Chapter 2: 1986–2017

Foreword

In the autumn of 2017 the Department recognized a need for an updated public account of its accomplishments and growth. The existing account, written in 1986 by then Chairman Helmut Fritzsche needed to be augmented with a second chapter recounting events from 1986 to 2017. I was asked to write this Chapter, to be used in the the Department's web site and its other publications. The text below is the result. It was written after consultations with several long-time faculty members and updated after soliciting comments from the faculty.

Any such account is doomed to fall short of capturing all the important achievements of the Department. The aim in the following account has been to trace movements and initiatives that had a strong impact on multiple faculty members. Many of these events involved other departments, notably in Astronomy and in Chemistry. In the narrative below these faculty are indicated by an asterisk. The account below owes much to extended consultations with Jeffrey Harvey, Dietrich Muller, Kathryn Levin, Emil Martinec, Stephan Meyer, Sidney Nagel, and Henry Frisch. Van Bistrow, Philippe Guyot-Sionnest, Eric Isaacs, Emil Martinec, Dietrich Muller, Sid Nagel, Jim Pilcher and Jon Rosner offered improvements to early versions. Still, responsibility for misstatements and omissions should rest with me.

—T. Witten, February, 2018

A month before the writing of Prof. Fritzsche's chapter above [1], the Zeitschrift für Physik received a striking report that was to preoccupy condensed matter physics for decades to come. Bednorz and Mueller had discovered a new form of electrical superconductivity that would eclipse our existing notions of macroscopic quantum coherence. It would also vastly increase the prospects for beneficial uses of superconductivity. The subsequent years have seen a succession of equally historic events in physics. Cosmology became a rich experimental science with a wealth of new data from the cosmic microwave background and astronomical observations from unprecedented distances. These observations corroborated two startling notions about the earliest observed universe: A rapid initial expansion called inflation and a new form of energy called dark energy. On a more local scale the long speculated gravitationally collapsed objects known as black holes were revealed with increasing certainty via space-based telescopes. In particle physics, experiments of heroic scale found the anticipated particles of the Standard Model [2]—culminating with the top quark and the Higgs Boson. They also established that neutrinos have mass of startlingly small size. The mastery of atomic trapping and cooling and the attainment of ultra-pure electronic conductors opened up a new domain of exquisite control of macroscopic quantum states. The new states are based on Boson condensation, fermion pairing and quantum degeneracies induced by magnetic fields or rotational symmetry breaking. They brought goals like quantum encryption and quantum computations steadily towards reality. In the last year physics has achieved another triumph in the detection gravitational waves.

Chicago physicists have played significant roles in some of these historical events, and these events have shaped our development and our priorities. Against the background of these events, Chicago physics has made an impact on science and on its practical implications across a broad front. The pages to follow recount some of these impacts. We begin with a snapshot of the department in 1986. Next we review the main directions and accomplishments in the subfields that we study.

Snapshot

The work of the Department in 1986 was dominated by the interdisciplinary Research Institutes, born of the conviction that discovery and innovation were best pursued by collaborations attacking a class of phenomena from diverse disciplinary perspectives. The larger Enrico Fermi Institute was the seat of particle physics, cosmic ray physics and chemistry, interplanetary physics and cosmology. Besides physics it included members of the chemistry, astronomy and geophysics departments concerned with these subjects. The complementary James Franck Institute studied many-body phenomena at the atomic scale, such as molecular quantum coherence, superconductivity, magnetism, surface science and glassy disorder. Its members came from chemistry and geoscience as well as physics.

The bulk of this research took place in the massive postwar Research Institutes Building and a cluster of satellite buildings northwest of Ellis Avenue and 57th Street. All new hires in physics required joint appointments in one of the Institutes, and virtually all PhD research was done there. The disciplinary core of physics was the new Kersten Physics Teaching building, adjacent to the Research Institutes. Here courses and instructional labs were taught, faculty meetings and colloquia were held and PhD's were celebrated. Each participating department in the Institutes was responsible for granting academic degrees in its own discipline. Thus, the Physics Department appointed a PhD committee to guide each physics PhD student towards their degree. Yet even in degree granting, there was disciplinary cross-fertilization. Often more than one discipline was represented on a PhD committee. Sometimes physicists supervised PhD students in other disciplines, as other faculty advised physics PhD students.

A major research effort in the Fermi Institute centered around accelerator-based experiments, largely at Fermilab, where proton-antiproton collisions with two TeV of energy had recently been realized. A second large effort was in cosmic ray physics, using space and ground-based detectors and high-altitude balloons. There were prominent and interacting theory groups in cosmology, general relativity and the radical string-theory approach to fundamental particle physics.

Physicists in the Franck Institute were largely preoccupied with exotic low-temperature magnetism and superconductivity. The emphasis was on new kinds of ordered phases and the exotic phase transitions leading to them. A second preoccupation was the scale-free fluctuations seen in continuous phase transitions noted above. New forms of scale-free fluctuations were being discovered in turbulent fluids and in growth phenomena. The amorphous, non-periodic state of glassy solids was an area of great interest, both for its very broad spectrum of structural relaxation time scales and for its unusual semiconducting properties.

Space physics and cosmic rays

John Simpson's program of probing the space environment with particle and dust detectors, noted in the last chapter [1], continued until 2000. Notably, these confirmed Eugene Parker's proposal of the solar wind, recognized by a National Medal of Science and numerous other prizes. In parallel the historic program to study cosmic rays at the highest energies continued into the 2000's. It determined the abundance of heavy atomic nuclei using orbiting and balloon-borne detectors. Here Dietrich Muller, Simon Swordy, Peter Meyer and collaborators sought clues to the violent events that might produce these energies. The group's later balloon experiments sought signs of antimatter from the early universe by detecting antiprotons and positrons. From 2003 Swordy and Scott Wakely played key roles in developing ground-based telescopes that see multi TeV gamma rays with directional precision via their Cerenkov radiation [3] in the atmosphere. This ground-based gamma-ray telescope cluster, called VERITAS [4], continues to pinpoint sources of high-energy cosmic rays.

The major Pierre Auger observatory [5] project, is aimed at greatly extending the upper energy limit of observable particles, using methodology developed in the nineties by James Cronin and Rene Ong (1991-2000) [6]. Since 2003 Auger's detectors, arrayed over a thousand square miles of territory, have observed the showers of particles produced when the primary particle enters earth's atmosphere. Since then the Auger observatory, involving some 400 collaborators, has confirmed the anticipated abundance of these very high energy particles and gained evidence that they originate in active galactic nuclei outside our galaxy. Paolo Privitera (from 2011) and Angela Olinto* play leadership roles. Auger's impact on particle physics is noted below.

Cosmology

By 1986 the big-bang scenario of the early universe had been firmly established owing to the observation of the 3-degree cosmic microwave background radiation. David Schramm and Michael Turner realized that aspects of the big bang were sufficiently well understood to predict details about the nuclear species that could emerge from it. By the late 80's these predictions had become a precise science. The large observed amount of deuterium relative to other light nuclei implied that the amount of baryonic matter was too small to explain the gravitational mass of galaxies and their halos. It was necessary to postulate some new form of "dark matter" that outweighs conventional matter by a substantial factor. A second constraint coming from nuclear abundances set an upper limit on the number of neutrinos available to participate in weak decays of hadrons. The ultimate limit of three neutrino species was later confirmed by accelerator-based experiments, thus giving important corroboration to the Standard Model.

The year 1997 marked another milestone in this subject, spurred by astronomical observations at unprecedented large red shifts—large enough to detect the expected slowdown of the universe's expansion due to self-gravitation. Startlingly, they saw the reverse: the expansion was speeding up, not slowing down, over time. Some effect was countering the known self-gravitation. Turner called this effect "dark energy", and the name stuck. These observations, coupled with megabytes of mapping information about the cosmic microwave radiation [7,8] led to a convergent picture of the hadronic plasma that created the observed universe. The Chicago cosmologists were major players in producing this synthesis. This convergence has only heightened the need to explain dark energy.

Increasingly, experiments were brought to bear in order to probe dark matter, dark energy and the big bang. From 2002 Juan Collar's and Luca Grandi's (hired 2013) liquid detectors have set strong bounds on the density of suspected dark matter particles. Historic experiments by John Carlstrom (hired 1995), Bruce Winstein, Abigail Vieregg (hired 2013) and their teams obtained unprecedented polarization information about the cosmic microwaves. Stephan Meyer played a pivotal role in WMAP, the most detailed cosmic microwave map to date. Combining the new data with existing astronomical methods gave strong constraints and corroboration to the notions of dark matter and dark energy. From 2000 Wayne Hu* used gravitational theory to devise observational tests. Andrey Kravtsov* and Carlstrom deduced further constraints by combining surveys of large scale structure with the microwave background maps and cosmological simulations. In 2004 Chicago's leadership was recognized in the founding of the Kavli Institute for Cosmological Physics [9]. From 2016 Chicago physicists Daniel Holz (hired 2011) and Robert Wald played important roles in another experiment of cosmological significance, LIGO's [10] detection of gravitational radiation from gravitational coalescence of stars.

Particle physics

Since the early days of Fermi the particle physics group has played a prominent role in accelerator-based particle physics. During the 1970s and early 80s this was through fixed-target experiments at the new Fermilab accelerator. By the late 1980s it was clear that the the road to understand short distance effects lay with colliding beam-beam experiments, such as the CERN Large Electron-Positron Accelerator, completed in 1989. Here Frank Merritt, Mark Oreglia and James Pilcher helped build and perform the OPAL [11] experiment to study high energy electron-positron annihilations. OPAL tested the electroweak theory with enough precision to predict the masses of the top quark and Higgs boson. At the same time Fermilab was building the proton-antiproton collider called the Tevatron. Henry Frisch and Melvyn Shochet played key roles in constructing and leading the CDF [12] experiment to study these collisions. Here, in 1995, they directly observed the top quark for the first time.

To move beyond these discoveries it was clear that greater energy and sensitivity was required, and the CERN Large Hadron Collider was being built to provide these. The Chicago group joined by Young Kee Kim helped build and lead the ATLAS [13] experiment to analyze these collisions. They discovered the Higgs boson in 2012 and tested its consistency with the Standard model in many ways.

This work was greatly facilitated by close interactions with the strong phenomenology group consisting of Jonathan Rosner, Carlos Wagner (hired 1999), Marcella Carena (hired 2008), and Lian-Tao Wang (hired 2011). Rosner predicted and explained many beautiful features of the Standard Model. Wagner, Carena and Wang have explored implications of the Large Hadron Collider data, identifying implications for cosmology. They also identified ways to see the first hints of supersymmetry [14], a powerful suspected symmetry that connects fermions and bosons.

Another major Chicago effort has been to understand the violation of CP [15] symmetry. This breakdown is required to explain the observed matter-antimatter asymmetry of the universe, but the effect in K mesons originally discovered by James Cronin is too small. A major effort to improve our understanding of CP violation in the neutral K meson system was led at Fermilab by Edward Blucher (hired 1993), Yau Wah and Bruce Winstein [16]. They showed convincingly that there are two sources of CP violation in the neutral K meson system. This work is being continued by Wah with the KOTO experiment in Japan.

Neutrinos have the potential to be another source of CP violation and it could be manifested in the properties of neutrino oscillations. Frank Merritt and Mark Oreglia performed the first accelerator-based search for neutrino oscillations at Fermilab in the early 80s. The properties of neutrino oscillations were later measured by Blucher with the Double CHOOZ [17] experiment in France and by David Schmitz (hired 2012) at Fermilab. This work is being extended with the ambitious Deep Underground Neutrino Experiment (DUNE) [18] of which Blucher is co-spokesperson. Its ultimate goal is to search for CP violation in the neutrino sector of the Standard Model through the study of neutrino oscillations.

The energies needed to see new particle phenomena have grown almost beyond the reach of accelerator experiments. Thus experiments have increasingly sought to probe these energies via naturally-occurring processes in the universe. Energetic cosmic rays can vastly exceed accelerator energies. The Auger project described above is a major advance in observing these particles.

Theory

The pages above have mentioned a wealth of recently identified new particles and startling phenomena. As with every period of physics, existing conceptual frameworks fall short, and we are driven to invent new ones. In modern times the boldest constructs have arisen to account for the properties of elementary particles. In this way the now-familiar flavor and color gauge symmetries of the Standard Model were postulated. However, the Standard Model in its present form is only predictive when restricted to currently accessible energies and length scales. String theory seeks a conceptual framework that avoids this restriction. The bold generalization proposed is to reimagine space, reversing its role from a fixed framework for physical phenomena to a physical phenomenon in its own right. Then the dimensionality of this space itself becomes a phenomenon to be explained, rather than a given fact.

During the 80's the Department made a major commitment to string theory with the hiring of Emil Martinec, Jeffrey Harvey, and subsequently David Kutasov (hired 1996) , Savdeep Sethi (hired 2000) and Dam Son (hired 2012). String theory describes elementary particles as excitations of an imagined one-dimensional string. The commitment has paid off. An early payoff stemmed from the 1984 Friedan-Shenker discovery mentioned in the Afterword above [19]. That discovery applied conformal symmetry to explain phase transition phenomena. In 1986 Martinec and coauthors showed that the same conformal description applied to the surface that a string sweeps out as it moves through time. This allowed a unified explanation of many string properties that had previously been found. The group has played a leading role in developing the widely recognized notion of complementary "dual" descriptions of a given string theory in which the strongly interacting degrees of freedom in one description become weakly interacting in the dual description. It also shed light on puzzling predictions about quantum black holes. The quantum tunneling phenomena identified by Hawking [20] amounted to an effective temperature of a black hole. Wald had played a key role in elucidating these thermodynamic properties. Only later did string theory provide a way of identifying the degrees of freedom responsible for the predicted black hole entropy and quantitatively accounting for its magnitude.

Theory at Chicago extends well beyond string theory. The strong, testable predictions using the Standard Model have been noted above. Theorists within and outside string theory have addressed the puzzle of matter-antimatter asymmetry in the universe, and the implications of the smallness of the neutrino masses. Major fundamental findings also occurred in hydrodynamics, superconductivity, two-dimensional electronic ground states and scale-invariant systems. These latter subjects were inspired by condensed matter phenomena, and we treat them below in the condensed matter section.

In 2013 the University recognized the importance of sustaining our strength in theory by launching a new theoretical institute. Intended as a center for uniting the many aspects of theoretical physics, it was named the Kadanoff Center for Theoretical Physics [21] after our distinguished late condensed matter physicist, Leo Kadanoff. The center was anchored by the initial appointment of University Professor Dam T. Son, joined by several theorists listed above and below. The Center now includes associate professors Shinsei Ryu (hired 2016) and Erez Berg (hired 2016).

Condensed matter

A central development in condensed matter shaped much of Chicago's condensed matter research in the eighties. This was the theoretical concept known as the "renormalization group". It was developed in order to address a long-standing puzzle in condensed matter behavior: the strong and pervasive fluctuations of a system at continuous phase transition between two different states, *eg.* , a liquid and a gas. These so-called critical systems had divergent thermodynamic properties and spatial correlations described by peculiar, non-integer power laws. Leo Kadanoff's seminal idea was to consider the effective system in which the finest scale degrees of freedom were removed and compare this to systems with more and more degrees of freedom removed. At a critical point, these effective descriptions must all have the same form. By the eighties, this strategy had been developed into a powerful and systematic description of a variety of critical phase transitions. All these depended on describing a given system at multiple spatial scales and inferring the "scaling symmetry" that emerged. Many of these exponents were constrained by the symmetry itself, and were thus unaffected by the specific realization of the transition; they were thus "universal".

Kadanoff arrived in Chicago in 1978 with the notion that this scaling approach could be applied to a host of important phenomena beyond phase transitions. Indeed, the approach could be applied to any scale-invariant phenomenon, from strange attractors in dynamical systems to hydrodynamic singularities to fractal growth to strong turbulence. By the mid eighties many of these subjects were bearing abundant fruit. By 1983 Kadanoff had attracted the senior experimentalist Albert Libchaber from the Ecole Normale Superieure in Paris to explore these subjects experimentally. The two senior researchers had attracted the junior theorist Thomas Halsey and a posse of passionate postdocs. It was a golden age.

A first collaboration established the experimental importance of recent results in chaos theory. Here Libchaber's experiments on electrically driven liquid mercury validated the predicted period-doubling cascade behavior [22] and also the phase-locking cascade predicted by Kolmogorov, Arnold and Moser [23]. This gave rise to the notion of a taxonomy of "routes to chaos." Next came a major new direction in probing strong turbulence via thermal convection instead of mechanical driving. This study stimulated a series of related studies that continue to the present day [24]. The collaboration continued with a study of many forms of driven interfacial pattern formation phenomena, such as the advance of a finger of fluid into a channel or the fission of a single mass of fluid (with Sidney Nagel and Wendy Zhang (hired 2003)) or the advance of a solidification front in cooled fluid. All of these yielded unexpected forms of scaling and surprising roles for small effects to alter this scaling. Libchaber's work was to be recognized by a Wolf Prize in 1986; Kadanoff's body of work was to be recognized by a National Medal of Science in 1999.

The renormalization approach gave a glimpse of many new types of phase transition, many accessible only at low temperatures. Thomas Rosenbaum's expertise fit well into this opportunity. His work demonstrated a new form of logarithmic universality in dipolar magnets, and explored new forms of phase coexistence in exotic magnetic phases. Meanwhile, the mysterious new high-temperature superconductors noted above demanded understanding. Chicago was to co-lead a multi-institution collaboration including theorist Kathryn Levin, Rosenbaum, Heinrich Jaeger and Thomas Halsey. This NSF-funded "Science/Technology center for superconductivity" spanned the decade from 1988 to 1998. Theorist Gene Mazenko explored the kinetics of phase separation in contexts ranging from cosmology to liquid crystals. His discovery of elastically degenerate directions in nematics was a forerunner of recent generalizations to nematic elastomers [25]. By the mid nineties, the development of ultra-pure semiconductors had revealed a wealth of new types of electronic order known as the fractional quantum Hall states. Woowon Kang (hired 1994) contributed to understanding transport in the more exotic phases. These early studies gave rise to the recognition that such systems supported so-called topological phases. At this writing an array of realizations and properties of these phases have been identified by theorists Paul Wiegmann (hired 1994), Michael Levin (hired 2014), Shensei Ryu, Erez Berg and Vincenzo Vitelli (hired 2016).

A concurrent activity in the James Franck Institute from the eighties addressed a second fundamental puzzle in the field: the transition from flowing liquid to frozen solid. Nagel's ongoing work on this transition in molecular liquids was soon to be joined by interest in simulated systems (Gene Mazenko) and in colloidal fluids (David Grier (1991–2003), Stuart Rice* and Norbert Scherer*). The micron-scale colloidal particles embodied the features deemed essential for solidification without the inessential details of specific molecules. New techniques allowed their motion to be perturbed and observed with a new level of detail. From the late eighties Nagel and Heinrich Jaeger (hired in 1991) were pursuing an even more radical realization: granular material. These had all the simplicity of colloids, with the additional simplicity that thermal motion and relaxation were absent. This "jamming" approach to solidification proved to have a rich body of scaling behavior of its own. By the late nineties, with participation from Susan Coppersmith (1995-2001) and Witten (hired 1989) it had grown in recognition to be a prominent approach to solidification and to dense suspension rheology [26]. Local practitioners have now grown to include theorist Vitelli. Nagel's work has earned him a Buckley Prize and election to the National Academy.

As colloids developed as a means of probing mechanical solidification, a new model system for gaining analogous control of quantum systems was invented. The demonstration of a quantum coherent Bose condensate in trapped atoms in 1995 [27] offered a new form of matter for studying many-body quantum coherence. The atoms offered unprecedented manipulability and measurability. Soon one could use them as a model system for creating coherent pairing of fermionic atoms, in analogy to electronic superconductivity. Cheng Chin, hired in 2005, and theorist Kathryn Levin were quick to recognize this potential. They showed how modes of pairing could lie on a continuum ranging from the interdependent, collective "BCS" pairing of conventional superconductors to independent molecular pairing into bosons under conventional Bose-Einstein condensation "BEC". Since then Chin has demonstrated a range of unimagined far-from-equilibrium coherent states of trapped atoms. Newer faculty members David Schuster (hired 2011) and Jon Simon (hired 2012) have added further forms of coherence: bound states of atoms or electrons with photons.

The hydrodynamic work from the eighties noted above concerned singular states at a moment of transition from one morphology to another. In 1997 our hydrodynamic work got a major new impetus via a new institute called the FLASH simulation center, led by Robert Rosner and advised by Leo Kadanoff [28]. It aimed to simulate the extreme conditions of an exploding star. In 2004 it identified a new focusing mechanism for setting off such explosions. The FLASH simulation code is still being upgraded and developed in 2017. With the hiring of William Irvine in 2011, the possibilities of hydrodynamics took on a new direction not appreciated elsewhere. His aim was to create coherent excited states of a fluid defined (as in some quantum hall states mentioned above) by *entanglement*. His realization of the trefoil-knot vortex in 2013 has given rise to a whole series of studies of different prepared states of vortex entanglement. The arrival of theorist Dam Son in 2012 enhanced this spirit of generalizing hydrodynamics. Son was famous for his minimum viscosity bound applicable to any fluid with entropy. He and Paul Wiegmann were keen to explore the predicted "odd viscosity" expected in two dimensional systems with broken time-reversal symmetry and topologically protected excitations. At this writing Irvine and Vitelli, as well as Schuster and Simon have intriguing and very different examples ripe for further exploration.

The same principle that creates the micron-scale colloidal particles discussed above also creates much smaller nanometer scale particles. Since the eighties Chicago physicists exploited this principle—arrested phase
separation—to create nanostructured materials. This work began with a collaboration between Jaeger and Witten in the late 80's. They aimed to create regular spatial patterns on surfaces at a ten-nanometer scale, using amphiphilic diblock copolymers through the nineties and early 2000s. Steven Sibener* has since shown how disorder in these patterns could be regulated and generalized. Soon the work expanded to nanoparticles based on inorganic precipitation arrested by surfactants. Semiconductors fashioned into nanoparticles are "quantum dots" whose electronic states can be tuned and stabilized, *eg.* , by cladding the inner particle with donor and accepter materials. The current level of such control is due largely to Philippe Guyot-Sionnest (hired 1991). As the recognition of electronic nanomaterials grew, the major Center for Nanoscale Materials was founded at the Argonne National Laboratory in 2006 under the leadership of faculty member Eric Isaacs. The Center's aid enabled several collaborative efforts with Jaeger, Rosenbaum and Talapin*. Jaeger showed how monolayers of these nanoparticles could form robust and well-ordered materials of exceptional thinness. Our work on nanostructure continues into the present, with collaborators Paul Nealey, Juan dePablo and Stuart Rowan at the Institute for Molecular Engineering, discussed below.

The early 2000s saw a convergence of interests between the University's Physical Science Division and the large, medically-oriented Biological Science Division. These two aspects of natural science had remained separate for decades and had not participated in the growing synergy between physics and biology seen elsewhere. A major initiative to unify the two branches of research led to the construction of a large complex to house the James Franck Institute and much of the basic science in the biological division. This "Gordon Center for Integrative Science" was completed in 2006.

Physicists had long felt that by ignoring living matter, physics was missing the chance to discover new fundamental phenomena. Our initial move towards biophysics was the hiring of Philippe Cluzel (2003-2008). Cluzel was soon revealing new physical principles in the sensory apparatus of e-coli cells and the patterns of epigenetic differentiation of these cells. Margaret Gardel's arrival in 2007 brought a complementary emphasis on the cell's control of its intracellular forces via actin networks. Her fruitful collaborations with biological scientists have produced fundamental new knowledge of how cell contractility arises, and how the cell marshals its actin into a multitude of forms as the need arises. Further biophysicists, David Biron (2009-2016) and Stephanie Palmer (from 2012), worked on the origins and intricacies of neurological functioning. At this writing the department has added Michael Rust (from 2011), theorist Arvind Murugan (hired 2015), who are uncovering new dynamical-system principles in the reaction networks that regulate cells.

Much of the research mentioned above addressed fundamental phenomena underlying applications of condensed matter. At other institutions such research is done in engineering schools in collaboration with those who can apply the new knowledge. Throughout the twentieth century the University had contemplated ways to include engineering within its purview. In 2011 a novel approach was devised. It took the form of a new Research Institute called the Institute of Molecular Engineering [29]. To house the Institute, an advanced laboratory building took shape on the site of the Research Institutes Building of the fifties. The Institute has hired several eminent physicists, and many of them collaborate with our faculty, as noted above.

Joint faculty with Argonne and Fermilab

Since the founding of Argonne National Lab and Fermilab, their scientists have played a role in the Chicago physics faculty. These scientists have broadened the faculty's awareness of fields outside its own scope. They extend our expertise in teaching and supervise PhD research. John Schiffer, a Distinguished Fellow at Argonne was our expert in nuclear physics until 2000. Guy Savard, also a Distinguished Fellow at Argonne has played this role from 2000 to the present. Our expertise in the rich dynamical systems physics of accelerated beams comes from Kwang-Je Kim, Distinguished Fellow of Argonne (from 2000), and Sergei Nagaitsev, Chief Accelerator Officer of Fermilab (from 2015). Senior Physicist Zheng-Tian Lu of Argonne has brought his insights in spectroscopic detection of trace elements since 2004. Since 2016 our connection to the exciting phenomena of intense x-ray excitation of atoms has come from Linda Young, also a Distinguished Fellow at Argonne.

Academic development

The Department's impact on students has grown greatly since 1986. Undergraduate course enrollment more than doubled to reach 840 in 2016-2016 while bachelors' degrees nearly tripled to reach 61 in 2016-2017. There was also growth in graduate teaching, with a 50 percent increase in graduate course enrollment and a stable number of PhD's awarded. Over this time the department has retained its commitment to conscientious and creative teaching, aided by a lower-than-typical teaching load. Notable structural changes included a thorough revamping of experimental instruction at both undergraduate and graduate level. Requirements for PhD Candidacy gradually diminished from a rigorous four-day exam to a short entrance exam and a course performance requirement. Since 2010 the demand for physics courses increased greatly. Class size expanded and classes can no longer be accommodated within the physics teaching building.

The high regard of students for the Department comes largely from its dedicated staff. Many generations of students passed through the hands of fondly remembered staff members James McConville, Kate Cleary, Joseph O'Gallagher, Dennis Gordon, Jesus Cuevas and Nobuko McNeil, as well as veteran current staff members Van Bistrow, David Reid, Mark Chantell and Stuart Gazes.

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