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SUBRAHMANYAN CHANDRASEKHAR

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A Biographical Memoir by

EUGENE N. PARKER

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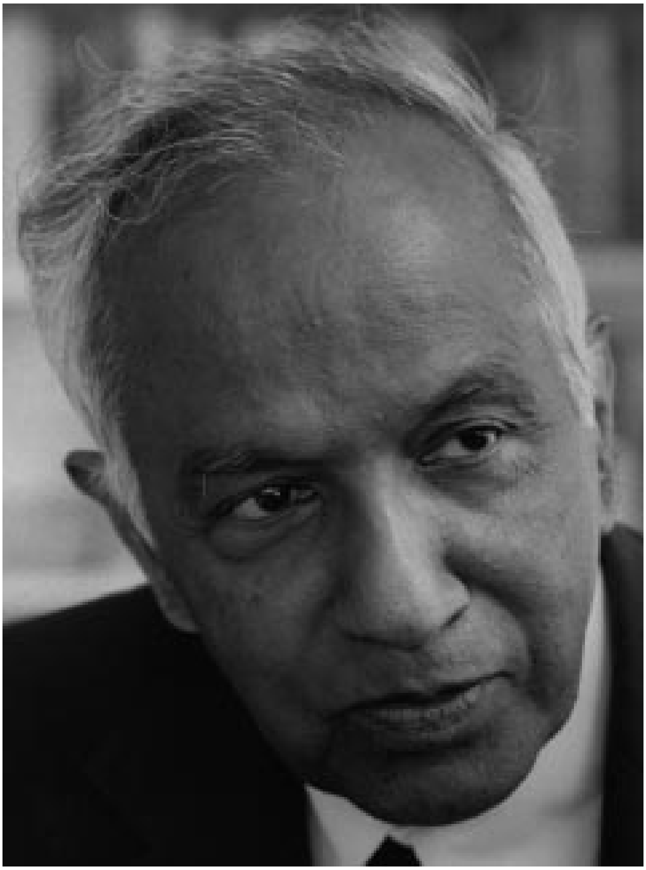

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S. Chandrasekhar

SUBRAHMANYAN CHANDRASEKHAR

October 13, 1910–August 21, 1995

BY EUGENE N. PARKER

SUBRAHMANYAN CHANDRASEKHAR was born into a free-thinking, Tamil-speaking Brahmin family in Lahore, India. He was preceded into the world by two sisters and followed by three brothers and four sisters. His mother Sitalakshmi had only a few years of formal education, in keeping with tradition, and a measure of her intellectual strength can be appreciated from her successful translation of Ibsen and Tolstoy into Tamil. His father C. S. Ayyar was a dynamic individual who rose to the top of the Indian Civil Service. It is not without interest that his paternal uncle Sir C. V. Raman was awarded a Nobel Prize in 1930 for the discovery of the Raman effect, providing direct demonstration of quantum effects in the scattering of light from molecules.

Education began at home with Sitalakshmi giving instruction in Tamil and English, while C. S. Ayyar taught his children English and arithmetic before departing for work in the morning and upon returning in the evening. The reader is referred to the excellent biography *Chandra, A Biography of S. Chandrasekhar* (University of Chicago Press, 1991) by Prof. Kameshwar C. Wali for an account of this remarkable family and the course of the third child through his distinguished career in science. Chandra is the name by which S. Chandrasekhar is universally known throughout the scientific world. Chandra's life was guided by a dedication to science that carried him out of his native culture to the alien culture of foreign shores. The crosscurrents that he navigated successfully, if not always happily, provide a fascinating tale. He was the foremost theoretical astrophysicist of his time, to paraphrase his own accounting of Sir Arthur Eddington.

The family moved to Madras in 1918 as C. S. Ayyar rose to deputy accountant general. Chandra and his brothers had private tutors then, with Chandra going to a regular school in 1921. His second year in school introduced algebra and geometry, which so attracted him that he worked his way through the textbooks the summer before the start of school.

Chandra entered Presidency College in Madras in 1925, studying physics, mathematics, chemistry, Sanskrit, and English. He found a growing liking for physics and mathematics and an ongoing attraction for English literature. One can assume that his fascination with English literature contributed to his own lucid and impeccable writing style.

Chandra was inspired by the mathematical accomplishments of S. Ramanujan, who had gone to England and distinguished himself among the distinguished Cambridge mathematicians until his early death in 1920. Chandra aspired to take mathematics honors, whereas his father saw the Indian Civil Service as the outstanding opportunity for a bright young man. Mathematics seemed poor preparation for the Civil Service. Sitalakshmi supported Chandra with the philosophy that one does best what one really likes to do. Chandra compromised with physics honors, which placated his father in view of the outstanding success of Sir C. V. Raman.

On his own initiative Chandra read Arnold Sommerfeld's book *Atomic Structures and Spectral Lines* and attended lectures in mathematics. His physics professors noticed that he was learning physics largely through independent reading and provided him with the freedom to attend mathematics lectures. In the autumn of 1928 Sommerfeld lectured at Presidency College. Chandra made it a point to meet Sommerfeld and was taken aback to learn that the old Bohr quantum mechanics, on which Sommerfeld's book was based, was superseded by the wave mechanics of Schroedinger, Heisenberg, Dirac, Pauli, et al., and that the Pauli exclusion principle replaced Boltzmann statistics with Fermi-Dirac statistics. Sommerfeld had already applied the new theory to electrons in metals and kindly provided Chandra with galley proofs of his paper. Chandra launched into an intensive study of the new quantum mechanics and statistics and wrote his first professional research paper "The Compton scattering and the new statistics" (1929). In January 1929 he communicated this work to Prof. R. H. Fowler at Cambridge for publication in the *Proceedings of the Royal Society of London*. The name Fowler suggested itself because Fowler had applied the new statistics to collapsed stars (i. e., white dwarfs). Fowler was an open-minded and generous individual who perceived the merit of Chandra's paper, which he duly communicated to the Royal Society. This contact was to play a crucial role a year later when Chandra arrived in England.

Heisenberg lectured at Presidency College in October 1929 and Chandra had the opportunity to carry on extensive discussion with him at the time. Then Meghnad Saha at Allahabad, known for the statistical mechanics that provided the interpretation of stellar spectra, invited Chandra for discussions of Chandra's paper in the *Proceedings of the Royal Society of London*. Wali, in his biography, contrasts this early appreciation of Chandra's work by the scientific community with the class snobbery of the British Raj on the personal level.

Final examinations at Presidency College came in March 1930 and Chandra established a record score. In February Chandra was informed that a special Government of India scholarship was to be offered to him to pursue study and research in England for three years. When the scholarship was announced publicly, Chandra experienced resentment from fellow Indians who perceived him as abandoning his country and his legacy. Worse, it was becoming clear that Sitalakshmi was terminally ill and, if Chandra went to England, he would not see her again. True to form Sitalakshmi decided the issue by declaring that Chandra was born for the world and not just for her.

Chandra informed the authorities that he wished to use his government scholarship to study and carry on research with R. H. Fowler at Cambridge. The Office of the High Commissioner of India proceeded with the arrangements. Chandra departed Bombay on July 31, 1930, bound for Venice, from where he traveled by rail to London, arriving August 19. He undertook the journey in his personal pursuit of science, and that journey was culturally irreversible, a departure from home from which he never really returned.

It is well known that Chandra spent his time on shipboard working out the statistical mechanics of the degenerate electron gas in white dwarf stars, appreciating, as Fowler had not, that the upper levels of the degenerate electron gas are relativistic. Since it is the upper levels that are affected by changes in density and temperature, it follows that a density change $\Delta\rho$ and pressure change Δp are related by $\rho\Delta p/p\Delta\rho = 4/3$ rather than the nonrelativistic value 5/3 employed earlier by Fowler. The value 4/3 meant that the pressure supporting the star against gravity grows no faster than the increasing gravitational force as the star contracts, with the result that there is a limiting mass above which the internal pressure of the white dwarf cannot support the star against collapse. This is in contrast with the familiar nonrelativistic situation where the pressure increases more rapidly than the gravitational forces so that sufficient contraction must ultimately provide a sufficient pressure to block further contraction. The limiting mass was clearly of the order of the mass $M_\odot$ of the Sun (2×10^{33} g). A precise value would require detailed calculations of the interior structure of the star with the precise value of $\rho\Delta p/p\Delta\rho$ for intermediate levels as well as the upper fully relativistic levels at each radius in the star. But the implication was clear. A massive star, of which there are many, cannot fade out as a white dwarf once its internal energy source is exhausted. Instead it shrinks without limit, always too hot to become completely degenerate, and disappears when the gravitational field above its surface becomes so strong that light cannot escape. In modern language, the massive star eventually becomes a black hole. The reasoning was straightforward and the conclusion was startling. The repercussions that ultimately followed his discovery served to push Chandra farther into the obscure and lonely byways of science in a foreign Western society and ever more distant from his cultural origins.

Upon arrival in London Chandra discovered that the Office of the Director of Public Instruction in Madras and the High Commissioner of India in London had thoroughly bungled his admission to Cambridge. What was more, the secretary for the high commissioner's office had not the least interest in correcting the mistake and was openly rude in his assertion of that fact. Chandra was saved only by the eventual firm intervention of Fowler, who was vacationing in Ireland at the time of Chandra's arrival in London. The consequences of Chandra's first research paper were more far reaching than anyone could have imagined.

Chandra took up his studies at Cambridge and spent a lonely but productive year in intensive study and research. Sitalakshmi died on May 21, 1931, adding grief to his loneliness. Chandra was introduced to the monthly meetings of the Royal Astronomical Society and became acquainted with E. A. Milne and P. A. M. Dirac. Chandra devoted his research efforts to calculating opacities and applying his results to the construction of an improved model for the limiting mass of the degenerate star. Milne was enthusiastic about the work, but it turned out later that his enthusiasm was based more on his rivalry with A. S. Eddington than on an appreciation of the scientific merits.

The year of intensive study at Cambridge moved Chandra to look for a change of scenery, and at the invitation of Max Born he spent the summer of 1931 at Born's institute at Gottingen. There he became acquainted with Ludwig Biermann, Edward Teller, Leon Brillouin, and Werner Heisenberg. Back at Cambridge in the autumn Chandra continued his work on atomic absorption coefficients and mean opacities, but with a growing sense of frustration from his feeling that he was abandoning mathematics through his pursuit of physics and abandoning pure physics through his pursuit of astrophysics. Chandra was invited to present his results on model stellar photospheres at the January 1932 meeting of the Royal Astronomical Society (RAS) and was complimented by both Milne and Eddington following the presentation.

Chandra's feeling of frustration with his "peripheral science" led to his spending his third year at Bohr's institute in Copenhagen. He adapted readily to the informal atmosphere and became acquainted with Victor Weisskopf, Leon Rosenfeld, M. Debrueck, H. Kopferman, and others. During the time in Copenhagen Chandra succeeded in convincing himself that his real strength lay in developing and expounding the implications of the basic physical laws of nature as distinct from the pursuit of new laws of nature. He found an interested and appreciative audience in the physics community for his work on degenerate stars. Chandra was invited to the University of Liege to lecture on his work, following which he was presented with a bronze medal. The overall experience of the year was to ease his mind and set him firmly on a path in theoretical astrophysics.

Chandra finished the year with four papers on rotating self-gravitating polytropes, which became his Ph.D. thesis. His government scholarship ran out in August 1933 and the question was what to do next. It was clear that there were no opportunities in India unless he rode on the coattails of his uncle Raman, which he was loathe to do. Fortunately he won one of the highly competitive appointments as a fellow of Trinity College, which ran for four years. Milne nominated Chandra for fellow of the RAS, and the future was clear for the immediate years at Cambridge. At the monthly meetings in Burlington House Chandra and such contemporaries as William McCrea generally sat in the back row, but became acquainted with some of the denizens of the front row (e.g., Sir James Jeans, Sir Arthur Eddington, Sir Frank Dyson, and such international visitors as Henry Norris Russell and Harlow Shapley).

Chandra spent four weeks in the Soviet Union in the summer of 1934 at the invitation of B. P. Gerasimovic, meeting L. D. Landau and V. A. Ambartsumian, along with many other enthusiastic young men. Unhappily only Landau and Ambartsumian survived the massive purges that were soon to follow. Ambartsumian grasped the significance of Chandra's work on dwarf stars and suggested that it was worth working out exactly (i.e., by direct radial integration of the exact equations, using the complete pressure-density relation). This moved Chandra to tackle that immense problem upon his return to Cambridge.

The work was accomplished with the aid of a hand calculator and was completed by the end of 1934. He submitted his results for presentation at the January 1935 meeting of the RAS. Eddington had taken an interest in the work through the autumn, often dropping by Chandra's room to see how things were progressing, but never saying a word to Chandra about his own private thoughts. Eddington suggested to the secretary of the RAS that Chandra's work merited double the usual fifteen minutes for presentation and then set himself up to present a paper with the title "Relativistic degeneracy" immediately following. Eddington refused to divulge the nature of his presentation beforehand. McCrea notes in his obituary for Chandra that Eddington began by pointing out that Chandra's calculations were entirely correct based on the relativistic degenerate electron gas. Eddington then noted that the result predicted that a white dwarf with mass in excess of the critical value ($\approx 1.4\ M_{\odot}$) would continue to radiate and shrink until it disappeared. Then Eddington went on to declare that stars do not behave in that way, and Chandra's calculations showed only that the theory of relativistic degeneracy is incorrect. Later he asserted that the Pauli exclusion principle does not apply to relativistic electrons. One might have asked Eddington how he knew that stars do not behave in that way, but Eddington was so formidable and influential a person that no one did, apparently. Egos were the same then as now, and one has only to read Eddington's remarkable monograph *Fundamental Theory* (Cambridge University Press, 1944) to realize that he was coming around to the idea that he could deduce the physical nature of the universe from his own personal declarations.

The physicists, Chandra's young contemporaries (e.g., Pauli, Rosenfeld, Dirac, and others), considered Eddington's assertions to be nonsense, but Eddington moved in a different world. R. H. Fowler and H. N. Russell did not voice the essential points in opposition to Eddington's assertions, evidently intimidated by Eddington's preeminence. Russell, for instance, refused to allow Chandra to say a few words in response to Eddington's hour long exposition of his personal views at the meeting of the International Astronomical Union (IAU) in Paris in July 1935. Chandra managed a brief comment at the "International Colloquium on Astrophysics: Novae and White Dwarfs" in Paris in July 1939, but Russell quickly closed the session before a discussion could proceed.

The question of returning to India was raised by C. S. Ayyar, but Chandra found himself increasingly out of sympathy with the political nature of academia in India. Then Harlow Shapley invited Chandra to visit the Harvard Observatory. Chandra arrived in Boston on December 8, 1935. He enjoyed the friendly atmosphere but was unhappy with the informality after the tightly structured society at Cambridge. He became acquainted with Fred Whipple, Gerard Kuiper, Jerry Mulders, and others. Shapley liked Chandra's lectures so well that he nominated Chandra for election to the Harvard Society of Fellows. Then Otto Struve invited Chandra to visit the Yerkes Observatory of the University of Chicago, followed by an offer of a position as research associate for a year with the expectation that it would become a tenure track appointment in a year. The formal offer came from the office of Chancellor Robert Maynard Hutchins. By the end of the month Chandra had returned to England.

The Eddington factor had the effect of closing the doors in England, and India offered no acceptable situation. So

Chandra accepted Struve's offer, much to the disgust of his father who saw his son receding farther into the mists of foreign culture.

Since his departure from India in July 1930 Chandra had corresponded occasionally with Lalitha Doraiswamy who had been a fellow student in physics at Presidency College. She was in Bangalore in 1935 working in Raman's laboratory. They were both aware that they did not know each other very well, and Chandra had fretted over whether a marriage relationship might interfere with his pursuit of science. Chandra returned to India for a visit in August 1936 and wrote to Lalitha that he would be at Madras. She took the train to Madras to meet him and his misgivings vanished when they met after six years of geographical separation. They were married September 11, 1936.

Chandra and Lalitha spent a month in Cambridge on their way to Boston and then the Yerkes Observatory. Struve contacted the legal counsel of the University of Chicago to arrange a visa for Chandra as a missionary, for otherwise there was no quota for Indians to enter the United States. They arrived at the Yerkes Observatory on Williams Bay on Lake Geneva in Wisconsin on December 21, 1936. They stayed a few days with the Kuipers until their house was ready, and the cold Wisconsin weather was offset by the friendliness of the atmosphere at the observatory.

Lalitha recognized the importance of Chandra's single-minded pursuit of science, and she supported him at the expense of her own career. She was active in the American Association of University Women and her outgoing sociability complemented Chandra's more austere view of life so that they got on very well in their new surroundings.

The University of Chicago provided Chandra with his scientific home for the next fifty-nine years, but there were difficult moments. Chancellor Hutchins intervened on more than one occasion to smooth the way. For instance, in 1938 Struve organized a course in astronomy on the campus of the university to be taught by members of the Yerkes Observatory. However Henry G. Gale, dean of physical sciences, vetoed Chandra's participation, evidently on grounds of skin color. When the problem was referred to Hutchins he said, "By all means have Mr. Chandrasekhar teach." At that point it became clear why the original offer of a position had come from the chancellor's office rather than through the dean.

In 1946 Princeton honored Chandra by offering him the office and position vacated by the retirement of Henry Norris Russell with a salary approximately double Chandra's salary at Chicago. Chandra was inclined to accept. Hutchins matched the Princeton salary and asked Chandra to come by his office to discuss the matter. In the course of the discussion Hutchins remarked that, if conditions for Chandra's research were better at Princeton, then he would not attempt to dissuade Chandra from leaving. When Chandra responded that he did not think so, Hutchins noted that Chicago could not offer Chandra the honor of succeeding a Henry Norris Russell because Chicago had no Russell. Then he asked Chandra for the name of the person who had succeeded to Kelvin's chair at the University of Glasgow. Chandra replied that he had no idea; to which Hutchins replied, "Well, there you are." Chandra declined the Princeton offer and Hutchins remarked on more than one occasion that acquiring Chandra for the University of Chicago was one of his major accomplishments as chancellor.

The course of Chandra's research is perhaps best summarized by the monographs that he wrote as he completed each phase of his work. *An Introduction to the Study of Stellar Structure* (1939) contains his development of the theory of stellar structure, including his work on degenerate stars and the mass limit for white dwarfs, and still makes an excellent textbook on the subject. *The Principles of Stellar Dynamics* (1943) and "Stochastic problems in physics and astronomy" (1943) outline his development of the theory of the dynamics of the motions of stars in the presence of many other stars, showing the frictional drag exerted by neighboring stars and setting up the basic theory for the evolution of clusters of stars. *Radiative Transfer* (1950) contains his systematic development of the radiative flow of energy in stellar interiors and photospheres including his work on the negative hydrogen ion that dominates the opacity at the surface of a star.

In 1952 the Department of Astronomy revamped its graduate curriculum to keep up with the rapid development in the fields of atomic physics, stellar atmospheres, and stellar evolution. Chandra had been offering a repertoire of basic courses in stellar structure and radiative transfer. These courses, based in large part on his own fundamental work, provided excellent background for the theoretical students, but were heavy going for the observational students and lacked up-to-date information needed by both groups of students. Chandra was alienated by the revision and Enrico Fermi seized the opportunity to invite Chandra to become a member of the Department of Physics and the Institute for Nuclear Studies (now the Enrico Fermi Institute). Chandra accepted the invitation and henceforth confined his teaching principally to the Department of Physics, commuting from Yerkes to Chicago two days a week to teach. In 1964 Chandra moved permanently to the Chicago campus, the transition catalyzed by John Simpson's offer of a spacious corner office in the newly constructed Laboratory for Astrophysics and Space Research.

It is ironic that 1952 was also the year Chandra took up the onerous task of managing editor of the *Astrophysical*

Journal. He carried on the responsibilities in his own style, personally attending to the problems of production, refereeing, and politics within the community. The editing was managed with the help of a secretary and an editorial assistant at the University of Chicago Press. Under Chandra's leadership the journal developed into the leading international journal in astrophysics. The journal was in reality privately owned by the University of Chicago. Chandra was its heart and soul, and Chandra realized the unstable character of the situation. In 1967 he set in motion a reorganization that would transfer the primary responsibility to the American Astronomical Society (AAS), although the actual production was to continue at the University of Chicago Press. The rapid expansion of the journal from six issues a year to two large issues a month made it increasingly difficult for a single editor to handle, particularly with Chandra's establishment of the *Astrophysical Journal Letters* in 1967. So Chandra proposed that there be associate editors to assist the managing editor. To make a long story short, the new order of things was approved by the American Astronomical Society, and Chandra was able to pass on his enormous burden to the new team in 1971. It is remarkable that during his years as editor Chandra carried on his scientific research at a rate not noticeably diminished at the same time that he taught his quota of courses in the Department of Physics. It is an example of the extraordinary feats that can be accomplished through dedication and self-discipline to the exclusion of nearly everything else in one's life. His retirement from the position as editor was a great relief to Chandra. He had never intended that the burden should have continued for so long.

Chandra and Lalitha were faced with the question of U.S. citizenship, and after thinking about it for a time came to the conclusion that it was the only realistic choice. It was a big step away from their origins, but to do otherwise would have ignored the fact of their permanent commitment to a life in the United States. So in 1953 they became naturalized citizens. Lalitha's careful explanation of the evolution of their thinking did little to assuage the bitter feelings of C. S. Ayyar who saw the move only as a betrayal of their cultural origins rather than an inevitable evolution in their circumstances. Following citizenship Chandra was elected to the National Academy of Sciences in 1955.

During Chandra's early years as editor, the field of plasma physics and the confinement of ionized gas in magnetic fields in the laboratory was coming into prominence, with the hope, still unrealized today, of producing available power through the fusion of hydrogen into helium. At the same time it was being appreciated that the physics of fully ionized gases (i.e., plasmas) is the basis for the dynamical behavior of stellar interiors, atmospheres, and the interstellar gas. Plasma conditions range all the way from the tenuous, essentially collisionless gases in space to the incredibly dense plasma in the central regions of a star. Chandra was attracted by the challenge of the unknown. He expounded the existing theory of collisionless plasma in a course on the foundations of plasma physics based on the standard free-particle approach and the collisionless Boltzmann equation. S. K. Trehan put together a book *Plasma Physics* (University of Chicago Press, 1960) based on the notes from that course. In collaboration with A. N. Kaufman and K. M. Watson Chandra carried through the immense calculation of the dynamical stability of the collisionless plasma confined in an axial magnetic field. At the same time Chandra entered into an extensive study of the dynamical stability of fluids in various configurations, including the presence of magnetic fields and rotation of the entire system. His contributions are summarized in his monograph *Hydrodynamic and Hydromagnetic Stability* (1961).

From there Chandra took up the classical and unfinished problem of the dynamics of rotating, self-gravitating spheroids of homogeneous incompressible fluids. The problem had been initiated by Newton in connection with the oblateness of Earth and carried on from there by such great names as Maclaurin, Reimann, Dedekind, Jacobi, Dirichlet, et al. Chandra reopened the unfinished problems with the tensor virial equations whose great power had not been appreciated up to that time. The results of that work appear in his monograph *Ellipsoidal Figures of Equilibrium* (1969).

The work on selfgravitating objects soon brought Chandra to the doorstep of general relativity as the basic theory of gravity. His efforts in that field led to development of the Chandrasekhar-Friedman-Schultz instability, which became a source of gravitational radiation from black holes. Extensive investigation of the Kerr metric and the rotating black hole led to the monograph *The Mathematical Theory of Black Holes* (1983). Chandra also developed the post-Newtonian approximation for treating the field equations of general relativity. It is now the means for calculating the gravitational radiation from multiple star systems, etc. He went on to work out a variety of exact solutions to the equations of general relativity in collaboration with B. C. Xanthopoulos and V. Ferrari, showing some of the remarkable singularities that turn up in the interaction of gravitational waves and at the apex of the conical space solutions. One of the more curious discoveries was that the radial pulsations of a star, which are known from Newtonian gravitation to exhibit overstability in the presence of dissipation (e.g., viscosity) become unstable in general relativity through the energy loss represented by the emission of gravitational waves. Thus the star without internal dissipation is stable according to

Newtonian theory, but unstable in the context of general relativity.

As a brief aside it is interesting to note that in 1982 Chandra was invited to lecture on Sir Arthur Eddington at the celebration at Cambridge of the hundredth anniversary of his birth. The lectures are published in the small book *Eddington, the Most Distinguished Astrophysicist of His Time* (1983). The lectures emphasize the remarkable insights of Eddington into stellar structure and his early recognition of the implications of Einstein's general relativity. Chandra's reflections on Eddington's assertions on electron degeneracy and the Pauli exclusion principle are of particular interest.

By 1990 Chandra had developed a growing interest and admiration for the work of Sir Isaac Newton, and over the next several years he constructed a detailed and critical review of Newton's *Principia.* The results of this effort are published as *Newton's Principia for the Common Reader* (1995). This was the first time that a world class physicist undertook a thorough reading and critical commentary of the *Principia,* dispelling such perpetuated notions that Newton's theory of the perturbations of the orbit of the Moon is in error, or that some of his diagrams were incorrectly drawn.

Chandra's book *Truth and Beauty* (1987) shows an entirely different side of his thinking. It includes his Ryerson Lecture "Shakespeare, Newton, and Beethoven" in which he explored and compared the motivations and feelings involved in the creation of science and art.

Chandra's scientific papers are collected in seven volumes under the title *Selected Papers, S. Chandrasekhar* (1989-96). They complement the monographs listed above and provide a more detailed historical picture of the day-by-day development of his thinking.

Chandra attached great importance to training Ph.D. students. He saw them clearly as the future of astrophysics when the present generation of working scientists has passed into retirement and beyond. Struve had assigned him the responsibility for the weekly colloquium, held on Monday afternoons, and Chandra saw to it that the graduate students were in regular attendance. The Yerkes faculty, graduate students, and visitors presented their work at appropriate times, and Chandra gave each hundredth colloquium himself, as well as many in between. The count of weekly colloquia passed 500 before Chandra moved to the campus. He also conducted seminars on Monday evenings for the edification of the graduate students, who took turns reporting on interesting papers that had appeared in the literature. Chandra supervised forty-six known Ph.D. research students, many of whom have become prominent in the field of astrophysics, and not a few of whom are members of the National Academy of Sciences. Chandra was a stern taskmaster who insisted on rigorous training and research. The graduate courses in theoretical astrophysics taught at Yerkes by Chandra were the usual preparation, until the early fifties. After that most of Chandra's students came through the Department of Physics. Once a student successfully completed the Ph.D., Chandra gave his full support in getting the student established in the scientific community. In fact Chandra's support was not limited to his students alone. He appeared at critical moments in the career of this writer, as with others as well.

It is no surprise, of course, to learn that Chandra was awarded many honorary degrees and medals. He was elected a fellow of the Royal Society in 1944, which awarded him the Bruce Medal in 1952. The Royal Astronomical Society awarded him its Gold Medal in 1953. He was awarded the National Medal of Science by President Lyndon Johnson in 1967. The fundamental nature of Chandra's mass limit for degenerate stars has come to be appreciated in the astronomy and physics communities, recognizing that it is perhaps the most direct and striking example of the effect of quantum physics on macroscopic bodies. Chandra was awarded a Nobel Prize by King Carl Gustav in 1983 in recognition of his work of fifty years before. On the other hand it must be appreciated that Chandra's work on radiative transfer, stellar dynamics, dynamical stability of fluids, plasmas and selfgravitating bodies, and gravitational theory collectively represent a much larger contribution to physics and astrophysics than the more spectacular mass limit.

Chandra's death in 1995 heralded the end of the era that developed the basic physics of the star. He was the most prolific and wide ranging of those who applied hard physics to astronomical problems.

I EXPRESS MY APPRECIATION to D. E. Osterbrock for his careful reading of the manuscript and several important suggestions and corrections from his own association with Chandra over the years.

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