Bohdan Paczyński

1940–2007

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
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NATIONAL ACADEMY OF SCIENCES

BOHDAN **PACZYŃSKI**

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Elected to the NAS, 1984

By Bruce T. Draine

Bohdan Paczyński was one of the greatest astronomers of the twentieth century, interested in all areas of astrophysics, from stellar interiors to cosmology. He was, above all, a clear and original thinker. He made many important contributions to our understanding of stars and stellar evolution, for both single stars and for close binary systems. He had the vision to recognize that the development of large CCD detectors would make possible the systematic study of microlensing. At a time when the standard dogma held that gamma-ray bursters had to be located in the Galaxy, he was nearly alone in stressing that there was no evidence whatsoever to support this view, and he was vindicated when later observations demonstrated unambiguously that gamma-ray bursts were extraordinarily powerful events occurring at cosmological distances. He championed the potential of small telescopes to make important astronomical discoveries; such programs are now highly productive. He was brilliant, original, extraordinarily productive, generous, and completely unpretentious. He is deeply missed.

Early years

Bohdan Paczyński was born in Soviet-occupied Wilno, Poland (now Vilnius, Lithuania), on February 8, 1940. The German army entered Vilnius in June 1941, when it attacked the Soviet Union. The Paczyński family survived the German occupation, moving to Poland after the return of Soviet forces to Lithuania in 1944. The family lived in Cracow from 1945 to 1947, then moved to Moscow for two years. They returned to Poland in 1949, settling in Warsaw.

From his early years, Paczyński was interested in science and the stars. At the age of 14, he participated in a program to monitor the variations in brightness of binary star systems, making his own visual observations. Throughout his life he took intellectual delight in the remarkably diverse ways in which stars in close binary systems influence one another, including the evolution of the mass, size, and brightness of each star.

Cover Photo: Bodhan Paczyński in his office, 1989. Photograph by R. P. Matthews, Princeton University.

Paczyński enrolled in 1957 as a student in the Faculty of Mathematics and Physics of Warsaw University. He coauthored his first publication—reporting the times of brightness minima of eclipsing binary stars—at the age of 18, and he began working as a technical assistant at Warsaw University Observatory at 19. He received his M.A. in astronomy in 1962; his master's thesis work, supervised by the noted professor and director of the observatory, S. L. Piotrowski, was a study of the dependence of starlight polarization on the extinction of starlight by interstellar dust on the path to the star, using data from the published literature.

Paczyński's brilliance was recognized early, and before long he was given the opportunity to cross the Iron Curtain and travel to the West for research. In 1962, at age 22, he began a year of work at Lick Observatory in California, the first of many visits to the West. In 1965, in Warsaw, he married Hanna Adamska; their daughter Agnieszka was born in 1967, and their son Marcin in 1974.

As part of the requirements for the equivalent of the Ph.D. degree at Warsaw University, he undertook a massive program of visually counting stars (on Palomar Observatory Sky Survey prints) in a 60° × 20° section of the Galactic Plane. From the fluctuations in the projected density of observable stars he was able to characterize the statistical properties of the 3-dimensional distribution of interstellar dust. The analysis was performed on a vacuum-tube-based computer belonging to the Polish Academy of Sciences. He received his Ph.D. in astronomy in 1964.

After this detour into extinction and polarization by interstellar dust, Paczyński returned to his long-term scientific passion—the stars.

The lives of the stars

Throughout his life Paczyński was enchanted by the amazing variety of things that stars do, either singly or when paired with another star.

His initial interests were focused on close binary star systems. In 1967, at a time when the very existence of gravitational wave radiation was controversial, he wrote a prescient paper pointing out that loss of angular momentum via gravitational wave radiation could significantly influence the evolution of known close binary-star systems, including dwarf novae and classical novae, thus allowing an indirect test for the existence of gravitational waves. This was seven years before Russell A. Hulse and Joseph H. Taylor, Jr., discovered the effects of gravitational radiation on the orbital parameters of a pulsar in a binary system.

In his office at Warsaw University Astronomical Observatory, 1974.
(Photo by Janusz Sobolewski.)

Paczyński studied the effects of mass transfer from one star in a binary system to its companion as the two stars evolved, writing a series of influential papers on the "Evolution of Close Binaries." He was the first to discuss clearly how close binary systems could sometimes evolve to become "common envelope" binaries, with two separate stellar cores orbiting within a common envelope, and he considered how this might explain the origin of "cataclysmic variable" stars. The numerical calculations of binary evolution were carried out on a small Danish-made GIER computer in Warsaw and on an IBM 7040 at Meudon Observatory in Paris. This series of papers constituted his dissertation for the degree of *doctor habilitatus* (a post Ph.D. degree required for a professorship in many European countries), conferred in 1967. The fifth paper in the series, published in 1967, proposed an explanation for the formation of then-enigmatic Wolf-Rayet stars—extremely luminous masssive stars with unusual spectra—as helium-burning stars that lost their hydrogen by mass transfer to a close binary companion. This is now the accepted scenario for the formation of Wolf-Rayet stars.

Paczyński soon decided that even the evolution of single stars was not sufficiently understood, and he entered the field of numerical stellar models. While the concepts and basic equations underlying the evolution of single stars (at least if rotation is neglected) were by this time well established, systematic numerical modeling was in its infancy. Although this was a time when astronomers in the West generally had access to superior computing facilities, Paczyński boldly entered the field of stellar evolutionary calculations and soon established himself as a leading authority on stellar structure and evolution. He wrote his own computer programs and ran the codes on computers in both Poland and the West.

His landmark 1970 paper on the evolution of a single star to either the formation of a white dwarf (for low-mass stars) or "ignition" of the star's carbon core (for more massive stars) was initiated during a one-year visit in 1968-69 to the Joint Institute for Laboratory Astrophysics (JILA) at the University of Colorado, where he had access to a CDC 6400, one of the most powerful computers of the time. In the first paper of the series he reported discovering, numerically, a remarkably simple relation between the mass of the carbon core and the luminosity of stars in the "double shell burning" phase, when the star is "burning"—that is, fusing—hydrogen to helium in an outer shell, and helium to carbon in an inner shell surrounding a carbon core. Succeeding Paczyński papers delved into (1) the delicate physics and numerics of such "shell burning" within giant stars, (2) modeling of the nuclei of planetary nebulae, and (3) the evolution of stars with masses up to $60M_\odot$ (in 1972).

Using the laws of physics to understand the interior structure of the stars and their evolution from one structure to another surely stands as one of the major scientific achievements of the twentieth century; Paczyński was widely acknowledged to be one of the leaders in this work.

Accretion disks

In the close binary systems that fascinated Paczyński, it was evident that the transfer of material from a donor star to a companion took place through an "accretion disk" circling around the receiving star. The theoretical study of such disks became one of his long-term scientific interests. While the original impetus for his focus on this area was provided by the accretion disks in close binary-star systems, the physics, of course, extends to accretion disks around both neutron stars and black holes being fed gas from either a companion star or the surrounding interstellar medium. This line of research on self-consistent models of accretion disks led to the "thick" disk models that became known as "Polish donut" models. His first papers on accretion disks were published in 1977, and he continued to publish on the physics of accretion disks until 2003.

Gravitational lensing

Paczyński had a long-term interest in gravitational lensing, where the bending of light by the gravitational field of a planet, star, galaxy, or galaxy cluster can magnify and distort the images of distant sources of light. He was the first to propose in print that the "giant luminous arcs" in galaxy clusters reported by Roger Lynds and Vahe Petrosian in 1987 were, in fact, highly sheared, gravitationally lensed images of background galaxies far behind the cluster. This interpretation has been confirmed through many subsequent observations in a number of systems, and such galaxy clusters are now regularly used as "gravitational telescopes" to magnify distant galaxies.

In the 1980s, observing the steadily increasing sizes of CCD cameras and parallel improvements in automated image processing and photometry, Paczyński recognized that it would soon be feasible to undertake a systematic search for the rare occurrence of "microlensing"—gravitational lensing by a star (or even a planet-sized mass). In 1986 he published a landmark paper on microlensing, pointing out that monitoring of the brightnesses of a few million stars in the Magellanic clouds—nearby dwarf galaxies visible from the Southern Hemisphere—was feasible and would allow measurement of the contribution of stellar-mass objects to the gravitational potential of the Milky Way. Paczyński noted that, in addition to enabling the detection and study of microlensing, such photometry would yield an invaluable dataset of accurate light curves for a variety of stellar types, deepening our understanding of stellar pulsations and outbursts. This seminal paper stimulated the formation of the OGLE (Optical Gravitational Lensing Experiment), MACHO (Massive Compact Halo Objects), DUO (Disk Unseen Objects), and EROS (Expérience pour la Recherche d'Objets Sombres) projects to observe microlensing of stars in the Magellanic Clouds and also of stars in our own Galactic Bulge. The OGLE project, which began as a Warsaw-Princeton-Carnegie Observatory collaboration, was initiated by Paczyński, with Andrzej Udalski taking the lead in developing and operating what would be a succession of telescopes and cameras. The first OGLE paper reporting a microlensing event was published in 1993.

In 1991, with Shude Mao, Paczyński explored the ways in which microlensing light curves would be modified if the lensing star had a binary companion or one or more planets. Mao and Paczyński showed that the light curves would often be modified by conspicuous "caustic" features that could be detected and measured, given photometry of sufficiently high cadence.

Various teams developed observing programs to monitor light curves. The first planet discovered by microlensing was observed in 2003 and reported in 2004 by the OGLE and MOA (Microlensing Observations in Astrophysics) collaborations. Many additional planet discoveries via microlensing, conducted by a variety of collaborations, followed. OGLE data played an important part in the discovery by microlensing of a 5.5 Earth-mass planet in 2006. Though he was already battling cancer, Paczyński enthusiastically participated in discussions from his hospital bed.

Gamma-Ray bursts

Beginning in 1967, U.S. Vela satellites monitoring compliance with the 1963 Partial Nuclear Test Ban Treaty discovered unexplained bursts of gamma rays that appeared to originate outside the Solar System. Release of this information to the scientific community in 1973 resulted in a theoretical frenzy, as astrophysicists attempted to explain these hitherto-unexpected gamma-ray bursts (GRBs). Nearly all of the proposed theoretical models invoked phenomena at the surfaces of neutron stars. The large energy fluxes in the observed bursts led almost all GRB modelers to assume that the “bursters”—whatever they were—had to be located within the Galaxy.

Perhaps because of his many years of exposure to Communism, Paczyński was keenly sensitive to the distinction between dogma and evidence, and he insisted that there was no evidence whatsoever that the gamma-ray bursters were located in the Galaxy, stressing that the possibility of an extragalactic origin could not be excluded. In 1986 he wrote a very important paper discussing an extragalactic origin for GRBs. In it he noted that the observed dN/dS relation (where N is the number of bursts with gamma-ray energy fluence exceeding S) could be accounted for if the sources were at cosmological distances.

The BATSE (Burst and Transient Source Experiment) instrument on the Compton Gamma Ray Observatory satellite, launched in 1991, measured the distribution of gamma-ray bursts on the sky. By 1994, after several hundred GRBs had been detected with a distribution that was statistically consistent with isotropy, it seemed clear to many that Paczyński was right—the GRBs had to be at cosmological distances—yet a substantial fraction of the astrophysical community continued to favor a Galactic origin. Because of the parallel of this controversy with the dispute in the early 20th century concerning the distances to the “spiral nebulae,” in April 1995 (the 75th anniversary of the famous Shapley-Curtis debate in 1920) a debate was held in Washington, D.C., on the distances to the GRBs. On one side was Donald Lamb, arguing for gamma-ray bursters being located in the Galactic Halo—an extended, roughly spherical component of the Galaxy, extending beyond the more luminous, central regions. Opposing him was Paczyński, arguing for the bursters being at cosmological distances. The debate was held in the same auditorium in the Smithsonian Museum of Natural History where the Shapley-Curtis debate took place. At the time of the debate, the available BATSE catalog had 585 GRBs, and was fully consistent with isotropy; a figure showing the distribution on the sky was central to Paczyński’s presentation. After both debaters had presented their views and evidence, the audience was invited to vote by a show of hands; the moderator, Astronomer Royal Sir Martin Rees, judged the vote to be a tie.

Compelling evidence for the extragalactic nature of GRBs, however, was soon provided by observations in 1997 of highly red-shifted absorption lines in the optical spectrum of a GRB "afterglow," after which it was undisputed that at least some GRBs are at cosmological distances. It is by now clear that essentially all bright GRBs are extragalactic—and therefore enormously more luminous than they would be if located within our Milky Way Galaxy.

Astronomy with small telescopes

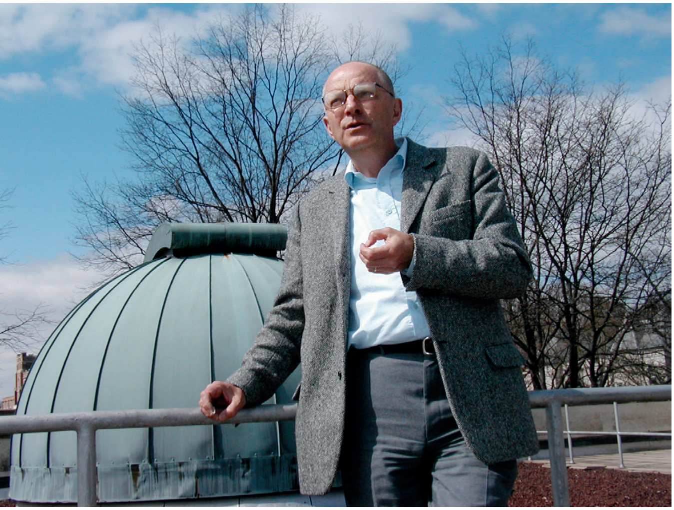
Paczyński was quick to remind us that our knowledge of transient phenomena in the sky was extremely limited, and that there was an enormous "discovery space" available to small telescopes that could routinely monitor the sky, with the possibility of discovering new examples of known types of transient events—such as known modes of stellar pulsations and variability, novae and supernovae, and microlensing events—but possibly also optical transients that were as yet undreamed of. In July 1996 he gave an invited talk in Paris where he stressed the potential of large-scale automated monitoring efforts. He corresponded with and encouraged serious amateurs who were putting commercial CCD cameras on their own telescopes. He encouraged a gifted Polish instrumentalist at the Warsaw Observatory, Grzegorz Pojmański, who designed instruments and developed automated data reduction procedures for what became the All Sky Automated Survey (ASAS), which continues operations to this day.

In 1999, at a conference in Budapest, he met a young Hungarian astronomer, Gáspár Bakos—then a third-year undergraduate at Eötvös University. Learning of Bakos's interest in automating small astronomical telescopes, he provided encouragement, helped arrange a small amount of funding, and invited him to visit Princeton in January 2001. Bakos created what is now the Hungarian Automated Telescope Network (HATNet). (I am delighted that Bakos joined the Princeton faculty in 2011; Bohdan would have been very pleased.) These and other automated telescope systems now routinely monitor the sky, discovering planetary transits, stellar variability, supernovae in other galaxies, etc.

Although by 2006 Paczyński was no longer able to walk, he traveled that year to the American Astronomical Society (AAS) summer meeting in Calgary to deliver his Russell Prize lecture, on "Astronomy with Small Telescopes." In addition to advocacy of small telescopes, in this lecture he also put forward the idea of a telescope in space, located between Earth and Sun at the Earth-Sun "L_1 point"; with a wide field of view pointing toward the Earth, such a telescope could provide early warning of impending impacts by small but still dangerous near-Earth objects (NEOs) that might otherwise have escaped notice until entering the atmosphere.

Paczyński style

Paczyński was mathematically talented—at age 17 he was runner-up in a national mathematics competition for Polish high school students—but in his work he always focused on simple physical arguments. He was a skilled and gifted programmer—the computer he used at Warsaw Observatory for stellar evolution calculations (programmed in ALGOL) could store only 1024 floating point numbers—and the Fortran stellar evolution code that he later developed to run on the CDC 6400 at JILA became a world standard. He had little interest in new programming languages—for example, C or later C++—on the grounds that Fortran was sufficient to calculate anything that he needed. By contrast, he was extremely excited by the development of microcomputers and the IBM personal computer. When these became available in the 1980s, he eagerly followed the ever-increasing clock speeds and memory capabilities, purchasing and using several generations of PCs and microcomputers.



On the roof of Peyton Hall, Princeton, 2002.
(Photo by Evelyn Tu, Princeton University.)

He loved scientific discussions on wide-ranging topics, and was delighted by the creation of the "Los Alamos preprint server," now arXiv.org. In fact, his paper (with Ramesh Narayan and Tsvi Piran) "Gamma-Ray Bursts as the Death Throes of Massive Binary Stars," was the very first "astro-ph" paper, appearing on April 13, 1992. At Princeton in the early 1990s he nucleated "astro-coffee" discussions each morning at which we informally discussed new papers that had appeared on astro-ph, announcements of new GRBs, observations of unusual microlensing light curves, and other scientific news. On any given day, discussion might range from models for GRBs, to techniques for image processing, to the astronomical potential of small telescopes.

When thinking about physical systems, Paczyński had a talent for picking out the important physical processes. He always aimed for clarity and simplicity—for example, he is credited with originating the simple but powerful argument connecting the observed light radiated by distant quasars to the numbers of supermassive black holes that must be present in the Universe today.

When considering scientific controversies, he also had a gift for identifying the important physical facts, relying whenever possible on purely geometric arguments, and without being blinded by whatever was considered at the time to be the conventional wisdom (which Paczyński would term "the party line"). Astro-coffee discussions occasionally ventured into what he termed "astro-psychology" to try to account for the sometimes strange behavioral and belief patterns of astronomers, such as the stubborn resistance to the notion that gamma-ray bursters could be at cosmological distances.

Paczyński was extraordinarily open and generous. The computer program he wrote to calculate stellar evolution—which became known as "The Paczyński Code"—was an early example of "open source" shareware. He was a strong advocate of making astronomical data quickly and widely available—saying that "The only way to realize the full scientific benefit of our observations is to share the data with our competition"—and the collaborations he inspired (OGLE and ASAS) practiced this. He was also generous with his ideas—more than one widely-quoted paper graciously acknowledges Paczyński as the source of the central idea.

He was always ready to entertain new ideas—such as cosmic strings or quark stars—so long as they weren't obviously in conflict with observations or the basic laws of physics.

Politics

Paczyński played an important role in the creation of the Copernicus Astronomical Center of the Polish Academy of Sciences, helping to persuade U.S. donors that their money would be better spent on constructing a building to house theorists rather than purchasing a new telescope for Poland. Planning began in the early 1970s, and the new institute began operations in 1978 with a modern DEC PDP-11/45 minicomputer. The Copernicus Center, with Paczyński as one of its stars, became recognized as one of the leading institutes for theoretical astrophysics in the world.

Paczyński made many trips to the West, accompanied by his family whenever possible, visiting the Lick Observatory (Santa Clara County, California); Meudon Observatory, (Paris); JILA (Boulder); the International Center for Theoretical Physics (Trieste); Princeton

University and the Institute for Advanced Study (Princeton); the Institute of Theoretical Astronomy (Cambridge, UK); the University of California (Berkeley); and Caltech (Pasadena). These visits were valuable in several ways, including contact with leading researchers and research developments, and access to more powerful computing facilities.

While Paczyński, with his family, was on one of these visits (as a Caltech Fairchild Fellow) in 1981, the Polish government imposed martial law on Poland in an effort to suppress the growing Solidarity movement, which was pushing for reforms. With this turn to repression, the Paczyńskis decided to delay their return home until the political situation improved.

Princeton University quickly offered him a professorship, which he accepted, joining the faculty in 1982 and remaining there for the rest of his career. His failure to return to Poland in 1982 was an illegal act as far as the Polish authorities were concerned, since he had been given permission for only a one-year visit to the United States. Given this situation, Paczyński could not safely return to Poland after accepting the Professorship in Princeton. Nevertheless, he remained intensely concerned with conditions in Poland and did whatever he could to help Polish science. He frequently invited Polish astronomers to visit Princeton, collaborated with them, and shipped personal computers and books to Poland.

He did not return to Poland until 1989, after a victory by the Solidarity party in elections for the newly established Polish Senate made it safe for him to do so. At this time Communism was crumbling throughout the Soviet bloc, the Soviet Union itself being dissolved in 1991.

Awards

Paczyński was elected a Foreign Associate of the U.S. National Academy of Sciences in 1984, and became a Member of the Academy in 1996. He was elected to membership in the Polish Academy of Sciences in 1991. He received many awards, including the Eddington Medal of the Royal Astronomical Society (1987), the Dannie Heineman Prize for Astrophysics (1992), the Henry Draper Medal of the National Academy of Sciences (1997), the Gold Medal of the Royal Astronomical Society (1999), the Marian Smoluchowski Medal of the Polish Physical Society (2000), the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific (2002), and the Henry Norris Russell Prize, the highest award of the American Astronomical Society (2006). The Henry Norris Russell Prize citation read:

> *For his highly original contributions to a wide variety of fields including advanced stellar evolution, the nature of gamma ray bursts, accretion in binary systems, gravitational lensing, and cosmology.*

Last Years

In fall of 2003 Paczyński was diagnosed with brain cancer (glioblastoma multiforme). He eventually lost the ability to walk, and had to use a wheelchair. The cancer was inoperable, with no known effective treatment, but he enrolled in an experimental program to test a proposed new treatment that sought to fight the cancer with chemotherapy delivered directly into the brain.

Nevertheless, his flame burned brightly—he continued to think and to work. As the cancer progressed, his ability to do mental arithmetic declined—as he himself noted—yet somehow he retained his deep understanding of physical phenomena, and—as before—he could often see connections between observations and theories more quickly than the rest of us. He continued to delight in science.

He faced both the cancer and the treatment with courage and humor. Unfortunately, the experimental treatment proved unsuccessful. He died at his Princeton home on April 19, 2007, survived by his wife, Hanna Paczyńska; his children, Agnieszka and Marcin; and his granddaughter, Nell. He is also survived by his many students, collaborators, and friends, who deeply miss the opportunity to discuss with him the latest developments in astronomy, physics, and the Universe.

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