NATIONAL ACADEMY OF SCIENCES

DAVID NORMAN SCHRAMM
1945—1997

A Biographical Memoir by
MICHAEL S. TURNER

DAVID NORMAN SCHRAMM

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BY MICHAEL S. TURNER

"HE LIVED LARGE IN ALL DIMENSIONS." That is how Leon Lederman began his eulogy of David N. Schramm at a memorial service held in Aspen, Colorado, in December 1997. His large presence in space went beyond his 6-foot, 4-inch, 240-pound frame and bright red hair. In spite of his tragic death in a plane crash at age 52, Schramm lived large in the time dimension, too. At 18, he was married, a father, and a freshman physics major at MIT. After receiving his Ph.D. in physics from Caltech at 25, Schramm joined the faculty at the University of Texas at Austin. He left for Chicago two years later, and became the chair of the Astronomy and Astrophysics Department at the University of Chicago at age 32. He was elected to the National Academy of Sciences in 1986 at 40, became chair of the National Research Council's Board on Physics and Astronomy at 47, and two years later became vice president for research at Chicago. He also had time for mountain climbing, summiting the highest peaks in five of the seven continents (missing Asia and Antarctica), driving a red Porsche with license plates that read "Big Bang," and flying—owning four airplanes over his 12-year flying career and logging hundreds of hours annually.

Schramm's impact in science was outsized for his short timeline. Beginning his career in nuclear astrophysics, he took the next step and more than anyone else was responsible for bringing particle physics and astrophysics together, creating the now vibrant field of particle astrophysics and cosmology. Sadly he died only weeks before the fruits of his labor began to be seen, with the discovery of dark energy, neutrino mass, and the use of cosmic microwave background anisotropy to pin down cosmological parameters. The golden age now being experienced in cosmology—the concordance model with its spatially flat Universe, dark matter and dark energy, and inflationary beginnings—is firmly rooted in the deep connections between particle physics and cosmology that he recognized early on and championed during his career.

EARLY YEARS

David Norman Schramm was born in St. Louis, Missouri, on October 25, 1945, the son of Marvin, a World War II veteran of the Army Air Force who worked for the U.S. Department of Housing and Urban Development, and Betty who was director of the St. Louis County Library. Throughout his life he was very much the big brother to younger brothers, Wayne and Daniel. Schramm's life began in a typical post-World War II sort of way: he attended public schools in St. Louis, played Little League baseball, and was an Eagle Scout. In his senior year at Hazelwood High School he was salutatorian, lettered in three sports—football, wrestling, and track—and won the state wrestling title at 163 pounds. He was offered a football scholarship to Dartmouth, but turned it down to go to MIT. His passion for athletics would persist throughout his life, especially wrestling, where he was a champion at MIT, an alternate for the 1968 U.S. Olympic team in Greco-Roman wrestling, and an assistant wrestling coach at Caltech (while a graduate student) and at the University of Chicago (as a faculty member). He was very authentic looking in the gym; it was not until years later that I realized the gym rat I met as an undergraduate at Caltech was my future mentor, astrophysicist David Schramm.

MIT AND CALTECH

Before going off to MIT, Schramm married his high school sweetheart Melinda Holzhauer, and his first son, David Cary, was born during his freshman year. Famous for his toughness on the playing field or while climbing mountains, he had a lifelong phobia of hospitals, needles, and blood. His best friend at MIT, fellow wrestler William G. Thilly, had to donate the pint of blood required from families of mothers going into Boston's Women's Lying-in Hospital. Married with a child and living off campus as a scholarship student was not easy. He used his ingenuity to stay afloat (e. g., snacking between classes on condiments left for the users of food machines and mixing free ketchup packets with water to create tomato juice). With signature energy and enthusiasm, Schramm found time to be a father, champion wrestler and rugby player; to participate in fraternity life (Delta Upsilon) and to give reading assignments and big-brotherly advice to his brothers back home; and to publish two papers on nuclear physics and climb his first peak, Mt. Washington in New Hampshire.

Shortly after he arrived at Caltech as a graduate student in physics in 1967, his second son, Derik Brett, was born, and he settled into William A. Fowler's famed Kellogg Lab. At Kellogg he is remembered variously as a smart young man in a hurry to get his graduate work behind him and destined for great impact in science if he could smooth off the rough edges; someone always playing to win, and for his ability to quickly grasp new concepts and make new connections.

It took two giants, Willy Fowler and Gerald J. Wasserburg, to supervise Schramm. Wasserburg worked with him on nucleocosmochronology, the use of the relative abundances of long-lived isotopes to date the age of the galaxy and the Universe. Fowler and Schramm focused on the synthesis of the heaviest elements by the r-process, the still poorly understood process of successive and rapid capture of neutrons by nuclei that is believed to have taken place in the explosions of massive stars.

The Kellogg Radiation Laboratory, under the leadership of future Nobel Laureate Willy Fowler, was "Cambridge West," the center of the nuclear astrophysics world on this side of the Atlantic. Kellogg was a beehive of activity, measuring key cross-sections for astrophysics, training students and post-docs, and bringing together the most influential scientists in the young field of nuclear astrophysics. The field had been launched by two papers: the 1957 Reviews of Modern Physics article by Geoff and Margaret Burbidge, Fowler, and Fred Hoyle entitled "The Synthesis of the Elements in Stars" and the lesser known Chalk River report by A. G. W. Cameron. It was at the peak of its excitement when Schramm arrived. At the same time, Kip Thorne's relativity group—with its graduate students (including future National Academy of Sciences members William Press, Clifford Will, and Saul Teukolsky), postdocs, and visitors (e.g., Chandrasekhar from Chicago and Igor Novikov from Moscow)—was at its zenith. Caltech was the place to be for an ambitious young astrophysicist, and Schramm was ambitious.

Schramm's ambition and competitiveness is well known, but bears discussion. It was rooted in the best tradition of amateur athletic competition: play as hard as you can, but fairly; get ahead on your own accomplishments, not by pushing others back; and last but not least, the success of others is good for everyone. In his remembrance essay in the New York Times in February 1998, Dennis Overbye called David the gentle giant of cosmology, and wrote, "He wouldn't hurt you—not unless you got in his way on a racquetball court or on a wrestling mat…or took issue with his classic computations on how the elements were formed in…the Big Bang." He was a tough competitor; after playing racquetball with him for six months, twice a week, I was winless. Frequently I would be well ahead with victory in sight and then I could feel Schramm's competitive energy take over the court and me.

He had the self-confidence of a champion athlete in everything he did, science or mountain climbing. Some mistook this self-confidence for hubris or even recklessness; I think that was wrong. Although he and David Dearborn were once stranded on the Eiger, and he and Aspenite Gene Johnston had to hang overnight from ropes on the face of Capitol dome in an unexpected summer sleet storm, all made it back safely. Whether hiking, skiing, rafting, or flying with Schramm, you were in good hands.

Back to Caltech, Fowler felt that Schramm needed some experimental experience before he left and so sent him off to work in the "Lunatic Asylum," the official name of Wasserburg's equally famous laboratory at Caltech. Schramm and Wasserburg wrote several papers on nucleocosmochronology. One paper set up the network of equations for age dating the Universe (1970) and was honored with the first Robert J. Trumpler Award of the Astronomical Society of the Pacific—awarded to "a recent recipient of the Ph.D. degree whose doctoral research is considered unusually important to astronomy." At a memorial for Schramm in January 1998 in Chicago, Wasserburg recounted the enthusiasm of the young Schramm, who showed up at his house late one evening with a big box full of computer output announcing that they were going to write a paper. Wasserburg asked what the paper would be about and Schramm replied something to the effect that there must be enough here to write a paper.

His one miss with Wasserburg was searching for Mg isotopic anomalies in what were then the oldest meteorites. As it turns out, the meteorites were not quite old enough. He did not succeed, but he defined the approach and the methodology that Typhoon Lee, a graduate student at the University of Texas whom Schramm sent to Caltech to work with Wasserburg, used to discover the first evidence for the short-lived ($\tau \sim 10^6$ years) isotope ^{26}Al in the early Solar System (1970). Whether ^{26}Al (and other short-lived isotopes subsequently discovered) was produced by a nearby supernova that exploded around the time the Solar System formed or by the Sun itself during its early evolution remains an important mystery.

While at Caltech, Schramm took a full court press approach to the origin of the chemical elements, studying their synthesis in exploding stars, cosmic rays, and the big bang and using their relative abundances as nuclear chronometers. With the discovery of the cosmic microwave background in 1965 and the realization that the lightest elements—D, ^{3}He, ^{4}He, and ^{7}Li—were made in the big bang and not stars, cosmology was becoming "real science" and part of nuclear astrophysics. Cosmology captured Schramm's attention and would become his primary focus for the rest of his career. A paper written with Fowler, Hubert Reeves, and Jean Audouze emphasized the role of deuterium as a means of determining the density of ordinary (baryonic) matter in the Universe (1973). Based upon fragmentary knowledge of the deuterium abundance, they arrived at a baryon density of $(3 \pm 1) \times 10^{-31}$ g/cc; this compares favorably with the abundance determined by precision measurements of the primordial deuterium abundance and cosmic microwave background anisotropy today, $(4.3 \pm 0.2) \times 10^{-31}$ g/cc.

TEXAS TO CHICAGO

Following a very brief postdoc in Kellogg, Schramm joined the faculty of the University of Texas at Austin in 1972. There he became a member of "the Texas mafia," the group of young Texan nuclear astrophysicists—Stanford Woosley and Donald Clayton at Rice, Beatrice Tinsley at the University of Texas at Dallas, W. David Arnett, and Schramm and their various students and postdocs at Austin—who summered in Cambridge, England, at Fred Hoyle's Institute of Astronomy. While his stay at Texas was short, it was productive: he supervised his first two graduate students, David Dearborn and James Lattimer; wrote a paper that foreshadowed a new style of cosmology; and, with James Lattimer, anticipated one of the currently accepted models for gamma-ray bursts—neutron star and black hole collisions—in their search for a site for the r-process (1974).

The cosmology paper, written with Tinsley, J. Richard Gott, and James Gunn, brought together existing cosmological data, from light element abundances and measurements of the Hubble constant to determinations of the average mass density and the deceleration parameter, in one constraint diagram to make the case for an ever expanding Universe (1975). The paper was correct except for its key assumption that the Universe today is made of atoms and nothing else. Dark matter and dark energy would come along 20 years later and change everything. The technique of combining a host of not so good cosmological data to arrive at significant cosmological conclusions or constraints to particle physics would be universally used until the quantity and quality of cosmological data improved dramatically in the late 1990s and ushered in the age of precision cosmology.

Texas and Schramm were not a match made in Heaven. Beyond the fact that David was a "long hair" in what was still redneck country, the Astronomy Department at Austin was not ready for the kind of rapid change to modern astrophysics that Schramm was ready to lead. The department had been created with the guidance of the University of Chicago (which had built and for many years managed its McDonald Observatory) and was now well established in more traditional areas of astronomy. Paradoxically, the University of Chicago itself was ready for change, and in 1974 Schramm moved there and stayed for the rest of his career.

Chicago provided a fertile environment for his science. When Schramm arrived, the cosmic-ray program led by John Simpson and Peter Meyer was at its acme; Edward Anders and Robert Clayton had leading programs in cosmochemistry; Gene Parker and Subrahmanyan Chandrasekhar were towering figures in theoretical astrophysics; and under the leadership of James Cronin, and with the proximity of Fermilab, high-energy physics at Chicago was becoming one of the best groups anywhere. Additionally, the Enrico Fermi Institute, which fostered interdisciplinary research in the style and tradition of Fermi, provided the conditions that would allow particle astrophysics to take root at Chicago.

From the halcyon days when Yerkes Observatory was one of the world centers of astrophysics and managed McDonald Observatory, astrophysics at Chicago in the 1970s had fallen on hard times. Chandrasekhar had moved his intellectual presence from the Department of Astronomy and Astrophysics to the Physics Department and was focusing his attention on the mathematical properties of black holes. The chair of the department, Robert O'Dell, announced he was leaving to be the chief scientist for the Hubble Space Telescope (HST). The dean of physical sciences, Adrian Albert, asked Gene Parker to chair the department and pick up the pieces.

Parker's solution was to hire Schramm, and three years after his arrival he was made acting chair of the Department of Astronomy and Astrophysics. He went on to serve as chair from 1978 to 1984. Through a combination of his own research, his broad interests and good taste in science, astute hiring, bold initiatives and partnerships, and most of all his infectious enthusiasm, Schramm revitalized the department. He was the department's biggest cheerleader, highlighting the research of his colleagues in his many talks around the world. During his tenure as chair, 10 new and very energetic faculty joined the department (including me in 1980), more than doubling the size of the department.

These new faculty not only changed the face of the department but in Schramm style and with his support and cheerleading they also initiated bold projects. Donald York led the charge to build the 3.5-meter Astrophysical Research Consortium (ARC) telescope at Apache Point Observatory in New Mexico and served as its first director. Richard Kron convened the O'Hare meetings that led to the Sloan Digital Sky Survey. The SDSS definitively mapped large-scale structure in the Universe, created a four-color, digital catalogue of one quarter of the sky, and changed the way astronomy is done. It pioneered the "astronomical experiment" (i.e., focused on a specific problem as opposed to a general purpose observatory); promoted survey science, where the bulk of the science is done by the larger astronomical community; and brought high-energy physicists into astronomy.

BIRTH OF A NEW FIELD

Schramm's most far-reaching initiative was his conception, with Leon Lederman, of an astrophysics group at Fermi National Accelerator Laboratory. The Fermilab astrophysics group created a lasting partnership with the University of Chicago, led to Fermilab's involvement in the SDSS, and made the combination of the University of Chicago and Fermilab a leading center of cosmology. It also marked the birth of a new interdisciplinary field—particle astrophysics and cosmology.

The idea of an astrophysics group at Fermilab came while Schramm and Lederman were hiking in the Dolomites in the summer of 1981. In part it grew out of a failed collaboration. In 1979 Schramm and Lederman put in a bid to NASA to have the Space Telescope Science Institute (STScI) sited at Fermilab. Architectural drawings for a bold and beautiful building were created. (In Schramm's style, he succeeded in convincing the University of Chicago administration that due to the tight schedule he needed to fly back from Norway on the Concorde for the site visit.) Fermilab lost out to Johns Hopkins University for the STScI, but what came from that walk in the Dolomites changed the direction of cosmology.

The idea of an astrophysics group at a particle physics lab was radical at the time; the two disciplines had little in common other than indifference for one another. Lederman, director of Fermilab, approached Hans Mark, deputy administrator at NASA, and challenged him to fund an astrophysics group at Fermilab. Mark told Lederman to send him a proposal; Schramm and Lederman sent Mark a proposal—and NASA funded it. In 1982 while still chair of the Astronomy Department, Schramm moved to a house on the Fermilab site (an hour's drive from the Chicago campus) to start up the astrophysics activities at Fermilab. His presence and a series of high-profile astrophysics seminar speakers began to introduce the two cultures to one another. With one giant foot in each field Schramm would play the role of the scientific matchmaker for a marriage that was made in Heaven.

He and Lederman persuaded Edward ("Rocky") Kolb, then at Los Alamos as an Oppenheimer fellow, and me to lead this new center, which we christened the NASA/Fermilab Astrophysics Center (NFAC). (I took a leave of absence from Chicago for the first year of NFAC and then for the next 15 years split my time between Chicago and Fermilab. Kolb received a joint appointment at Chicago, and today he is the chair of the Department of Astronomy and Astrophysics.) With the strong support and enthusiasm of Schramm and Lederman, close connections with the Department of Astronomy and Astrophysics at Chicago, and the backing of both the Department of Energy and NASA, NFAC flourished and became the “mother church” for the young interdisciplinary field of particle astrophysics and cosmology. NFAC convened the first meeting on the subject in 1984, Inner Space/Outer Space; trained a large fraction of the postdocs and graduate students working in the field; and gave substance and legitimacy to this fledgling activity.

Today NFAC is part of Fermilab’s larger Center for Particle Astrophysics, and particle astrophysics is one of Fermilab’s (and high-energy physics’) three strategic thrusts. Both the Stanford Linear Accelerator Center (SLAC) and the Lawrence Berkeley National Laboratory now have particle astrophysics and cosmology groups, as do particle physics laboratories and universities around the world. This interdisciplinary activity is central to both particle physics and astrophysics. The 1981 hike in the Dolomites had an impact felt around the world.

Schramm’s research accomplishments were just as important in “bringing the physics of the very small and the very big together.” (As he often said.) Around the time he came to Chicago, weak neutral currents were discovered. He (and others) realized that because neutrinos play a central role in the supernova explosion of massive stars, neutral currents would significantly change earlier results. In a series of papers with coauthors W. David Arnett, David Tubbs, Rocky Kolb, and Duane Dicus he explored the implications of the discovery of neutral currents for stellar collapse (1975, 1976).

The detection of 19 neutrinos from SN 1987A by the Kamiokande and IMB water Cherenkov detectors provided a stunning confirmation of the role that neutrinos play in the final evolution of massive stars, and the discovery itself illustrates the rich interplay of particle physics and astrophysics/cosmology. These two large underground experiments were built to search for proton decay, a prediction of grand unified theories and an essential element in baryogenesis (the theory of how the Universe evolved its matter/antimatter asymmetry). IMB and Kamiokande did not discover proton decay, but they did detect neutrinos from the heavens (from the Sun and those produced in the atmosphere by cosmic rays.) Their study of astrophysical neutrinos has had profound consequences for both astrophysics and particle physics.

While his papers on neutrinos and core collapse began to build a bridge between astrophysics and particle physics, the most influential paper by far was the one he wrote in 1977 with Gary Steigman and James Gunn on the cosmological limit to the number of light neutrino species (less than seven) based upon the big-bang production of ^{4}He. It caught the attention of particle physicists. Since there is one neutrino for each generation of quarks and leptons, this paper boldly stated that the number of generations was at most six, at a time when quarks and leptons were still being discovered and arguments about how many should be found were lacking.

At first the paper attracted mostly scrutiny and criticism, but in the end it garnered respect. It demonstrated the power of the heavenly laboratory to probe fundamental physics in regimes beyond the reach of the terrestrial laboratory, and today particle physicists routinely check their new ideas for consistency with the cosmos. The 1978 paper written with Gunn, Benjamin Lee, Ian Lerche, and Steigman constraining the properties of a hypothetical massive neutrino postulated by Lee and Steven Weinberg, served to illustrate the range and power of astrophysical arguments, as well as the fun of seeing how the consequences of a new idea in particle physics would play out in the Universe.

By 1989, with better knowledge of the ^{4}He abundance, the big-bang nucleosynthesis (BBN) neutrino limit had tightened to at most three generations of quarks and leptons. That year electron-positron colliders at SLAC and at CERN began producing copious numbers of Z-bosons. The first measurements of the width of the Z-boson confirmed Schramm's prediction of only three generations. This was the proudest moment of David Schramm's scientific career.

Schramm and his collaborators used BBN to constraint other particles and their properties as well as cosmology. In particular (as noted earlier), the abundance of deuterium is a powerful "baryometer." The measurement of the deuterium abundance in the local interstellar medium provided a lower limit to the big-bang production (astrophysical processes only destroy deuterium), and thereby an upper limit to baryon density of about 10 percent of the critical density (big-bang deuterium production decreases with increasing baryon density). At the same time, astronomers were measuring the amount of mass in the Universe (most of it dark matter), and finding it to be around 20 percent of the critical density and certainly greater than 10 percent. This discrepancy became the case for nonbaryonic dark matter, and Schramm's deuterium argument was the linchpin. Just months before Schramm's death, David Tytler and his student Scott Burles measured the primordial deuterium abundance in a high-redshift hydrogen cloud; this measurement pegged the baryon density precisely at 4.5 percent of the critical density, making the case for nonbaryonic dark matter airtight.

Schramm didn't stay neutral in the discussion of particle candidates for the dark matter: he championed neutrinos (known as hot dark matter). In a prescient paper entitled "A Neutrino Dominated Universe" (1981), he and Steigman made the case that the dark matter was comprised of neutrinos of mass 30 eV or so. A year later a Soviet experiment studying the end point of tritium beta decay reported evidence for an electron neutrino mass of just this size. As it turned out, the Soviet experiment was wrong. Nonetheless, both papers helped to get the idea of particles as dark matter accepted in the astronomical and particle physics communities. We now know that neutrinos do have mass, but comprise a tiny fraction of dark matter. The bulk of the dark matter is so-called cold dark matter particles.

Neutrinos along with cosmic rays were career-spanning themes of Schramm's research. His research on neutrinos started with his interest in their role in stellar collapse, moved on to a very early interest in high-energy neutrino astronomy (and the ill-fated DUMAND project), then focused on big-bang nucleosynthesis and dark matter, and finally ventured into neutrino oscillations and the solar neutrino problem. His cosmic-ray research began with the study of their role as a probe of nucleosynthesis and evolved into an interest in the highest-energy cosmic rays and their possible cosmological production by the decay of superheavy relics of the big bang.

ASPEN

Schramm fell in love with Aspen on his very first visit to the Aspen Center for Physics in the summer of 1978, and spent time there every summer thereafter (with the exception of 1979). Aspen combined the mountains—for climbing, hiking, biking, and skiing—with a place to do great science and escape from Chicago's hot and humid summers. Aspen occupied a growing part of his life, both personal and scientific. He bought a house there in 1980; joined the Board of the Aspen Center for Physics (ACP) in 1984; was married there in 1986; chaired the Board of the ACP from 1992 to 1997; and died flying to Aspen in December 1997 in a plane crash near Denver. Schramm is buried less than a mile from his Aspen home in Red Butte cemetery, and a powerful sculpture of him designed by his wife, Judy, and son Cary sits atop his grave with a clear view of the heavens.

Schramm helped shape the Aspen Center for Physics through his own science, by supporting and stimulating the creative efforts of others and by his administrative leadership (his familiar formula). With its goal of focusing on the most timely and urgent areas of theoretical physics and its ability to quickly schedule workshops and attract leading scientists, the ACP provided a fertile environment for particle cosmology. And it thrived there. Astrophysics grew from a small activity into a full partner with particle physics and condensed matter physics. Schramm helped Martin Block to initiate the weeklong winter workshops, modeled after the Moriond workshops held at ski resorts in the French Alps. They gave him yet another reason to spend time in Aspen and ski. His early skiing was energetic and enthusiastic, but with time he developed into a skilled skier who took down the most challenging runs with both speed and style.

Schramm became chairman of the Board of Trustees just after the ACP had obtained title to its 3.5-acre campus on the Aspen Meadows. The time had come to replace Hilbert Hall, the temporary building paid for by the Department of Energy to house the team that designed Fermilab. Schramm did a masterful job of identifying the right architect for the job (Harry Teague), convincing his skeptical colleagues (including me) that Teague was the right one, and leading the fundraising activities. Through charm and enthusiasm he raised $3 million, largely from the Aspen community.

David married Judith Jane Zielinski, Leon Lederman's director's assistant, in Aspen on June 20, 1986. The bride, groom, and about 60 attendees hiked the 1.8-mile path from the Maroon Lake parking lot up to Crater Lake. After the ceremony there, the bride and groom continued up the trail for a honeymoon of camping. In the years that followed, David and Judy spent more time in their Aspen home, and it became the preferred location for family get-togethers that included David's two sons, Cary and Brett, and Judy's children, Tegan, Eric, Laura, and Amy.

Aspen fueled Schramm's passion for flying, giving him a reason to buy larger, more powerful airplanes and more excuses to fly. While in Aspen, Schramm would fly friends to Crested Butte and other mountain towns for dinner. He took Stephen Hawking, a longtime friend, and his nurses for a sightseeing flight over the Colorado Rockies (the nurses got airsick, Hawking did not). Leon and Ellen Lederman's beloved standard poodle Chloe was transported by Big Bang Aviation (he was a licensed commercial pilot) from her breeder's home in Denver to Chicago (air travel had the same effect on Chloe as on Hawking's nurses). The crash that took his life in December 1997, occurred when Schramm was en route to Aspen for the Christmas holidays.

MENTORING STUDENTS AND POSTDOCS

Schramm's ambition and energy were matched only by his generosity of spirit, especially to younger scientists. Over his career he supervised the Ph.D. work of 24 graduate students and mentored many more postdocs. His support and encouragement of his students and postdocs included making sure that they met the right people, attended meetings, gave talks, got jobs, awards, and recognition; it lasted for a lifetime. His former students can be found at universities (e.g., Brad Filippone at Caltech, James Lattimer at Stony

Brook, and Keith Olive at Minnesota), National Labs (e.g., David Tubbs at Los Alamos, David Dearborn at Livermore, and Demos Kazanas at Goddard Space Flight Center), and on Wall Street (Frank Luo at HSBC Bank). The University of Chicago recognized his outstanding abilities in graduate education with its graduate teaching award in 1994. His former postdocs include Alexander A. Szalay (Johns Hopkins University), James A. Fry (University of Florida), and Craig J. Hogan (Fermilab and University of Chicago).

Mentoring went beyond his own academic family. He always had time to encourage a young scientist, and he made sure that young people were invited speakers at the meetings he helped organize. As he was leaving Texas, Schramm played a role in recruiting J. Craig Wheeler, including encouraging Wheeler, then an assistant professor at Harvard, to hold out for tenure at Texas (which he got). At a steadier pace Wheeler accomplished many of the things at Texas that Schramm might have. I can personally attest to Schramm's role as an effective and lifelong mentor, having been his postdoc and a young faculty member while he was chair at Chicago. Just weeks before his death, Schramm convinced Bruce and Diana Rauner to endow a chair for me at Chicago.

In a field dominated by men (especially 30 years ago) Schramm was an early champion of women in physics and astrophysics. While at Texas, he and Arnett pushed for a position that matched the extraordinary talents of Beatrice Tinsley; he mentored graduate students Katherine Freese (professor of physics at the University of Michigan) and Jane Charlton (professor of astronomy at Penn State) and postdoc Angela Olinto (professor of astronomy and astrophysics at Chicago and its first female chair). Several now prominent women in the National Academy of Sciences have benefited from Schramm's advice and actions on their behalf.

STATESMAN FOR SCIENCE

With a powerful and effective voice for basic research, Schramm played an important role as a statesman for science—from promoting the field of particle astrophysics and cosmology to more broadly advocating for science on the national and international scene. Within astrophysics, cosmology, and particle physics he helped to organize nearly a hundred meetings and brought the Texas Symposium on Relativistic Astrophysics to Chicago in 1986. He was a valued adviser to the National Science Foundation; Department of Energy; and the National Research Council (NRC), serving on more than 40 committees and panels. He was also a member of the Fermilab Board of Overseers for Universities Research Association from 1991 until his death.

An enthusiastic and sought-after speaker, Schramm gave more than 100 public lectures across the country and around the world as well as numerous named lectureships in physics and astronomy departments. He was an early recipient of the American Physical Society's prestigious Lilienfeld Prize (in 1993), which recognizes the combination of scientific achievements and ability to communicate to wider audiences. He also received the Richtmeyer Memorial Award from the American Association of Physics Teachers (in 1984).

Schramm served on the NRC's Board on Physics and Astronomy (BPA) starting in 1989, and chaired the BPA from 1993 until just before his death. Among his important activities on the BPA was the shaping of the Physics Decadal Surveys and the Astronomy and Astrophysics Decadal Survey for the 1990's. The BPA put out two key reports under his leadership in 1995: an influential cosmology briefing, *Cosmology: A Research Briefing*, and the report that recommended the public/private partnership in astronomy that is the core strategy today, *A Strategy for Ground-based Optical and Infrared Astronomy*.

By many accounts Schramm's most enjoyable statesman activity was serving on the British-North American Committee (BNAC), which he joined in 1990. The BNAC brought together leaders from business, labor, and academia in the United Kingdom, the United States, and Canada to enhance relations among the three countries. Its members (with their spouses) met regularly to discuss major economic, scientific, and policy issues. David and Judy fit right in with this group dominated by corporate leaders from both sides of the Atlantic (e.g., the CEOs of BP, British Air, Rolls Royce) and as a team represented science well.

Over the years Schramm was courted for various academic administrative positions, but he didn't want to completely give up his role in scientific research and was reluctant to leave Chicago. In 1995 he was offered a job that would let him continue his research, stay in Chicago, and shape science on a larger stage: vice president for research at the University of Chicago. The position had been unfilled for a number of years, and as at many universities, its portfolio was not yet well defined. For Schramm the setup was perfect; he could shape the position with his vision. He convened a national forum of vice presidents (and provosts) to give the position more influence and prominence. At Chicago he defined his portfolio to be anything and everything associated with research, from faculty appointments to the Argonne National Laboratory (ANL). The University of Chicago had managed ANL since its inception in 1946 as the first national laboratory. For much of that time the university's general counsel oversaw the ANL, and the university derived little intellectual benefit from Argonne. Schramm set out to change the model, and while he died before significant change occurred, his model for relations between ANL and the university is now being implemented, with a vice president for national labs and emphasis on joint appointments and collaborative projects.

SUMMING UP

David Norman Schramm was memorialized in a service at the Rockefeller Memorial Chapel on the campus of the University of Chicago on January 31, 1998. The event, which Dennis Overbye described as “the academic equivalent of a star’s send off,” was attended by close to a thousand friends, family, and colleagues from across the country. Among those who spoke were President Hugo Sonnenschein and Provost Geoffrey Stone, John Bahcall, Leon Lederman, Gerald Wasserburg, fellow BNAC member Malcolm Lovell Jr., and Schramm’s sons Cary and Brett and brother Dan. There were written tributes from leading scientists and colleagues, lab directors and policy makers, program officers from the funding agencies, former postdocs and students and the World Economic Forum. Sir Martin Rees said of Schramm, “He was big in every sense. He lived and worked at twice the normal rate, and in his foreshortened life achieved and experienced more than most would in a long one. But rather than being a consolation, that actually doubles our loss.” Stephen Hawking added, “His death is a great loss to physics.” The comments of Don Shapero (director of the BPA) helped to explain the number and diversity of the attendees. “David was that rare scientist who blossoms into a man of the world who understands the bigger forces that affect the scientific community and the greater role science plays in society.”

Schramm’s scientific legacy was bringing together particle physics and cosmology to create the field of particle astrophysics and cosmology. He did this through his science—the most notable contributions being his big-bang nucleosynthesis constraint to the number of neutrino types and the deuterium linchpin in the case for particle dark matter—his ability to bridge cultures, and most especially, with his relentless energy to promote the field and people in it. The fruits of his labors are seen today in the vibrancy of these fields—from dark matter and dark energy to inflationary cosmology, from neutrino oscillations and mass to neutrino astronomy, from high-energy gamma-ray astronomy to ultra-high-energy cosmic-ray astronomy—and the young scientists that he mentored who are making the discoveries and moving the field forward. Both astrophysics and particle physics have greatly benefitted from this coming together, and their scientific agendas have been forever changed.

POSTSCRIPT

When David Schramm died, he was survived by his mother, Betty; brothers, Daniel and Wayne; his wife, Judith; two sons, Brett and Cary; and four step-children, Amy, Eric, Tegan, and Laura. The Sloan Digital Sky Survey was on the brink of bankruptcy, and the golden age of cosmology was only months away.

Today he has seven grandchildren, including one named David, and his mother and oldest son Cary have passed away. The Sloan project has just finished its second successful phase and is entering its third. In 2005, 2006, and 2007 the SDSS was the most impactful astronomical observatory in the world, beating out HST, Keck, and the European Very Large Telescope for this title; it has indeed changed how astronomy is done. The cosmology program he began and built in Chicago has now been endowed by the Kavli Foundation, as the Kavli Institute for Cosmological Physics (KICP). The Theoretical Astrophysics Group at Fermilab has evolved into the larger Center for Particle Astrophysics with Craig Hogan as its director. Dark matter, dark energy, and inflation are now part of what particle physics calls its third frontier—the cosmic frontier—and cosmology is experiencing a golden age powered by ideas coming from the marriage of particle physics and cosmology. The Nobel Prize in Physics was awarded in 2002 for the discovery of astrophysical neutrinos (Davis and Koshiba) and in 2006 for the discovery of CMB anisotropy (Mather and Smoot).

Schramm has been remembered and honored in a number of ways, including an endowed graduate fellowship in the Department of Astronomy and Astrophysics at Chicago, the David N. Schramm Award for High Energy Astrophysics Science Journalism created by the High-energy Astrophysics Division of the American Astronomical Society, a sculpture dedicated to his memory at the Aspen Center for Physics, an interaction room in the KICP named in his honor and financed by a former student, and the David N. Schramm Conference Room at Los Alamos. His best friend at MIT, Bill Thilly, kept a commitment for both of them and at their 40th reunion created a fund at MIT to help struggling MIT undergraduates like themselves.

I AM GRATEFUL FOR the help I received from Judith Schramm, Wayne Schramm, Jerry Wasserburg, Gene Parker, W. David Arnett, and William Thilly, as well as thoughtful comments from other colleagues who knew David well, including Don Shapero, Dennis Overbye, Rocky Kolb, J. Craig Wheeler, David Lambert, Craig Hogan, Josh Frieman, Bruce Winstein, and James Truran.

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