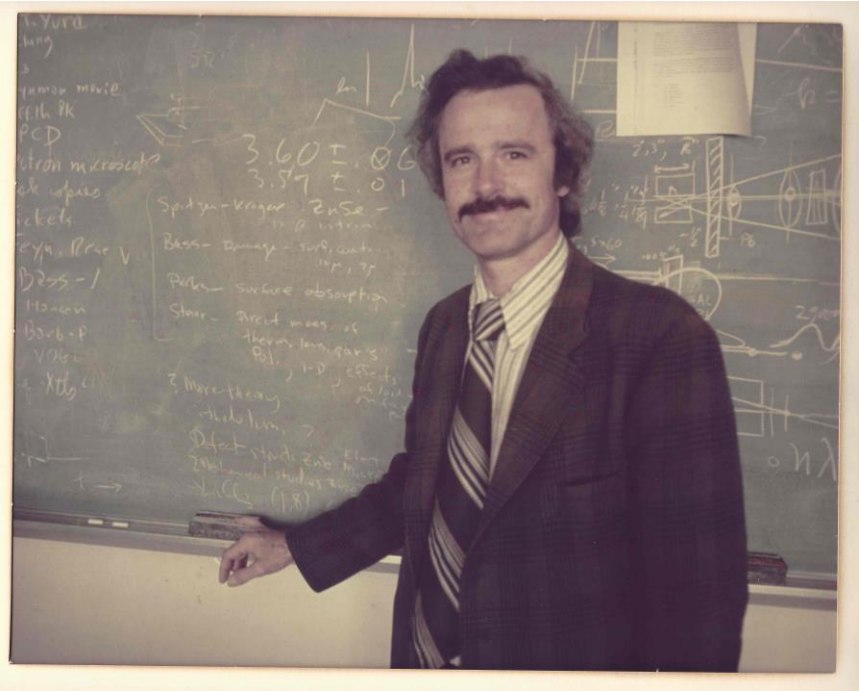
Robert W. Hellwarth, physicist and laser innovator, 1930 – 2021



Bob Hellwarth at USC in 1974.

Robert W. Hellwarth, a professor of physics and electrical engineering for nearly 50 years at the University of Southern California, was happily immersed for most of his life in advancing his chosen scientific frontiers, including optics and quantum electronics, and made an early career mark in 1960 with an invention that supercharged the usefulness of the laser by boosting its power a millionfold, opening the gates to the field of high-power lasers.

Even after retiring late in life, Hellwarth continued to ponder such cosmic fascinations as the interplay of protons and electrons in the so-called dark matter of the universe, until his death on January 20, 2021, in Santa Monica, California, of complications from Covid-19.

He was 90, and in an elite group that can claim membership in both the (U.S.) National Academy of Sciences and the National Academy of Engineering, although he would have been the last to toot his horn about these or any of his many honors and achievements – like having written or co-authored more than 200 papers and articles, the last of which was published in 2018, shortly before his 88th birthday. The title is a reminder that his brand of physics was like an art form that few could truly appreciate: "Azimuthally polarized hollow beams in free space: Exact vector solutions to Maxwell's equations."

Hellwarth was, in many respects, an archetypical absent-minded professor, mustachioed for most of his life, and with requisite sartorial quirks. But unlike the chalk-dusted bumblers often sent from central casting, this professor was 6-foot-2 and athletic – a fun-loving mashup of Indiana Jones and "Doc" Emmett Brown, with an optimistic, self-effacing mien, and an easygoing kindness that Mr. Rogers would have admired.

Science was to him both job and hobby – "fun" was probably the word he most often used to characterize his esoteric work. But Hellwarth, known to anyone he met as Bob, had other hobbies, music perhaps topping the list. He had perfect pitch and could play virtually anything on the piano (or accordion or harmonica). He often relaxed by practicing Bach and Beethoven pieces – either by ear or while reading sheet music, the intricacies reminiscent of the long equations he penciled on his notepads.

He once sat in on accordion – using the same instrument he'd had since childhood – with the Irish band the Pogues, in the 1990s, at a Los Angeles party. He played along on their hit "Fairytale of New York." Two decades earlier, he mortified his teenage daughter by tootling on his harmonica while they waited in line for a movie. He loved a good game of chess. His car of choice, in auto-obsessed Los Angeles, was a VW bus.

Driving along Sunset Boulevard one day, Hellwarth spotted a book signing with Andy Warhol, so made an impromptu pit stop at a nearby market. A Warhol fan, Hellwarth quickly bought a can of Campbell's tomato soup, then joined the line of book buyers to ask the famed pop artist to sign the can, which Warhol gladly did, in black Sharpie, with a giddy flourish.

Hellwarth was also a strong skier, having taken up the sport in the era of lace-up boots and wooden skis, and continued to attack challenging slopes well into his 60s. For many years, biking and roller skating with his kids along LA's Venice Boardwalk were welcome diversions.

Hellwarth was valedictorian of his class of about 850 at Princeton, the Ivy League having been a new cultural and geographic frontier for a public-school kid from the Midwest. He got a dual undergraduate degree in physics and electrical engineering, in 1952. He was selected as a Rhodes Scholar and spent the next three years in Oxford, earning his doctorate in physics, in 1955, and becoming an Anglophile in the process. He then moved to Southern California to work for the Hughes Aircraft Company and to be a postdoctoral fellow at Caltech, the California Institute of Technology, where he maintained several academic roles throughout the 1960s while working at Hughes. In 1971, he joined the USC faculty to help build its physics and electrical engineering programs, which he actively did for almost the next half century.

A basement tinkerer as a boy growing up in Detroit, Hellwarth was not yet 30 years old when the first laser was demonstrated in early 1960 by a colleague at the newly-built Hughes Research Laboratories, overlooking Surfrider Beach, in Malibu. Hellwarth, a staff scientist, was among the first to see that this ruby laser, while obviously revolutionary, produced a red beam that, in a sense, flickered – it came out in fits and starts, known as "spikes" – rather than as a smooth, continuous beam.

While other researchers went to work trying to figure out how to eliminate the spikes, Hellwarth took a different approach: Instead of getting rid of the spikes, why not find a way to make them much bigger? That would generate light pulses far more powerful than the beam itself – more than a million times more powerful – and those giant pulses could ultimately be more useful.

It was one of those puzzles that required know-how in both physics and electrical engineering, and it was also indicative of Hellwarth's scientific modus operandi: the more ways you have of looking at a problem, the better chance you have of making some progress – "like shining lights on all the different edges of the same old block," he once said.

Hellwarth went ahead and devised a method to make the spikes much stronger with a technique called "Q-switching," because of how it involved switching, or "spoiling," the laser cavity's inherent light-bouncing quality, in order to create an ultra-powerful light pulse. Roughly speaking, Q-switching a laser is like holding a thumb on a garden hose to produce a burst of water when the thumb is lifted.

Q-switching opened up the field of high-power lasers, which were often central to Hellwarth's research over the years. Aided by the power-boosting effect of Q-switching, lasers soon proved valuable for the Hughes Aircraft Company, especially in the midst of the Cold War, notably in the development of advanced radar systems for the U.S. Air Force.

Q-switched lasers have since found applications in everything from tattoo removal to surgical procedures to metal cutting to the quest for laser-induced nuclear fusion, in which lasers are used to fuse the nuclei of atoms, a key to creating an abundant, carbon-free energy source, using isotopes of hydrogen, and without producing the radioactive waste of conventional nuclear fission. Laser fusion was long a favorite puzzle for Hellwarth, and major attempts at realizing laser fusion continue, at specialized facilities like the Lawrence Livermore National Laboratory, one of Hellwarth's many destinations as a consultant and brainstormer over the years. Others included the Clarendon Laboratory, in Oxford, the Max Planck Institute for Physics, in Munich, and the Institut d'Optique, in Paris.

In the intense and complex debate over President Ronald Reagan's Strategic Defense Initiative, nicknamed "Star Wars," which envisioned the deployment of an X-ray laser, Hellwarth sided with the scientists who opposed the program.

A few years before Q-switching the first laser, Hellwarth was in his first year as a postdoc at Caltech, in 1955, when he met Richard Feynman, a faculty member and already a famously iconoclastic quantum theorist who would share the Nobel Prize in Physics in 1965 and, to Hellwarth, become a friend and mentor.

Feynman was in the audience when Hellwarth nervously gave a lecture that touched on his thesis work with microwaves at Oxford. Intrigued, Feynman approached Hellwarth afterward, ushered the young postdoc into his office and struck up the kind of conversation only certain physicists can have, bouncing bright ideas around like the light reflected between mirrors inside a laser. A third Caltech scientist, grad student Frank Vernon Jr., joined in.

That conversation became the basis of a paper the trio co-authored: "Geometrical Representation of the Schrödinger Equation for Solving Maser Problems." (The maser was a precursor to the laser – the "l" in laser stands for light, while the "m" in maser stands for microwave.) Their paper, published in early 1957 in the Journal of Applied Physics, considered electromagnetic resonances in matter, a fundamental tool for studying the structure of matter. It

proposed a more streamlined, intuitive approach than the cumbersome mathematics typically employed to describe resonances for a variety of radio- and microwave-frequency circuit components.

The paper was among Hellwarth's first to become widely known, although not right away, which didn't matter much to the young scientist. Besides, it was great fun. "I don't think anybody read this paper at the time. None of us were certainly ever invited to talk about it. It lay – as far as I can remember – totally unnoticed, as one of the great joys in life," Hellwarth recalled in a 1985 oral history interview with the American Institute of Physics.

But then, about eight years later, there emerged an interest in "photon echoes," a phenomenon involving short light pulses, and with it an appreciation that turned the paper into an oft-cited staple of physics textbooks. "As soon as the photon echo business came in, and then probably thereafter, it was referred to more than any other paper I ever wrote," Hellwarth mused.

In 1962 he co-authored a second paper with Feynman, "Mobility of Slow Electrons in a Polar Crystal," published in Physical Review, which gained fame for its study of "polarons," a quasiparticle used in condensed matter physics to understand the interactions between electrons and atoms in a solid material.

During the late 1950s and throughout the 1960s, Hellwarth divided his time between his staff job at Hughes and several ongoing roles at Caltech, mainly senior research fellow. He took an invitation to be a visiting professor of physics and electrical engineering at the University of Illinois at Urbana-Champaign for the 1964-65 academic year, working with the theoretical physicist Gordon Baym, another colleague who became a friend and remained active for years – Baym is being honored in 2021 with the American Physical Society's Medal for Exceptional Achievement in Research.

In a 2015 lecture at USC about some of his career highlights, Hellwarth recalled that an article about charged plasmas he wrote back in the 1960s with Baym – "Nonlinear Interactions of Radiation in Plasmas" – remained a personal favorite. "There were four or five papers about it that were clearly wrong when we looked at them," he recalled. Their article was published in 1966 in the text *Physics of Quantum Electronics,* a book of the kind that filled the overstuffed shelves of Hellwarth's longtime USC office at Seaver Science Center – and his modest home in Santa Monica. "If anyone wants to know about nonlinear effects in charged plasmas," Hellwarth said matter-of-factly, "I would recommend that paper."

In 1970, Hellwarth returned to Oxford on a National Science Foundation fellowship, spending a year among colleagues, teaching and doing research, with his first wife and three young children along to share in his love for Oxford, to which he returned many times for the rest of his life.

The following year, he took an offer to join the USC faculty as a professor of physics and electrical engineering, later adding professor of astronomy to his title. He published papers and articles with marvelously esoteric titles, mentored countless students from all over the world, inspired colleagues, and nudged his beloved fields of science into the future – as was the case

with his development of what became a widely employed method for generating the time-reversed version of a light wave, called "optical phase conjugation using four-wave mixing." He also invented widely used laser-spectroscopic techniques, which he named Raman-induced Kerr effect and Raman-induced phase-conjugation. (C.V. Raman was an Indian physicist and Nobel laureate in 1930; John Kerr was a 19th-century Scottish physicist.)

At USC, Hellwarth had a standing arrangement with his friend Feynman, by then a living physics legend, to come entertain graduate-student questions during one class each semester. Feynman had two ground rules: No announcement that he was coming to campus; no professors allowed in the audience.

From the time they first met at Caltech, Hellwarth and Feynman continued to bounce ideas off each other, until Feynman's death, from abdominal cancer, in 1988. Just a couple of years earlier, he had been the best man at Hellwarth's second wedding.

Robert Willis Hellwarth was born in Ann Arbor, Michigan, on December 10, 1930, the son of a farm-boy-turned-engineer who then worked for the Detroit Edison Company, and a college-educated homemaking mother. Young Bob was the oldest of four boys. He attended neighborhood public schools and graduated from Cooley High School, a couple of blocks from his family's home at 14429 Terry Street.

He often spent time in the summer among relatives on their farms in northwestern Ohio, where a narrow two-lane blacktop called Hellwarth Road still runs for several miles straight through the surrounding fields. As a boy, Hellwarth tumbled out of a hay truck and suffered a concussion, an injury not taken as seriously in the 1930s that might have proved fatal. Around the age of twelve he had another close call, this time with spinal meningitis, which landed him in the hospital for an extended stay. But for most of his life he enjoyed good health and fitness.

He was a sharp student – a grade-school paper on Ohm's law showed his early promise, and genuine interest, in science and math. He credited a talented cadre of high school teachers for nurturing that interest.

He had three younger brothers – George and Jim, who were close in age, followed by John, who was born just as Bob left for Princeton. All of the brothers went into the field of engineering. The family basement was a trove of electronic flotsam, the sort of leftover parts their father, Arlen, might pick up around the Detroit Edison Company. There were tools and gadgets of the kind you'd expect to find in the lair of an old-school do-it-yourselfer like Arlen – grinders, drills, automotive essentials. The grandson of German immigrants, Arlen was strict but also happy to show his sons the mechanical and electrical ropes. As a teenager, Bob struck a deal with his father: if he could successfully rebuild a junker, then he could drive it. They found an old car, and Bob got it running – in far less time than his father guessed it might take, an early brake malfunction notwithstanding.

While not a high school all-star, Bob Hellwarth was an adept athlete and a varsity swimmer, his wherewithal in water no doubt fostered by visits to nearby lakes, especially Clark Lake, where some relatives lived. Based on his College Board exam scores, he was offered a

scholarship to Princeton, but turned it down, content to attend the University of Michigan, closer to home. His father had studied electrical engineering there, after growing up on a farm among the fields where Bob fell off the hay truck. But a family kerfuffle changed Bob's mind. He wrote to Princeton and asked if he could reclaim his scholarship and attend. The answer was yes.

At Princeton Hellwarth joined one of the dining clubs and delved into his studies, but also made time for assorted extracurricular activities. He sang in the Tigertones, the campus a cappella group. He got onto the football team, taking his place among the benchwarmers, which often meant serving as defenders in practices. But Hellwarth would laughingly point out that, in those years, he at least had the chance to tackle Dick Kazmaier, a college sports icon who, in 1951, became Princeton's only winner of the Heisman Trophy, the last from the Ivy League.

For the summer of 1951, after his junior year, Hellwarth had arranged to work in a Danish shipyard, and bought a motorcycle (not his first) upon arrival in Rotterdam to get to the port at Helsingør. On the passenger ship he took to return to the U.S., he met Abigail Gurfein, who had toured Europe with a student group and was on her way back to New York City and her junior year at Barnard College – not so far from Princeton. They dined and spent time together on board the SS *Volendam*, an aging vessel that took eleven days to cross the Atlantic.

The two young travelers dated and stayed in touch, eventually marrying, but first came Hellwarth's Rhodes Scholarship to do his graduate studies, at St. John's College in Oxford. The thesis he produced over the next three years is the first paper on his long list of publications, but not the last with a title best understood by physicists only: "An Investigation of Hyperfine Structure Using the Atomic Beam Magnetic Resonance Method." To earn extra money, Hellwarth took a job teaching the basics of physics and electrical engineering to recruits at Royal Air Force Station Brize Norton, about twenty miles west of Oxford.

Recognizing he'd need a car when he got to Los Angeles, and having had a taste of British sports cars, Hellwarth bought an Austin Healey and had it shipped to the states. He got an apartment in the La Brea area, putting him roughly halfway between Caltech, in Pasadena, and the Culver City offices of Hughes Aircraft Company, where he was based before the research laboratories in Malibu opened, not long before the advent of the first working laser.

He and Abby Gurfein were married in New York City, her hometown, in September 1957. After a couple of apartment-dwelling years, they bought an old Spanish-style house in the Brentwood section of West Los Angeles. They had three children and the house was the family hub until it was sold in 1982, a few years after the marriage ended in divorce.

In late 1983, friends set Hellwarth up on a date with Theresia de Vroom, a USC graduate student in English and accomplished pianist. Their first date was at Barney's Beanery in Hollywood. Hellwarth wore a corduroy jacket and his trademark New Balance running shoes, size 13. He had been an early adopter of casual footwear in the workplace, perhaps a lesser-known contribution to fashion trends, at least among scientists. He made a more subtle fashion statement with his trouser pockets, which he always found to be impractically shallow, especially for a man over six feet tall. So he had the pockets of his khakis tailored and extended, almost to his knees. He literally had deep pockets.

Sartorial splendor notwithstanding, there was a second date, for a concert at the Schoenberg Institute at USC. Two weeks later, the couple decided to move in together. They were married in the little living room of their modest, Spanish-style Santa Monica home, on December 20, 1985, with Feynman as best man. About three-dozen guests attended, many of them family members, including de Vroom's parents and brother, and Hellwarth's three adult children, all in their 20s. The couple had a son, William, born in 1991. De Vroom became a tenured English professor at Loyola Marymount University in Los Angeles, which ensured that the new family could remain based in Santa Monica.

One of the couple's early purchases was a Bluthner piano, a concert grand that barely fit into either of the main rooms of their house. But it would anchor many a lively gathering, its keys accessible to any guest – whether curious child or gifted pianist – in a way that Hellwarth's work could never be.

Bob Hellwarth is survived by his wife, Theresia de Vroom, and their son, William, of Los Angeles; the three children from his first marriage, Ben, of Santa Monica; Margaret, of San Diego; and Tom, of Bend, Oregon; four grandchildren: Sutter, Camryn, Grace, and Evan; and Hellwarth's brother Jim, of Carrollton, Texas.

Entertaining family at home, March 22, 2015.

– By Ben Hellwarth