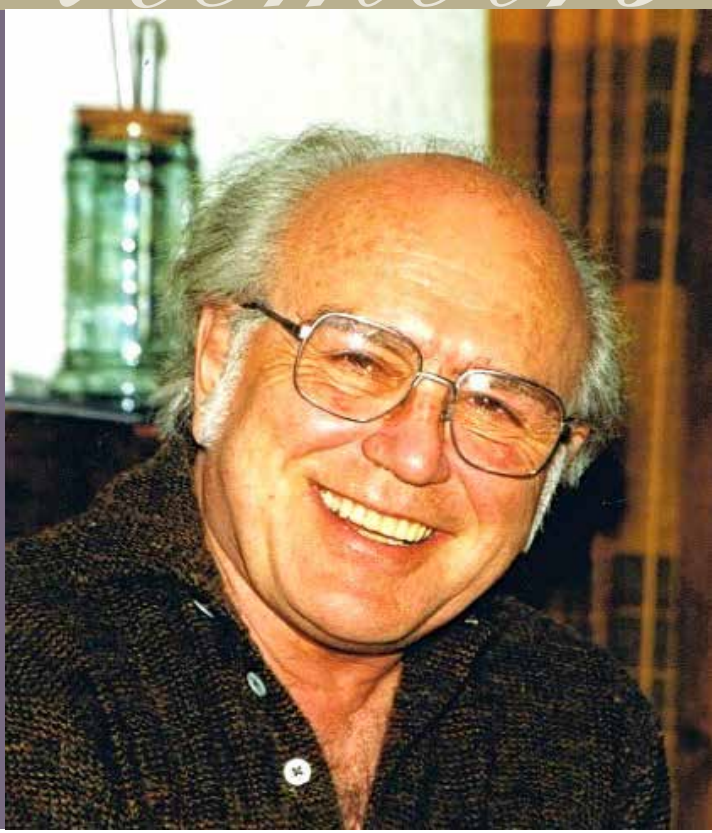
Bruno Zumino

1923–2014

BIOGRAPHICAL *Memoirs*



A Biographical Memoir by
Mary K. Gaillard

NATIONAL ACADEMY OF SCIENCES

BRUNO **ZUMINO**

April 28, 1923–June 21, 2014

Elected to the NAS, 1985

By Mary K. Gaillard

Bruno Zumino, an influential theoretical physicist, was known for his proof of the CPT theorem (the combined operations of charge conjugation, parity, and time reversal) with Gerhart Lüders; the elucidation of chiral Lagrangians with Julius Wess and others; the discovery of supersymmetry in four space-time dimensions with Wess; and the formulation of supergravity—the supersymmetric version of Einstein's theory of relativity—with Stanley Deser. Part of his rich legacy is that supersymmetry—a theory that doubles the number of particles present in the Standard Model of particle physics—is currently the subject of intense experimental searches using the Large Hadron Collider at the European Organization for Nuclear Research (CERN) near Geneva, Switzerland. Bruno was elected to the U.S. National Academy of Sciences in 1985. He received many awards and honors, including the 1987 Dirac Medal and the 1988 Heineman Prize of the American Physical Society.

Bruno was born in Rome, Italy, the son of Romeo Achille Zumino, an engineer from a family of artists in Majana, Italy, and Concetta Bruno of Rome. Growing up under Mussolini's reign and during the years of World War ll left painful memories that Bruno spoke of rarely, except to mention that his education was delayed while he was in hiding to avoid being drafted into the fascist army. He resisted pressure from his father to become an engineer. Instead, Bruno studied physics and mathematics. He received his doctoral degree in mathematical science, under the supervision of Bruno Ferreti, at the University of Rome in 1945.

Bruno held postdoctoral and teaching positions in Rome until 1949, when he accepted a research appointment at the Max Planck Institute for Physics in Göttingen, under the direction of Werner Heisenberg. There Bruno met Richard Courant, who invited him to what is now the Courant Institute of Mathematical Sciences at New York University

(NYU). Bruno held research and teaching positions at NYU until 1956, when he was fired, so he told me, because he did not want to work on the applied physics topic favored by his supervisor. Bruno moved to the Stevens Institute of Technology in Hoboken, New Jersey, but returned to the NYU faculty a year later, becoming head of the department of physics in 1961, a position he held until moving to CERN in 1969. Bruno became an American citizen on January 8, 1962—a decision largely motivated by the congressional hearings that eventually brought Sen. Joseph McCarthy's witch hunts to an end.

During his time in New York Bruno made many close and often life-long friends, among them the physicists Grace and Larry Spruch and the mathematician Joseph Keller. He also left a deep impression on the NYU physics department. The following letter from Massimo Porrati and his NYU colleagues was read at a memorial service for Bruno held at the University of California, Berkeley, campus on October 24, 2014:

Bruno as a teenager with his parents and sister Gigliola at the Piazza San Marco in Venice. (Photo courtesy Salvina Cacciapaglia.)

Bruno Zumino played a crucial role in the development of the physics department at NYU. During several years in the 1960s, he was the chair of the department, which was located on two sites: downtown, near Washington Square; and uptown in the Bronx. During that time, thanks to Bruno's efforts, a number of distinguished senior physicists, as well as young, promising theorists, joined the NYU faculty.

The first group included Kurt Symanzik and Wolfhart Zimmerman, two of the world's leading field theorists (who received joint appointments in the physics department and the Courant Institute); Henry Stroke, a distinguished atomic and molecular physicist; and Mal Ruderman, a noted astrophysicist. The second group included Alberto Sirlin, Dan Zwanziger, Richard Brandt, and John Lowenstein, who joined the NYU faculty in 1959, 1967, 1969, and 1972, respectively.

"There were also several distinguished visitors. Julius Wess visited NYU a number of times to pursue his seminal work with Bruno that would lead to the foundations of supersymmetry. The group of visitors included also Alfred Mueller, Hirotaka Sugawara, Gianfausto DellAntonio, Claudio Orzalesi, Giuliano Preparata, Hector Rubinstein, Guido Altarelli, Giorgio Velo, Antonio Masiero, Jean-Loup Gervais, and Joel Scherk.

Bruno was a very clear lecturer. In fact, several advanced graduate students at Columbia University used to commute downtown to attend Bruno's lectures on quantum field theory. This is particularly remarkable considering that half of the Columbia physics faculty at the time were already or would become Nobel Prize winners.

At one stage, Bruno conceived the idea of creating an exchange program between French and NYU physicists. In order to obtain financial support for the program, he approached André Meyer, a noted French banker who had moved his operations to New York; he was a trustee of NYU and father of Philippe Meyer, a well-known French physicist. Instead, André Meyer offered to provide substantial funds to construct a new physics building. This turned out to be very important because, at that time, the space and facilities in the downtown department were very inadequate. Bruno's initiative led to the construction of the André and Bella Meyer Hall of Physics that at present houses also the Center for Neural Sciences and the psychology department.

Bruno left NYU in 1968 to become a permanent staff member of CERN and later a professor at the University of California, Berkeley. However, his memory at NYU is still vivid today and his legacy lives on.

It was during this period in New York that Bruno made his first major contribution to physics: the proof, with Gerhart Lüders, that the combined operations of charge conjugation (turning particles into their antiparticles), parity (mirror reflection), and time reversal left any local quantum field theory invariant. The first in a series of three papers on this proof was written by Lüders alone. Bruno once told me that even though they had actually done the work together, Gerhart wrote it up himself, simply forgetting that Bruno had been involved. Bruno apparently took him at his word and bore him no grudge. They then coauthored the second and third papers. Upon Lüder's death in 1995, Bruno wrote to his widow: "He was a very dear friend who helped me very much, especially when I was young, with his advice and his example. I shall never forget him."

During his NYU years Bruno also wrote influential papers applying symmetry concepts to the study of the strong nuclear interactions; his couthors included Tsung Dao Lee, Norman Kroll, Julius Wess, Sydney Coleman, and Curtis Callan. In an interview for one of Bruno's obituaries, our friend and colleague Steven Weinberg (the 1979 Nobel laureate) said, "I think Bruno understood earlier than most people how important symmetry was going to be in the development of physics."

In 1968 Bruno married Shirley Noakes. They moved to Geneva in 1969 when Bruno joined the senior staff of CERN, where he served as the Theory Division leader from 1970 to 1973. Bruno and Shirley divorced in 1975, but they remained friends throughout Bruno's life. In a note to me after his death, she described him as a "wonderful, warm, and inspiring man."

It was at CERN that Bruno made major contributions that continue to underlie much of the activity in particle physics today. In 1971, he and Julius Wess wrote an important paper on anomalies—quantum effects that spoil the symmetries of classical field theories. It introduced what came to be known as "Wess-Zumino terms," and had far-reaching ramifications both in physics and mathematics.

Later, in 1974, Bruno and Julius were studying string theory—according to which the point particles of quantum field theory are replaced by tiny two-dimensional objects, or "strings," to describe the strong force. Originally formulated as a theory of bosons—particles with integer spin, or intrinsic angular momentum, string theory was generalized by Pierre Ramond, and by André Neveu and John Schwarz, to include fermions—half-integer spin particles. After these three physicists introduced a symmetry relating bosons and fermions in the two-dimensional system that described the coor-

dinate along the string as a function of time, Julius and Bruno asked themselves if a similar symmetry—now known as supersymmetry—could be realized in our four-dimensional world. They succeeded, then constructed the first interacting theory with such a symmetry, now known as the Wess-Zumino model. And they formulated the supersymmetric version of quantum electrodynamics, the theory of electric and magnetic interactions.

Although Julius and Bruno subsequently learned that their discovery had been anticipated in the Soviet Union—first in Moscow by Yuri Golfand and Evgeny Likhtman, then in Kharkov by Dmitrij Volkov, Vladimir Akulov, and Vyacheslav Soroka—it was the Wess-Zumino papers that put supersymmetry on solid ground and brought it to international attention. The Yuri Golfand Memorial Volume contains a graph that shows the remarkably fast increase in the number of papers on supersymmetry as a function of time after the first three preprints had appeared carrying the names of Wess and Zumino.[1] Bruno went on to write many important papers on the properties of supersymmetry and its implications with Julius, Jean Iliopoulos, and Sergio Ferrara. In 1976, together with Stanley Deser, Bruno formulated supergravity—the supersymmetric version of Einstein's general relativity—which was discovered independently by Ferrara, Daniel Freedman, and Peter van Nieuwenhuizen.

I first met Bruno in 1963, when he was a visiting scientist at CERN. However, we did not collaborate until 1980, after John Ellis, Luciano Maiani, Bruno, and I had become interested in what was known as "N = 8 supergravity." This was a version of Einstein's general relativity with eight supersymmetries, instead of just one, as in the supergravity theory discovered in 1976. This new theory had properties that made it a candidate for the realization of Einstein's dream—the unification of all the forces of nature, including gravity. But it also possessed a symmetry under the interchange of electric and magnetic fields, and in order for it to do the task of describing nature as we observe it, there had to be an associated conserved quantum number. Bruno and I found that this was indeed the case, and although N = 8 supergravity was later abandoned as the potential theory uniting all the forces, our paper turned out to have important applications in string theory—now applied to gravity rather than just the strong interaction—and currently the leading candidate theory for realizing Einstein's dream. It was duing this collaboration that Bruno and I became a couple; we married after moving to Berkeley.

1 Shifman, M. 2000. *The many faces of the superworld: Yuri Golfand memorial volume.* Singapore: World Scientific.

Bruno and I moved to the University of California, Berkeley, in 1981, with him taking a cut in salary. He did this willingly so that we could stay together; although I myself was a prominent physicist who became the first woman on the Berkeley physics faculty, CERN was unwilling to hire me. (At that time there were no women among the senior scientific staff there.)

Bruno signing the National Academy of Sciences registrar in 1986.

During his earlier years at Berkeley, Bruno made important contributions in the areas of differential geometry and quantum groups—an alternative approach to incorporating gravity into the quantum field theory that successfully describes the strong, weak, and electromagnetic interactions—and he was invited to give many talks at conferences during this period. In recent years, together with Ferrara, postdoctoral scholars, and students, he resumed work on the electric-magnetic symmetry that we had studied together, in particular its applications to string theories and the physics of black holes.

Bruno's teaching at Berkeley was every bit as distinguished as it had been at New York University. During his first year he taught a seminar course on supersymmetry and supergravity that was attended not only by advanced graduate students but also by essentially all of the particle theory faculty and Lawrence Berkeley Laboratory staff. He was widely appreciated both for his classroom teaching and for his mentorship of graduate students and postdoctoral scholars. He referred to his research students as his "kids," and they were very devoted to him. Two of his recently graduated students, Anthony Tagliaferro and Shannon McCurdy, made moving tributes to him at his memorial service, in front of the many faculty who where gathered there.

Bruno's concern for students went beyond his own teaching and mentoring. When, together with Julius Wess, he was awarded the Dannie Heineman Prize of the American Physical Society (APS) in 1988, he donated his prize money to the Berkeley physics department for financial support of foreign doctoral students. He considered prize money as "free money" that one shouldn't just spend in an ordinary way. This inspired

Julius Weiss, Mary K. Gaillard, and Bruno Zumino at the April 1988 meeting of the American Physical Society in Baltimore, where Bruno and Julius were awarded the Dannie Heineman Prize for Mathematical Physics.

me to make a similar gesture when I won an APS prize five years later. When we were approached about an initiative to encourage faculty to provide seed funds for graduate-student fellowships, Bruno asked me, "Couldn't we each contribute half?" Thus the Benjamin Lee[2] and Julius Wess Fellowship fund was born.

Bruno and Julius first met when Bruno was visiting the University of Vienna at the invitation of Walter Thirring, who was Julius's doctoral thesis advisor. As Bruno told it, Walter said to him that "there was this very good student"—and could Bruno take care of him? Julius and Bruno became good friends, and they remained very close, both professionally and personally, until Julius's death in 2007. Their collaboration that started in Vienna continued in many other places, most often when Bruno visited Julius in Kalsruhe, Germany, where Julius was a professor for many years (until he moved to the Max Planck Institute in Munich), and also during Julius's frequent visits to CERN. Their joint work earned them several shared awards. I remember many happy moments with Bruno and Julius, including hiking on the French Salève Mountain near Geneva and, to our surprise, ending up on a newly constructed golf course where we were scolded for being inappropriately attired.

Bruno and I both spoke at Julius's 70th birthday symposium in 2005. Then just three years later, on Election Day in November 2008, we flew to Munich again for his memorial conference. This time I was not a speaker. Jan Louis, who picked us up at the airport, first apologized that we had missed the chance to vote in an historic American election. I assured him that we had already voted by mail. Then he explained that all the speakers would be different from those at the earlier symposium, with the exception of Bruno, who was the highlighted speaker at both events. The loss of his younger and very close friend Julius was "a very heavy blow" for Bruno, as he wrote to Walter Thirring.

2 Benjamin Lee wrote one paper with Bruno, but he and I collaborated on several influential papers, and were very close friends until his untimely death in 1977.

Although Bruno was no longer able to actively engage in research during the last two years of his life, his students visited him on several occasions, and just a month before his death—which occurred in his sleep on June 21, 2014, at the age of 91—he attended the graduation ceremony for his last student, Darren Shih. Darren wrote, "I will always respect Bruno as one of the greatest persons I have had the honor to work with and to learn from in my life."

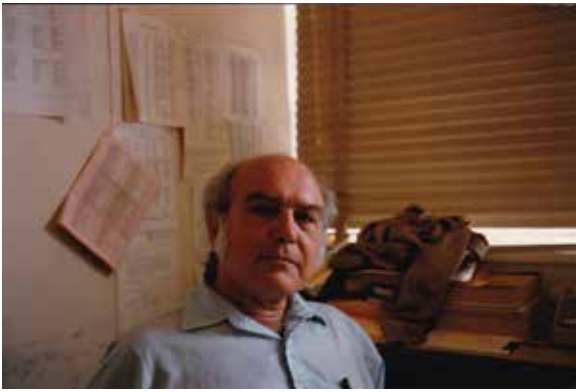
Similarly, upon learning of Bruno's passing many of his colleagues wrote that he was a "giant of physics" as well as a warm and generous person whom they remembered for his sense of humor and the "twinkle in his eye."

Bruno's impact on physics was far-reaching. His work influenced the searches for supersymmetry at the Large Hadron Collider, the searches for dark matter in the universe, and many theoretical developments. To quote Steve Weinberg: "Supersymmetry is so beautiful and suggestive that most of us think it has to show up sometime in nature, although so far it hasn't." Lawrence Hall, our colleague at Berkeley, said, "Bruno had an uncanny ability to work on theories important both for their mathematical structure and for their connection to experiments. When he introduced supersymmetry, he could have had no idea that 40 years later there would be a laboratory at CERN with more than 4,000 people looking for evidence of the theory."

At the memorial service at Berkeley, Petr Hořava said that Bruno "changed peoples lives and influenced people so deeply," referring to his scientific contributions. Others spoke about his friendly and unassuming manner. In a similar vein, while most of Bruno's obituaries focused on his scientific achievements, the one in the Berkeley student publication *The Daily Californian* addressed his more personal attributes:

> *Though Zumino was internationally lauded for his groundbreaking research, he was well known on campus for his friendly demeanor.*
>
> *"He was a very kind and generous man, and I really just absolutely loved having him around as a colleague," said Raphael Bousso, Zumino's former colleague and a current professor at the Berkeley Center for Theoretical Physics. "He made me feel very welcome when I arrived at Berkeley about 10 years ago, and I'll always be grateful for that."*
>
> *On Bousso's first day on the job, Bruno walked into his office, leaving him "in awe." The senior professor welcomed his new coworker and then began to pick crumbs up off of the office floor, apparently unhappy that*

it had been left in that condition. "This unbelievable man, whom I so admired, was standing there cleaning my office," Bousso said, laughing. "But that's the kind of guy he was. He was totally unassuming, and at the same time you could see he was a tremendous intellectual force."



Bruno in his Lawrence Berkeley Laboratory office.

Yasunori Nomura, another professor at the Center for Theoretical Physics, said he didn't detect the slightest hint of arrogance upon first meeting Zumino. He introduced himself by saying "ciao" and proceeded to ask Nomura about the Japanese language and culture–which Nomura, then a recent immigrant with poor English skills, said came as something of a relief. "I guessed that he was an old professor, but didn't know he was Bruno Zumino, one of the 'gods' in our field."

These themes were reflected in many of the letters I received after Bruno's death, a sampling of which follows:

He will always be remembered for his work, but those of us who have had the privilege to know him have lost a dear friend.
-John Iliopoulos

He was a brilliant physicist and also a very kind and wonderful person.
-Won-Yong Lee

He expressed himself in writing and speaking with great elegance—an elegance that was not a superficial window dressing but a reflection of his deep understanding of physics. And I greatly enjoyed his sense of humor.
-Kurt Gottfried

He was for me a friend, a colleague, and a teacher.
-Sergio Ferrara

Family and friends gathering for a surprise celebration of the author's 60th birthday.

Bruno had a huge impact on many lives. His professional achievements changed the direction of the field, and many people owe him an enormous gratitude for that. In addition, I was always impressed by his kindness and generosity.
-Nathan Sieberg

Bruno was one of my heroes in physics not only through his monumental contributions but also for the elegance of his thinking, lecturing, and writing. And thanks to my years in Berkeley I had a chance to appreciate what a wonderful human being he was in many other respects.
-Fabio Zwirner

It is hard to imagine a man who could be more humble in the face of his overwhelming accomplishments. I have once heard it said that 'Great people want you to be great.' That would describe Bruno Zumino....When

confronted with an error (rare though they were!) or a difficulty, I can picture him simply shrugging and smiling.
-Brent Nelson

Bruno had no children of his own, but he became very attached to my children from a previous marriage. At Christmas we regularly skied with various members of my family in Verbier, Switzerland, or in Alta, Utah. In the summers we hiked, sometimes with one of my children, in Aspen, Colorado, or in Verbier. When we were invited to visit China in 1985 by Tsung Dao Lee and Zhou Guangzhao, my eldest children, Alain and Dominique, accompanied us. Dominique took advantage of this trip to arrange for her last year at the University of California, Santa Cruz, to take place instead in Beijing, and she then spent several years in Taiwan, where Bruno and I and my youngest son (also named Bruno) visited her.

Bruno Zumino told friends how much he enjoyed being part of my family, and how he loved being called "Grandpa" by my grandchildren. My youngest grandchildren were particularly attached to him. During a brief informal memorial at our theory group retreat at Lake Tahoe in September, 2014, my 10-year-old granddaughter Kaeli spoke about her part in making the book of family pictures for him when he was hospitalized. Unfortunately, his more than two-month hospital stay took place during the conference celebrating his 90th birthday. With some effort, we were able to convince his medical team to allow him to attend the conference reception, which was just two blocks from the hospital. My son Bruno and a caregiver brought him to the reception in a wheelchair, and he was able to meet most of the conference attendees.

Bruno loved the mountains and hiking. We used to take long walks in Tilden Park, just behind our house in the north Berkeley Hills. He was also a great lover of music in general and of opera in particular. Although he didn't play an instrument himself, he often said that if he hadn't become a physicist he would liked to have been a music critic.

In addition to myself, Bruno is survived by his stepchildren Alain, Dominique, and Bruno Gaillard, his nephew Maurizio Saglio and his cousin Salvina Cacciapaglia and their families, and my seven grandchildren, whom he considered as his own.

SELECTED BIBLIOGRAPHY

1957 With G. Luders. Some consequences of TCP-invariance. *Phys. Rev.* 106:385–386.

1958 With G. Luders. Connection between spin and statistics. *Phys. Rev.* 110:1450–1453.

1967 With N. M. Kroll and T. D. Lee. Neutral vector mesons and the hadronic electromagnetic current. *Phys. Rev.* 157:1376–1399.

1969 With S. R. Coleman and J. Wess. Structure of phenomenological Lagrangians 1. *Phys.Rev.* 177:2239–2247.

With C. G. Callan, Jr., S. R. Coleman, and J. Wess. Structure of phenomenological Lagrangians 2. *Phys.Rev.* 177:2247–2250.

1971 With J. Wess. Consequences of anomalous Ward identities. *Phys. Lett. B* 37:95–97.

1974 With J. Wess. A Lagrangian model invariant under supergauge transformations. *Phys. Lett. B* 49:52–54.

With J. Wess. Supergauge transformations in four dimensions. *Nucl. Phys. B* 70:39–50.

With J. Iliopoulos. Broken supergauge symmetry and renormalization. *Nucl. Phys. B* 76:310–332.

With J. Wess. Supergauge invariant extension of quantum electrodynamics. *Nucl. Phys. B* 78:1–13.

1975 With S. Ferrara. Transformation properties of the supercurrent. *Nucl. Phys. B* 87:207–220.

Supersymmetry and the vacuum. *Nucl. Phys. B* 89:535–546.

1976 With S. Deser. Consistent supergravity. *Phys. Lett. B* 62:335–337.

With S. Deser. A complete action for the spinning string. *Phys. Lett. B* 65:369–373.

1977 With J. Wess. Superspace formulation of supergravity. *Phys. Lett. B* 66:361–364.

With S. Deser. Broken supersymmetry and supergravity. *Phys. Rev. Lett.* 38:1433–1436.

1979 Supersymmetry and Kahler manifolds. *Phys. Lett. B* 87:203–206.

1981 With M. K. Gaillard. Duality rotations for interacting fields. *Nucl. Phys. B* 193:221–244.

1984 With Y. S. Wu and A. Zee. Chiral anomalies, higher dimensions, and differential geometry. *Nucl. Phys. B* 239:477–507.

With W. A. Bardeen. Consistent and covariant anomalies in gauge and gravitational theories. *Nucl. Phys. B* 244:421–453.

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