Summer 1998

Caltech PMA Communique

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New Division Chairman Thomas A. Tombrello, William R. Kenan, Jr. Professor of Physics effective August 1, 1998

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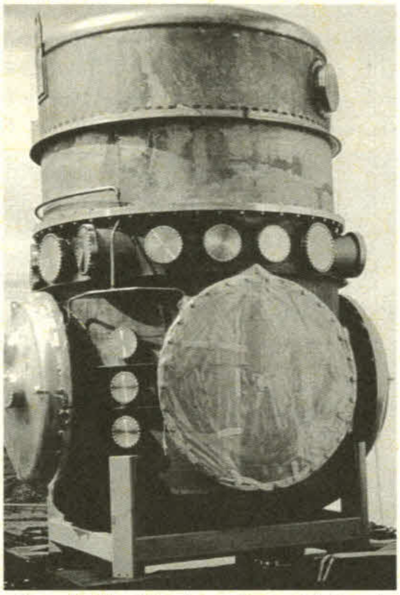
LIGO's Scientific Mission Two Years Away

Construction of the $272 million Laser Interferometer Gravitational-Wave Observatory (LIGO) is now more than two-thirds complete with the starting date for its scientific mission just two years away. Designed to prove the existence of gravitational waves predicted by Einstein, and to search for and study objects in the universe that elude detection by conventional telescopes, LIGO will also feature technological advances that have never been achieved before.



Beam Splitter Chamber at the end station at Hanford, WA

LIGO, a project run jointly by Caltech and MIT, is being constructed on two sites (Hanford, WA and Livingston, LA) to serve as a national research facility for detecting gravitational waves in the universe.

Although gravitational waves have never been

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Chairman's Note

by Dr. Charles Peck

This newsletter is the first of what we hope will be a regular series designed to maintain contact with the alumni and friends of the PMA Division. We will try to keep you informed about the current research and teaching activities of the faculty, both old and new. 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, 103-33 Caltech, Pasadena, CA 91125.◆

Gamma Ray Bursts Still A Mystery

The mystery behind the intense flashes of light that have puzzled astronomers for over 30 years may soon be solved. Last year, an optical source was correlated with a gamma-ray burst, so called because these bursts are brief and intense radiation flashes that appear in the gamma-ray spectrum. It was originally detected by the Dutch-Italian satellite BeppoSAX, and pinpointed on the sky by Howard Bond, an astronomer with the Space Telescope Science Institute. The Caltech group showed that the burst occurred several billion light-years away from the Milky Way, demonstrating that at least some of the enigmatic gamma-ray bursts are extragalactic in origin.

"Gamma-ray bursts are like an explosion on a cosmic scale," said Caltech Professor of Astronomy Shrinivas Kulkarni. Discovering where they originate has helped rule out a few theories about the bursts, but "what can cause this fantastic release of energy is still a mystery," he said.

With present detectors, gamma-ray bursts are observed a couple of times a day. These brilliant flashes seem to appear from random

see Gamma: page 5

Quantum Information and Computation Project

A team led by Caltech physicists has taken the first steps toward envisioning, designing, and even making components that could be integral to a future quantum computer. Called the Quantum Information and Computation Project, or QUIC, this collaboration of three research groups at Caltech, and one each at MIT and USC, is striving to achieve completely new capabilities for the processing and distribution of information, including possibilities that are impossible for classical computers.

QUIC includes Jeff Kimble, Caltech's William L. Valentine Professor and Professor of Physics; Steve Koonin, Caltech's Vice President and Provost, Professor of Theoretical Physics, and a Caltech alumnus (BS '72); John Preskill, Professor of Theoretical Physics at Caltech; Al Despain,

see QUIC: page 2

Space Infrared Telescope Facility

The Space Infrared Telescope Facility (SIRTF) is still four years from its launch date, but the infrastructure required to handle the expected deluge of proposals for science programs using the satellite and to analyze its data is already taking shape. Providing unprecedented sensitivity and wavelength coverage in the infrared region of the electromagnetic spectrum, SIRTF will collect images of the birth of stars and galaxies over its five-year lifespan. It will study the very cold regions of space, observing objects ranging from nearby comets and asteroids to the distant beacons of quasars and forming galaxies, and searching for solar systems around other stars in ways impossible for optical telescopes.

Last year, Caltech Professor of Physics and alumnus Tom Soifer '68 was named director of the SIRTF Science Center, which will be located at the Institute. The Center will solicit and process the proposals, specify observations, schedule observing times, operate the instruments on the satellite, reduce and calibrate the data, and deliver data to proposers. In addition to the planning and scheduling of the observations, "the value added of the Science Center," said Soifer, "is to understand and do the calibrations to support the hundreds of observers" who can then conduct their SIRTF research projects from their offices.

Recognized by the National Research Council as the highest priority major new mission for U.S. astronomy in the 1990's (the "Decade of the Infrared"), SIRTF is scheduled for launch on a Delta rocket from Cape Canaveral on Dec. 1, 2001. This sun orbiting observatory will complete

"One of the most exciting things about SIRTF is the surprise"

NASA's "Great Observatories" telescopes, which also include the Hubble Space Telescope, the Compton Gamma Ray Observatory, and the Advanced X-ray Astrophysics Facility (likely to be launched this year). These four telescopes will cover the entire electromagnetic spectrum from infrared radiation to gamma rays.

The three instruments on board the spacecraft are the Infrared Array Camera and the Multiband Imaging Photometer, which together will provide imaging at all infrared wavelengths between 3 and 200 microns, and the Infrared Spectrograph, which will study the spectra of objects from 5 to 40 microns.

SIRTF will be 1,000 times more sensitive than the Infrared Astronomical Satellite (IRAS), launched in 1983, which only gathered data for

see SIRTF: back page

QUIC continued from front page

Powell Professor of Computer Engineering at USC; and Seth Lloyd, Assistant Professor of Mechanical Engineering at MIT and a former Caltech postdoc.

The long-range goal of the group is to develop a quantum computer that would directly use the principles of quantum mechanics to perform, in a massively parallel fashion, calculations that are impossible on today's digital computers. It could lead to new encryption systems and solve numerous problems, including rapidly factoring large numbers that would take the fastest conventional supercomputer hundreds of millions of years to examine.

Classical computers work by sending bits—the distinction between two alternatives: 0 or 1—as pulses of electrical current. At locations called logic gates, a bit is "flipped," or changed to its opposite state, if a specific combination of bits is present. A quantum computer would work by using the principles of quantum mechanics, which govern particles too tiny to obey the laws of classical physics. In contrast to the situation in classical mechanics, a particle in a definite quantum mechanical state is simultaneously in a "superposition" of other states. Since a collection of such quantum particles can exist in an exponentially large number of states simultaneously, a computer that "thinks" quantum mechanically could do many different calculations at once in a way that even the most sophisticated conventional computer could not.

The QUIC Team, Feb. '97

In 1995, the QUIC collaboration received a 5-year grant from the Defense Department's Advanced Research Projects Agency (DARPA) to study quantum computing. Preskill said that the group has made significant progress toward achieving the goals it proposed to DARPA.

Kimble, the experimentalist in QUIC, was one of the first scientists to demonstrate a quantum gate. He has in effect created a rudimentary quantum logic gate by shooting photons at a single atom in an optical cavity. Preskill was one of the first theorists to figure out how to correct errors in a quantum computer. Since checking for errors in a quantum computer by interrupting its operation to take measurements would destroy the quantum state, Preskill and others devised a method in which a suitable accuracy threshold could be coded into the quantum computer. "This would make quantum computing work with complete accuracy as long as its components were not too error prone," Preskill said.

While researchers around the world are racing to develop a quantum computer, Preskill said that the Caltech collaboration is unique because its researchers are working together to cover all aspects of the problem, including experimentation, simulation, algorithm development, and error correction. "You could have a quantum system with only 40 to 50 atoms that might be able to do something that would totally baffle and surprise us," Preskill said. "We'd like to scale up what Jeff Kimble is doing from a few bits of information—a single logic gate—to thousands or millions of computations. I believe that, in the long run, the difficulties of doing [illegible] can be overcome and large-size quantum computers can be built and operated, and people will feel that it will have been worth the effort."

More information and the latest updates on the QUIC Project can be found at http://theory.caltech.edu/~quic/index.html. ◆

CALTECH CAN BE FIRST!

A RACE TO THE BEGINNING

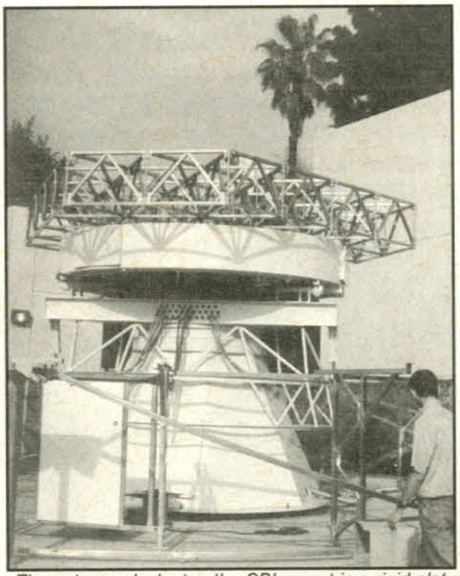
The Cosmic Background Imager (CBI), an array of 13 1-meter radio telescopes mounted on a 6-meter platform, will make real images of the embryonic universe as it was 14 billion years ago—just 300,000 years after the Big Bang and one billion years before the appearance of the first galaxies and quasars. And it is critical, as Tony Readhead, Professor of Astronomy and Principal Investigator on the project, is quick to point out, that Caltech be the first to capture these images. "We're in a race with a space project the Microwave Anisotropy Probe (MAP) scheduled for launch in 2000, and if we're not observing by early in 1999, then there's a real danger of us losing that race. There may be this one clean observation to do and then the job's done. However, the more likely scenario is that nature will have some real surprises for us, and that a number of ground-based and balloon projects, including Andy Lange's BOOMERANG project, will combine their data in order to understand what's going on in this new astronomical window."

Prof. Readhead describes the four main scientific goals. First, the CBI will provide a new window on the universe, which is of primary importance completely independent of any theory. Second, it is hoped that it will lay a firm foundation for understanding the formation of structures in the universe from clusters of galaxies to galaxies and down to stars and planets. Third, there is an important connection with particle physics to be explored since

Assembly of the CBI mount on the Caltech campus in January 1998.

events in the very early universe have left their imprint on the cosmic background that the CBI will be imaging. Finally, CBI should cast important light on the nature of "Dark Matter" which constitutes at least 90% of the matter in the universe.

The CBI will study the epoch when the universe was 300,000 years old, and has the promise of measuring at least one-and



The antenna deck atop the CBI mount is a rigid platform which will hold the 13 antennas. Here we see also part of the frame of the dome before the installation of the dome fabric cover (Feb. 1998)

possibly all three—of the cosmological parameters: the density parameter (i.e. will the universe go on expanding indefinitely or eventually collapse?), the Hubble constant (i.e. the size and age of the universe), and the cosmological constant (i.e. does space have "anti-gravity"?). These quantities are absolutely basic to cosmology, and must be measured with high accuracy to provide a firm base for the discipline.

Additionally, the CBI will image cosmic microwave background radiation on a small scale for the first time. This type of radiation was discovered by Arno Penzias and Robert Wilson in 1965, shortly after Wilson received his Ph.D. from Caltech. They received the Nobel Prize for their discovery in 1978.

Prof. Readhead leads the small but very experienced Caltech team building the CBI. The key instrumentalist on the team is Steve Padin, the project scientist. Walter Schaal BS'58 has been responsible for the mechanical design of the instrument; Tim Pearson, Senior Research Associate in Astronomy, is responsible for the data analysis software, Martin Shepherd, a staff member in Astronomy, is writing the telescope control software and the data acquisition software; John Cartwright, a third-year astronomy graduate student, is building the key low-noise amplifiers, and a number of other components of the instrument; and John Yamasaki, a staff member, has done much of the detailed digital design. First year graduate student, Patricia Udomprasert, has just joined the project and is carrying out an in-depth study of radio sources which contaminate the microwave background observations.

Caltech is leading the CBI project, which is also drawing on efforts of astronomers from the Universidad de Chile, the University of Chicago, the University of Pennsylvania, and the Marshall Space Flight Center.

The CBI has a number of novel aspects:

- Very compact electronics so that it all fits on the back of the telescope platform and moves with the telescope, thus reducing systematic instrumental errors,
- Ten frequency channels to help discriminate between microwave background and galactic foregrounds,
- Ability to rotate about the optical axis, in order to discriminate between low-level instrumental noise and the signals from the sky.

The CBI will be located at a beautiful

The paved road at ~16,000 feet in the Chilean Andes passes within 15 miles of the site. The conical volcano "Licancabur", or Mountain of the People, lies on the Bolivian border.

but remote site in the Atacama Desert in Chile, 16,600 feet above sea level.

The total cost of the CBI is $8M. So far, the National Science Foundation has given $3.7M toward the project and Caltech has provided $1.4M in matching funds. Dr. Readhead is looking for a sponsor for the additional $3M: quite a bargain considering the potential impact on fundamental science. "The CBI provides an extraordinary opportunity for making a fundamental contribution to knowledge at comparatively modest cost," said Readhead. "The science per dollar is fantastic. It is a plum that Caltech must pluck, or we will have missed one of our greatest opportunities."

More information and the latest updates on the CBI project can be found at http://astro.caltech.edu/~tjp/CBI/. ◆

PHYSICS 11

by Professor Tom Tombrello

Admission to Ph11 is based on a competition open to all Caltech freshmen in the first quarter of the year. They have four weeks to work on each of two problems ("hurdles"). They cannot collaborate but can utilize any reference materials. One of the hurdles for 1998 is given below:

The contemporary philosopher John Rawls has formulated the principle that in a free society individuals tolerate inequalities only to the extent that they provide benefits to those that are less advantaged.

l-r:Andrew Ren, Duang Hang, Aaron Simons (has accepted admission for Fall of 1998), Prof. Tom Tombrello, and Cecile Lim

One might hope to quantify this "difference principle" for the economy. For example, the fact that some individuals become rich may provide explicit and implicit benefits for the poor, i.e., more jobs, tax diversion through a graduated income tax, "trickle down", etc.

Set up an economic model that provides a way for the maximum inequality to be estimated. Since the answer is likely to depend on the assumptions you make, define the model you choose in detail. It is important to determine the degree to which the answer depends on the assumptions made.

The 1998 group consists of seven students from Caltech (and eight high school students from around the USA), who survived the competition. One of the Caltech freshmen, Travis Hime, was awarded the first Brewer Prize for his performance.

The course begins with the second quarter and runs for a calendar year; the students are paid at the SURF rate for ten weeks in the summer. There is a weekly tutorial session in which the students discuss their progress on original research problems.

Approximately half of the students in Ph11 produce successful publications in regular scientific journals. Virtually all go on to successful Summer Undergraduate Research Fellowship (SURF) experiences elsewhere at Caltech in subsequent years. Since the fall of 1989 when the course began, these students have won the majority of the research prizes at Caltech, even though they're a tiny fraction of the student body. They also dominate the list of students who win merit-based scholarships at Caltech, Goldwater Scholarships, etc.

When they graduate from Caltech they are admitted to the best graduate schools and, as of the most recent accounting, are beginning to finish in record time and begin postdoctoral studies. For example, Jon Pelletier, who was in the first Ph11 group (1990), is back at Caltech as the O.K. Earle Postdoctoral Scholar in Geology.

There have been two outgrowths of Ph11. The first is its extension to promising high school students; four in the summer of 1997 and eight in 1998. These students must cope with the same hurdles as the Caltech freshmen; their performance has been impressive. In 1998 this program has been supported by CACR and the Provost.

The second is announcement of the first Bagnold-Sharp Prize. The details of this competition are as follows:

A prize of $5,000 will be awarded to the Caltech undergraduate (or team of Caltech undergraduates) who provides a solution to the following problem before October 1, 1998. Entries will be judged by a committee of internationally recognized experts in the field.

Some (but not all) dune sands from a number of places in the world are known to "boom"; i.e., when loosely packed booming sand on a dune avalanches, an ~100 Hz sound is produced. Although there are a number of proposed explanations for this phenomenon, none of them is widely accepted.

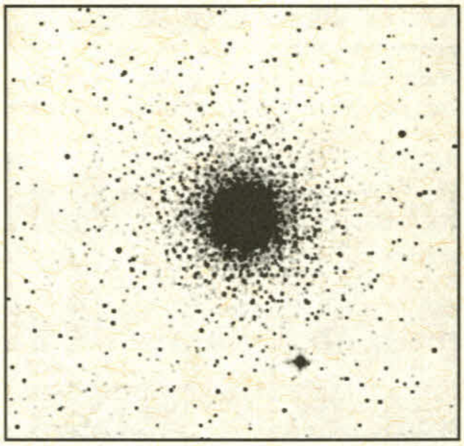
An entry will be judged on the basis of the likelihood that it is a correct explanation of the phenomenon. All entries must be supported by detailed analysis, observations, data, etc. Although we are not interested in a library search of what others have proposed, the limitations of these previous attempts should be discussed, and their relation to your explanation should be made explicit.◆

DIGITAL PALOMAR OBSERVATORY SKY SURVEY

by Professor George Djorgovski with Mike Rogers

For over 40 years, the first Palomar Observatory Sky Survey (POSS-I), a photographic atlas of some two thirds of the sky, has been a basic sky map for astronomical research. An improved version of this sky atlas, the Second Palomar Observatory Sky Survey (POSS-II), was started about 10 years ago, and and is now approaching completion, under the direction of Robert Brucato, ably assisted by Niell Reid, Sr. Research Associate. Wal Sargent, has also been instrumental in the project. The survey group membership has included Jeff Phinney, Jean Mueller, Kevin Rykoski, Cynthia Brewer, and David Mendenhalunder, under the supervision of Bob Thicksten. POSS-II will consist of 894 fields photographed three times each, in the blue, red, and the near infrared bandpasses. Most recently we have learned that the blue section of POSS-II was completed on June 1, 1998. Copies of the survey's photographic plates are now being distributed to the astronomical community.

However, in order to do science with the survey, the photographic images must be converted to a computer-usable digital format, and then analyzed. This is now being done at the Space Telescope Science Institute in collaboration with Caltech. Each plate is 6.5 x 6.5 degrees in size—or 13 x 13 Full Moons—although only the central regions (6 degrees in diameter) are actually useful for most scientific purposes. The outermost edges of the plate 'see' only a part of the primary mirror of the Oschin Telescope. This gives about 1 gigabyte per plate scan, or about 3 terabytes of digital information total, which is equivalent to the amount of information in about six million books.



In order to process this vast amount of information, Caltech astronomers and the JPL Artificial Intelligence group collaborated to develop a new software system called SKy Image Cataloging and Analysis Tool (SKICAT). The system automatically catalogs

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Hale Telescope Poised to Begin Second Half-Century of Discovery

Courtesy of Caltech Media Relations

June 3, 1998 marked the 50th anniversary of the dedication of the 200-inch Hale Telescope at Caltech's Palomar Observatory. Looking back at the accomplishments of the astronomers from Caltech and from the Carnegie Institution of Washington's Mount Wilson Observatory is to review the astounding advances in our understanding of the universe.

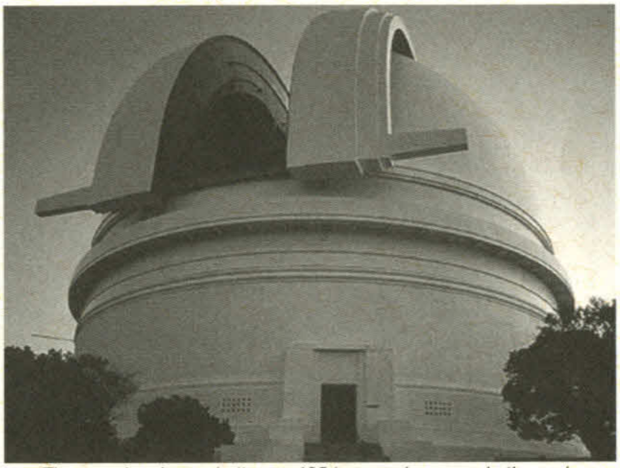
Designed and built in the 1930s with a grant to Caltech from the Rockefeller Foundation, completed following World War II, and dedicated to the memory of George Ellery Hale, the 200-inch telescope has played a major role in some of the most important discoveries in the second half of the 20th century.

Almost immediately after it began service, Walter Baade made a series of observations with the Hale Telescope that, when finished, resulted in a complete revision of our estimates of cosmological distances—the galaxies, in fact, were found to be more than twice as far away as previously thought—and the age of the universe itself was increased to about 20 billion years.

In subsequent years, the 200-inch provided the observational material to match the theoretical studies describing how individual stars evolve with time, it established the optical identification of a new class of radio sources—the quasars—and later provided evidence of their very great distances and intrinsic luminosities, and it supported a whole community of astronomers in the less spectacular but equally important process of discovery by slow, bit-by-bit labor.

Furthermore, new methods of observing were employed, if not developed, at Palomar as new technological techniques became available. The 200-inch telescope was one of the first to be used to observe at infrared wavelengths of light, opening a whole new view of the cosmos.

At the same time, the 48-inch Oschin Telescope (built as a companion to the 200-inch and designed to survey the sky for new, faint stars and galaxies) was used in the 1940s and 1950s to create a photographic atlas of the sky—the Palomar Observatory-National Geographic Society Sky Survey—that has been a mainstay of astronomical research for half a century.



The massive dome shutters -- 125 tons each -- open in the early evening to prepare for the night's run.
(Danner/Hogg)

Although the look back over Palomar's history provides a sense of the progress in astronomy, it also serves as a point of reference for a look to the future. Just as the advent of space-based astronomy has changed the way ground-based telescopes are used, the recent construction of new, larger telescopes—such as the two 10-meter (400-inch) Keck Telescopes built in Hawaii by Caltech and the University of California—altered the mission of the 200-inch.

To understand the conditions in the early universe and the formation of the first stars and galaxies, astronomers must study objects of almost inconceivable distances and of incredible faintness. The 10-meter Keck Telescopes, designed with just such work in mind, are used to collect the feeble light that, after traveling through space for perhaps 15 billion years (about 95 percent of the entire existence of the universe), is now reaching Earth.

But there are many questions to be answered, there is a great deal of work to be done, and observing time on these powerful instruments is at a premium. As a result, the Hale Telescope is being used more and more to prepare the way for projects at Keck.

Caltech astronomer Chuck Steidel, for example, used the Hale Telescope to locate very distant galaxies in the process of formation, and then used the Keck Telescope for more detailed studies. Similarly, Shri Kulkarni and George Djorgovski used the 200-inch to find the optical counterpart of a gamma-ray burster—a class of very elusive objects that emit an enormous pulse of gamma rays (detected only from space-based telescopes) that fade back into oblivion in a matter of hours or days—and later used the Keck Telescope to record its spectrum, proving that these enigmatic objects are at cosmological distances.

These are just two examples of how the Hale Telescope will function, first, to guide Keck observing and, second, to relieve the observing pressure on the larger instruments.

For further information on Palomar Observatory and the Hale Telescope please visit their website at http://astro.caltech.edu/observatories/palomar/index.html.◆

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Physics

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Angus, Ian G. PHD '86
Auler, Luiz T. MS '70
Baron, William F. MS '71
Becker, Robert A. PHD '41
Bennett, Foster C. MS '37
Blewitt, Geoffrey PHD '86
Boyd, Charles G. PHD '91
Brown, Ronald E. PHD '62
Butler, Malcolm N. PHD '88
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Chien, Chi-Bin PHD '90
Christodoulou, Haris MS '84
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Henry, Irvin G. MS '54
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Markey, John K. PHD '85
Marshall, Max PHD '80
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Matus Bloch, Ivan J. PHD '88
Mitra, Subir K. MS '74
Monteiro, Vivek C. MS '70
Morris, Duncan A. PHD '87
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Otto, Steven W. PHD '83
Patel, Apoorva D. PHD '84
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Pi, Te-Hsien PHD '44
Polychronakos, Alexios P. PHD'87
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Randeria, Mohit MS '82
Rao, Sanjeev K. MS '91
Rau, Raymond L. MS '83
Rivlis, Gil PHD '91
Rosenthal, Ann J. MS '82
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Yeh, Gong P. MS '77
Yip, Sin-Nim S. MS '89
Yuan, Ren-Feng PHD '88
Zhu, Yanong PHD '89
Zwiebach, Barton PHD '83
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Sahai, Raghvendra PHD '85
Selman, Fernando J. MS '93
Smith, Lewis L. MS '61
Yee, Howard K. PHD '81
Zuo, Lin PHD '92

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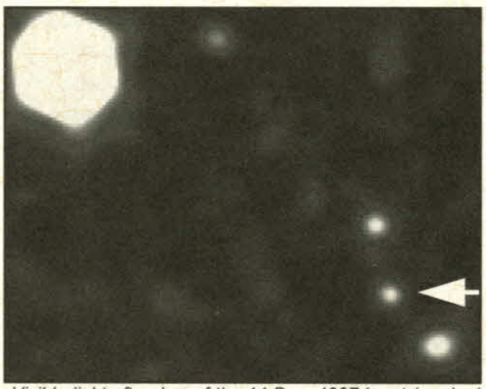
Gamma *continued from front page*

directions in space and typically last a few seconds. The Earth's atmosphere blocks gamma rays, so they cannot be detected by ground-based telescopes.

Over the last 30 years, many theories were developed to explain the bursts. "At first they were thought to be neutron stars—the end stage of massive stars," said Kulkarni. "They were also thought to be star quakes or solar flares—extreme versions of the Aurora lights. It was thought that the bursts originated only a few hundred light years away, since it was reasoned that they had to be that close to be that bright."

In 1993, it was discovered that the sources of gamma-ray bursts were not concentrated at the galactic center. Some scientists thought that comets caused them, while others thought that they came from the halo around the sun. It was also theorized that the source must be extragalactic. "If that is the case," Kulkarni said, "then the energy output would have to be of the order 10^{52} ergs, about 10^{18} times the sun's energy output for 10 seconds."



Visible-light afterglow of the 14 Dec. 1997 burst (marked with an arrow). It was obtained about two days after the burst, while it was still relatively bright.

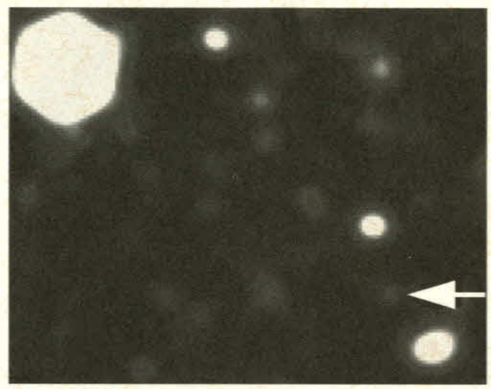
In late 1996, BeppoSAX was launched, and this satellite, for the first time, provided a rapid and accurate position in the sky for studying gamma-ray bursts. The BeppoSAX team agreed to alert the Caltech group as soon as it discovered a gamma-ray burst.

"Last May, we got a call from BeppoSAX that the satellite had discovered a gamma-ray burst," said Kulkarni. "Within hours we had the Palomar 200-inch telescope on the location and had confirmed a sky position just announced by Howard Bond. Later, at the W. M. Keck Observatory, we got a spectrum that showed us that the intergalactic clouds between us and the source had absorption lines with a redshift of about 0.8. This showed that the gamma-ray burst was located in a galaxy other than our own. Separately our radio effort at the Very Large Array detected the gamma-ray burst. For a couple of weeks the radio source strength was flickering strongly, but then became steady. The flickering is analogous to the twinkle of stars caused, in this case, by gas clouds in our Galaxy. This observation implies that the source initially has a tiny angular size, like a star, but then it gets bigger, eventually getting big enough that, like a planet, it stops twinkling. This means that the source's size is increasing at a great speed, seemingly faster than the speed of light."

The demonstration of the cosmological nature of one burster is widely considered to be a landmark discovery. This result was due to the combined effort of Professors of Astronomy S. George Djorgovski, Shrinivas R. Kulkarni, and Charles C. Steidel (PhD, Caltech '90), Assistant Professor of Astronomy Mark R. Metzger, and their students and post-doctoral fellows.

The team is now attempting to study the galaxy where the burst originated using the Keck telescopes. "It is not clear whether gamma-ray bursts come from the large galaxies or not," said Djorgovski. "Many astronomers think gamma-ray bursts are associated with star formation. So this takes us into the issue of how galaxies are formed. The neutron star is a good model for a gamma-ray burst, but it's just a model. Maybe they come from the deaths of some unusual star. Maybe gamma-ray bursts are from the death of something more extreme than a supernova. We don't know."

Since May, the Caltech group has analyzed about one burst every two months. To better understand these bursts, astronomers need more examples to study. This could be provided by a new space observatory being designed by a group of researchers from Caltech, Princeton, and Columbia University, called the Broadband Observatory for Localization of Transients (BOLT). This gamma-ray observatory would include a rotation modulation collimator that could position bursts to accuracy of a few arcseconds, compared to BeppoSAX's 1-3 arcminutes. The team estimates that BOLT will be able to localize bursts to the above mentioned exquisite precision quite frequently. This combination of precision and frequency should propel this subfield into the mainstream. With their superb access to optical and radio facilities, Caltech astronomers are in an excellent position to continue to lead in this field.



The same field as seen about two months later, after the burst afterglow has faded away, revealing a faint galaxy at its position (also marked with an arrow).

"We could have accurate positions on about 150 bursts per year," said Fiona Harrison, Assistant Professor of Physics at Caltech. "We would also be able to get the positions down to the ground in seconds, instead of hours, so emissions could be studied in more detail while they are still bright, so we'd have a better chance of understanding what causes them." Harrison said that the group is preparing a cost analysis for NASA, and hopes to have BOLT aboard the Small Explorer Mission in 2001 or 2002.

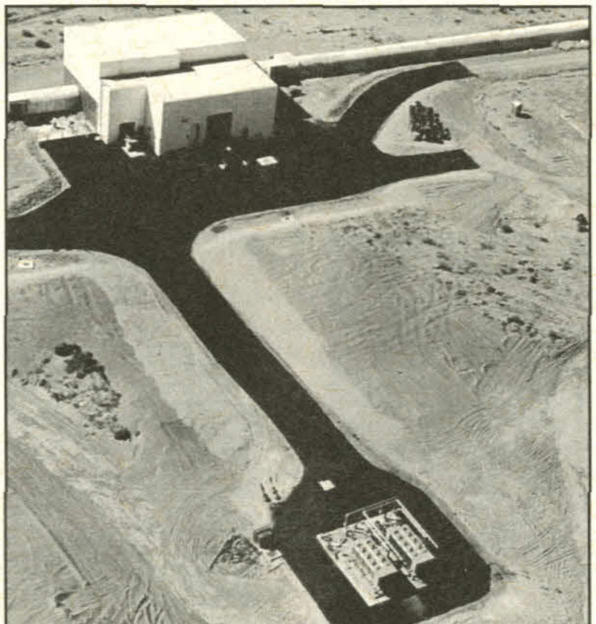
Most recently, we learned of even more progress in this exciting field. Profs. Kulkarni and Djorgovski announced that the gamma-ray burst of 14 December 1997 is associated with a galaxy at a distance of 12 billion light years. The inferred energy release is stupendous, even by astronomical standards, and involves the energy released by annihilating one tenth the mass of the sun. It is possible that gamma-ray bursters outshine the visible output of the entire Universe for a few seconds. This result received (not surprisingly) large publicity in the press, radio, and TV. This result and other recent work by the Caltech GRB group suggests that gamma-ray bursters may have something to do with star formation and perhaps the birth of stellar black holes.◆

LIGO *continued from front page*

detected before, researchers are optimistic that LIGO will be able to find them.

"It might not happen at the time we anticipate, but I don't see any fundamental obstacles," said Barry Barish, the LIGO principal investigator and the Ronald and Maxine Linde Professor of Physics at Caltech. "We should be able to detect them within 10 years from now and, if nature is kind, it could be as early as five years."

LIGO's detectors (one at each site) are designed to work together to detect gravitational waves. These waves are distortions of spacetime caused by accelerating masses, such as exploding stars or vibrating black holes. Einstein first predicted gravitational waves in 1916 in his work on general relativity. While attempts have been made to measure them, they have so far escaped detection.



Aerial view of the mid-station and chiller yard on the y-arm at Hanford

In the early 1980's, Caltech and MIT together embarked on the LIGO project to detect gravitational waves. This project was based on pioneering research by MIT Professor of Physics Rainer Weiss, Caltech Professor of Physics Ronald Drever, and Kip Thorne, Caltech's Richard P. Feynman Professor of Theoretical Physics, and their research groups. During the late 1980's and early 1990's, under the leadership of Rochus Vogt, Caltech's R. Stanton Avery Distinguished Service Professor and Professor of Physics, a conceptual design for LIGO was developed and funding was tentatively approved by Congress and the National Science Foundation. Final approval came in 1994 under Barish's leadership. The project then moved through a final design stage and into construction.

The LIGO detectors are set up in such a way that very slight distortions of spacetime in the vicinity of the 4-kilometer long L-shaped arms of the detectors' antennae will cause them to stretch or shrink. This shrinkage is fantastically small—about equal to one-thousandth the diameter of a proton. This nearly imperceptible change is measured with precisely tuned laser beams located within the antennae which sit in huge vacuum tubes. Coincidentally, observation of this phenomenon in two separate detectors is necessary to rule out the effects of local disturbances.

After the sites are operational, it should take 12 to 18 mo[illegible] to perfect the system. At the end of 2001, the detectors should be working at full sensitivity. "That's when the science begins," said Gary Sanders, the LIGO project manager. When LIGO comes on line it will have a sensitivity that gives it a chance to observe gravitational waves, but designs to increase the sensitivity are already underway. "If we reach ultimate sensitivity and we haven't seen gravitational waves, that would be an incredible scientific result too, and would indicate that either the universe is quite different than we thought, or general relativity theory has problems," he said.

Besides detecting gravitational waves, LIGO will help astronomers see objects in the universe that they cannot see using conventional telescopes. "Much of the matter in the universe is so dense that light can't pass through it, or emits so little electromagnetic radiation that we can't see it," Sanders said. "We think that up to 90% of the universe hasn't been observed." LIGO might enable astronomers to see colliding neutron stars, colliding black holes, pulsars, the stellar collapses that trigger supernovae, and violence in the very early universe. "This will be a tool to study how the universe was formed."

Building LIGO has involved c[illegible]structing state-of-the-art seismic isolation systems, unique vacuum systems, and mirrors that are so smooth that Sanders said it's difficult to even measure their smoothness. LIGO's principal aim is science, although spin-off technologies will benefit industry.

"The challenge of doing something with so many precise requirements is interesting from a technical standpoint, but the science is most interesting to me," Barish said. "No one's ever seen a gravitational wave before, and the fact that we can see it and pursue science is extremely exciting. That's hard to beat."

More information on LIGO can be found at the LIGO website at http://www.ligo.caltech.edu.◆

1998 Physics Graduate Wins Clauser Prize

Courtesy of Caltech Media Relations

When you're beginning a career in cosmology, it's only fitting to start with a bang.

That's what Ben Owen will do now that he has his doctorate in physics. Not only did Owen win the annual Clauser Prize for the best dissertation at the June 12 commencement, but his work has also been the subject of an international symposium. In September, he'll fly to Germany for a new job at the Albert Einstein Institute (where the symposium was held) as a postdoctoral researcher.

The work of Ben Owen, Lee Lindblom, and Sharon Morsink on how gravitational waves are produced by sloshing in the oceans of young neutron stars raises a vista of new questions, with which cosmologists and gravity-wave experimenters worldwide are now struggling.

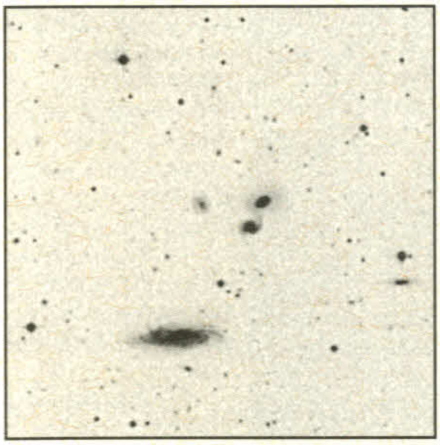
Just how large does the sloshing in a young neutron star get, and what limits its growth? Can LIGO experimenters redesign their computer programs to find Owen's predicted waves in LIGO's plethora of data? What other kinds of stars will slosh wildly, like Owen's newborn neutron stars, and what will that sloshing do to them, and can LIGO be tuned to find their gravitational waves?

Dr. Kip Thorne, Richard P. Feynman Professo[illegible]f Theoretical Physics was Ben's thesis supervisor. Dan Kennefick received the Clauser Prize at the 1997 commencement, making Ben Owen Prof. Thorne's second consecutive student to be awarded the prize.◆

DPOSS ***continued on page 4***

and measures sources detected in the survey images, classifies them as stars or galaxies, and assists astronomers in performing scientific analysis of the resulting object catalogs.

The result of this effort, led by Professor of Astronomy George Djorgovski and including postdoctoral scholars Steve Odewahn and Robert Brunner, graduate student Roy Gal, and a number of Caltech undergraduates, is the Digital Palomar Observatory Sky Survey (DPOSS), consisting of digitized POSS-II images, the resulting catalogs of detected objects, and an extensive amount of calibrations also obtained at Palomar Observatory. The cataloging effort itself is sponsored by the Kenneth T. and Eileen L. Norris Foundation, and the final catalog will be known as the Palomar-Norris Sky Catalog (PNSC). It is expected to contain up to 100 million galaxies and more than two billion stars. This is the largest astronomical digital sky survey to date, and it will be the main source of visible-light information for the northern sky for a number of years.



Although not yet ready for general distribution, some subsets of DPOSS data might be made available later this year. That would enable astronomers around the world to access the survey from their computers and actually conduct research. Some of the possible projects include: studies of the large-scale structure in the universe; galaxy evolution and clustering; structure of our own galaxy; searches for rare types of objects, such as quasars at high redshifts; and so on. Caltech astronomers have already started to work on a number of these projects.

Eventually, DPOSS information (which is based on visible-light measurements) will be combined with an infrared sky survey, 2MASS. Data processing for the 2MASS survey is being carried out on behalf of NASA and a consortium of institutions at Caltech/JPL's Infrared Processing and Analysis Center (IPAC). This union of surveys will be done within the Digital Sky Project, led by Professor of Physics Tom Prince. The Digital Sky will develop the means by which such large datasets, e.g., DPOSS and 2MASS, can be combined and explored quickly and effectively, using modern high-performance computing hardware and software technology.

More information can be found at http://astro.caltech.edu/~george/dposs/dposs.html and http://astro.caltech.edu/~rrg/science/dposs.html. ◆

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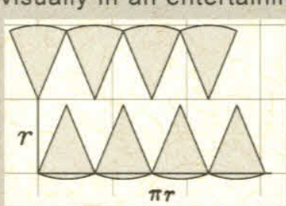
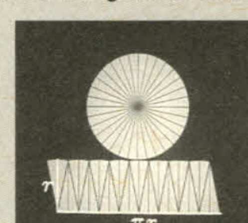
PROJECT MATHEMATICS! IS TEN YEARS OLD

by Professor Emeritus Tom M. Apostol

Exactly ten years ago, Project MATHEMATICS! produced "The Theorem of Pythagoras," the first in a series of computer-animated videotapes designed as support material for mathematics classrooms in grades 8 through 13. Each videotape presents basic mathematical concepts in ways that cannot be done at the chalkboard or in a textbook. Using the full power of video technology, words and images are combined with music and special effects to provide a valuable pedagogical tool to attract young students to the joys of mathematics. In one sequence, for example, animation divides a circular disk into thin triangular pieces that march in time to music, forming a rectangular figure with the same area. The formula for the area of the disk is revealed visually in an entertaining way that increases understanding.



Project MATHEMATICS! was created at Caltech by Professor Tom M. Apostol, author of the calculus texts known to two generations of Caltech undergraduates as "Tommy I" and "Tommy II." With major funding from the National Science Foundation and additional support from Hewlett-Packard and the Intel Foundation, Project MATHEMATICS! has produced nine videotapes that have captured a dozen gold or silver medals at international festivals. Each tape is accompanied by a workbook/study guide.



During the past decade, more than 10 million students have been turned on to mathematics by one or more of these tapes. They are used in classrooms nationwide and abroad, and are also broadcast on many educational TV networks and on the NASA Channel. Recently Israel Educational TV produced a Hebrew translation of the series.

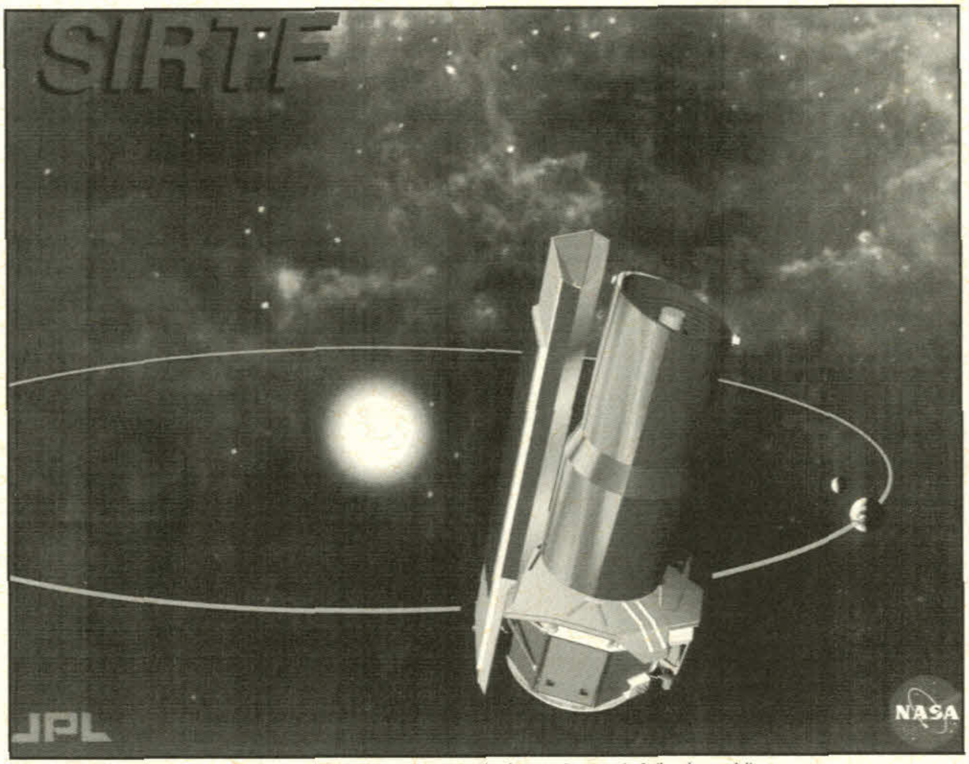
To keep abreast of emerging technology, Project MATHEMATICS! is currently producing interactive discovery-based material for the World Wide Web. All young children have natural curiosity, the prerequisite for learning mathematics. They love to solve puzzles and discover patterns, and the Project is developing activities to enhance this curiosity and show children of all ages that learning mathematics can be exciting and intellectually rewarding.

To learn more about the project and how to acquire the videos and workbooks from the Caltech Bookstore, consult the website http://www.projmath.caltech.edu/. To see a draft/preview of a web activity, consult http://www.projmath.caltech.edu/dsample.html. ◆

SIRTF ***continued from page 2***

10 months. SIRTF's improved sensitivity is largely due to its sophisticated detectors, including tens of thousands of detectors in IR arrays. This compares to the 62 hand-assembled detectors on IRAS. SIRTF will also be two orders of magnitude more sensitive than Europe's Infrared Space Observatory, enabling it to study both young galaxies at the epoch in which they're forming and debris disks around nearby stars.

The Science Center, which will employ up to 120 astronomers, programmers, and others when it is at full strength, will start to solicit proposals for SIRTF about two years before the launch. "We have to have one year of observations ready to go before launch," Soifer said, because of its finite lifetime and expected heavy demand. "Because so much of what researchers do will be based on what they find, we'll want the first year of observing to be exploratory. Then researchers will want to go back and do follow-up observations on what they fo[illegible] using SIRTF."



Space Infrared Telescope Facility in a solar earth-following orbit

While some of the researchers whose proposals are approved will have one year of proprietary usage of the data gathered for them by SIRTF, the data becomes public after that. Part of the Science Center's mission is to create an archive of this data so that researchers from around the world can use it.

"One of the most exciting things about SIRTF is the surprise," said Soifer. "I'll be truly disappointed if I'm not surprised by what we find."

More information and the latest updates can be found at http://ssc.ipac.caltech.edu/sirtf. ◆

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