Summer 1999

Caltech PMA Communiqué

A Publication for Caltech's Physics, Mathematics & Astronomy Division No. 2

INSIDE:

FLIGHT OF THE BOOMERANG

BY ANDREW LANGE

A unique telescope has succeeded in detecting and resolving the faint structures that have long been predicted to exist in the Cosmic Microwave Background (CMB). This long-awaited breakthrough resulted from deploying state-of-the-art detectors developed at JPL on a balloon-borne telescope that circumnavigated the Antarctic continent during a 10-day flight. Analysis of the images obtained during the flight should soon yield the first precise direct measurement of the geometry of the universe.

BOOMERang, on the Ross Ice Shelf, just prior to launch. Mt. Erebus is in the background.

The CMB is the relic of the primeval fireball that filled the very early universe. What was originally a blue-white light of blinding intensity has cooled and dimmed as the universe has expanded. Today, the radiation is detectable only at the high end of the microwave band—roughly 30 to 300 GHz—as a faint and almost perfectly isotropic glow that fills the sky.

The CMB provides us a clear view of the universe at a time long before the first stars and galaxies formed. Just 300,000 years after the big bang (at only about 25 ppm of its current age), the universe had cooled sufficiently to allow the first atoms to form. At this epoch the opaque plasma of electrons and nucleons that filled the universe from its infancy was suddenly transformed to a perfectly transparent gas of hydrogen and helium. The CMB has traveled through the universe unperturbed ever since.

What do we expect images of the CMB to look like? Early observations showed that the CMB is remarkably isotropic, consistent with a very homogenous early universe. In fact, until the beginning of this decade, no departure from isotropy was detected aside from a one part per thousand "dipole anisotropy." This smooth variation in temperature across the sky is believed to be due to our own motion (at about 300 km/s) relative to the rest frame of the CMB.

The structure intrinsic to the CMB is of intense interest to cosmologists, as the values of most of the parameters that govern the

see BOOMERANG: page 4 ▸

NOTE FROM THE CHAIR

BY THOMAS TOMBRELLO

This is the second newsletter in this regular series that was created to keep us in contact with our alumni and friends. The articles that are included do not provide a complete summary of the division's activities; rather, they represent a few of the highlights of the past year. This spring we have received acceptances from three new professors: Alexander Givental, Professor of Mathematics; Marc Kamionkowski, Professor of Theoretical Physics and Astrophysics; and Richard Ellis, Professor of Astronomy. Givental's work in geometry is expected to strengthen the mathematical foundations of our expanded program in string theory. Kamionkowski adds theoretical depth to the existing observational work on anisotropies in cosmic microwave background. Ellis will be Deputy Director of the Palomar Observatory and supervise our astronomical instrumentation projects. This allows the Director of Palomar, Professor Wallace Sargent, to chair a committee that is studying the feasibility of building an extremely large optical/infrared telescope with a mirror diameter greater than 25 meters. This project is called CELT, California's Extremely Large Telescope.

Please feel welcome to send any comments you may have on the content or format of the newsletter, including suggestions for future articles, to PMA Division Chair, Caltech 103–33, Pasadena CA 91125.◆

Awards & Honors

By Michelle Vine

Tom Apostol
- 1997 Trevor Evans Award by the Mathematical Association of America

Barry Barish
- 1999 Distinguished Engineering & Science Research Project Award from the Engineering Council received by the LIGO Team

Roger Blandford
- 1999 Eddington Medal for Theoretical Astronomy by the Royal Astronomical Society
- 1998 Dannie Heineman Prize for Astrophysics

Peter Goldreich
- 1999 Antoinette de Vaucouleurs Memorial Lectureship & Medal from the University of Texas
- 1999 ASCIT Teaching Award

David L. Goodstein
- 1999 Oersted Medal from the American Association of Physics Teachers

Emlyn Hughes
- 1999 Richard P. Feynman Prize for Excellence in Teaching, CIT
- 1997 ASCIT Teaching Award
- 1997 Alfred P. Sloan Fellowship

H. Jeff Kimble
- Science Magazine's Top Ten Advances in 1999 for Experiment on Quantum Teleportation
- 1998 Int'l Award on Quantum Communications from the 4th Int'l Conference on Quantum Communication Measurement & Computing

Steven E. Koonin
- 1998 E. O. Lawrence Award in Physics, from the Department of Energy

Ken Libbrecht
- 1997 Fellow of the American Association for the Advancement of Science

Hideo Mabuchi
- 1999 Alfred P. Sloan Fellowship

Gerry Neugebauer
- 1998 Herschel Medal from the Royal Astronomical Society

Rahul Pandharipande
- 1999 Alfred P. Sloan Fellowship

E. Sterl Phinney
- 1999 ASCIT Teaching Award

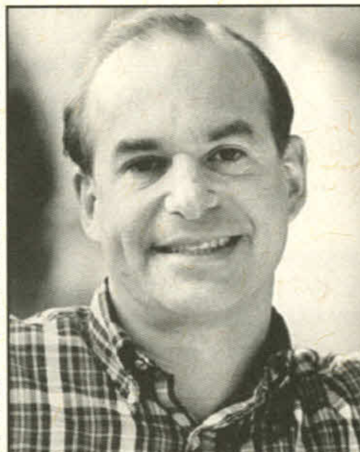
Anneila Sargent
- President of the American Astronomical Society - Starting June 2000 for 2 years.
- 1998 NASA Public Service Medal

String Theory Initiatives

By John Schwarz

Twenty-five years ago Joel Scherk and I proposed that a unified theory of all forces, including gravity, could be based on fundamental, one-dimensional structures called strings. Wide acceptance of this theory took ten years and the discoveries of "the first superstring revolution." Fifteen more years of development and the dramatic discoveries of "the second superstring revolution," have made the subject a main focus of theoretical high energy physics research worldwide. Leading US physics departments have recognized the importance of this research and are making professorial appointments in this area.

In its commitment to advance this research, Caltech has recently received an agreement from one of the field's intellectual leaders, Edward Witten, to spend the academic year 1999–2000 on a sabbatical visit to our string theory group. In addition to Witten, who is currently a professor at the Institute for Advanced Study in Princeton, Caltech has succeeded in arranging that Hirosi Ooguri, a professor at UC Berkeley, spend his sabbatical year in the string theory group. Five graduate students and new postdoctoral fellows will be working with Witten and Ooguri. Finally, four other leading string theorists have agreed to spend a month or more on campus.



John H. Schwarz
Harold Brown Professor of Theoretical Physics

In the Caltech spirit of creating the best research environment with the best scientists, we have pooled our resources with the University of Southern California (USC). This exciting opportunity will establish a closer relationship between the two institutions, and allow collaboration between USC's strong string theory group, including four tenured professors, and Caltech's team. Chiara Nappi, another string theorist with an impressive record (and Dr. Witten's wife) will also be joining the USC team as a visiting professor.

The plan is to establish a "Caltech/USC Center for Theoretical Physics (CTP)" primarily based at USC in the beginning. The focus of the center for the first year will be limited to string theory. If that proves to be as successful as expected, it would then be natural to expand into other areas of theoretical physics.

The Caltech/USC CTP will be sponsoring a conference entitled "String Theory at the Millennium" on the Caltech campus, January 12–15, 2000. We estimate that 200 to 300 string theorists will attend. The format of the first three days of the Millennium Conference will be four speakers, allotted a full hour each followed by ample time for discussion. The final day of the conference will address a broader physics audience. Eight of the most distinguished senior theoretical physicists will be asked to describe their vision for the future of string theory, in particular, as well as for the future of all of particle physics and cosmology.

Following the conference, the Caltech/USC CTP will implement a visitor's program that will run for a five-month period. Most visitors (perhaps about five or six at a time) will have their primary offices at USC, but there will still be a lot of added activity at Caltech.

It is clear that during the next year Southern California will be the leading center for string theory research. Our hope is that we will be able to build on this new beginning in future years.◆

Protogalaxies and Protoclusters in the Early Universe:
Looking for the Formation of First Structures

by George Djorgovski & Charles Steidel

Understanding of the formation and evolution of galaxies and large-scale structure in the universe remains among the central topics of modern cosmology. Great progress has been made in this field over the past few years, in no small part due to studies using the Palomar and Keck telescopes.

We now have a fairly good understanding of galaxy evolution over the past half or two-thirds of the age of the universe, i.e., the past 6 to 9 billion years. However, our understanding of the earlier phases of galaxy and structure formation is still very incomplete. These are the frontiers of observational cosmology, and Caltech astronomers are actively working to map out the youth of galaxies. Astronomers use "redshift"—a measure of how much the universe has expanded since the light was emitted—as a measure of distance, and thus the "lookback time" to distant objects. Redshifts greater than 4 correspond roughly to the lookback times of about 90% of the present age of the universe, or to the times

see PROTOGALAXIES: insert ▸

Tuning Superconductivity with Spin-Polarized Electrical Current

By Nai-Chang Yeh, R.P. Vasquez, J.Y.T. Wei, and C.C. Fu

The occurrence of superconductivity is known to be associated with the formation of *Cooper pairs*, which are paired conducting electrons bound together below a superconducting transition temperature T_c by an attractive interaction in certain types of metals. Each bound pair consists of electrons with opposite spins and opposite momenta. The total energy of the superconducting system is lowered relative to its normal metallic state by an energy Δ, known as the superconducting energy gap, and the paired electrons exhibit strong correction, in contrast to the non-correlated conducting electrons (known as electron gas) in the normal metallic state. (See Figure 1.)

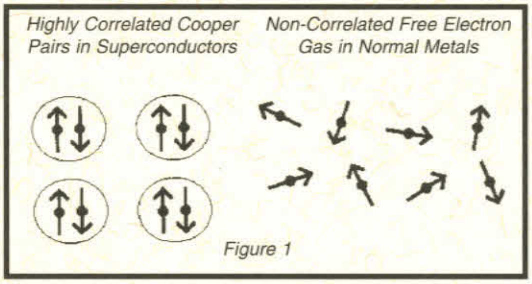


Figure 1

A number of sensitive devices based on the unique properties of superconductors have been developed. Some well-known examples include: ultra-sensitive voltage (to $<10^{-12}$ V) and magnetic field (to $<10^{-15}$ tesla) detectors; ultra-stable oscillators for frequency standards (to one part in 10^{18}); high-resolution thermometry (to $<10^{-10}$ K); bolometers, fast switches, and low-noise microwave communication components, such as filters, mixers, antenna, phase shifters, amplifiers, etc. These applications are largely determined by the superconducting parameters Δ and T_c, as well as by the critical current density J_c, defined as the maximum current density allowed in a superconductor without generating electrical losses. It would be interesting if these superconducting parameters of a given material could be "tuned" to yield tunable microelectronic devices for use in communications and signal detection.

The presence of localized magnetic moments in a superconductor is known to degrade superconductivity, due to its effect on breaking the *time reversal symmetry* (the zero-spin configuration) of the Cooper pairs. Traditionally, this *magnetic pair-breaking* effect is studied by adding magnetic impurities into a superconductor, and it has been shown that Δ, T_c, and J_c degrade with increasing concentration of magnetic impurities, and that superconductivity eventually vanishes at a critical concentration. It is, however, not practical to design tunable superconducting devices based on varying the concentration of magnetic impurities, because of the difficulties in removing the impurities from a superconductor after they are introduced. On the other hand, if a spin-polarized electrical current can be generated and injected into a superconductor, the device-relevant parameters Δ, T_c, and J_c may be tuned continuously as a function of the amount of injection current I_m.

We have recently demonstrated the concept of tunable superconductivity in thin-film heterostructures of a ferromagnet-insulator-superconductor (F-I-S) system. The constituent materials of these heterostructures have similar structures known as the *perovskite oxides*. The superconducting layer consists of high-temperature superconducting cuprates, the insulating layer consists of dielectric oxides, and the ferromagnetic layer consists of perovskite manganites known as *half metals*.

see TUNING: page 6 ▸

Many Honors Garnered by Caltech Mathematicians

Tom Apostol, professor emeritus of mathematics and project director of *Project Mathematics!*, received the Trevor Evans Award from the Mathematical Association of America. Apostol was awarded the prize in recognition of his article "What Is the Most Surprising Result in Mathematics? (Part II)," *Math Horizons*, February 1997.

According to the award citation, the answer to Apostol's question is "the Prime Number Theorem. The article traces the history of the theorem and shows how the riddle of the distribution of the primes drove Euler, Riemann, and many others to unearth fertile new areas of mathematics."

Apostol has been a professor at Caltech since 1950 and is the author of the calculus texts known to two generations of Caltech undergraduates as Tommy I and Tommy II.

Rahul Pandharipande, associate professor of mathematics, has been chosen to receive the Alfred P. Sloan Research Fellowship. The fellowship carries with it a grant of $35,000 to be used "in a flexible and largely unrestricted manner so as to provide the most constructive possible support" of the recipient's research. Sloan recipients are selected on an extraordinarily competitive basis from a group of nominees representing the very best of young scientists.

Pandharipande joined the Caltech math department in 1998. He is an expert on the algebro-geometric aspects of the exciting new field of Gromov-Witten invariants.

Barry Simon, IBM professor of mathematics and theoretical physics and currently executive officer for mathematics, has received Technion-Israel Institute of Technology's highest honor, the Doctor Scientarium Honoris Causa. The honorary doctorate is in recognition of Simon's "contributions to mathematical physics in general and to quantum field theory, statistical physics, and quantum mechanics in particular," as well as to his "ground-breaking contributions to the spectral theory of Schrödinger operators." He was also recognized for his "outstanding gift as an expositor of soft and hard analysis and to the education of a whole generation of analysts and mathematical physicists through influential and lucid textbooks," and for his "promotion of scientific cooperation with Israel and the Technion."

see MATH AWARDS: page 7 ▸

Awards & Honors

Wal Sargent
- 1998 Associate of the Society, Royal Astronomical Society

John Schwarz
- 1997 Elected to the National Academy of Sciences

Barry Simon
- 1999 Doctor Scientarium Honoris Causa from Technion-Israel Institute of Technology

Kip Thorne
- 1999 Member, American Philosophical Society,
- 1999 Foreign Member, Russian Academy of Sciences

Thomas A. Tombrello
- 1998 Technology Assessment Officer
- 1998 Distinguished Alumni Award, Rice University
- 1997 William R. Kenan Jr. Professor
- 1997 PhD Honoris Causa, Uppsala University, Sweden

Richard Wilson
- 1997 ASCIT Teaching Award

Thomas Wolff
- 1999 Bôcher Prize by the American Mathematical Society

Nai-Chang Yeh
- 1998 Outstanding Young Researcher Award - Overseas Chinese Physics Association

Ahmed Zewail
- 1999 Doctor of The University Honoris Causa, Swinburne University of Technology, Australia
- 1998 E. O. Lawrence Award in Chemistry by the Department of Energy
- 1998 William H. Nichols Medal, awarded by the Chemical Society and the Nichols Medal Jury
- 1997 Linus Pauling Medal

SOFIA: Flying High and Dry

Water—H_2O—we drink it every day, and use it in countless ways. Where did it come from? We now know that water is found not just on the Earth's surface, but also in large quantities throughout the Universe. For instance, water ice is a major constituent of comets in our solar system. Water is also found in the molecular gases that form giant interstellar clouds—these are the clouds which give birth to stars. Water also forms an icy coating on the tiny dust grains that are found in such clouds. These various reservoirs of water may all be related: water molecules in interstellar clouds can freeze onto the dust grains (or evaporate from them); the clouds form stars, which at birth are surrounded by dense "protostellar" disks; in turn these disks, which are made up of material from the cloud, are thought to form planetary systems. The comets in our own solar system may have been formed largely through the accretion of interstellar dust and ices in such a "protosolar" disk. This idea is supported by recent observations of deuterated ("heavy") water (HDO) in comets Hyakutake and Hale-Bopp made at the Caltech Submillimeter Observatory (CSO) and Caltech's Owens Valley Radio Observatory (OVRO). Finally, the water on the Earth's surface may actually have been originally brought to the Earth by comets (although this issue is controversial).

Observing water in astronomical objects is not easy. The technique for identifying atoms and molecules is spectroscopy: one analyzes the radiation ("light") emitted by the object, and searches for emission or absorption features at certain wavelengths or frequencies, that are characteristic "fingerprints" of the species in question. In the case of water, these characteristic wavelengths are associated with the rotational and vibrational motions of the molecule, and lie in the infrared and submillimeter bands. Of course, water vapor in the Earth's own atmosphere can also absorb and emit at the same wavelengths; this effect can be so strong that it is impossible to even "see" through the atmosphere. In fact, the water in the Earth's atmosphere blocks much of the infrared wavelength band—this is part of the reason why infrared observatories in space (such as the SIRTF project being carried out at JPL/Caltech) are necessary.

An airplane flying above most of the water vapor in the Earth's atmosphere provides another solution. In fact, NASA has had an active airborne astronomy program for more than thirty years, beginning with the Lear Jet Observatory in the late 1960's, and continuing with the larger Kuiper Airborne Observatory (KAO) starting in the mid 1970's. The KAO was a Lockheed C-141 aircraft, carrying a 0.85m (36-inch) diameter telescope. A number of Calt
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have participated in this
instruments for aboar

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Infrared Astronomy—is th
observatory. SOFIA, a jc
and the German Aerospa
Boeing 747SP aircraft, ca
scope (see Fig. 1). SOFI
than the KAO: its telesco
collecting area, and will ha
lar resolution. The develo
vatory is being carried out
tract to NASA, led by

CBI Is On Its

The Cosmic Background I
interferometer designed t
the cosmic microwave ba
the Big Bang, has been underg
since September of last year. F
achieved on January 23, and the first radio images were made in May. The tests in Pasadena are completed, and the telescope set sail from Long Beach/San Pedro h r on August 9. The BI should arrive in Chile at the end of August, and then on to its final destination at an altitude of 16,600 feet in the Atacama desert of northern Chile. At this altitude, emission from Earth's atmosphere will not be a limiting factor and the

CBI

instrument should achieve a sen
in a few hours. It should start pr
the cosmic microwave backgrou

The cosmic microwave backg
tain information which will provi
cosmology but also for the theor
in the universe—from superclus
planets. The project is jointly fun
gifts from Ronald and Maxine
Drinkward, and by the National

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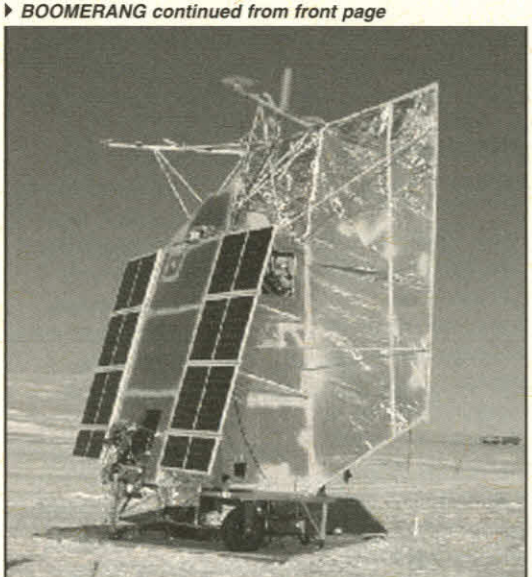
▸ BOOMERANG continued from front page



BOOMERang—fully assembled and ready for launch

standard cosmological model are believed to be encoded in their characteristic amplitude and angular size. Theorists such as Prof. Marc Kamionkowski (who has just joined the Caltech faculty) have calculated that an image of the CMB with angular resolution of about 0.2 degrees and sensitivity of 10 ppm of the absolute brightness of the CMB will be necessary to resolve the structures that are of interest.

Thus motivated, physicists have been hard at work ever since the 1964 discovery of the CMB to develop powerful new instruments capable of mapping the microwave sky with very high sensitivity. In 1990, after more than 25 years of effort, NASA's Cosmic Background Explorer (COBE) satellite reported the first unambiguous evidence for structure intrinsic to the CMB. Though the COBE result was an important step, it represented only a statistical detection of structure, and lacked both the angular resolution and sensitivity to resolve the structure of interest.

During the 1990's the race has been on resolving the structure in the CMB that encodes the cosmological parameters. The BOOMERang experiment began in 1992 as a collaboration between my group (then at UC Berkeley) and that of Prof. Paolo deBernardis of the University of Rome. Our strategy was to combine several new technologies to build an instrument that would achieve a great leap in sensitivity. A novel detector system developed by my group in collaboration with Dr. Jamie Bock at JPL provided very high sensitivity to be achieved over a broad range of frequencies. A (then) new technology of flying payloads on high-altitude balloons that circumnavigated the Antarctic promised more than 10 days of observing at altitudes in excess of 120,000 feet. The Italian group furnished the telescope, the gondola, and a sophisticated cyrogenic system that cooled the Caltech/JPL detector system to below 0.3 K for weeks at a time, sufficient to make use of the long balloon flight.

After many years of work, including a 5-hour test flight fr North America in the summer of 1997, the BOOMERang experiment was shipped by boat to McMurdo Station, Antarctica in August of last year. Our team—which now included collaborators from UC Santa Barbara (Prof. John Ruhl and students), UMass (Prof. Phil

News & Missing Alumni

Last year we asked if you would let us know about you. Thank you to all the alumni, family, and friends who sent us updates. Unfortunately, due to a computer glitch, we cannot retrieve that information. We would like to ask you to once again to send updates on what you have been doing. Update us on your personal and professional activities, and if you know the whereabouts of any of the alumni listed below, please let us know by sending an e-mail to bettina_ozaki@caltech.edu or a fax to 626/792-0486. Thank you.

Davie Ackley, BS '58 PH, MS '59 EE
Roberto Alazar, BS '72 MA, MS '72 MA
Ioannis O. Alevizos, BS '75 PH
Dikran Antreasyan, BS '73 PH
Syed Aamer Azam, BS '90 PH
Clinton L. Ballard, BS '84 MA
William David Banks, BS '86 MA
Steven V.W. Beckwith, PHD '78 PH
Michael F. Behrens, BS '63 MA
Mihir Bellare, BS '86 MA
Douglas Jon Bennett, MS '86 MA
Robert Eric Betzig, BS '83 PH
Egil K. Bjornerud, PHD '55 PH
Richard H. Bishop, BS '39, MS '43
Neville Anthony Black, BS '60 PH
Alan Phillipe Blanchard, BS '80 MA
Edward M. Bloomberg, BS '65 MA
Julian Brody, BS '50 MA
Clark Donald Brooks, BS '83 MA
Erik John Brune, BS '75 MA
Eugene Brunner, BS '33 PH , PHD '38 PH
Raymond Peter Buland, BS '70
Thomas R. Burnight, BS '37 PH
Bret Steven Burns, BS '81 APH
Jonathan F. Buss, BS '82 MA
Arthur Jun Buto, BS '78 AY
David G. Byles, BS '58 PH
Clark E. Carroll, BS '59 PH
David Carta, BS '62 PH, MS '63 ES
Joseph Cauley, BS '60 PH, MS '61 PH
Joseph C. Chang, BS '84 PH
Chung-Yao Chao, PHD '30 PH
Stanley F. Chen, BS '89 MA
Tien-yee Chen, BS '91 MA
Yi-Hong Chen, BS '85 APH
William S. Cheng, BS '64 PH
Robert Mark Claudson, BS '78 PH
Alan Comer, BS '77 PH, BS '78 ENG
Martin David Cooper, BS '67 PH
Brian Tevis Cox, BS '71 MA
James Martin Cummings, BS '83 PH
Ronald Cusson, PHD '65 PH
Kent Douglas Daniel, BS '81 PH
Richard W. Davies, BS '46 MA
Duygu M. Demirlioglu, BS '64 PH
Jerry Lynn Dessinger, BS '67 AY
Barry Dibble Jr., BS '39 PH
Peter Gerard Dodds, PHD '69 MA
Martin J. Dowd, BS '69 PH
Brian B. Dunne, BS '45 PH
Leonard Dvorson, BS '96 PH
Stanton L. Eilenberg, BS '53 PH
Lewis F. Ellmore, BS '55 PH
Veit Elser, BS '79 PH
Klaus H. Engelhardt, BS '75 PH
Donald Edward Fahnline, BS '61 PH
Margaret Mary Farrell, BS '85 PH
Jacqueline Fernandez, BS '83 MA
Philip J. Ferrell, BS '55 PH
Thomas Millar Fink, BS '94 PH
Charles Henry Fisher, BS '69 PH
Robert Burns Fisher III, BS '74 MA
Harvey Junior Fletcher, MS '48 PH
Courtenay P. Footman, BS '80 PH
Jay Reynolds Freeman, BS '68 PH
Robert Douglas Frisbee, BS '72 MA
Michael Steven Garet, BS '69 MA
Nikos E. Georgopoulos, BS '76 PH
Nadeem Ghani, BS '88 PH
Gregory Earl Gibbons, BS '76 MA
Balasubramania Girish, BS '93 PH
E. Mark Gold, BS '56 MA
Stuart Gondrici, BS '84 PH
Peter J. Grieve, BS '84 PH
Arnold Willard Guess, MS '52 PH
Daniel Paul Haake, BS '73 PH
Kenneth Kang Hee Hahn, BS '86 PH
Shahram Hamidi, BS '81 PH, PHD '87 PH
Sigmund Hammer, BS '52 PH
Brian Thomas Hayes, BS '89 PH
Ralph Hayward, BS '75 EC, BS '75 MA
John Colville Helmer, MS '52 PH
Frank Stephen Henyey, PHD '67 PH
Karl William Heuer, BS '82 MA
Jeffrey M. Hicks, BS '84 APH
Artie Hodges, BS '79 PH
John Lincoln Holmes, BS '51 MA
Ronald E. Hutton, BS '65 PH
Mihail Stilianov Iotov, PHD '98 PH
Richard O. Ireland, BS '53 PH
Bart Jackson, BS '77 PH
Stephen Craig Jackson, BS '79 MA
Maneesh Jain, BS '90 PH, BS '90 EE
Frank John Jakovac, BS '78 PH
Andrew John Jankevics, BS '76 AY
Eric B. Johansson, BS '50 PH
Robert Ralph Johns, BS '43 PH
Mark Alan Johnson, PHD '86 PH
Marion A. Joncich, BS '55 PH
Robert Bernard Jordan, BS '45 PH
Gerard Joseph Jungman, BS '87 PH
Pui-Tak Kan, BS '85 MA
Sarbmeet S. Kanwal, PHD '83 PH
Ara Kassabian, BS '86 PH
Steven Kauffmann, BS '65 PH, PHD '73 PH
Sanza T Kazadi, BS '95 PH
Edward Neal Keller, BS '78 PH
James Joseph Kelly, BS '77 PH
Thomas G. Kennedy, BS '77 MA
Serge P. Keshishian, MS '87 PH
Young Kim, BS '83 PH, MS '88 APH
Brian Kjerulf, BS '94 AY
Allen Ivar Knutson, BS '91 MA
Scott Michael Konishi, BS '80 PH
Betty Puifun Kwan, BS '74 PH
Chung-Mo Kwok, BS '64 MA
Serge Lang, BS '46 PH
Richard Latter, BS '42 PH, PHD '49 PH
Anthony S. Lau, BS '63 PH
Sai-Kit A. Law, BS '72 PH
William Stuart Lawson, BS '80 PH
Henry Laxen, BS '75 MA, MS '75 MA
Alan Stuart Lederman, BS '71 MA
Adam Henry Lewenberg, BS '86 MA
Drew Thomas Lindberg, BS '86 PH
Donald R. Lortz, BS '61 PH
Stephen J. Luner, BS '61 PH
Erin Margaret Lynch, BS '98 MA
Ernest Seu-Keung Ma, BS '66 PH
Moses Lin Ma, BS '78 PH
Miloje Makivic, MS '87 PH, PHD '91 PH
George E. Mager, BS '64 PH
Thomas O. Mahon Jr., BS '69 MA
John Mark Mahony, BS '84 MA
Rahul Malhotra, BS '96 PH
Robert Maltz, BS '59 PH
Aneesh Vasant Manohar, BS '81 PH
Victor J. Manzella Jr., BS '79 MA
Olivier Martin, MS '82 PH, PHD '83 PH
Maclen B. Marvit, BS '83 PH
Kirk Alan Mathews, BS '71 PH
Lloyd Murat Maxson, BS '78 PH
Richard Moore McIntyre, BS '50 PH
Kevin Shane McLoughlin, BS '80 PH
Michael Meo, BS '69 AY
Kay Merritt, PHD '81 PH
Donald T. Meyer, BS '57 PH
Guy Scott Miller, BS '79 AY
Larry Robert Miller, BS '66 PH
Themistoklis P. Mitsis, PHD '98 MA
Frances Y. Jackson, PHD '98 MA
William C. Moss, BS '75 PH
David Muraki, BS '83 MA, MS '83 ME
Johanna Neaderhouser, BS '94 MA
Richard B. Nelson, BS '35 PH
Robert C. Neveln, BS '67 MA
Richard Allan Newcomer, BS '60 MA
Michael Newton, BS '81 MA, MS '85 CS
Frederick Nordby, BS '88 PH, MS '90 CS
Kenneth Hugh Nordsieck, BS '67 AY
Michael Lester Norman, BS '75 AY
Jonathan Pakianathan, BS '92 PH
Joseph W. Parmelee, BS '69 PH
Basil R. Parnes, BS '52 PH
Roy W. Paul, BS '55 MA
Vipul Periwal, BS '83 PH
Adam Perse, BS '90 PH, BS '90 EE
Allen Pfeffer, BS '63 MA, PHD '66 MA
Ralph Edward Pixley, PHD '57 PH
Gerald M. Pjerrou, BS '58 PH
Fred Poole, BS '17 EE, PHD '27 PH
Stephen Patrick Pope, BS '78 MA
Gary James Prohaska, BS '73 AY
Forrest C. Quinn, BS '82 MA
George E. Radke Jr., BS '64 PH
Zinovy Boris Reichstein, BS '83 MA
David Benjamin Reiss, PHD '81 PH
Tim Rentsch, BS '79 MA, MS '79 ES
Douglas Eric Reul, BS '70 PH
Stefan C. Riesenfeldt, BS '70 PH
Marion C. Rinehart, BS '49 PH
Rev. Robert R. Roberts, BS '65 MA
True W. Robinson, BS '29 PH
David Judson Ross, BS '92 PH
Stanley Roth, BS '59 MA
Michael Rubinstein, BS '79 PH
Sarabjit S. Sabharwal, BS '81 PH
Bruce Jones Sams, BS '83 AY
Marco Antonio Santos, BS '97 PH
Alan Bruce Saul, BS '76 MA
William B. Schmidke Jr., BS '80 PH
Stephen R. Schnetzer, BS '74 PH

see ALUMNI: reserve side ▸

▸ *ALUMNI continued from other side*

Steven Schwarz, BS '59 PH , PHD '64 EE
Francis F. Scott, BS '54 PH
Audrey Lee Seymour, BS '77 MA
David C. Shafer, BS '80 PH
Gene G. Shakespeare, BS '51 PH
Richard Alan Shaw, BS '73 MA
Hubert H. Han Shen, BS '76 PH
Jamie Sherman, BS '94 AMA
Robert Michael Shore, BS '82 MA
David S. Siegel, BS '63 MA
Armando Silva-Moreira, BS '70 PH
Peter Siracusa, BS '84 AMA
Neal D. Smith, BS '25 PHE
Timothy William Smith, BS '82 MA
Hyman Solomon, BS '33 PH, MS '33 EE
Paul N. Spathis, BS '81 PH
William N. Spence, BS '56 MA
Charles C. Spencer, BS '68 PH
Will G. Spiegelman, BS '63 MA
Srinivas Sridhar, PHD '83 PH
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Antony Stark, BS '75 AY, BS '75 PH
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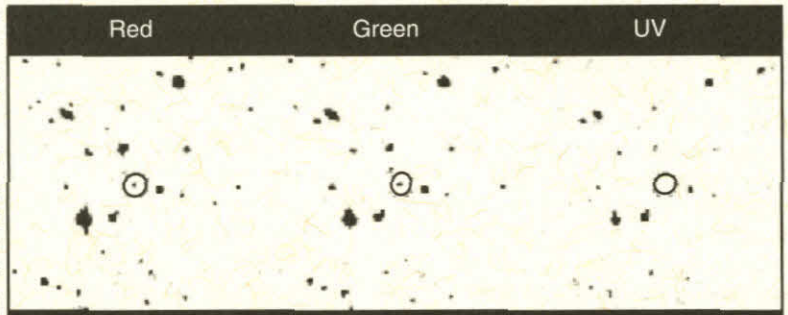
▸ *PROTOGALAXIES continued from page 2*

when galaxies were less than a billion years old.

One prediction of cosmological theories is that the earliest galaxies should be forming in the regions of future clusters of galaxies, the densest parts of the universe. It is now generally believed that galaxies and larger structures grow out of the tiny density enhancements in the early universe, which are generated in quantum processes a fraction of a second after the big bang. The densest clumps in the early universe, which should be the first ones to condense and make stars, are expected to be clustered together. These so-called "biased" galaxy formation models thus predict that the first protogalaxies should be found in protoclusters: the formation of galaxies and of the larger-scale structures are intimately connected. This prediction seems to be supported by the new Keck observations.

Chuck Steidel and his collaborators have refined a method, first successfully applied in the fall of 1995, for efficiently locating extremely distant galaxies from among the myriad "foreground" objects. It is essentially a culling process, using deep CCD images obtained at the Palomar 200-inch telescope in random regions of the sky, to find the few percent of faint galaxies that lie at very large distances (as opposed to those that are intrinsically faint but at smaller distances), providing targets for spectroscopy at the Keck telescopes. The efficiency of the technique, which makes use of the unique "color" signature of the most distant objects, has allowed construction of the first comprehensive three-dimensional "maps" of galaxies within representative volumes when the universe was only 10-15% of its current age. This includes the discovery of nascent clusters of galaxies, and also large regions of space that are essentially devoid of galaxies. The current sample of distant galaxies now numbers several thousand (more than 800 have spectroscopically measured distances) and allows the quantification of the general clustering properties of distant galaxies, providing empirical information for comparison to theoretical simulations of the galaxy formation process in the early universe. The general clustering properties of galaxies indicate, as expected under the prevailing paradigm of structure formation in the universe, that bright galaxies in the early universe are "born" highly clustered and likely trace the rare high peaks in the general distribution of matter. At the same time, the large samples that are now available have allowed many other global, statistical properties of early galaxies to be characterized.

Using a somewhat different approach, Prof. Djorgovski and his group are looking for clustered protogalaxies around known quasars at these high redshifts. (The quasars themselves are discovered in a research program carried out at Palomar, based on the digital sky survey, the DPOSS.) Quasars are luminous objects in the nuclei of some galaxies, and can be thousands of times more luminous than normal galaxies; they are likely powered by massive black holes, formed in the early stages of protogalactic collapse and merging.



Images of a distant galaxy (circled), taken with three filters: red, green, and ultraviolet. The galaxy appears to be about equally bright in the red and green filters, but disappears in the ultraviolet image, since its light at these short wavelengths is being completely absorbed by neutral hydrogen along the line of sight. This imaging technique enables astronomers to select large numbers of very distant galaxies, for studies of galaxy and cluster formation.

The idea is that the quasars, which almost surely reside in the cores of future massive galaxies, serve as beacons marking the possible sites of early galaxy formation. Djorgovski and collaborators then look for fainter protogalaxies in the quasar's vicinity. Indeed, a number of such clustered protogalaxies have been found in these regions. The early indications are that the number densities of these objects may be hundreds or thousands of times larger in these special regions than in the average volume of the universe at that time. This is exactly what one might expect if these early quasars and their companions reside in the cores of future clusters of galaxies, and it supports the basic idea of biased galaxy formation.

The work on these projects continues, with the goal of quantifying these effects in a way that would provide useful hints and constraints for theoretical models of galaxy and structure formation.◆

THE "PMA COMMUNIQUÉ" IS PUBLISHED PERIODICALLY BY CALTECH'S
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BY JONAS ZMUIDZINAS

altech faculty, including Profs. Soifer, Blake, and Zmuidzinas, his program and developed ard the K... atospheric Observatory for the next-generation airborne joint project between NASA space agency DLR, will be a carrying a 2.7m diameter tele- FIA will be far more capable scope will have ten times the have three times better angu- elopment of the SOFIA obser- out by a consortium under con- by the Universities Space Research Association (USRA), and including: Raytheon, for the aircraft engineering and modifications; United Airlines, for operations; and Sterling Software. The telescope itself is being built in Germany by an industrial consortium. SOFIA is expected to begin astronomical observations in 2002.

Artist's conception of SOFIA: a 747 aircraft, with a 2.7–m diameter telescope mounted behind the wings. SOFIA will fly at an altitude of 45,000 feet.

One of the seven instruments selected for "first light" observations is being developed at Caltech, by Prof. Zmuidzinas's group. This instrument—the Caltech Submillimeter Interstellar Medium Investigations Receiver, or "CASIMIR," will be a high-resolution heterodyne spectrometer for the 500–2000 GHz frequency range. The instrument will take advantage of novel sensitive superconducting detector technology that is being developed at JPL and Caltech. CASIMIR will be ideal for observations of interstellar water; in particular, detailed studies of water using the much rarer oxygen-18 isotope will be possible. CASIMIR will also be capable of addressing a broad range of astronomical topics, ranging from studies of galaxies undergoing dramatic bursts of star formation, to the measurement of the abundance of ions and molecules of key importance in the chemistry of the interstellar medium.◆

...TS WAY TO CHILE

BY ANTHONY READHEAD

...d Imager (CBI), a 13-antenna radio ...d to make high sensitivity images of ... background radiation left over from ...ergoing extensive testing on campus ... First light at radio frequencies was

CBI being moved onto its flat rack for shipping.

...sensitivity level below ten microkelvin ... producing high-sensitivity images of ...round in October.

...ckground radiation is believed to con- ...rovide a firm foundation not only for ...eory of the formation of all structures ...lusters of galaxies down to stars and ...funded by Caltech, through generous ...ne Linde and from Cecil and Sally ...nal Science Foundation.◆

FOR THE PMA DIVISION REUNION

Mauskopf), Millikan Fellow Barth Netterfield (now Prof. of Physics at Univ. of Toronto) and Caltech graduate student Brendan Crill, as well as Italian scientists and engineers—arrived in McMurdo in early November to assemble and calibrate the telescope and detector system.

After almost 2 months of 24-hours-of-sunlight, round-the-clock work, the payload was launched on December 29, 1998. The instrument performed flawlessly on its maiden flight, mapping almost 2000 square degrees of sky with better than 0.2 degree resolution. During the 10.5-day flight, the payload was carried in an almost circular trajectory and landed just 30 miles inland from the launch site after a 5,000-mile journey around the South Pole.

The data gathered represent a map with ~100 times the number of pixels as contained in the COBE map, each with temperature resolution of ±0.00002 K. Analysis of this large data set is proceeding quickly. The images produced to date verify that the experiment has succeeded in resolving very clearly the structures that have long been predicted to exist. A preliminary analysis of the characteristic size and amplitude of these structures should be complete by year's end.

BOOMERang is just one of several experiments that will reveal the detailed structure of the CMB in the coming decade, and Caltech will play a pivotal role in what promises to be a very exciting field. As this is being written, a sophisticated interferometer—the Cosmic Background Imager (CBI) developed by Prof. Tony Readhead's group—is on its way to Chile. A sister interferometer, DASI, developed by former Caltech Prof. John Carlstrom (now at U. of Chicago) with heavy Caltech involvement, is being deployed simultaneously to the South Pole. Observations with the CBI and with DASI will complement those of BOOMERang in important ways when these instruments go on line at the beginning of 2000. Several new experiments currently under development by my group and others will extend CMB measurements to still higher angular resolution, and will attempt to measure the polarization of the CMB, which has yet to be detected.

Black line represents BOOMERang's trajectory

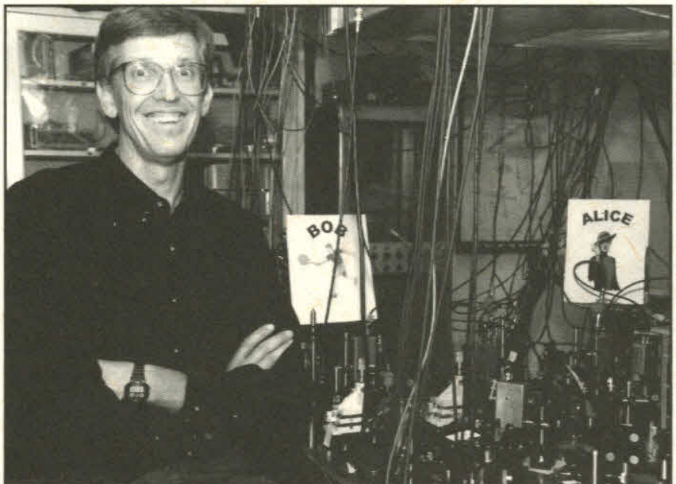
In 1997, the European Space Agency launched the Planck Surveyor, which is being billed as "the definitive CMB experiment." Planck is a 1.5-m orbital telescope that will map the entire sky from the vantage point of the second Lagrangian point of the Sun-Earth system (a position one million miles from the earth in the anti-sun direction). The key technologies for Planck—a bolometric detector system derived from that just flown on BOOMERang, sensitive radio frequency amplifiers operating at 100 GHz, and a sophisticated 20 K sorption cooler—were developed at Caltech and JPL with NASA funding. As excited as I am about what Planck will achieve, I doubt that it will be the "definitive" experiment. The field of CMB research is still in its infancy, and there are sure to be many exciting surprises in the future.◆

Caltech Physicists Achieve First Bona Fide Quantum Teleportation

By Robert Tindol

In the October 23, 1998 issue of the journal *Science*, Caltech physics professor H. Jeff Kimble and his colleagues write of their success in transporting a quantum state of light from one side of an optical bench to the other without it traversing any physical medium in between.

"True quantum teleportation involves an unknown quantum state entering Alice's apparatus and a similar unknown state emerging from Bob's remote station," says Kimble. "Moreover, the similarity of input and output, as quantified by the fidelity, must exceed that which would be possible if Alice and Bob only communicated by classical means—for instance, by normal telephone wiring."



H. Jeff Kimble, William L. Valentine Professor and Professor of Physics with Bob and Alice at the optical bench.

"Although there has been wonderful progress in the field, until now there has not been an actual demonstration of teleportation that meets these criteria."

In the experiment, the Caltech team generated exotic forms of light known as "squeezed vacua," which are split in such a way that Alice and Bob each receive a beam that is the quantum mechanical "twin" of the other. These EPR beams, named after the historic Einstein-Podolsky-Rosen (EPR) paradox of 1935, are among the strangest of the predictions of quantum mechanics. It was their theoretical possibility that led Einstein to reject the idea that quantum mechanics might be a fundamental physical law.

In this sense, quantum teleportation is similar to the far-fetched "transporter" technology used in the television series "Star Trek." In place of the actual propagation of a light beam, teleportation makes use of a delicate quantum-mechanical phenomenon known as "quantum entanglement," the quintessential ingredient in the emerging field of quantum information science.

"In our case the distance was only a meter, but the scheme would work just as well over much larger distances," says Professor Samuel Braunstein, a co-author from the University of Wales in Bangor, United Kingdom, who, with Kimble, conceived the scheme. "Our work is an important step toward the realization of networks for distributing quantum information—a kind of quantum Internet."

Teleportation of this kind was first proposed theoretically by IBM scientist Charles H. Bennett and colleagues in 1993. The Caltech experiment represents the first time quantum teleportation has actually been performed with a high degree of "fidelity." The fidelity describes how well a receiver, "Bob," can reproduce quantum states from a sender, "Alice."

Although quantum teleportation was recently announced by two independent labs in Europe, neither experiment achieved a fidelity that unambiguously required the use of quantum entanglement between Alice and Bob.

A trademark of quantum mechanics is that the very act of measurement limits the controllability of light in ways not observed in the macroscopic world: even the most delicate measurements can cause uncontrollable disturbances. Nevertheless, in certain circumstances, these restrictions can be exploited to do things that were unimaginable in classical physics.

Here, photons from the EPR beams delivered to Alice and Bob can share information that has no independent existence in either beam alone. Through this "entanglement," the act of measurement in one place can influence the quantum state of light in another.

Once Alice and Bob have received their spatially separate but entangled components of the EPR beams, Alice performs certain joint measurements on the light beam she wishes to teleport together with her half of the EPR "twins." This destroys the input beam, but she then sends her measurement outcomes to Bob via a "classical" communication channel. Bob uses this classical information to trans-

see TELEPORTATION: back cover ▸

▸ TUNING continued from page 3

In normal metals, the population of up and down spins of conducting electrons is identical, whereas in ferromagnetic materials, one of the spin species exceeds the other, thereby yielding a net spin polarization. The degree of spin polarization in most ferromagnetic systems is generally small, e.g., 11% for nickel. On the other hand, the spin polarization in half-metallic ferromagnets is ~100%. Consequently, if an electrical current is sent through a half-metallic ferromagnet, the conduction electrons become mostly spin-polarized. A spin-polarized electrical current injected into a superconductor can result in suppression of superconductivity, and therefore a decrease in the superconducting critical currents and breaking of Cooper pairs, provided that the spin polarization of conduction electrons may be preserved across the interface and over a finite distance into the superconductor.

In contrast, if the ferromagnetic layer of the F-I-S heterostructure is replaced by a non-magnetic perovskite metal, electrical currents passing through the normal metal do not acquire spin polarization, and we expect negligible effect on the suppression of superconductivity. As shown in Figure 2, a distinct effect of J_c suppression is observed in the perovskite F-I-S heterostructures with increasing injection current I_m. This is in contrast to the absence of J_c suppression in the normal metal-insulator-superconductor (N-I-S) systems. Similarly, by using a scanning tunneling microscope (STM) to study the electron tunneling spectrum of the superconductor in the F-I-S and N-I-S heterostructures, we find evidence of increasing *quasiparticle density of states* (i.e., increasing fragments of broken Cooper pairs) with increasing I_m only in the F-I-S system. Hence, the effect of spin-polarized electrical currents on modifying the superconducting properties of high-temperature superconducting cuprates has been demonstrated unambiguously.

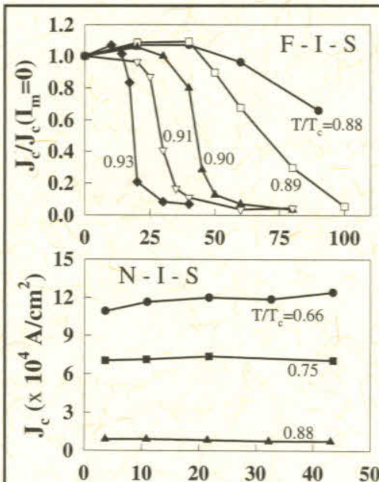


Figure 2: Comparison of Critical Current (J_c) Between F-I-S and N-I-S Heterostructures

We have also estimated the lifetime (known as the spin diffusion time) and the spin diffusion length of the spin-polarized conduction electrons in high-temperature superconductors. These findings are expected to provide better understanding of the microscopic origin for the occurrence of high-temperature superconductivity, and to yield useful designs for tunable microelectronic devices.◆

THE SPIN OF THE PROTON

BY EMLYN HUGHES

Understanding the structure of the atom has been one of the fundamental problems in modern physics. The behavior of the simplest atom, hydrogen, h[illegible]een mapped out with incredible precision in atomic physics experiments and can be understood in the context of quantum mechanics and quantum electrodynamics (QED). We know, for example, experimentally the hyperfine splitting (hfs) of the ground state of hydrogen to 13 digits of precision, $\Delta\nu_{hfs}$ = 1420405751.767 Hz. And we know theoretically, from QED corrections, that $\Delta\nu_{hfs}$ is understood to a precision of approximately a few parts per million (ppm). At the level of a few ppm, however, the theoretical understanding of this splitting becomes limited due to uncertainties dependent on the structure of the proton itself. In other words, the fact that the proton is not a pointlike Dirac particle (like the electron) means that the hydrogen atom as a whole and the motion of the electron, in particular, become complicated. In fact, it is probably fair to say that understanding the structure of the proton and understanding an isolated hydrogen atom have become essentially equivalent problems.

Caltech has had a long history of studying the substructure of the proton. Feynman and Gell-Mann were pioneers in the development of the quark model and Quantum Chromodynamics (QCD), the theory of the strong interactions, and won Nobel Prizes for their work in 1965 and 1969, respectively. On the experimental side, neutrino experiments at Fermilab in Chicago (under the leadership of Barish and Scuilli) performed detailed studies of the quark content of the proton. These experiments along with electron scattering experiments at the Stanford Linear Accelerator Center (SLAC) and neutrino programs at CERN (a high energy laboratory in Geneva) mapped out the quark contribution to the proton's structure. This field of high energy physics continues today at enormous energies using an electron-proton collider machine located at the DESY laboratory in Hamburg.

Over the last decade, a second related study has grown to connect the simple spin ½ of the proton to its internal structure. In an experiment performed at CERN in 1987, it was discovered that the quarks only account for a relatively small fraction of the proton's total spin. In fact, if one writes the proton's spin as ½ = Δq (quarks) + ΔG (gluons), it was found that the quarks only account for about 20% of the proton's spin. This surprisingly low value effectively called into question the entire quark model's interpretation of the proton's substructure, launching a large nuclear and high energy physics community to study the subject in greater depth.

The research group at the Kellogg Radiation Laboratory at Caltech has been conducting a series of experiments to unravel the mysterious role that the quarks play in their relation to the proton's spin. A collaboration at SLAC under the leadership of Professor Hughes ran the first experiment using a high energy polarized electron beam scattering off a polarized helium-3 target. The experiment gave information on the spin substructure of the neutron, a valuable check compared to the proton results. Professors Filippone and McKeown have performed similar measurements in the HERMES experiment at DESY. Here electrons from the DESY storage ring are scattered by pure polarized hydrogen, deuterium, and helium-3 gas targets. All three Kellogg professors have been active in the development of the polarized beams, polarized targets, and detector technologies used in electron scattering experiments at numerous laboratories around the world (DESY, Jefferson Lab in Virginia, MIT-Bates, and SLAC).

Professor Hughes's group continues to study the polarized helium-3 target, which has been moved to the Kellogg Radiation Laboratory. It now serves as a research laboratory directed at studying in detail the polarization properties of spin-polarized noble gases. These studies are important both as a testing and training ground for the targets used in lower energy electron scattering experiments now being conducted at the new Jefferson Laboratory in Virginia and as a new instrument for biomedical imaging. Noble gases (like helium) are safe to the body and can be used as sensitive probes for NMR imaging in materials and tissues. A close look at the research being conducted in Kellogg today reveals a broad science program ranging from quantum computing (Summer 1998 *PMA Communiqué*), artificial life, nuclear and high energy physics, and biomedical imaging.

Right to left, top row: Dave Pripstein, Jaideep Singh, Emlyn Hughes, Steffen Jensen, Katie Mack, Mark Jones, Titus Brown. Right to left, bottom row: Michelle Cyrier, Klejda Bega, Tina Pavlin, Peter Mastromarino.

To summarize where this article began, it is interesting to note that although the highest energy electron machines probably give the most relevant information on the spin-dependent quark distributions in the proton, it is the low energy machines that map out the measurements most relevant to understanding the hyperfine splitting in hydrogen's ground state. It is, in fact, the lack of knowledge of spin-dependent interactions in the proton that give the largest theoretical uncertainty in extracting $\Delta\nu_{hfs}$ theoretically. High and low energy electron scattering experiments are still needed to understand the proton's complicated substructure and serve complementary roles.◆

▸ ***MATH AWARDS continued from page 3***

Thomas Wolff, professor of mathematics, has been selected as a co-recipient of the 1999 Bôcher Prize. The prize, awarded by the American Mathematical Society, is given every five years for a notable research memoir in analysis.

Wolff was honored for his work in harmonic analysis, "notably the work presented in his papers, 'A Kakeya type problem for circles,' *Amer. J. Math.* 119 (1997), 9[illegible]1026, and 'An improved bound for Kakeya type maximal functions,' *Rev. Mat. Iberoamericana* 11 (1995), 651–674. The techniques presented there represent an important contribution to our understanding of the structure of subsets of Euclidean space, involving the interplay between geometric measure theory and harmonic analysis." The award was also made "in acknowledgment of Wolff's work on harmonic measure and unique continuation."

In its best finish in recent years, a team of Caltech undergraduates placed fourth in the 59th **Putnam Mathematical Competition**. A total of 2,581 undergraduates from 419 colleges and universities in Canada and the U.S. participated. There were teams from 319 institutions.

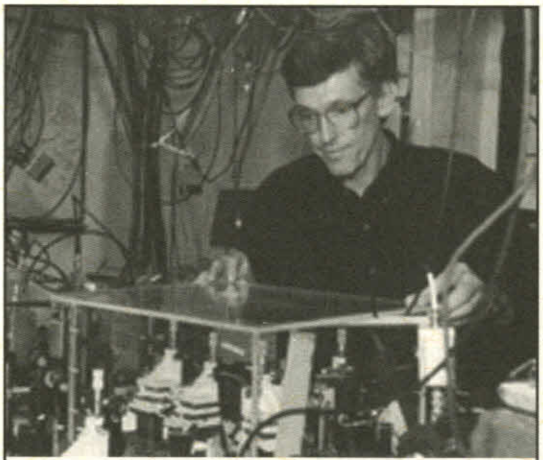
Caltech's winning team was composed of Christopher Chang, Christopher Hirata, and Hanhui Yuan; their supervisor was Richard Wilson, professor of mathematics and a faculty member since 1980.

In addition to team honors, Caltech undergraduates won individual prizes. Christopher Chang for ranking 7–15; Scott Carnahan for ranking 16–25.5; Frederick Eaton, Christopher Hirata, and Mark Tilford g[illegible]onorable mention for ranking 28–58. The Putnam competition began in 1938 and is designed "to stimulate a healthful rivalry in mathematical studies in the colleges and universities of the United States and Canada."◆

▸ TELEPORTATION continued from page 6

form his component of the EPR beam into an output beam that closely mimics the input to Alice, resurrecting at a distance the original unknown quantum state.

A unique feature of Kimble's experiment is a third party called "Victor," who "verifies" various aspects of the protocol performed by Alice and Bob. It is Victor who generates and sends an input to Alice for teleportation, and who afterward inspects the output from Bob to judge its fidelity with the original input.



Professor Kimble at the optical bench

"The situation is akin to having a sort of quantum telephone company managed by Alice and Bob," says Kimble. "Having opened an account with an agreed–upon protocol, a customer (here Victor) utilizes the services of Alice and Bob unconditionally for the teleportation of quantum states without revealing these states to the company. Victor can further perform an independent assessment of the quality of the service provided by Alice and Bob."

The experiment by the Kimble group shows that the strange "connections" between entities in the quantum realm can be gainfully employed for tasks that have no counterpart in the classical world known to our senses.

"Taking quantum teleportation from a purely theoretical concept to an actual experiment brings the quantum world a little closer to our everyday lives," says Christopher Fuchs, a Prize Postdoctoral Scholar at Caltech and a co-author. "Since the earliest days of the theory, physicists have treated the quantum world as a great mystery. Maybe making it part of our everyday business is just w s been needed for making a little sense of it."

This demonstration of teleportation follows other work the Kimble group has done in recent years, including the first results showing that individual photons can strongly interact to form a quantum logic gate. Kimble's work suggests that the quantum nature of light may someday be exploited for building a quantum computer, a machine that would in certain applications have computational power vastly superior to that of present-day "classical" computers.

For the latest news on teleportation at Caltech, check out the website at http://www.its.caltech.edu/~qoptics/teleport.html.◆

60TH BIRTHDAY SYMPOSIUM FOR KIP THORNE

Kip Thorne, Feynman Professor of Theoretical Physics, who has been part of the Institute's life for 35 years, will be feted with an event starting on his 60th birthday, June 1, 2000. Two days of invited scientific talks will demonstrate the range and impact of his contributions to physics. This will be followed on Saturday, June 3, by a day of popular talks meant to honor Kip's commitment to bringing science to the public. The Saturday event in Beckman Auditorium will include talks by Tim Ferris, Stephen Hawking, Alan Lightman, and Igor Novikov. *–Richard Price*

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