attempted (unsuccessfully by a factor of 100 000) to explain Jansky's radio flux from the center of our galaxy as hot dust. By 1938, Reber made his first observation using a homemade receiver, but the receiver, operating at 3.3 GHz, found nothing. He then opted for lower frequencies at which he could build receivers with less internal noise and higher sensitivity. After a succession of failures at 910 MHz, he moved to a lower frequency of 160 MHz. Catching a few hours' sleep after dinner, Reber observed at night to avoid car ignition static and worked during the day at his job designing receivers at the Stewart Warner radio factory in Chicago.

In early April 1939, he successfully detected galactic radio noise at 160 MHz. Reber published those preliminary results, which confirmed Jansky's detection of radio emission from the plane of our galaxy, in 1940. In his article, which appeared in the *Astrophysical Journal*, he remarked that, based on the hot dust hypothesis, the intensity was weaker than expected. After a stint at the National Bureau of Standards during World War II, he built a new receiver and undertook a full survey of the sky. Eventually, Reber had sufficient data to make a contour map of radio flux. He had difficulty, though, getting these observations published: Astronomers were skeptical and some even thought Reber's map of the radio sky was a hoax.

Otto Struve, editor of the *Astrophysical Journal*, sent Reber's contour map manuscript to astronomers and radio engineers for review, but it fell between fields. (Reber once remarked, "If an astronomer wanted a radio, he would go to the store and buy one.") So Struve sent two astrophysicists, Louis Henyey and Philip Keenan, to examine Reber's setup in Wheaton. They concluded that Reber's research was credible. His contour map, published in the journal in 1944, compares favorably with modern maps. A companion article by Henyey and Keenan explored the idea that bremsstrahlung in ionized hydrogen was responsible; they found that unreasonably high temperatures were required. It was not until after the war that the origin of this radio noise was finally explained as synchrotron radiation from energetic electrons in the galactic magnetic field.

By 1944, news of Jansky's and Reber's observations had reached German-occupied Holland. In a mental leap from his world of optical astronomy and dynamics, Jan Oort mentioned to Henrick van de Hulst the possibility that spectral radio lines might exist. That conversation led to van de Hulst's suggestion in 1945 of the 1420-MHz line from hyperfine splitting in the ground state of neutral hydrogen. The HI line was later (1951) detected by "Doc" Ewen and Ed Purcell at Harvard University, thus beginning a new era of discovery.

During his investigations in 1946, Reber discovered surprisingly intense storms of radio noise from the Sun. He made sensitive observations at 480 MHz and detected the galactic noise, but at a flux lower than at 160 MHz. In 1955, he traveled to Tasmania to pursue radio astronomy at the much lower frequencies that might penetrate the ionosphere during solar minimum. There, in a pasture near Bothwell, he built an electronically steerable one-square-kilometer array that operated at 2 MHz. While other scientists pushed to microwave frequencies seeking higher resolution and molecular lines in the new science of radio astronomy, Reber characteristically went the other way. With data from his array and a similar one in Ottawa, he found evidence of absorption by ionized gas in the Galaxy.

Reber's scientific curiosity extended far beyond astronomy: His experiments on the handedness of vine growth were published in botanical journals and his work on cosmic rays was published in 1966. He also published research in radio circuitry, ionospheric physics, and carbon dating of aboriginal campfire sites. He was active in a variety of issues involving science and society. He argued against the increased use of fossil fuels and against "big science." But it was the stubborn persistence of this solitary amateur experimentalist and his explorations of the radio universe that ushered in a new era in astrophysics. Reber transformed Jansky's faint hiss static into a flux-frequency map of the sky that astronomers could understand. He catalyzed and focused the dramatic growth in radio astronomy worldwide, leading to a revisionist view of our universe as a violent stage on which scenarios involving collapsed objects and jets of relativistic particles are played out.

Awards normally bestowed on professional astronomers were presented to Reber, including the Henry Norris Russell Lectureship of the American Astronomical Society (1962) and the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific (1962). In 1963, he received the Franklin Institute's Cresson Medal.

Reber's scientific curiosity was most likely sparked at a young age at home. His mother, Harriet Grote, was an elementary school teacher in Wheaton and had earlier played another important role in astronomical history: Among her seventh and eighth grade students at Longfellow School in Wheaton was young Edwin Hubble.

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Peter Gabriel Bergmann

Peter Gabriel Bergmann, who introduced general relativity into modern physics through his influential book *Introduction to the Theory of Relativity* (Prentice Hall, 1942), died on 19 October 2002 in Seattle, Washington, following a lengthy illness.

Peter was born in Berlin, Germany, on 24 March 1915. His mother was a pediatrician and his father would later be a professor of chemistry at the Rockefeller Institute for Medical Research. Peter began his undergraduate studies in theoretical physics at the University of Freiburg in 1931. Concerned that Peter would not be able to continue his studies in Nazi Germany, his mother secretly wrote to Albert Einstein in the summer of 1933 to ask whether he would consider accepting her son as a PhD candidate. Einstein demurred and suggested that Peter study with Wolfgang Pauli first. After studying at Freiburg for two years, Peter left Germany for Prague. He received his PhD in physics in 1936 under Philipp Frank at the German University in Prague. His thesis, "The Harmonic Oscillator in a Spherical Space," began his work in general relativity.

Following a strong recommendation from Frank and without knowing of his mother's earlier contact with Einstein, the 21-year-old postdoc arrived in Princeton, New Jersey, in 1936 and worked as a research assistant to Einstein at the Institute for Advanced Study until 1941. A fruit of their collaboration was their paper "On a Generalization of Kaluza's Theory of Electricity," which, unlike Theodore Kaluza's 1919 paper, ascribed physical reality to the fifth dimension. The letters between Einstein and Peter during the time they worked on their paper reveal the seminal contributions of the young physicist who was introducing a new point of view.

In 1942, when Peter was 27, his book *Introduction to the Theory of Relativity*, with a foreword by Einstein, was published. Einstein wrote: "Much effort has gone into making this book logically and pedagogically satisfactory, and Dr. Bergmann has spent many hours with me which were devoted to this end." This magisterial text, translated into several languages, remained for many years the canonical survey of Einstein's ideas on special and general relativity and contains the first systematic development of Kaluza's theory. Peter showed that gauge transformations were nothing else but coordinate transformations in the higher-dimensional space. And with a simple transformation, he made clear that Pauli's projective relativity was nothing other than standard Kaluza theory.

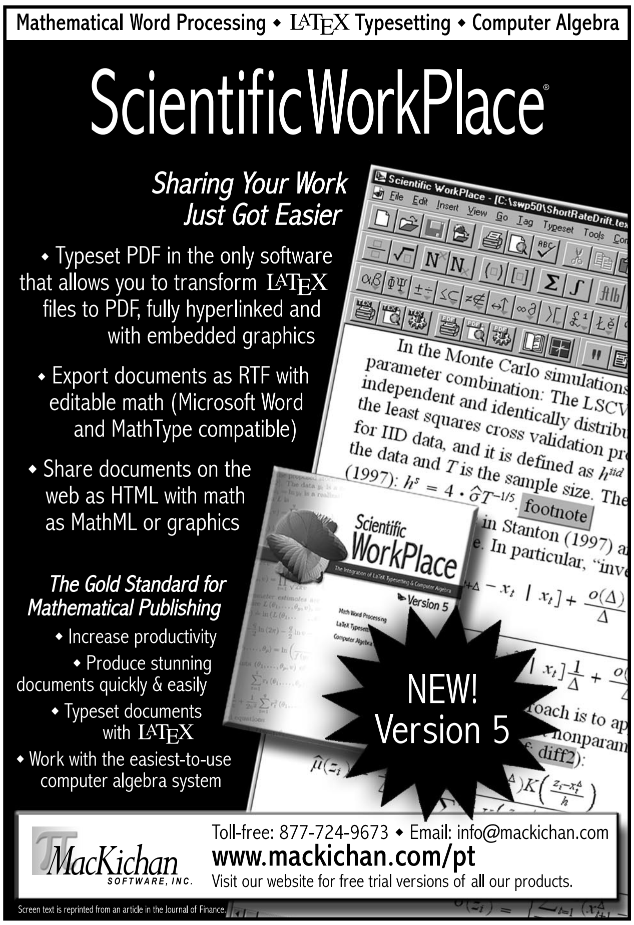
After completing his appointment as research assistant to Einstein, Peter spent the year 1941–42 as an assistant professor at Black Mountain College in North Carolina and then from 1942 to 1944 as an assistant professor of physics at Lehigh University. For the next three years, he was engaged in war research on underwater sound at Columbia University and the Woods Hole Oceanographic Institution. In 1947, he was appointed assistant professor in the Syracuse University department of physics, where he rose to become professor in 1953. Except for the year

Peter Gabriel Bergmann

1963–64, when he was at Yeshiva University in New York City, Peter remained at Syracuse until his retirement in 1982. At that time, he was appointed visiting professor at New York University, a position he kept until shortly before his death.

When Peter began his career at Syracuse in 1947, no US physics department had a center for research in general relativity. Indeed, very few physicists considered the area worthy of their time. Within the Syracuse physics department, Peter created one of the first groups specifically concerned with studying the general theory of relativity with the intent of reconciling that field with quantum theory. The publication in the *Physical Review* of his 1949 paper "Nonlinear Field Theories" was the first fruit of Peter's research program to unify general relativity and quantum theory. That paper contained the major conceptual ideas of nonperturbative canonical general relativity. Those ideas were the main thrust of his research for the rest of his career. He was concerned with the meaning of general covariance and introduced the search for observables whose commutation relations are essential for the successful quantization of gravity.

Up to the mid-1950s, Peter and his students were the major contributors to the literature in general relativity. Twenty years later, there were more than a dozen centers of active research in general relativity. Now, general relativity is in the mainstream of current physics research—in astrophysics and cosmology, in supergravity, in string theory, as well as in Einstein's original theory. The field supports the international General



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Relativity and Gravitation Society, which organizes triennial conferences and publishes the journal *General Relativity & Gravitation*. Peter played a central role in that growth through his research and teaching. He also devoted time to the society through the informal international committee by helping to draft the constitution and structure of the present formal organization, through his membership on the executive committee, and by service to the journal's editorial board. In 1963, Peter, with one of us (Schucking), Ivor Robinson, and Alfred Schild, helped organize the inaugural Texas Symposium on Relativistic Astrophysics.

Peter kept up an interest in thermodynamics and statistical mechanics and in epistemological questions, particularly the theory of measurement. He studied the measurement process in quantum theory and introduced the notion of an ensemble corresponding to time symmetry by selecting a sample using both initial and final states rather than just the fixing of the initial state. He extended to general relativity the Bohr–Rosenfeld argument on the measurement of field strengths. His result showed that the Riemann tensor is the measurable field and that its measurement with infinite precision requires a lattice of infinite rigidity. Peter carried out that work with one of his last students when he was a research professor at New York University.

Peter the teacher, research scientist, colleague, and friend touched and inspired a large number of physicists. During his 40 years at Syracuse, he guided 32 people through their dissertations and contributed actively to the research efforts of many more. In addition, a comparable number of postdocs spent up to two years at Syracuse, either as research associates or visiting professors. They were stimulated by his clear, sharp physical insights and by his personal warmth. His reputation as an outstanding teacher came from the thoughtful individual attention that he gave to students. He always had time for those who were serious in their study and research. His sensitivity to students and their need for support is demonstrated by the following anecdote. Once, during a faculty meeting, Peter was asked how he came to give an A grade to a student who was failing most of his other courses. Peter left the meeting, examined his grade book, returned, and responded, "It was a low A."

At the end of September 2002, Peter, together with John Wheeler, was awarded the Einstein Prize by the American Physical Society for "pioneering investigations in general relativity, including gravitational radiation, black holes, spacetime singularities, and symmetries in Einstein's equations, and for leadership and inspiration to generations of researchers in general relativity." He learned about the award shortly before his death.

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Robert Lull Forward

MARTHA FORWARD

Robert Lull Forward

Physicist and science-fiction author Robert Lull Forward died on 21 September 2002 in Seattle, Washington, from brain cancer. A leader in gravitational radiation astronomy and advanced space propulsion, he contributed particularly to gravitational and inertial sensors and low-loss electronics.

Forward was born on 15 August 1932 in Geneva, New York. He obtained his BS in physics from the University of Maryland in 1954, an MS in applied physics from UCLA in 1958, and his PhD from the University of Maryland in 1965. For his thesis, he built and operated the first bar antenna for gravitational wave detection; he did this work under the direction of Joseph Weber and David Zipoy. His antenna was on display in a Smithsonian Institution museum and is now in storage there.

Beginning in 1956 and for the next 31 years, Forward worked at the Hughes Aircraft Research Laboratories in Malibu, California, rising to senior scientist on the director's staff. In his early years at Hughes, he invented and developed gravitational radiation detectors and explored many new ideas in space applications. One such invention was the rotating cruciform gravity gradiometer mass detector, which measures Earth's subsurface mass variations or gravitational multipole moments. In 1960, he was the first to point out that a laser interferometer gravity-wave detector could be built to be photon noise limited, and that scaling it up would make extreme events in the universe detectable.

Retirement for Forward was a simply a new category of innovation and activity. He took early retirement in 1987 and founded Forward Unlimited. The appropriately named company emphasized space propulsion methods, including using laser- and microwave-driven sails and antimatter propulsion for high velocities.

Through his concepts for matter and antimatter rockets and laser- and microwave-driven sails, he explored the only technically credible ways of sending probes to the stars; such craft can reach speeds necessary for those vast gulfs. His book *Mirror Matter: Pioneering Antimatter Physics* (Wiley, 1988), written with Joel Davis, presents his ideas on matter and antimatter rockets.

In 1992, Forward formed Tethers Unlimited Inc with Robert Hoyt. The company specializes in innovations for space travel using elegant mechanical methods. He retired again just before his death.

Forward's written work consists of 157 technical publications and 71 popular science articles. His 14 book-length works include science fact and science fiction. His best known novels are *Dragon's Egg* (Ballantine, 2000), which is about life on a neutron star and is still used in astrophysics courses, and *Rocheworld* (Baen Books, 1990), which is based on his concept for propulsion using laser-driven sails. He was among the most rigorous of the "hard" science fiction writers. His best nonfiction summary work is *Indistinguishable From Magic* (Baen Books, 1995), based on Arthur C. Clarke's Third Law, "Any sufficiently advanced technology is indistinguishable from magic."

Elegance of concept marked his many inventions; in all, Forward obtained 20 patents. Orbital tethers will be both graceful and useful. In a long series of papers, many with Hoyt, he calculated how light cables could be used to transfer energy and momen-