His quest during these 'general relativity years' is perhaps best summarized in the passage from Virginia Woolf's *The Waves* that he himself liked to quote:

There is a square; there is an oblong. The players take the square and place it upon the oblong. They place it very accurately; they make a perfect dwelling-place. Very little is left outside. The structure is now visible; what is inchoate is here stated; we are not so various or so mean; we have made oblongs and stood them upon squares. This is our triumph; this is our consolation.

1. Chandrasekhar, S., The Increasing Role of General Relativity in Astronomy, Halley Lecture, *The Observatory*, 1972, **92**, 160–174.
2. Chandrasekhar, S., The role of general relativity in astronomy: retrospect and prospect, *J. Astrophys. Astron.*, 1980, **I**, 33–45.
3. Chandrasekhar, S., in *A Commentary on Dirac's Views on 'The Excellence of General Relativity'* (ed. Winter, K.), Festi-Val – Festschrift for Val Telegdi, Elsevier, Amsterdam, 1988.
4. Chandrasekhar, S., How one may explore the physical content of the general theory of relativity, in The Proceedings of the Gibbs Symposium (eds Caldi, D. G. and Mostow, C. D.), American Mathematical Society and American Institute of Physics, 1989.
5. Chandrasekhar, S., *Einstein and general relativity – Historical Perspectives*, Oppenheimer memorial lecture, LASL-78-91, 1991.
6. Chandrasekhar, S., *The series of paintings by Claude Monet and the landscape of general relativity*, address delivered at the inauguration of the Inter-University Center for Astronomy and Astrophysics, Poona, IUCAA publications, 1993.

ACKNOWLEDGEMENTS. I am grateful to John Friedman and Kameshwar Wali for discussions.

Chandra remembered

Kameshwar C. Wali

Physics Department, Syracuse University, Syracuse, New York 13244-1130, USA

The article contains a brief biographical sketch of S. Chandrasekhar, his many accomplishments and his multi-faceted personality.

With the sudden death of S. Chandrasekhar on 21 August 1995, the world lost one of the foremost scientists of the twentieth century. Known simply as Chandra throughout the scientific world, he dominated, by his prolific contributions, the fields of theoretical astrophysics, physics and applied mathematics. Writing about his death, scientists from around the world highlighted Chandra's scientific achievements and his unique style of research – how he would occupy himself with a particular area of research for a period of five to ten years, publish a long series of papers, and when he felt that he had accumulated a sufficient body of knowledge in that area and developed a view of his own, he would present it as a coherent account with 'order, form and structure' in a monograph.

Chandra was born on 19 October 1910 (19–10–1910, as Chandra was fond of saying), in Lahore, Pakistan (then a part of colonial British India). His father, C. S. Ayyar was in the Government Service, serving as the Deputy Auditor General of the Northwestern Railways. Chandra was the first son and the third child in a family of four sons and six daughters. His mother was a remarkable woman of great talent and intellectual attainments. Although she had received only a few years of formal elementary education, she had learned English on her own well enough to translate Ibsen's *A Doll House* into Tamil. Intensely ambitious for her children, she played a pivotal role in Chandra's pursuit of a career in pure science. Chandra's early education, till he was twelve, was at home, taught by his parents and private tutors. When he was twelve, his father was transferred to Madras, and Chandra began his regular school in the Hindu High School, Triplicane, during the years 1922–25, followed by his university education at the Presidency College, Madras, graduating with a B Sc. (Hons.) degree in 1930. Lalitha Doraiswamy, his future wife, was a fellow undergraduate studying physics.

An exceptionally brilliant student throughout his student career, Chandra had become nationally known by presenting an original research paper in physics as an undergraduate during the Indian Science Congress Meetings in 1929. Before even he graduated, he learned that he was awarded a Government of India Scholarship to continue his studies in England. By then he had established contact with R. H. Fowler in Cambridge and had decided to work under his guidance for his doctoral degree. On his long voyage across the Indian Ocean in 1930, young Chandra was to pioneer the discovery of the critical mass condition known as the 'Chandrasekhar Limit', which is now hailed as one of the fundamental discoveries of this century.

The Chandrasekhar limiting mass condition says that a star whose mass is greater than a certain critical mass cannot become a white dwarf. This was an inevitable

conclusion that was derived from combining the new quantum mechanical Fermi–Dirac statistics with Einstein's special theory of relativity. Chandra showed that if the mass of a star was greater than the limiting mass, the gravitational forces would be too strong to overcome. The star would not rest in an equilibrium stage of a white dwarf, which was considered, in the middle and late twenties, as the only terminal stage for all stars during the course of their evolution. What then was the fate of more massive stars (mass > the critical mass) that certainly existed in the universe? Are there terminal stages other than the white dwarf stage? Unfortunately, the appreciation of the tremendous significance of such questions did not come forth immediately because of a totally unexpected controversy that developed between Chandra and Sir Arthur Stanley Eddington. In the January 1935 meeting of the Royal Astronomical Society, London, Eddington openly ridiculed the ideas leading to 'relativistic degeneracy' on which Chandra's analysis was based and cast serious doubt on Chandra's discovery. Chandra, then just graduated and almost a newcomer to the research arena was pitted against an established, internationally renowned Eddington whose authority, prestige and fame carried the day. It was nearly two decades before the Chandrasekhar limit became an established fact and found its genuine role in astrophysical research. It pioneered the way to the discovery of other terminal stages of stars – the neutron star and the black hole. Five decades would pass before Chandra would be awarded the Nobel Prize. It is to Chandra's credit that he turned this traumatic event into a turning point in his life. He became inward bound. A distinctive style, a quest for perspectives, a complete mastery of a certain area and once that was accomplished, leaving it for good for another area – thus constantly rejuvenating himself – became Chandra's unique style in his scientific pursuits.

'There have been seven periods in my life', said Chandra. They are briefly: 1) stellar structure, including the theory of white dwarfs (1929–39); 2) stellar dynamics, including the theory of Brownian motion (1938–43); 3) the theory of radiative transfer and the quantum theory of the negative ion of hydrogen (1943–50); 4) hydrodynamic and hydromagnetic stability (1952–61); 5) the equilibrium and the stability of ellipsoidal figures of equilibrium (1961–68); 6) the general theory of relativity and relativistic astrophysics (1962–71); and 7) the mathematical theory of black holes (1974–83). To this we might add an eighth period: 8) colliding gravitational waves, radial and nonradial oscillations of a star and Newton's *Principia*. I will not dwell further on Chandra's contributions during each of these periods and their impact on the ongoing research. That is the task allotted to various experts whose articles appear in the rest of this issue.

However, reflecting upon Chandra's work, particularly on general relativity during the eighth period, one cannot fail to be reminded of Monet's serial paintings. When I saw an exhibition of these paintings in Boston, I was instantly reminded of Chandra's descriptions in the article, 'How One may Explore the Physical Content of the General Theory of Relativity' (*Selected Papers*, vol. 6, p. 697. The University of Chicago Press, 1991). A close analogy came to mind. In Monet's paintings, the same scene is depicted over and over again under different natural illuminations and seasonal variations. The valley, the trees and the fields, the hay stacks are the same. Superficially, they may appear boring and repetitive, but the different paintings, however, radiate totally different aesthetic content. In the same way, the seemingly same equations and solutions in Chandra's hands describe vastly different physics. I was pleasantly surprised to find later, the same analogy had struck Chandra and made it into his talk on the occasion of the inauguration of the Inter-University Centre for Astronomy and Astrophysics (IUCAA), in Pune, India.

The years I spent in writing Chandra's biography are among the most enjoyable and creative years in my life. After the completion of the book, my visits with Chandra became less frequent, but our friendship continued to grow and develop. During the summer of 1994, Chandra and Lalitha and my wife and I spent a week's vacation at the Stratford Shakespeare festival in Canada. 'Get the best seats for the plays,' Chandra had said. When I had called Chandra a few days earlier, he said he was rereading the Shakespeare plays, *Othello*, *Hamlet* and *Twelfth Night* that we were going to see. He was also listening to the records. Thus he came fully prepared to enjoy his rare vacation, setting aside his preoccupation with Newton at the time. We all had such good time, seeing a new play every day and taking sightseeing trips surrounding Stratford. It was pleasantly surprising to see Chandra as a full-time tourist, so light-hearted and impulsive in enjoying himself. I was not bugging him with questions about his life, his childhood, his days in Madras and Cambridge, his encounters with Eddington and Milne, the Yerkes Observatory and the University of Chicago, or the University of Chicago Press with which he was strongly attached as the editor of the *Astrophysical Journal* for nearly twenty years. Over the years I had made him tell and retell these stories. Without showing the least annoyance, he had obliged, without ever saying, 'How many times do you want me to repeat?' I was indeed fortunate to have had the opportunity to tell his life story.

The last time I talked to him on the phone was during the first week of August 1995, when I received a complimentary copy of his Newton's *Principia* that had come out in June. He was surprised that I received it so late. I thanked him and congratulated him. We both

agreed that the Oxford University had done a commendable job in producing the book so elegantly. I said, 'Chandra, I have no doubt this work of yours will go in history as monumental.' He had his doubts, but accepted the compliment and said he no longer had the energy or stamina to do hard work. He complained about exhaustion and how he had to be helped back home when he was taking a short talk near where he lived. Those were grueling, hot days in Chicago. I explained that to him and said, essentially, I forbid you to work hard anymore. You must relax and enjoy. He responded agreeing with me. 'That is exactly what I am going to do. Just two short papers to finish writing with Valeria Ferrari. I am indeed relaxing, reading *Les Miserables*(!).'

I was about to say, think of that essay you wanted to write about Newton and Michelangelo, but I refrained myself, because of the sudden fear that it might get him into another serious entanglement. The book on Newton had its partial origin in my suggestion in the late eighties, to him and the University of Chicago Press, that he publish a small book containing his one or two lectures in which he would take a proposition from Newton's *Principia*, present his own modern proofs and compare them with the proofs of Newton. In his lecture 'The *Principia*: The Intellectual Achievement That It Is,' he had stated,

> I first constructed for myself proofs for them [Newton's propositions]. Then I compared my proofs with those of Newton. The experience was a sobering one. Each time I was left in sheer wonder at the elegance, the careful arrangement, the imperial style, the incredible originality, and above all the astonishing lightness of Newton's proofs; and each time I felt like a school boy admonished by his Master.

I had visualized a small book in the style of Herman Weyl's swan song *Symmetry* published by the Princeton University Press. Printed artistically on half of the page, with beautiful illustrations, it is gem of a book describing the role of symmetries in art, architecture and science. I thought of Newton's proofs on one side and Chandra's hand-written proofs on the side facing it would indeed be a marvelous last book for Chandra. Chandra signed a contract with the University of Chicago Press, but as he delved more and more into *Principia* and proved more and more propositions in Books I and III of the *Principia* that bear on the universal law of gravitation, the material grew in size and shaped into a mathematical tome of some 400 pages with numerous illustrations. When Clarendon Press offered to undertake the job, he canceled his contract with the U.C. Press and wholeheartedly devoted himself to Newton.

In addition to Newton's *Principia*, Chandra's abiding interest in the eighties was in getting a bust of Srinivasa Ramanujan made and presented to Janaki Ammal, the widow of Ramanujan. As is well known, Chandra had a life-long interest in Ramanujan. He was hardly ten when he was woken up by his mother to tell him about an item in the newspaper concerning the death of a famous Indian mathematician recently returned from England. At the time, neither Chandra's mother nor Chandra had any idea of what kind of a mathematical genius Ramanujan was. For that matter, very few Indians knew or understood Ramanujan's genius. But as Chandra says, 'Ramanujan's role for the development of science in India did not depend upon his being understood! The fact that his early years were spent in a mathematically and scientifically sterile atmosphere, that his life in India was not without hardships, that under circumstances that appeared to most Indians as nothing short of miraculous he had gone to Cambridge, supported by eminent mathematicians, and had returned to India with every assurance that he would be considered, in time, as one of the most original mathematicians of the century – these facts were enough, more than enough, for aspiring young Indian students to break their bonds of intellectual confinement and perhaps soar the way Ramanujan had.' Indeed Ramanujan greatly influenced Chandra; he was his role model for a life dedicated to the pursuit of science.

Chandra vehemently disagreed with statements often made by some of the contemporaries of Ramanujan that Ramanujan had some special connection with God. The colourful stories concerning Ramanujan's devotion to the family Goddess, Namakkal, and how she gave him all the formulas in his dreams are even now commonly heard. Quoting from a letter by G. H. Hardy to him in 1936, Chandra said he was more inclined to accept Hardy's view that '... at bottom and to a first approximation, Ramanujan was (intellectually) as sound an infidel as Bertrand Russell or Littlewood.... One thing I am sure, Ramanujan was not in the least an 'inspired idiot' that some people seem to have thought him.'

Over the years, Chandra had taken active interest in perpetuating the memory of Ramanujan. In the late 1940s, he was instrumental in founding the Ramanujan Institute of Mathematics in Madras with the financial help of a former classmate, Alagappa Chettiar. After the death of Chettiar, when reports reached Chandra about the imminent death of the Institute, he wrote to Jawaharlal Nehru and secured Nehru's personal intervention and saved the Institute. The Institute owes a great deal to Chandra and the mathematician Andre Weil for its continued existence after Nehru. They served as advisors to the Madras government in the choice of the Institute's director and administration. Furthermore, due largely to Chandra's efforts, Mrs Ramanujan's pension was more than doubled in 1962 so that she could live modestly but comfortably in Madras till her death. Prior to 1962, she received a meager pension of 150 rupees a month and was living in poverty.

More recently, in 1976, when more of Ramanujan's work was discovered accidentally by George Andrews and the story of the 'Lost Notebook,' hit headlines, Janaki Ammal had lamented in an interview with the newspaper, *The Hindu*, the fact that a statue of Ramanujan had never been made, although one had been promised. Richard Askey of the University of Wisconsin then took the initiative and approached Chandra with the idea of commissioning a bust to be made. The sculptor, Paul Granlund, needed at least three orders to accept the commission. When government and institutional support was slow in coming, Chandra and Lalitha agreed to buy two busts, the third one made possible from small contributions from mathematicians around the world. Chandra took personal initiative in shipping the bust shipped to Ramanujan's widow and subsequently, Chandra and Lalitha donated their two busts, one to Indian Academy of Sciences in Bangalore and the other to the Royal Society, London.

Reflecting on his own life, Chandra had said,

> ...I have a feeling of disappointment because the hope for contentment and a peaceful outlook on life as a result of pursuing a goal has remained unfulfilled (*CHANDRA: A Biography of S. Chandrasekhar*, The University of Chicago Press, 1991, p. 305).

For many reviewers of the biography and friends, this was a baffling statement, an unhappy epitaph to such an ideal, inspiring and successful life. How is it possible? Reviewers and friends asked. If the single-minded pursuit of science on one's own terms, seeking personal satisfaction and comprehending nature with such enormous success, leaves one discontented, what else is there?

Was there then some sort of faith, a simple system of beliefs that transcend rational thinking and scientific approach that is necessary to acquire a sense of fulfilment and contentment? Chandra's response was in the negative. He said emphatically, No, I don't have the faith. I am an atheist. It is just that the sense of harmony that I had hoped for when I was young, I don't have. I have persevered in science for five decades and more, devoting minuscule amount of attention to other endeavours. But that does not mean I regret the past or I wish I had done things differently, (*CHANDRA, Ibid*, p. 306).

'I don't have any fear or foreboding of death,' Chandra had said once. 'If some one were to tell me I have cancer and will die in three months, I don't think it would make much difference to me. But there are other kinds of problems that worry me. What would happen to Lalitha? I know financially she will be all right. However, wouldn't she be very lonely?' He had the same worry when he had the heart attack in 1974. 'I felt an enormous sense of peace. Then suddenly the thought occurred to me. What would happen to Lalitha?' He had also expressed a strong wish against being under medication or his life being prolonged by artificial support. 'I would like to keep open the 'option' of dying by heart attack – it is the best way,' he had said.

Chandra had left a sealed letter to be opened after his death with Robert Wald, forbidding any fanfare or a memorial in the customary fashion. A reunion arranged by Lalitha on 18 October 1995 brought together a few friends and associates to commemorate his memory.

So ends the life of a man whom Res Jost had described:

> There is a secret society whose activities transcend all limits in space and time and Dr Chandrasekhar is one of its members. It is the ideal community of geniuses who weave and compose the fabric of our culture.

Chandra, Newton and the *Principia*

Jayant V. Narlikar

Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India

In this special section dedicated to Chandra, experts have tried to highlight his multi-faceted contributions. This short article is devoted to his last love, namely Isaac Newton, especially the three-volume work, the *Principia* by Newton. True to his style Chandra worked hard on the *Principia* for several years in order to write a commentary on it. This he wrote in the form of a book which was published by the Oxford University Press only a few weeks before his death. Following are the thoughts that came to my mind on perusing this last book by Chandra.

Newton's *Principia* for the common reader

In the humanities, commentaries are written on classic texts. A few commentaries and the commentators in due course themselves become classic. Thus Mallinatha's commentaries on the texts of Kalidasa are read avidly by scholars who wish to derive the maximum enjoyment and appreciation of the poet's work.

This, however, is rare in science. So when a distinguished scientist with several accolades including the Nobel Prize, writes on the *Principia*, a scientific classic