BETHE FEST: A TRIBUTE TO A TITAN OF MODERN PHYSICS

Physicists and friends celebrating Hans Bethe's scientific ingenuity and moral influence throughout his first 60 years at Cornell University.

Even at the age of 88, Hans Albrecht Bethe is one of the world's most resourceful and responsible physicists. He also is one of the most universally admired—not only for his scientific accomplishments but also for his courage in taking on many sensitive political issues and his ability to attract some of the best and brightest students. So his colleagues, students and friends found it irresistible to mark his 60 years at Cornell University, where he arrived in 1935 as an emigré from Nazi Germany and where he has remained ever since. In just about every respect the Bethe Fest on the Cornell campus on 31 March and 1 April was a fitting reflection of the man himself: scientific talks on the frontiers of physics and astrophysics and an abundance of cordiality, warmth, humor and good food.

The occasion was more of a leap into the future than a trip through the past, though several speakers, mostly Bethe's students, offered some reminiscences, and the university provided a 24-minute film on his life and times. The organizers knew when they undertook the project that it would be impossible to represent more than a smidgen of Bethe's contributions to science, teaching and public policy. "If you know his work," said John Bahcall, an astrophysicist at the Institute for Advanced Study in Princeton, New Jersey, "you might be inclined to think he is really several people, all of whom are engaged in a conspiracy to sign their work with the same name."

Bethe is indeed a legend in his own time. Physicists often speculate that theorists, like athletes, usually peak at about 30. Bahcall says he finds it difficult to think of anyone who has contributed significantly to theoretical physics past the age of 50. But Bethe's career, beginning in the late 1920s as a student of Arnold Sommerfeld at the University of Munich, has spanned the evolution of nuclear physics and shows no sign of slowing down.

Since his retirement from teaching in 1975, Bethe has devoted much of his time to astrophysics, the field in which he earned a Nobel Prize in 1967 for elucidating how stars shine. In other work, he has written papers with Bahcall trying to explain why the Sun seems to spew forth fewer neutrinos than predicted by standard physics. Five years ago, Bethe apprenticed himself to Gerald E. Brown of the State University of New York at Stony Brook to apply lattice gauge theory to problems in astrophysics. Brown recalled in his talk at the symposium how he got Bethe interested in the dynamics of supernova explosions. When Brown first asked what he knew about collapsing stars, Bethe said he knew little about the subject. But when Brown said explosions were important to the collapse, Bethe "admitted he knew quite a bit about certain explosions."

In 1978 a group known as BABL, which derives from the names of its members— Bethe, James Applegate of Columbia University, James Lattimer of Stony Brook, and Brown), published a paper in *Nuclear Physics A* on the death of massive stars, which spend a mere 10 million years or so burning peacefully, passing through various stages of development, and then, when they run out of nuclear fuel, collapse in a few seconds with a mighty explosion. During the collapse, the core implodes, which BABL figured was not a chaotic process but an orderly one. Their paper pointed out that an initially low entropy is necessary for the complete collapse to occur. "Entropy was a currency for Hans in calculating explosions, not only in stars but in other things we won't talk about here," said Brown, alluding to the nuclear bombs developed at Los Alamos in the Manhattan Project, for which Bethe was director of the theoretical division. When Brown told Bethe of the entropy level involved in prior theories, Brown stated, "Hans said with his characteristic humility, 'Well, they're wrong!' Hans was right."

With Brown, Bethe worked out the "maximum scrunch," the instant when the core of a collapsing star reaches its highest density and then rebounds, converting pressure waves into shock waves and initiating a supernova. At a meeting in Seattle in 1989 Bethe reported the convection involved—without the help of supercomputer models, Brown noted, but relying on his slide rule. Using numbers inferred from supernova 1987a, Bethe calculated the net energy generated by two competing nuclear reactions involving neutrinos and electrons, respectively. He and Brown now believe the explosion of 1987a took about 3 seconds, generated neutrinos for 12 seconds and then dissolved into a black hole of 1.5 solar masses. "We have not ended our adventure," Brown told his audience. "Hans had a case of the flu in January, but wait until I get hold of him after this meeting. We will be off again." Bethe admits that he continues to "do everything with algebra. So that makes me very happy."

At the start of his talk, Brown regaled the audience with tales of Bethe's other idiosyncracies: "Hans never began work without spending 45 minutes in a bathtub, where he could think," and "after a good meal, Hans could always find room for a big dessert." Bahcall opened his talk with an anecdote that sought to dispel the supposition that Bethe is one of the best-known scientists of the 20th century. At a recent dinner at the Institute for Advanced Study, Bahcall found himself seated between two mathematicians. When Bahcall told them he would be attending a celebration of Bethe's 60 years at Cornell, one of the mathematicians boasted that he knew all about Bethe and compared him to Hermann Weyl, who was known for his insights rather than his computational skills. The other disagreed and said he knew Bethe's work, which clearly showed his technical strength, and as evidence of his own erudition he argued that Bethe's greatest contribution was the invention of beta decay.

Bethe's talk was characteristically modest and good natured. He found Brown's account of their work on supernovae to be "even more fun than I had remembered all those 16 or 17 years." He recalled that he and Rudolf Peierls, whom he met in Sommerfeld's seminars, wrote a letter to *Nature* in 1934 declaring that neutrinos were not likely to ever be observed. But Bethe's talk did not dwell on the old days; it concentrated instead on recent scientific developments and hopes for future discoveries. He spoke about recent evidence for nonvanishing neutrino masses and looked forward to the findings of the Sudbury Neutrino Observatory in Canada, where a detector containing 1000 tons of heavy water surrounded by light water might see 5 to 15 unambiguous solar-neutrino collisions per day. Bethe, whose deep and resonant voice still bears a distinctively German accent, spoke for 75 minutes with exceptional clarity and precision. When he finished he received a standing ovation that lasted almost two minutes.

'I can do that'

One of the highlights of the second afternoon was a film called "I Can Do That," made by Cornell's Office of Communications Strategies, the physics department and Rose Films. The title comes from Bethe's own recollections of two of his principal achievements—the theory of how energy is produced in the nuclear reactions within stars and the reexamination of the Lamb shift, which led to the development of quantum electrodynamics. In both cases Bethe faced uncertainties and a lack of understanding among physicists. But he said to himself, "I can do that," and then proceeded to do just that.

In the film Bethe admits that theoretical physicists are "too conceited." So at Los Alamos, where his work was basic to making nuclear bombs, "I was not surprised when the first atomic bomb actually worked."

The film opens with Dale Corson, a retired physics professor and president of Cornell, who observes that Bethe was "central to physics at Cornell," setting the standard for teaching and research. Kurt Gottfried, one of Bethe's protégés at the university, points out that Cornell wasn't "on the map" for physics when Bethe came in 1935. Gottfried and Ed Salpeter, a Cornell astrophysicist, say at different points that among Bethe's greatest attributes is his sensitivity in teaching. "Hans gave problems perfectly suited to the student's ability," Gottfried says. Salpeter ascribes that teaching method to Sommerfeld, Bethe's professor in Munich.

The film goes on to describe those early years in Bethe's career. Bethe was considered by Sommerfeld to be among his most gifted students. That was high praise indeed, for Sommerfeld's protégés included Max von Laue, Wolfgang Pauli, Peierls, Peter Debye and Werner Heisenberg. Bethe received his doctorate *summa cum laude* in 1928 with an impressive paper on electron diffraction in crystalline solids, and he then took the post of assistant to Paul Ewald, professor of theoretical physics at the Technical University of Stuttgart (who was to become his father-in-law a decade later when Bethe married Rose Ewald, then a student at Smith College). After returning to Munich to collaborate with Sommerfeld on the electron theory of metals, Bethe was awarded fellowships in 1930 and 1931 that enabled him to visit the famous physics labs in Cambridge, England, and Rome, where he worked with Enrico Fermi. By 1932, when he took his first teaching position at the University of Tübingen, Bethe was recognized as one of the leading theorists of his generation. He had developed the quantum mechanical theory that described how charged particles lose energy when traversing matter, and had reviewed the one- and two-electron-atom problem. The papers on both topics became classics as soon as they were published.

The following year, after Adolf Hitler became chancellor and imposed several anti-Jewish edicts, Bethe, whose mother was Jewish, was dismissed from his position at Tübingen. With the help of Sommerfeld, Bethe obtained a fellowship to lecture for the 1933–34 academic year at the University of Manchester in England, and he spent the fall semester of 1934 at Bristol University. While in England, he received a letter that began in a casual way: "Perhaps you will recall a brief meeting that we had in Rome in March 1932, when Dr. L. P. Smith and I visited Professor Fermi's laboratory and found you working there." The letter writer, R. Clifton Gibbs, the newly named chairman of Cornell's physics department, wanted to know if Bethe would be interested in an appointment as acting assistant professor for the academic year 1934–35. The timing was exactly right for Bethe, and he accepted at once. In February 1935 he arrived at Cornell. He was 28 years old.

Freeman Dyson of the Institute for Advanced Study says in the Bethe film that coming to Cornell in 1947 "was the greatest piece of luck that ever happened to me. Bethe had just completed his first calculation of the Lamb shift, which was the cornerstone of the new physics." Dyson, with Julian Schwinger and Richard Feynman, a member of Bethe's theory group at Los Alamos, founded QED.

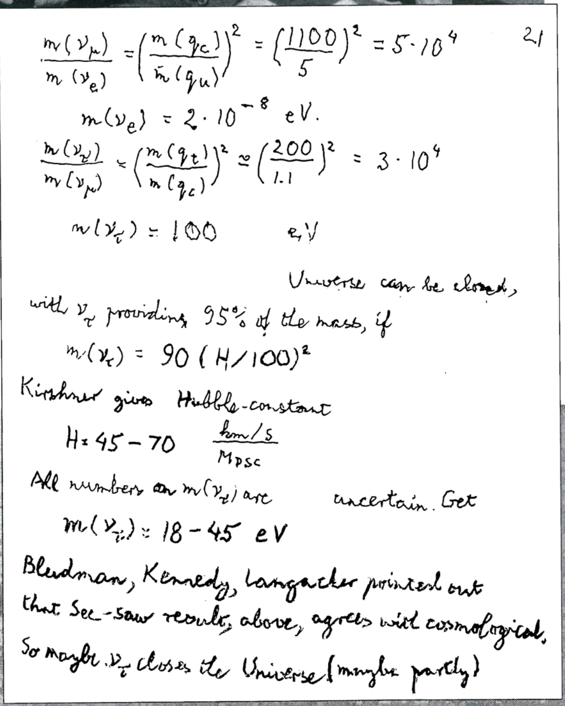
The film also pays tribute to Bethe as a persistent champion of nuclear arms control, helping to persuade the White House to ban atmospheric nuclear tests in 1963 and antiballistic missile systems in 1972. In 1983 Bethe attended a dinner at the White House with other scientists just before President Reagan announced the Strategic Defense Initiative. Richard Garwin of IBM describes in the film how Bethe stood resolutely against the Reagan proposal as "unworkable." In an article in *Scientific American* in October 1984, Bethe, Garwin, Gottfried and Henry Kendall of MIT argued against Star Wars as technically impossible and politically destabilizing. In 1991 Bethe, with Gottfried and Robert S. McNamara, a Secretary of Defense in the Kennedy and Johnson years, wrote an essay in the *New York Review of Books* urging the US and Soviet Union to slash their nuclear arsenals to 1000 warheads each.

Silvan S. Schweber, a physicist at Brandeis University who was a postdoc at Cornell under Bethe and is now writing his biography, says in the film that Bethe's reputation for integrity has made him one of the most admired physicists of the 20th century.

The film ends with Bethe lecturing to an audience of nonstudents. "Many people believe that [Heisenberg's] uncertainty principle has made everything uncertain," says Bethe. "It has done the exact opposite. Without quantum mechanics and the related uncertainty principle there couldn't exist any atoms and there couldn't be any certainty in the behavior of matter whatever. So it is really the certainty principle."

IRWIN GOODWIN ■

HANS BETHE AMONG FRIENDS. Shown above are a few of the many celebrants who gathered at Cornell to honor him. Front row, left to right: Freeman Dyson, Victor Weisskopf, Bethe, Richard Dalitz and Edwin Salpeter. Second and third rows: McGeorge Bundy, Wayne Bowers, Ernest Henley, Richard Garwin, Boyce McDaniel, John Negele and Dale Corson. At right is one of Bethe's legendary, carefully prepared viewgraphs; this one was used during his lecture on neutrino oscillations (below).



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$$\frac{m(\nu_\mu)}{m(\nu_e)} = \left(\frac{m(q_c)}{m(q_u)}\right)^2 = \left(\frac{1100}{5}\right)^2 = 5 \cdot 10^4$$

$$m(\nu_e) = 2 \cdot 10^{-8} \text{ eV.}$$

$$\frac{m(\nu_\tau)}{m(\nu_\mu)} \approx \left(\frac{m(q_t)}{m(q_c)}\right)^2 \approx \left(\frac{200}{1.1}\right)^2 = 3 \cdot 10^4$$

$$m(\nu_\tau) = 100 \quad \text{eV}$$

Universe can be closed, with ν_τ providing 95% of the mass, if

$$m(\nu_\tau) = 90\,(H/100)^2$$

Kirshner gives Hubble-constant

$$H = 45 - 70 \ \frac{\text{km/s}}{\text{Mpsc}}$$

All numbers on $m(\nu_\tau)$ are uncertain. Get

$$m(\nu_\tau) = 18 - 45 \text{ eV}$$

Bludman, Kennedy, Langacker pointed out that See-saw result, above, agrees with cosmological. So maybe ν_τ closes the Universe (maybe partly)