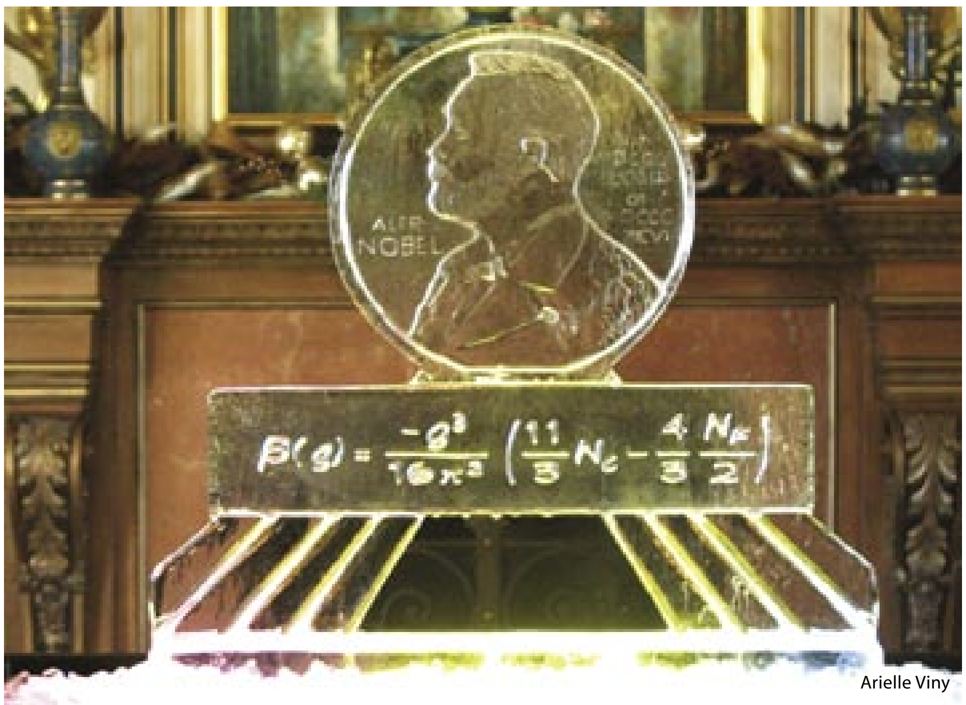
KITP Director Awarded 2004 Nobel Prize in Physics

DAVID J. GROSS, director of the Kavli Institute for Theoretical Physics (KITP) and the first incumbent of the Frederick W. Gluck Chair in Theoretical Physics at the University of California, Santa Barbara, was awarded the 2004 Nobel Prize in Physics for solving in 1973 the last great remaining problem of what has since come to be called "the Standard Model" of the quantum mechanical picture of reality. He and his co-recipients discovered how the nucleus of atoms works.

Gross shares the prize with Frank Wilczek, who was Gross's graduate student at Princeton University, when the pair completed the calculation that resulted in the discovery for which they have received the Nobel Prize. Wilczek, now a physics professor at the Massachusetts Institute of Technology, was a permanent member of the then Institute for Theoretical Physics (ITP) at Santa Barbara from 1980 to 1988. The other recipient, H. David Politzer, a physics professor at the California Institute of Technology, was working independently on a similar calculation.



Arielle Viny

Frozen momentarily is the equation that garnered the Nobel Prize for David Gross. The ice sculpture was created for a Bon Voyage à Stockholm party in Gross's honor, hosted by Fred and Linda Gluck at their Montecito home. Gluck endowed the chair in theoretical physics that Gross holds at UC Santa Barbara.

Gross was awoken shortly after 2:30 a.m. PST by a call from the Royal Swedish Academy of Sciences and participated by phone in the press conference under way in Stockholm.

Gross said, "This Nobel Prize recognizes the efforts not only by us, but also the community of high energy physics. Scientific explorations into fundamental reality are no longer the province of the lone genius such as Galileo or Newton or Einstein, but a collaborative effort by a community of scientists. Hundreds of experimental physicists at the world's accelerator laboratories have designed and run the experiments that gave us early hints about how the strong force operates and then, after we published our theory, proved it. The effort to explore the subtleties of the nuclear force continues today; we still have many implications of the theory to work out."

The Swedish Academy cited the winners "for the discovery of asymptotic freedom in the theory of the strong interaction."

SEE **NOBEL** ON PAGE 4

INSIDE…

New Kohn Hall Proves Whole Can Be More Than Sum Of Old and New Parts

Michael Graves Executes Design to Enhance Collaborations Among Physicists

FOR 10 YEARS THE KEY LANDMARK for arrivals at the principal entrance to the ocean-side campus of the University of California, Santa Barbara (UCSB) has been the flat-topped, orange tower of Kohn Hall, home of the Kavli Institute for Theoretical Physics (KITP), which celebrated its 25-year existence under the aegis of the National Science Foundation (NSF) with an international conference on "The Future of Physics," from Oct. 7 to 9, 2004. A decade after the opening of Kohn Hall (named for KITP founding director and winner of the 1998 Nobel Prize, Walter Kohn), an addition was dedicated at the outset of the conference on Oct. 7.

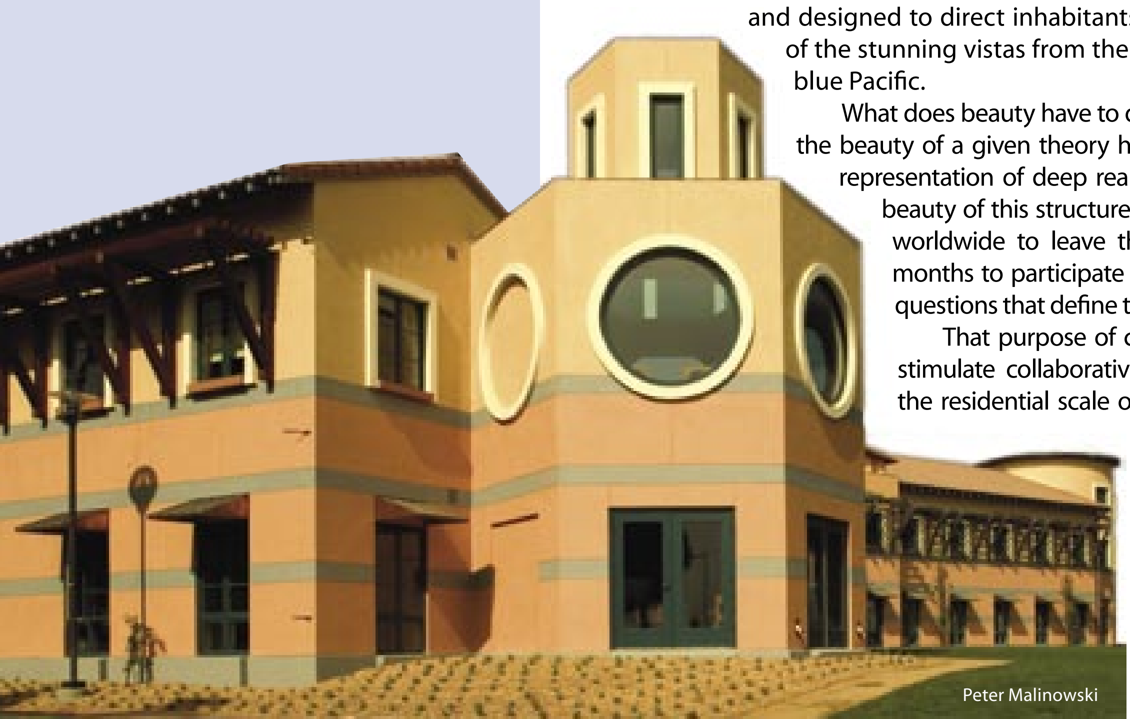
Michael Graves, internationally known for the startling eclecticism of his postmodernist design, is the architect for both the original building and the new wing. The result—more than the sum of old plus new parts—is a wholly integrated and transformed structure superbly designed to enhance the practice of theoretical physics.

First and foremost, Kohn Hall, both inside and out, with its predominant shades of muted orange from peach tones to copper, is beautiful. The structure is both sited and designed to direct inhabitants' points of view to take advantage of the stunning vistas from the location on a bluff overlooking the blue Pacific.

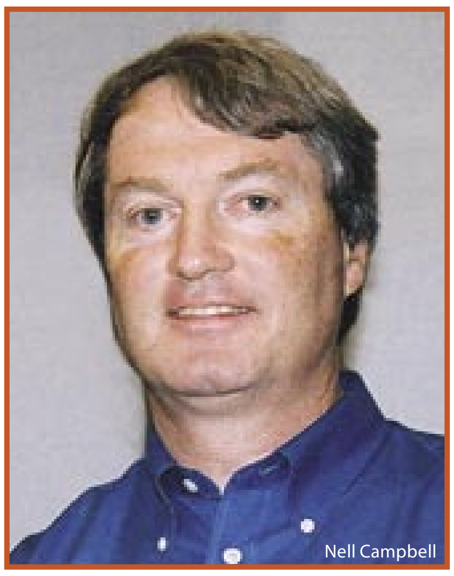
What does beauty have to do with physics? Over and over again, the beauty of a given theory has been an indication of its accurate representation of deep reality. But less fanciful a reason for the beauty of this structure is its purpose in attracting physicists worldwide to leave their home institutions for weeks or months to participate in KITP programs, which address the questions that define the leading edge of scientific research.

That purpose of creating a home away from home to stimulate collaborative scientific exploration accounts for the residential scale of the two-story KITP structure. Clean but intimate architectural shaping of space—complemented by a surround of soft orange pigments and light maple wood—creates a warm, inviting environment that

SEE **NEW WING** ON PAGE 10



Peter Malinowski



Nell Campbell

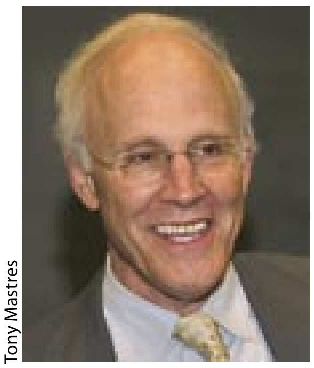
Polchinski Elected To National Academy of Sciences

JOSEPH G. POLCHINSKI, professor of physics at the University of California, Santa Barbara (UCSB) and a permanent member of the Kavli Institute for Theoretical Physics (KITP), has been elected a member of the National Academy of Sciences at the annual spring meeting. He was cited as one of the "leading field and string theorists of his generation, contributing many significant ideas to both quantum field theory and to string theory."

Polchinski's discovery of D-branes and their properties is, according to the Academy citation, "one of the most important insights in 30 years of work on string theory."

SEE **POLCHINSKI** ON PAGE 2

From the Director


Tony Mastres

2004-05 HAS BEEN AN EXCITING YEAR FOR THE KITP. We celebrated our 25th anniversary with a special conference, and we inaugurated our new wing.

The conference on "The Future of Physics" celebrated not only the 25th anniversary of the Institute, but also the unity of physics, which is, after all, the assumption on which the KITP is founded. Physics still has a common language and a common community who do all these different things from string theory to biology; physics is still one field though moving in all these different directions [see page 11 for 25 questions that represent the diversity of direction]. Special thanks go to the Kavli Foundation and to the University of California, Santa Barbara for the support that made this stimulating conference possible.

The new wing is more than an addition. It has given us an opportunity to re-conceive and thereby do more with the pre-existing space in Kohn Hall. I especially like the new enclosed courtyard because it provides such a spectacular, centrally located meeting space, where conference participants and visitors can confer via outdoor blackboards or eat together under blue skies or a sun-shading canopy.

The addition was prompted by the need for more space to accommodate more science, and indeed we are now able to run three programs at the same time. We tried this before the addition, and had to limit the number of participants so that each of the programs lacked the critical mass for the most productive of intellectual exchanges. We still have more applicants than places for our programs (see the exciting line-up for 2006 on the back page), which speaks well, we think, for our programming efforts; but because we can routinely welcome enough participants to each of three simultaneous programs, we are now much better able to serve the diverse research interests of the community.

Rapid response

More space has made possible a new initiative of "rapid response" workshops enabling timely response to new experimental discoveries or new ideas. Such workshops are being organized within the time frame of six months instead of the 18- to 24-month lead-time customary for our programs. The first such rapid response, two-week workshop occurs in February of 2006 and addresses a fascinating phenomenon in condensed matter physics—solids with super-fluid behavior—for which there is experimental evidence, but theoretical confusion.

Another new initiative is this newsletter itself, made possible by the general support for our activities provided through membership in the Friends of KITP. With the newsletter we hope to inform both the community of friends and the community of physicists who are the users of the KITP about what is going on at the Institute and what is coming up in the future; and we hope most of all to provide a sense of the transformative research that is occurring here at the KITP.

Reaching out

Our "Friends" come from the Santa Barbara community. This organization with various levels of participation has grown up over the last few years under guidance from members of the Director's Council, especially Derek Westen. The Director's Council [members noted on page 9] is made up of leaders in fields other than physics, but with an interest in physics, who meet several times a year to provide the KITP leadership with invaluable support and advice.

In addition to our public lecture series, Friends are invited to a host of other activities such as:

- *chalk talks by KITP permanent members,*
- *performances, exclusive for the Friends, of plays with a science theme such as "Proof" and "Humble Boy,"*
- *presentations at the Santa Barbara Lobero Theatre by physicists such as Brian Greene giving a condensed version of the PBS "NOVA" mini-series based on his book* The Elegant Universe, *or by myself explaining why I was awarded the Nobel Prize in physics in 2004.*

Another outreach program beginning this fall sends our postdocs into the local high schools to give talks on their research and to describe what it's like to be a scientist and a physicist. Our postdocs are enthusiastic about this opportunity to act as role models for young students. This wonderful idea was initiated and implemented by two UCSB physicists, KITP permanent member Lars Bildsten and former KITP deputy director Dan Hone, who has agreed to act as our director of outreach and education.

Talking directly to high school students is new, but we have addressed their teachers since 1999 when we instituted our extremely successful annual conferences for secondary school teachers of science. Because these conferences for teachers are held in conjunction with one of our conferences for physicists, about 100 high school teachers from all over the United States are able to hear scientists at the forefront of their fields and to interact with them one-to-one. The focus this coming spring is on nanoscience and quantum computing.

Our quintessential outreach tool is the Internet. Via our website, www.kitp.ucsb.edu, physicists throughout the world can access the presentations given in our workshops, programs, and conferences. The website averages 75,000 hits a day. We invite you to log on.

David Gross

Newsletter from the KITP

Volume 1, No 1, Fall / Winter 2005

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STRINGS

CONTINUED FROM PAGE 3

about the old instability argument against the existence of cosmic strings in terms of Tye's brane-antibrane Inflation, particularly as worked out in detail by six physicists in a 2003 paper, "Towards Inflation in String Theory."

Do cosmic strings exist?

Using that model, Polchinski, Copeland, and Myers calculated the decay rates for cosmic strings and discovered how slow the rates could be—so slow, in fact, that the strings would survive to the present day. By "survive" they mean not just detecting the gravitational footprint left long ago in the cosmic microwave background and "seen" by looking back in time, but actually seeing the gravitational effects of cosmic strings existing if not now, then billions of years after the genesis of the universe.

Polchinski said their calculations showed that both F and D cosmic strings could exist and that the *JHEP* article explains how to distinguish the signature of one from the other. He also pointed out that Gia Dvali (New York University) and Alexander Vilenkin (Tufts University) have independently made the same point about cosmic D strings in March 2004 in another on-line publication, the *Journal of Cosmology and Astroparticle Physics (JCAP)*.

Finally, and most importantly, the *JHEP* authors show, said Polchinski, "how we can see cosmic strings. They are dark, but because they are massive and moving pretty fast, they tend to emit a lot of gravitational waves."

During the "Superstring Cosmology" program at the KITP, Alessandra Buonanno (Institut d'Astrophysique de Paris) provided an overview of the possible gravitational wave signatures from the early universe. "When she gave the talk," said Polchinski, "I didn't pay careful attention because I wasn't thinking about that, but later I went back to her talk in the KITP online series and started clicking through and got to where she talked about gravitational waves from cosmic strings. She had these graphs which were quite amazing."

The large-scale, long-term experiment to detect gravitational waves has three stages, LIGO I and II and the satellite LISA, with each successive stage affording a markedly higher degree of sensitivity. Most of the gravitational signatures of cosmic events are so weak that they will probably only be visible in the later stages of the experiment. But, according to Polchinski, "the gravitational signatures from cosmic strings are remarkable because they are potentially visible even from the early stages of LIGO! That means 'potentially visible' over the next year."

Gravitational waves have yet to be directly detected, which is the mission of the LIGO and LISA experiments. So in addition to the possibility of confirming string theory, the *JHEP* paper offers a better target for initial LIGO detection of gravitational waves than any other from cosmic events.

Will LIGO detect whiplash?

Identifying the gravitational signature of cosmic strings is the work of Vilenkin and Thibault Damour (Institut des Hautes Etudes Scientifiques, France). They figured out that when cosmic strings oscillate, every once in a while, they crack like a whip. "It's surprising," said Polchinski, "but when you write out the equations for an oscillating string, a little piece of the string snaps and moves very fast. Basically, the tip will move at the speed of light. When a string cracks like this, it emits a cone of gravitational waves, which is a remarkably intense and distinctive signal, which LIGO can detect."

Polchinski said that the biggest question mark in the whole argument has to do with the stability of the strings over billions of years. But, he added, "There has been a fair amount of discussion about the signature of string theory in cosmology, and this is by far the most likely. What excites me most is how much we could learn about string theory if LIGO were to detect the signal from cosmic strings."

Another way of 'seeing' a cosmic string is through lensing by its gravitational field. In 2003 a group led by Mikhail Sazhin of the Sternberg Astronomical Institute in Moscow reported a very symmetric double image of a galaxy. Such an image is not consistent with the usual gravitational lensing sources, but would be produced by a linear object (a string) lying between us and the galaxy. More recent observations remain consistent with the string interpretation. Hubble observations are scheduled in the coming year to look for a telltale edge between the two images, as expected if it is due to a string.

POLCHINSKI

CONTINUED FROM PAGE 1

String theory affords the best approach to date to a grand theory that encompasses gravity and the other three forces described by the Standard Model of particle physics (the electromagnetic, weak and strong forces). Strings and branes are the essential structures in string theory.

Polchinsk is the author of a two-volume text on string theory, which is already a classic in the field.

David Gross, KITP director, said, "Joe Polchinski's many important contributions to particle theory are characterized by great elegance, clarity and impact. He has an amazing ability to focus on what is essential. He has had many of the most fruitful ideas about gauge theories, string theories, and the relations between them. He is one of the most important theoretical physicists of his generation."

A native New Yorker, Polchinski received in BA degree from the California Institute of Technology in 1975 and his PhD from Berkeley in 1980. After two two-year stints as a research associate, first at the Stanford Linear Accelerator (SLAC) and then at Harvard, Polchinski joined the faculty at the University of Texas at Austin as an assistant professor in 1984. He advanced to associate professor there in 1987 and to professor in 1990. He accepted his professorial appointment at Santa Barbara in 1992.

Recipient of an Alfred P. Sloan Fellowship from 1985 to 1989, Polchinski was elected a fellow of the American Physical Society in 1997 and a member of the American Academy of Arts and Sciences in 2002.

Newly Devised Test May Soon Confirm Strings As Fundamental Constituent of Matter, Energy

KITP Program Heralds Birth of String Cosmology

ACCORDING TO STRING THEORY, all the different particles that constitute physical reality are made of the same thing—tiny looped strings whose different vibrations give rise to the different fundamental particles that make up everything we know. Whether this theory correctly portrays fundamental reality is one of the biggest questions facing physicists.

As a result of a KITP program, three theoretical physicists have proposed the most viable test to date for determining whether string theory is on the right track. The effect that they describe could be discovered by LIGO (Laser Interferometer Gravitational-Wave Observatory), a facility for detecting gravitational waves that has just become operational and that could provide support for string theory within the year.

When physicists look at fundamental particles—electrons, quarks, and photons—with the best magnifiers available (huge particle accelerators such as those at Fermilab in Illinois or CERN in Switzerland), the particles' structures appear point-like. In order to see directly whether that point-like structure is really a looped string, physicists would have to figure out how to magnify particles 15 orders of magnitude more than the 13 orders of magnitude afforded by today's best magnifying techniques—a feat unlikely to occur ever.

The three physicists propose looking instead for the gravitational signature of strings left over from the creation of the universe. Joseph Polchinski of the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara, Edmund Copeland of Sussex University in England, and Robert Myers of the Perimeter Institute and Waterloo University in Canada describe their proposition in a paper "Cosmic F and D Strings," published in the June 2004 on-line *Journal of High Energy Physics (JHEP)*.

The international collaboration began at a semester-long program on "Superstring Cosmology" held in the fall of 2003. According to Polchinski, the KITP program that produced the test for string theory was the first sustained effort ever to bring cosmologists and string theorists together to advance the newly emerging field of string cosmology. Two-thirds of the roughly 100 participants were string theorists; and the other third, astrophysicists.

The lash of strings stretched with the expanding universe (artist's rendition) may emit gravitational waves that can soon be detected. Cosmic strings may also be detected through their gravitational lensing of light, which would produce double images of distant galaxies.

Can initial strings grow?

In the mid-1980s Edward Witten, now at the Institute for Advanced Study in Princeton, asked whether miniscule strings produced in the early universe would grow with the universe to a size that would make them visible today. Witten answered his own question negatively by raising three objections to the idea. Because of subsequent developments, all three objections have, in turn, now been answered, according to Polchinski and his collaborators, who dispelled the last objection and then proposed a way of detecting those strings.

The first objection depends on a property of strings called "tension," which is the mass of a string per unit length.

"One way to characterize that number," said Polchinski, "involves the gravitational effect of the string. If you look at a string end on while a couple of light rays go past it on either side, the light rays will bend towards the string. So light rays that started out parallel to each other will now meet at some angle. The heavier the string, the more those light rays will bend, and the bigger the angle."

When Witten first worked on the problem, string theorists thought that angle had to be one degree. If it were one degree, the satellite COBE (Cosmic Background Explorer) would have detected that imprint in the microwave background radiation, which pervades the universe and which was released when the early universe cooled enough for matter and energy to decouple some 300,000 years after the hot birth of the universe. The maps of the early universe that COBE produced show no such imprint and, furthermore, put an upper limit on that angle of no more than one hundredth of a degree. The satellite WMAP (Wilkinson Microwave Anisotropy Probe) has now reduced it to one thousandth of a degree.

In the mid-1990s string theory underwent profound developments. One of the consequences of those developments was the realization that the tension of the string, and therefore its gravitational effect, could be much less than had been thought when Witten made his initial calculation of the angle of separation between light rays affected gravitationally by a string.

Henry Tye of Cornell and his collaborators showed that in some string theory models the angle of separation would be between a thousandth of a degree and a billionth of a degree—far too small for COBE to have detected.

Tye and collaborators also demolished the second objection to cosmic strings having to do with "Inflation," which can be thought of as an intensification of the explosion and rapid expansion of the early universe following rapidly on the heels of the universe's genesis in the "Big Bang." Witten, back in the '80s, had argued that the strings produced by the Big Bang would be both heavy enough and produced so early that Inflation would have diluted them beyond visibility.

String theory pre-supposes nine or 10 spatial dimensions—that is, six or seven more spatial dimensions than have heretofore been assumed to exist—in addition to the one dimension of time. Some of the "extra" dimensions are thought to be curled up or compactified and therefore exceedingly small; and some, to be larger, perhaps infinite.

Is our reality contained?

In his attempts to understand Inflation in terms of string theory, Tye and collaborators envisioned our reality as contained in a three-dimensional "brane" sitting in higher dimensional space.

Branes, a key conceptual breakthrough discovered by Polchinski in 1995, are essential structures in string theory in addition to strings. Instead of being only one-dimensional like strings, branes can have any dimensionality, including one. One-dimensional branes are called "D1 branes or D strings." So there are essentially two types of strings— the heterotic string or "F" (for "fundamental") string, which physicists knew about prior to 1995, and the "D string," or one-dimensional brane.

Tye and collaborators explained Inflation in terms of a brane and an anti-brane separating from each other and then attracting back together and annihilating. So a brane and an anti-brane existing in the extra dimensions would thereby provide the energy responsible for Inflation. Everything existing afterwards—our universe—is the product of their annihilation. And, according to the Tye models, at the end of Inflation, when brane and anti-brane annihilate, not only does their annihilation produce heat and light, but also long closed strings that could grow with the expansion of the universe.

At the outset of the KITP program in fall 2003, the only remaining objection to cosmic strings was what Polchinski calls summarily "the stability argument," first made by Witten back in the '80s. If, on the one hand, the post-Inflation strings were charged, then they would pull back together and collapse before they could grow to any great size. If the strings weren't charged, then they would tend to break into pieces. Either way—collapsing or breaking—the strings couldn't survive until today.

Copeland, one of the *JHEP* paper's authors, went to a talk at the KITP by Stanford string theorist Eva Silverstein, who was interested in networking F and D strings—hooking them together to form something analogous to a wire mesh or screen. After the talk, Copeland wondered aloud to Polchinski whether Silverstein (who was thinking string theory mathematics, not cosmology) was inadvertently describing a mechanism for the dark matter—that as yet unidentified, non-radiating component of the universe which must exist in much greater abundance than all the ordinary "baryonic" matter of which we are aware.

Polchinski and Copeland worked out why Silverstein's scenario could not pertain to dark matter, but the engagement with that question got Polchinski to thinking

SEE **STRINGS** ON PAGE 2

NOBEL PRIZE

CONTINUED FROM PAGE 1

Gross and Wilczek, and independently, Politzer, made the key discovery of how the "strong" force works to bind the constituent elements, called "quarks," of protons and neutrons (the particles that make up the nucleus of atoms). The other three forces of nature—electromagnetism, the weak force (responsible for radioactive decay), and gravity all diminish in strength with distance. They discovered that the strong force grows weaker at short distances.

This discovery, called "asymptotic freedom," means that quarks when observed at very high energies behave as essentially freely moving particles. This finding has had enormous implications for the design and conduct of experiments at the world's large accelerator facilities because it has enabled physicists to calculate what the results of the experiments should be. Discrepancies from those calculated results in turn provide invaluable clues to new physics—*i.e.*, physics beyond the Standard Model.

The flip side of "asymptotic freedom" has been described as "infra-red slavery." Since the force that binds quarks inside protons and neutrons grows stronger with distance, protons and neutrons can't be dismantled into constituent quarks. This part of the Gross-Wilczek discovery is called "confinement."

The discovery of asymptotic freedom led Gross and Wilczek to propose a comprehensive theory of the strong or nuclear force called Quantum Chromodynamics (QCD), whose three color charges are analogous to the positive and negative charges in the theory of the electromagnetic force or Quantum Electrodynamics (QED). Because QCD bears remarkable mathematical similarity to QED and also to the theory of the weak force, the key discovery of asymptotic freedom has brought "physics one step closer to fulfilling a grand dream, to formulate a unified theory comprising gravity as well—a theory of everything," according to the announcement by the Swedish Academy.

After obtaining his PhD from UC Berkeley in 1966, Gross was invited to join the select group of junior fellows at Harvard. Having accepted an appointment as assistant professor at Princeton in 1969, he was promoted to professor in 1972 and later named to two endowed chairs: first as Eugene Higgins Professor of Physics and then as Thomas Jones Professor of Mathematical Physics.

In addition to a trip to Stockholm in December 2004 to receive his Nobel Prize, Gross attended ceremonies the previous month in Paris, where he received France's highest scientific honor, the Grande Médaille D'Or (the Grand Gold Medal).

Winner of a prestigious MacArthur Foundation fellowship in 1987, Gross was elected an American Physical Society fellow in 1974, an American Academy of Arts and Sciences member in 1985, a National Academy of Sciences member in 1986, and an American Association for the Advancement of Science fellow in 1987. He is the recipient of the J. J. Sakurai Prize of the American Physical Society in 1986, the Dirac Medal in 1988, the Oscar Klein Medal in 2000, the Harvey Prize of the Technion in 2000, and the High Energy and Particle Physics Prize of the European Physical Society in 2003. He has received two honorary degrees.

Tony Mastres

Above, at the impromptu press conference held at KITP, laureate David Gross is flanked by the two "Freds" (Gluck [l] and Kavli), both generous Institute benefactors.

Courtesy Nobel Foundation

At right, Gross gives the banquet address in Stockholm on behalf of the physics laureates.

Courtesy Nobel Foundation

Above, the stage setting for awarding of the 2004 Nobel Prizes. David Gross as the eldest physicist occupies first position (l) in the front row left of laureates; the Swedish Royals occupy front row right.

Courtesy Whitehouse Communications

The White House traditionally holds a reception honoring American laureates each year. President George Bush received laureate David Gross and his wife Jackie in the Oval Office.

Marking Einstein's *Annus Mirabilis*

Above, UCSB science Nobel laureates and physicists David Gross (l), Walter Kohn, Herbert Kroemer, and Alan Heeger at the Goleta studio of Recording for the Blind and Dyslexic.

Photos by Nell Campbell

WALTER KOHN AND DAVID GROSS, respectively the founding and the current directors of the KITP and winners of Nobel Prizes, joined two other UCSB Nobel-Prize-winning physicists, Herbert Kroemer and Alan Heeger, to commemorate this "Year of Physics" by reading Einstein's only popular science book, *The Evolution of Physics: The Growth of Ideas From Early Concepts to Relativity and Quanta,* for Recording for the Blind and Dyslexic.

The Year of Physics celebrates the 100th anniversary of Einstein's *annus mirabilis* of 1905—the year he published three landmark papers (each in a different area of physics) that changed the course of physics forever and radically altered human conceptions of reality.

Einstein himself received the Nobel Prize in Physics in 1921 for insights into the "photoelectric" effect reported in his first paper of that most remarkable year.

Photoelectric effect

He deduced that light itself must be considered as consisting of quanta of energy or particles (photons) with energy determined by the frequency of light. Having proposed for the first time the existence of a new particle of light, he used that hypothesis to explain and to make quantitative predictions about the so-called photoelectric effect.

It had been observed that when high intensity light is shown on metal, electrons are emitted. That phenomenon was not understood nor could it be understood within the classical theory of electromagnetism. Einstein used the hypothesis of light as quanta of energy to predict the energies of the emitted electrons. His predictions were later confirmed by experiment.

Einstein himself believed this first to be the most revolutionary of his three big papers of 1905 because it pushed forward the then embryonic development of quantum theory, the basis for today's high technology.

Brownian motion

The second paper addressed the theory of Brownian motion originally observed by the botanist Robert Brown 70 years earlier in the apparently random motion of pollens suspended in a liquid.

Some scientists thought that the pollen particles were being jiggled by the liquid's atoms and molecules.

Realizing that they were right, Einstein, a master of statistical mechanics, gave for the first time a mathematical treatment of the random motion of the pollen grains. Assuming random hits of the pollen grains by atoms in the liquid, he calculated on average what such motion would look like (*i.e.*, a drunken walk).

He thereby provided a direct quantitative way to test for the existence of atoms that could not be seen, but could be sensed in the erratic motion of pollen grains. His quantitative theory could be tested. Experimental verification 10 to 15 years later of his predictions confirmed the atomic hypothesis. Heretofore, atoms had been useful "devices" for calculating the properties of matter, but some people had not really believed atoms existed because they could not as yet be seen.

Special relativity

The third paper—the one for which Einstein is most famous—presents the theory of special relativity. Einstein realized that the theory of electromagnetism as set forth in Maxwell's equations required a modification of Newton's theory of mechanics, which took time to be absolute.

Before 1905 people had postulated the existence of "ether," which was thought to fill the universe and in which electromagnetic waves propagated. Einstein, who said "no" to the existence of ether, considered instead assumptions about how space and time are defined and measured.

Assuming the constancy of the speed of light (which is a consequence of Maxwell's equations), Einstein showed by simple and beautiful arguments that in different moving frames space and time can appear different—*i.e.*, particular lengths can be contracted and time can be dilated in moving frames as observed by an observer in another frame.

$E=mc^2$

In a follow-up paper, Einstein went on to build on the theory of special relativity to show that mass and energy are equivalent and to derive the famous equation $E=mc^2$. He argued that anything that has energy has inertial mass, so mass and energy are the same. This follow-up paper says, in effect, that if the notions of space and time change, then so do the notions of energy and momentum.

The fifth and final paper of 1905 used the theory of Brownian motion (advanced in the second paper) to measure the size of molecules and atoms and thereby provided predictions for the experimental testing alluded to above.

Having remarked that it is not unusual for a theoretical physicist to publish five papers in one year, Gross said, "It is, however, clearly pretty unusual that three such spectacular contributions would come from an unknown patent clerk all in one year. And that's why physicists are using this occasion to celebrate physics and Einstein."

Einstein co-authored his one book-length attempt at popular science writing with his friend and fellow physicist and refugee Leopold Infeld. The book was published in 1938 by Simon and Schuster. Einstein was then at the Institute for Advanced Study in Princeton, where Infeld visited during the collaboration.

The book consists of four chapters—one read by each of the UCSB Nobel Prize winners for recording: "The Rise of the Mechanical View," "The Decline of the Mechanical View," "Field, Relativity," and "Quanta."

Einstein's 'idealized reader'

As Einstein and Infeld intimate in the "Preface," the text is noteworthy for its lack of equations: "Whilst writing the book we had long discussions as to the characteristics of our idealized reader and worried a good deal about him. We had him making up for a complete lack of any concrete knowledge of physics and mathematics by quite a great number of virtues. We found him interested in physical and philosophical ideas and we were forced to admire the patience with which he struggled through the less interesting and more difficult passages. He knew that a scientific book, even though popular, must not be read in the same way as a novel."

A disproportionate number of the books that Recording for the Blind and Dyslexic makes audible concern scientific or technical subjects that do not attract the wider audience and therefore profitable market of novels and commercial non-fiction works.

Several works by Einstein were considered, but his popular book was selected on the recommendation of Gross, who received it at age 13 as a present from Infeld's cousin, and who was "turned onto physics" from reading it.

Though all readers were physicists, Kohn, a physics professor, won the 1998 chemistry prize; Kroemer, an engineering professor, won the 2000 physics prize; Heeger, a physics professor, won the 2000 chemistry prize; and Gross, a physics professor, won the 2004 physics prize.

Celebrations internationally

Gross, whose Nobel Prize was awarded for explaining the strong force and whose later research focuses on string theory and the attempt to unify all four forces, has given a talk on "Einstein and the Search for Unification" at 2005 commemorative conferences hosted by the Einstein Forum in Berlin, by the Eidgenössische Technische Hochscule (ETH) in Zurich, by the Israeli Academy of Sciences in Jerusalem, by the Skirball Cultural Center in Los Angeles, by the National Academy of Sciences in Washington, D.C., and by Warsaw University.

The talk features a retrospective of Einstein's failed search for unification, which is, however, vindicated by the contemporary quest for unification of all the four forces of nature, including gravity.

How Do Physics and Biology Go Together?

TWENTY-FIVE TO SEVENTY-FIVE years ago, a scientist working at the intersection of physics and biology—a biophysicist—would, more likely than not, have been making tools, such as electron microscopes, for biologists to use. With its former connotation of physicist as tool-maker, the term "biophysics" may not be as appropriate to describe today's current research efforts at the intersection of physics and biology as other terms that have been variously suggested: "theoretical biology," "fundamental biology," "living matter physics," or "biological physics."

The last term is favored by the first KITP permanent member to focus on a physics approach to biology—Boris Shraiman—to describe his own research interests and community. According to Shraiman, who declines a request to define the term, what "biological physics" means is being defined by what biological physicists are now doing.

Not only Shraiman's appointment, but also KITP programming efforts focusing on biological questions, signal the Institute's full engagement with this rapidly evolving physics sub-discipline. As the new century unfolds, biological physics is likely to become more and more important if there is indeed real meaning to the concept of a theory of biology.

Boosting KITP programming efforts in biological physics is a generous gift by Gus Gurley, a Santa-Barbara-based entrepreneur and member of the KITP Director's Council. The Gurley gift directly supports the Distinguished Fellows in Biophysics program.

The articles on this and the following three pages attempt to understand the new mix of physics and biology mostly through the musings and examples of practitioners. Shraiman was trained and worked as a condensed matter theorist before being seduced by biology. KITP postdoctoral fellow Ila Prasad Fiete made the transition from condensed matter to neuroscience much earlier in her career than did Shraiman—mid-way through graduate school. Arnold Levine is a senior molecular biologist with a current penchant for hiring physicists and mathematicians into his theory research group. William Bialek, an organizer of the recent Brain workshop, has been interested in biology from a physics perspective throughout his scientific career.

With Shraiman's Appointment Biological Physics Enters Permanent Ranks at KITP

Kevin Barron

BORIS SHRAIMAN IS THE NEWEST of the five permanent members of the Kavli Institute for Theoretical Physics and the first to specialize in biological physics.

His conversion from statistical and condensed matter physics, with research interests ranging from pattern formation and turbulence to superconductivity, took place gradually in the early 1990s at Bell Labs in New Jersey, where he worked for 17 years after completing his 1983 PhD at Harvard and a postdoctoral fellowship at the University of Chicago. At Bell Labs, David Kleinfeld, a friend and a computational neuroscientist (now at UC San Diego), persuaded Shraiman to attend a journal club called "Brains R Us."

"I really knew nothing about biology," said Shraiman, who left St. Petersburg at the time it was called "Leningrad." "All my education was in mathematics and physics. I was largely educated in the Russian system. There you go one or the other way. So I was ignorant of biology, and I really got excited that there were all these things in the world that I knew nothing about."

Brains R Us provided Shraiman with his introduction to biology, "largely along the lines of computational neuroscience." His appetite whetted, Shraiman went off to Woods Hole for, in effect, a crash course on neuroscience.

There he discovered what really interested him was not computational neuroscience, but molecular biology. "I got interested in the molecular mechanism of vision. How does a photon trigger a chain of events in the retina, which culminates in the firing of a neuron? How does a photon turn into an electrical signal first in the retina and then in the brain?" Engagement with those questions, said Shraiman, "set me on the slippery slope of molecular biology, though for some time I continued working in turbulence." Eventually, biology took over.

"How is physics relevant to biology?" Shraiman muses. "There are certain things that are relevant directly. We are trained to model—to look at nature and to extract and distill some simplified quantitative approximate description. We are not trying to capture all the details, only the essential aspects so additional details can be added that won't perturb the description.

"But I find my engagement with biology exercises a different part of the brain, so to speak, than my engagement with condensed matter physics questions. When I worked on turbulence or anti-ferromagnetic insulators, I always dealt with hard, but well-posed problems that had been formulated by someone else."

In the case of turbulence, the equations describing fluid flow were written down by Euler and by Navier and Stokes and have been known for more than a century. "These people had already formulated the correct problem," said Shraiman, "which happened to be mathematically complex; *i.e.*, it is difficult to figure out how these equations describe observed behavior.

"The situation in biology is very, very different. When it comes to problems, we now are often pioneers. As the first ones stepping into these forests, we have to find our own way. Of course we are not the first ones in the sense that we work on phenomena that have been studied in great depth experimentally, but there are no quantitative models, no quantitative descriptions equivalent to the Navier-Stokes equations. We have to find our own way.

"In many ways even worse," said Shraiman, "very often it is not entirely clear what question to ask, what property to understand. With materials we know it is important to understand conductivity, magnetic susceptibility, viscosity, momentum, or heat transport. We know that there are well-defined measurable quantities that describe the properties of the material. Just exactly what is the most insightful way of quantitatively describing biological systems is a big question."

What are the parts?

"On one level we want to know," he said, "what are the parts. What genes and what proteins are important for a given behavior?" This "parts" approach has been, according to Shraiman, the key emphasis in molecular biology, and very often experiments answer parts questions in a binary "yes" or "no" fashion—Is a given gene important for a given phenomenon?

"But once we know what parts are important—the genes and the proteins—then, we want to ask more quantitative questions," said Shraiman. "How do the parts interact? How does a bunch of genes and proteins behave on a systems level?"

How do parts interact?

"In phototransduction, for example, it is relatively simple to know the input and the output; the input is the photon, and the output is electrical current. You can ask what happens to the output as a function of light intensity. In other words, you can start describing phototransduction almost as a physical system."

The next level of understanding encompasses the adaptive properties of the system. What happens, for example, when "eyes" adjust to seeing in a dark room? At first we see nothing. Then the phototransduction system adapts to a low light level. How does adaptation occur? Or, as Shraiman metaphorically asks the question, "What internal knobs do the photoreceptor cells tune in order to adjust properly their signal transduction response?"

How do systems adapt?

"Then," said Shraiman, "there is the third layer of questions. These systems are very complex; they have lots of bits and pieces; how is it that they work with so many parts and parameters; is there some internal regulatory mechanism which adjusts them until they function properly?

"The dogmatic response focuses on genetic hardwiring. But perhaps genes hardwire not the exact parameters of a system, but a program that adaptively adjusts these parameters till the system functions well enough.

How do networks evolve?

Finally, to understand how biological networks of systems operate requires thinking in terms of evolution—long-term. Where do the networks come from, and where are they going?

"Life, as we know it," said Shraiman, "is a snapshot of some particular corner of the living universe at a particular time. Understanding why phototransduction in the rod cells of vertebrates involves a particular set of interacting proteins in a particular fashion requires a comparison of signaling systems between different cells in different contexts to identify common aspects."

It would seem from Shraiman's interrogatory mode of discourse that the real quest of biological physics is for interesting, insightful questions.

Shraiman identifies two types of questions: (1) How does a particular system work in order to cure or treat a disease and to develop drugs, and (2) What are the forces shaping networks of these systems. Much, if not most, biological research now focuses on the first type of question. The second type tries to get at general aspects of biological systems design that can only be understood in the context of evolution. Examples of this type of question are: What forces shape biological networks? Are certain designs more likely to have evolved than others?

The first type of question, Shraiman points out, is homo-centric; the second type is not.

Whither the biological physics quest for questions? "We are still very much in the dark," said Shraiman. "The game here is to try to narrow the questions, focus on particular systems, which are rich enough for making general inferences yet specific enough for experiments. As physicists our interests are biased towards the general and fundamental. The challenge for biological physics is to reach for those general principles while standing firmly on the ground of biological experiments past, present, or future."

'How Is Birdsong Like a Tennis Serve?' *Asks Neuroscientist and Postdoctoral Fellow*

ONLY MALE SONGBIRDS SING. They sing to impress both females and other males—to attract the former and to scare off the latter. But male birds are not born knowing how to sing. To learn the baby has to grow up hearing an adult male sing. That tutor is necessary but not sufficient for birdsong learning.

How the young bird learns song appears to bear a striking resemblance not only to how a human baby learns speech, but also to how general goal-directed behaviors involving fine muscle control are learned. Or at least that is the working hypothesis for much of Ila Prasad Fiete's research.

Fiete, a three-year postdoctoral fellow at the Kavli Institute for Theoretical Physics, is a theoretical neuroscientist.

During her third year of graduate school in physics at Harvard, she attended a biophysics course given by Sebastian Seung. A theoretical neuroscientist at the Massachusetts Institute of Technology, Seung had been a student of Harvard condensed matter physicist David Nelson.

"I learned about protein kinetics in cells," said Fiete, "and I learned about how neurons fire and communicate with each other." She also learned that she, like Seung before her, wanted to switch fields from hard condensed matter to neuroscience. Having become Seung's student, Fiete still collaborates with him and with two other physicists-turned-neuroscientists, Michael Fee and Richard Hahnloser, on songbird learning.

Song by trial and error

If the baby bird grows up in isolation, Fiete explains, "he does not, in fact, learn how to sing anything recognizable as a successful song for mating." On the other hand, if the juvenile bird is exposed to the tutor's song even briefly, and the tutor is removed before the baby bird has begun to practice its song, he will still eventually learn to produce an excellent match to the song of the adult (even if the two are unrelated). So, Fiete points out, the baby must rapidly acquire a template of the tutor song in his head.

Learning to generate an accurate vocal copy of this template is slow. At first the baby produces sounds that are the bird equivalent of babbling. At this stage auditory feedback is critical. If the bird is deafened after acquiring the template but before it has mastered song production, it will never be able to reproduce the tutor song. A normal bird, after much trial and error, eventually learns how to reproduce the song.

"So," said Fiete, "even though the bird has the template in his mind, he can't just play off the template in his vocal chords and produce the right song." The bird has to be able to hear himself and in effect compare the sounds he makes with the tutor template and then gradually alter the vocal apparatus in order more closely to approximate the tutor song.

"He has to practice to get it right," said Fiete. "It's what we all do!"

"Let's say I want to learn to serve a tennis ball," she said. "My goal is to get the ball to the other side of the court. So I know roughly what I want done, but I don't know how to do it. Specifically, my neurons have no idea how to do it. Even if I hire a tennis coach who tells me how to swing the racket, she can guide my hand and swing my racket for me, but she can't tell me which neurons I should fire with greater or lesser intensity to make the muscles contract to make the ball do what I want it to do. In such an instance of goal-directed motor control, there are tens to hundreds of thousands of neurons involved in controlling the trajectory of the arm.

Peter Allen

"My own research focuses on how individually 'dumb' neurons might each locally figure out how to change in order to learn to perform collectively a goal-directed task. Birdsong is just one example; the tennis serve is another. We know on a behavioral level we do it by trial and error, but don't know what drives that behavior on the level of single neurons."

Monte Carlo

"In my work with Sebastian, we hypothesize (like a few others before us) that to perform goal-directed learning, the brain itself performs Monte Carlo-like simulations on itself to decide how to change to improve performance! Our contribution is to provide a specific, biologically plausible algorithm through which realistic networks of neurons may do so."

Monte Carlo simulation is a catchall name for algorithms that use random exploration to estimate answers to problems that cannot be solved analytically.

Said Fiete, "We hypothesize that a dedicated group of neurons in the brain acts as a source of randomness to drive variations in the activities of the motor control neurons, thereby producing behavioral variations that are necessary for trial-and-error learning."

If, at a certain time during a motor action, a neuron receives a noise input that makes it momentarily more active than usual at that time, and if that event is followed by reinforcement, the neuron should strengthen all its incoming synapses (connections between neurons) that were active at the time. Conversely, if the noise temporarily suppresses activity and this is followed by reinforcement, then the active synapse should be weakened.

"We can mathematically prove," said Fiete, "that this learning rule will optimize performance on the task, and what's more, will do so in very general models of neural networks. Neurons in the brain certainly have enough machinery to implement this rule, and we await experiments that can verify our strong predictions on how activity and reinforcement in the brain may drive synaptic change."

Reductionist mind set

"One of the qualities that a physicist brings to the study of biology, for better or worse, is a reductionist mind set," said Fiete. "You asked me what exactly do I use in neuroscience that I learned in physics. The answer is the valuable mathematical tools of our training and a physics outlook. I look at the world and think, "Wow, is it complex!' But as a physicist I believe that there are some essential features underlying the complexity and that I can make 'toy' models that capture a few of the very important ingredients and that reproduce a lot of complexity.

"Biologists by training are very descriptive. They tend to emphasize the richness and complexity of the phenomena they study and don't always believe in reductionist views of the underlying dynamics," said Fiete.

"So in some biologist circles, 'reductionism' used to be a bad word. But these attitudes have been rapidly changing due to the sudden influx of huge amounts of genomic and neural data that call out for quantitative mining and due to increasing numbers of fruitful collaborations between physicists and biologists.

"In fact, however," she added, "a suspicion of reductionism may be partly justified because biology could be a new frontier, where the complexity is such that we cannot go to the same level of reductionism as we can in physics.

"But even then, if you don't believe in reductionism at some level, it's hard to understand anything," said Fiete. "If you replace a complex phenomenon by an equally complex model, you haven't gotten very far."

On being a postdoc

Fiete has just completed her first year as a postdoctoral fellow. "There are a lot of advantages to being a postdoc at the KITP," she said—"a lot of free time and a lot of independence to develop an individualized research program in a way I probably would not be able to do in most places as a postdoc. Most postdocs elsewhere are tied to one particular faculty member or a faculty member's grant to do a specific project. Here postdocs are just hired for their interests and their potential broadly defined.

"These three years allow me to explore what I want to do," said Fiete. "It's the greatest opportunity because I have complete freedom to work on the problems I find exciting."

Eminent Biologist Embraces Physics

ARNOLD LEVINE, a molecular biologist and an authority on the molecular basis of cancer, gave one of the KITP 2005 Public Lectures on "Genetic Predispositions for Cancer in Humans." He also served as co-director with Boris Shraiman of a February 2005 mini-program on "Growth, Death and Aging." Why is a cancer expert giving a public lecture and leading a research program at an institute for theoretical physics?

Levine has two professorial appointments at two different institutions with distinctly different characters: the School of Natural Sciences at the Institute for Advanced Studies (IAS) in Princeton, N.J., where he directs the Center for Systems Biology, and the Cancer Institute of New Jersey at the Robert Wood Johnson School of Medicine in nearby New Brunswick. His theory group is located at the former; and his research labs, at the latter.

Best known as co-discoverer of p53 (a key tumor suppressor protein), Levine is pioneering with his IAS group a modus operandi for theoretical biology. The IAS group consists of physicists, mathematicians, computer scientists, and a physical chemist. Two of the physicists were trained as string theorists.

"For the first time," Levine said, "biology is working a lot like physics—with theorists making hypotheses and predictions and biologists going back to the laboratory to test those predictions. That approach is entirely new to biology. Biology hasn't had great theorists other than Darwin. The field begins with him. It's interesting that a field not known for theory should have begun with a theorist."

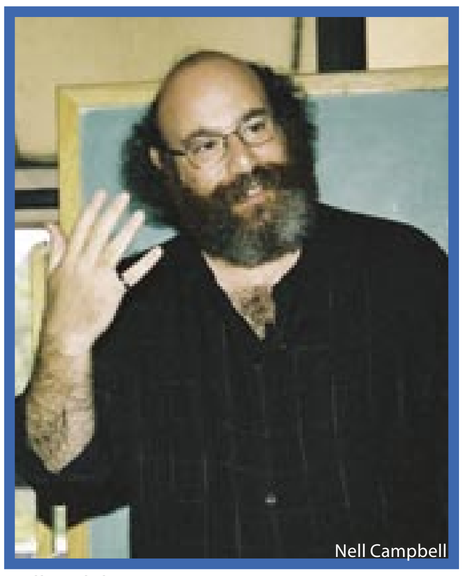
As described in his public lecture, Levine's research now focuses on genetic polymorphisms. Unlike mutations, polymorphisms represent small genetic differences among people. With the completion of the sequencing of the human genome in 2000, "We now know," said Levine, "that any two people are 99.9 percent identical. But the other 0.1 percent accounts for three million differences. We want to know which of those differences might predispose a person to cancer. So far, we have been able to identify three such structural changes. One small change we found [published in Nov. 2004 *Cell*] can give rise to cancer at an early age. That change exists in 11 percent of the Caucasian population, and some subset of those will be developing cancer at a young age."

Identifying such genetic susceptibilities to disease will enable vulnerable people to undergo routine diagnostic tests to screen for and to detect cancer "early, when treatments are most effective, and cure is a real possibility," according to Levine.

"Our task," said Levine, "is to design methods to probe three billion bits of information. That task requires algorithms for manipulating these huge databases. The more quantitative sciences have developed the statistical and analytic tools we are now applying to biology. But their contributions go well beyond informatics. I have seen in this workshop here at the KITP that physicists come up with novel questions that do not occur to biologists.

"I see the emerging role for physics in biology as providing a new research paradigm with dynamic interaction between theory and experiment," said Levine.

'Understanding the Brain': *The Ultimate Interdisciplinary Rendezvous?*



Nell Campbell

Bill Bialek

HERE'S A QUESTION that appeals to physicists: Is the way in which we represent and process information in our brains deeply related to the structure of the world in which we live?

Here's another question: What does the first question imply about the interests and approach of physicists exploring the phenomenon of life, in contrast to biologists?

University of Pennsylvania physicist Vijay Balasubramanian, one of seven organizers of the three-month, 2004 KITP workshop "Understanding the Brain," is collaborating with Penn neuroscientist Peter Sterling to investigate how the structure of natural scenes influences the design of retinal cells. The formulation of that research question shows what physicists can bring to collaboration with biomedical scientists—*i.e.*, point of view. In a way, the physicist looks at the eye from the outside in, whereas biologists have generally looked at the eye from the inside out.

Point of view is strikingly evinced by the title of a KITP public lecture by another of the "Brain" workshop organizers, Princeton physicist William Bialek, who headlined his talk "From Photons to Perception: A Physicist Looks at the Brain."

Why the emphasis on photons and eyes when the subject is the brain? In a discussion after his public lecture, Bialek said, "Pick a neuron in the human brain, in any primate brain for that matter. That neuron is most likely involved in vision."

"Armed with eyes, ears, noses, and the sensors in our skin," said Bialek, "our brains take in enormous amounts of data, and for the most part we make sense out of all these data without even being aware that we are solving very difficult problems—problems that still defeat the most powerful computers. There are obvious advantages to accomplishing these tasks more efficiently, but the laws of physics tell us that there are limits to how precisely an organism or machine could function. Remarkably, animals operate very close to these fundamental physical limits, so that our sensory systems are 'almost perfect.'"

In his talk Bialek gave examples of this perfection and showed that in order for organisms to operate near the physical limits they build "special mechanisms whose structure we can predict from physical principles."

In effect, said Bialek, "It means aspects of our biology are driven by the world around us."

The "Brain" workshop is not the first venture of the KITP into the realm of biology and the brain. Beginning with a program on "Neural Networks" in 1986 and one on "Physics of Biomembranes" in 1994, the interval between biologically oriented programs has been growing dramatically shorter. "Electrostatic Effects in Complex Fluids and Biophysics" occurred in 1998, and "Statistical Physics of Biological Information" in 2001. Two of the six programs in 2003 focused on biological issues: "Bio-Molecular Networks" and "Pattern Formation in Physics and Biology."

Bialek was himself a postdoctoral fellow at the KITP from 1984 to 1986. Unlike many a biophysicist such as Balasubramanian the string theorist, Bialek was always and only a biophysicist. He got his PhD through an interdepartmental program spanning the departments of physics at Berkeley and a biology department, which typical of biology departments over the last quarter century of the field's rapid evolution, "has changed its name several times," said Bialek.

Asked why he was attracted to biophysics from the outset of his career, Bialek said, "I liked the mathematical style in physics departments—the way physicists thought about problems. On the other hand, the objects of study in biology departments interested me more. I think some disciplines define themselves by the object of study; and others, by the style of inquiry. I would like to think physics is a subject defined by style of inquiry. People who study different objects can enjoy each other in physics departments; you don't find that in biology departments. There is some uniformity of inquiry in molecular biology, but fundamentally biology is defined by object of study. So it means something to be a physicist interested in the phenomena of life, which is different from being a biologist who happens to use ideas and tools from physics."

Or, to answer in more "phenomenological" if not psychological terms, Bialek said, "I would go to biology seminars and be fascinated about what they were talking about, but not satisfied with the approach and would have ideas about what I wanted to do. In physics seminars I would appreciate what they were doing, but I didn't have any original ideas about what to do next."

The KITP 2004 "Brain" workshop represents the merger of two competing proposals for an originally planned one-month workshop.

Neural coding

One proposal focused on neural coding. According to Bialek, "All the information we take in from the outside world and all the information we send out to our muscles and presumably all the internal representations of our thoughts and dreams are sequences of pulses called action potentials or 'spikes.' There's a longstanding question of trying to understand the structure of that code, and there are very practical reasons for understanding it. For instance, for people paralyzed it would be delightful to read out from their motor cortex the plans they envision sending to their muscles and send them to a robot arm. At the same time, there are theoretical reasons to be interested in why the nervous system chose the code it did: Why and in what way are the codes adaptive? Do the codes serve to optimize abstract quantities like the amount of information and the efficiency with which the information is represented?

"Thinking about those optimization problems leads to thinking about the relationship between the code the nervous system has constructed and the structure of the physical world," said Bialek. And, in fact, the other proposal for a "Brain" workshop focused on "optimization" in its many different forms.

And optimization

"If you compare a cross-section of a human brain with a cross-section of a mouse brain," said Bialek, " a striking difference is in the amount of the white matter for long distance connections. The amount is gigantic in humans whereas in the mouse the amount is much smaller, even in proportion to the size of the brain.

"Take a cubic millimeter of human brain," said Bialek, "and trace the wires that pass through it and lay them end to end; they extend four kilometers. Many people are interested in whether the basic structure of the brain is shaped by the need simply to solve the physical problem of packing in all the connections, much the way the design of computer chips is dominated by the problem of connecting everything."

Questions about energy efficiency also arise. "The cost of running the brain is substantial," said Bialek, "and we run close to the margin—*i.e.*, we can't go long without feeding the brain without passing out. What is all that energy going for? What is the cost of representing and processing information?"

Finally is the problem of noise, whose effect scales up when size scales down. "The tremendous miniaturization in the brain means that we do things with shockingly few molecules," said Bialek. "In extreme cases we are capable of responding to individual molecular events as when we see single photons in the retina."

Packing and connection, energy efficiency, noise in conjunction with miniaturization represent a complex of issues surrounding the idea of optimization, but also pertain to ideas of coding. "There was enough of an overlap between issues of coding and of optimization," said Bialek, "that we decided to bring the two together for a three-month workshop.

"The discussions have been productive," he said. "There is real interaction among the different disciplines [represented by the 76 participants]. What is special here is that the physics community has taken the lead, and at one of the premier places for physicists to get together. That means people are wandering the halls of a theoretical physics institute who haven't set foot in a physics department since they were freshmen."

The brain, so it seems, may be the quintessential meeting place for the disciplines.

In addition to physicists, Bialek and Balasubramanian, workshop organizers included University of Pittsburgh neuroscientist Andrew Schwartz, Princeton molecular biologist Michael Berry, Cold Spring Harbor neuroscientist Dmitri Chklovskii, Cambridge zoologist Simon Laughlin, and Arizona State University electrical engineer Jennie Si. Both Berry and Chklovskii also trained as physicists.

Point of View: *Physicists and Biologists Watch Fruitfly Movie*

AN ENGLISH LITERATURE professor remarked to his graduate students in a class on 20th century American novelists, "Point of view is everything in fiction." He was talking about the central role of the narrator in novels. In life as in fiction, what is told depends on who does the telling, as historians have long recognized. Scientists, however, like to think that what they see and tell is more or less independent of the identity of the see-er, despite the admonitions of Heisenberg, who pointed out that the see-er himself or herself is implicated deeply at the quantum level in what is seen (*i.e.*, our ability to measure a particle's position or momentum, but not both).

Thomas Gregor made a movie of fruitfly embryo development. He began his scientific career in Europe as a physicist, came to Princeton in the United States as a theoretical chemist, and made the fruitfly movie in conjunction with a research collaboration among three Princeton scientists: William Bialek, a theorist and professor of physics; David Tank, an experimentalist who is professor of both physics and molecular biology; and Eric Wieschaus, a developmental biologist who is professor of molecular biology and co-recipient of the 1995 Nobel Prize for Physiology or Medicine.

The movie features the half-millimeter-long fruitfly embryo. Supporting roles are played by the earlier sub-micron stages of embryo development: Cell nuclei come to the surface of the embryo; they are somewhat ordered but not completely ordered as in a perfect lattice. The nuclei divide and duplicate, and the lattice disorders. The cells rearrange and order again. That process repeats. For some stages the duplication of the nuclei seems almost perfectly synchronous. Then the action becomes asynchronous in such a way that a wave appears to pass over the embryo.

"Physicists watching the movie immediately want to know how ordered things are in space," said Bialek. "And how accurately synchronized in time—and ask what is the signal that generates the synchronicity. On the other hand, biologists watching the movie are much more engaged by the slightly later phenomenon of gastrulation—whereby the embryo assumes a form consisting of a hollow, two-layered cellular cup. Biologists focus on the large-scale movements of the embryo turning into itself. Physicists are attracted to the early stage of simple but rich dynamics."

Admittedly the findings about disciplinary points of view are merely anecdotal, but Bialek said, "It is fascinating to me to watch the reactions. There is something about our culture as physicists that means that when confronted with this movie, physicists who know absolutely nothing about the relevant biology will ask similar questions, which are different from the questions the biologists ask."

KITP Scientific Advisers

An independent science advisory board exercises oversight of Kavli Institute for Theoretical Physics proceedings and deliberates biannually on the selection of topics for the workshops, programs, and conferences hosted by the Institute. Members are leading theoretical physicists at U.S. institutions; for instance, nine Nobel Prize winners have served as advisers.

William Bialek, whose roles as "Brain" workshop coordinator and biological physics researcher are featured in the adjacent articles, is serving as chair of the 2004-05 advisory board. Other members are the following:

ADAM BURROWS	NEAL LANE	ALLAN H. MACDONALD	JORGE PULLIN
LAURA H. GREENE	ANDREA J. LIU	CRISTINA MARCHETTI	SUBIR SACHDEV
LAWRENCE J. HALL	JOSEPH D. LYKKEN	CHRISTOPHER F. MCKEE	NATHAN SEIBERG
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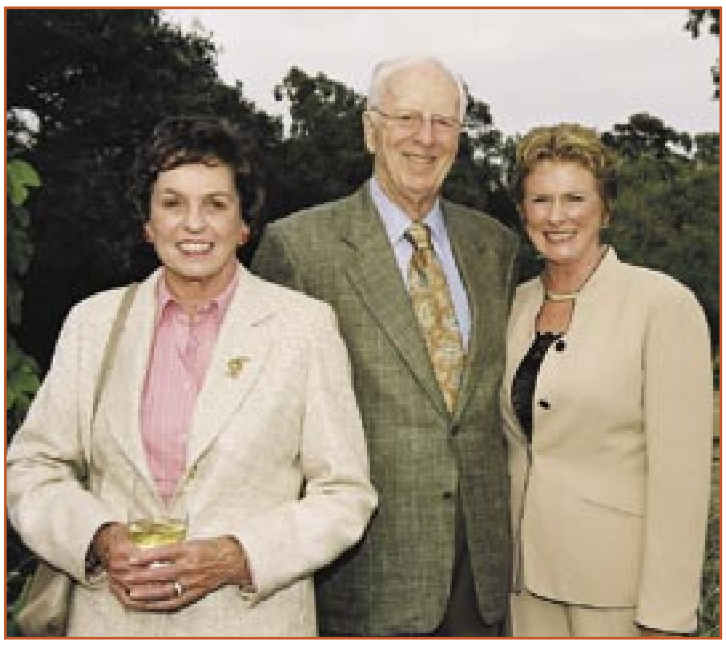
Hunter Hosts Biological Physics Talk by Bill Bialek for Friends of KITP

Bruce Mc Fadden and Host Virginia Castagnola-Hunter



Ruth and Gene Ellis with Linda Gluck (r)

Stuart Mabon with Tunny and Joe Alibrandi (r)

Photos by Nell Campbell

Hugh and Susie Vos and Bob Morefield (r)

Optimization: *the Renewed Quest for a Physics of Biology*

ONE OF THE MAIN MISSIONS of the KITP is to catalyze and to promote collaborations, the hallmark of 21-century science. Programs are designed to stimulate new collaborations, but also to reinvigorate old ones between collaborators once in close proximity, but now separated geographically. Such is the case with two participants in the 2004 “Brain” workshop: physicists William Bialek of Princeton and Rob de Ruyter van Steveninck of Indiana University. The former is a theorist; the latter, an experimentalist.

Fresh from his PhD program in biophysics at Berkeley, Bialek headed to Holland in 1983 for a one-year postdoctoral position at Groningen. There he met and worked with de Ruyter, a graduate student at the time. After another postdoctoral position at the KITP and a stint as an assistant professor of physics and biophysics at Berkeley, Bialek worked for 10 years at the research laboratory in Princeton of the large Japanese electronics company NEC. Shortly after Bialek’s arrival, Steveninck joined the NEC team. And their initial relationship, begun in Holland, blossomed into a 10-year collaboration, remarkable for the close interaction between theory and experiment.

“It was,” said Bialek, “a fantastic arrangement. My office and Rob’s office were next door to each other, and his lab was across from my office. The postdocs and students who worked with each of us were all located in the same area. That arrangement meant daily interactions between theory and experiment. Theory influenced not just the analysis and interpretation of experiment, but the nitty-gritty of experimental design. Conversely, there was the now rare opportunity for raw data to impact theoretical thinking.”

What especially appeals to Bialek about working on a biological problem is “the relatively quick turn-around in experiment. Rob could do interesting experiments that could be accomplished in a year, but which addressed real conceptual challenges. Not too many things that physicists are thinking about today have that property because the mainstream fields of physics have matured to the extent that there is now a much greater lead-time in the dynamical interactions of theory and experiment.”

Such close interplay between theory and experiment is particularly good as a training ground for students and postdocs, said Bialek. “Even by the time I was a student in the early ‘80s, many theoretical questions had been purified away from phenomenological beginnings. It is enormously exciting to look with fresh eyes at phenomena in biology that physicists haven’t been climbing all over and ask when confronted by data, “What is the question? What moves me? What am I, as a physicist, curious about?”

How do flys steer?

Bialek and de Ruyter collaborated on exploring the way in which the fly takes its visual input and computes how fast it’s moving relative to the world and how it encodes the answer in the spike trains of its neurons. In a long series of theory-experiment projects, they were able to illustrate how this system reaches optimal performance both in the problem of estimating and in the problem of coding, as well as the role that adaptation understood as real-time (rather than evolutionary-time) optimization plays both for computing and representing the answer. The simple form of the question they were asking is how do flies steer.

The pair used, in Bialek’s words, “the fly’s visual system and in particular the little corner of the fly’s brain that extracts information about motion as a testing ground for ideas about optimization. The fly is almost as reliable as it can be in estimating motion given that its view of the world is blurred by diffraction through the lenses of the compound eye and through the random arrival of photons at its retina. And the fly seems to be optimized in its representation of the answer—its strategy for encoding the results of its computations in the spikes of its neurons. The beauty of these experiments,” said Bialek, “is that you can see changes in computation and coding strategy on the laboratory time-scale of seconds (in contrast to the evolutionary time-scale of years or millennia). Those results opened up the possibility of testing the ideas of optimization much more deeply.”

Bialek explains, “If optimization happens only over evolutionary time, then it happened once. If we do not understand all the constraints on optimization, the resultant theory may not be adequate. On the other hand, if we can observe the dynamics of optimization, we have a much bigger playground for testing ideas about optimization in terms of the statistical structure of the world in which we live.”

Many people, said Bialek, have pursued the idea that the nervous system and brain are optimal. “I would say that we deserve some share of credit for revitalizing that idea, but we are not the only ones."

Find simplest first

“If optimization were true only in one system, it wouldn’t be a very interesting idea,” he said. “In order for the ideas associated with optimization to gain any credibility at all, it’s vital that lots of people work on them. It’s nice to work on flies, but it’s eminently clear to me that we as humans cannot be intrinsically interested in the fly brain per se, but as an accessible example of some more general principle. The physicist’s style is to find the simplest example first and to understand what’s going on.”

“From the perspective of our current understanding of neuroscience, the idea that the same principles are applicable to very different nervous systems really would be a discovery—seeing, that is, the principles in the second and third instances sufficiently apart on an evolutionary tree to enable us to say, ‘Yes, this principle happens in other systems.’ There may be a time when it will be obvious that these principles are supposed to be universal, but we’re not there yet. At the moment all ideas have multiple sources because the discoveries of their applicability in different systems are really discoveries.”

KITP Director’s Council

The Director’s Council is made up of leaders in fields other than physics, but with an interest in physics, who meet several times a year to provide the KITP leadership with invaluable support and advice. Co-chaired by Joe Alibrandi and Fred Gluck, the Council also includes Virginia Castagnola-Hunter, K.C. Cole, Michael Ditmore, Eli Luria, Gus Gurley, Stuart Mabon, John Mackall, and Derek Westen.

NEW WING

CONTINUED FROM PAGE 1

simultaneously relaxes and alerts the visitor's mind.

What distinguishes the design process is the clever collaboration of Michael Graves & Associates and physicists, especially KITP director David Gross and permanent member Lars Bildsten, as well as KITP manager Deborah Storm. In other words, the professionals who have worked and organized programming in the original structure were able to bring their experiences to bear on the design of the new one.

Catalyzing research

The whole point of this users' facility for physicists is to promote the interaction among ideas—the hallmark of 21st century science—that catalyzes transformative research. Theoretical physics now depends for advancements on the cross-fertilization of minds, and the new Kohn Hall has been designed to accomplish that purpose in three principal ways:

(1) the liberal addition of interaction spaces in conjunction with that principal tool of theoretical physicists—the blackboard;
(2) altered circulation routes, which encourage the meeting and convergence of scientists at the interaction sites;
(3) conversion of a facility initially conceived in terms of a banker's nine-to-five workday to one that accommodates the more erratic schedule of the scientific researcher freed from the routine duties of his or her home institution, who may want to work anytime in the 24-hour day, seven days a week.

The footprint of the original two-story structure resembles a squat capital "E," with the top and bottom horizontal lines representing corridors with offices on both sides and the vertical a thicker block which

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Hexagonal tower provides visual counterpoint to original iconic round tower.

houses the two-story auditorium at one end and the tower at the other.

In place of the middle bar of the "E" was a three-sided courtyard. Three double doors provided entry to the courtyard from nine to five Monday through Friday. Because those doors enabled access from the exterior, they had to be locked at other times. So a physicist working at, say, 6:00 p.m. had to leave via the principal entrance and walk halfway round the building to sit in the courtyard after hours. Most afternoons, sunlight baking the courtyard made it an inhospitable space for either collaborative conversation or the lone thinker.

The two-story addition closes off the courtyard to exterior access, thereby adding to Kohn Hall the signature element of its Mediterranean (as adapted to Southern California) architectural style the

Peter Malinowski

Auditorium designed for broadcast quality recording.

enclosed court. Steel beams with orange stucco bases, that match in material and color the building's façade, support a multi-sectional awning, electronically operated to close selected panels to screen users from direct sunlight, while leaving another section open to maintain a sense of airy, outdoors environment.

The courtyard's terracotta concrete floor does not extend all the way to the top and bottom bars of the old "E." Plants will grow in those spaces. Trellises to train trumpet vines line the walls. And the thick mullions sectioning the windows have been removed from the three old double-door accesses to the courtyard—making the former inside commons room, where afternoon coffee and tea are served, lighter and brighter.

Across the new enclosed courtyard and accessible by double doors is another signature element of the new Kohn Hall—a one-story auditorium shaped like the semicircle of a Greek amphitheatre (above). The curved side closes the courtyard. On four large panels of that convex side of the courtyard are four large blackboards made of the only material for such purpose that can resist the weathering of the outdoor environment—Vermont slate. Next to those real slate blackboards are niches for chalk and erasers. The idea, of course, is that the physicists can continue to work via their preferred medium—the blackboard—in the courtyard screened from the sun.

Worldwide lecture access

The auditorium is designed for broadcast quality recording. KITP director Gross instituted the practice of recording scientific presentations for web-cast to physicists throughout the world, thereby making the KITP a users' facility not only for physicists in attendance at the programs, conferences, and workshops, but also for those located anywhere in the world with web access. (The website [www.kitp.ucsb.edu] averages 75,000 hits a day.)

The old Kohn Hall was designed and built before the widespread use of the Internet, so that video and audio recording of presentations in the old auditorium is cumbersome. The new auditorium has been designed for the task. Fifteen microphones in the low ceiling enable the recording of every question as well as the speaker's response. Provisions have been made for video equipment to capture not only the speaker, but also the audience. The full dynamics of intellectual interaction can now be transmitted to physicists worldwide.

Accordingly, the auditorium is much wider than long, with three rows of fixed seats in a semicircle facing a wide expanse of blackboard. Everybody can see everybody, and physicists seated in the front row can dash to the blackboard to illustrate or work out their points. Three separate, motorized drop-down screens enable projection of visual presentations, whether view-graphs or PowerPoint or Keynote. The screens deploy in such a way that the blackboards can be available for either further elaboration by the speaker or rejoinder by audience members. And the lighting adjusts to screen or blackboard without somebody having to jump up and down to manipulate light switches. A corridor flanks the perimeter of the semicircle so that latecomers can find seats without disrupting the presentation.

With all this utility the most striking feature of the auditorium is its beauty, created by the deft use of shades of orange in conjunction with two non-utilitarian architectural elements—four decorative columns and a ceiling of stepped semicircular soffits that mirror the pattern of the tiered seats. On the second floor above the auditorium is a large semicircular room for graduate students. It overlooks the courtyard. Across the hall is a bank of offices. Next to the graduate student space is a shower room—suggested by many a visitor who bikes in from his or her temporary abode in the vicinity of the campus.

With regard to the "E" footprint, the part of the new addition with the auditorium is positioned to close the "E," but the rest extends out towards the ocean beyond the top horizontal of the "E," not in the straight line of an arrow but the curving shape of a bow. That outward extension towards the ocean is at less than a 90-degree angle from the old structure. Bildsten, an astrophysicist with a keen interest in architecture, describes the elements that enable that bowing as "knuckles."

In the first "knuckle" near the auditorium is located the new principal entrance to the KITP with a reception area and a nearby mailroom where parcels arriving by vehicle can readily be deposited. Between the curvilinear knuckles is a lovely divided maple staircase located at the principal intersection of the newly conceived building. Hallways used to end in grey metal fire doors. Now, the hallway forming the top of the "E" has the old tower with its first floor Founder's Room and second floor two-story library at one end and the divided stairway with its centered French window at the other, and the corridor between runs through a series of rectilinearly shaped spaces.

That area of divided stairs is the principal interaction space of the building. In addition to the mailroom, a pantry with visitors' coffee cups is there. Blackboards line the walls.

Patron gives digital canvas

The space facilitates and stimulates interaction not only with these utilitarian accoutrements but with artistic ones as well. Two large plasma screens—made possible by a generous gift from Eli Luria (Director's Council member) and his wife Leatrice—provide a 21st-century digital canvas for KITP artist-in-residence Jean-Pierre Hébert to open windows onto the cosmos. Other artwork by Hébert, characterized by a conceptual purity associated with its mathematical and scientific representations, has been on exhibition at the KITP this past year, notably in niches in the knuckles and adjacent new-wing hallways.

Interaction spaces are important because physics proceeds not only through collaboration but also through individual concentration. As Bildsten describes the problem, offices tend to be shared by visiting physicists. So someone dropping by to talk to one of the office's inhabitants disturbs the concentration of the other. Collaborators need therefore to leave the office to talk, and they have to have somewhere to go where their conversation won't bother office inhabitants; hence the liberal use of spaces for interaction, both inside and out, in the newly conceived KITP.

In addition to the old commons room, there is now the courtyard and the large entryway buffered from the new office wings by the knuckles containing non-office facilities. An office mid-way down the first floor corridor of the old wing (topping the "E") has been turned into an entrance to a lawn with a meandering path connecting outside the old and new wings. Another interaction space is being created in that entryway.

The path leads to a distinctive, charming architectural feature of the new building—a Venetian staircase—reminiscent of the walkway bridges arcing over canals in Venice. Compliance with building code necessitated a second-floor exit from the projecting wing, so Bildsten suggested the use of a Venetian staircase. The staircase parallels the outside exterior wall, thereby enabling a balcony above and a first-floor exit in a large semicircular expanse of glass below.

In order to keep the new wing that extends out towards the ocean from obstructing the ocean views of offices in the original building, offices are placed only off one side of the wing that extends towards the ocean. That wing ends in the most distinctive feature of the new structure, the hexagonal tower, which forms a visually distinct counterpart to the original iconic KITP round tower.

"It took some time," said Bildsten, "for us here at the KITP to come to grips with the design concept for that hexagonal tower. It is all Michael Graves, and it is inspired."

The director's office is located in the first floor of the tower. The second floor affords an extraordinary interactive space. Four walls have large round windows 6.5


Peter Malinowski

feet in diameter. One wall contains the ever-prevalent blackboard, and another wall the entryway. Above projects a smaller lantern-like hexagonal structure painted blue in contrast to the orange hues that prevail throughout the building. In each of the six sides is a slim clerestory window providing, in effect, indirect lighting for this exceptional space.

Director Gross said that he told architect Graves that he wanted the top tower to be completely glass-encircled to afford the greatest possible view such that the out-looker would feel that he were outside. Graves told Gross that if he wanted to feel that he was outside, he should go outside. Buildings should frame the views, Graves told Gross. "I can see now that Michael was right," said Gross. "Now it's like looking out portholes at the sea—each view framed differently."

Bildsten recommends looking at the hexagonal tower from the outside at night. He describes the sight as "magical. That's when its resemblance to a lighthouse becomes most evident," he said.

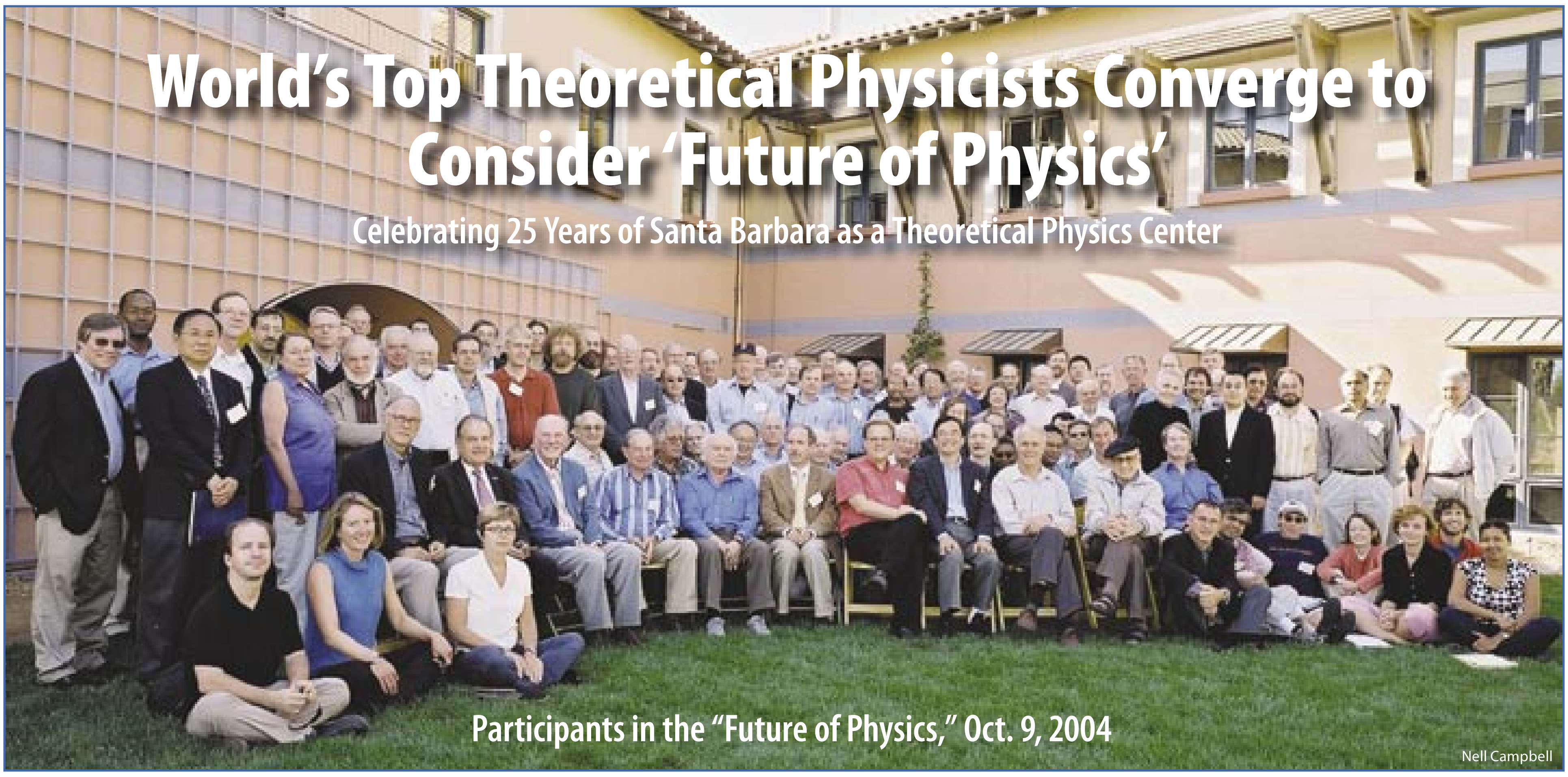
Surveying the new structure, UC Santa Barbara Chancellor Henry Yang said, "The KITP is internationally renowned and enviously emulated in so many countries as a place where the world's top scientists gather and where great science happens. This signature piece of expanded architecture—the new Kohn Hall designed by Michael Graves—beautifully complements the science and the people there. We are enormously grateful to Fred Kavli, whose gift made the project possible, and to Professor Gross, whose vision and energy made this building a reality."

The original KITP comprised 16,296 assignable square footage (ASF), of which 1,850 ASF have been renovated in conjunction with construction of the addition. The new structure adds 4,889 ASF, including 17 new office spaces.

Enclosed courtyard with canopy supports and outdoor blackboards.

World's Top Theoretical Physicists Converge to Consider 'Future of Physics'

Celebrating 25 Years of Santa Barbara as a Theoretical Physics Center



Participants in the "Future of Physics," Oct. 9, 2004

Nell Campbell

"THE FUTURE OF PHYSICS" was the subject of a singular conference hosted by the Kavli Institute for Theoretical Physics last October. Over 150 of the world's top theoretical physicists, including many Nobel laureates and leaders of the various physics fields, participated.

The conference was timed to coincide with the dedication of the new addition to Kohn Hall, which houses the KITP.

Most of the conference participants spoke, but they did not give their standard talks describing the status of their own research. In formats designed to enhance discussion, they identified, debated, and summarized the key developments in physics over the past 25 years; they assessed the current status of the physics fields; and they envisioned the course of physics over the next 25 years.

Commemorating the 25th anniversary of the Kavli Institute for Theoretical Physics under the aegis of the National Science Foundation (NSF), the conference aspired to be an event that epitomizes its mission. "We aim through our programming," said KITP director David Gross, "to provide the intellectual equivalent of a lightning rod for physics and all its unfolding 21st-century ramifications—in terms of string theory, quantum computing, nanoscience, biological physics, and neuroscience—as well as for developments in the more traditional fields of 20th-century physics, such as particle and condensed matter physics and astrophysics."

The final presentation of the conference addressed the questions that participants submitted beforehand as the key foci for developments in physics over the next quarter century. Gross gave that talk. Here are the questions:

1. *How did the universe begin?*
2. *What is the nature of the dark matter that permeates the universe?*
3. *What is the nature of the dark energy that causes the accelerated expansion of the universe?*
4. *How are stars and planets formed?*
5. *Does Einstein's theory of general relativity work in situations of very strong gravity?*
6. *Is quantum mechanics the ultimate description of nature?*
7. *What is the origin of the strange spectrum of the masses of elementary particles?*
8. *Is supersymmetry a true feature of nature? And where will it show up?*
9. *Can we solve Quantum Chromodynamics (QCD)?*
10. *What is string theory?*
11. *What is the true nature of space and time?*
12. *Is physics an environmental science?*
13. *Should kinematics and dynamics be distinct?*
14. *Are there new states of condensed solid matter?*
15. *Can we develop a truly quantitative understanding of complex, chaotic dynamical systems?*
16. *Will quantum computers be quiet or deaf?*
17. *Is it possible to construct a room temperature superconductor?*
18. *Is there a general theory of biology? Do we need to develop new mathematics for biology?*
19. *Can we make genomics into a predictive science?*
20. *What is the physical basis for consciousness? Can one measure the onset of consciousness in an infant?*
21. *When will computers be able to be creative theoretical physicists, and how should we train them?*
22. *Can physics remain unified and not split into various disciplines?*
23. *Is the behavior of big things entirely determined, at least in principle, by that of the little things?*
24. *What is the appropriate role of theoretical physics—the handmaiden of experiment or the achievement of a higher level of understanding?*
25. *How do we deal with the serious dangers facing big science as new instruments become more and more expensive?*

Kavli Institute for Theoretical Physics
UC Santa Barbara
Santa Barbara, CA 93106-4030

ONGOING & UPCOMING

For Physicists…

Programs

Mathematical Structures in String Theory
Robbert Dijkgraaf, Michael Douglas, David Ellwood, Maxim Kontsevich, Greg Moore, Nikita Nekrasov, Hirosi Ooguri
Aug. 1 – Dec. 16, 2005

From the Atomic to the Tectonic: Friction, Fracture and Earthquake Physics*
James Dieterich, Michael Falk, Mark Robbins
Aug. 8 – Dec. 16, 2005

Scanning New Horizons: GR Beyond 4 Dimensions
Luis Lehner, Donald Marolf, Robert Myers
Jan. 9 – March 10, 2006

The SuperNova Gamma-Ray Burst Connection
Chris Fryer, Shri Kulkarni, Ken Nomoto, Philip Pinto
Jan. 9 – March 31, 2006

Topological Phases and Quantum Computation*
Sander Bais, Chetan Nayak, John Preskill
Feb. 21 – May 19, 2006

Spintronics*
David Awschalom, Gerrit Bauer, Michael Flatte, Daniel Loss, Allan MacDonald, Dan Ralph
March 13 – June 23, 2006

Molecular and Cellular Machines
David Bensimon, Robijn Bruinsma, Philip Nelson, Adrian Parsegian
April 3 – June 30, 2006

Physics of Galactic Nuclei*
Martin Haehnelt, Scott Hughes, David Merritt, Roeland van der Marel
May 22 – July 28, 2006

Attosecond Science*
Andre Bandrauk, Nathaniel Fisch, Anthony Starace
July 31 – Sept. 15, 2006

Stochastic Geometry and Field Theory*
Ilya Gruzberg, Pierre LeDoussal, Andreas Ludwig, Paul Wiegmann
Aug. 7 – Dec. 15, 2006

String Phenomenology*
Michael Dine, Shamit Kachru, Gordon Kane, Joseph Lykken, Fernando Quevedo, Eva Silverstein
Aug. 7 – Dec. 15, 2006

Applications of Gravitational Lensing: Unique Insights into Galaxy Formation and Evolution*
Leon Koopmans, Chung-Pei Ma, Ben Moore, Peter Schneider, Tommaso Treu
Sept. 18 – Nov. 4, 2006

**Indicates a program-related conference was held (or is planned to be held) during the program.*

Mini-Programs and Teacher's Conferences

The Supersolid State of Matter
(D. Ceperley and M. Chan)
Feb. 6 – 17, 2006

Nanoscience and Quantum Computing**
(D. Awschalom et al.)
March 25, 2006

Cardiac Dynamics
Eberhard Bodenschatz, Emilia Entcheva, Robert Gilmour, Alain Karma
July 10 – Aug. 4, 2006

*** Indicates a Conference for Secondary School Science Teachers*

For details of programs go to our website: http://www.kitp.ucsb.edu/activities/

For Friends of KITP…

SEPTEMBER ***Command performance of "Humble Boy"***

OCTOBER ***Public Lecture at KITP by Sir Michael Atiyah on "The Nature of Space"***

NOVEMBER ***Behind-the-scenes private tour of the Jet Propulsion Laboratory with Dan McCleese, chief scientist for NASA's Mars Exploration Program, exclusively for members of the Galileo and Einstein Circles, followed by dinner at a nearby restaurant***

Chalk Talk at the KITP by string mathematician David Morrison on "Stalking the Shape of the Universe: Geometrical Structures and Physical Reality"

2006 ***Chalk Talk at the KITP by permanent member Lars Bildsten on "The Physics of California."***
Private events, public lectures, Chalk Talks, art and science activities

For information about events and membership, contact Charmien Carrier at (805) 893-3178 or charmien@kitp.ucsb.edu. For other Friends queries, contact Sarah Vaughan, director of development and community relations at (805) 893-7313.