BIOGRAPHICAL MEMOIRS

Richard Alan McCray

1937–2021

Elected to the NAS, 1989

A Biographical Memoir by Roger Chevalier and J. Michael Shull

Richard "Dick" McCray was a man with many interests and talents: family man, astrophysicist, science advisor, athlete, educator, adventurer. He approached issues with an open mind and was sought after for his trusted advice. His most influential astrophysics research involved studies of cosmic X-ray sources, stellar wind bubbles, supershells of expanding gas, and the myriad phenomena observed in the nearby supernova (SN) 1987A. With colleagues, he laid out the structure and evolution of hot bubbles in the interstellar medium generated by the fast winds from massive stars. Strong stellar winds from hot, massive stars had recently been discovered in ultraviolet observations from space. The wind bubbles, combined with the supernova explosions of massive stars, can sweep up large amounts of interstellar gas and produce large supershells that extend above the galactic disk plane. In addition to his superbubble research, his novel studies of diverse phenomena in SN 1987A illuminated many facets of the explosion and its aftermath over the following decades. He spent most of his career at the University of Colorado Boulder, on the faculty of the Department of Astrophysical and Planetary Sciences.

Biographical Overview

Dick was born to Ruth Woodworth McCray and Alan Archer McCray on November 24, 1937, in Los Angeles, California. His father was a successful businessperson with an engineering background. The company he founded with his brothers, JABSCO, produced marine pumps. Dick was the oldest son and heir-apparent to the manufacturing enterprise, but his dreams were elsewhere. He entered Stanford University in 1955 and graduated with a bachelor's degree in physics in 1959. The following year, he married childhood friend Sandra Broomfield and spent the next several years teaching high-school science at the Harvard School in Los Angeles. In 1962, he began graduate studies at the University of California, Los Angeles, under the supervision of Peter Goldreich and earned a Ph.D. in physics in 1967. His thesis research focused on calculating the emission from quasi-stellar synchrotron sources. He then became a research fellow at the California Institute of Technology for a year and then was hired as an assistant professor at Harvard University.

At Harvard, Dick collaborated with Alex Dalgarno, writing an influential review on physical processes in a two-phase interstellar medium, with a warm, low-density intercloud medium and a cold, dense cloud medium.[1] He and Delgarno also worked on molecule formation in space, a topic to which he returned later in life when molecular emission was discovered in a supernova. In 1971, Dick and his family, which now included two daughters, crossed the country for Dick's new position at the University of Colorado Boulder (CU), where he had been hired as a fellow in JILA (formerly the Joint Institute for Laboratory Astrophysics) and a faculty member in the Department of Physics and Astrophysics. Dick was a Guggenheim Foundation Fellow for the 1975–76 academic year. In 1980, he transferred to the Department of Astrophysical and Planetary Sciences, and in 1997 he was named the George Gamow Distinguished Professor of Astrophysics. During his career, McCray was a visiting scholar at the NASA Goddard Space Flight Center (1983-84), Peking University and Nanjing University (1987), the Space Telescope Science Institute (1988), and Columbia University (1990). In 1989 he was elected a member of the National Academy of Sciences and in 2004 a Fellow of the American Association for the Advancement of Science. In 1990 he received the Danny Heinemann Prize for Astrophysics of the American Astronomical Society and American Institute of Physics. He retired in 2004 and spent 2013 to 2018 as a visiting scholar in the Astronomy Department of the University of California, Berkeley, before returning to Colorado.

Wind-Blown Bubbles

In Boulder, Dick developed the theory of circumstellar bubbles.[2,3] In the early 1970s, space missions such as the *Copernicus* telescope and International Ultraviolet Explorer (IUE) made possible observations at ultraviolet (UV) wavelengths. Massive stars radiate most of their luminosity in the UV, and their spectra showed broad lines implying wind velocities of 1000 to 3000 km/s (compared to 400 km/s for the solar wind) and mass loss rates of 10^{-6} solar masses per year, about eight orders of magnitude larger than that of the solar wind. The properties of the winds in the interstellar medium show that they can be a significant power source for the interstellar medium. Dick and his colleagues worked on the physical processes in the interstellar bubbles to make predictions for observations. They calculated the hydrodynamics of the bubble expansion and allowed for heat conduction between hot and cool phases of the interstellar medium, as well as the radiative heating and cooling of the gas. Their models were consistent with UV observations that a line of sight through a shell showed some of the expected five-times ionized oxygen (O VI) column densities of a conduction front. They also allowed for the motion of the massive star through the interstellar medium, giving rise to a bow shock. A subsequent paper a decade later explored infrared (IR) emission from bow shocks.[4] These models explained the observations as dust emission from swept-up bubble shells preceding individual fast-moving stars, such as Zeta Ophiuchus. The infrared space telescopes Infrared Astronomical Satellite (IRAS), Spitzer, and the Wide-field Infrared Survey Explorer (WISE) enabled the observations.

In continuing research on the large-scale Galactic interstellar medium, Dick and his colleagues noted that massive stars are born in groups or associations, correlated in both space and time. The multiple strong winds could result in a larger bubble, or superbubble. The additional power results in larger bubbles (several hundred light years in diameter), as has been observed in some neutral hydrogen (HI) expanding shells.[5] The size is comparable to the width of the galactic plane, so the result can be a shell blow-out from the galactic plane. Also, one section of the shell can be subject to gravitational instability, giving rise to propagating star formation by superbubbles.

Broad Interests

Dick had numerous international engagements, including collaborations in the Soviet Union with Rashid Sunyaev, Mikhail Basko, and Andrei Illarionov and in Germany with Reinhard Genzel. In the early 1980s, during a sabbatical visit to Nanjing University, Dick opened collaborations with China. His initial motivation was to attract excellent students to the United States, and his efforts resulted in many graduate students coming to several U.S. universities. In this work, he found that he had an affinity for Chinese culture and the Chinese people, leading to his study of the Mandarin language and making numerous trips to China over his lifetime.

In an active teaching career at the University of Colorado, McCray led classroom initiatives for undergraduate learning assistants (LAs) and, together with School of Education Professor Valerie Otero, helped to devise new methods in delivering interactive science instruction. He and his colleagues won the American Physical Society's 2019 Excellence in Physics Education Award for this effort. The LA model has since been imitated internationally, throughout the United States and in twenty-eight other countries.

One of us (Chevalier) first met Dick in the 1970s when he came to Tucson, Arizona, to give a colloquium on his interstellar bubbles work. I was on the staff of Kitt Peak National Observatory at the time and had invited Dick to give the talk. He showed up at my office mid-day, and his first question was whether there was a pool at the University of Arizona where he could go for a swim before his talk. Indeed, there was. Dick sought to swim a mile every day, no matter where he was. In 1997, there was a meeting in La Serena, Chile, for the tenth anniversary of Supernova 1987A. There being no swimming pools, Dick headed for the ocean. The wind roiled the ocean that day and a rip-tide current developed. The lifeguard on duty jumped in and headed for Dick. Once they were safely on shore, Dick was asked to sign off in a little booklet that he had been rescued. Dick signed but was bemused. He said he knew how to swim in a rip tide and was never in any danger. Dick was an athlete, excelling at swimming and squash. In Boulder, he won several age-group swimming championships. Later in life Dick was slowed by a chronic illness. He continued to swim but found his standard distance took twice as long.

The other of us (Shull) met McCray in 1976, during Dick's colloquium visit to Princeton University. I recall discussing his recently published (1975) paper on stellar wind-driven bubbles, as they might explain UV observations of highly ionized gas (O VI) seen by the Copernicus satellite.[6] In 1977, Dick convinced me to move to Boulder, where we were long-term colleagues at the University of Colorado. He was a valued mentor who consistently provided excellent advice in many areas, both academic and personal. These included wise comments that helped guide career decisions, as well as attendance at my wedding in 1986 and in 2013 at that of our son. In the summer of 1985, following an astrophysics conference in Copenhagen, Dick and I spent two weeks touring the former Soviet Union, including Moscow, St Petersburg, and Kiev, and visiting two astrophysics colleagues, Mikhail Basko and Andrei Illarionov, in Moscow. I especially recall the amazing cultural tours in Moscow and St. Petersburg, late-night conversations with young Russians, and trips to the surrounding countryside outside Kiev. Because I read and spoke Russian, Dick managed to get me involved in a memorable interaction at the KGB headquarters in Kiev. This was an exciting event, but today I regard myself as fortunate that it ended well.

Dick was always eager for an adventure. His summer excursions included a trip with several astrophysics colleagues (Rashid Sunyaev, Jeremiah Ostriker, Claes Fransson, and Joachim Trümper) along the "Silk Road" from former Soviet republics through Kashgar, China across the mountains into western China. At a stop in China, Dick and Claes Fransson explored the mountainous surroundings. Heavy rain during the day led to the collapse of the road, blocking them from returning to their colleagues. Fortunately, they were offered refuge for the night at a Chinese army camp. The next day the road was quickly made passable, and they re-joined their group after some delay. Overall, the trip was successful thanks to Rashid Sunyaev's ability to communicate with the Turkic speaking people along the way.

Dick also was an amateur pilot, sharing ownership of a small plane. Many of his CU colleagues enjoyed seeing the Colorado Rocky Mountains from the air, including trips to Aspen, Snowmass, and Leadville. His wife and daughters were also frequent passengers, although they were sometimes skeptical of the wisdom of his flight plans.

Dick served on many science advisory committees, especially those of the National Academy of Sciences/National Research Council (NAS/NRC) and National Science Foundation (NSF). In 1990, he served on the Astronomy & Astrophysics Decadal Survey (Bahcall Committee) of the NRC and influenced support for theoretical astrophysics as well as national facilities for space- and ground-based telescopes. He was frequently asked to serve on committees that did not emphasize the scientific topics with which he was best acquainted because he was someone who gave thoughtful, unbiased advice.

In April 1982, Dick was a member of the NSF Astronomy Advisory Committee when it met to compare the merits of a 25-meter millimeter wave dish versus the radio Very Long Baseline Array (VLBA). Radio astronomer Ken Kellermann was at the meeting and noted: "After a morning of presentations and heated debate, when the committee reconvened in the afternoon, Dick, who had been a strong supporter of the mm telescope, in his characteristic quiet voice calmly said that perhaps the time for the mm telescope had passed and that the VLBA presented a new opportunity. The committee then unanimously recommended that the NSF fund the VLBA."[7]

In 1994, Kellermann served on an optical and infrared subcommittee of the Committee on Astronomy and Astrophysics (CAA) chaired by Dick. The charge was to deal with the thorny issue of NSF funding for the elite private observatories, such as Palomar, McDonald, and Steward, versus the publicly available national observatories. The report, which was largely authored by Dick, recommended that in return for receiving NSF funds, the private observatories had to make a fraction of their observing time open to the public in return for instrumentation funds. This arrangement became the very effective Telescope System Instrumentation Program (TSIP) of the NSF.

SUPERNOVA 1987A

Astronomers remember when they first heard of the supernova SN 1987A in a nearby galaxy, the Large Magellanic Cloud. It was the brightest supernova in more than 400 years. The most spectacular observation of the event was the detection of twenty neutrinos on a timescale of about ten seconds on February 23, 1987. The energy in these neutrinos corresponded to the binding energy of a central neutron star, as predicted by Stirling Colgate in the 1960s and confirming a core collapse supernova. Other power sources are radioactivity and circumstellar interaction. The presence of

^{56}Co (77-day half life) and its nucleosynthetic amount could be determined by the light curve of the supernova and its evolution. Over days 300 to 1,300 since the explosion, the bolometric light curve closely followed the exponential decay of ^{56}Co, with the implication that 0.07 solar masses of ^{56}Ni were synthesized and ejected in the explosion.

Dick had an excellent skill set for working on the astrophysics of SN 1987A, and with Michael Shull and Peter Sutherland published one of the first papers on the subject.[8] X-rays had been observed in the early evolution of supernovae and were interpreted as emission from gas heated by shock waves from circumstellar interaction. Such emission was not observed from SN 1987A for the first months, implying a low circumstellar density. Dick and his colleagues suggested another mechanism that might give rise to X-rays. Power from radioactivity initially takes the form of energetic (MeV) photons that Compton scatter with electrons in the freely expanding gas of the supernova ejecta. In view of the expansion of the gas, the scattering decreases the energy of the photons. The photons form a continuum extending from the energy of the gamma-ray line down to an energy of about 20 keV, at which point photoelectric absorption becomes the dominant interaction process. In August 1987, X-rays were detected from SN 1987A with the Japanese Ginga satellite.[9] The properties of the emission were in broad agreement with the predictions by Dick and colleagues if one allowed for some outward mixing of the radioactive elements. The successful prediction attracted global attention, and Dick was set on the path of modeling both the present and future evolution of SN 1987A over a range of wavelengths. Dick later wrote two important summaries of this remnant's evolution.[10,11]

The observational capability to carry out this program became available in the years after the supernova, starting with the IUE satellite, which observed spectroscopic signatures of SN 1987A on the surrounding gas. The Hubble Space Telescope (HST) was launched in 1989 but reached its intended resolution only after a servicing Space Shuttle mission in 1993. This led to the exquisite imaging of SN 1987A that provided the data for the modeling by Dick and his colleagues. The complex circumstellar region showed a clumpy equatorial ring, outer rings along an axis of symmetry, and gradual brightening of the emission.

One prediction was that the gas in the supernova envelope should recombine and then show H and He lines as the neutral gas was excited upon passing the collisionless shock wave. The prediction was borne out in HST observations made in 1997. The H emission comes from a narrow region at the reverse shock front, which is created by the interaction of freely expanding supernova ejecta with slow-moving circumstellar matter.[12] Dick realized that, as the data on SN 1987A improved, it would be possible to map out the position of the reverse shock front in three dimensions because the ejecta move at constant velocity from the time of the explosion. The improving data show that this is in fact possible, providing constraints for hydrodynamic simulations.

A key prediction was to estimate the time at which the rapidly moving ejecta reach the surrounding ring and cause the emission of the ring to increase. An article in *The New York Times* on February 15, 2000, quoted Robert Kirshner saying that "Dick McCray and Roger Chevalier did a reasonable job of predicting the collision." The problem was the clumpy structure of the ring, which caused protrusions pointing inward towards the supernova. This structure was not anticipated and is probably the result of hydrodynamic instabilities when the ring formed.

The HST was the first of several new observatories providing the spatial resolution needed to resolve the equatorial ring and other features of the surroundings of SN 1987A. As described above, Dick was active in organizing groups to work on projects that became possible with the high resolution. This was also possible in X-rays with the launch of the Chandra X-ray Observatory in 1999 and with the completion of the Atacama Large Millimeter/Submillimeter Array (ALMA) in 2013 in Chile. With his background in X-ray astronomy, Dick played a role in obtaining high spectral resolution data on SN 1987A. The data shed light on the shock waves in the supernova remnant. ALMA was able to clearly resolve the inner emission from the ejecta and the equatorial ring, which showed both dust and molecules.

Conclusion

Sandra passed away in December 2012, and Dick married Susan Bloch in 2016. Dick died on October 26, 2021, in Wheat Ridge, a suburb of Denver. He is survived by his two children, The Very Rev. Julia McCray-Goldsmith and Carla McCray, and two grandchildren, Amos McCray-Goldsmith and Aaron McCray-Goldsmith. On December 25, 2021, the James Webb Space Telescope (JWST) was launched. It delivers high spatial resolution and spectroscopy at low- and mid-infrared wavelengths. Its capabilities are ideal for the study of SN 1987A and, in 2024, it found strong evidence for the predicted neutron star in SN 1987A.[13] Dick would be thrilled. The authors are grateful to Ken Kellermann and Julia McCray-Goldsmith for comments.

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