



Martin Schwarzschild

1912–1997

BIOGRAPHICAL

Memoirs

*A Biographical Memoir by
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NATIONAL ACADEMY OF SCIENCES

MARTIN SCHWARZSCHILD

May 31, 1912—April 10, 1997

Elected to the NAS, 1956

Astrophysics, as a theoretical discipline for better understanding the observable universe, was born, came of age, and flourished in the 20th century. Astronomy, though perhaps the oldest quantitative science, had been almost exclusively concerned before 1900 with the positions and motions—the dynamics—of planets and stars. For dynamical purposes, planets and stars could be treated as point objects. Only in the 20th century did we seriously begin to inquire into the interior structure, into the origin and evolution, of these “points.” Martin Schwarzschild was at the center of this scientific transformation, and he was its most influential leader.

In 1964, as I was completing my doctorate, Schwarzschild’s text *Structure and Evolution of the Stars* was republished by Dover Press. It had become the bible of stellar astrophysics. When offered a position at Princeton, I accepted in large part because of Schwarzschild’s presence there. In this text, building on earlier work of others on the equilibrium structure of stars, he established a new paradigm. What determines the evolution of stars? What are the physical processes, what are the corresponding equations, and what are the appropriate computational tools to solve these equations? The science of stellar interiors and evolution gave us a first quantitative understanding of the interior structure, history, and fate of stars as finite objects.



Martin Schwarzschild

By Jeremiah P. Ostriker

Photography Courtesy AIP Emilio Segre Archives.

Son of a prominent physicist, Schwarzschild was born and educated in Germany and arrived in the United States in 1937 at the age of 25. After a decade of military service and junior positions at Harvard and Columbia, he moved to Princeton as a professor. There he joined Lyman Spitzer, Jr., where the two scientists established the Princeton University Observatory as a center of excellence in theoretical astrophysics. They often worked together throughout their careers until they both died—within weeks of one another—almost exactly one-half century from their initial appointments in the spring of 1947.

Background and early years in Europe

Nature and nurture conspired to provide an ideal scientific environment for Martin Schwarzschild, but the early years must have been difficult. He was born to a distinguished and assimilated German-Jewish family in 1912—two years before the outbreak of World War I—when his father, Karl Schwarzschild, was director of the renowned Potsdam Observatory. This institution, said to have been visited by Einstein in 1913, was designing a solar observatory for testing the general theory of relativity, which had been published in 1911. Before any results were established, however, war broke out and Karl enlisted in the German army. In the midst of this fierce war, Karl derived the first solution of Einstein's equations for a "point mass" (which we now call a "black hole") while serving in the trenches on the eastern front, where he contracted pemphigus (a deadly skin disease) and died in 1916. The solution is still called the "Schwarzschild solution" and the critical inner radius is termed the "Schwarzschild radius." Martin's uncle by marriage, Robert Emden, a professor of physics and meteorology, had published the famous book *Gaskugeln* ("Gas spheres") in 1907, establishing the terms of the discussion for stars as gaseous bodies within which the forces of Newton's gravity and gas pressure are balanced in equilibrium.

After Karl's death, Martin's mother (following directives of her husband's will) moved back to Göttingen, where Karl had been a professor at Göttingen University (and director of the observatory) before the family's relocation to Potsdam in 1909. Martin grew up in this pretty university town during the years between the wars, attending the local gymnasium and taking his final exams at Easter 1931. He started at Göttingen by studying mathematics under the eminent Professor Richard Courant, but then, after one semester in Berlin, he returned to Göttingen to study astronomy and theoretical physics. Given that Adolf Hitler soon became chancellor of Germany (in 1933), it is clear that Martin experienced his university-student days during a period of great political turmoil in Germany.

In his career, Schwarzschild always combined a primary focus on theoretical understanding with a real-life immersion in the nitty-gritty of astronomical observation, and his thesis work began in that mode. He wrote (in some handwritten autobiographical notes compiled in English in 1935): "In order to obtain the doctorate, I first started with spectral photometry of Polaris [a low-amplitude Cepheid variable star]. But the weather conditions of 1934/35 were so bad that I did not get on so quickly as my situation seemed to demand. Therefore I finally chose some problems in the pulsation theory, in which I had already been interested, for my thesis. I took the examination for the doctor

degree in December 1935.” With World War II looming and the situation for those of Jewish extraction ever more perilous,¹ Schwarzschild visited the Leiden Observatory in the Netherlands, where he finished a short observational paper and interacted with Einar Hertzsprung, who recommended him for a position at Swarthmore College. We have from Hertzsprung (a native German living in the Netherlands) a measured but enthusiastic “impression that [Schwarzschild’s] theoretical foundation and ability is considerably above the average and I think that he will be able as a teacher to communicate his knowledge to others....He appears to be a very modest young man who is extremely interested in various astronomical problems [and] is both congenial and cooperative. One feels in his behavior the suppressed position, [while] the race to which he partly belongs undergoes under the present conditions in Germany.”

The move to America

Schwarzschild did not obtain the Swarthmore position. He spent a postdoctoral year (1936-37) with Svein Rosseland in Norway; then, after a brief visit to Cambridge, he took a three-year Littauer fellowship at the Harvard College Observatory, supported by Harlow Shapley and Cecilia Payne-Gaposhkin. During that period, Schwarzschild’s fortuitous meeting with another brilliant young theorist, Lyman Spitzer, resulted in a long and synergistic interaction that was to powerfully shape the careers of both scientists.

At Harvard, Schwarzschild worked mainly on Cepheid variable stars, which had enormous importance in that their intrinsic luminosities were known to be closely linked to their pulsation periods. An understanding of this relationship would allow them to be more effectively used as distance indicators. This was the era when the extragalactic distance scale was being calibrated and established, and Cepheids became a critical tool in establishing the size and expansion rate of the universe.

After his fellowship, Schwarzschild’s first regular academic position was as a lecturer (1940-44) and then as an assistant professor (1944-47) at Columbia University, where he worked on problems in stellar structure. The professional world that he moved in was intimate and of the highest quality. To convey its flavor, consider this quote from

1 Martin’s mother did not have a Jewish background. So technically, and from his own point of view, he was not Jewish. But the Germans had a different view of the matter. During a visit to Göttingen 60 years later, a distinguished professor of physics explained to this author that “Of course we could not let him use the library for his thesis work, but we did make a special accommodation and allowed others to bring...books and manuscripts to his home.”

a paper written by Schwarzschild at Columbia in 1942 and submitted through Sir Arthur Eddington to the British journal *Monthly Notices of the Royal Astronomical Society*: “Dr. Bethe, Dr. Fermi, and Dr. Teller have kindly made available a rough estimate of the cross-section for an ionizing collision of an electron with a hydrogen atom”—no formal reference given. Similarly, in a paper he wrote while in Norway, Schwarzschild thanked S. Chandrasekhar for his helpful scientific advice. This was of course a pre-Internet world, but it clearly permitted a rich web of communications among the young scientific leaders of the planet.

While retaining his position at Columbia, Schwarzschild enlisted in the U.S. Army as a private in 1941 and obtained a commission in 1942 when he became a U.S. citizen. Based on his German-language ability, he joined the Army intelligence unit. He also volunteered for active duty and accompanied the Allied troops pushing north in Italy toward Germany. For his wartime service he was ultimately awarded the Bronze Star and the Legion of Merit.

Princeton

Schwarzschild and Spitzer first met at Harvard before the war, but during and after the war they were in close contact at Columbia, where each made an enormous impression on the other. Then, in 1945 and '46, intense negotiations took place between Columbia, Yale, Caltech, and Princeton concerning which of these brilliant young men would join which institution. Spitzer landed at Princeton and soon issued a “Long-Range Plan for the Princeton University Observatory” in which he mentioned Schwarzschild explicitly. But not only did Lyman need to persuade Princeton, he also had to persuade Schwarzschild, who had been offered a directorship by President Lee DuBridge of Caltech. What followed was a long and intense, but exceedingly polite, courtship by Princeton, concluding in a brief but ecstatic letter of acceptance, in Schwarzschild’s precise hand, dated April 20, 1947:



Schwarzschild (L) with Lyman Spitzer, date unknown.

(Photo courtesy AIP Emilio Serge Archives.)

At Princeton, Schwarzschild became a leading developer of the theory of stellar evolution. Largely because of his major contributions to this field, we can now follow the progress of a typical star after it contracts out of the interstellar medium and begins to burn its nuclear fuel through a sequence of phases: main sequence (like the sun) to red giant (like our neighbor Arcturus) to degenerate dwarf (like another neighbor, Sirius B). By now there have been innumerable quantitative tests of the theory. And it works!

Dear Lyman,

This is just to tell you with how much enormous joy and gratefulness we have received the big letter from Princeton on Friday, and to congratulate you heartily on your own great appointment.

Thus, 50 years to the month before they both passed on, commenced the lasting partnership of these two great scientists. They arrived together at Princeton and they left this planet together. During that half-century they wrote several very important papers together, but much more than that, they established a center of intellectual excellence, open inquiry, fierce intelligence, and extraordinary cordiality. It is fitting that Schwarzschild was awarded the highest scientific honor of this nation—the National Medal of Science—posthumously on April 30, 1997, on the basis of a nomination prepared by Lyman Spitzer and written in a fashion similar to nominations by Schwarzschild for awards

that Spitzer received. Their mutual regard and support transcended their lives.

At Princeton, Schwarzschild became a leading developer of the theory of stellar evolution. Largely because of his major contributions to this field, we can now follow the progress of a typical star after it contracts out of the interstellar medium and begins to burn its nuclear fuel through a sequence of phases: main sequence (like the sun) to red giant (like our neighbor Arcturus) to degenerate dwarf (like another neighbor, Sirius B). By now there have been innumerable quantitative tests of the theory. And it works! A normal star of mass similar to that of the sun spends several billion years burning hydrogen (via complicated nuclear processes first outlined by Hans Bethe) in its core, with very little change in its temperature or luminosity. Then, as this primary fuel is exhausted, there are much shorter phases during which helium and heavier elements undergo fusion to still heavier elements, with the star becoming increasingly inhomogeneous. As noted below, the elucidation of the layered structure and the consequent expansion to the luminous “red giant” phase was a signal triumph of Schwarzschild’s

scientific career. The division of the brightest stars in the sky into two classes by Walter Baade in the 1940s—blue giants and red giants—became comprehensible in light of Schwarzschild’s work. The former were massive un-evolved stars and the latter were lower-mass stars near the ends of their lives.

One must consider it the greatest triumph of astrophysical theory in the 20th century that despite some remaining issues² there is such an extraordinarily good match between the detailed computation of theoretical models for stars and the bulk of the astronomical evidence.

An exceptional body of work

Schwarzschild’s style as a scientist combined traits rarely found together in a single individual: a broad and vigorous creativity that was based on a thorough understanding of physical principles; a passion for detailed and precise numerical work to determine the consequences of physical models; and an enormous respect for observations, with the facts of nature seen as the ultimate arbiters of truth.

A few examples underscore these points. In one of his first publications on stellar interiors (submitted when he was still at Columbia in 1946), Schwarzschild noted that the simple knowledge of the mass, radius, and luminosity of the sun—along with the recently discovered work by Bethe on nuclear-energy generation—allowed a determination of the solar helium content. Helium is rare on earth, and it was a bit of a surprise when this first calculation of the interior composition of the sun found the element to account for roughly 40 percent of the solar mass. The model assumed uniform composition, but it was not far off; the current estimate gives the sun’s surface composition to be 24 percent and the core to be roughly 60 percent helium by mass. Schwarzschild’s result then provided strong support to the early work on Big Bang nucleosynthesis, which predicted a large helium abundance.

Most early work on stellar structure had treated stars as being of uniform composition, and as noted in his earliest papers, and above, Schwarzschild made this standard assumption too. But in a series of papers with many associates (including Alan Sandage and Fred Hoyle) that began in the late 1940s and continued through the early 1970s, he realized that, quite naturally, through the expected processes of nuclear burning, stars would develop discontinuities in chemical composition that could have dramatic effects on stellar structure; there could be internal effects such as burning in unstable

² The nature of type II supernovae, for example, is an important remaining puzzle.



At the 1957 launching of Stratoscope I, the first astronomical telescope to take pictures from above the earth's atmosphere. Martin and Barbara Schwarzschild are first and second from left.

shells or externally observed effects such as extended red-giant envelopes. Approximate analytic theory, or perturbation theory applied to existing exact analytic solutions, could not begin to address even the qualitative nature of these effects; the tools that were available at the time for the needed detailed computations were rudimentary at best, as the equations of stellar structure are highly nonlinear and involve two point (center and surface) boundary conditions. It was therefore necessary to develop new numerical algorithms and even new methods of computation. As a result, Schwarzschild worked with John von Neumann in the 1940s at Princeton to develop the first digital electronic computers used for scientific research.

Schwarzschild's work was not limited to stellar interiors and evolution. A second field of interest was galactic structure (before it became a fashionable subject) and the mass distribution within normal galaxies. In 1954, he wrote a prescient paper that noted the flat rotation curves within nearby galaxies and the increasing

mass-to-light ratio with increasing distance from the center. With these conclusions he was decades ahead of the work at Princeton and elsewhere that finally led to the acceptance of massive dark-matter galactic halos.

Third, Schwarzschild was a leader in realizing the potential for observations from above the Earth's distorting and obscuring atmosphere. In his balloon-based experiments with Stratoscope I and II in the 1950s and '60s, he showed for the first time the scientific value of diffraction-limited optics from a 20-km altitude—essentially the first “space observations.” In a 1993 summary of Schwarzschild's career accomplishments, the three eminent astrophysicists S. Chandrasekhar, E. Salpeter, and A. Sandage credited his “use

of space telescopes for precise imagery of the sun, planets, and stellar systems. His Stratoscope I, a 12-inch-diameter solar telescope lifted to 80,000 feet altitude by balloon, was the first instrument to obtain sharp photographs above most of the earth's fluctuating atmosphere, and [Stratoscope I] gave fascinating new information on dynamical processes in the sun's atmosphere. His subsequent Stratoscope II, with a mirror 36 inches in diameter, gave similar first-of-a-kind results on the outer planets and galactic nuclei. Technically, this instrument opened the pathway to other diffraction-limited instruments, including NASA's Hubble Space Telescope" and subsequent tools, which have revolutionized observational astronomy.

A final example is taken from an entirely different field, one that reaches back into the heart of theoretical astronomy. It is the dynamics of stars within galaxies, a subject to which Schwarzschild returned after his (formal) retirement in 1979. He had realized that the normal assumption concerning the symmetry of galaxies—that they were essentially symmetrical around an axis of rotation—was a largely untested assumption. He then began a series of studies to examine the issue experimentally and to see if self-consistent models could be constructed that deviated from this assumption and that were in agreement with observations. The work again involved massive numerical computations, and it quite revolutionized our understanding of "elliptical" stellar systems, which are now known to be typically triaxial—i.e., rotation is not their principal dynamical force.

His influence on our understanding of the domain of stars was comparable to that of Edwin Hubble at an earlier time in the 20th century regarding the domain of galaxies. The word "astronomy" is based on the Greek word for "star." Stars have been and still are the central subject of astronomy, and Martin Schwarzschild contributed more than any other individual to our scientific understanding of the nature of stars.

Schwarzschild the teacher

Schwarzschild's capacity to strip all problems to their essential elements, combined with his vivacious personality, produced one of the great teachers and expositors of his discipline. His skill, patience, and human concern were legendary. He was famous for his intimate ties to and guidance of his students, and equally famous for large public lectures that informed and delighted a wider audience. A person of enormous modesty and charm, Schwarzschild was loved by peers, colleagues, and students, as well as by others (in all occupations) whom he met in daily life.

The recipient of essentially every major honor available to a theoretical astrophysicist, including election to the National Academy of Sciences in 1956, Schwarzschild was awarded the U.S. National Medal of Science—unfortunately, posthumously—on April 30, 1997, only 20 days after his death. As noted in the medal’s citation:

“For his seminal contributions to the theory of the evolution of stars; his creative insights into galactic dynamics [that] form the basis of much of the contemporary astrophysics; and his lifetime of dedication to students. His influence on U.S. astronomy in the second half of this century is unsurpassed.”

A thoroughly cosmopolitan scientist, Schwarzschild was as honored in the United Kingdom as in the United States. He won the gold medal of the Royal Astronomical Society in 1969 and was elected a foreign member of the Royal Society in 1996.

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