THE UNIVERSITY OF CHICAGO | Department of Physics

CHICAGO PHYSICS 2

Tied in Knots

Welcome to the second issue of Chicago Physics! This past year has been an eventful one for our Department.

In our last issue, we discussed the series of public events that were being planned to commemorate and discuss Chicago Pile-1 and the complex legacy of what transpired on December 2, 1942. Over the course of that commemoration, many aspects were discussed in front of a large and interested audience.

On a separate front, we opened the renovated Physics Research Center, which is new home to the Enrico Fermi Institute, founded shortly after World War II to pursue experimental and theoretical research in high-energy particle physics, astrophysics, plasma physics and other fields; and to the Kadanoff Center for Theoretical Physics, which brings together theorists across disciplines, from condensed matter physics to string theory and hydrodynamics. We hope that many of you will come back to campus to visit these wonderful new facilities.

Of course, over the past year, our Department members continued to pursue outstanding research questions. You will learn about some of their successes in this annual newsletter. 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

COVER PHOTO: WILLIAM IRVINE,
Associate Professor
Department of Physics, the University of Chicago

Contents

This issue of Chicago Physics 2 has been put together by a number of us in the hope that it is of interest to those who have brushed against the Physics Department in the University of Chicago.

Issues should have issues, and this issue is topology.

Topology is that annoying mathematical topic which tries to convince you that a donut and a coffee cup are somehow equivalent. It turns out that this apparently arcane subject has invaded physics recently in several very different fields, and because a few of our faculty are leading research in this area, we have selected some research highlights to explain what is happening.

We are used to the idea that classical physics is local—forces are applied and responses are felt in the same region of space. But every sailor understands the concept of a knot—a distortion in the fabric of space which is not simply connected. William Irvine explains here how to build knots out of fluids, even when the starting condition is that knottiness = zero.

Quantum mechanics has no pretention to locality, though this remains one of its oddest features. One remarkable discovery of recent years is that the quantum numbers in which some otherwise uninteresting solids live, in comparison to the boring vacuum outside them, has a winding number (like the index of your mug). That means that some materials automatically have a quantized current flowing over their surface. We hear about this from Shinsei Ryu, and in particular how this absurd effect might provide the basis for decoherence-free quantum computation, something that was brought to light by our own Woowon Kang in experiments on the quantum Hall effects. It turns out that one can build analogs of such systems with light, using photon engineering as pioneered by Jon Simon. Here he explains the generation and uses of "twisted light." Of course theorists like invariances, and topology is great for this—you simply need to know how to count. A candidate for a 'theory of everything' would surely be one that depended on mathematics alone, no "fundamental" constants provided. The current incarnation of that is string theory, and Emil Martinec explains how our modern understanding of quantum topology is driving that theory forward.

These four articles cover some of the breadth of what we do—quite literally from the nanoscale to the cosmic scale—but also the unity of our subject in terms of the concepts that drive us all. Another reminder of our inclusivity is provided by Margaret Gardel, writing here as director of the MRSEC (Materials Research Science and Engineering Center) that crosscuts from materials to biology to engineering, and has been operating in Chicago under different guises for several decades. Also here are some pieces by a few of our students, who remain as intense, fascinating, and creative as any teacher could wish. As well as a calendar of activities, and a reminder that all are welcome to our events.

We also celebrate here the lives of James Cronin, Dean Eastman, Peter Freund, Hellmut Fritzsche and Leon Lederman who died this year and left indelible imprints in Chicago and globally. We miss them, and we are proud of them.

- Peter Littlewood

Knotted Vortices

WILLIAM IRVINE

Conservation laws, such as conservation of energy, underpin our most fundamental understanding of physical phenomena. The equations of fluid motion are a prime example: themselves an expression of conservation of momentum, mass and energy, they capture the myriad of fluid motions we see in the world. One of the most familiar examples of these structures is the hydrodynamic vortex—and even in real fluids with viscosity, vorticity is nearly conserved. But it was only in 1961 that Moreau showed that within the Euler equations of fluid motion there lurked an additional conservation law—that of hydrodynamic helicity, which counts the linking of vortex lines. This is illustrated in Figure 1—the linked vortex lines on the right carry helicity, whereas the unlinked vortices do not.

Since vortices are transported by the velocity field, in an ideal Eulerian fluid, they do not cross. This means that in principle one should be able to construct knots in vortices which would have a permanent existence in an ideal fluid.

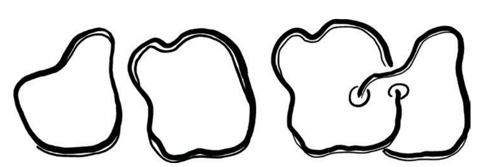


Figure 1

As a concept this goes back to Lord Kelvin, who proposed in 1869 that atoms could be interpreted as knotted vortices in the ether, at the time believed to be an invisible fluid that filled all of space. The existence of the ether was discredited theoretically by Maxwell and most famously experimentally by Michelson and Morley in 1887, but Kelvin's intuition has persisted in fluid mechanics and is now central to our understanding of turbulent fluids.

In a viscous fluid, vortices can "reconnect"—cross and separate—and understanding this process is a key to modelling processes such as turbulence in the earth's atmosphere, the generation of the earth's magnetic field,

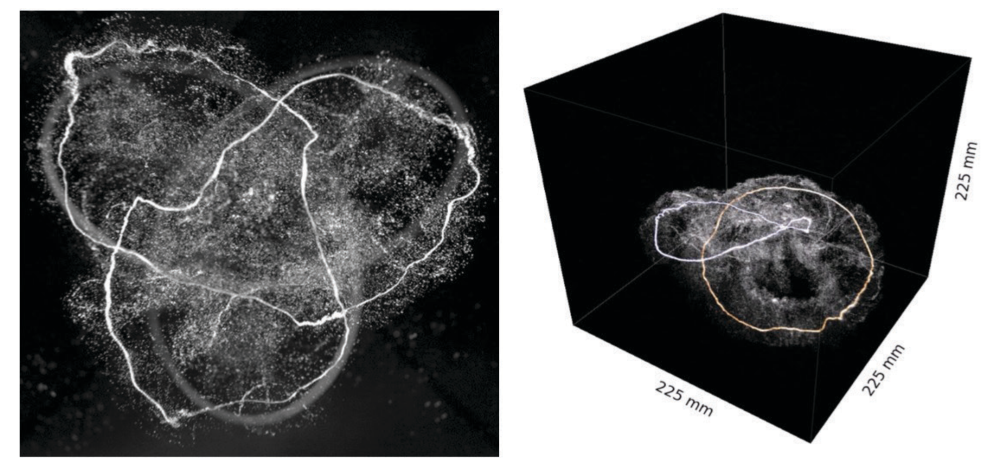


Figure 2

"Careful studies of the dynamics of the cores have in fact demonstrated an apparently paradoxical result—that the action of viscosity can be to create helicity."

thermonuclear fusion in the laboratory, superfluids, and the solar corona. Or indeed more practically the design of more efficient wind turbines or aircraft wings. But the understanding of the reconnection process has been largely theoretical until now.

William Irvine's lab has used numerical modelling and additive manufacturing to construct flows that realized knotted vortices with helicity in water, for example the trefoil knot (Kelvin's simplest "atom") and the linked vortex loops in Figure 2.

Of course, these knots do rapidly reconnect, but it turns out that careful inspection shows that the helicity remains. A real vortex is not an infinitely thin line, but can be thought of as a braid of yarn (see Fig 3), and the helicity of two reconnecting loops can be separated into "link" helicity (left), "writhe" (center) and "twist" (right). Remarkably, when for example two loops reconnect into one, the helicity is transferred from "link" to "writhe." This resolves one of the central issues of the large scale theory of turbulent fluids (which have widely distributed vorticity)—that reconnection does not necessarily destroy helicity. Careful studies of the dynamics of the cores have in fact demonstrated an apparently paradoxical result—that the action of viscosity can be to create helicity. The reason for this is that twist is a local contribution to helicity (and therefore can dissipate readily) whereas writhe and link helicity are topologically protected because they are non-local.

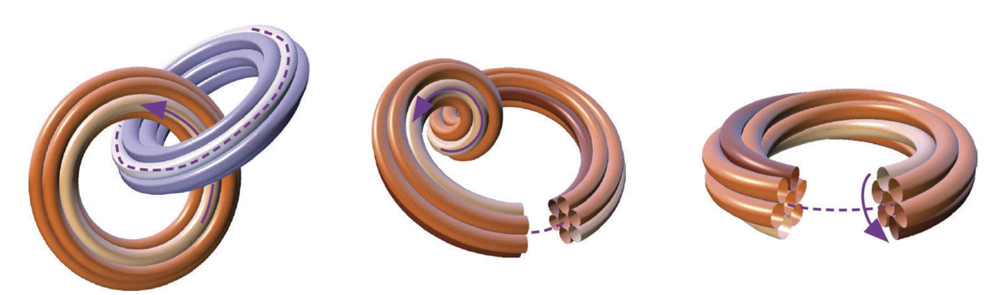


Figure 3

Quantities that are "conserved," or stay constant in time, "give you powerful ways to look at complicated problems," Irvine explains. "Understanding a new conserved quantity, helicity, could have a huge impact on how we understand flows. It's one of those holy grails."

Topological Materials Made of Light

JON SIMON

Topology is the study of global properties that are insensitive to local deformations. It has recently become pivotal in developing the understanding of a new class of materials whose electrical properties are robust to material imperfections (they are said to be "quantized"). These materials provide a high-quality resistance standard and presenting a new topological route to error-resilient quantum computing.

It is becoming apparent that these topological materials are in fact robust to a broader range of deformations than was previously understood and that they can be categorized by different quantized responses to different deformations—for example a quantized heat conductivity reflects the "central charge" of the material. Most interestingly for our purposes is that some of the required "deformations" cannot be realized in the laboratory: it was predicted, for example, that electrons bunch-up in a quantized way around the spatial curvature created by a massive object like a black hole. The basic idea is that under the right conditions, surface curvature can act to effectively increase the local magnetic field strength, shrinking particle orbits, thereby increasing particle density.

In the Simon Lab at the University of Chicago, we make materials out light—photons instead of electrons, protons and neutrons—and explore their unique properties. We have recently developed photonic topological materials and have found that photons in the lab quite naturally behave like electrons near curvature! In short, we have the opportunity to explore the behaviours of electrons near black holes using analogs made of photons.

To make this happen, we have learned a lot about photons, and have taught photons a few things along the way: (1) by trapping photons between precisely spaced, high-quality optical mirrors we trained them to have mass- that is, a transverse speed that depends upon their momentum; (2) by trapping the photons between four mirrors instead of two, we add a twist to the photons' back-and-forth motion, thus training them to behave as charged particles in magnetic fields. To our surprise, we discovered that these massive, charged photons naturally act like they live on a curved surface—such is the magic of synthetic materials: what's exotic for traditional (electronic) materials is often natural for synthetic materials, and vice-versa.

To explore the black-hole physics of electrons using these photons, we have developed a scanning-tunneling microscope for light. The results, shown in Fig. 1, reflect the enhanced density near the curvature—the first experimental validation in any platform that curvature acts like a magnetic field.

In separate works we have also taught photons to collide with one another and even crystallize, quite a challenge since we do not live in a world where photons naturally bounce off one another like Star Wars lightsabers.

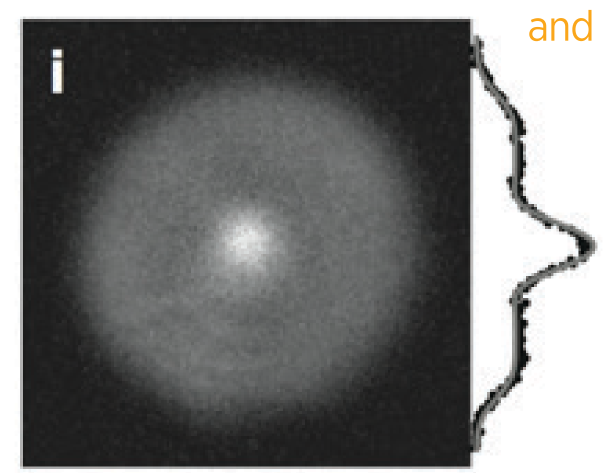


Figure 1

Photonic density of states measured for photons residing in the lowest Landau level of a cone; the enhanced density near the cone tip is the first experimental observation of the "Wen-Zee Shift," where the curvature of a surface can act like a magnetic field.

"To our surprise, we discovered that these massive, charged photons naturally act like they live on a curved surface—such is the magic of synthetic materials: what's exotic for traditional (electronic) materials is often natural for synthetic materials, and vice-versa."

We are now harnessing these colliding, twisting photons to explore topological quantum fluids, writhing froths of entangled light whose excitations have been proposed as the bits of a quantum computing. This new frontier in quantum science takes inspiration from electrons in magnetic fields: we expect that working with photons will bring many exciting surprises to light.

Puzzle rings pave the way for stable quantum computers

SHINSEI RYU

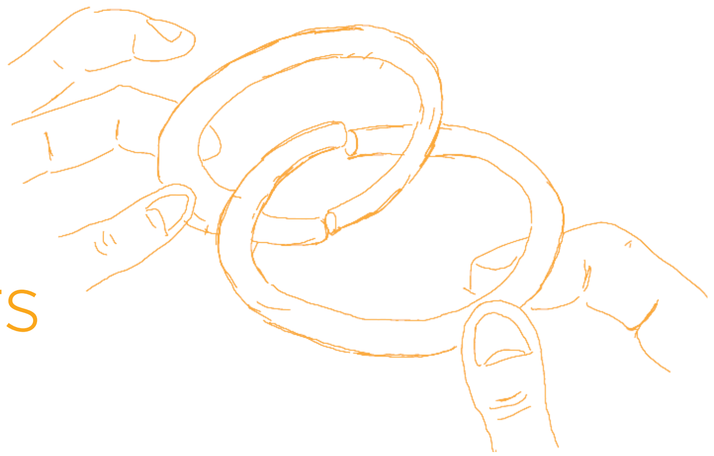
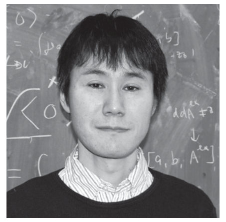


Figure 1



Have you ever tried a puzzle ring? Typically, it consists of a few metallic parts which are tangled together. You are supposed to disentangle these parts without breaking them. A typical example looks like Figure 1.

You may be surprised to know that certain types of quantum computers use the idea rooted in puzzle rings.

Quantum computers are a recently very hot topic. Academics, as well as many private companies, are putting a lot of efforts (and money too) to realize them. Contrasting to conventional computers ("classical" computers), the operating principle of quantum computers is quantum mechanics, which governs physics at atomic scales. They are expected to have many advantages over classical computers. For example, they are expected to be more powerful in solving certain problems, e.g., decrypting secret messages (codes), and can be a game changer.

A crucial question to have successful quantum computers is stability—quantum computers are known to be much more difficult to realize than classical computers. Quantum states and processes used in quantum computers can be easily damaged or destroyed by noises and errors. If we don't protect them in some way, we cannot do anything useful. For these reasons, quantum computers usually operate at very low temperatures. It's been also challenging to build a quantum computer which can handle a large number of qubits (quantum mechanical analog of bits).

How can puzzle rings solve the problem of quantum computers? Putting all details aside, for a certain type of quantum computer, it is possible to represent quantum processes in terms of a set of diagrams. A typical diagram may look like Figure 2. There, a set of special particle—so-called anyons—are created (marked by stars in Figure 2), and manipulated, and finally measured.

Now, processes which are stable are those which are not easy to untangle. In fact, ideal quantum processes, namely, processes which are absolutely stable, correspond to puzzles which cannot be untangled at all. Actual quantum processes can sometimes be "untangled" (i.e., fail to operate properly). However, researchers believe that, by improving technologies and deepening our understanding of underlying physics, the probability for such errors to occur can be made sufficiently small—just like crafting very difficult puzzle rings! (Puzzle rings which cannot be solved at all are rather boring—challenging with these puzzles, you may lose your friends if you don't tell them that they are actually not possible to untangle! On the other hand, they are perfect to realize stable quantum computers.)

Presented here is the scheme of a version of quantum computers—topological quantum computers—which make use of a special kind of states of matter—topologically ordered states of matter—which host special kinds of particles (anyons). Topologically ordered phases can be realized in condensed matter systems at very low temperatures or can be engineered in systems consisting of many qubits.

"Quantum states and processes used in quantum computers can be easily damaged or destroyed by noises and errors. If we don't protect them in some way, we cannot do anything useful."

The key word common to puzzle rings and topological quantum computers is topology. Topology is a subfield of mathematics which deals with properties of geometrical objects (lines, surfaces, hypersurfaces, etc.), which are stable against under deformations. Puzzle rings can be studied using topology—those which cannot be untangled are said to be topologically distinct from those which can be untangled. Similarly, quantum processes in topologically ordered phases can be studied by using topology.

Even besides quantum computers, topology has been recently recognized as a governing principle of quantum condensed matter physics—a subfield of physics which deals with different states of matter consisting of a macroscopic number of quantum mechanical particles, such as electrons in solids. Researchers have started to realize that, just like we make a distinction between different spaces/surfaces in terms of the loose criterion of topology, different states of matter can then be distinguished by different topologies of electron wave functions. Quite a few in the condensed matter physics community, even here at UChicago (including me), now use this new paradigm to study and explore phases of matter, expecting that many new fundamental phenomena are yet to be discovered—we hope you'll be looking forward to them!

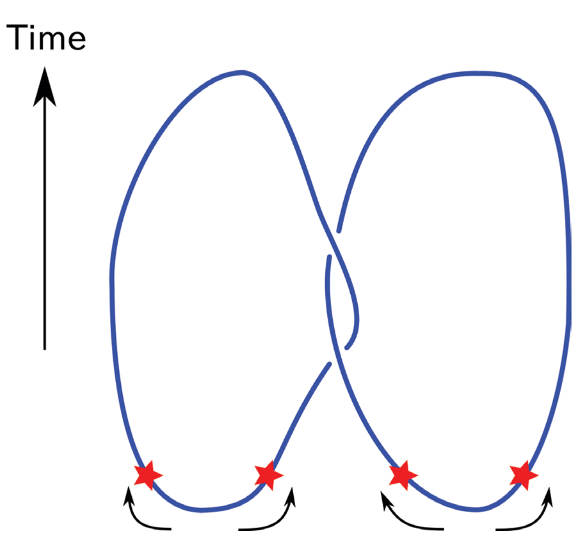
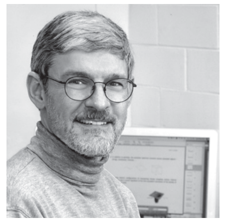


Figure 2

Topology in String Theory

EMIL MARTINEC



Progress in theoretical physics has always gone hand in hand with progress in mathematics, from Newton's development of calculus to formulate classical mechanics, to Einstein's discovery that gravity is fundamentally related to the curvature of spacetime, to Heisenberg's realization that linear algebra underlies quantum mechanics. In myriad ways, string theory represents the apotheosis of this intellectual symbiosis, no more so than in the area of topology. Indeed, the resurgence of string theory in 1984 was sparked by the demonstration that string theory was free from "anomalies"—potential topological obstructions to its mathematical self-consistency. Topology is ubiquitous in string theory, and a key mathematical tool to gaining insight into its properties.

A prime example comes from the investigation of black holes in Einstein's theory of gravity. Jacob Bekenstein and Stephen Hawking showed in the early 1970's that a black hole has an enormous thermodynamic entropy, proportional to the area of its event horizon in so-called Planck units. For instance, a black hole the mass of the Sun would have an entropy 10^{77}, some twenty orders of magnitude larger than the entropy of the Sun itself. This entropy is a measure of the number of internal states available to the black hole, yet general relativity provides no explanation what this state space might consist of; in fact, quite the opposite—there are "no-hair" theorems positing that the black hole solution to Einstein's equations is unique.

For over two decades, the origin of black hole entropy remained a mystery. Then in 1996, Andrew Strominger and Cumrun Vafa showed how to compute the entropy of a special class of black holes in string theory. Remarkably, their answer relied in an essential way on the topology of "extra dimensions" in string theory. It had been something of an embarrassment that the cancellation of anomalies in string theory requires that there be six or seven additional dimensions of space, beyond the three that are readily apparent in the world around us. In order to be compatible with observation, these extra dimensions must be extraordinarily small; but they still have structure. Strominger and Vafa showed that, supposing the black hole is merely a large object built out of the fundamental constituents of string theory—strings, membranes, etc.—that the number of ways that one could wrap those extended objects around the topology of the extra dimensions precisely accounts for the black hole entropy. Tiny extra dimensions (and their intricate topology) turn out to be necessary ingredients to explain the internal states of these particular black holes.

"Tiny extra dimensions (and their intricate topology) turn out to be necessary ingredients to explain the internal states of these particular black holes."

In many ways, we are still coming to grips with the implications of this landmark result. The topological nature of their computation left unanswered precisely where the internal states of the black hole are supported—is it at the horizon? At the singularity? And how does string theory evade the "no-hair" theorems of Einstein's gravity? My own research aims to answer these questions. The appearance of Planck's constant ℏ in the entropy indicates a quantum origin of the black hole microstates, and there is some evidence that the way string theory resolves certain puzzles about black hole thermodynamics is by creating structures that are quantum-mechanically coherent over the horizon scale (that's about 1km for a solar mass black hole!). We are starting to see hints of what these structures are, and are investigating their properties using a variety of techniques in geometry, topology and string theory.

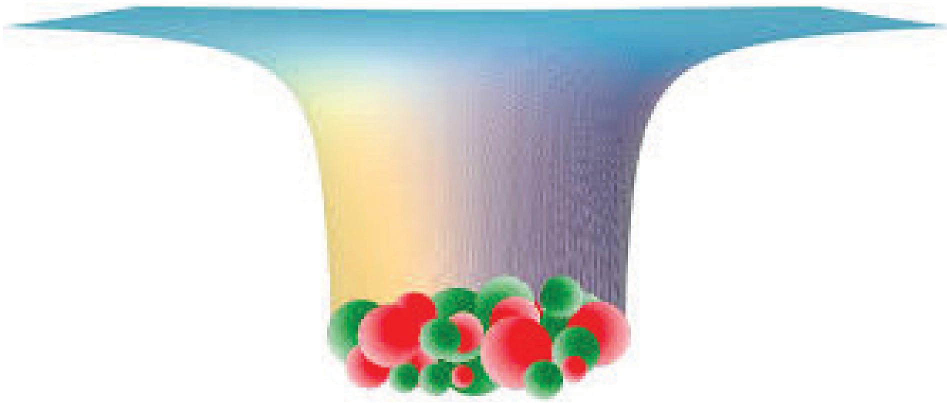


Figure 1

The information about what formed the black hole, or later fell into it, is thought to be stored in these diffuse, extended structures, and later radiated out via the thermal processes known as Hawking radiation. There are many similarities between this diffuse storage of quantum information by exotic "stringy" matter in the context of black holes, and the way quantum information is stored in exotic quantum materials being explored in condensed matter physics, a topic where topology also plays an integral role.

This convergence is an exciting trend of current research in theoretical physics, holding out the hope that progress in either area can drive progress in the other. A central aim of our new Kadanoff Center for Theoretical Physics is to provide a forum for the exchange of ideas and to foster cross-disciplinary collaborations, and I am eager to see what the future brings.

Materials Science at UChicago

EILEEN SHEU & MARGARET GARDEL

If you've ever wandered through the James Franck Institute, you might overhear a number of conversations on scientific issues or engage in one yourself. The often-spectacular research that results from this intensely interactive environment is partially credited to the research flexibility enabled through block funding by the National Science Foundation (NSF). Originally initiated as an IDL (Inter-Disciplinary Laboratory) in 1961, the award transitioned to a MRL (Materials Research Laboratory), then into its current configuration as a Materials Research Science and Engineering Center (MRSEC). Through this award, the NSF mandates not only the highest-caliber multidisciplinary collaborative research, but also requires the incorporation of underrepresented groups into the research mission, maintaining shared facilities, educational outreach to the public, and knowledge transfer to industry, thus adding value to the scientific enterprise of the Center and impelling researchers to adopt a broader outlook.

In its current configuration, the MRSEC involves the work of around 40 investigators, their postdocs and students, and is overseen by the Director, Prof. Margaret Gardel. The research activities are organized into three interdisciplinary research groups (IRGs) each focused on theme at the forefront of modern materials science:

IRG 1 on Dynamics at Soft Interfaces focuses on both scientific challenges and technological opportunities that arise from controlling and manipulating how fast and to what extent a soft interface forms or deforms. Here Physics faculty Heinrich Jaeger, Arvind Murugan, Sid Nagel, Vincenzo Vitelli and Tom Witten team with faculty from Chemistry (Ka Yee Lee, Binhua Lin, Stuart Rice) and the Institute of Molecular Engineering (Stuart Rowan, Juan De Pablo) to study systems ranging from nanoscale colloids to suspensions of micron-scale particles to truly macroscopic granular materials. By examining how stress variations at an interface can alter

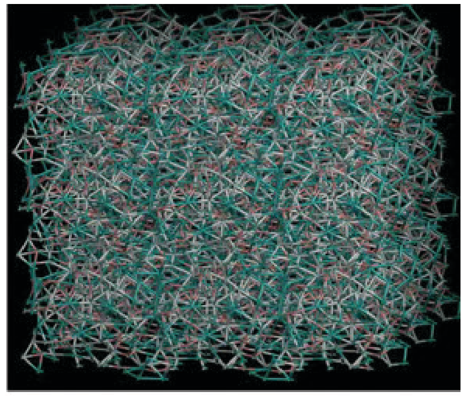


Figure 1

properties in the bulk and, conversely, how tailoring bulk parameters can guide interfacial dynamics, the research endeavors to establish the link between processes occurring at the interface and the properties of the material as a whole. Establishing such a link opens up opportunities for designing specific material responses and provides a pathway towards innovative applications. One thrust is to create materials with a mechanical response that varies as a function of applied stress. To this end, IRG 1 developed a new design platform of mechanical metamaterials (Fig. 1).

IRG 2 on Control of Active and Shape-Changing Materials aims to understand and exploit the myriad ways that biology has evolved to construct materials that spontaneously change shape or generate force. A key feature of such biological materials is that they contain distributed molecular elements that convert chemical energy into mechanical work, and a central question this IRG seeks to address is how such activity relates to specific materials properties. To this end, Physics faculty Margaret Gardel, William Irvine, Vincenzo Vitelli and Tom Witten collaborate with Chemists (Aaron Dinner, Norbert Scherer, Bozhi Tian, Suri Vaikunathan, Gregory Voth and Lupin Yu) and Cell Biologist (David Kovar) to construct novel active matter. This IRG aspires to achieve control of active materials and ultimately to create novel molecular assemblies for robust tunable shape change. Success of the IRG would result in the identification of minimal combinations of elements capable of programmable amorphous shape changes, autonomous movement and collective behavior, and materials that could be tailored to environments and situations beyond the reach of biological systems. Recently, using these approaches William Irvine and Vincenzo Vitelli demonstrated a new type of active materials construct from a large collection of rotating magnets.

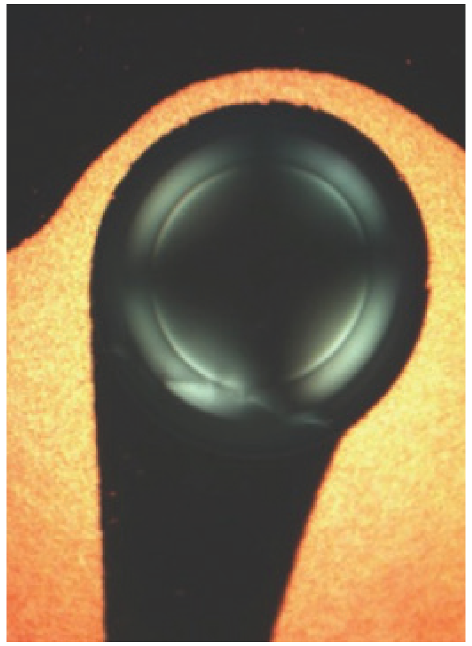


Figure 2

IRG 3 on Engineering Quantum Materials and Interactions seeks to elucidate the critical issues of control and coherence in both individual and in collective-mode quantum systems, with the goal of manipulating and exploiting quantum coherence in materials over a large range of length scales, from individual quantum centers to macroscopically entangled materials. This research is expected to directly advance applications in quantum sensing, fabricate materials for quantum information as well as create the next generation of characterization tools for traditional materials. Physics faculty of David Awschalom, Cheng Chin, Kathy Levin, David Schuster, and Jon Simon work collaboratively with faculty from Chemistry (Steve Sibener) and the Institute Molecular Engineering (Andrew Cleland, Aashish Clerk, Guilia Galli) to construct new Quantum Materials. Recently, Chin and Levin explored non-equilibrium behavior of ultracold atom gases, resulting in matter wave "jets" (Figure 3).

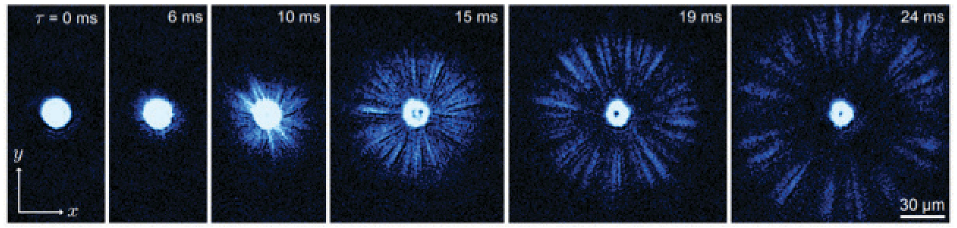


Figure 3

In addition to its research activities, the MRSEC operates 10 Shared Facilities that provide vital support for research. The MRSEC also participates in the Materials Research Facilities Network (https://mrfn.org) which provides access to the facilities for researchers from outside the University of Chicago. MRSEC educational programs target the research community with specialized workshops and exceptional training, and our local neighborhood through science enrichment opportunities. We run research experiences programs for undergraduates and high school students. Our annual physics show and open house for the public brings in visitors who may have never previously talked to a scientist. Research-related exhibits are developed in collaboration with the Museum of Science and Industry (Chicago) and the Exploratorium (San Francisco). Knowledge transfer activities engage industry in collaborative research, and provide students with opportunities to experience these environments through internships.

New Faculty:

VINCENZO VITELLI

Since I was a child, I have been intrigued by a short poem from the Italian polymath Leonardo Sinisgalli: Come il ragno costruisco col niente, lo sputo, la polvere, un po' di geometria (Like a spider I build out of nothing, spit, dust, a bit of geometry). In retrospect, these verses crystallize my vision of theoretical physics as the never-ending search for a representation of reality that is both minimalist and visionary.

One of the joys of being a physicist is to witness the emergence of universal concepts and mathematical ideas capable of explaining natural phenomena across very different energy, time and length scales. To avoid being overwhelmed by this sense of freedom, some constraints are needed to orient abstract thinking. It is for this reason that I have decided to focus my theoretical research towards the study of materials, a context where the constraints of reality and industrial applications are most stringent and stimulating.

My group is mostly interested in many particle systems whose rich behavior emerges from collective effects, rather than the complexity of the basic components, which can be macroscopic grains, molecules or the revolving mechanisms of a complicated mechanical device. Usually, newcomers to this field make a clear-cut decision between studying hard materials (where quantum effects are dominant) or soft materials (ruled by classical physics). I have tried to sit on the fence between the two, unable to see much of a distinction at the level of mathematical models. In the end, much of my work concerns soft materials (membranes, liquid crystals, glasses, grains, polymers, complex fluids etc.), but it is often related to quantum matter.

There are three recurrent features present (sometimes simultaneously) in the materials we study: they are often out of equilibrium, non-linear and disordered. A many body system far from equilibrium can evolve in time and usually displays a rich phenomenology difficult to predict using statistical mechanics formalism. Non-linear behavior occurs whenever the response of a material is not simply proportional to the applied perturbation, e.g. a sand pile that collapses when just a couple of extra grains are added. An extra complication that we often face is that the structure of soft materials is amorphous or disordered.

> "Exploiting topological invariants is not only desirable from the perspective of mathematical modeling—it can be a useful principle in the design of robust materials and devices."

Analytical progress on these complex problems is sometimes possible by concentrating on topological properties that are unaffected by smooth changes in material's geometry and parameters. Exploiting topological invariants is not only desirable from the perspective of mathematical modelling—it can be a useful principle in the design of robust materials and devices. The pursuit of topological materials has traditionally concentrated on electronic properties. My group has investigated classical mechanical structures that mimic their topological quantum counterparts and often exhibit additional unexpected non-linear response (see Figure 1(a–b)). A recent highlight was to show how topologically protected surface patterning (similar to the Thouless pumping of Mott insulators) can arise from the interplay of thermal fluctuations and interactions in two dimensional classical systems composed of directed polymers or vortex lines (see Figure 1c).

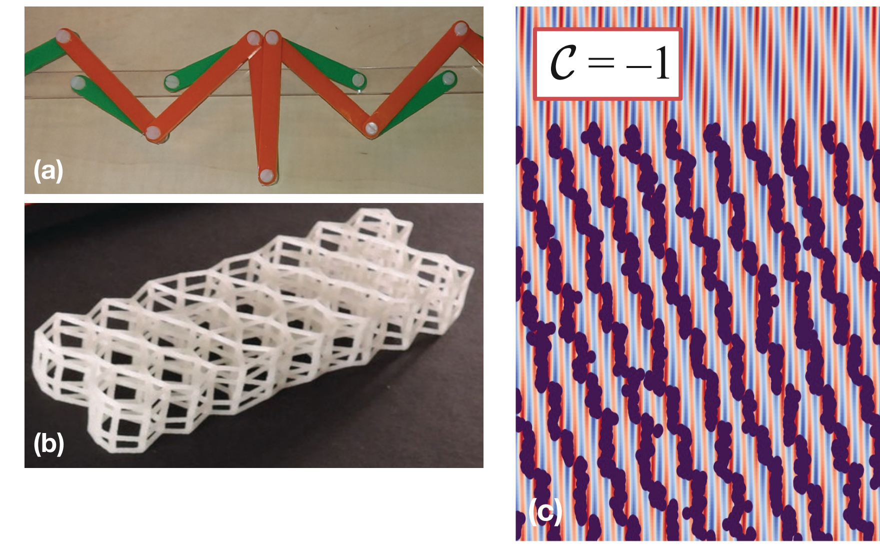


Figure 1

(a) A linkage that exhibit topologically edge state motion that smoothly evolves into non-linear moving objects called solitons.

(b) Topological control of material failure via buckling in a flexible metamaterial.

(c) Interacting and thermally fluctuating polymer lines (red) on a substrate acquire a collective tilt. The angle that measures the orientationof the red line is quantized and proportional to an integer valued topological invariant, C, called Chern number.

(For videos, see: home.uchicago.edu/~vitelli/videos.html)

Current efforts in my group are targeting a class of materials called active because they are composed of many interacting microscopic components each endowed with an internal source of energy of biological or synthetic origin. The central question that guides our efforts in this area is the following. How can we extend the time honored physics and engineering framework of Continuum Mechanics to enable the theoretical description of active solids and fluids for which energy is not conserved?

Student Voices:

CLARE SINGER

I grew up in Maryland just outside of DC. As a little kid I loved math; my parents used to buy me math workbooks in addition to coloring books for long car trips! I took my first physics class during the fall semester of 9th grade (it was algebra based mechanics). My high school teacher Mr. Schafer was fantastic and physics quickly became my favorite subject. I took two more physics classes in high school (modern physics and calculus based mechanics and e&m), but I think I had subconsciously decided I wanted to study physics in college after that first semester!

I've always been a very driven person and I like to challenge myself, so I knew I wanted to go to college somewhere that would challenge me. UChicago initially caught my attention because of the reputation of our physics department and the pride we have in being quirky. Ultimately though I chose UChicago because of the Core curriculum: I wanted to have a college experience that pushed me out of my intellectual comfort zone and let me take classes like Introduction to the Hebrew Bible or Language and Violence.

I'm not sure I knew what to expect when coming to UChicago, so I can't say if it's been what I expected, but it has been fantastic! The research opportunities I've had with UChicago faculty and UChicago programs have been way beyond my imagination: from building 20 foot tall towers of plastic Z-shapes with Heinrich Jaeger to spending a summer in Israel developing ink-jet printing technologies for water filtration membranes in collaboration with the IME to participating in an international field campaign for 4 weeks in Nepal researching the Asian Monsoon with Liz Moyer.

Outside of classes and my research one of the most meaningful things I've been involved with at UChicago has been The Society of Women in Physics (or SWiP). I joined SWiP as a first year and went with a group of older students to the Conference for Undergraduate Women in Physics (CUWiP) in Michigan. Since then I have become the president of the organization. It's amazing to be able to contribute so much to the department and it inspires me to see so many younger students joining research labs and doing great internships. This year I was especially excited to be able to go back to CUWiP, this time in Iowa, and take a group of 15 younger students with me! Young-Kee Kim has been doing incredible things for our department and I am so grateful for her support of SWiP.

This summer I'm taking a little time off after graduation before starting a PhD at Caltech in the fall. I will be in the Environmental Science and Engineering department working with Tapio Schneider and John Seinfeld researching stratocumulus cloud dynamics. Longer term, I want to stay in research, maybe as a professor or working at a national lab, but I'm also hoping to get more involved in science policy outreach.

Scav is still going strong. This year I was a captain of the Burton-Judson Scav team and we got up to our usual mischief and shenanigans: Michelin tire signed by a 3-star Michelin chef, many Kattenstoet festivities, working mechanical replica of Solomon's Throne.

Student Voices:

KATRINA MILLER

I grew up in Mesa, Arizona and actually graduated from high school without ever taking a physics course. I didn't like the other science courses, so I never imagined I would enjoy physics, especially since it had a reputation for being tedious and difficult. I did, however, discover that I had an affinity for mathematics—I enjoyed setting up equations and manipulating numbers to solve problems, and I even participated in competitions with the school math club. But math is intimately tied to physics, so in retrospect it was only a matter of time before I developed a passion for physics as well.

I first came to UChicago as an undergraduate REU student the summer before my senior year of college, and it was during this program that I cemented my interest in astro/particle physics because of the all the amazing research I was exposed to. So I knew that if I wanted to research in this area, UChicago was the place to be. And yes, I did find what I expected! UChicago has such a rich astro/particle research environment. I worked on dark matter detection during my first two years of graduate school and transitioned into the world of neutrino oscillations just this summer.

UChicago definitely turned me on to physics—the graduate student curriculum is demanding, but I have grown so much as a scientific thinker and researcher. My favorite research experience so far was spending a few weeks in Italy last summer collecting data for the XENON1T experiment at LNGS. This was the first time I had ever been a part of such a large collaboration of scientists, and I felt so important running the detector! It put into perspective the magnitude of what I could accomplish in graduate school.

Since coming here I have discovered that I love to teach! I was a teaching assistant last year for the introductory physics courses, which gave me direct access to undergraduate students considering a physics major. This was an important role for me because the positive interactions I had with professors and TAs in my undergraduate physics department greatly influenced my decision to become a physicist. Teaching also gave me a fresh appreciation for the subject I know and love, because I learned how to think about the same physical concepts in the many new and creative ways my students came up with.

I won't do much in the winter here because I hate the cold, but I come out of social hibernation in the summertime. You'll always catch me at some happy hour, music festival, or just out exploring different neighborhoods in the city, as long as the weather is sunny and warm!

Sometimes I think I'll stay in academic research, other times I think about teaching at a liberal arts college, or even going the national lab route. The most important requirement for me is that I'm fulfilling my passions—doing physics and teaching physics—but there are so many different ways I can do that. I know for sure I won't be staying in Chicago—it's too cold! As soon as I graduate I'm hoping to head back closer to home.

Fun fact: when I finish my degree, I'll be the third Black woman to earn her PhD from the UChicago physics department. Willetta Greene-Johnson (1987) is now a professor at Loyola and Cacey Stevens Bester (2015) is now a post-doc at Duke. I'm excited to continue their legacy and hope that it paves the way for even more representation in the future.

Prizes & Awards

Stuart Gazes has received a 2018 Quantrell Award for Excellence in Undergraduate Teaching

The Llewellyn John and Harriet Manchester Quantrell Awards, believed to be the nation's oldest prize for undergraduate teaching, reflect the College's commitment to honor inspiring teachers. The Faculty Awards for Excellence in Graduate Teaching and Mentoring recognize tenure-track and tenured faculty in the Biological Sciences, Divinity School, Humanities, Institute for Molecular Engineering, Physical Sciences and Social Sciences.

AWARDS & ELECTIONS

EUGENE PARKER was awarded the APS Medal for Exceptional Achievement in Research for his "many fundamental contributions to space physics, plasma physics, solar physics and astrophysics for over 60 years."

HEINRICH JAEGER was elected as a 2018 Fellow of the American Academy of Arts and Sciences; also awarded the Sewell L. Avery Distinguished Service Professorship

SHINSEI RYU was recently been named a Simons Investigator by the Simons Foundation. This award is given to outstanding theoretical scientists.

ABIGAIL VIEREGG was recently been named a 2018 Cottrell Scholar by Research Corporation for being an outstanding early career teacher-scholar.

MARK OREGLIA was elected as a Fellow of the American Physical Society "for broad contributions to electron-position and proton-proton collider physics."

VINCENZO VITELLI was elected as a Fellow of the American Physical Society "for theoretical contributions to the field of topological mechanics."

LIANTAO WANG was elected as a Fellow of the American Physical Society "for novel contributions to jet sub-structure studies..., facilitating LHC searches for Higgs boson, dark matter, supersymmetry and new dynamics in the electroweak sector."

APPOINTMENTS & PROMOTIONS

DAVID AWSCHALOM has a new appointment in the Department of Physics. He is also a Professor in the Institute for Molecular Engineering.

DANIEL HOLZ and **LIANTAO WANG** were recently promoted to full Professor.

DAVID SCHUSTER and **JON SIMON** were recently promoted to Associate Professor.

Alumni Reflection

SATOMI SHIRAISHI

Recently, I had the pleasure of speaking with physics students during a career night at the Kersten Physics Training Center. Meeting students nearing important crossroads reminded me of the myriad forms the post-graduation journey can assume.

I was born in Japan, and my grandparents were Nagasaki survivors. Just as their experiences had changed their lives, the stories they shared changed mine, as well. As I grew, I began to realize the good that radiation could bring to humanity and hoped one day to contribute to it. As the time came to put out college applications, the University of Chicago caught my attention for its history of scientific discovery and innovation, including Enrico Fermi's controlled nuclear chain reaction. My research projects during my undergraduate and graduate studies included experimental particle physics, analyzing the top quark lifetime at CDF, and pushing frontiers in laser-plasma accelerator technologies with Dr. Wim Leemans at the Lawrence Berkeley National Laboratory. I finished my AB in physics in 2007 and Ph.D. in 2013 under the mentorship of Professor Young-Kee Kim. Since then, I have pursued further studies in the medical physics of radiation oncology, including post-doctoral research and clinical residency training. This July, I started as a faculty member at Mayo Clinic in Rochester, Minnesota. I am excited to deepen my involvement in treating cancer patients in this role, as well as to research ways to advance radiation therapy with accelerator-based photon and proton treatments.

The coursework, learning philosophy, and research opportunities at UChicago turned out to be excellent preparation for my career in medical physics. What to do with the knowledge you gain at UChicago depends on who you are and what excites you. My advice to those graduating: follow your heart and don't give up!

Recent Happenings

New display in the Department of Physics recognizing UChicago National Medal of Science awardees. Marvin Cohen, PhD '64, now the University Professor of Physics at UC Berkeley pictured above with current Physics Graduate Students.

The 17 faculty and alumni of UChicago's Department of Physics who won National Medals of Science discovered the muon neutrino, disproved symmetry and described the lives of stars.

Their ranks include the queen of carbon (Mildred Dresselhaus) and the father of energy efficiency (Arthur Rosenfeld). They fostered new fields, solved some of the 20th century's greatest scientific puzzles and literally set the standards for modern science. They built accelerators and cosmic ray detectors and predicted the behavior of electrons; but they also contributed to touchscreens, radar and MRIs, advised presidents on nuclear security and helped spread energy efficiency across the U.S.

All 17 were honored Jan. 12 with a ceremony at the University's Kersten Physics Teaching Center, where Provost Daniel Diermeier and Prof. Young-Kee Kim, chair of the Department of Physics, unveiled a display along the building's top floor highlighting each awardee.

"This is a wonderful opportunity to honor this department's extraordinary history of scientific achievement," said Kim. "This floor has high student traffic, so we wanted to give them a sense of history and pride, as well as encouragement—many of these great scientists were once students here on this campus, just like them."

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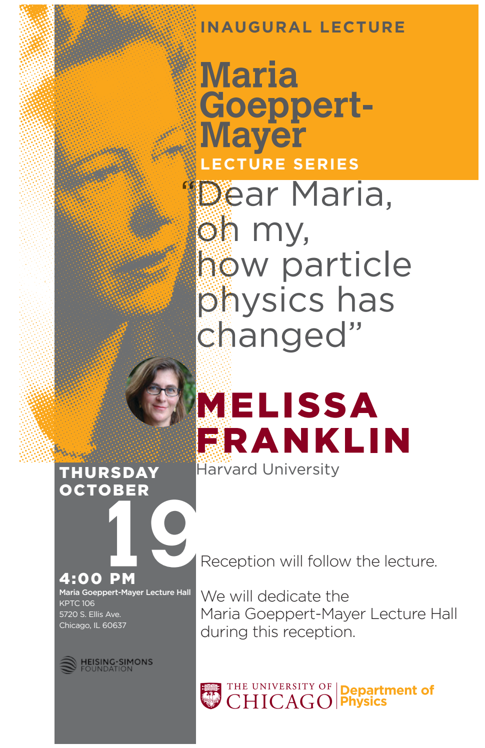
[Text: Louise Lerner, Photo: Jean Lachat, Event Poster: Graphic Arts]



Melissa Franklin, the Mallinckrodt Professor of Physics at Harvard University, gave the first annual Maria Goeppert-Mayer Lecture on October 19, 2017.

Her lecture "Dear Maria, Oh My, How Particle Physics Has Changed" explored both a brief history of the particle accelerators that have made remarkable discoveries in particle physics possible and the slow turn of experimentalists attention from the discovery of the building blocks of matter to the study of the universe with nothing in it, the so-called vacuum.

These lectures are annually given by outstanding women physicists, in honor of Maria Goeppert-Mayer. Goeppert-Mayer was a theoretical physicist who developed the nuclear shell model while at Argonne National Laboratory and the University of Chicago from 1946 to 1959. She received the 1963 Nobel Prize in Physics for her "discoveries concerning nuclear shell structure."

On August 12th, NASA's Parker Solar Probe blasted off into the predawn darkness, on its way to explore the sun on a mission that will send it closer to our star than any previous spacecraft.

With its liftoff, University of Chicago Professor Emeritus Eugene Parker became the first person to witness the launch of a namesake spacecraft. The Parker Space Probe is the first NASA mission named in honor of a living person.

"All I can say is wow, here we go," said Parker, who is the S. Chandrasekhar Distinguished Service Professor Emeritus in Physics at UChicago. "[Now I] really have to turn from biting my nails...to thinking about all the interesting things which I don't know yet. We're in for some learning the next several years."

[Source: https://news.uchicago.edu/story/nasa-solar-probe-named-after-uchicago-scientist-begins-historic-mission?]

Events

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

PAST

NOVEMBER 1, 2018
Argonne National Lab
The American Physical Society has named Argonne National Laboratory an historic physics site in recognition of the pioneering work of former Argonne physicist and Nobel laureate Maria Goeppert Mayer.

DECEMBER 7, 2018
VanFEST
A celebration of Van Bistrow's 40+ years at the University of Chicago and his contributions to physics instructional labs.

DECEMBER 8, 2018
Physics with a Bang!
Professors Heinrich Jaeger and Sid Nagel are the hosts for this fun holiday lecture for children, families, students and teachers.

DECEMBER 8, 2018
Forget the Year
The annual holiday event for the Department of Physics.

UPCOMING

JANUARY 11, 2019
Physics Career Day

MARCH 1, 2019
Graduate Student Open House

MARCH 6, 2019
APS Alumni Event, Boston

JUNE 14, 2019
The Department of Physics Graduation Reception

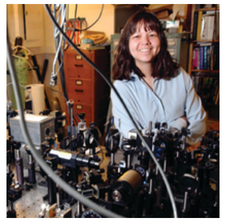
Physics with a Bang! 2018

Forget the Year 2018

Department of Physics Graduation, 2018

Development

DEPARTMENT OF PHYSICS ESTABLISHES THE DEBORAH JIN FELLOWSHIP



Deborah (Debbie) Jin was an internationally renowned physicist. In 2003, she received a MacArthur Fellowship (commonly known as a "genius grant") from the John D. and Catherine T. MacArthur Foundation. In 2013, she was named the L'Oreal-UNESCO For Women in Science Laureate for North America. Her other prestigious awards include a 2002 Maria Goeppert Mayer Award, a 2004 Scientific American "Research Leader of the Year," a 2008 Benjamin Franklin Medal in Physics, a 2014 Institute of Physics Isaac Newton Medal, and the 2014 Comstock Prize in Physics. At the time of her election in 2005, Jin was the youngest member of the National Academy of Sciences.

Debbie Jin passed away September 15, 2016, after a courageous battle with cancer. She was 47. Jin earned an A.B. in physics from Princeton in 1990, and a Ph.D. in physics from the University of Chicago in 1995 under supervision of Thomas Rosenbaum. From 1995 to 1997, she was a National Research Council research associate at JILA, where she was hired in 1997 as a NIST physicist and assistant professor at the University of Colorado, Boulder.

About the Fellowship
Debbie Jin was a role model and inspiration for scientists, men and women alike. The Department is establishing the Fellowship to bring more outstanding women into science. Gifts of all sizes are appreciated. The Fellowship will be given to an incoming female physics graduate student at the University of Chicago.

THE SOCIETY OF WOMEN IN PHYSICS

The Society of Women in Physics (SWiP) group was established to provide supportive environment for undergraduate women and access to resources for success in higher physics. While our society has largely grown in the last several years, we aim to increase the number of resources for women to learn about careers in physics as well as highlight the ongoing achievements of successful female physicists. We intend on expanding our current mentorship program that fosters connections between graduate and undergraduate women, as well as pilot an outreach program at local schools to expose and raise interest in physics with younger girls as well. We are also very excited to bring back our quarterly speaker series, with the goal of celebrating and learning about the work and experiences of local female physicists every term.

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/support**

In Fond Memory...

JAMES W. CRONIN

1931–2016

Professor Emeritus James W. Cronin, a pioneering scientist who shared the Nobel Prize in physics in 1980 for his groundbreaking work on the laws governing matter and antimatter and their role in the universe. Cronin, SM'53, PhD'55, spent much of his career at the University of Chicago, first as a student and then a professor. A University Professor Emeritus of Physics and Astronomy & Astrophysics, he was remembered this week as a mentor, collaborator and visionary.

"He inspired us all to reach further into the unknown with deep intuition, solid scientific backing and poetic vision," said Angela Olinto, the Homer J. Livingston Distinguished Service Professor in Astronomy and Astrophysics. "He accepted his many recognitions and accolades with so much humility that he encouraged many generations to follow his vision."

[Source: https://news.uchicago.edu/story/james-w-cronin-nobel-laureate-and-pioneering-physicist-1931-2016]

DEAN EASTMAN

1940–2018

Dean Eastman, director of Argonne from 1996–1998 and professor emeritus at the University of Chicago, died on March 4, 2018, at the age of 78. His tenure at the lab saw the Advanced Photon Source begin its operations and the Gammasphere (part of the Argonne Tandem Linac Accelerator System) make its first move from Lawrence Berkeley National Laboratory to Argonne.

[Source: https://researchinnovation.uchicago.edu/2018/04/10/in-memoriam-dean-eastman/]

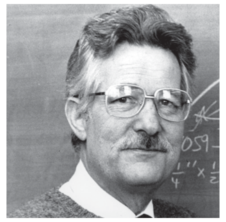
PETER FREUND

1936–2018

Professor Peter Freund was both a particle physicist and writer who joined the physics faculty at the university in 1965. His wide-ranging work in theoretical physics had a strong mathematical flavor. "He was frequently an early contributor in fields and theories that later rose to prominence," said Jeff Harvey, the Enrico Fermi Distinguished Service Professor of Physics. "He had good taste."

These included supersymmetry and string theory, including a branch that tied string theory with a mathematical concept called p-adic numbers, as well as a concept called AdS/CFT correspondence, which relates quantum models of particles with quantum models of gravity.

[https://news.uchicago.edu/story/peter-freund-particle-physicist-and-fiction-writer-1936-2018]



HELLMUT FRITZSCHE

1927–2018

Professor Emeritus Hellmut Fritzsche spent his career exploring semiconductors—materials that are the foundation of modern electronics. In particular, the experimental physicist became one of the world's foremost experts on amorphous semiconductors, working with inventor Stan Ovshinsky to turn these materials into technology that would define the late 20th century—TV displays, computer memory and solar panels.

A member of the UChicago faculty for nearly 40 years and a former chairman of the Department of Physics, Fritzsche died June 17 at age 91. Colleagues remembered Fritzsche's passion and energy, his intellectual generosity and his inventiveness in the laboratory.

(Louise Learner)

LEON LEDERMAN

1922–2018

Professor Emeritus Leon Lederman was a Nobel-winning physicist and scientific leader with a passion for science education. With a career that spanned more than 60 years, Lederman, the Frank L. Sulzberger Prof. Emeritus of Physics, became one of the most important figures in the history of particle physics. He was responsible for several breakthrough discoveries, uncovering new particles that elevated our understanding of the fundamental universe, and he led the construction of the Tevatron at Fermi National Accelerator Laboratory, which was the highest-energy accelerator in the world for 30 years.

[Source: https://news.uchicago.edu/story/leon-lederman-nobel-winning-physicist-and-former-fermilab-director-1922-2018]

THE UNIVERSITY OF CHICAGO
Department of Physics
Kersten Physics Teaching Center
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