STANFORD LINEAR ACCELERATOR CENTER

# Beam Line

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# Beam Line

A PERIODICAL OF PARTICLE PHYSICS

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*Cover: The cover photo was taken in 1917, plus or minus about one year. The photographer is unknown or unremembered. The young lad shown in the photo with his telescope in the garden of his home in Pretoria, South Africa, is Alan Cousins, at the age of about fourteen (he was born in 1903).*

*Dr. Cousins' first contribution to the astronomical literature was published in 1924. Seventy-four years have passed since then, but Alan William James Cousins is still at work at his home base, the South African Astronomical Observatory (SAAO), having recently published his latest paper ("Atmospheric Extinction,"* The Observatory, *April 1998). He will be 95 in August of this year, continuing a long life among the stars. Happy birthday!*

CREATION DU C.E.E.N.

Genève, 15 février 1952

Professor I. Rabi,
Columbia University,
New York, N.Y.

We have just signed the Agreement which constitutes the official birth of the project you fathered at Florence. Mother and child are doing well, and the Doctors send you their greetings.


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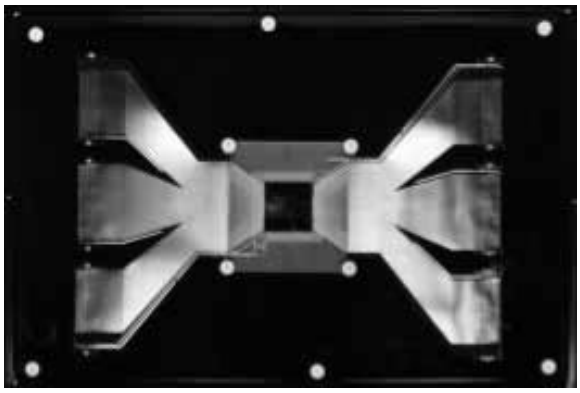
## FEATURES





## DEPARTMENTS



*Contributing Editor Gordon Fraser follows up on his piece on the origins of international collaboration in Europe (Winter 1997) to describe the creation of CERN. This article is adapted from a chapter in his book* The Quark Machines *on the political history of particle physics and the parallel evolution of its big machines.*

# All We Want Is th

CREATION DU C. E. R. N.

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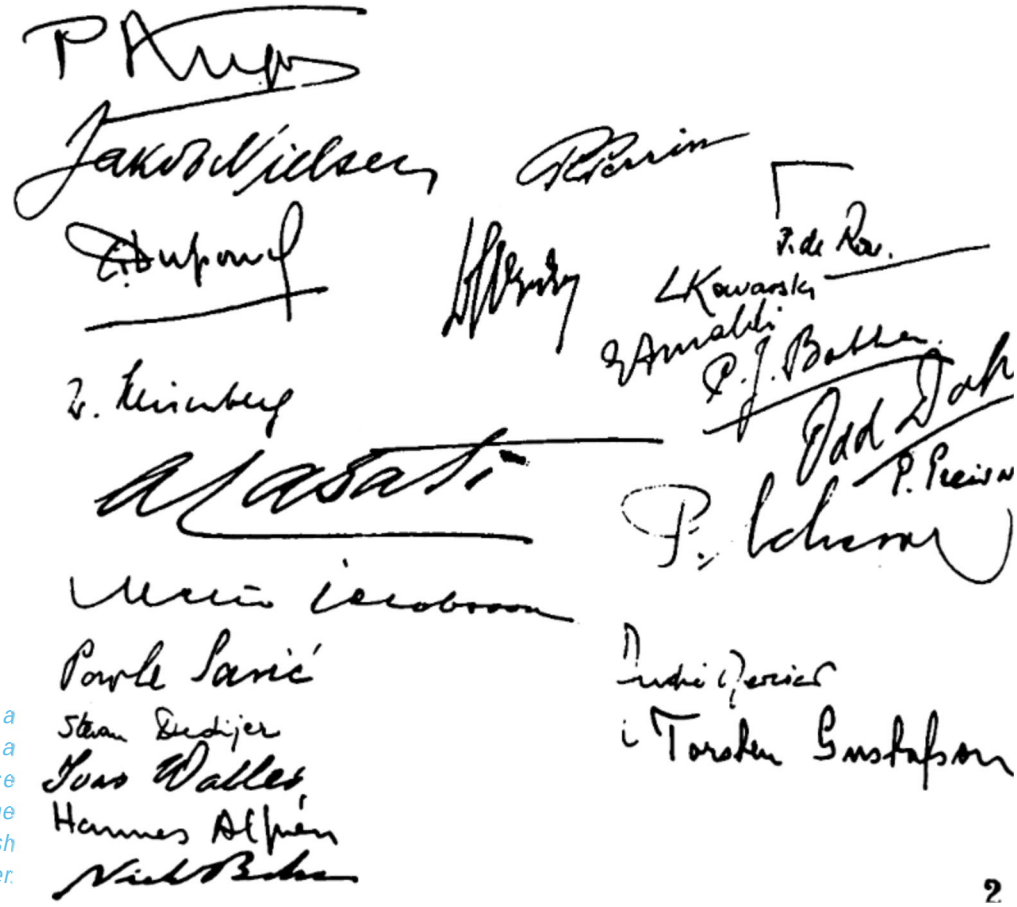

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*Isidor Rabi had proposed the idea of a European physics laboratory at a UNESCO conference in Florence in June 1950. The signatories to the initial 1952 agreement to establish CERN sent him this letter.*

# World's Biggest Machine!

by GORDON FRASER

BETWEEN 1949 AND 1959, the dream of an international European laboratory for particle physics—'CERN'—became a reality, briefly sporting the world's highest energy proton synchrotron. In those ten years, scientists from countries that had been at war only a few years earlier set aside their differences and collaborated in a dramatic demonstration of what could be achieved when national characteristics dovetail smoothly in the achievement of a common goal. The ideals and insights of CERN's founding fathers provide vital lessons in the continued quest for wider international collaboration in particle physics.

Scientific objectivity is a common bond between nations. In every country, scientists address the same problems. If one nation hushes up its research findings, the knowledge will ultimately be acquired elsewhere. Scientific curiosity cannot be quenched. In the aftermath of World War II, science was seen as a potential olive branch. However the war had shifted much of the scenery. Major efforts to harness fission and microwaves had demonstrated the value of large-scale collaboration. Militant national pride had given way to new international awareness. Embarrassed by having caused so much strife and inflicting it on the rest of the planet, Europe felt it had to present a more united front.

The United States, as the leading postwar scientific power, attracted scientific emigrants from Europe in what would eventually be called the "brain drain." This leak first had to be stemmed if the Continent was not to find itself starved of talent. Following the Congress of Europe in The Hague in May 1949, the European Cultural Conference in Lausanne in December 1949, attended by 170 influential people from 22 countries, helped set the stage.

At Lausanne, the Swiss writer Denis de Rougemont, founder of the European Cultural Centre, deplored an increasing trend towards secrecy in nuclear physics and advocated a "European centre for atomic research." Then Raoul Dautry, Administrator-General of the French Atomic Energy Commission, read a message from Louis de Broglie, winner of the 1929 Nobel prize for his elucidation of particle waves. De Broglie maintained that scientific collaboration between European countries could open up projects that were beyond the means of individual nations. Following up with his own ideas, Dautry affirmed that astronomy and astrophysics on one hand, and atomic energy on the other, would be ideal vehicles for such international collaboration.

Dautry could call on powerful colleagues in France. One was Pierre Auger, who had made important contributions to atomic and nuclear physics in the 1930s and became Director of Exact and Natural Sciences of the new United Nations Educational, Scientific and Cultural Organization (UNESCO). Another prominent French figure was nuclear fission pioneer Lew Kowarski, who had worked in Britain during the war and understood the special position of the United Kingdom, which was trying to "go it alone."

At the UNESCO General Conference held in Florence in June 1950, however, the seed planted at Lausanne still lay dormant. In the U.S. delegation was Isidor Rabi, winner of the 1944 Nobel physics prize who had supervised research at the MIT Radiation Laboratory during the war. After the war Rabi, with Norman Ramsey, had pushed for the establishment of a major new U.S. research laboratory, Brookhaven, on New York's Long Island. In Rabi's mind this was a role model for what could be achieved elsewhere.

*Edoardo Amaldi in 1971 at the age of 63. One of Europe's leading postwar scientific statesmen, he played a key administrative role in the founding of CERN. (Courtesy CERN)*

Upon arriving at Florence, Rabi was surprised to discover that the agenda included no mention of the European physics collaboration mooted at Lausanne. Setting up physics laboratories was something Rabi knew well, but international committee work was not. The first thing was to get an item onto the agenda, overcoming the apparent indifference of his American colleagues. More helpful were Auger and the Italian physicist Edoardo Amaldi, who had worked in Enrico Fermi's Rome laboratory before the war. Invited to the United States by Fermi, Amaldi preferred to stay in Italy and help restore Italian physics after the chaos of the war. Amaldi went on to become one of Europe's great postwar scientific statesmen, his achievements appearing to stem from a deep sense of duty rather than personal ambition.

Drafted with the assistance of Auger and Amaldi, the proposal from Rabi at Florence requested UNESCO "to assist and encourage the formation and organization of regional research centres and laboratories in order to increase and make more fruitful the international collaboration of scientists in the search for new knowledge in fields where the effort of any one country in the region is insufficient for the task." Rabi pointed out that the initiative "was primarily intended to help countries which had previously made great contributions to science," and that "the creation of a centre in Europe . . . might give the impetus to the creation of similar centres in other parts of the world." The motion was unanimously accepted. Where Europeans had failed to reach a consensus, an American resolution for Europe at a meeting of a United Nations agency had opened a new door.

The two men who took Rabi's baton and sprinted with it were just those who had helped him draft the Florence resolution—Amaldi and Auger. Just a few weeks later, Amaldi was stimulated by a visit to Brookhaven, where the Cosmotron was already taking shape. Few Europeans had ever seen a physics effort of such proportions. "*Colossale*," he remarked.

Under the auspices of the European Cultural Centre, a meeting was organized in Geneva in December 1950 with delegates from Belgium, France, Italy, the Netherlands, Norway, and Switzerland. Auger unveiled a plan for a new laboratory dedicated to the physics of elementary particles. He knew that intriguing new discoveries had already been made in cosmic rays, but that this windfall sprouting could become a major harvest once the big new U.S. accelerators were up and running.

Initial contacts with Britain had established that while its physicists were not against the idea of a European laboratory, they still wanted to go their own way. Their support was vital to get the idea off the ground, however, as in Europe only Britain had experience in major projects. Possible sites mentioned for the new European laboratory included Geneva and Copenhagen.

The resolution passed at the Geneva meeting was startling. It recommended the creation of a laboratory for the construction of a particle accelerator whose energy should exceed those of machines currently under construction elsewhere

(which meant the mighty 3 GeV Cosmotron and the even bigger 6 GeV Berkeley Bevatron). In a field where, apart from Britain, Europe had no tradition and little expertise, the plan was simply to jump into the lead by cash and enthusiasm. These bold proposals were enthusiastically endorsed in Italy, Belgium, France, Norway, Sweden, and Switzerland. In Britain, where physicists were busy building several new accelerators, there was astonishment and skepticism. "Who is behind the scheme?" thundered P. M. S. Blackett, "Is it serious?"

A study group to define the new accelerator included Cornelis Bakker from the Netherlands, who had built a synchrocyclotron at Amsterdam, Odd Dahl from Norway, a talented engineer responsible for the first nuclear reactor to be built outside the original "nuclear club," and Frank Goward, a British physicist who had graduated into wartime radar work. In a flush of modesty after the initial strident proclamation, the new advertised goal was to copy the 6 GeV Berkeley machine instead of the original idea of building the world's largest machine.

One suggestion was to use Niels Bohr's laboratory in Copenhagen as a home for the new institute, an idea that also found favor in Britain, and naturally stimulated interest in Norway and Sweden. Bohr, who had not been party to the previous discussions around the Auger-Amaldi axis, began to exert his considerable influence. Others thought that he was past his prime. The remoteness of Copenhagen and the difficulty of the Danish language were also a deterrent.

To sidestep the challenge of going straight for the world's largest machine, a new plan envisioned a smaller initial machine to launch the new laboratory. Proposals were put forward for a 500 MeV synchrocyclotron and a 5 GeV proton synchrotron, with design and construction proceeding in parallel. European physicists seemed optimistic about government funding. On the question of the site, new criteria, designed to undermine Copenhagen's case, stipulated the use of a major language.

A November 1951 meeting in Paris suggested that the energy goal of the new synchrotron could be as high as 10 GeV, but to defuse the thorny siting issue, the respective group leaders would remain at their home bases—Dahl in Norway working on the synchrotron, Bakker in The Netherlands on the synchrocyclotron, Kowarski in France on infrastructure, and Bohr in Copenhagen on theory, with Amaldi's administrative hub in Rome.

A meeting at Paris that December brought representatives together from thirteen European nations, including West Germany. The Netherlands delegation put forward a fivefold plan, with two points designed to appeal to the Northern faction, expressing interest in using the existing Copenhagen center and Britain's accelerators, and the remaining points designed to appeal to Franco-Italian sentiment, covering the

*In 1951, before a site for the new laboratory had been chosen, Odd Dahl of Norway (standing) was appointed head of CERN's proton synchrotron group and Cornelis Bakker of the Netherlands (seated) head of the synchrocyclotron group. After a trip to the U.S. in 1952 where he learned of the invention of strong focusing, Dahl wisely pushed for the CERN synchrotron to adopt the new, as yet untested technique. But with the decision to build the machine in Geneva, Dahl retired from the project in 1954. In 1955, following the resignation of CERN's first Director General, Felix Bloch, Bakker succeeded him. (Courtesy CERN)*

*An early CERN Council meeting in 1953. Left to right, Jean Bannier representing The Netherlands, and Pierre Auger and Jean Mussard of UNESCO. (Courtesy CERN)*

construction of two new machines and the establishment of a "European Council for Nuclear Research" —in French "Conseil Européen pour la Recherche Nucléaire." The acronym CERN was born.

The meeting was continued in February 1952 in Geneva, where the provisional CERN Council was asked to prepare plans for a laboratory. The proposal was immediately accepted by Germany, the Netherlands and Yugoslavia, and accepted subject to ratification by Belgium, Denmark, France, Greece, Italy, Norway, Sweden, and Switzerland. Denmark offered the new Council the use of the premises at the Institute of Theoretical Physics of the University of Copenhagen. While this meeting was a major step forward, the enigmatic British were not even present.

Emphasis switched from negotiation to organization and planning. With the new organization open for business, the word "Council" was no longer appropriate. However nobody could think of a better acronym, especially when it had to have multilingual appeal, and CERN has stuck ever since. With the four groups dispersed and Amaldi still in Rome, the organization advanced only slowly.

A major international physics meeting at Copenhagen in June 1952 heard that the first beams had been produced by the new Cosmotron. A CERN Council meeting immediately advocated that Dahl's group aim for a scaled-up Cosmotron to operate in the energy range 10–20 GeV.

To make their scaled-up version of the Cosmotron, the group needed to go to Brookhaven and inspect the new machine. That August, Dahl and Goward made the trip. Also passing through was accelerator pioneer Rolf Wideröe, then working on betatrons. To receive their European visitors, M. Stanley Livingston had organized a think tank. The Cosmotron's C-shaped magnets all faced

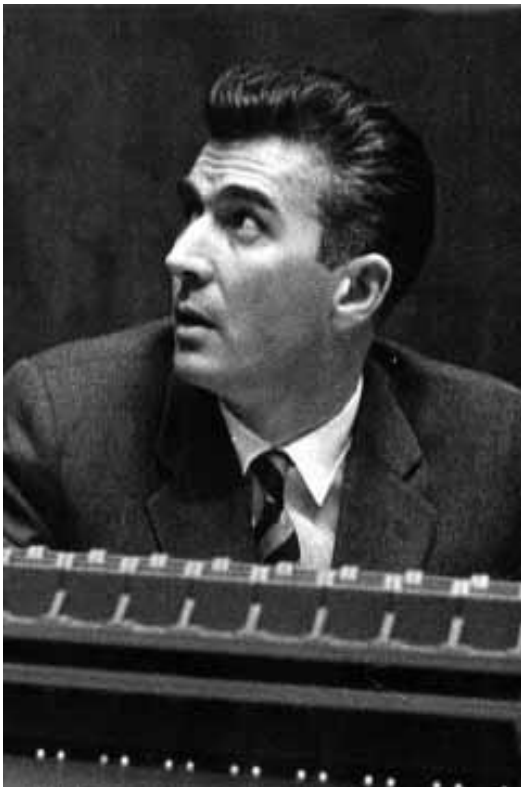
outwards, making it easy for negatively charged particles to be extracted, but not positive ones. "Why not have the magnets alternately facing inward and outward?" suggested Livingston. Ernest Courant, Hartland Snyder, and John Blewett seized on the suggestion and quickly realized that this increased the focusing power of the magnets. The new suggestion, variously called "strong focusing" or "alternating gradient," might allow the proton beam to be squeezed into a pipe a few centimeters across, instead of the 20×60 centimeters of the Cosmotron beam pipe. The relative cost of the surrounding magnet, the most expensive single item in synchrotron construction, would be greatly reduced.

The European visitors arrived at Brookhaven prepared to learn how to make a replica of the Cosmotron and discovered instead that the design had suddenly become outdated. This 1952 visit set the tone for the relationship between the new European generation of physicists and their American counterparts. Based on mutual respect and colored by a healthy spirit of competition, this relationship was to work to their mutual advantage. Untempered, competition can lead to jealousy and secrecy, but in particle physics this has rarely occurred. Although each side has striven to push its own pet projects, collaboration and assistance have always been available, and the community as a whole welcomes and admires breakthroughs and developments, wherever they may be made.

Dahl was adamant that the new strong-focusing technique had to be used for the CERN machine they were planning. It would open up the prospect of at least 20, and possibly 30 GeV, and save money. The only problem was that nobody had built one yet. Although a gamble, taking this unexplored strong-focusing route turned out to be one of the most important decisions in CERN's history. In Britain, the strong-focusing proposal gave a new appeal to the European project. The traditional national approach and the more ambitious international venture became complementary. However before Britain could be persuaded to join CERN, key figures had to be convinced, including the formidable Lord Cherwell, Winston Churchill's staunch friend and scientific advisor.

In December 1952 Edoardo Amaldi was given a frosty reception by Cherwell in London. Within minutes, Cherwell told Amaldi in no uncertain terms that he was skeptical of the CERN idea. Undeterred, Amaldi wanted to meet some of the young Britons who might be interested in joining Dahl's group. Delegated to drive Amaldi from London to Harwell was John Adams, a young engineer who had moved to synchrotron development after wartime radar work. At Harwell, Amaldi met others who were working on both the CERN machine design and a major new British machine.

With the national machine committed to the old weak-focusing design, Adams and colleagues had been taking a close look at strong focusing, and discovered that the initial idea was optimistic. Small errors in the magnets—tiny misalignments and field variations—would be naturally amplified and might cause the beam to blow up. To allow for this possibility, the aperture of the strong



*Fate led British engineer John Adams to become head of CERN's proton synchrotron project in 1954 at the age of 34. Under his inspired leadership, CERN was to fulfill the dreams of its founding fathers. (Courtesy CERN)*

focusing machines would have to be larger than the Brookhaven physicists had initially suggested. To accommodate a larger tube, the enveloping magnet had to be much larger too, and the design energy of the CERN machine was compromised to 25 GeV.

In parallel with these technical advances, the British suddenly switched from aloofness and formally joined CERN, which finally decided on Geneva as the site for the new laboratory. On the map, the canton of Geneva appears as a curious appendage at the extreme west of Switzerland. Almost totally surrounded by France, it is joined to the rest of Switzerland by an umbilical cord a few kilometers across. Beginning with the Red Cross in 1863, the city of Geneva has become the home of many international organizations.

An advance party of the proton synchrotron group arriving in Geneva was joined by John and Hildred Blewett from Brookhaven. After bestowing crucial insights, Dahl preferred to remain in Bergen, first appointing Goward as his on-site supervisor, and finally resigning from the new project. Just a few months later, in March 1954 and only 33 years old, Goward died of a brain tumor. At the tender age of 34, Adams became leader of CERN's proton synchrotron project. Fate had provided the new project with its leader. John Adams was to be the Moses who would take CERN into the Promised Land.

CERN's first machine, the 600 MeV synchrocyclotron, was commissioned in 1957 and soon began producing useful physics. However it was far outgunned by the Cosmotron and Bevatron, by the big new

*On November 24, 1959, CERN's proton synchrotron accelerated protons to 25 GeV and briefly became the world's highest energy accelerator. Here a jubilant Gilberto Bernardini from Italy embraces John Adams.*

Dubna Synchrophasotron attaining 10 GeV, and even by Britain's 1 GeV synchrotron at Birmingham. Eyes were focused on the race between the two proton synchrotron teams at Brookhaven and CERN.

On November 4, 1959, CERN's new proton synchrotron unexpectedly accelerated protons all the way to 25 GeV, becoming the world's highest energy machine, easily outstripping Dubna's 10 GeV. The CERN team was jubilant, and emotional and dramatic scenes offered a sharp contrast in national stereotypes. Gilberto Bernardini from Italy jubilantly kissed a disconcerted Adams on both cheeks. The laconic Adams phoned Alec Merrison, who later recalled, "He did not tell me in highly excited tones. He said 'Remember those scintillation counters you and Fidecaro put in the ring? Will they detect 20 GeV protons?' I paused long enough to grab a bottle of whisky and Professor Fidecaro, in that order, and came along to celebrate."

The following day, at a special news meeting for CERN staff, Adams showed a vodka bottle he had been given several months earlier on a trip to Russia with strict instructions that it should be drunk when the CERN synchrotron surpassed Dubna's energy. The bottle was now empty.

But Dubna's vodka bottle was not the only unfilled thing at CERN. Also very empty were the experimental halls around the new synchrotron. In the rush to build the new machine, few people had paid attention to the instrumentation needed to carry out experiments. At Brookhaven, the new Alternating Gradient Synchrotron (AGS), the twin of the new CERN machine, did not accelerate a beam until six months later. But this delay was more than compensated by the enthusiasm and ingenuity that went into planning experiments. U.S. physicists had cut their high energy accelerator teeth on the Cosmotron and the Bevatron. Within a few years of its commissioning, the AGS reaped an impressive harvest of important new physics results.

CERN had risen to the challenge of building the world's most powerful machine from scratch in just a few years, but developing research infrastructure and fostering experimental prowess was to take somewhat longer.

# Searching for Neutrino Oscillations

by MAURY GOODMAN

*Experiments of the past forty years have revealed three families of the ghostly particles called neutrinos. Continuing studies hint that a neutrino of one family might sometimes change into a neutrino of a different family, by a mechanism known as neutrino oscillation. The author describes why understanding this phenomenon might be critical to the question of whether neutrinos have mass.*

PHYSICISTS FROM AROUND the world are engaged in a wide variety of experiments to determine whether neutrinos have mass. This possibility has intrigued physicists and cosmologists for two decades, ever since neutrinos emerged as a leading candidate for the dark matter thought to inhabit the Universe. A comprehensive new experiment is being built in Illinois and Minnesota to study neutrinos from an intense new Fermilab beam impinging on a detector 500 miles away. It is one of the most ambitious of a new round of experiments being planned and proposed to search for neutrino oscillations, a process in which neutrinos can transform from one kind into another—if they have mass. A positive result could have implications for the density of the Universe, as well as for the generation of energy by the Sun.

Often, given a well-defined physics problem, one or two well-designed experiments can answer the question one way or the other. But this is not the case for neutrino mass, because there are three different kinds of neutrinos and a wide range of possible mass scales. This situation has led physicists to attempt a large number of experiments that are quite different from each other.

In this article, I relate why so many physicists are excited by neutrino-oscillation experiments. First, I describe the properties of neutrinos themselves. Then I cover some of the experimental hints supporting neutrino oscillations. Finally, I close with a description of the Fermilab-to-Soudan, Minnesota, long-baseline neutrino project, an ambitious program to search for changes in the properties of a neutrino beam as it speeds silently beneath the farms and prairies of the American Midwest.

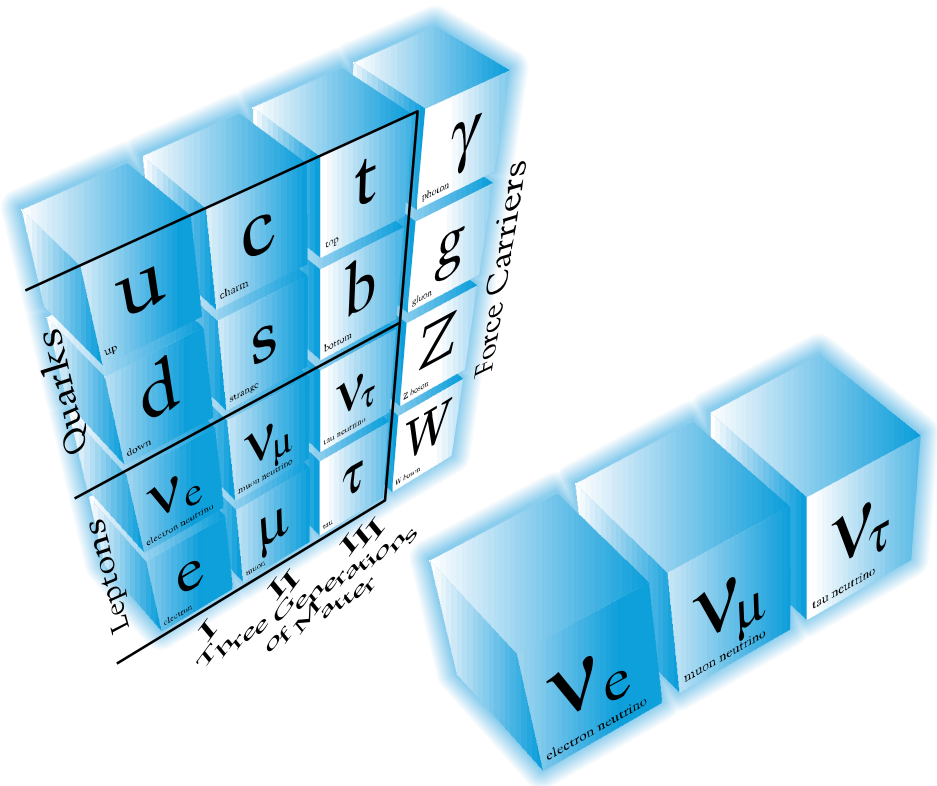
*Melvin Schwartz in front of the Brookhaven detector that showed experimenters in 1962 that the muon had its own neutrino, different from the electron neutrino. Schwartz, Leon Lederman, and Jack Steinberger won the Nobel Prize in 1987 for this discovery. (Courtesy Brookhaven National Laboratory)*

THERE ARE THREE "flavors" of neutrinos, the electron neutrino $\nu_e$, the muon neutrino $\nu_\mu$, and the tau neutrino $\nu_\tau$. Each is closely related to the corresponding lepton: the electron, muon, and tau lepton. These six leptons together with six quarks constitute the fundamental "matter" particles of the Standard Model of high energy physics.

The three neutrinos interact very weakly with ordinary matter. Physicists originally thought that the great weakness of the interaction would make them impossible to detect, but neutrinos have been seen coming from accelerators, from nuclear reactors, from cosmic-ray interactions in the atmosphere, from the sun, and from Supernova 1987A. (Nuclear weapon explosions are also the source of copious neutrinos, but I am not aware of any experiment that has detected them.) Neutrinos are either massless or far lighter than the quarks and other leptons. This difference might be related to the fact that neutrinos have no electric charge, while the quarks and other leptons do have charge. The question of mass remains one of the big mysteries remaining in particle physics. There is no clear prediction relating the masses of the nine charged fermions, and none for whether the neutrino masses are zero or just very small.

However, most physicists expect that if neutrinos do have mass, even a tiny amount, the phenomenon of neutrino oscillations should exist (see the box on the opposite page). These transformations are closely related to the quantum-mechanical phenomenon of mixing. If neutrinos oscillate, they can be produced in one flavor, such as $\nu_\mu$, and be detected as another flavor, such as $\nu_\tau$, some distance away.

When Pauli predicted the existence of the neutrino in 1930, he did not suppose there would be more than one kind. He was only trying to explain the wide distribution of electron energies observed in nuclear beta decay. The idea that neutrinos come in different flavors became accepted in 1962, when an experiment at Brookhaven National Laboratory directed neutrinos from pion decay at a target and found that almost all of the events had a muon, and not an electron, emerging from the point of the neutrino interaction. This result led to the idea that each lepton flavor ($e$, $\mu$, $\tau$) has a conserved quantity—something that doesn't change in an



interaction—associated with it. When the pion decays, it almost always becomes a muon and a neutrino and hardly ever an electron and a neutrino. The Brookhaven National Laboratory result could be explained if the $\pi^+$ decays into a $\mu^+$ and a $\nu_\mu$; when they interact with the target nuclei, the $\nu_\mu$'s generate muons, not electrons.

When the third lepton, the tau, was discovered at the Stanford Linear Accelerator Center in 1975, it was natural to conjure up a third neutrino, the $\nu_\tau$, to account for missing energy in tau decays. In the 1980s physicists discovered and began producing copious numbers of $Z$ bosons; this particle served as a neutrino counter because its decay rate is proportional to the number of fundamental particles with less than half its mass. Measurements of this rate at CERN and SLAC confirmed that there are only three neutrino-like particles in the elementary particle zoo—a result that had been predicted by cosmologists. So far, there has not been any convincing evidence that the $\nu_\tau$ interacts with nuclei to make taus in a manner equivalent to the other two neutrinos. But a current Fermilab experiment is expected to find these $\nu_\tau$ interactions.

The two factors affecting neutrino oscillations (see adjacent box) that are under the control of the experimenter are the neutrino energy $E_\nu$ and the distance $L$ between their source and the detector. These appear in the ratio $L/E_\nu$, so an experiment designer needs a large distance and low energies in order to measure small values of the mass difference between two neutrino types. This requirement must be balanced against the fact that large distance and low energy both make it more difficult to detect a large number of neutrino events.

Let's go back to the Brookhaven experiment that discovered the muon neutrino. If the mixing strength and mass difference had both been large enough, that experiment would not have been able to discover the $\nu_\mu$. It would have seen both electrons and muons coming from the point of the neutrino interactions! We can use the success of that experiment to place limits on the combination of the two parameters. We usually do this by making a graph in the parameter space called the "$\Delta m^2 - \sin^2(2\theta)$ plane," these being two parameters that specify the mixing strength and mass difference (see the box on the next page). An

### Probability of Neutrino Oscillations

IN ORDER TO MEASURE neutrino oscillations, the experimenter wants the probability that one neutrino transforms into another to be as large as possible. This probability is given by

$$P_{\nu_1 \to \nu_2} = \sin^2(2\theta_{12})\sin^2(1.27\Delta m^2_{12} L/E_\nu),$$

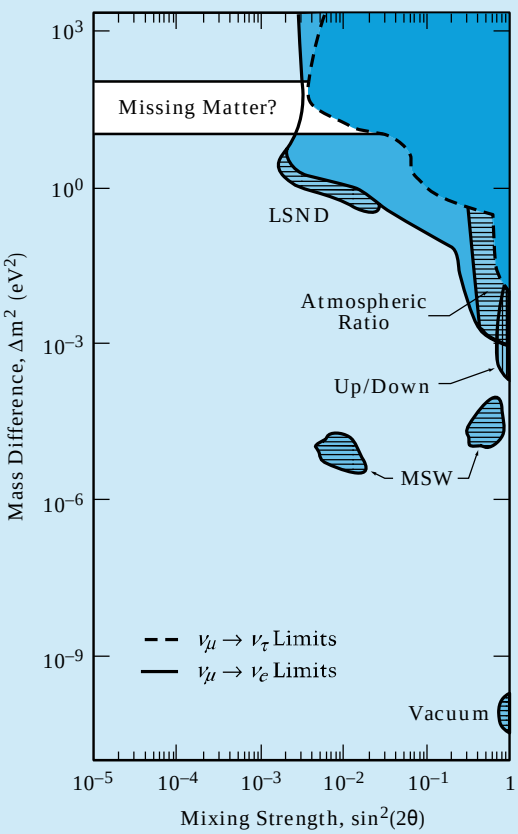
where $\sin^2(2\theta_{12})$ is the mixing angle, $\Delta m^2_{12} = m_1^2 - m_2^2$ is the difference in mass squares of the two neutrinos, $L$ is the distance (in km) from the neutrino production point to the experiment, and $E_\nu$ is the neutrino energy in GeV. If either $\sin^2(2\theta) = 0$ or $\Delta m^2 = 0$, the phenomenon of neutrino oscillations does not exist. If all three neutrinos are massless, $\Delta m^2 = 0$.

As a result of the above equation, the neutrino "oscillates" with a strength $\sin^2(2\theta)$ and an "oscillation length"

$$L_{osc} = \frac{\pi E_\nu}{1.27\Delta m^2}$$

The oscillation probability varies as $\sin^2(\pi L/L_{osc})$. It is the sinusoidal nature which gives the name to "neutrino oscillations."

## Relevant Neutrino Parameter Space




This graph shows the regions of neutrino mass ($\Delta m^2$) and mixing strength [$\sin^2(2\theta)$] which are suggested and ruled out by present data. The shaded regions are ruled out above and to the right of the curves labeled $\nu_\mu \to \nu_e$ and $\nu_\mu \to \nu_\tau$. The hatched areas are suggested regions of parameter space from the LSND, atmospheric, and solar neutrino experiments. The band labeled "Missing Matter" is where one might expect to find neutrino oscillations if neutrinos contribute significantly to the Dark Matter problem. New long-baseline experiments will explore the region of parameter space suggested by the atmospheric ratio and up/down results.

experiment that is consistent with small or no neutrino oscillations corresponds to a curve in that plane that excludes the values of mixing strength and mass difference above and to the right of the curve.

Since the early 1960s, neutrino experiments at Brookhaven, Fermilab, CERN, and the Institute for High Energy Physics at Serpukhov, Russia, have grown from tens to thousands to millions of neutrino events. None of these experiments has witnessed evidence for $\nu_\mu \to \nu_e$ or $\nu_\mu \to \nu_\tau$ oscillations. And at the same time, experiments at nuclear reactors have found no evidence for $\nu_e$ oscillations in detectors situated up to a kilometer from the reactor. The published limits have steadily crept to lower values of the neutrino mixing strength and mass difference.

BUT THE STORY by no means ends there. While experiments at reactors and high energy accelerators have found no evidence for them, four hints have emerged suggesting the real possibility of neutrino oscillations and hence mass. These are the solar neutrino deficit, the atmospheric neutrino deficit, the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos National Laboratory, and the missing matter problem. These hints suggest the existence of neutrino oscillations in regions of the parameter space that have not been completely ruled out by accelerator experiments.

The solar-neutrino deficit has been around for thirty years. (See "What Have We Learned About Solar Neutrinos" by John Bahcall in the Fall 1994 issue of the *Beam Line*.) Simply put, five solar-neutrino experiments have measured a significantly smaller number of neutrino interactions than expected, based on the measured heat output of the Sun and nuclear physics models of both the Sun and the detectors. Each experiment observed fewer neutrinos than expected, but the actual deficit each measures depends on the detecting medium and energy threshold. While it is not possible to explain the data with alternate models of the Sun, one can account for all the data within the framework of neutrino oscillations.

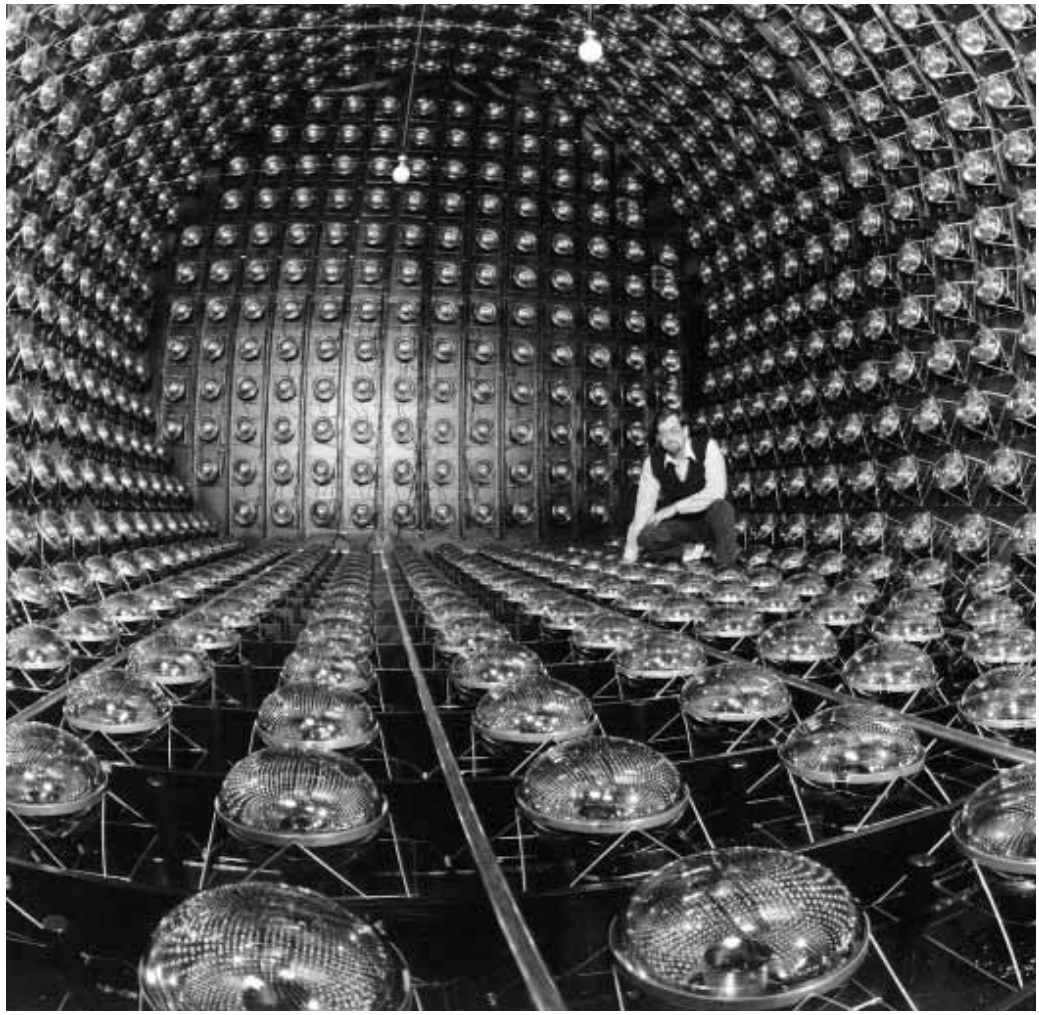
As discussed in the box on page 11, the length scale of an experiment provides a possible oscillation length. There are two possible scales for solar neutrinos: the distance from the Sun to the Earth and the radius of the Sun. Each length scale leads to a separate neutrino-oscillation solution for the solar neutrino deficit. One (labeled "vacuum" in the illustration on the left) arises from a straightforward solution of the relationship between neutrino mass and oscillations (see the box on the left). The other solutions (labeled "MSW" after Stanislav Mikheyev, Alexei Smirnov, and Lincoln Wolfenstein, who formulated the relevant theory) obey more complicated equations that take into account the huge density and density gradients of matter in the Sun, and how they can affect neutrinos emerging from its core. Both of these solutions involve oscillations of electron neutrinos into other kinds.

The atmospheric neutrino deficit takes us underground to experiments that were originally built for another purpose—to search for proton decay.

These massive detectors, which weigh from one to fifty thousand tons, haven't discovered proton decay, but they do observe about a hundred interactions of atmospheric neutrinos per year for every thousand tons of detector mass. These neutrinos are created near the top of the atmosphere when cosmic-ray protons initiate a particle cascade, making one or more charged pions, each of which decays into a muon and a $\nu_\mu$. The muon subsequently decays into an electron, a $\nu_\mu$, and a $\nu_e$. Thus, the ratio of $\nu_\mu$ flux to the $\nu_e$ flux observed in an underground detector should be about two. This is quite a strong prediction, regardless of cosmic-ray rates and the subtleties of calculating the number of particles produced in the cosmic-ray cascades. Underground detectors seem to be measuring the expected number of electron neutrinos, but only sixty percent of the expected muon neutrinos. This $\nu_\mu$ deficit could be explained by $\nu_\mu \rightarrow \nu_\tau$ oscillations, with the $\nu_\tau$ too low in energy to produce a tau lepton by interacting with a nucleus. This deficit seems to indicate a value of $\Delta m^2$ betyween $10^{-3}$ and 1 $eV^2$ (see region labeled "Atmospheric Ratio" in the illustration on page 12).

The distance that atmospheric neutrinos travel before hitting a detector varies from 25 kilometers for those coming from overhead to 12,000 kilometers for those coming from the other side of the Earth. This provides an opportunity to determine whether there is any difference in the signal between the up-going and the down-going neutrinos. If so, the oscillation length for typical atmospheric neutrino energies (500 MeV) would be between 25 km and 12,000 km. There is strong evidence from the SuperKamiokande experiment this is the case. This "up/down asymmetry" observed seems to favor a value of $\Delta m^2$ between $10^{-4}$ and $10^{-2}$ $eV^2$ (region labeled "Up/Down" in the illustration).

The LSND experiment at Los Alamos, unlike the solar and atmospheric neutrino experiments, was explicitly built to look for neutrino oscillations. Operating near the target of the LAMPF accelerator, it uses a very intense $\pi^+$ beam. The pions stop in the target, decay into a $\mu^+$ and a $\nu_\mu$, and the $\mu^+$ decays into an $e^+$, a $\nu_\mu$, and a $\nu_e$. Except for a small and calculable background from negative pion decays, there are no $\bar{\nu}_e$'s in the beam. So if excess numbers of these particles are detected, they probably arose from $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$'s oscillations. The experiment has a 170 ton tank of mineral oil that can detect the reaction $\bar{\nu}_e p \rightarrow n e^+$ by measuring a 15–30 MeV positron in coincidence with a signal



*The LSND detector is designed to search for the presence of electron anti-neutrinos with great sensitivity. Over 1200 photomultiplier tubes line the inner surface of the oil tank, shown above with LSND physicist Richard Bolton of Los Alamos. (Courtesy Los Alamos National Laboratory)*

from neutron capture, which yields a 2.2 MeV gamma ray. The experiment has reported a signal that could be explained by neutrino oscillations with a strength $P_{(\nu_\mu \rightarrow \nu_e)} = 0.003$.

Unlike the atmospheric and solar neutrino deficits, the LSND signal has been observed in only one experiment. In fact, other experiments that are sensitive to these oscillations over similar regions of parameter space have obtained negative results. The region favored by LSND but not ruled out by other experiments (labeled "LSND" in the figure on page 12) suggests a value of $\Delta m^2$ around 1 $eV^2$.

The final hint, the missing matter problem, is really suggestive of neutrino mass rather than oscillations. There is a critical density of matter in the Universe (see article by Alan Guth in the Fall 1997 issue of the *Beam Line*, Vol. 27, No. 3), about one hydrogen atom per cubic meter, above which the Universe is closed and will someday collapse back into a single point. If the density is at or below this critical density, the Universe is open and will expand forever. There are strong theoretical arguments that the density should just equal the critical value, though there are recent observational data which suggest only twenty percent of that value. Ordinary baryons, the stuff that makes up stars and stuffed pizza, is only about five percent of the critical value, based on both observational data and the rates of light element production during the Big Bang. Some of this missing matter may well be neutrinos; there are hundreds of them in every cubic centimeter of the Universe. If they had a mass of just 5 eV, neutrinos would outweigh all the stars and pizza in the Universe.

Experimenters want to confront these hints of neutrino oscillations with more definitive measurements. New solar neutrino experiments are determining the size, time dependence, and energy dependence of the solar neutrino deficit. New short-baseline oscillation experiments are studying mass differences in the region of the missing matter problem. The reported LSND effect will be sought by another collaboration at the Rutherford Laboratory in Britain, and there is a proposal for a future follow-up detector at Fermilab (see table on the left for a small selection of these experiments).

**Select Present/Future Neutrino Experiments[a]**

| Experiments | Neutrino Energy | Location | Status |
|---|---|---|---|
| *Solar* | | | |
| SuperKamiokande | 7 MeV | Kamioka, Japan | Current |
| Sudbury (SNO) | 4 MeV | Ontario, Canada | Beginning |
| *Atmospheric* | | | |
| Soudan 2 | 600 MeV | Minnesota | Current |
| MACRO | 5 GeV | Gran Sasso, Italy | Current |
| *Reactor* | | | |
| Chooz | 5 MeV | France | Current |
| Palo Verde | 5 MeV | Arizona | Future |
| *Short-baseline* | | | |
| NOMAD | 50 GeV | Geneva, Switzerland | Current |
| LSND | 40 MeV | Los Alamos | Current |
| *Long-baseline* | | | |
| MINOS | 20 GeV | Fermilab to Minnesota | Future |
| ICARUS | 30 GeV | Switzerland to Italy | Future |
| K2K | 1 GeV | Tsukuba to Kamioka, Japan | Future |

[a]A more complete list of neutrino experiments can be found at http://www.hep.anl.gov/ndk/hypertext/nu_industry.html

WHILE UNDERGROUND experiments will continue to study the atmospheric neutrino deficit, there is another plan to study possible neutrino oscillations in the same region of parameter space. These are the long-baseline experiments. While short-baseline experiments are typically one kilometer from the point where the neutrinos are produced, long-baseline

experiments in the United States and Europe will be located 730 km away from the source. And another experiment in Japan will have 250 km between neutrino production and detector. All three of these choices are matters of convenience—the distances between existing accelerators and existing underground facilities. As luck would have it, however, all three projects will substantively address the possibility that the atmospheric neutrino deficit is due to neutrino oscillations.

As an example of one of the most ambitious new neutrino oscillation projects, I will now focus on the Fermilab-to-Soudan long-baseline project (see map on the right). There are three elements to the project: the neutrino beam, a near detector at Fermilab, and a far detector at the Soudan underground physics laboratory in northern Minnesota.

A high-intensity neutrino beam from Fermilab will be made possible by a new high-intensity 120 GeV proton source called the Main Injector. Scheduled for completion in 1999, this facility is being built to replace the present Main Ring as one stage of acceleration. The Main Injector will also allow a very high-intensity neutrino program, known as NuMI for "Neutrinos at the Main Injector," to be run simultaneously with other experiments . The intense proton beam makes a neutrino beam by hitting a target to make the maximum number of pions and kaons, which are focused forward to give a beam with as little divergence as possible. Then they travel through a one kilometer pipe where many of them decay into neutrinos, which continue moving forward. The kinematics of the pion decay results in an average angle between a neutrino and the original beam of about 1/20th of a degree.

One obvious concern in aiming a beam at a target so far away is the precision required to hit it, but this turns out to be only a minor problem. Hitting the target is a similar to aiming a flashlight at the moon. Most people could hold the flashlight and point accurately enough. The problem comes in seeing the flashlight while standing on the moon. This could only be accomplished with a powerful enough light. The long-baseline neutrino problem is similar. The neutrino beam spreads out as it recedes from Fermilab, losing its intensity. And, neutrinos are very weakly interacting, so one needs a very massive target in order to detect just a few of them. In order to study such long oscillation lengths, the detectors must be far away from the source and can only intercept a small fraction of the beam. Thus it is necessary to make the beam very intense at its origin.

The far detector will be located in an old iron mine beneath the Soudan State Park in Minnesota. A half mile beneath the surface—at the deepest level of a historic iron mine—is the existing Soudan 2 fine-grained detector. The mine, which operated for almost one hundred years, is currently being maintained for tourists by the State of Minnesota Department of Natural Resources. Scientists plan to bring ten thousand tons of iron to build the MINOS detector, which will join the one thousand tons already in Soudan 2, to study neutrinos from Fermilab. It's a bit like taking coal to Newcastle.


*Map showing long-baseline neutrino experiment planned from Fermilab in Illinois to Soudan in Minnesota.*

*The home of the MINOS detector—a cavern in Soudan, Minnesota—being installed in the 1980s. (Courtesy Fermilab)*

*The headframe atop a former iron mine at Soudan in northern Minnesota. (Courtesy Fermilab)*

The new MINOS (for "Main Injector Neutrino Oscillation Search") detector will measure about twelve thousand neutrino interactions per year out of the five trillion that pass through. It will consist of six hundred layers each of scintillation counters and magnetized iron. If the atmospheric neutrino deficit is due to $\nu_\mu \rightarrow \nu_\tau$ oscillations, MINOS will observe different rates of events, different fractions of events with muons, and different energy distributions from those seen in the near detector.

A small version of the MINOS detector at Fermilab is a necessary part of the experiment. This detector will be used to understand the beam and calibrate its intensity, by measuring the interactions of neutrinos before they have had any chance to oscillate into other species.

Physicists hope to begin taking data with the existing Soudan detector and the first sections of the new MINOS detector in 2002. Given all the other neutrino experiments around the world, I can promise that there will be substantial progress in understanding neutrinos and the possibility of neutrino oscillations during the next decade. But I suspect that progress will come slowly and gradually. The large and growing effort being devoted to neutrino experiments is indicative not only of the interest in these ghostly particles but also the difficulty of doing precision work in this field. Even if we definitively show that neutrino oscillations exist, there will be a large set of neutrino mass and mixing parameters to determine. And if neutrino oscillations do not turn up, we will need alternative explanations for the present observational hints. In one form or another, the experimental study of neutrino oscillations will probably continue for the next twenty years!

# Physics with Charm

by JEFFREY A. APPEL

*Physicists recognize that the Standard Model conceals as much as it reveals about the ultimate workings of matter. Might the study of the charm quark help open the way to the physics beyond the Standard Model?*

MAYBE WE SHOULD CALL IT something different. "The Standard Model" sounds so definite, so final. Perhaps another name would better describe the part-monument, part-punching-bag nature of the world's best theory of how matter is put together at the smallest scale. The Standard Model *is* a monument—a monument to the power of theory and experiment to explore and explain the seemingly trackless inner reaches of the matter around us. But it is a punching bag, too, the so-far intact target of experimental jabs and thrusts attempting to expose its weaknesses. The punches have included searches for forbidden processes, neutrino mass, and other symmetry violation. Now, in a dizzying mix of metaphor, the Standard Model has become something else as well—a curtain that physicists know is about to go up, revealing the true drama on the stage behind it: The Physics Beyond the Standard Model. For we know that the Standard Model conceals as much as it reveals about the ultimate workings of matter. We know that marvelous scenes will unfold before us, if only we can find which rope to pull to make the curtain rise.

Most of the theoretical and experimental energy of the field of particle physics at the end of the twentieth century is concentrated on raising the Standard Model curtain on the drama that will be twenty-first century physics. And most of these efforts are devoted to pulling on two ropes: high-energy searches for the origin of mass and the quest to find matter-antimatter asymmetry in the behavior of mesons containing the bottom quark. But besides these mainstream efforts, might there be another way to raise the curtain? Might we at least lift its corner by using—charm?

***The charm quark has intrigued particle physicists as a unique particle, the first of the heavy quarks—and more.***

Since its famous discovery almost a quarter century ago, the charm quark has intrigued particle physicists as a unique particle, the first of the heavy quarks—and more. It is the only quark with charge +2/3 that is both unstable (unlike the up quark) and yet survives long enough (unlike the top quark) to bind with other quarks and form observable particles. Thus the charm quark offers a unique way to discover effects that may occur only in this "up-quark" neighborhood of the particle world. Such effects might never show up in the down, strange and bottom quarks, with their −1/3 charges. Charm might give us a longed-for peek beyond the Standard Model curtain.

## FASCINATION OF CHARM

Until 1974, three kinds of quarks had appeared in experiments: up, down and strange. But theorists, reasoning that quarks should come in even numbers, predicted a fourth kind, dubbed charm. If it existed, besides evening up the quark score, charm would explain a puzzle: why do neutral kaons decay only very rarely into a pair of muons? Charm did indeed materialize, simultaneously on the east and west coasts of the United States, and it proved to have the properties the theorists had said it would. Since its appearance, the charm quark has taught physicists much about the strong and weak nuclear forces and how they interact.

Charm also teaches us about ordinary matter. Most of the matter that we see is made of quarks, held together by gluons, in neutrons and protons. Producing charm particles at fixed-target experiments (where beams of moving particles hit stationary matter, instead of colliding with beams of particles coming the other way) has elucidated the distribution of the gluons inside garden-variety hadrons containing up and down quarks, and even within less ordinary hadrons containing strange quarks. (A hadron is a particle made of quarks held together by gluons.)

The fusion of a photon with a gluon from a target hadron is the dominant process for producing charm-anticharm pairs with a photon beam. The fusion of two gluons in hadron-hadron interactions is the dominant process for creating charm quarks in that environment. Both of these processes depend on the distributions of gluons in hadrons. By carefully studying the characteristics of charm production, we work backward to the way gluons are distributed in target neutrons and protons, as well as in beam hadrons, such as pions, kaons and protons. Gluon distributions in pions and kaons (each comprising a quark and an antiquark held together by gluons) appear to be similar. In protons, which are made of three quarks, the gluons are "softer," that is they keep closer to the quarks. Charm particles interest the experimenter because they allow the identification of well-defined gluon interactions and give us a window into what is going on in the mainstream matter of the Universe.

In the story of charm, as in the story of all particle physics, technology is the *deus ex machina* that moves the plot forward. Advances in accelerator, detector, and computing technology have let us make the acquaintance of charm, and advances in technology will take us still further in the study of its character. Learning more about charm will not only help us understand the gluons, but illuminate the differences between the quarks and—and!—get to that physics beyond the You-Know-What. For charm particles may hold clues to why, for example, charm is one of only six quarks, and why those six come two by two, like creatures from Noah's Ark.

## THE DISCRETE CHARM OF FERMILAB FIXED-TARGET EXPERIMENTS

The fixed-target run that ended in September 1997 may have seen the last dedicated charm experiment at Fermilab. This moment—the end of an era of charm—is a good time to look at where we have come so far in charm research and at where we might be going.

Today, precision results on charm physics come from electron-positron collision experiments at Cornell's CESR and from Fermilab's fixed-target experiments. Where Fermilab's precision measurements come to the fore, we can credit the large numbers

of fully reconstructed decays observed and the cleanliness (with respect to background) of the experimental signals. The Fermilab experiment with the most prodigious sample of clean, reconstructed charm decays now has 200,000; but it will soon relinquish its title to a charm experiment from the last fixed-target run that projects a million or more, all told. When we consider that charm appears only once in every 200 relevant photon interactions and once in every thousand hadron interactions, and add in the fact that experiments typically reconstruct only about half a percent of these, we realize that experimenters are looking for one clean decay in about 100,000 interactions.

The nature of fixed-target experiments can lead to clean charm signals. Most of the charm particles produced move rapidly in the direction of the incident beam. They live long enough (about a picosecond) to move a few millimeters beyond their production point before they decay. Experimenters can observe this distance, but it requires precision measurement of the trajectories of the decay products, uncluttered by a lot of distracting "junk" in the way. Depending on how the charm particle decays, knowing the identity of the decay products leads to the cleanest signals. In the electron-positron machines used so far to study charm, the charm particles are at rest or moving slowly at production, so they decay on top of the production point—a much messier situation. In fixed-target experiments, physicists can use the decay topology to select only those interactions that could contain charm particles. For those, they then examine only those particles coming from single vertices.

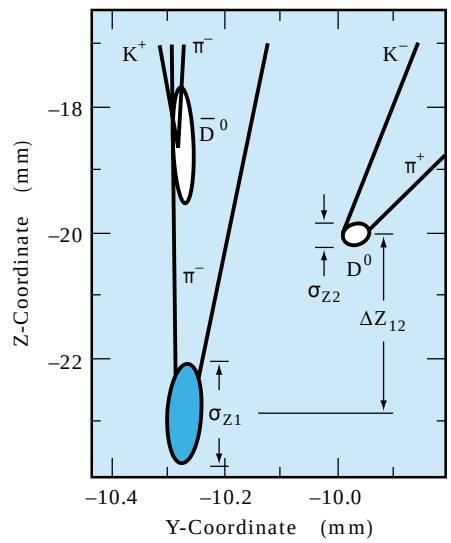
The combination of these steps helps to select the precious charm events from the more copious, uninteresting false candidate events. Applying selection criteria using vertex separation and particle identification reduces background much faster than signal. The more certain we are that a charm decay vertex candidate is separated cleanly from the event's interaction vertex, the more certain we can be that we have observed a real charm decay.

The methods developed for these fixed-target experiments have not only bagged many a charm particle, but have influenced the design for hadron colliders doing bottom and top quark research and for asymmetric *B* factories where we need to measure the separation between the decay sites of the particles containing bottom quarks.

## TECHNOLOGY OF CHARM

Advances in three areas of technology have produced today's large, clean samples of charm in fixed-target experiments. Silicon microstrip detectors (SMDs), videotape storage, and computer farms—all linked together—have taken charm physics to new levels.

The figure above right shows how the history of production and decay of charm particles in one event can be reconstructed from the trajectories of the resulting charged particles. Tracks (the records of particle trajectories) emerging from the primary interaction vertex and the two charm decay vertices (one for the charm and one for the simultaneously produced

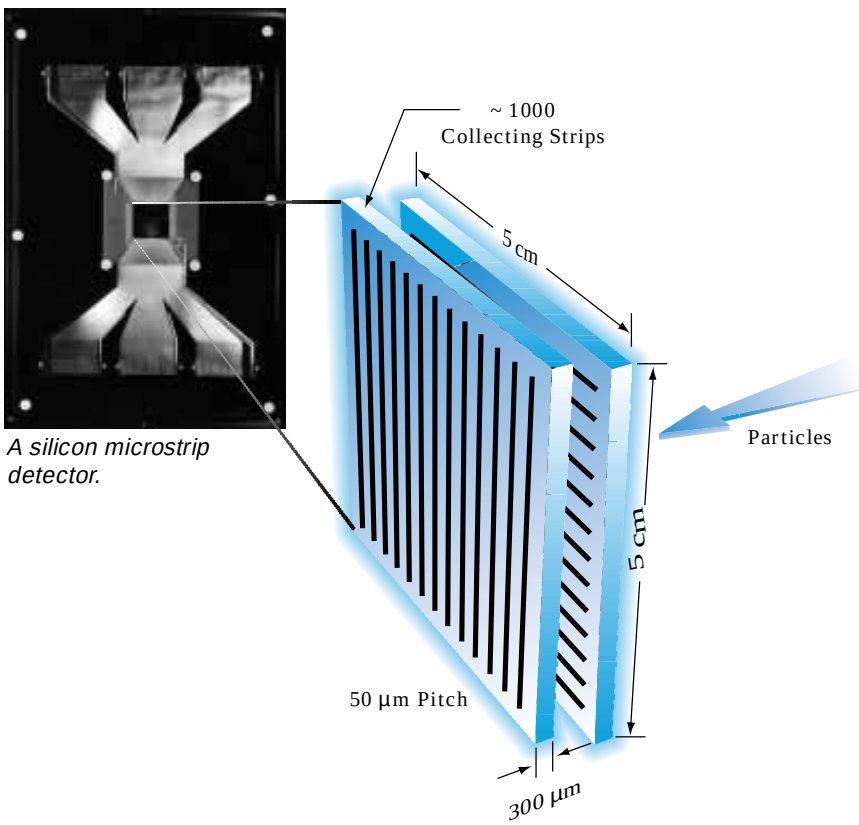



*A charm production event from Fermilab experiment E691. The two white areas represent regions from which tracks emerge and are separated from the initial collision point. This indicates that charm particles $D^0$ and $\bar{D}^0$ were produced and decayed in these regions.*

## Silicon Microstrip Detectors

MODERN MICROELECTRONIC TECHNIQUES make possible the silicon microstrip detectors that have brought charm physics such a long way. How do SMDs work? When a charged particle traverses a thin crystal of pure silicon, it deposits energy that frees electric charges to migrate.

If an appropriate voltage is applied across the crystal, the migrating charges will produce signals on metal electrodes. The signals, suitably amplified by sensitive electronics off the silicon plate, are digitized and recorded for later analysis. On SMDs, the electrodes are closely spaced




*A silicon microstrip detector.*

strips, typically 25 to 50 microns from center to center, with amplifiers attached to each strip. The large number of strips allows experimenters to record the passage of many charged particles through each detector, reduces the capacitative load on the fronts of the amplifiers, and improves the achievable spatial resolution. The SMD signal collection takes just a few billionths of a second, making SMDs useful in the intense, high-rate environments that characterize more and more particle physics experiments.

anticharm) appear to emerge from distinct vertices. This is only possible if the charm particles live long enough, if they are moving fast enough, and if the tracking resolution is sufficiently fine. A charm meson that decays after one typical lifetime has traveled several millimeters in the direction parallel to the incident beam and 150 microns in the transverse direction. SMDs provide resolutions about ten times more precise than these distances. This provides powerful separation between combinations of tracks that emerge from charm decay vertices and background.

Over the past fifteen years, the raw data from fixed-target experiments has gone from a few gigabytes to 50,000 gigabytes. It would have cost a fortune to handle so much data using the old open-reel magnetic tape system. Fortunately, new technology in the form of 8 mm videotape came to the rescue with greater capacity at a far lower price. However, because of the less-than-lightning speed of an individual 8-mm tape-writing device, one fixed-target charm experiment used 42 of the tape drives writing out events in parallel. The data-acquisition architecture supported this parallel tape writing, along with parallel-path data accumulation from the front-end electronics.

Massive new data sets also required greater economy in analysis computing. Charm experiment E691 first used massive parallel-processing computer farms at Fermilab for this purpose. At that time, experimenters used laboratory-designed, single-board computers (over a hundred in one system) with commercial CPU chips and home-built control software.

Later, commercial workstations tied together with custom software became more cost effective. This approach of using large data sets combined with simple early event selection offers certain advantages, including the ability to do analysis after detector calibrations are tuned up and sophisticated computer codes are debugged. The analysis can then apply final track- and vertex-finding. This approach works better than the use of only the cruder information available at data-taking time, which necessarily throws away some of the interesting charm events. It also helped that the price of computing power dropped rapidly in the interval between the purchase of systems for on-line and those for off-line use.

## CHARM OF THE FUTURE

Massive data storage, massively parallel computing and silicon microstrip detectors have all become part of the standard tool box for modern high-energy physics experiments. The experiments that discovered the top quark at Fermilab's Tevatron collider, the experiments that study bottom quark physics in *Z* decay at SLAC and CERN, and experiments that will study CP violation in asymmetric *B* factories all used, use or will use these techniques. Charm showed the way.

But now, whither charm physics itself? Have the present technologies run their course for charm? A look at the likely landscape of future physics experiments shows few if any long runs of sufficiently energetic beams to produce great numbers of charm particles. Would-be charm investigators will need some sort of new environment to pursue their explorations. Two possibilities suggest themselves: asymmetric electron-positron colliders and the forward regions of hadron colliders. Both remain to be explored, although both offer the promise of opening new realms of charm.

As in the past, we will need new technologies to deepen our knowledge of charm. But if we are inventive enough, and alert to new technical opportunities, it is possible that we may look to charm for its unique potential to raise the curtain on the opening act of that riveting all-star production, "Physics Beyond the Standard Model," coming soon to a theater near you.

### Growth of Data Acquisition Parallelism at Fermilab's Tagged Photon Laboratory

| Year | Experiment | Number Events (M) | Data Set Size (GB) | Number Reconstructed Charm Decays |
|---|---|---|---|---|
| 1980–81 | E516 | 20 | 70 | 100 |
| 1984–85 | E691 | 100 | 400 | 10,000 |
| 1987–88 | E769 | 400 | 1500 | 4000 |
| 1991–92 | E791 | 20,000 | 50,000 | 200,000 |

### 8 Millimeter Tape Technology

Don Summers

THE FIRST 8 MM videotapes held the equivalent of thirteen of the old open-reel tapes in use before 1990, and current versions hold two times that amount. To put it in perspective, a typical weekend of data-taking in experiment E769 resulted in a forklift of open-reel tapes (see photo above). In the next series of fixed-target runs, E791 recorded a comparable amount of data in three hours and stored it in a tray of 8 mm tapes (see photo below).

Fermilab Visual Media Services

*Fermilab physicist Catherine James holds a tray of 8 mm tapes.*

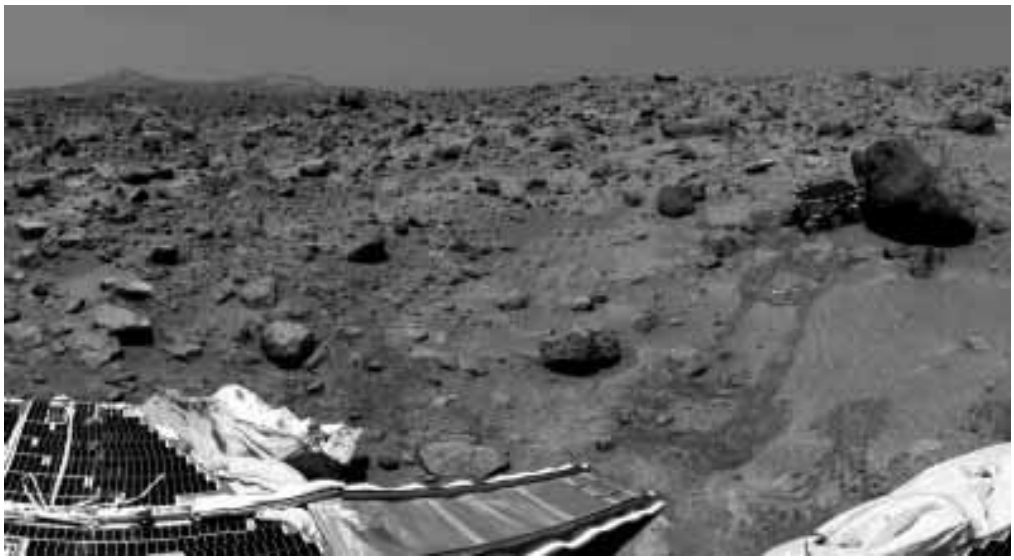
by VIRGINIA TRIMBLE

# This Was the Year That Was (Astrophysics in 1997)

*THE PROGRESS of science is not generally much like that of a kangaroo. Rather, we tend to advance amoeba-like, cautiously extending pseudopods in some directions and retracting them in others. 1997 witnessed at least its share of advances and retreats, with perhaps a leap or two. The following sections are meant to be logically independent and readable (or at least no less readable) in any order.*

## MICRO- AND MACRO-MARS: WATER, WATER, EVERYWHERE

Readers my age may remember when "I don't think so" was an expression of genuine doubt. Last year's announcement of possible microfossils in a meteorite that had come to us (or anyhow to Antarctica) from Mars provided an opportunity to try out the X-generation meaning of the phrase. Our curmudgeonly pessimism has been justified. After several months of rat-like gnawings on the edges of the evidence by other experts, the original proponents have essentially withdrawn the suggestion. Tactfully, they switched from *Science* to *Nature* for the recantation.



*Mars Pathfinder. The view is not so very different from that recorded by the Viking lander a couple of decades ago, but the device itself, including the rover, is clearly much more elaborate. Additional data on additional particular rocks makes clear that Mars, like Earth, has experienced a variety of processes, leading to a variety of minerologies and petrologies. (Courtesy Jet Propulsion Laboratory, California Institute of Technology, and NASA)*

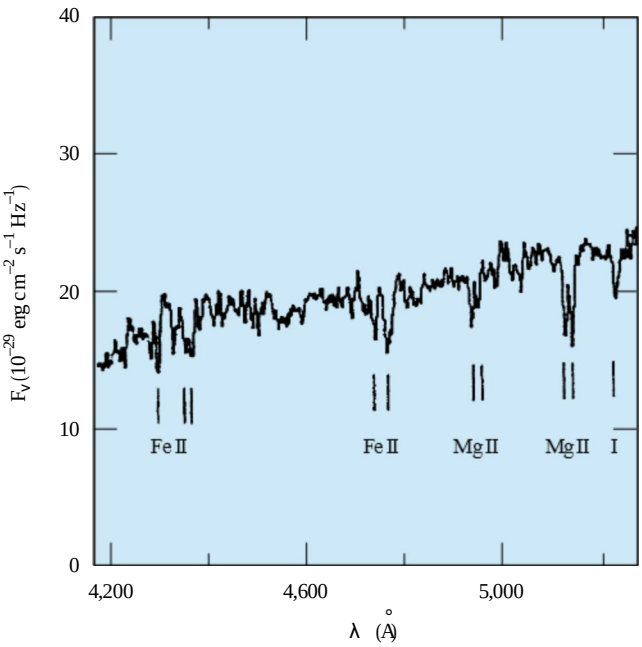
Meanwhile, a number of Martians have acquired personal names. But it's no use calling them, because, like cats and Victor Borge's children, they don't come anyhow. In fact, they all seem to be rocks. And while reports from the Sagan Memorial Station indicate that the said rocks have carefully washed their hands for dinner, there doesn't seem to be anything to eat. Continued analysis of Pathfinder data will probably yield additional information on Martian geology,* but more advanced probes will be needed to dig below the surface and look for possible relics of early pre-biological or biological evolution. If you happen to have some old slides of the Viking lander site lying around, you can check my impression that the topography of Mars has changed less in the last twenty years than that of our faces.

Liquid water continues its role as the probable limiting factor for the development of chemically based life. It may, however, not be so very rare. Besides the Earth and Mars, wet places in the solar system appear to include subsurface regions of two moons of Jupiter, Europa and Ganymede. Lots of images are already in from the Galileo mission, which, after staring at Jupiter for a while, has begun contemplating the moons, and will continue to do so into 1998.

Gaseous and solid water are all over the place. We have always suspected this from their prominence in comets and other reservoirs of local volatile material, but the inventorying has not been very easy. The problem is terrestrial water—a very good thing in its way, but given to smearing its absorption features across any spectrogram you take from Earth's surface. ISO, the Infrared Space Observatory, a mostly-European effort with good resolution in both wavelength and position on the sky, has finally climbed above even the very highest terrestrial ice crystals and water vapor molecules. It sees $H_2O$ emission and absorption features in star formation regions, in shells around evolved stars, in external galaxies, in the planets, and just about anyplace where it is cool enough for molecules to remain bound and perhaps clump together. The water features are often so strong and numerous that they in effect constitute the noise in investigations of other species that emit and absorb primarily at infrared wavelengths. Just what you would have expected in retrospect.

Nevertheless, not all water is created equal, at least not in its ratio of deuterium to hydrogen. That ratio has now been measured in three bright comets, Halley, Hyakutake, and Hale Bopp. In all three cases, D/H is about twice the ratio in terrestrial ocean water. This means that water supplies from comet impacts cannot be the primary source of terrestrial water, unless there is a comet reservoir not yet probed by the observations. The old-fashioned source of volatiles was outgassing of material trapped when the Earth formed.

**Areology would seem to be the obvious word, but it just hasn't caught on.*




*Spectrum of the GRB 970508 in blue light. The features marked are absorption lines due to singly ionized iron and magnesium in intervening gas clouds. The fact that the lines are doublets makes them fairly easy to recognize, and similar lines are common in the spectra of quasars with redshifts of one or more. The more redshifted of the two systems in the GRB is at z = 0.83, telling us that the event itself must have occurred at still larger distance. The visible source has faded enormously since May 1997, and the spectrogram could not now be duplicated. (Reprinted with permission from* Nature *© 1997 Macmillan Magazines Ltd. and the GRB team, Palomar Observatory.)*

*This is perhaps as good a place as any to tell you that the animal pictures come from a Dover volume called* Animals, *whose cover specifically declares the images to be free of copyright restrictions.*

## THE FAT LADY BURSTS

I have been told on equal authority (that is, none) that the pulchritudinous person in question was either Kate Smith rendering "God Bless America" to end a baseball game or a Sutherland-like soprano expressing the desire to leave Paris shortly before the end of *La Traviata* (not at all a bad thing to do, particularly if the performance happens to be in Paris). I would not presume to choose between them. But we were told with equal authority about three years ago* that the gamma-ray bursters were located either in the halo of our own galaxy or in other galaxies at distances comparable with the size of the observable Universe. This choice is now easy. They are at cosmological distances.

GRBs are, tautologically, bursts of gamma rays (meaning anything above 50 keV or so) that come to us at completely unpredictable times from completely random directions in the sky, at a rate of about one per day (given the sensitivity of the detectors now orbiting on the Compton Gamma Ray Observatory). Most last from a tenth of a second to a few hundred seconds, show substructure and complex spectra, and dump from $10^{-8}$ to $10^{-4}$ erg/cm$^2$ at the top of the Earth's atmosphere, with the faintest ones being commonest. Oh yes. And until February 1997, none of them had ever been caught doing anything detectable at any other wavelength.

CGRO data had additionally confounded expectations by showing that we see the edge of the GRB distribution in space, despite seeming to be at the center of it (see box on the next page). Thus the edge was supposed to be either the edge of an enormous halo of our own galaxy (not host to any other known sort of object) or an optical illusion, introduced by the redshifting of the energy of sources far enough away that cosmic expansion is important.

In the last year, a suitable satellite, the mostly-European BeppoSAX, began picking up X-ray tails to the

**At a 75th anniversary restaging of the Curtis-Shapley debate, whose proceedings appear in the December 1995 issue of* Publications of the Astronomical Society of the Pacific.

## COUNTING SOURCES OF RADIATION

I HAVEN'T SUBJECTED YOU to a calculation for a long time, and this one is just too much fun to miss out. Suppose static space is littered uniformly with candles of a fixed, standard intrinsic luminosity. Count all the ones you can see down to apparent brightness $S$. You will get $N(S) \sim S^{-3/2}$, where the 3 is the dimensionality of space, and the 2 is the inverse square law. Add a second population with a different intrinsic luminosity. It, too, will contribute a power-law $N(S)$, and, no matter how many classes you add together, $N(S)$ is always proportional to $S^{-3/2}$. Counts of GRBs rise toward faint $S$, but not as steeply as $S^{-3/2}$. Thus either distant events are rare (we are in the center of a finite distribution, and Copernicus is unhappy), or the bursts are being redshifted so that the $S$ we see is the Newtonian one cut down by a factor $(1+z)^2$, and distant events are lost from the sample equally in all directions.

bursts fast enough and with good enough angular precision to swing other telescopes toward their locations before all the fireworks were over. Three events, in February, May, and December, have been recorded—briefly!—in visible light, and the May one as a radio source. They are not all the same. The February location has an underlying steady, fuzzy visible object that is probably a distant faint galaxy. Most important, the May event (see figure on page 24) had sharp absorption lines in its spectrum that could be identified as being produced by Mg II and Fe II in clouds of gas between it and us. The lines had a redshift of 0.83, meaning that the source had to be further away than that (but not beyond a redshift of about 2). And no, I am not going to tell you how much that is in light years because it depends VERY much on your favorite values of the Hubble constant and other cosmological fudge factors.

Theorists had, of course, modeled most of the possibilities long before February. But knowing where the events are and roughly how much energy each must put into gamma rays ($10^{51}$ ergs or more, unless the photons are strongly beamed) has triggered a new round of simulating . Most of the simulees involve at least one neutron star or black hole, or sometimes two in a binary system. Given the sub-second time scales of many bursts, there aren't really a lot of other possibilities.

## PEOPLE AND PLACES

This can only be a "good news/bad news" section. The astronomical community lost more members than ever before (not surprising; we are, like most of the sciences, an aging community), but Alan Cousins, a South African stellar observer (see cover photo), set what appears to be a new world record for longevity in publication, with papers in 1924 and 1998.

The SAGE detector for solar neutrinos managed to resist for another year having its gallium resold for commercial purposes, but the HEGRA detector for extensive air showers partially burned soon after it had confirmed the second extragalactic source of TeV gamma rays, a quasar previously seen from the Whipple Observatory. SAGE also survived a calibration run with a radioactive source, showing that, if neutrinos get to it in their electron-flavored garments, it sees them, while SuperKamiokande came on line in Japan and confirmed that, for the highest energy neutrinos expected from the sun, only about half the predicted flux is arriving in due order and technically correct.

Some important satellite launches failed, including what was to have been the High Energy Transient Explorer (HETE) , left looking up the rear end of its launch partner after they failed to separate. Others did just what they should, including the Japanese X-ray mission that carries both the acronym HALCA and the name Haruka (a type of bird).*

**Yes, they really are nearly identical in pronunciation. The unvoiced vowel "u" may be familiar from "sukiyaki." As for the seemingly-double-valued consonant, about all I can suggest is that you try saying "rocket flights" and "locket frights" quickly, in alternation, until they start to sound the same.*

The literature contemplated itself, with conclusions that Einstein (a) really did write down "his" equations before David Hilbert and (b) had tackled calculations of gravitational lensing as early as 1912, but thought the results hardly worth publishing. A couple of colleagues introduced into the literature the words "isopedic" and "enstrophy." Yes, of course you could look them up, but isn't it more fun to guess "having the same feet" and "a nourishing thermodynamic quantity?" And the gremlins of typography and copy editing brought us many treats, of which my favorite is the acknowledgment "to the TIRGO tune allocation committee for the award of telescope time. At most observatories, TAC is an acronym for "time allocation committee," but having once shared nights at Mt. Palomar with a colleague who kept awake by singing music of the old Polish church, I can see that the other might sometimes also be needed. If only they had allocated me "99 bottles of beer on the wall" (those were long winter nights), or even *La Traviata*.

## DON'T GIVE UP YOUR DAY JOB

Non-Hollywoodites may need reminding that, along with "don't call us, we'll call you," these are words spoken to an aspiring actor or musician who may not be quite ready for the big time. Here I have in mind cases where somebody went out on a limb (often a very sturdy-looking, oak one) only to have some portion of it sawed off from under him. Additional examples include the Martian micro-fossils and Type I supernovae as distance indicators mentioned in other sections.

Our own Local Group of galaxies consists of two big ones (us and the Andromeda Nebula) and a whole bunch of little ones, whose number has seemed to increase at about one per year of late. But the 1992 and 1996 "discoveries," small, faint galaxies a million or two light years away in the directions of the constellations Tucana and Antlia were actually catalogued back in 1977. New at least as confirmed LG members? Perhaps not even that. Antlia is probably further away than the million-parsec limit of gravitational binding to the Local Group.

Accretion disks around proto-stars, white dwarfs, neutron stars, black holes, and prominent theorists appear in every year's highlights of astrophysics because they are part of the standard models of quasars, X-ray sources, nova explosions, bipolar molecular outflows, and all sorts of other (real, observed) phenomena. The first, persuasive data-based proposal came in 1956 from John Crawford and Robert Kraft, who concluded that AE Aqr (a nova-like variable) must be a binary system with an accretion disk of material from its normal star swirling around the white dwarf. The latest word is that AE Aqr is actually a net excretor. Accretion of course persists for most of the other advertised objects, preferentially this past year in the form of "advection dominated accretion," meaning that it carries a good deal of heat and kinetic energy with it down the tubes. The concept, then unnamed, can be traced in the literature at least back to 1977.

*One of the dwarf spheroidal galaxies that just barely belongs gravitationally to our Local Group (or just misses). Perhaps the most remarkable point is that anybody can succeed in finding and recognizing little smears like Antlia as galaxies in the first place. (Courtesy Mike Irwin, Royal Greenwich Observatory, UK)*

Planetary companions to nearby stars, mostly with masses like Jupiter but shorter orbit periods, glimmered out of press releases from the October 1995 announcement of 51 Peg onward. Perversely, much of the community embraced with enthusiasm a late 1996 suggestion that no such planets were orbiting. Instead, said David Gray of Western Ontario, we were merely seeing winds and waves in the atmospheres of (unaccompanied) stars. These would perturb profiles of stellar absorption lines and mimic the effects of small, orbiting companions. A pair of January 1998 papers, from him and from an

independent group at University of Texas, will have given us back our planets by the time you read this.

Yes, we live in a screwy Universe, but is it also chiral? Theorists have predicted and observers not seen for decades any indication that space-time is rotating or skewed on cosmic scales. This spring, a *Physical Review Letter*, from theorists in Kansas, announced net rotation, based on details of polarization of radio emission from sources at redshifts exceeding 0.3. The announcers had, however, relied on data that they had not collected themselves (always risky) and that were mostly well over a decade old, non-uniformly collected around the sky, and of sufficiently poor angular resolution that bits of the sources with different intrinsic polarization were smeared together. Owners and operators of more recent, more suitable data sets rapidly fired back upper limits to the twisting of space considerably below the positive value claimed in the *Letter*.

In fact (pause for the modest cough of a minor poet) the previous year had seen a published upper limit slightly below the PRL number, which, naturally, went uncited. Probably only two people in the world noticed this, Maurice Goldhaber and yours truly, the authors of the limit paper!

Some things really do have net chirality, including, unexpectedly, some of the amino acids in the Murchison meteorite. Contamination by the sticky fingers of meteoriticists, you will say? Apparently not, for the 5–10 percent excess of L-enantiomers occurs both in some amino acids that terrestrial creatures don't use and in association with non-terrestrial values of nitrogen isotope ratios.

## HIP, HIP, HIPPARCOS SAVES THE UNIVERSE, OR, TWO AND A HALF CHEERS FOR OUR SIDE

Hipparcos is an acronym (origins lost in the mists of time), a slight misspelling of the name of a Greek compiler of star catalogues, Hipparchus, and a (mostly European) satellite that scanned the skies for several years, establishing a coordinate system made up of precise positions for more than 100,000 stars. In the process, it also determined for each star its annual parallactic shift (that is, its distance) and its angular motion across the plane of the sky (that is, two-dimensional velocity, if you know the distance). The community had been counting on Hipparcos for quite some time to improve our knowledge of the brightnesses and kinematics of a number of kinds of stars that are either interesting for their own sake or important in climbing up the "distance ladder" to far away galaxies and the Universe.

The Hipparcos satellite. Its launch was almost a failure (owing to maloperation of nearly the only part on it of U.S. manufacture), leading to an elliptical rather than circular orbit; but close to100 percent of the expected data were obtained over several years. Hipparcos established its own coordinate system on the sky by swinging back and forth from star to star to (more than $10^5$ stars), and this needs to be tied to other systems of earth-centered coordinates. (Courtesy European Space Agency)

The splashiest press release belonged to a problem that has been around for half a century, "the age of the Universe." The time scale of the Universe implied by its measured expansion rate (the Hubble constant) has sporadically seemed to be rather less than the ages of the oldest stars we see. And this particular example of "old wine in less old bottles" has never been one we were happy with. Fifty years ago, it led to the invention of the Steady State model of the Universe. More recently, the faint at heart had been driven to invoking Einstein's notorious cosmological constant or even to doubting the

correctness of the basic picture of a universe expanding out of a hot dense state (a.k.a. Big Bang).

Two solutions are possible—make the Universe older (that is the Hubble constant smaller, by deciding that the galaxies you used to calibrate it are further away than you had thought) or make the stars younger (also achieved by shoving them away from you, so that they are brighter and use up their fuel faster). One way of looking at stars measured by Hipparcos seemed to do exactly these two things. Parallaxes of a set of stars called Cepheid variables (a traditional distance calibrator) were a bit smaller than expected, nominally both increasing the time 1/H and decreasing stellar ages. Unfortunately, equally valid ways of looking at the data, using young clusters of stars to calibrate the Cepheids and statistics of stellar motions to get brightnesses of the old ones, have precisely the opposite effect. 1/H gets smaller, and the stars get older. Some assembly is apparently still required.

Any astronomer who had planned ahead by asking in 1982 was entitled to some slice of Hipparcos data. My proposal (with George Herbig, then of Lick Observatory) was inspiringly titled "parallaxes and proper motions of prototypes of astrophysically interesting classes of stars," but you must read the archival literature to find out what we learned (other than that fifteen years is a long time even to the middle aged). The hundreds of astronomers who were also 1982 proposers have thus far probably produced an average of one paper each, and many more are expected, clarifying the evolutionary status of Barium II stars and other problems you never even knew you had.

## WE KNEW YOU HAD IT IN YOU

Some discoveries were bound to be made eventually and fall largely by luck to the first person who happens to turn the right sort of telescope or equation in the right direction, much like the case in *Moby Dick*, where Captain Ahab nails a gold doubloon to the mast for the first person to spot the whale, or, said Richard Armour, the first person up on deck after dark with a claw-headed hammer. Finding the optical counterpart of the May 8th gamma-ray burster was one of these. Some other 1997 examples follow:

- Radio pulsations from Geminga. This gamma-ray source in Gemini was long a mystery because it seemed (like the bursters) to have no counterpart at any other wavelength. Sensitive X-ray and optical detectors remedied this several years ago and also showed that it was a rotation-powered neutron star ("true" pulsar), with a period of 0.237 seconds. But all proper pulsars should beep radio signals at us (that is, after all, how they were discovered in 1967), and Geminga seemed to be a failure. Three groups, all centered in Russia, have finally found the radio pulses, more or less simultaneously (and each has published the discovery at least twice, once in the Russian literature and once elsewhere). The problem was that the source is simply very faint and steep-spectrumed, so that the best bet for catching it was at lower radio frequencies than are usually used for the purpose.
- A spiral wave in the accretion disk of a cataclysmic variable. Theorists have been predicting these for some time, because a spiral or $m = 2$ perturbation is the natural consequence of having a large point mass off to the side of a disk (hence the particularly spectacular arms in spiral galaxies with close companions like M51). IP Peg is the first cataclysmic where the wave has been spotted, via a clever mapping technique that uses changes in shapes of spectral lines through the orbit period of the system to locate bits of gas with different densities and velocities.

*Reconstructed distribution of density in the disk surrounding the white dwarf in IP Peg. The central star is blacked out and contrast somewhat enhanced. (Courtesy D. Steeghs, E. Harlaftis, K. Horne, Astronomy Group, Univ. St. Andrews, UK)*

- Central black holes in galaxies. These have become so common they no longer make the *New York Times*. Whoever happens to get the first HST images and spectra of the center of a nearby galaxy is just about guaranteed to find a black hole somewhere in the range

$10^6$–$10^9$ solar masses. In a few cases, where more than one technique has been brought to bear on a particular galaxy, the results for BH mass are in clear disagreement. You can argue about whether this constitutes progress, but it does at least guarantee employment for future generations of astronomers. Our Milky Way is part of the great majority with a central black hole of $2–3\times10^6$ solar masses as the only possible explanation of the details of the motions of stars and gas near its center.

• Broad absorption lines in a radio quasar. Proper quasars are strong sources of radio emission (the others are QSOs or quasi-stellar-objects, unless you are feeling lazy). BALs or broad absorption lines are saturated ones with redshifts just a smidge less than the redshift of the emission lines. They are attributed to gas being blown out of or around the QSO nucleus. Until 1997, the radio-loud and BAL sets were disjoint. And it took a survey of something like $10^5$ radio sources to find the first, faint overlap (this is a pun; the survey is called FIRST). The source's telephone number is 1551+3517 (actually its location in the sky) in case you want to call.

• The most distant galaxy. There is a new one of these practically every year, and quite often it is really a QSO. The 1997 queen for a day, at a redshift of 4.92, is an ordinary galaxy. It is visible at that distance partly because it is forming stars like mad (and new, massive stars are the brightest kind) and partly because it is gravitationally lensed and amplified by a foreground cluster at $z = 0.23$.

• The most distant supernova. Here too records are falling constantly, and the current one at $z = 0.9$ or thereabouts is not very important for its own sake. Distant galaxies contain heavy elements, so we know they must already have had supernova explosions. But the members of one class of supernova (called Type Ia) all seem to have the same intrinsic luminosity and so can be used to measure very large distances and get global values for the cosmic expansion rate (H) and its change with time, the deceleration parameter, $q_0$. These, in turn, are algebraically related to the mean density of the Universe. Through most of 1997, the supernova method seemed to be the one hold-out in finding a $q_0$ or density value large enough to stop the expansion of the Universe in the (very remote) future, while a number of other methods that looked at masses of clusters of galaxies or their distribution in space were finding perhaps 30 percent of that critical density. But the result came from a very small number of distant Ia's. With a larger sample of about fifteen events, the best fit is a smaller deceleration parameter, or a density of 30–40 percent of the critical value, agreeing with the other methods.

• A new class of pulsating variable star. This is a beautiful case of theory and observation rising to meet each other. Even as a group of French Canadian modelers of stars were predicting that a particular kind should be unstable to pulsations with periods near one hour, a group of South African observers of stars were serendipitously discovering a handful of stars whose brightnesses vary with several modes near one hour, in just the part of luminosity-temperature space where they were predicted. So far, they are merely called pulsating sdB stars (where "sd" says they are faint, compact, and evolved, and "B" says they have surface temperatures of 15–20,000 K), and my efforts to coin the term SubDued Bumpers has met with resounding failure.

## EVERY DOG IS ENTITLED TO ONE BITE

*The fact that the parts of a picture can be made to fit together does not guarantee this is the way Nature actually does things.*

This is my attitude, as one of the adjectival editors of a fairly prestigious journal, toward authors bearing papers about which one is tempted to quote Pauli, "It isn't even wrong." Because there are lots of journals, many of these ideas turn up as "new" year after year. Still, isn't it a sort of relief from the seriousness of transverse optical phonons to contemplate.

a. A model of star formation that produces cylindrical stars.
b. A universe whose metric oscillates with a period of 160 minutes, and so accounts both for that period

in the sun and for the peak mode of the variable star Delta Scuti (actually 162 minutes).

c. A scenario for making gamma-ray bursters in the heliosphere.
d. Dark matter candidates in the form of a vector-based theory of gravity or solid hydrogen.
e. Redshifts quantized by "giving up the arbitrary hypothesis of the differentiability of space-time."


## ACKNOWLEDGMENTS

I asked the editor to perch the amoeba atop the kangaroo in the first picture so as to have an excuse for mentioning Robert K. Merton, author of *On the Shoulders of Giants* (no, Newton was not the first to say it), who has been an occasional, generous reader of these maunderings for some time. Reviewers, even more than other scientists, are indeed supported by their colleagues.

The series, *Astrophysics in 199x*, arose from a suggestion by Howard E. Bond, the immediate past editor of *Publications of the Astronomical Society of the Pacific*, who must often have felt like the parent of Rosemary's baby, and who also just happens to have been the chap who first spotted the optical counterpart of the May 8th, 1997, gamma-ray burst—that was the one that had a measurable redshift, but he couldn't measure it, because he was using a 0.9 meter telescope (it took the Keck 10-meter). I am grateful both to him and to my some-time co-authors, Peter Leonard and Lucy-Ann McFadden, for their contributions to the series (and also to the IRS for the schedule C deduction that has enabled me to pay the page charges for its publication most years).


## READ ON

The complete text of "Astrophysics in 1997" by V. Trimble and L. A. McFadden appears in the March 1998 issue of *Publications of the Astronomical Society of the Pacific.*

The proceedings of the 75th anniversary restaging of the Curtis-Shapley debate, with contributions from R. J. Nemiroff (organizer), V. Trimble (on the original C-S event), G. J. Fishman (on observations of gamma-ray bursters), D. Q. Lamb (arguing for events in the halo of our own galaxy), and B. Paczyński (arguing for events in very distant galaxies) appear in PASP **107**, 1131-1176, with a summary by M. J. Rees, the moderator.

The announcement of cosmic chirality is found in B. Nodland and J. P. Ralston, Phys. Rev. Lett. **78**, 3143 (1997). One of the refutations is J. F. C. Wardle et al. Phys. Rev. Lett. **79**, 1801 (1997); and the premature upper limit appears in M. Goldhaber and V. Trimble, J. Astrophys. Astron. **17**, 17 (1996) . . . and next time we're going to publish in a prestigious journal too!

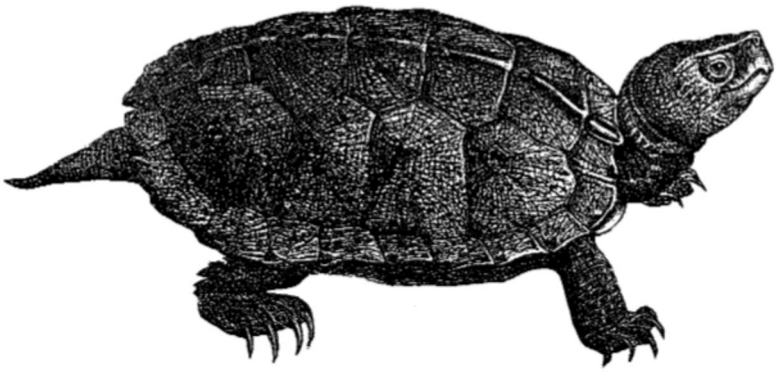
# CONTRIBUTORS

GORDON FRASER studied at London's Imperial College in the mid-1960s, when theoretical physicists were attacking spontaneous symmetry breaking under Tom Kibble and relativistic SU(6) theory under Abdus Salam and Paul Matthews. Fraser also wrote short-story fiction and became side-tracked into journalism. He returned to physics as a science writer, eventually transferring to CERN. He is editor of the monthly *CERN Courier*; co-author, with Egil Lillestol and Inge Sellevag, of *The Search for Infinity* (New York, Facts on File, 1995) which has been published in ten other languages; and author of *The Quark Machines* (Bristol, Institute of Physics Publishing, 1997). He is also editor of *Particle Century*, a collection of contributions to be published by Institute of Physics Publishing later this year.

MAURY GOODMAN is a physicist in the High Enery Physics Division of Argonne National Laboratory. He received his BS from the Massachusetts Institute of Technology. His 1979 PhD from the University of Illinois at Urbana came on a photoproduction experiment with Al Wattenberg. After a postdoc at MIT working on a Fermilab neutrino experiment, he joined the Soudan group at ANL, where he studies atmospheric neutrinos and is searching for evidence of nucleon decay. He was an early advocate of a long-baseline neutrino program at Fermilab and is now a member of the MINOS collaboration.

JEFFREY A. APPEL has been a physicist at Fermilab since 1975. Most recently he has been spokesperson for Fermilab experiment E769 and cospokesperson for E791. For eight years ending in March of this year, he headed the Physics Section and follow-on Experimental Physics Projects. Appel received his PhD from Harvard University. He is a Fellow of the American Physical Society and has coauthored over 120 articles in professional journals.

Appel's interests extend beyond the purely scientific and technical. For many years he chaired the Fermilab Auditorium Committee that organized the arts, lectures, and exhibition series there. He also initiated a special Illinois Research Corridor summer jobs program for outstanding science and math teachers. His present interests are radiation-hard vertex detectors and the BTeV research and development program.



VIRGINIA TRIMBLE is not sure that she was a turtle in a previous lifetime or deserves to be one in the next, but members of the genera testudo and pseudymis (order Chelonia) are her favorite companion animals. Her graduate days at Caltech (1964–68) were brightened by the silent sympathy of Triton (a snapper who more than earned his name), Beauregard (a button turtle), Aragorn (a red-eared slider), Golum (a Lousiana soft-shell), and others. Each entered our home about the size of the silver dollar that was the hourly salary of a graduate student in those days, and each somewhat outweighed the printed thesis by the time we came to a parting of the ways. Oscillating yearly between the University of California and the University of Maryland is too hard a lifestyle for a turtle (and sometimes marginal for a human being), but someday I hope to have another opportunity to listen for the voice of the turtle in the bathtub.

# DATES TO REMEMBER

| | |
|---|---|
| Jul 22–30 | 29th International Conference on High-Energy Physics, Vancouver, Canada (ICHEP 98) (astbury@triumf.ca) |
| July 31 | Sid Drell Symposium, Stanford, California (mpeskin@slac.stanford.edu) |
| Aug 3–14 | 26th SLAC Summer Institute on Particle Physics: Gravity—From the Hubble Length to the Planck Length (SSI 98), Stanford, California (Lilian DePorcel: Conference Coordinator, SLAC, MS 62, PO Box 4349, Stanford, CA 94309, or ssi@slac.stanford.edu) |
| Aug 4–8 | 6th International Conference on Biophysics and Synchrotron Radiation, Argonne, Illinois (Susan Strasser, Conference Coordinator, APS, bsr98@aps.anl.gov) |
| Aug 10–14 | 10th International Conference on X-ray Absorption Fine Structure, Chicago, Illinois (Tim Morrison, Conference Chairman, phys_morriso@minna.acc.iit.edu) |
| Aug 23–28 | 19th International Linear Accelerator Conference (LINAC 98), Chicago, Illinois (linac98@aps.anl.gov) |
| Aug 23–Sep 5 | 1998 European School of High-Energy Physics, St. Andrews, Scotland (Miss Susannah Tracy, School of Physics, CERN/DSU, 1211 Geneva 23, Switzerland, or Susannah.Tracy@cern.ch) |
| Aug 31–Sep 4 | International Conference on Computing in High-Energy Physics (CHEP 98), Chicago, Illinois (sak@hep.anl.gov or lprice@anl.gov) |
| Sep 6–19 | 1998 CERN School of Computing (CSC 98), Funchal, Madeira, Portugal (Miss Jacqueline Turner, CERN School of Computing, 1211 Geneva 23, Switzerland, or Computing.School@cern.ch) |
| Sep 7–12 | 17th International Conference on High-Energy Accelerators (HEACC 98), Dubna, Russia (Natalia Dokalenko, Intern. Department JINR, Dubna, Moscow Region, RU-141980, Russia, or heacc98@sunse.jinr.ru) |
| Sep 14–18 | International Computational Accelerator Physics Conference (ICAP 98), Monterey, California (icap98@slac.stanford.edu) |
| Oct 13–14 | 9th Users Meeting for the Advanced Photon Source, Argonne, Illinois (Susan Strasser, Conference Coordinator, APS, carlson@aps.anl.gov) |
| Oct 14–15 | Advanced Photon Source Users Organization Workshops, Argonne, Illinois (Susan Strasser, Conference Coordinator, APS, carlson@aps.anl.gov) |
| Oct 19–20 | 25th Annual SSRL Users Conference, Stanford, California (Suzanne Barrett, SSRL, PO Box 4349, Stanford, CA 94309, or barrett@slac.stanford.edu) |
| Oct 22–23 | ALS Users Association Annual Meeting, Berkeley, California (Ruth Pepe, Lawrence Berkeley National Laboratory, Advanced Light Source, MS 80-101, Berkeley, CA 94720, or alsuser@lbl.gov) |