was less than one tenth of one billionth of a second old (age ~ 10^{-10} seconds). At the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland, we create the highest energy human-made collisions ever between two particles. We do this in a laboratory setting instead of waiting for the cosmos to do it for us, and we do it 40 million times per second. With this technology we have to ability to manipulate and control the studies of never-before-seen phenomena in a way that is different from and complementary to the outward-looking telescopes of our astrophysics colleagues, and allows us to not only open a new window on the Universe but to also climb through it.

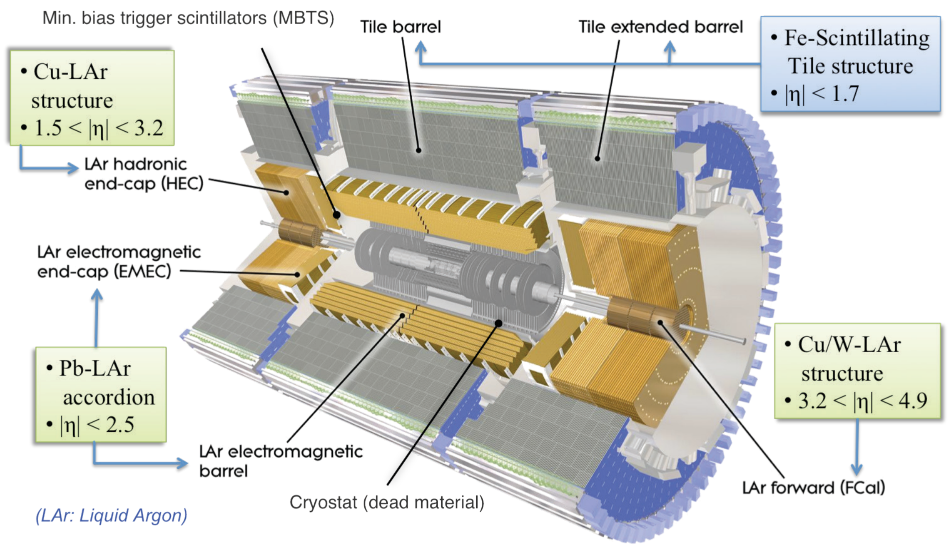
The work of experimental high energy particle physics—besides digesting that mouthful of a description!—is therefore to study in great detail the existence, properties, and interactions of the fundamental building blocks of our Universe: particles. We seek to answer a question that is simultaneously very real and very existential: What is the Universe made of and how do those pieces fit together? A modern particle physics experiment is therefore an observatory of the subatomic structure of nature. We conduct simultaneous measurements millions of times per second using a multitude of technologies, wavelengths, time domains, and methodologies. We study processes that take place in less than a trillionth of a second and search for the existence of never-before-seen phenomena. The extreme energies of the proton collisions at facilities such as the Large Hadron Collider yield an unprecedented resolving power for these measurements. With the experimental data that we collect at these observatories, we conduct searches for dark matter and new forces of nature; we look to further understand the composition of the particle universe; and we aim to precisely measure the exotic properties of particles that we have known about for years, but which we are able to see in a new light with these new technologies.

Much like any area of breakthrough science, we may only be able to answer these questions by building the tools that allow us to ask them correctly. In short: we must continuously invent new paths that will lead us to our discoveries. That is where the real work lies. Here at Chicago, the questions that we are asking about the nature of the Higgs boson, the unseen properties of other massive particles like the W and Z bosons or top quarks, as well as the existence of dark matter, all require novel technologies and methodologies that push the boundaries of high-speed electronics, pattern recognition algorithms, and theoretical understanding.

Calorimetry

One of the most important pieces of instrumentation for a high energy collider physics experiment is the calorimeter. This system, as the name suggests, measures energy; energy not in terms of the calories like in your favorite Swiss chocolate bar, but rather in terms of the amount of energy that a fast-moving particle has that was produced in the LHC collisions. In particular, as part of the ATLAS experiment at the LHC, the so-called Tile Calorimeter—so named because of its design in the form of "tiles"—is essential for measuring the energy and direction of quarks and gluons produced in the collisions. These appear in the detector as jets of charged and neutral particles. The calorimeter consists of a fine-grained steel matrix with 430,000 "tiles" of plastic scintillator dispersed in the matrix. Optical fibers from the tiles are grouped into 5,000

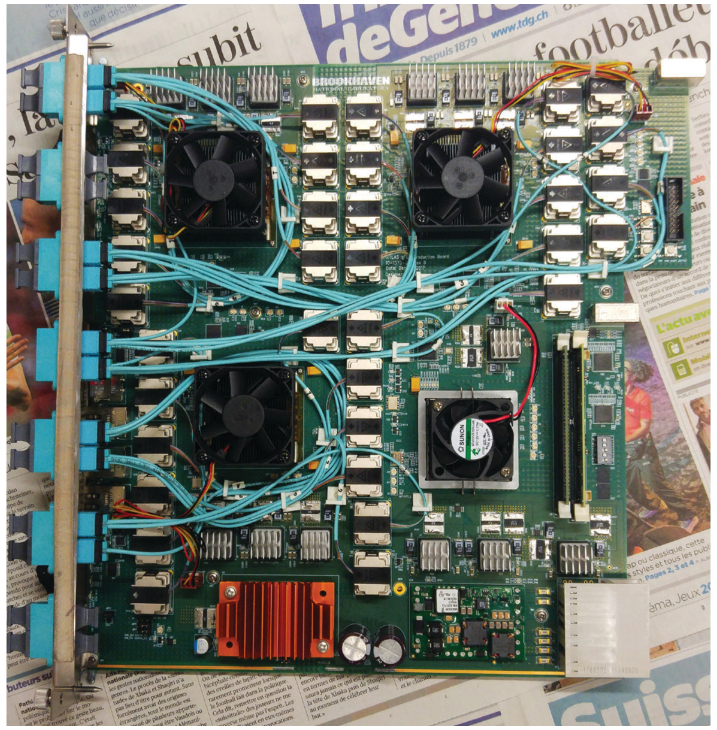




Top:
The original construction of the ATLAS central hadronic calorimeter (or, TileCal).

Bottom:
Structure of the various calorimeter systems of the ATLAS experiment.

calorimeter cells, whose signals are detected and recorded by 10,000 photomultiplier tubes and associated readout electronics. Signals from each photomultiplier are digitized every 25 ns and processed with dedicated electronics to obtain energy and time measurements. The Chicago ATLAS group played a leading role in designing, constructing, and commissioning the Tile Calorimeter system, and is currently responsible for the calibration of the readout electronics and participates in the maintenance and operation of the calorimeter as a whole. We are currently in the midst of redesigning, building, testing, and eventually installing brand new electronics that will be able to cope with the higher radiation levels expected to be created by the LHC in a few years, and to take advantage of technology improvements since the time of the original design.



The new custom electronics system for the ATLAS global Feature Extraction (or, gFEX) hardware trigger for Run 3 of the LHC.

High-speed electronics

One of the grand challenges of our time is filtering and processing the mountains of images and data—measured in petabytes and soon exabytes—that large-scale scientific facilities such as the LHC produce in order to find the exceedingly rare examples of the discoveries that are waiting. Bandwidths of raw data that we collect can exceed 100 Tb/s of heterogeneous, high-dimensional images and data points. To combat this overwhelming and mostly noisy avalanche of data, we at Chicago have been designing, building, and commissioning so-called trigger systems that implement algorithms to reduce the data volume by carefully selecting only about one out of every hundred thousand events that are created. At a hadron collider like the LHC, the biggest source of “uninteresting” data—data that we do not prioritize for discoveries, at least—comes from exactly the sorts of physics processes that the Tile Calorimeter is designed to measure: jets. Our trigger systems have been designed to focus on distinguishing between jets that are the result of potential new and interesting physics processes, from those that are the result of extraneous and very “uninteresting” processes in terms of the discoveries that we think await. In particular, the Chicago group has played a leading role in developing the Global Feature Extraction Trigger (gFEX) system. This novel device brings new capability to the very first level of the real-time hardware trigger system, by receiving the entire complement of calorimeter data on a single high-speed electronics board for online event selection. With both high-speed field-programmable gate arrays and innovative multi-processor system-on-chip capabilities, this addition to the ATLAS experiment will provide a new window into identifying and measuring new particles that decay to Higgs bosons, top quarks, and other extremely massive particles.

New directions

Outside of the direct aims of the ATLAS experiment, we are involved in developing new ideas for trigger systems in general, as well as algorithmic improvements to particle identification, reconstruction, and calibration. These efforts include the development of the first symmetry-group based machine learning architecture for particle identification in particle physics, the Lorentz Group Network. We are also investigating paradigm shifts in trigger and data processing systems that incorporate machine learning approaches to real-time data reduction, filtering, and even online continuous learning. For these projects, the group works closely with a range of Computer Science faculty, postdocs, and students, including joint publications and funding models.

Opening the window for the next generation of scientists

Our group at Chicago is able to conduct a multi-faceted collider physics program by combining decades of expertise in instrumentation, physics analysis, and data-intensive computation with novel ideas and new endeavors in both machine learning and electronics design. But it is the students and the postdocs who are carrying out this work and dramatically increasing sensitivities to groundbreaking discoveries. Inherent to the complete experimental particle physics program at Chicago is the training, support, and mentorship of undergraduate and graduate students and postdoctoral researchers in a broad range of methods, experimental design, leadership, and communication. Furthermore, we have a deep and strong commitment to diversity and inclusion that is essential for bringing the most impactful ideas to bear on the research problems we face. Only in this way can we ensure that we are able to fully open the windows unto the Universe for generations to come.

Honoring the Department of Physics Staff

SHADLA CYCHOLL

In this issue of CP-4, we have asked the staff of the Physics Department to share some of their experiences in adapting their work with students and faculty during these extrodinary circumstances.

As the department administrator, I have been amazed by the efforts by our staff to adapt and even improve the department's activities over the past year. This spring, we held a virtal reception attended by faculty, postdocs and students to recognize these contributions. Young-Kee presented each staff member with a plaque in appreciation for their outstanding work. The efforts by staff have contributed greatly to keeping the UChicago Physics community connected and thriving during this time and we cannot thank them enough!

Clockwise from top left:

Mark Chantell
Stuart Gazes
Zosia Krusberg
Tiffany Kurns
David McCowan
Andrew Nadlman
Putri Kusumo
David Reid
Kevin Van De Bogart

Adaptations in 2020

CHANGES IN TEACHING LABS

MARK CHANTELL, KEVIN VAN DE BOGART AND DAVID MCCOWAN

In March 2020 when the University made the decision to close campus and switch to remote teaching, many across campus scrambled to translate lectures and discussions into virtual experiences. But the job of the Physics Instructional Laboratories staff was even more challenging: how to move the inherently "hands-on" practice of experimental physics to a completely "hands-off" world?

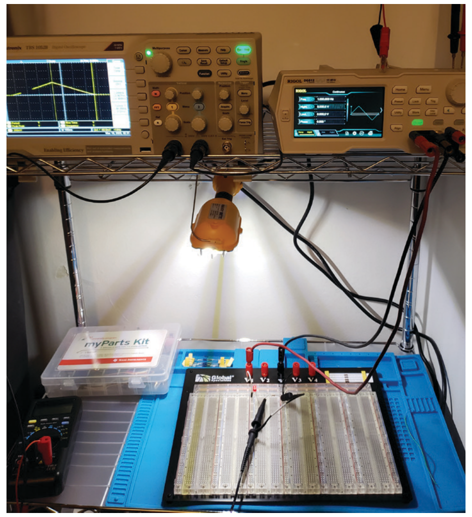
From the start, we viewed the situation as not just a technical challenge to be met, but also as an opportunity to reconsider the role of the instructional labs within the broader physics curriculum. While it would be possible, for example, to provide students previously-collected data or videos of staff doing the experiments, these solutions seemed artificial; they met the definition of lab work, but did not get at the heart of what it means to engage in experimental physics. Instead, we stepped back and asked "What are the unique lessons that experimental labs can convey that cannot be taught in lecture?" Surprisingly, many of these lessons had nothing to do with being in the lab, and as we redesigned content, we discovered that there are many positive changes that likely will remain even after we return to a regular in-person format.

For the introductory labs (PHYS 120s, 130s, and 140s), we shifted the focus away from apparatus and towards teaching the "process" of doing experimental physics—how do you decide what to measure? How do you test a model? How do you design an experiment to investigate a hypothesis? We used realistic online simulations or asked students to put together simple setups from household materials, and we invited students to explore topics more deeply and ask their own experimental questions. Moving into Autumn Quarter, these labs have changed further into 2-week open-ended projects, and TAs have shifted from someone students ask for help when the apparatus is broken to someone who mentors and guides the group. At present, these labs serve 750 students and are led by 39 lab TAs!

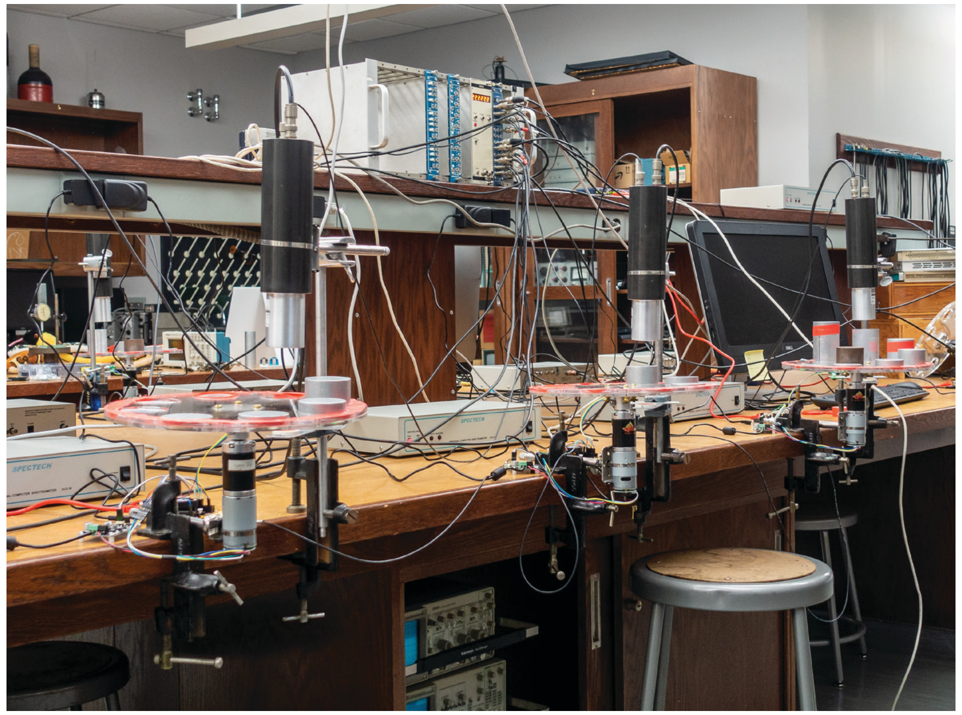
For the electronics course (PHYS 226), the problem was quite different; this class requires making (and breaking) circuits in order to understand how components work, and switching to online simulations or theoretical discussions would simply not work as a substitute. Therefore, we shipped a complete kit to each student—including an oscilloscope, function generator, breadboard and a wide assortment of electronic components, cables, and connectors—so they could build, test, and debug circuits at home. These expansive setups allowed students to complete nearly the same exercises they would have done in a normal quarter, and even afforded them more flexibility and time to explore and develop circuits between meetings. Students got creative at the end of the course, and pursued small (but sometimes still quite ambitious) projects of their own choice for the last week and a half.

Finally, for the advanced labs (PHYS 211), we developed a two-prong approach to give our physics majors as realistic an experience as possible. First, for several experiments, we were able to rebuild apparatus to allow students to connect remotely over the internet to control the equipment. In these experiments, the students had many of the same abilities they would have had were they in the lab—e.g to move components, to collect and process detector signals, and to record extended data runs—but with the chance to return and collect more (and different) data as often as they wanted. Second, experiments that could not be modified in this way could still be run on a proposal-based system. In this format, groups researched the available equipment and then designed and directed specific experiments that the lab staff on campus carried out. These experiences mirrored the way that a scientist might request observation time on a telescope (which a technician would operate) or plan an experiment at the Advanced Photon Source at Argonne (which would be scheduled for a slot in between other experiments run on the same device). With both styles of experiments, students were given several weeks to plan and iterate, and worked in larger groups to build collaboration skills. The result was much closer to a short research project than a traditional lab, and students responded well to the freedom and expansive nature that these labs provided.

Although 2020 has been a very challenging year for the lab staff, we have enjoyed the opportunity to experiment and try out new and different lab concepts—including some things which we likely would never have attempted under ordinary circumstances. Not every idea has worked smoothly, but overall the results (and feedback from students) have exceeded our expectations. This new way of thinking about instructional lab pedagogy will carry forward into future years, and we are excited about the possibilities when we are able to return to in-person teaching.



Students in PHYS 226 had access to a full suite of circuit components and test equipment touse at home. This photo shows the complete setup being beta tested out of a closet at thehome of one of the lab staff.



In PHYS 211, we were able to manufacture and program a version of a gamma cross section experiment that was remotely operable over the internet from anywhere in the world. This photo was taken while the apparatuses were in use by students, with platters whirring to change absorber thicknesses and detectors collecting and counting photon pulses.

Adaptations in 2020

VIRTUAL DEMONSTRATIONS

ANDREW NADLMAN

In mid-March, as the University began preparations for remote instruction, I had serious doubts about the effectiveness of a remote demonstrations program. The purpose of lecture demonstrations is to allow students to see real phenomena in the classroom in a way that can only be imitated by diagrams, animations, and pre-recorded videos. There is a long tradition and a rich history behind many of our demonstrations, some of which have been in continuous use since the founding of the University.

With only a few weeks to develop a new approach before the Spring Quarter, I started producing videos of our demonstrations that I hoped would overcome the inherent distance and inauthenticity of most pre-recorded content. My goal was to give the students a clearer view of the demonstrations than they would have even seen in the front row of the lecture hall.

I have no training in filmmaking but I quickly discovered that to create a sense of fidelity for students I would have to learn to use the basics of cinematography: composition, lighting, frame rate, focus, depth of field. Simply putting the apparatus on the table and pressing record would not be enough to engage the students.

Some of the demonstration videos I created, of course, were more successful than others. Working on my own, I often had to settle for acceptable but timely results instead of exceptional quality. Some demonstrations were also a challenge to capture because of fundamental differences between the human eye and a digital camera. The time required to edit and render each video was significant but this again was an opportunity to learn new techniques and tools to make post-production as quick and painless as possible.

With the return to limited in-person instruction in the fall quarter, the demonstration program has returned to a more traditional form. Students are once again able to see real phenomena and instructors can ground and reinforce the conceptual and mathematical course content. As the academic year continues, I expect the demos program to continue in this hybridized form with a mix of carefully crafted pre-recorded content and the traditional live demonstrations.

A still frame from the new tuning forks lecture demonstration video.

EQUITY, DIVERSITY & INCLUSION

DAVID REID

In recent years, particularly under the leadership of Professor Kim, the Department of Physics has become increasingly more committed to Equity, Diversity, and Inclusion (EDI). When the pandemic struck, we were determined not to lose the momentum we've built up. The department's EDI committee, chaired by Professor Linda Young,and receiving invaluable help from Neli Fanning (Equity, Diversity, and Inclusion Director for the PSD), continued to meet to forge our plans to build a more inclusive environment for positive impact on the academic life of the department at all levels including students (undergraduate and graduate), post-docs, faculty, and staff. In addition to continuing work, our EDI efforts expanded when Professor Kim formed a 14-member team to join the new network being formed by the American Physical Society dubbed IDEA (Inclusion, Diversity, and Equity Alliance), which, at the time of this writing, has approximately 100 teams and an active multi-year program underway.

Then, on May 25, 2020, the killing of George Floyd in Minneapolis, and the recognition it brought to other similar incidents, sparked many around the nation (and the world) to suddenly, and perhaps finally, begin to take active measures to combat the ravages caused by racism and bias against Black and other minoritized populations. We too have intensified our efforts which include the following: Our EDI committee was expanded for increased representation from within the department. Steps were taken to ensure continuity between the previous committee and the new larger committee, chaired by David Schmitz. Professor Kim took steps to form new groups for Racial and Ethnic Minorities in Physics and LGBT+ Physicists to help these populations form a sense of community, which was more difficult to do under the socially distanced conditions of the pandemic. The EDI committee works closely with the Anti-racism Working Group run by several very committed and compassionate students. And working with the Physical Science Division we have reaffirmed our commitment to the actions both underway and being planned despite a controversial Executive Order issued by the legislative branch of the government.

So, on the EDI front, the pandemic has not slowed us down. We look forward to substantial results in the months and years ahead.

Adaptations in 2020

CHANGES FOR GRADUATE STUDENTS

ZOSIA KRUSBERG

In March, our graduate students' lives were inexorably transformed by Covid-19. As authorities tried to curb the virus' rapid spread through citywide, and sometimes nationwide, lockdowns, some of our students chose to remain in Chicago, while others returned to their families in the United States or abroad. In the first few weeks, there was a pervasive sense of uncertainty, anxiety, and fear about the future. Soon, however, students' lives settled into a new normal. Classes moved online, as did the study groups students formed to collaborate on problem sets from around the world. With offices and labs shut down, advisors held research meetings and social events on Zoom to stay connected with their students and to check in on their general well-being. Thesis committee meetings and thesis defenses were held remotely—the latter to the excitement of many friends and family members. (Since the early days of the lockdown, close to thirty thesis committee meetings have taken place, and sixteen students have successfully defended their dissertations!) And, early this fall, we welcomed the members of our largest-ever incoming class to the department with virtual GDEs, orientation events, and Physics 300 meetings. As the number of Covid-19 cases has risen dramatically in recent weeks, our students are bracing for continued Zoom-based graduate study. However, we are longing desperately for the day where we can all get together for tea, coffee, and cookies in KPTC again!

CHANGES FOR UNDERGRADUATE STUDENTS

STUART GAZES

In March 2020, just before Winter quarter finals, UChicago students quickly left campus and the Physics Department (as well as the rest of the University) had to suddenly shift to remote exams. Since then, we have been adjusting to the "new normal" of asynchronous lectures, remote labs, and online tests.

Instructors in Physics have approached this in different ways. Some have taught synchronous lectures via Zoom, while others have used Panopto to deliver pre-recorded lectures. And when Internet connectivity became an issue, one class streamed via YouTube.

The Department has made it a goal to incorporate research-based approaches to physics pedagogy, with an emphasis on active learning. And despite the constraints imposed by online teaching, for some instructors this has presented an opportunity to explore the "flipped classroom" approach. Zoom-based classes, for example, make it relatively easy to incorporate "breakout rooms".

One thing that many Instructors have found is that some of the practices imposed by the pandemic have their own set of virtues. For example, we have learned new ways to deal with the problem of ever-increasing enrollments in our introductory courses. As a result, a return to in-person classes won't entirely be a return to the old way of doing things. New data – even from unplanned "experiments" – will help inform our teaching moving forward.

REMOTE COLLOQUIUM

TIFFANY KURNS

Physics Colloquium is a series of talks by speakers from the University of Chicago and guests from various universities and places worldwide. Lectures cover a broad range of topics within physics and sometimes outside of physics. It is an excellent opportunity to learn and enjoy new ideas, discoveries, and become introduced to physics. March 2020, we enjoyed our weekly lecture until Coronavirus 2019 (COVID-19) made it impossible to hold in-person lectures. We had to rethink if we were going to continue with the talks. We decided to cancel the remaining Winter and Spring speakers out of caution.

During the summer of 2020, we decided to bring back our colloquium series virtually. Colloquium came back in a bi-weekly online format with "Physics Tea Time" before the lecture. Tea time provided an opportunity for many discussions outside of physics and helped with morale overall; with much interest and positive feedback, bringing the talks back was an excellent way to get everyone together.

2020 OPEN HOUSE

PUTRI KUSUMO

The COVID-19 pandemic has caused so many things to happen, some predictable, others not. Our way of life in Physics, the last couple years, was always social with a Physics Colloquium every Thursday afternoon, weekly seminars, graduate student town hall with the chair, thesis defenses and department get-togethers. Since March 2020, we unthinkingly accepted that our reality lives in cyberspace and no longer in common spaces. We all had to rediscover the value and power of community by integrating our "at-home" self to our professional self while still being home.

Not surprisingly, our physics orientation this year was held virtually. Instead of welcoming our incoming first year students to our department, they welcomed us to their home-wherever they were around the world. This opportunity allowed for more creative introductions, information sessions and research presentations. Our Department Chair, Young-Kee Kim, opened the orientation with an embracing welcome that reached as far as India and China. Our Director of Graduate Studies, Zosia Krusberg, led the following session of introductions of the department staff and sharing nuggets of knowledge about graduate school. Our current graduate students participated by leading sessions about diversity and at a safe distance gave a tour of campus for students who already moved to Chicago. Each session was attended successfully and we are happy our students kept their cameras on, joined in on lively discussions and asked a wealth of questions.

Excited for this academic year, we hope all our students stay connected, safely, and know that we are all in this together. The Physics Department will continue to put honest effort and attention to whatever it is that students may need. To our incoming class of 2020, thank you for the mass attendance, we are glad that you know orientation matters. Welcome to Chicago, the city of unpredictable weather but please know that you will be OK even if you are cooled to -273.15C.

New Faces

NEW FACULTY

The Department of Physics welcomes its newest faculty members. Professor **DAVID DEMILLE** joined the Department of Physics and the James Franck Institute in September 2020. He uses precise quantum control over diatomic molecules to address a broad range of scientific questions.

Associate Professor **JEFFREY MCMAHON** is an experimentalist who studies cosmology and fundamental physics through measurements of the cosmic microwave background. He is a member of Department of Astronomy and Astrophysics, Department of Physics, Kavli Institute for Cosmological Physics and Enrico Fermi Institute.

NEW ADMINISTRATION

PUTRI KUSUMO is the Graduate Affairs Administrator in the Department Physics. In her role, Putri works with the Director of Graduate Affairs and is responsible for organizing and implementing policies and procedures for current graduate students. She provides operational support for graduate faculty committees and initiatives. She serves as a liaison between students and administration. Putri holds a Bachelor's degree in Organizational Communication, and a Master's degree in Human Resources, both from DePaul University. She has spent the past seven years working in academia in various student-related positions.

The Department of Physics welcomes the 2020-2021 Graduate Students!

- **THOMAS ALFORD**
- **HENRY ANDO**
- **ANUJ APTE**
- **GRACE CHESMORE**
- **CHUN TUNG CHEUNG**
- **SHOSHANA CHIPMAN**
- **SANSKRITI CHITRANSH**
- **DAVI COSTA**
- **PRATITI DEB**
- **CHUNYANG DING**
- **EGE EREN**
- **HARRY FOSBINDER-ELKINS**
- **DIEGO GARCIA SEPULVEDA**
- **JOEY GOLEC**
- **JUAN PABLO GONZALEZ AGUILERA**
- **ZHEN HAN**
- **ALEXANDRA HANSELMAN**
- **ELISE HINKLE**
- **OWEN HOWELL**
- **PEIRAN HU**
- **GEORGE ISKANDER**
- **MUNJUNG JUNG**
- **YAOCHENG (DESMOND) LI**
- **MINZHAO (HENRY) LIU**
- **YINRUI LIU**
- **SHAE MACHLUS**
- **QINGHAO MAO**
- **SRAVAN MUNAGAVALASA**
- **DAVID NEWSOM**
- **YUXIANG PEI**
- **DUNCAN ROCHA**
- **MATTEO SABATO**
- **MATTHEW SCHMITT**
- **CARLOS SIERRA**
- **AUSTIN STOVER**
- **SHREYA SUTARIYA**
- **CHIN YI TAN**
- **MAXIM TOPEL**
- **SYRIAN TRUONG**
- **LYNN TUNG**
- **MOHIT VERMA**
- **LAUREN WEISS**
- **LI WEN**
- **BIN (BRADY) WU**
- **RACHANA YAJUR**
- **LANQING (FAROUT) YUAN**
- **MAXIM ZELENKO**
- **GEOFFREY ZHENG**
- **VICTOR ZHANG**
- **JINWEI ZHU**

Prizes & Awards

FACULTY AWARDS

Congratulations to our following faculty:

Professor **SIDNEY NAGEL** has been elected to the American Philosophical Society, the oldest learned society in the United States. He is currently interested in how disordered systems can exhibit more flexible behavior than their ordered counterparts. He is also a pioneer in studying non-linear and far-from-equilibrium behavior in fluids.

Professor **JOHN CARLSTROM** has been named a fellow of the American Association for the Advancement of Science.

Professor **PAOLO PRIVITERA** has been named a recipient of the Faculty Award for Excellence in Graduate Teaching and Mentoring.

Professor **MARGARET GARDEL** was awarded the Sackler Prize in Biophysics.

Professor **ROBERT ROSNER** has been elected to the presidency of the American Physical Society. He will assume the position in 2023, when he will become the eighth UChicago scientist to do so.

Professor **YOUNG-KEE KIM** has chaired the Division of Particles and Fields of the American Physical Society.

Professor **SERGEI NAGAITSEV** has chaired the Division of Physics of Beams of the American Physical Society.

Professor **DANIEL HOLZ** has been elected to chair the Division of Astrophysics in 2022.

CHARLES L. KANE, theoretical physicist known for his work characterizing quantum electronic states of matter, will receive the Honorary Degree of Doctor of Science in 2021.

APPOINTMENTS & PROMOTIONS

YOUNG-KEE KIM was recently appointed Senior Advisor to the Provost for Global Scientific Initiatives.

DAVID MILLER was recently promoted to Associate Professor with tenure in the Department of Physics and the Enrico Fermi Institute.

ARVIND MURUGAN was recently reappointed to a second term as Assistant Professor in the Department of Physics at the James Franck Institute.

Events

For full and future event listings, please visit:
physics.uchicago.edu/events/

UPCOMING EVENTS

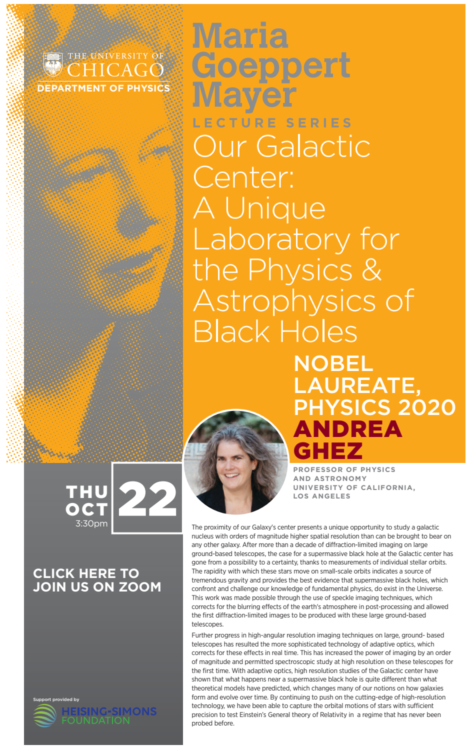
MAY 13, 2021
Zachariasen Lecture
Horowitz Gary, University of California, Santa Barbara

MAY 17, 2021
Physics Colloquium
Walter E. Massey, Senior Advisor to President Zimmer and former UChicago Physics Faculty

OCTOBER 21, 2021
Maria Goeppert-Mayer Lecture
Myriam Sarachik, City College of New York

PAST EVENTS

The 2020 Maria Goeppert-Mayer Lecture featured Nobel Laureate Andrea Ghez. The lecture attracted a diverse audience of about 2,500 people from around the world, including Provost Ka Yee, Vice Provost Melissa Gilliam, Vice Provost Karen Kim, Dean of Physical Sciences Division Angela Olinto, Maria Goeppert-Mayer's grand-daughter Tania DeBeau, the 1st, 2nd, and 3rd Maria Goeppert-Mayer lecturers (Melissa Franklin from Harvard, Helen Quinn from SLAC, and 2018 Nobel laureate Donna Strickland from Waterloo), Program Director of the Heising-Simons Foundation Cyndi Atherton, Andrea Ghez's mother Susanne Ghez, Andrea's high school chemistry teacher from the Lab Schools Judy Keane, and Interim Director of the U.Chicago Lab Schools Dave Magill.



THE UNIVERSITY OF CHICAGO
DEPARTMENT OF PHYSICS

Maria Goeppert Mayer
LECTURE SERIES

Our Galactic Center: A Unique Laboratory for the Physics & Astrophysics of Black Holes

NOBEL LAUREATE, PHYSICS 2020
ANDREA GHEZ
PROFESSOR OF PHYSICS AND ASTRONOMY
UNIVERSITY OF CALIFORNIA, LOS ANGELES

THU OCT 22
3:30pm

CLICK HERE TO JOIN US ON ZOOM

The proximity of our Galaxy's center presents a unique opportunity to study a galactic nucleus with orders of magnitude higher spatial resolution than can be brought to bear on any other galaxy. After more than a decade of diffraction-limited imaging on large ground-based telescopes, the case for a supermassive black hole at the Galactic center has gone from a possibility to a certainty, thanks to measurements of individual stellar orbits. The rapidity with which these stars move on small-scale orbits indicates a source of tremendous gravity and provides the best evidence that supermassive black holes, which confront and challenge our knowledge of fundamental physics, do exist in the Universe. This work was made possible through the use of speckle imaging techniques, which corrects for the blurring effects of the earth's atmosphere in post-processing and allowed the first diffraction-limited images to be produced with these large ground-based telescopes.

Further progress in high-angular resolution imaging techniques on large, ground- based telescopes has resulted the more sophisticated technology of adaptive optics, which corrects for these effects in real time. This has increased the power of imaging by an order of magnitude and permitted spectroscopic study at high resolution on these telescopes for the first time. With adaptive optics, high resolution studies of the Galactic center have shown that what happens near a supermassive black hole is quite different than what theoretical models have predicted, which changes many of our notions on how galaxies form and evolve over time. By continuing to push on the cutting-edge of high-resolution technology, we have been able to capture the orbital motions of stars with sufficient precision to test Einstein's General theory of Relativity in a regime that has never been probed before.

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HEISING-SIMONS FOUNDATION

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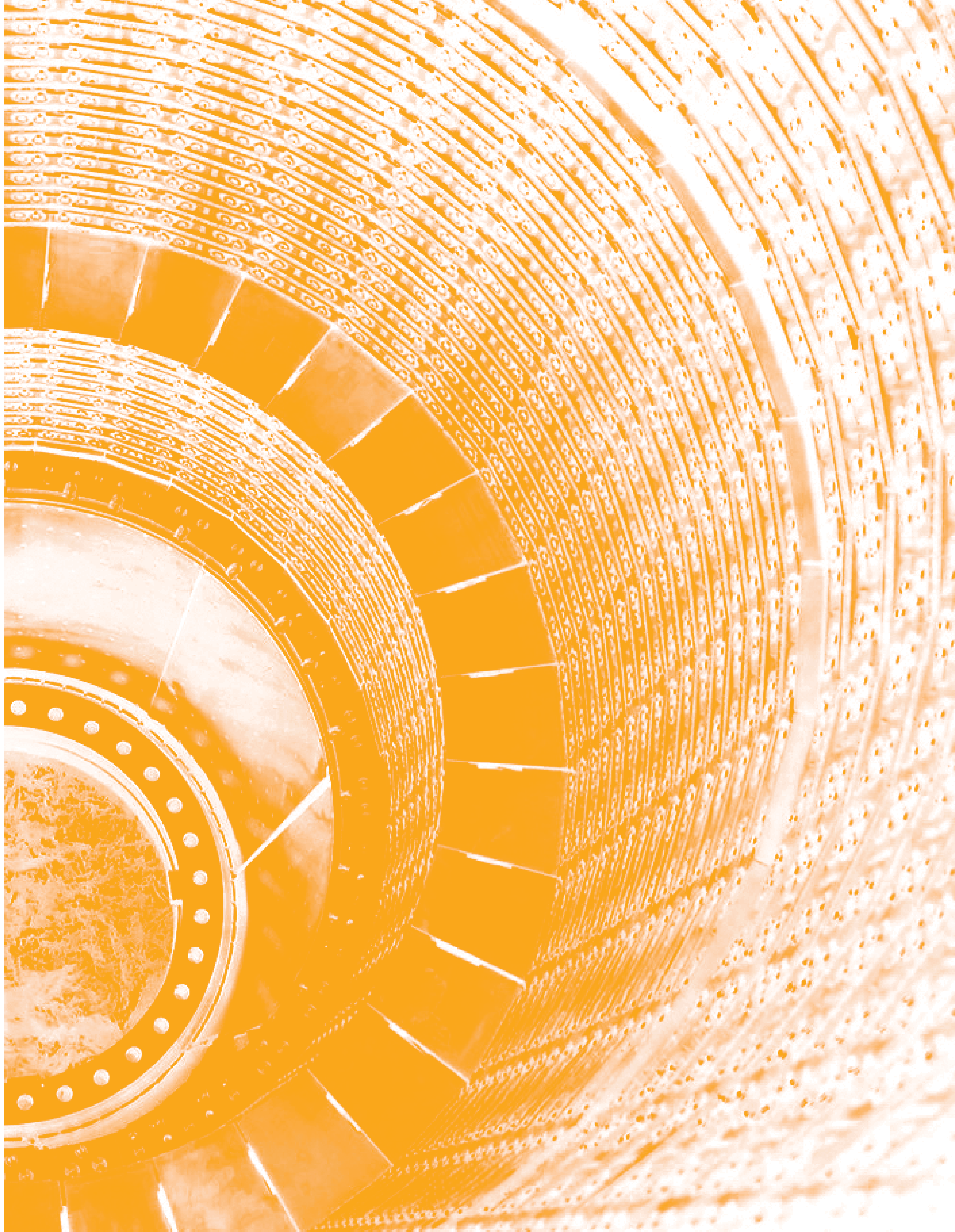

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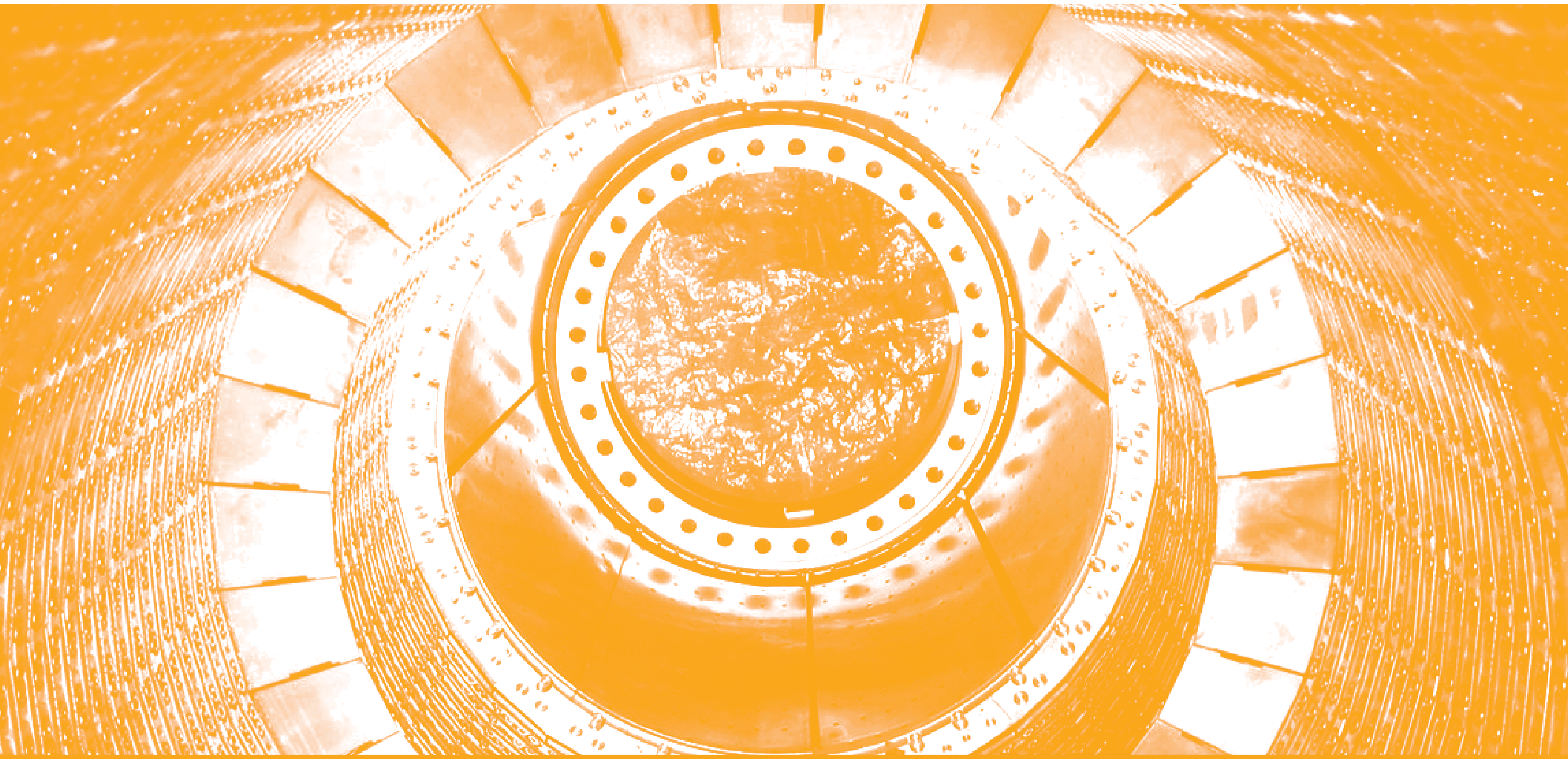

So many of the accomplishments associated with Physics at the University of Chicago have been made possible by the generous support of alumni, families, and friends through direct contributions and estate gifts. If you would like to support programs and places at the Department of Physics that are particularly meaningful to you, please visit our webpage:

physics.uchicago.edu/give