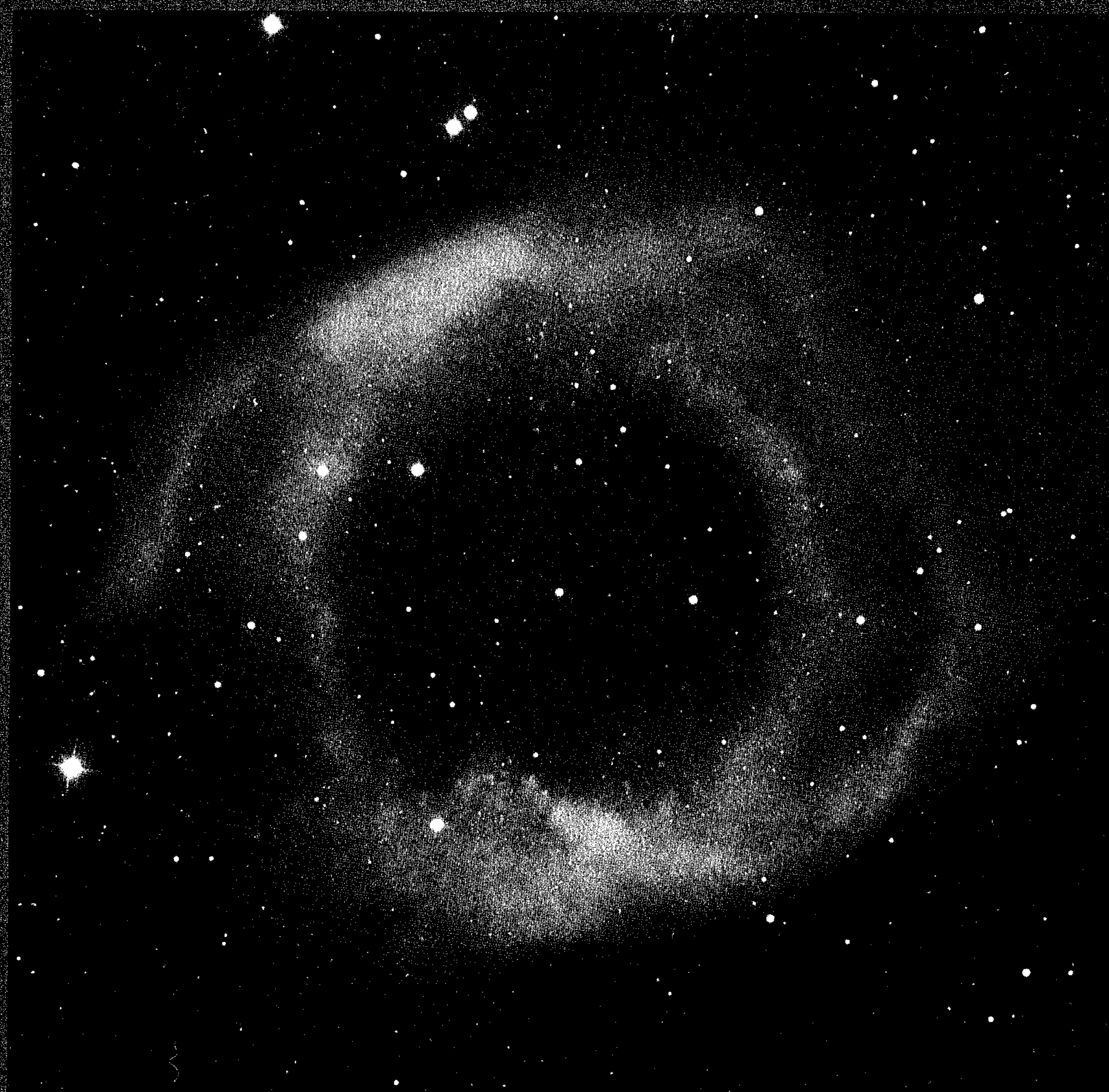
STANFORD LINEAR ACCELERATOR CENTER

Beam Line

Fall 1991, Vol. 21, No. 3



Beam Line

A PERIODICAL OF PARTICLE PHYSICS

FALL 1991 VOL. 21, NUMBER 3

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Cover: A photograph of a planetary nebula in Aquarius, taken with the 200-in. telescope on Mt. Palomar. Planetary nebulae are the ejected outer layers of dying stars of relatively low mass. The relic cores become the white dwarfs discussed in Virginia Trimble's article in this issue. Photo courtesy of California Institute of Technology.

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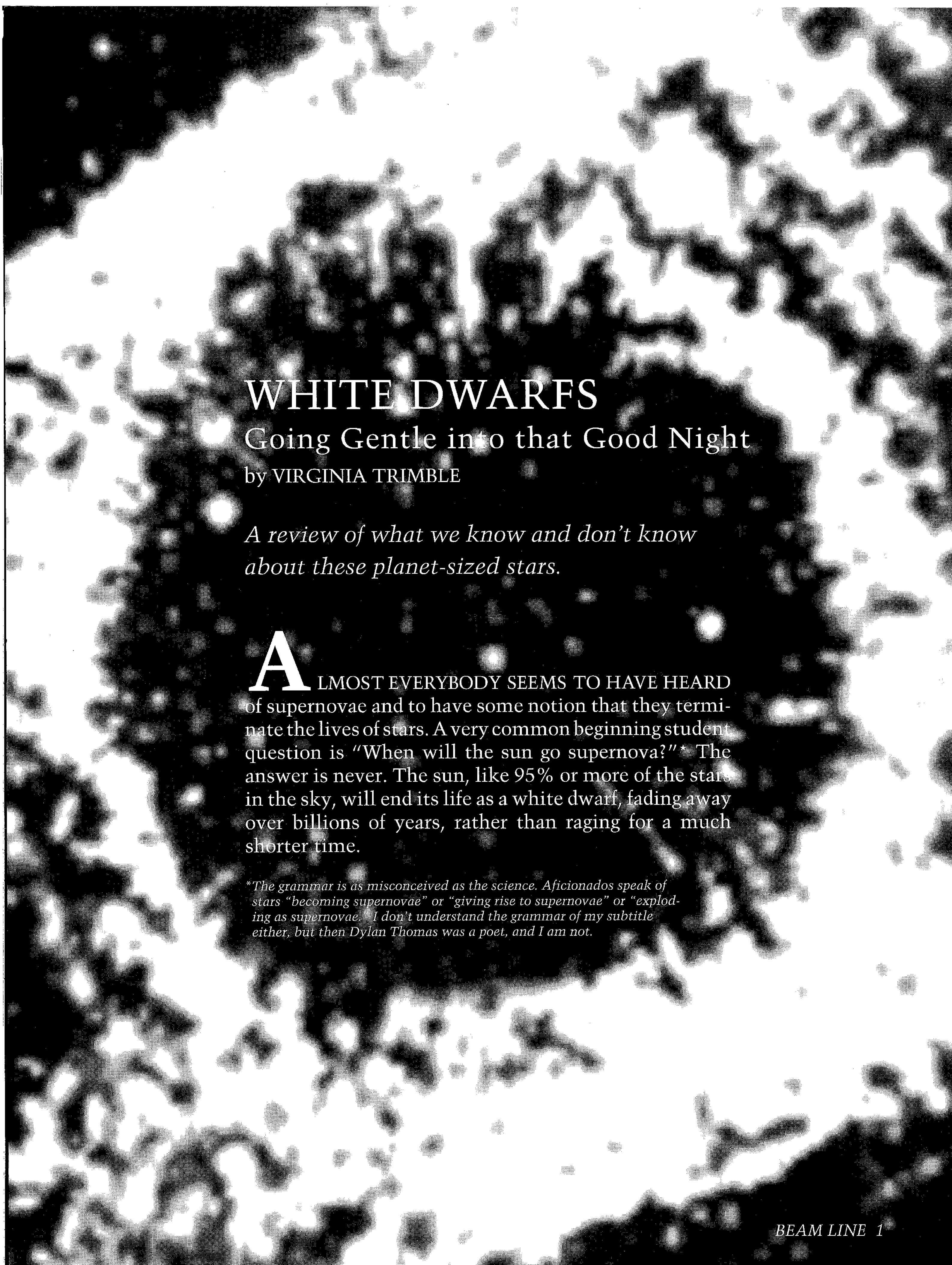


WHITE DWARFS

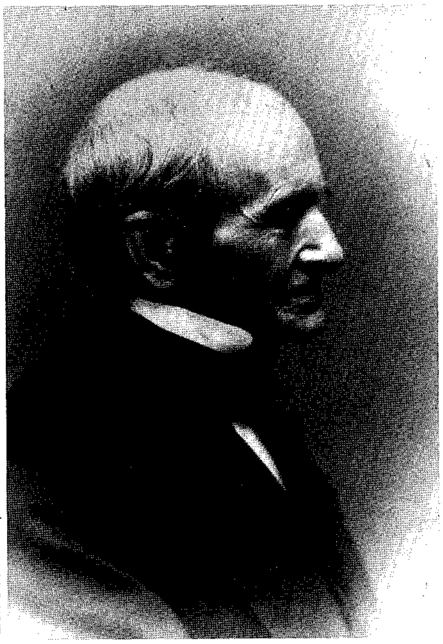
Going Gentle into that Good Night

by VIRGINIA TRIMBLE

A review of what we know and don't know about these planet-sized stars.

ALMOST EVERYBODY SEEMS TO HAVE HEARD of supernovae and to have some notion that they terminate the lives of stars. A very common beginning student question is "When will the sun go supernova?"* The answer is never. The sun, like 95% or more of the stars in the sky, will end its life as a white dwarf, fading away over billions of years, rather than raging for a much shorter time.

**The grammar is as misconceived as the science. Aficionados speak of stars "becoming supernovae" or "giving rise to supernovae" or "exploding as supernovae." I don't understand the grammar of my subtitle either, but then Dylan Thomas was a poet, and I am not.*



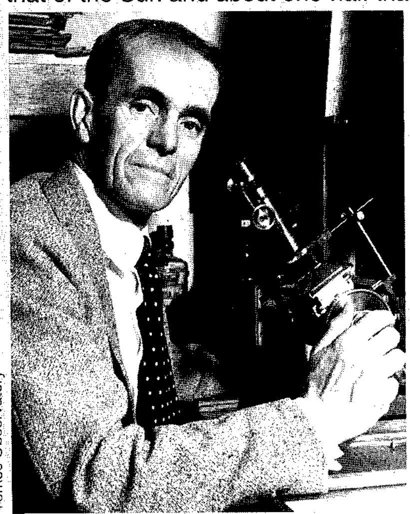
Lick Observatory Archives

Alvan Clark

WE HAVE MADE several attempts during the past two years to secure a spectrum of the companion of Sirius. . . .The great mass of the star, equal to that of the Sun and about one-half that of Sirius, and its low luminosity, one one-hundredth part of that of the Sun and one ten-thousandth part of that of Sirius, make the character of its spectrum a matter of exceptional interest. . . .

The line spectrum of the companion is identical with that of Sirius in all respects so far as can be judged from a close comparison of the spectra. . . .

Direct photographs taken by Dr. van Maanen with and without the use of a yellow color screen agree with the spectrographic results in indicating that the companion of Sirius has a color index not appreciably different from that of the principal star.



Yerkes Observatory

Walter Adams

"The Spectrum of the Companion of Sirius," Walter S. Adams, *Publications of the Astronomical Society of the Pacific* 27, 236–237 (1915) reproduced in *A Source Book in Astronomy and Astrophysics, 1900–1975*, Lang and Gingerich, Editors, Harvard, 1979.

Only a very few stars that begin their lives with more than six to eight times the mass of our sun will end spectacularly. In other words, if you allowed every star a vote,* then white dwarfs would win, hands down, but supernovae seem to have much better public relations. Admittedly, they are easier to make sound exciting, being responsible for the production of heavy elements like uranium and thorium (and the distribution of most of the rest), for accelerating cosmic rays, leaving pulsars behind, and (perhaps) triggering new generations of star formation. Still, numbers should count for something, and white dwarfs have the additional, parochial attraction of showing us what our sun will eventually become—unfortunately not in time to prevent the next round of presidential primaries, but only after five or six billion years.

Briefly, a white dwarf contains the mass of a star, crammed into a volume the size of a planet, and has therefore a density larger than that of terrestrial substances by a factor of a million. The force of gravity holding stars together is balanced by ordinary ($PV = nRT$) thermal-gas pressure in stars like the sun, but by electron degeneracy pressure in white dwarfs.

HISTORY

Friedrich Bessel (as in functions) advocated massive, dark companions as the cause of wiggles in the motion of Sirius and Procyon that he had seen in data from a couple of decades up to 1844. The companion of Sirius advanced from dark to dim in 1862 through the intervention of Alvan G. Clark, arguably the last optical astronomer to make a fundamental discovery with a telescope he had designed and built himself.** Turning a newly-ground 18.5-inch lens toward the brightest star in the sky, he saw separately the 0.01% of the photons that come from the companion, 10 arc-sec away from the glare of Sirius A. Procyon B turned up as a separate point of light in 1894.

White dwarfs counted as a problem, however, only after the onset of serious classification of stellar spectra and the recognition that absorption line patterns, stellar colors (hence temperatures), and luminosities were nearly always strongly correlated. The properties of Sirius B, reported in 1914 by Walter S. Adams at Mt. Wilson Observatory, defied the correlations. The star was blue (hot) and yet faint. A handful of additional white dwarfs joined in the defiance over the next decades.

Theoretical understanding began with R.H. Fowler's development of (non-relativistic) quantum statistics in 1926 and was essentially complete when S. Chandrasekhar presented the exact equation of state for relativistically degenerate electrons and the properties of stars dominated by that degeneracy between 1930 and 1935. His contemporaries were slow to understand the correctness and importance of what he had done, but I think this belongs more to the

**Of course, if stars are allowed to vote, then they should also pay taxes. One dollar per star in our Milky Way galaxy would just about take care of this year's budget deficit (which I decline absolutely to describe as "astronomical.")*

***A point which may not be totally irrelevant to recently revealed problems in optical telescope design.*

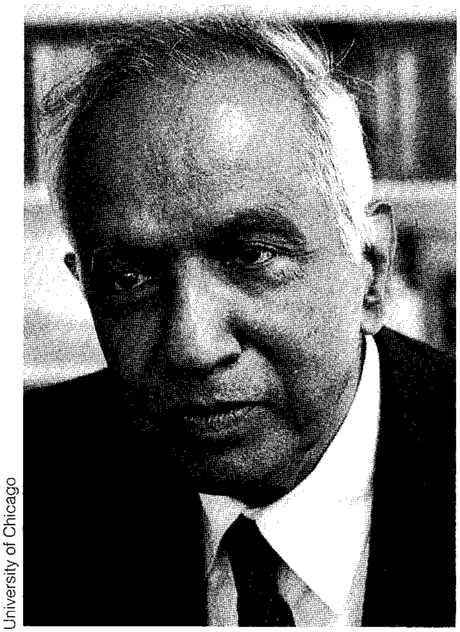
realm of sociology than to history of science. Incidentally, 20 years between recognition of an astronomical problem and arrival at a solution that then holds up for much longer is a fairly typical time scale.

THINGS WE UNDERSTAND

About one white dwarf per year forms somewhere in our galaxy, a number arrived at independently by counting the young (hot, relatively bright) ones, by counting prospective progenitors, and by counting the nebulae ejected in the intermediate "thin shell" phase (called planetary nebulae, and if you want to know why, you must read a real astronomy book). Ten percent or more of a complete stellar inventory consists of white dwarfs, just sitting there, radiating away the thermal (kinetic) energy of their carbon and oxygen nuclei from underneath very thin skins of hydrogen and helium. They will continue this uneventful course until the universe recontracts, their baryons decay, or they collapse to black holes by barrier penetration.*

Half or so of all stars have companions close enough for gas to flow from one to the other. Material transferred to a white dwarf falls into a deep potential well, hence radiating copiously as it goes, and exploding from time to time, when it piles up to fusion temperatures and densities. Collectively such systems are called cataclysmic variables, botanically divided among novae, dwarf novae, and a good many others. Enough astronomers earn a living studying CVs to permit gatherings of a hundred or two every few years.

Very occasionally, mass transfer or merging in white dwarf pairs may trigger explosive burning of the carbon and oxygen core material up to iron. The stars are blown to smithereens called Type I supernovae. (Massive stars make type II, commoner but less bright.)



University of Chicago

Subrahmanhan Chandrasekhar

The Great Scheme of Things

AT LEAST BY THE STANDARDS OF ASTROPHYSICS, stellar structure and evolution are in pretty good shape—meaning we can marshall a set of coupled, non-linear differential equations and their solutions to support what is said in the next few paragraphs.

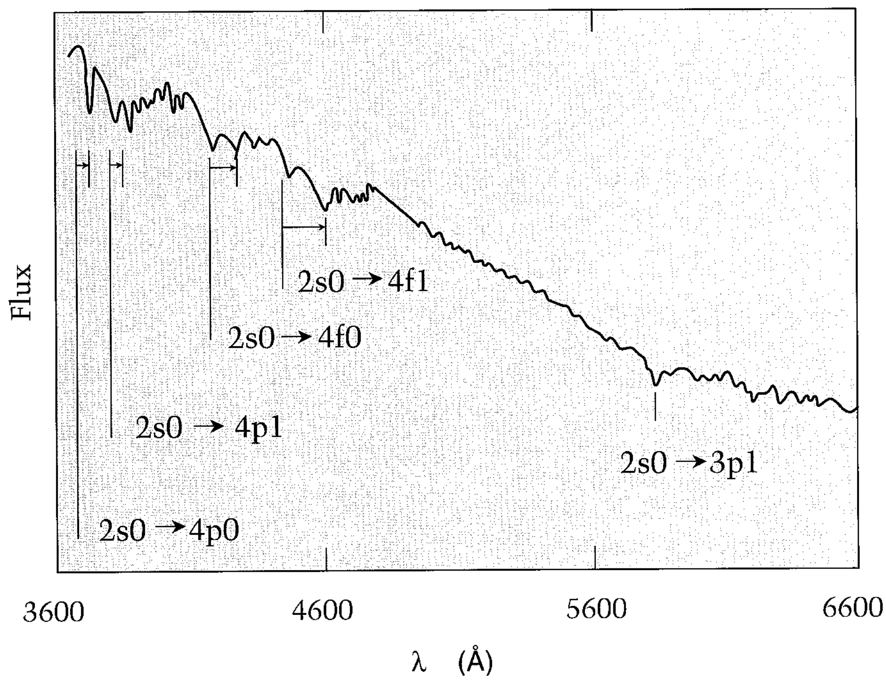
Stars are, by definition, stable objects deriving their energy from nuclear reactions. A gas cloud of standard composition (about 3/4 hydrogen, 1/4 helium, and 2% everything else) and mass = 0.085 –100 solar masses [one solar mass ($M_\odot$) = 2×10^{33} g] will contract to form such a star. Smaller masses do not get hot enough for any fusion reactions; bigger ones are unstable. All stars spend 90 percent or more of their lives fusing hydrogen to helium. The time to exhaust hydrogen fuel is, very crudely, t = [10^{10} yr/($M/M_\odot$)^2], that is, millions of years for big stars, billions for little ones, including the sun.

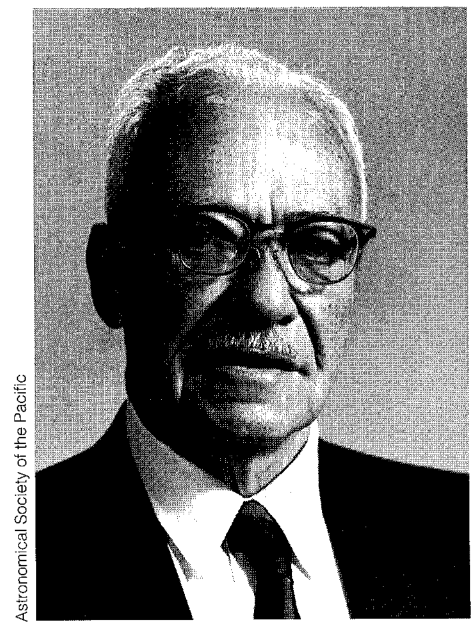
Masses less than about 0.4 $M_\odot$ leave their helium cinders so degenerate that no further contraction, heating, or fusion can occur. The universe is not yet old enough for this to have happened to any isolated star. But stripping of outer layers can occur among close stellar pairs, leaving low-mass helium cores in shorter times. There exist low-mass white dwarf binaries where the stars are tearing each other apart viciously enough that the layers accessible to spectroscopy confirm the mostly-helium composition predicted for these cores.

Larger masses all heat to at least 10^8 K at their centers and so fuse helium to carbon and oxygen, in roughly equal amounts, first in their cores and then in thin shells. A combination of radiation pressure and pulsational instability in this "thin-shell" phase ejects much of the hydrogen-rich envelope. Thus initial masses up to 6 or 8 $M_\odot$ are stripped down to carbon-oxygen cores of 0.4–1.4 $M_\odot$. These degenerate C-O cores are much the commonest kind of stellar relic.

Only higher masses still go on to fuse carbon and oxygen to heavier elements and eventually make supernovae. A few on the ragged edge may burn out en route, leaving degenerate cores of oxygen, neon, and magnesium, a third category of white dwarf. The C-O and O-Ne-Mg compositions are confirmed spectroscopically in nova explosions that eject some material from white dwarfs in more massive close pairs.

**Likely time scales for these three outcomes are 10^{14}, 10^{33}, and $10^{10^{76}}$(years for the first two and for the third one it doesn't matter).*





Rudolph Minkowski

Observed spectrum and line identifications in the magnetic white dwarf PG 1031+234 (greatly simplified from G.D. Schmidt 1987, in A.G.D. Philip et al., Eds. IAU Colloq. 95, the Second Conference on Faint Blue Stars, Schenectady: L. Davis Press, p. 377). The wiggly line is observed flux vs. wavelength. Long vertical lines are placed at the wavelengths of the indicated transitions for magnetic fields of 200-300 MG; arrows and shorter vertical lines indicate the range of wavelengths of absorption in those transitions for somewhat stronger fields. The lines you expect to see are those that reach turning points or asymptotes, so that wavelength changes only slowly with field strength in the 100 MG range. Remember that, for hydrogen in the absence of a magnetic field, all components of 2→3 (called H α or Balmer α) are at 6562.8 Å, and all components of 2→4 (called H β or Balmer β) are at 4861.3 Å. The strong field breaks the degeneracy of the transitions as well as shifting absorption wavelengths.

AND THINGS WE DON'T

Why are white dwarfs such slow rotators? Why do a few have enormously strong magnetic fields and most very little? Why are there so few faint white dwarfs? Where are the Type I supernova progenitors? There are lots of others, but these are my favorites and will do to get on with.

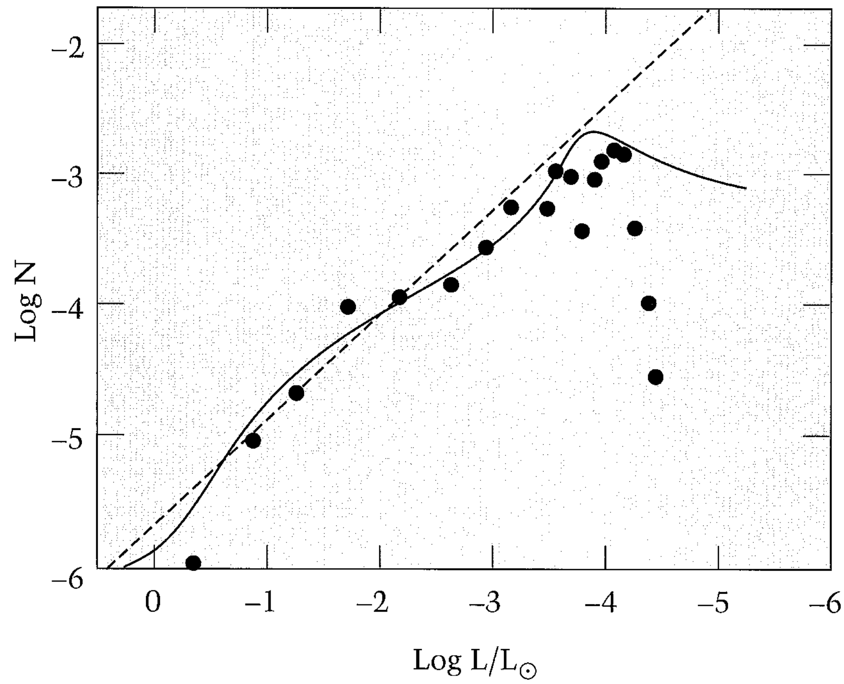
ROTATION. A spinning white dwarf begins to break up only for rotation periods shorter than a few seconds. Conservation of angular momentum in layers as stars evolve from initial hydrogen burners to degenerate cores should lead to rotation periods of minutes to hours. In most cases, we know only limits to rotation speeds (from absence of Doppler blurring of spectral lines) and periods (from absence of changing surface magnetic field patterns). The limits range from hours upward to years.

Neutron stars left by supernovae exhibit the same phenomenon. Most of them are not born spinning nearly as rapidly as stability permits or as angular momentum conservation in layers predicts. Evidently stars are good at transporting angular momentum outward, through turbulence, magnetic fields, or some other form of coupling. But we cannot currently describe the process well in words, let alone in differential equations.

MAGNETIC FIELDS. For the majority of white dwarfs, absence of quadratic Zeeman shift tells us that surface fields are $\lesssim 10^5$ G (10 Tesla*). Conservation of flux from a 1–10 G solar dipole through the contraction process brings us within this limit. But a few percent of single degenerate dwarfs and 10–20% of the close binary ones have fields between 1 and 1000 MG. Wavelengths of atomic transitions are so distorted by such fields that absorption lines in magnetic white dwarfs remained unidentified for some 40 years after Rudolph Minkowski recorded the first spectrogram of one in 1939. Early field determinations thus came from measurements of circular polarization. Recognition that the random-looking features were just the shifted Balmer lines of hydrogen came gradually and from close interplay of theory, observations, and laboratory experiments. The largest stellar field

**White dwarfs seem to be the only objects in the universe for which the Tesla is a reasonable-size unit, which is undoubtedly why we never use it.*

Jesse Greenstein



Observed vs. expected numbers of white dwarfs in the solar neighborhood as a function of luminosity in solar units. Dots are observed numbers per cubic parsec per decade in L (from J. Liebert, C. Dahn and D.G. Monet, 1989, Astrophysical Journal 332, 891). Dashed curve is the simplest possible model, with constant birthrate and constant ratio of surface to central temperature, roughly normalized to the intermediate points. Solid curve is a model with constant birthrate but much better treatment of radiative transfer and other physics (from F. D'Antona and I. Mazzitelli 1989, Astrophysical Journal 347, 934). Both clearly predict too many faint stars. The observed cutoff below Log L /L$_0$ = −4 can be achieved by having the faint stars cool very suddenly or by imposing an upper limit to ages of 6-8×10^9 yr (vs. 12–17×10^9 yr for the halo stars in our galaxy).

for which deconvolution has been achieved approaches 300 MG (work in progress by Jesse L. Greenstein at Caltech on G 240–72).

It is permitted to attribute the range of fields to exact flux conservation from main sequence progenitors with 1–3×10^4 G dipole fields. This does not explain the excess of strong fields in binary white dwarfs or the difference from neutron stars, all of which start with 10$^{12–13}$ G fields, though their progenitors presumably have a wide range. In any case, the genesis of stellar magnetic fields in general is not understood, so one is merely pushing the problem back a step in time.

FAINT WHITE DWARFS. Start with the plausible assumptions that white dwarfs have formed at a constant rate since the galactic disk has been around and cooled as black body radiators ever since, drawing on their internal kinetic energy supply. Then, after a lot of hard work (occasioned by crystalization of the core, radiative transfer through partly degenerate gas, and so forth) you can predict what the current distribution of white dwarf brightnesses should be. You generally get the wrong answer. We see far fewer faint white dwarfs than expected unless (a) some serious physics has been left out of the parentheses a couple of sentences back or (b) the galactic disk is not very old. Notice that if more stars formed in the past, the problem gets worse.

Blaming everything on the second cause yields a disk much younger than the galactic halo stars (globular clusters), and we have learned something about galaxy formation and evolution. Active researchers are about equally divided on whether or not a young disk is required by white dwarf statistics; the rest of us are sitting on the side lines, attempting to make encouraging noises.

PROGENITORS OF TYPE 1 SUPERNOVAE. Having confidently told you that we know these nuclear explosions come from binary white dwarfs, I must now back off and confess that there are no known examples of the most promising sort of system. To get the requisite explosion, pairs must be (a) close enough for angular momentum loss in gravitational radiation to bring the stars together in the age of the universe and (b) massive enough that the merged pair will comfortably exceed the Chandrasekhar limit to masses supported by electron degeneracy (about 1.4 $M_\odot$). But the known close pairs are all low mass, and the known massive ones are too wide to merge. There the problem sits, and has sat through about five years of increasingly serious searches for massive close pairs.

IF YOU HAVE STAYED with us this far, I will try your patience a moment longer and explain my own involvement with white dwarfs over the years. All Caltech graduate students in astronomy were (and are) required to complete a test research project before settling on a PhD dissertation topic. The one assigned to me in 1965 was measurement of radial velocities of about 60 white dwarfs, based on 200-in. telescope prime focus spectrograms obtained by Jesse L. Greenstein in the 50s and 60s. In retrospect, I think this may have been partly because the task was thought to be impossible, and female graduate students were new, at least to Caltech, in those days.

The task turned out to be difficult (pressure broadening makes the spectral lines of white dwarfs remarkably broad) but not impossible. The measurements led to an estimate of the amount of gravitational redshift and so to values for masses of single white dwarfs, not otherwise available. Our average value, 0.75 $M_\odot$, was slightly larger than the modern average, 0.6 $M_\odot$, as found from pressure effects on the shape of the stars' spectral continua. Deep down, I still believe the larger value, and, after all, every scientist is entitled to be cranky about one or two points.

These same radial velocity data produced the 10^5 G limit on magnetic fields for typical white dwarfs mentioned above and were the source of the first list of candidate massive double degenerate stars, none of which have actually turned out to be likely SN Ia progenitors. In April 1991, I submitted a proposal to look for coronal x rays from single, cool magnetic white dwarfs using the ROSAT satellite in collaboration with Keith Arnaud of Goddard Space Flight Center.

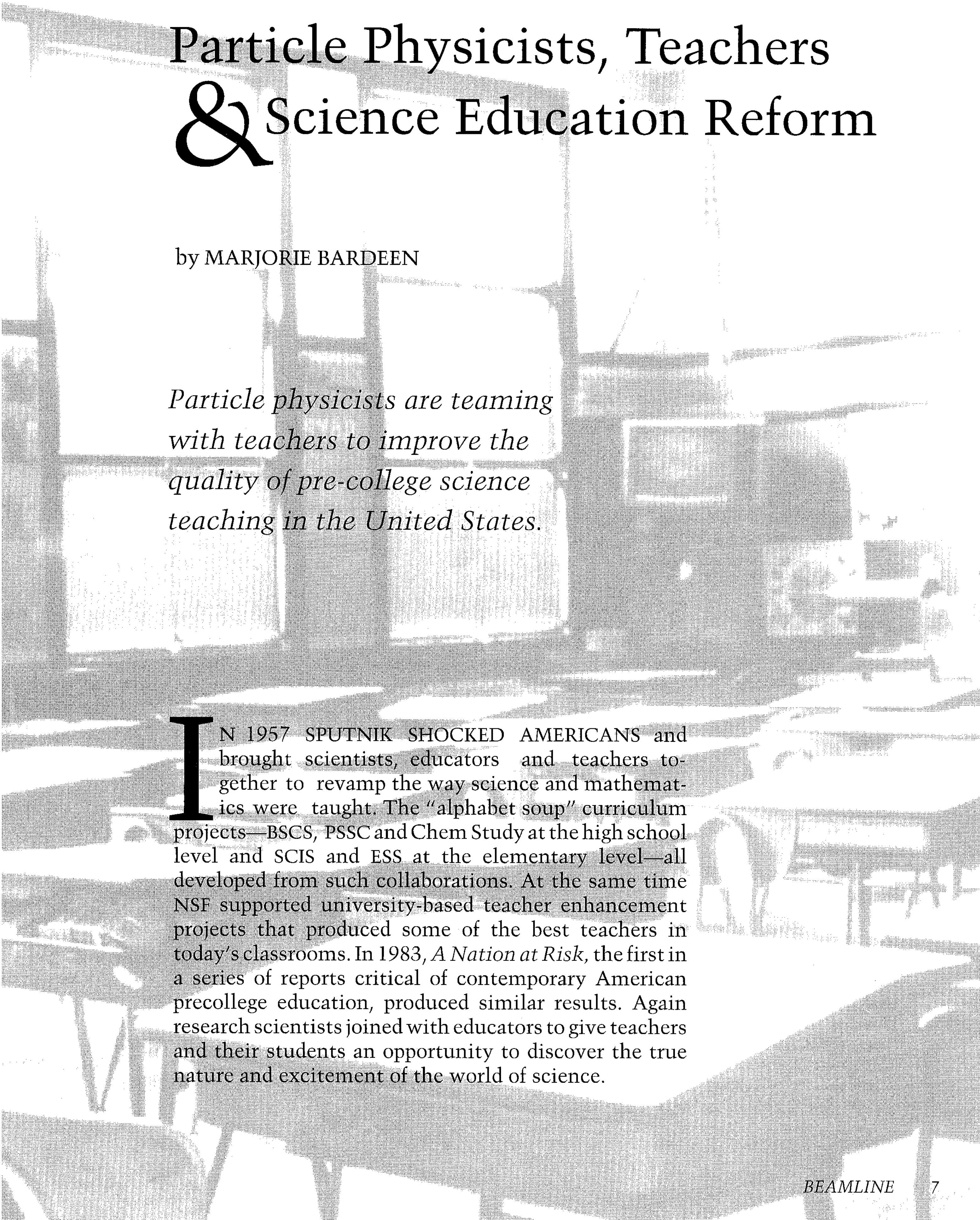
SUGGESTIONS FOR FURTHER READING

G. Wegner, Ed., *White Dwarfs*, Springer-Verlag, 1989.

F. D'Antona and I. Mazzatelli, "Cooling of White Dwarfs," *Annual Reviews of Astronomy and Astrophysics* 28, 139 (1990).

Note From the Editors

For those readers who may be interested in moving on (in?) to even more compact objects than white dwarfs, we commend to your attention a recent survey article written by the same author: Virginia Trimble, "Neutron Stars and Black Holes in Binary Systems," Contemporary Physics **32**, 2, 103–119, 1991. This is a masterly synthesis of what is and is not known about these fascinating objects, and it is written with the author's customary clarity and wit.

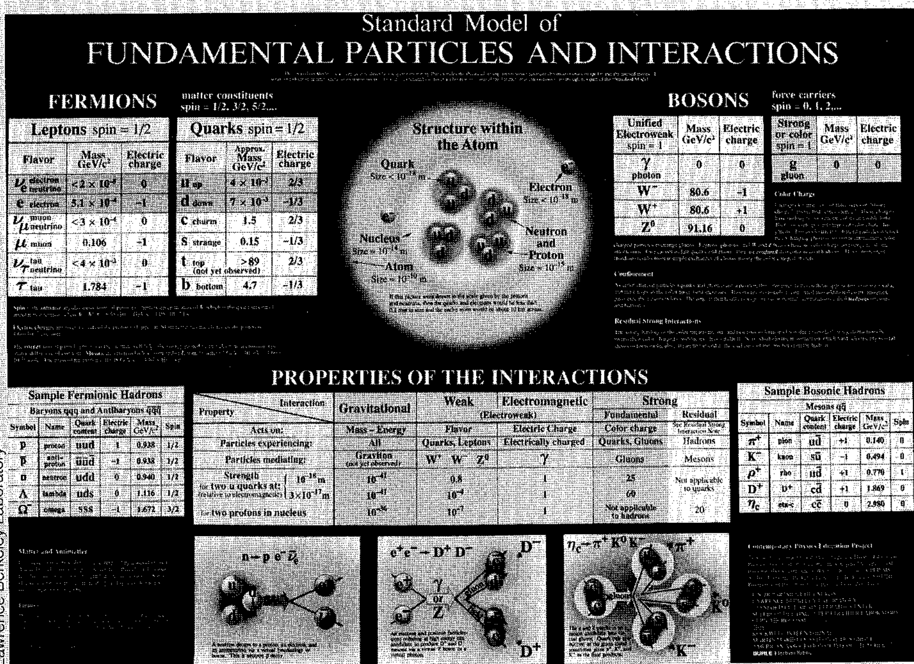


Particle Physicists, Teachers & Science Education Reform

by MARJORIE BARDEEN

Particle physicists are teaming with teachers to improve the quality of pre-college science teaching in the United States.

IN 1957 SPUTNIK SHOCKED AMERICANS and brought scientists, educators and teachers together to revamp the way science and mathematics were taught. The "alphabet soup" curriculum projects—BSCS, PSSC and Chem Study at the high school level and SCIS and ESS at the elementary level—all developed from such collaborations. At the same time NSF supported university-based teacher enhancement projects that produced some of the best teachers in today's classrooms. In 1983, *A Nation at Risk,* the first in a series of reports critical of contemporary American precollege education, produced similar results. Again research scientists joined with educators to give teachers and their students an opportunity to discover the true nature and excitement of the world of science.



Lawrence Berkeley Laboratory

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Particle physicists have been leaders in this effort since 1979 when Leon M. Lederman, director of Fermilab, started *Saturday Morning Physics* for high school students. At the time Fermilab funds could not be spent on precollege education programs, so Lederman encouraged the establishment of Friends of Fermilab, a not-for-profit corporation dedicated to supporting Fermilab precollege programs. Since its incorporation in 1983, Friends of Fermilab has raised over $2,600,000 from public and private sources including DOE, NSF, the state of Illinois, and various private foundations.

The Conference on the Teaching of Modern Physics was held at Fermilab in 1986. Organized by the American Association of Physics Teachers and Fermilab, the Conference brought high school teachers and college professors together to develop ways of translating the excitement of modern physics to introductory physics classrooms. An important collaboration to emerge from the Conference was the Contemporary Physics Education Project based at LBL and SLAC. This group of 20 educators and scientists has created the first physics equivalent of the Periodic Table of the Elements. The Particle Chart is the centerpiece of a package of teaching materials (above) that includes interactive HyperCard software for the Macintosh computer. A student book and a teacher's packet are being developed under the leadership of R. Michael Barnett, Lawrence Berkeley Laboratory, and Helen R. Quinn, SLAC. Workshops for teachers are an essential aspect of the project—SLAC held a one-week workshop this summer, and *The Modern Physics Institute,* held at Westminster College, New Wilmington, Pennsylvania, has close ties to the Project. Workshops have also been presented in conjunction with professional meetings.

SINCE 1989 OTHER PARTICLE physics laboratories funded by DOE have initiated precollege education programs in response to Secretary of Energy James D. Watkins' aggressive education policy opening laboratory doors to schools. For example, at Bates Linear Accelerator in Massachusetts, Ernest J. Moniz has inaugurated a program to augment high school teachers' knowledge about nuclear and particle physics. Three high school teachers worked with local staff mentors to produce a draft resource manual that will be used in a fall lecture series for high school teachers. The course will be team taught by the teachers and faculty members from MIT, Boston University, and Northeastern University. Under the leadership of Beverly Hartline, a partnership between the Continuous Electron Beam Facility (CEBAF) in Virginia and the Newport News Public Schools offers a program for fifth and sixth graders called *Becoming Enthusiastic About Math and Science* (BEAMS). BEAMS brings regular classes and their teachers to the Laboratory for week-long visits. The classes follow their normal curriculum augmented by special activities conducted by CEBAF scientists, engineers and technicians. A parent open house is held one evening during the week.

The Superconducting Super Collider Laboratory (SSCL) has developed a program, *Adopt a Magnet,* to help students in kindergarten through fifth grade understand the purpose and function of the SSC. The younger students are introduced to the SSC through songs and games. Older students do various electronic projects. Upon completion of the program, participating schools "adopt" one of the more than 10,000 SSC magnets. Schools receive an adoption certificate, and the school's name is placed on the adopted magnet.


Robin Dombeck

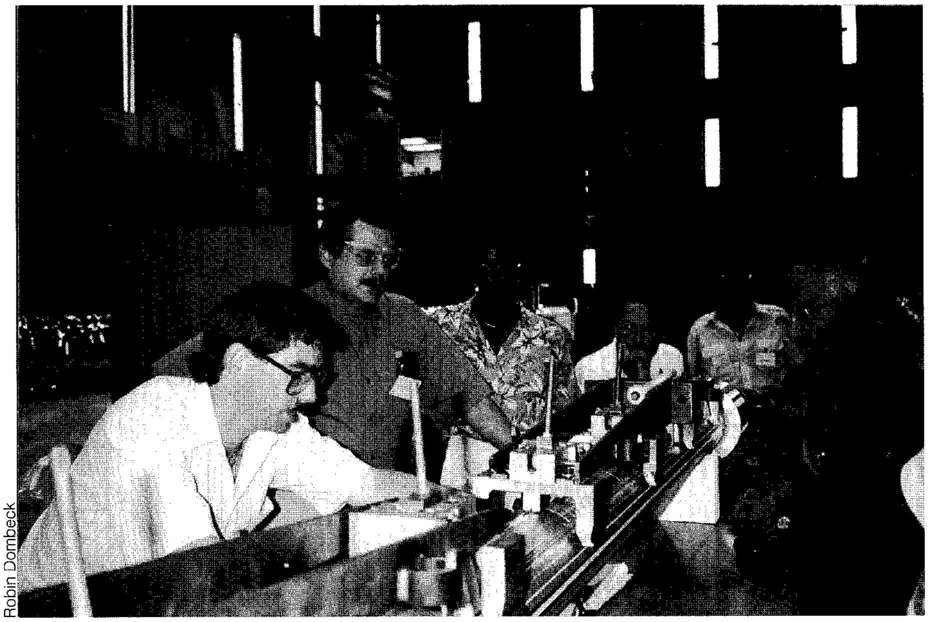
Physicist Jim Strait listens intently to Zelda Tetebaum during the Summer Science Project at Fermi National Accelerator Laboratory.

Particle physicists based at universities also participate in school reform. For example, Howard S. Goldberg leads a team of scientists and mathematicians from the University of Illinois at Chicago which is developing a K–8 curriculum, *Teaching Integrated Mathematics and Science* (TIMS). This initiative, based on understanding fundamental concepts and processes, integrates the teaching of science and mathematics while remaining faithful to the spirit of both disciplines. The conceptual framework for TIMS experiments includes a four-step format that contains the essence of the scientific method allowing students to define the two primary variables, measure the responding variable after having set up an appropriate experiment and analyze the results.

Kenneth G. Wilson participates in *The Ohio Mathematics/Science Discovery Project,* led jointly by the Ohio board of Regents, the Ohio State University and Miami University. Initially, the project is aimed at improving the way science and mathematics are taught to fifth- through ninth-graders by enabling them to recreate some of the most fundamental discoveries in science through their own hands-on experiments. Resource centers for teachers will be established across the state. The new extended community of teachers, faculty, and researchers created by this program will ensure that every classroom teacher has state-of-the-art advice and assistance available every day.

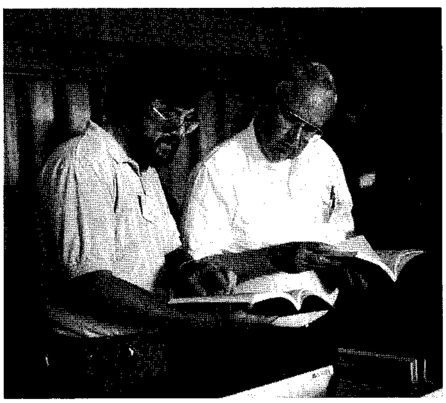
Other particle physicists are involved with hands-on science museums modeled after the Exploratorium in San Francisco, California, founded by Frank Oppenheimer. MICROCOSM is a new science museum at CERN. Hannu I. Miettinen is a founder and former director of Heureka, the Finnish Science Centre. SciTech, a science museum in Aurora, Illinois, was founded by Ernest Malamud.

AT FERMILAB THE OLDEST continuing collaboration between particle physicists and educators is responsible for the 35 precollege education programs offered in 1990 for over 10,000 students and 2100 teachers. The following description of those Fermilab programs focused directly



Robin Dombeck

Physicist Steven Delchamps, left, explains the process of superconducting magnet making to teachers during the Summer Science Project at Fermi National Accelerator Laboratory.



Mark Alleman

Middle: California high school physics teachers Richard Taylor, left, and Earl Boynton review material during SLAC's week-long Teacher Workshop. Above: Visitors to SciTech in Aurora, Illinois, enjoy the three-armed Chaotic Pendulum, one of over 130 hands-on exhibits. Scitech, an interactive science and technology center, had over 62,000 visitors its first year.

on particle physics serves as an example of what a research facility can offer.

HIGH SCHOOL PROGRAMS. Fermilab's high school programs include research participation, institutes and workshops, classes, support networks, instructional materials, and Public Information Office guided tours.

Fermilab has offered summer research appointments to teachers since 1983. A first-hand experience in the laboratory can translate into enhanced teaching strategies and new instructional materials for teachers who may never have worked in a research environment. Current appointments are supported in part by the *DOE Teacher Research Associates Program* (TRAC).

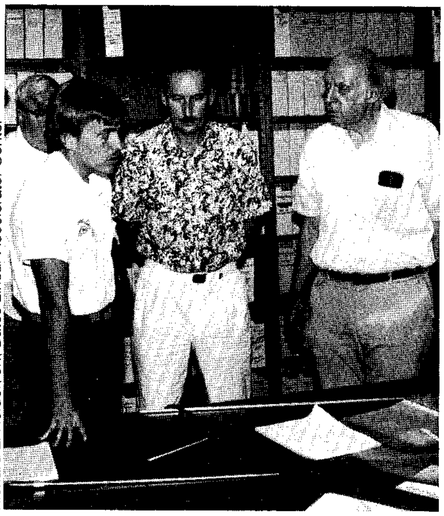
Institutes and workshops offer opportunities to enhance teachers' backgrounds in basic science, model successful teaching strategies, and present new instructional materials. Fermilab has offered the *Summer Institute for Science and Mathematics Teachers* (Summer Institute) since 1983. Today, the Summer Institute is sponsored jointly by Fermilab and Chicago State University and is hosted at the university primarily for Chicago public high school teachers. The program combines the expertise of scientists and mathematicians who give seminars on current research topics with the expertise of master teachers who lead laboratory sessions that present the topics at a high school level.

One of the most effective spinoffs of the Summer Institute is *Physics West,* a teacher support network. Teachers meet on a monthly basis during the school year to share successful teaching strategies and instructional materials. A corps of dedicated teachers keeps the network alive, and Fermilab supports the newsletter.

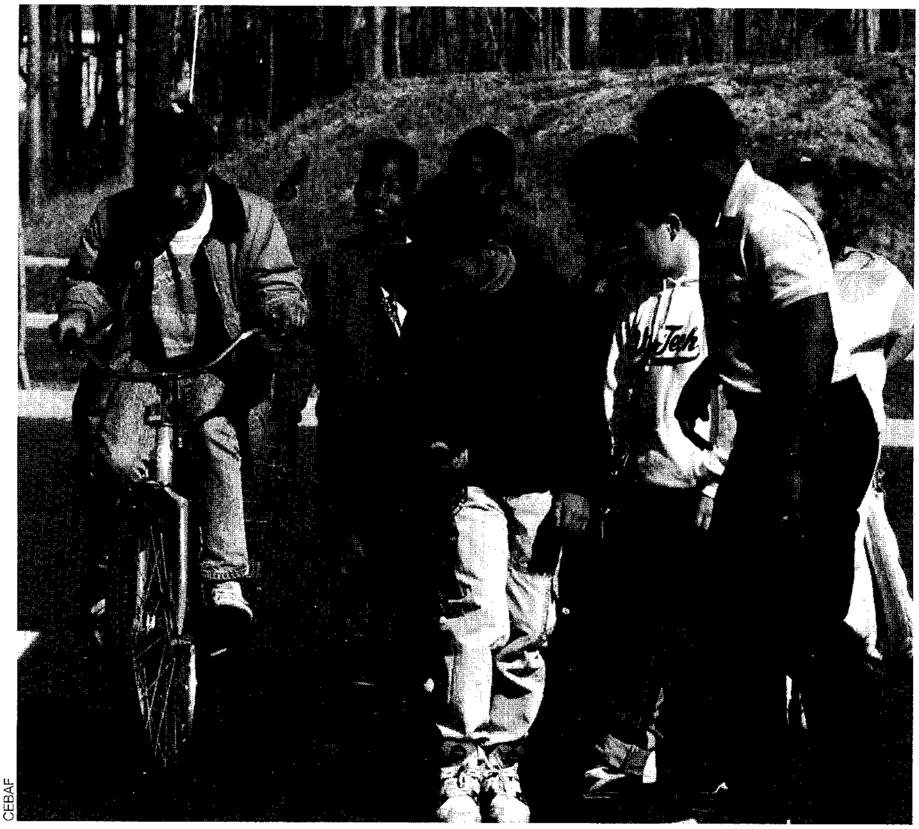
Topics in Modern Physics is a collection of instructional materials developed from *Saturday Morning Physics,* the Summer Institute and the 1986 Conference. Included are a three-volume teacher resource manual, a series of 15 videotapes from the Fermilab archives and several posters. Fermilab provides the materials at cost, and the six physics teachers who prepared the collection give presentations and workshops at professional meetings and on request.

Three sessions of *Saturday Morning Physics* are offered annually for high school students. The class, which meets for three hours on ten Saturdays, includes a lecture by a senior scientist and small discussion groups and tours of the Laboratory with postdoctoral students.

Research experiences are offered to high school students who have the background to join either an experiment or a technical group. Two programs, *the DOE High School Honors Research program* and *Target: Science and Engineering,* enhance the research experience with



Richard L. Heider, Jr., Bates Linear Accelerator Center



CEBAF

seminars or classroom work on a related science project.

MIDDLE/ELEMENTARY SCHOOL PROGRAMS. Fermilab makes research appointments to middle school teachers in the TRAC Program, offers institutes and workshops, supports a middle school teacher network, and provides instructional materials. Students may visit the Laboratory and participate in a variety of science experiences. Two particle physics programs are described below.

Beauty and Charm: an Introduction to Particle Physics includes an instructional unit, a tour, and a teacher training workshop. The purpose of the unit is to provide an experience in science to broaden and enrich attitudes and to develop an appreciation for physics. Students who study the unit at school may tour the Laboratory and meet with a physicist.

The Summer Science Project is a summer institute for middle school teachers who receive training as lead teachers. During the institute participants develop a dissemination project to implement during the following school year. The curriculum includes seminars on basic science, training sessions on effective science instruction and inservice techniques, laboratory sessions where participants try out hands-on classroom activities, and tours.

In 1983 it was not at all clear that a research facility was an appropriate setting for a major science reform initiative. Teachers and students have given us the answer: "Yes!" Precollege education programs work at DOE national laboratories because it is *not* business as usual. Teachers come to a world class high energy physics research laboratory for a unique opportunity to witness science conducted at the frontiers of human understanding and to learn from leading research scientists. Students have an experience in science that broadens and enriches their attitudes and develops their appreciation for science. Students see, perhaps for the first time, what the world of science is really like, and they like what they see.

Above left: High school teachers from Massachusetts engage Professor Jerome I. Friedman, right, one of last year's Physics Nobel Laureates, in discussion after his talk to the group. The program is supported by Bates Linear Accelerator Center and the National Science Foundation. The "mentors" helping the teachers are supported by the Department of Energy, an example of collaboration among funding agencies to improve the quality of pre-college science education. Above right: Students in CEBAF's BEAMS program compete in a "slow" bicycle race, computing their average velocity by measuring their time and distance.

H. Breuil, *Four Hundred Centuries of Cave Art*

Workshops Target THE NEXT LINEAR COLLIDER

A review of recent linear collider conferences in Lapland and Protvino by two participants.

by DAVID BURKE and EWAN PATERSON

TWO WORKSHOPS CONVERGED THIS FALL to focus and sharpen the goals and development of future electron-positron linear colliders. These two meetings, one centered around the particle physics of e^+e^- collisions, and the other around the accelerator physics and technology of linear colliders, were attended by a total of nearly 250 physicists from all parts of the globe. Together they marked the first opportunity for such a broad representation of particle and accelerator physicists to meet for serious discussions aimed at the realization of the next high-energy electron-positron linear collider.

The First International Workshop on Physics and Experiments with Linear Colliders was held at Saariselkä in Finnish Lapland the second week in September and was followed a week later by the gathering of accelerator physicists in Protvino, USSR, for the Third International Workshop on the Accelerator Physics and Technology of Linear Colliders. These meetings were spawned by recommendations from the International Committee on Future Accelerators (ICFA) and were organized by the Finnish Institute for High Energy Physics (SEFT) and by the Branch of the Institute for Nuclear Physics at Protvino (BINP). The tightly coupled sequence of two meetings created a most effective format.

Burton Richter (SLAC) opened the Saariselkä meeting with a report on the recent performance of the SLC and an overview of progress in the advancement from the SLC to the next linear collider. Gus Voss (DESY) introduced the audience to the variety of work and problems being addressed by accelerator physicists around the world, and Michael Peskin (SLAC) outlined the particle physics issues to be confronted by the workshop participants.

The opening session was followed by extensive parallel meetings in which various studies and results were presented and critically compared. A unique and compelling program of physics to be addressed by a collider capable of reaching 300–500 GeV emerged in the synthesis of work reported by European, Japanese, Soviet, and American scientists. Detailed studies of the production and decay of top quarks, studies of the interactions of electroweak gauge bosons, and exhaustive searches for scalar particles comprise the heart of the physics program for the next linear collider. These investigations will directly and decisively probe the most puzzling of the outstanding problems of the Standard Model of electroweak interactions. Displayed throughout the plenary talks that ended the conference, this consensus of the participants was succinctly put forth by Björn Wiik (DESY) in his final summary: "The physics programme of a 300–500 GeV e^+e^- collider with luminosity 10 fb^{-1} per year has unique features and is complementary to the physics programme at the hadron colliders LHC and SSC."

It is remarkable that the mass of the top quark is (apparently) greater than that of the electroweak gauge bosons, and furthermore, approaches the vacuum expectation value of the Higgs field. Understanding the role of this particle in the hierarchy of nature is an important goal for the future. The analysis techniques and machine parameters required for experimental investigation of the top quark were extensively discussed and considerably sharpened at Saariselkä [Peter Zerwas (DESY) and Keisuke Fujii (KEK)]. Helicity analyses of the production and decay of top quarks will provide constraints of a few per cent on the static moments of the top quantum state and similar constraints on unexpected components in its charged electroweak coupling (*e.g.*, a right-handed current). These analyses are significantly enhanced by the ability to control the spin of the incident electrons to project out different polarization states of the produced $t\bar{t}$ pairs.

The top quark may also be a source of new particles. It will be particularly important to look for decays such as $t \rightarrow bH^+$ or $t \rightarrow \tilde{t}\tilde{\gamma}$. Some of these may occur with significant branching fractions, and are easily isolated at an electron-positron collider. With sufficient luminosity (30–50 fb^{-1}) it will be possible to measure the cross section for production of the $Z^0t\bar{t}$ final state, which allows a determination of the Higgs Yukawa coupling of the top quark. This first probe of the Yukawa piece of the Standard Model Lagrangian will constitute a major test of our understanding of the origin of mass.

Scan of the $t\bar{t}$ threshold region will allow measurement of the mass of the top quark to better than 0.5 GeV. This is an interesting measurement in itself, and, when combined with expected improvements in measurements of the W mass at CDF and LEP II, will constrain the Higgs mass with accuracies of 20–30%. This would comprise the ultimate test of radiative corrections to the Standard Model. These same data will pin down the strong coupling constant $\alpha_s(2m_t)$ to within 5%—comparable to measurements made at the Z^0 with LEP, and with studies of QCD at center of mass energies above the $t\bar{t}$ threshold [Siegfried Bethke (Heidelberg) and Valery Khoze (St. Petersburg)].

Many new and beautiful studies of the physics of gauge boson interactions were reported at the workshop [Kaoru Hagiwara (KEK) and Timothy Barklow (SLAC)]. The fundamental structure of the massive W and Z^0 boson states and their self interactions remain an important untested sector of the Standard Model. The static magnetic dipole and electric quadrupole moments of the charged W bosons can be measured with accuracies of 1–2% by careful analysis of the helicity structure of the WW final state produced at 400–500 GeV center of mass. This elegant technique is fully able to resolve the differing couplings of the photon and Z^0 boson to the W from a single data set; the improvement in accuracy of more than an order of magnitude over similar measurements to be made at LEP II is attributable to the rapid growth with center-of-mass energy of the production of longitudinal gauge bosons—the remnants of the Higgs fields that are essential to the Standard Model. Confirmation that the interactions of these new massive polarization states are described correctly by the Standard Model is essential, and no other technique will provide the precision and discrimination offered by an electron-positron collider.

Production of multiple gauge bosons will allow further investigation of the three-boson coupling prescribed by the Standard Model, and samples of tagged W-pairs as large as 10^5 can be accumulated and used to search for anomalous W-decays. Beam energies of 200–250 GeV yield the largest cross sections and best detection efficiencies for these studies. At considerably higher energies and luminosities it will begin to be possible to study W-W scattering processes [Ken-Ichi Hikasa (KEK)]. Unfortunately, in the absence of TeV-scale resonant structures, the event rates for such process are extremely low, and it will require machines with TeV center-of-mass energies and luminosities approaching $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to resolve differing models of strong W_L interactions. This clearly awaits a future generation collider.

A centerpiece of experimental particle physics for the foreseeable future is the systematic search for scalar particles that can play the role of Higgs fields. It is essential that no possible avenue of escape be left for these states and that we fully understand the spectrum of such particles and their interactions. Extensive analyses reported at the conference [Howard Haber (Santa Cruz) and Sachio Komamiya (Tokyo)] made clear that data samples well below the performance expectations of various accelerator designs will be sufficient to illuminate even the most complex Higgs spectra. As with LEP, these studies are limited only by the energy of the accelerator; masses up to 70% or so of the nominal center of mass are accessible. Of particular interest is the fact that recent calculations of loop corrections increase the upper limit on Higgs masses that can be tolerated within the parameter space of the Minimal Supersymmetric Standard Model (MSSM). These limits exceed the grasp of LEP II but are well within the reach of the next linear collider. The SUSY theory working group concluded [Fabio Zwirner (CERN)] that a linear collider with center-of-mass energy of 500 GeV is guaranteed either to find at least one Higgs (and most probably three neutral states and the charged states), or the Minimal Supersymmetric Standard Model is ruled out. These new states generally appear in the intermediate mass region where discovery and investigation at hadron colliders are difficult tasks.

Initial studies of more subtle, but equally important, aspects of Higgs physics were also reported—searches for non-dominant decay modes were among the most interesting. The exciting prospect of measuring the coupling of the Higgs to two photons was explored in some detail. Photon-photon collisions, created by backscattering laser beams from the incoming electrons and positrons just prior to the interaction point, provide a rich variety of final states for study [Valery Telnov (Novosibirsk)]. Production of Higgs particles by this mechanism occurs with good rate in most cases and is easily detected. The $H^0\gamma\gamma$ coupling is attributable to triangle graphs and receives contributions from all particles that carry electric charge and whose mass is generated by the Higgs mechanism. This is true regardless of the mass of the particle in the loop (!), and it endows this measurement with a spectacularly large discovery reach.

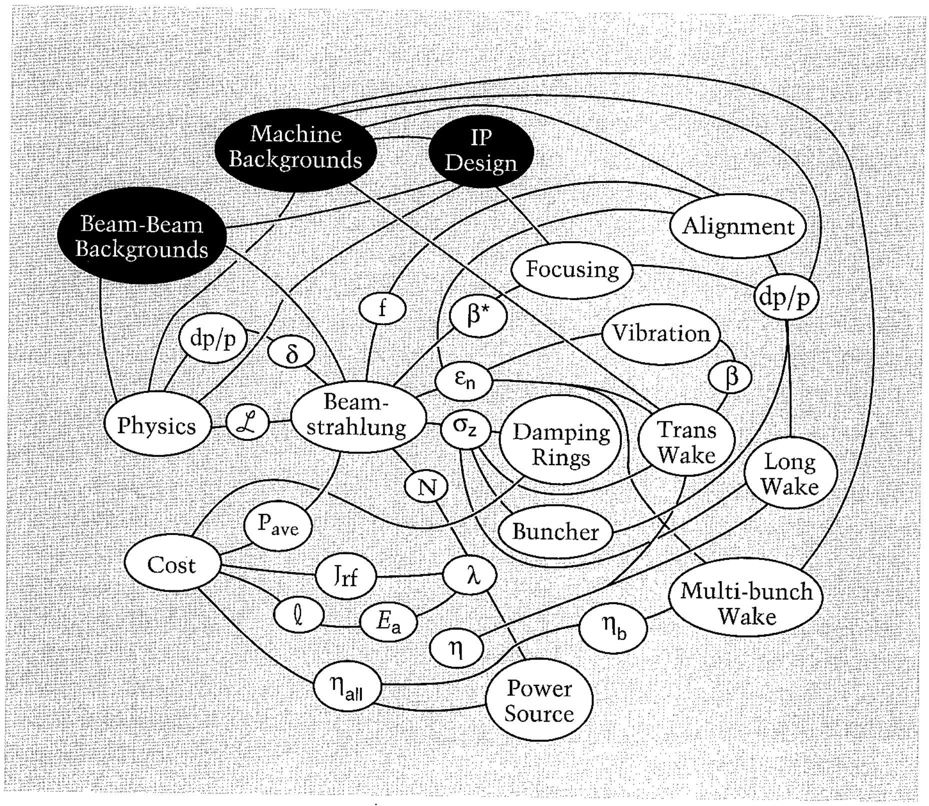
Historically electron-positron colliders have been ideal hunting grounds for new particle states, and a wide variety of search goals and strategies were presented at the workshop. These ranged from exotic leptonic states like heavy Majorana neutrinos [Wilfred Buchmüller (DESY)] to the familiar spectra of particles predicted to exist in models of supersymmetry [Jean-Francois Grivaz (LAL)]. While colored objects such as squarks and gluinos are copiously produced at hadron colliders, it will require successful experiments with e^+e^- colliders to find and sort the spectra of colorless sleptons, charginos, and Higgsinos.

THE PARTICIPANTS LEFT the autumn colors of Saariselkä (300 kilometers north of the Arctic Circle) with a crisp view of the future of electron-positron physics and looking forward to the next workshop in this series to be held on the balmy shores of Hawaii in the spring of 1993. For many, however, the road to Hawaii passed through the Soviet Union, where the Third International Workshop on Linear Colliders (LC91) was held in Protvino, 100 kilometers south of Moscow. Nearly 100 scientists from Europe, Japan, the U.S., and the USSR met for ten days of discussion and review of current issues in the development of future linear colliders.

A report from the Saariselkä workshop [David Burke (SLAC)] set the stage for two days of plenary sessions in which updates were heard from each of the laboratories working to develop linear colliders. The encouraging performance of the SLC during the past year, and the lessons that have been learned from it, were reviewed by Stan Ecklund (SLAC). After considerable upgrading of the infrastructure of the accelerator and with maturation of the control and feedback systems, the luminosity and efficiency of accelerator operations have shown dramatic improvement; the SLC met all of its luminosity goals for this past year's run. The SLD detector was rolled onto the beam line, and was able to successfully complete an engineering test run. Further improvements are expected in the next year, and with the polarized gun also being installed and debugged, the SLD group is anticipating a fruitful run for particle physics in 1992 and 1993.

Linear colliders can be broadly categorized by the method used to generate and utilize rf power and the structure of the main accelerator. The DESY/Darmstadt Collaboration [Thomas Weiland (THD)] has made considerable progress toward understanding the limits of machine designs based on existing S-band (2.8 GHz) klystrons for rf generation. Meanwhile KEK [Koji Takata] and SLAC [Ron Ruth] are pressing klystron technologies toward higher frequency (X-band at 11.4 GHz) where higher accelerating gradients are expected to be achievable. The SLC provides the experimental tool required for further development of S-band accelerators, but stand-alone facilities are needed to test new X-band technologies. Both SLAC and KEK are planning such test beds. Klystrons suitable for incorporation into these facilities are under development at SLAC and are expected to be available soon. High-power tests of rf pulse-compression techniques modeled after the SLED cavities used at SLAC will be completed within the year. Success with these tests will allow completion of the necessary engineering and the start of construction of full-scale sections of X-band accelerators with gradients of 50–100 MeV/m.

A slightly higher frequency (14 GHz) is being pursued by the group from Protvino working on the VLEPP Project [Vladimir Balakin (BINP)]. The VLEPP rf system uses a novel coaxial long pulse charge-storage network that is discharged to drive 14 GHz klystron tubes. Key elements in the klystron are a multicell gridded cathode used to control the current and a permanent magnet focusing system. One of the highlights of the workshop was a tour of the 20-meter-long test facility, presently under construction in the laboratory at Protvino, that will be used to test these systems later next year.



Robert Palmer's original Guide to Linear Collider Design (in white). As noted on page 17, the three topics shown at the top of the figure are recent additions to the design matrix.

The advent of superconducting linacs offers another approach to linear collider design that is being studied by the TESLA Collaboration [Dieter Proch (DESY)]. Very long (msec) low-frequency (1.5 GHz) rf pulses are generated by conventional klystrons, stored in superconducting structures, and used to accelerate a large number (~1000) of electron or positron bunches. Spot sizes of a few tenths of a micron can then be used to reach the required luminosity. The large spacing between bunches and the small luminosity per bunch crossing that are inherent to this technique eliminate many of the problems created by the high-brightness beam-beam interactions incorporated into other design philosophies. Unfortunately, these machines require extensive refrigeration plants, and much of the length of the linac is consumed by cryostats and other plumbing. The challenge to this collaboration is to arrive at a cost-effective design.

Progress is continuing at CERN on development of a two-beam linac for CLIC [Wolfgang Schnell (CERN)].

These accelerators differ rather fundamentally from existing accelerators in that generation of rf power is not done in klystron tubes but is created by a low-energy high-current beam of electrons that is transported alongside the high-energy low-current beam that is being accelerated. Radio-frequency power is periodically extracted from this secondary beam and fed to the accelerating structure of the main linac. The energy is replaced using low frequency (353 MHz) superconducting cavities. The secondary beam and its transport structure are in essence a single multi-port klystron that operates at very high frequency (30 GHz in the CLIC design). Tests of structures are underway, and a test facility is expected to be operating in about a year.

The opening plenary sessions were concluded with summary talks on the recent improvements in the modeling of the interactions of high-energy, high-intensity beams [Kaoru Yokoya (KEK)], and a status report from the Final Focus Test Beam Collaboration (FFTB) [Alexander Mikhailichenko (Novosibirsk and BINP)]. The FFTB is well underway. Approximately one half of the magnets fabricated at Novosibirsk have been delivered to SLAC for installation, and the remaining magnets are expected to be completed and installed by spring of next year. It is anticipated that the beam line will begin operations at the beginning of 1993.

The participants separated into four working groups and continued more detailed discussions of the problems confronting the building blocks of linear colliders. A group chaired by Jean-Pierre Delahaye (CERN) reviewed the preparation of low-energy, low-emittance beams. Integration of the properties of electron guns and bunching systems, positron sources, damping rings, and bunch compressors to achieve optimum performance is an intricate problem that received much attention in this group. New approaches to positron production using wigglers or channeling crystals were discussed, and the use of pre-damping or collector rings with large acceptance was reviewed.

A group chaired by Gilbert Guignard (CERN) worked on problems of beam dynamics and control during acceleration in various structures. The main topics were single and multibunch beam stability and alignment and trajectory correction techniques. Much of the discussion centered on beam-based alignment techniques that have worked well at the SLC. It is important that the ultimate accuracy of these procedures and the instrumentation required to make them successful be fully understood. More work remains to be done. Strategies for controlling multibunch instabilities using tuned accelerating structures were discussed at some length. Here, too, more work is waiting to be done. Optimization of BNS damping and linac focusing to maintain control over emittance growth generated by single-bunch wakes was also discussed. This is, by now, a well established technique that is incorporated into nearly every machine design.

A large group organized by Seishi Takeda (KEK) reviewed problems in the development of high-power rf sources and accelerating structures. Everyone was interested in the VLEPP 14 GHz klystron. Inefficiencies in beam transmission have prevented these tubes from reaching full voltage, but the Protvino group is optimistic that additional design changes will alleviate this problem. SLAC and KEK are making steady progress with tube development at X-band. The latest tubes in this series have generated microsecond pulses with 40 MW of delivered power; 50 MW is the initial goal. Everybody is experimenting with high-power output windows as damage is a problem already at 40 MW. There are several designs for large area windows that look attractive.

Careful examination of calculations of wakefields created by intense bunches in detuned or damped accelerating structures led to optimism that the complexity of adding damping slots can be avoided and that detuned structures will provide adequate control of these wakefields to allow multiple bunches to be accelerated on each rf pulse. There also was useful discussion on manufacturing techniques for accelerator structures, and in particular, the advantages and disadvantages of cell-by-cell tuning strategies and the problems and costs of maintaining precision during fabrication.

John Irwin (SLAC) organized a fourth group to concentrate on problems particular to the final-focus and interaction region. This group covered several topics including optics designs, problems associated with the beam-beam interaction, detector backgrounds, and instrumentation. There was an interesting discussion of wide-bandwidth optics designs [Reinhard Brinkman (DESY)], and in particular, evaluation of mechanical and electrical tolerances needed to make them work. Also discussed was a new concern that the finite resistance of the metal in the beam pipe of the final quadrupole lens might destroy the emittance of the beam. This was found not to be a problem, but it did place a limit on the aperture of the final lenses used near the interaction point. This limit will have to be incorporated into future designs.

Experience with the SLC has made it clear that the experimental detectors are an integral part of the machine, and control of non-physics backgrounds is a challenge for accelerator and particle physicists alike. Problems in beam collimation and detector shielding are being attacked by a growing number of accelerator and particle physicists, and much work has gone forward in the calculation of the backgrounds that can be produced in the interactions of small intense beams. The peripheral photon flux that accompanies the electron beams grows with increasing energy, and can become a troublesome source of background if the luminosity produced by the collider within the resolving time of the detector becomes too large. This ultimately will constrain machine designs to favor higher repetition rates and lower luminosities per bunch crossing. Of particular interest at the workshop were new calculations of hadronic photon-photon processes [Manual Drees (DESY)] that may pose further limitations on machine and detector designs. It remains for future work to sharpen these issues, but it is apparent that Robert Palmer's Guide to Linear Collider Design on page 15 is more complex than one might have imagined!

IN VIEW OF THE VERY difficult and uncertain conditions in the host country, the Workshop at Protvino was organized and conducted in a remarkably gracious atmosphere well-suited to intellectual exchange and growth. The conference fulfilled an important function for the international community, and served as a useful professional experience for all who attended. As the pace of work on linear colliders accelerates, so too will the need for physicists and engineers to gather to discuss and redirect their efforts. The next in this series of workshops (LC92) will be held next Summer in Garmisch Partenkirchen, Germany.

DATES TO REMEMBER

Nov 26–29	Second KEK Topical Conference on e^+e^- Collision Physics, Tsukuba, Japan (T. Matsui, KEK, Tsukuba, Ibaraki-ken, 305 Japan or TOPIC91@JPNKEKVM)
Jan 6–17, 1992	U. S. Particle Accelerator School, Austin, TX (USPAS, Fermilab, MS 125, P. O. Box 500, Batavia, IL 60510 or USPAS@FNAL)
Jan 25–Feb 1	27th Rencontre de Moriond: Tests of Fundamental Laws in Physics, France (Tran Thanh Van, Rencontres de Moriond, Batiment 211, Universite de Paris-Sud, F-91405 Orsay Cedex, France)
Mar 4–6	4th Annual International Industrial Symposium on the Supercollider and Exhibition, New Orleans, LA (Pamela Patterson, IISSC, P. O. Box 171551, San Diego, CA 92197)
Mar 16–20	General Meeting of the American Physical Society, Indianapolis, IN (N. R. Werthamer, American Physical Society, 335 E. 45th Street, New York, NY 10017)
Mar 16–20	CERN Accelerator School: Magnetic Measurement and Alignment, Montreux, Switzerland (S. von Wartburg, CERN Accelerator School, SL Division, 1211 Geneva 23, Switzerland, or BITNET CASMAG@CERNVM)
Mar 22–26	9th International Workshop on Photon-Photon Collisions, Santa Barbara, CA (Physics Department, UC Santa Barbara, Santa Barbara, CA 93106 or DLA@SBHEP.PHYSICS.UCSB.EDU)
Mar 24–28	Third European Particle Accelerator Conference (EPAC 92), Berlin Germany (H. Bottcher, EPAC 92 Conference Secretariat, Einsteinufer 1, D-1000, Berlin, Germany)
Apr 13–15	SSC Physics Symposium, Madison, WI (Linda Dolan, Physics Department, University of Wisconsin, Madison, WI 53706 or LDOLAN@WISCPHEN)
Jun 24–27	3rd History of Particle Physics Symposium, Stanford Linear Accelertor Center, Stanford, CA (Nina Stolar, SLAC, MS 70, P. O. Box 4349, Stanford, CA 94309 or NINA@SLACVM)
Jul 20–24	15th International Conference on High Energy Accelerators, Hamburg, Germany (invitation may be requested from F. Willeke, DESY, Notkestrasse 95, 2000 Hamburg 52, Germany or HEAC92@DHHDESY3).

The Accelerator Test Facility at KEK

KOJI TAKATA

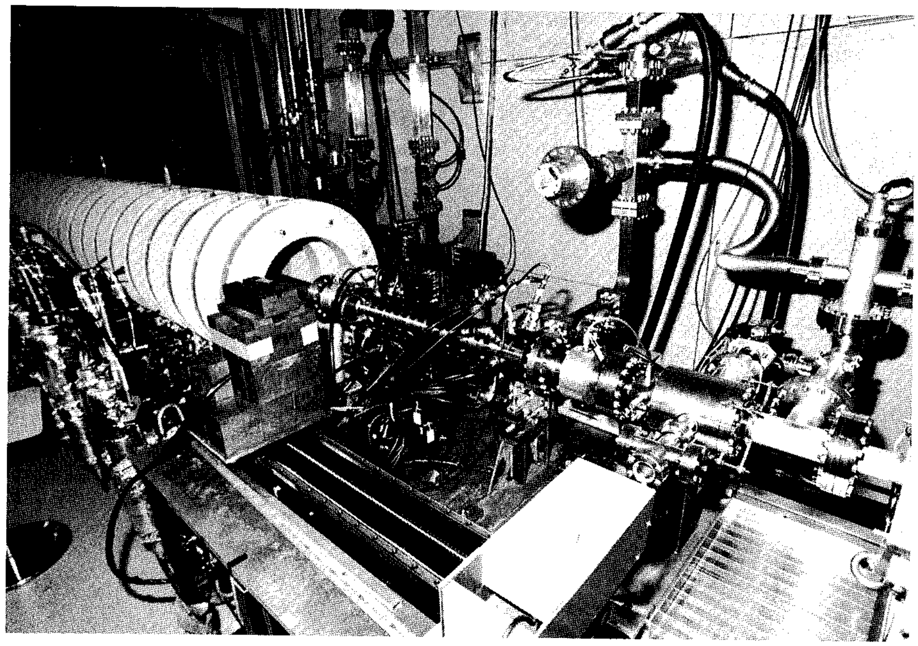
THE ACCELERATOR TEST FACILITY (ATF) was created to promote TeV linear collider research at KEK, the National Laboratory for High Energy Physics in Tsukuba, Japan. The Japanese high energy physics community has been investigating the feasibility of next generation TeV electron-positron linear colliders similar to the Next Linear Collider (NLC) under study in the United States. We call our collider the Japan Linear Collider or JLC. Studies for the JLC were initiated as early as 1982, when construction of the 30 GeV TRISTAN storage ring, the first high energy electron-positron collider in Japan, was at its height.

We have been examining the realistic possibilities that would enable us to reach a luminosity greater than $10^{33}\text{cm}^{-2}\text{s}^{-1}$ at center-of-mass energy around 1 TeV. In a linear collider there are two identical main linacs that accelerate beams from a few GeV to several hundred GeV facing each other—one for electrons and the other for positrons. We decided that the main linac should use the well-established technology of conventional linacs. The acceleration gradient should be 100 MV/m or more so that the linacs are not too long, and the wall plug power should be less than 200 MW, the maximum available at KEK. Those considerations have led us to the following JLC design parameters: (1) the main linacs are at X-band frequency (11.4 GHz, four times the SLAC S-band frequency of 2856 MHz); (2) these linacs accelerate ten beam bunches and have a repetition rate of 150 Hz; and (3) the beam size at the collision point would be about 5 nm high by 600 nm wide.

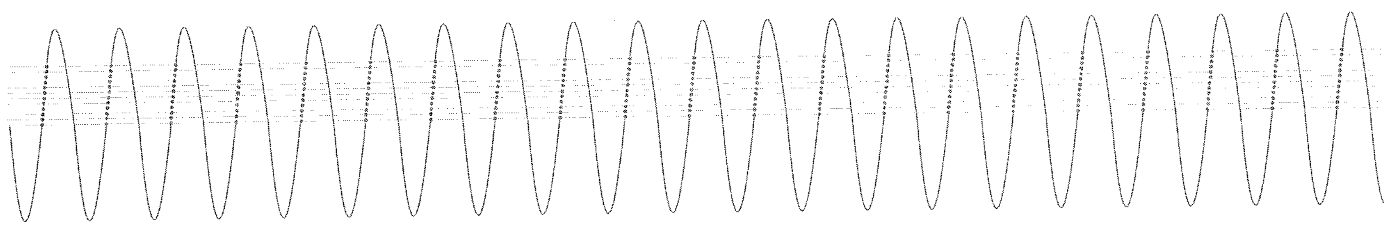
CONVENTIONAL S-BAND LINACS still play important roles in high energy linear colliders as injectors and positron production linacs because of their capability of accelerating high currents. Therefore, although research for the X-band linac is key, S-band technology is still being pursued intensively. A 2.5 GeV S-band linac has been in operation at KEK since 1982 as the injector for the Photon Factory and later on for the TRISTAN Accumulation Ring. Such a busy machine is not useful for experimental accelerator studies, and when we founded the ATF in 1987 we started to build a test S-band linac. We wanted this linac to accelerate the very short, high current bunches required by the JLC design and to have an accelerating gradient higher than the conventional 10 MV/m so we could gain experience with high gradient operation. We plan to test a 1.5 GeV damping ring (also an important part of a linear collider complex), and the linac was to be extended to the damping ring injection energy if enough space was available.

Even at S-band the rf source was a central issue. The most powerful S-band klystron then available in Japan was a 30 MW tube that was not reliable partly due to the old design of the electron gun. Therefore, we were grateful to SLAC when several 5045 tubes, the state-of-the-art klystron used for the SLC, were shipped to KEK in 1987 and 1988 according to the US/Japan Cooperative Agreement in high energy physics. We designed the test linac to use these powerful tubes. It has a bunching section with subharmonic cavities to capture the beam and a short SLAC-type structure to accelerate it to 40 MeV. The regular part of the linac has 3 m long SLAC-type structures with a gradient of 40 MeV/m. The peak rf power required is high, and the SLED system is used to compress the klystron output power. Using the 5045 tubes and the SLED system, only six klystrons will be needed to get to 1.5 GeV. This should be compared with more than 40 klystrons for the KEK 2.5 GeV linac.

We have set-up the linac on the 25 m by 25 m floor of an unused TRISTAN experimental hall, where radiation safety regulations can be



The high gradient test setup at the ATF. Using this 66.5 cm long S-band structure an average gradient of 92 MV/m was attained with an input power of more than 160 MW. Beside the structure Helmholtz coils are shown that are part of the test S-band linac being constructed at the ATF.



easily satisfied. We prepared an area surrounded by shielding blocks for the injection section and one or two regular structures in addition. We have used precision beds to easily place linac components to a precision of a few tens of microns. The injection section has been completed, and a couple of regular structures are being manufactured. Outside the shield we set up four rf systems, each consisting of a modulator, klystron and evacuated waveguides, capable of delivering a peak power of 100 MW with 1 μs duration.

The test linac construction is not the only activity at the ATF. The rf systems have been very useful for other R&D including having big modulators for developing X-band klystrons and developing low power rf components and control circuits to meet the stringent specifications of the JLC.

THE MOST IMPORTANT research at the ATF has been high gradient tests with S-band structures. Without high power X-band klystrons, such tests are usually done at S-band. Information obtained is valuable for estimating the performance of X-band structures at 100 MV/m. When the 30 MW klystron was our only high power source, we tested a short structure using a special waveguide system to boost the rf power. The rise time of the power pulse was long and the flat top short, but we reached 100 MV/m anyway. The 5045 tubes have enabled us to test a longer structure by driving it directly with sufficiently long, rectangular rf pulses. A peak power of 200 MW with a 1 μs duration is possible if we combine outputs from two klystrons. We fabricated a SLAC-type structure 66.5 cm long with a high shunt impedance to try to reach 100 MV/m with this rf pulse.

We began rf processing the structure mid-1989, and after 900 integrated hours of processing at 25 Hz we reached 92 MV/m. Beam acceleration was tested with these fields. We were particularly concerned by field-emitted dark currents, since they are a crucial factor in operating at such high gradients. Currents increased drastically as the gradient approached 100 MV/m. Their behavior was in good agreement with that observed in experiments at SLAC. The energy spectra had a low-energy component due to local discharges and a broader one that was the result of acceleration over the structure. This structure was fabricated by a Japanese firm in the same way conventional linacs for medical use were. We are now testing a second one that has the same geometrical shape but was fabricated more carefully with less surface contamination. The processing time seems much shorter as expected.

AS MENTIONED ABOVE one goal of the ATF is to construct a 1.5 GeV damping ring. The beam emittance required at the JLC is 1 to 2 orders of magnitude smaller than that of presently operating storage rings. A promising way to achieve this is to use wiggler magnets. The wiggler fields are complicated, and we want to study the beam dynamics and verify reaching low emittance experimentally. This is the reason, which we consider a strong one, that we wish to construct a test damping ring. The ring will have a racetrack shape about 60 m long by 30 m wide.

One of problems associated with this plan has been finding a space large enough for the linac and ring. To solve it, we are clearing a building that had been used to assemble TRISTAN rf cavities. Substantial civil construction is needed to reinforce the floor to hold shielding and to meet radiation safety regulations. We hope that the construction of the linac and ring complex will be completed by the end of 1994.

Although the main activity is construction of the S-band linac, we are pursuing other R&D for the JLC. The X-band klystron and structure are particularly important issues and need a great deal of fundamental study. If we are fortunate in carrying out this work, we will set up a short section of the X-band linac beside the damping ring and accelerate small emittance beams extracted from it. At that point it will be possible to judge whether technologies have matured enough to construct the JLC.

FROM THE EDITORS' DESK


Lawrence Berkeley Laboratory

Edwin M. McMillan, 1907-1991

THIS IS THE SIXTH ISSUE of the new version of the *Beam Line*, which may be a time for us to pause briefly to take stock. Our masthead says "A Periodical of Particle Physics," and particle physics has in fact been the subject of most of the articles that have appeared since our first issue in the summer of 1990. But the niche we are trying to carve for the *Beam Line* might better be described as "A periodical of particle physics and other things that the particle physics community is likely to be interested in." (Not a very elegant masthead.) Thus in the present issue we have articles on white dwarfs and science education, and in earlier issues there have been pieces on cosmology and science policy.

This is all to the good. We hope to continue this mix of high-energy physics (HEP) and related fields, of the factual and the speculative, of the specific and the general. We have articles in train on possible new accelerators, on detectors for the SSC and for gravity waves, and on computation developments in particle physics. We continue to be very interested in soliciting articles and ideas for articles. We have a special interest in speculative or opinion pieces about where the field of HEP is going, or should be going. Give us a call, electronic mail, or FAX and let's talk about it.

WE TAKE NOTE OF THE RECENT DEATH of Edwin M. McMillan, one of the great names in our field of physics. A particularly warm and interesting tribute to McMillan, written by J. David Jackson, appeared in *Nature* **353**, 602 (1991).

We also take note of the devastating fire in mid-October that destroyed several thousand homes in the hills above Oakland and Berkeley, California. We know of ten of our particle-physics colleagues and 45 others from Lawrence Berkeley Laboratory who lost their homes in this inferno. And this rather hard upon the heels of the large earthquake almost two years earlier. Our sincere sympathies to those affected.

Bill Kirk

Rene Donaldson

LETTERS TO THE EDITORS

Why SSC?

In most cases I write letters to the editor out of anguish, to protest some thing or the other. This time it is praise. I find the article on "Why SSC" (for short) by Riordan to be excellent. Probably the best I read on the subject so far. I urge you to try to give it wider circulation by sending it to other journals. Would the CERN *Courier* take it?

DRASKO JOVANOVIC
Fermilab

We give our permission to anyone who wishes to reprint Riordan's article "Why Are We Building the SSC?" providing they acknowledge the Beam Line. We do not know what the CERN Courier's reaction would be to reprinting the article; however, we would be happy to publish an article on the LHC.

The Beam Line has a distribution of about 4500. If you would like to receive it, send electronic mail to BEAMLINE@SLACVM or regular mail to the Beam Line Editors, SLAC, P.O. Box 4349, Stanford, CA 94309 USA.

91 PAC

It's not that letter writing is a lost art, this *[electronic mail]* is just a lot easier.

In the Summer 1991 issue, in a review of the '91 Particle Accelerator Conference, Robert Siemann said "The second absence is disturbing: Advanced accelerator concepts were not well represented." I hope this was in reference to the number of papers and not to their content. The AWA (Argonne Wakefield Accelerator) group had a few papers at the conference, and we had a few collaborators at SLAC who also used some "advanced techniques" to measure new concepts in accelerator design. We think the ideas were represented well.

It is true that new concepts are lost in the ocean of engineering work being done on accelerators. One factor which bothers me is the lack of accelerator engineering programs at universities. The technology is stable enough and the applications are growing to the point where businesses are buying accelerators for production work. The search for new methods of building accelerators should be a much smaller group than the improved engineering design of applications already in place.

I don't think there is an absence of advanced accelerator concepts. There is so much room for improvement of all the old concepts that it just swamps out the new ideas by volume. Once a new idea is shown to work it becomes an old one and more people work on improving it. With the number of accelerators on line in the world for specific purposes it's hard to see where there is time for pure accelerator research.

The AWA mission is higher gradients, an "advanced accelerator activity." We are very lucky to be able to focus on research without having to worry about users. I agree with Siemann that more groups similar to the AWA should exist, but I doubt that they will ever seem to be "well represented" in numbers compared to all the other accelerator work now taking place.

MIKE ROSING
Argonne National Laboratory

Robert Siemann replies: About ten years ago was a time of ferment in advanced accelerators. Plasma-based accelerators, grating accelerators, inverse free electron lasers, two-beam accelerators, collective implosion accelerators, wakefield accelerators, ...were actively discussed. The presentations of those ideas and the discussions about them were, to me, highlights of the PAC's of the 1980s. They were never a large fraction of the papers, but they were among the most interesting.

Times have changed, and advanced accelerator physics has matured. Some ideas were explored and found to be wanting. Others were found sufficiently interesting that they have become part of the mainstream of accelerator physics. I missed the ferment at the 1991 PAC and my comment was addressed to that. I didn't hear new ideas for reaching 1 GeV/m, for using recent advances in laser technology for accelerators, etc. Maybe the realities are too hard, or maybe we are in a consolidation phase following a creative flurry.

Whatever the cause for my perception about the 1991 PAC, I value advanced accelerator work and was using the Beam Line article to express my concern for it. It needs resources and people, and here I am in complete agreement with Dr. Rosing.

EGS

In our *Beam Line* article, "EGS—A Technology Spinoff to Medicine," we neglected to mention the important contributions made by Hideo Hirayama of KEK and Ray Cowan of MIT. In particular, the cover photograph was produced by means of the SHOWGRAF graphics package developed for EGS by Dr. Cowan.

RALPH NELSON, *SLAC*
ALEX BIELAJEW, *NRC, Ottawa, Canada*

We are indebted to Ray Cowan for the cover of the Spring 1991 issue of the Beam Line.

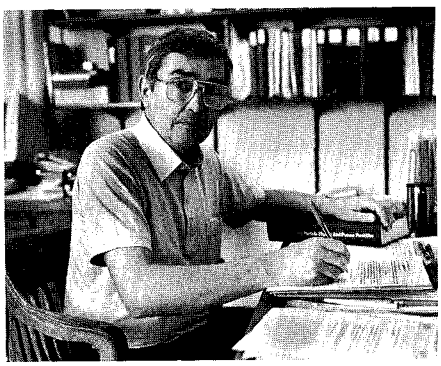
CONTRIBUTORS

Astronomical Society of the Pacific

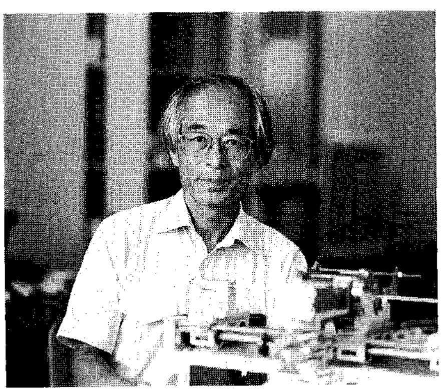
VIRGINIA TRIMBLE oscillates at a frequency of 63.4 nHz between the Physics Department of the University of California, Irvine (where she has tenure) and the Astronomy Department of the University of Maryland, College Park (where her husband, physicist Joseph Weber, is Professor Emeritus). Her degrees come from UCLA (B.A.), California Institute of Technology (M.S., Ph.D.), and Cambridge University (M.A.). She was the 1986 recipient of the U. S. National Academy of Sciences Award for scientific reviewing and currently serves as editor of *Comments on Astrophysics* and associate editor of the *Astrophysical Journal*. Virginia is interested in stars and galaxies and other structures that require relatively little maintenance.

MARJORIE G. BARDEEN is Program Director of the Fermi National Accelerator Laboratory (Fermilab) Education Office and is the Vice President of Friends of Fermilab, a not-for-profit corporation whose sole purpose is to develop and conduct precollege education programs at Fermilab in Batavia, Illinois. She is also an elected member of the Board of Trustees, College of DuPage, in Glen Ellyn, Illinois, and is currently the Chairman. Marge holds a B.A. in Mathematics from the University of Minnesota and an Educational Certificate (Mathematics) from Elmhurst College, Elmhurst, Illinois. Under her leadership numerous needs assesment workshops with teachers, school administrators, and community leaders have been conducted to develop science education programs, and 40 such programs currently make a wealth of resources available to elementary and secondary teachers and students at Fermilab.

DAVID BURKE, a regular contributor to the *Beam Line*, is head of Experimental Group I, established as part of SLAC's effort on the accelerator physics and technology of the Next Linear Collider (NLC), in addition to playing a major role in the construction and instrumentation of the Final Focus Test Beam (Vol. 20, No. 2, 1990). David came to SLAC in 1978 and distinguished himself in the commissioning of the Stanford Linear Collider and as a key member of the Mark II Collaboration. He served on the Organizing Committee of the Saariselkä conference and organized the NLC study efforts at previous Snowmass (Colorado) meetings.



Ewan Paterson is a Professor at SLAC and is Assistant Director for Accelerator Systems. He has been at SLAC for almost 20 years and has been involved in the commissioning, development, and construction of all the accelerators on the site. He is interested in many areas of advanced accelerator development from next-generation linear colliders to next-generation synchrotron light sources.



Koji Takata is head of KEK's TRISTAN accelerator department. He came to KEK in 1972 and became engaged in developing fast kicker magnets for the 12 GeV proton synchrotron. In 1977 he became responsible for design, construction, and operation of the rf system of the Photon Factory 2.5 GeV electron storage ring, and then in 1980 also of the TRISTAN 30 GeV electron-positron storage ring. Since 1982 he has been supervising R&D work at KEK for TeV linear collider technologies.

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