OBITUARY

From White Dwarfs to Black Holes

Subrahmanyan Chandrasekhar: 1910-1995

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Prof. S. Chandrasekhar, Nobel Laureate astrophysicist from the University of Chicago, died of heart failure on August 21, 1995, in Chicago. This is a tribute to the man and his achievements.

Astronomy has a long tradition of being at the forefront of human endeavour. From the ancient civilizations of Asia and North Africa, then later in the golden age of the Greeks, or still later in India from Aryabhatta to Bhaskara, followed by the European lead of Copernicus, Galileo and Kepler, to the dawn of modern physics with Isaac Newton, one finds the human curiosity about the cosmos as the chief motivator of our understanding of nature.

When Subrahmanyan Chandrasekhar was born (on October 19, 1910) in Lahore in British India, astronomy had lost much of the glamour of earlier epochs. In terms of scientific priorities it was replaced by the laboratory physics of thermodynamics, electromagnetic theory, special relativity and, of course, the newly emerging discipline of quantum mechanics. Unwittingly, Chandrasekhar (or, Chandra as he was popularly referred to) was to play a lead role in the revival of scientific interest in astronomy.

Chandra's father, C. Subrahmanyan Ayyar, was employed in the railway service that took its officers all over India, which explains how a South Indian was born in the western part of Punjab. His father's brother was chandrasekhar Venkata Raman, who himself was to win a Nobel Prize for physics in 1928. Chandra received his early education at home, followed by the Hindu High School in Triplicane, Madras, for his father by then had a job in Madras. Afterwards he joined the Presidency College, Madras, as an undergraduate.

The signs of a future pathbreaker in physics were already apparent in the undergraduate at Madras. Chandra at the age of 19 wrote his first research paper on "The Compton Scattering and New Statistics" which appeared in the prestigious journal, the *Proceedings of the Royal Society,* London. And so he was set on a scientific career. However, in those days the priorities of a successful Indian were to enrol for a career in the Indian Civil Service preferably through higher education at Oxford or Cambridge. But Chandra wished to go to Cambridge to do research in an environment that had the flourishing Cavendish Laboratory under Rutherford, distinguished physicists and mathematicians like Fowler, Eddington and Dirac..., in short an ambience wherein physics was receiving new directions.

Chandra's priorities were then, and later throughout his subsequent career, on mathematics as a polished tool for solving problems and astrophysics. In 1930, on the steamer bound for the UK, he set himself a problem to

solve, a problem whose logical conclusion was to bring him fame in the early part of his career. The problem concerned the so-called white dwarf stars.

The White Dwarfs

The classic book of Eddington *The Internal Constitution of the Stars* had already set the scene for an understanding of stellar structure. Thus in a pioneering attempt, Eddington had set up basic equations of internal equilibrium and heat transfer in a star like the Sun, concluding that nuclear fusion of hydrogen to helium would provide the stellar energy that makes a star shine and provides the crucial pressures for its support against gravity. The star's mass therefore determines its internal structure including the march of temperature and pressure all the way from the center to the surface. And production of energy at the center sustains this steady distribution. This picture works well for the stars like the Sun which have a thermonuclear energy reservoir in the central core: but what about those stars for which there is no such source of energy on tap? The white dwarfs are such stars.

The white dwarfs are very faint and tiny stars when compared to the Sun. The radius of a white dwarf may be a few percent of the solar radius. But how massive can a white dwarf be?

The work of R.H. Fowler had shown that in the absence of sufficient pressures a star would go on contracting until its shrinkage is opposed by a new kind of pressure called the *quantum degeneracy pressure*. This pressure arises when the electrons in the star are so densely packed that the rules of quantum statistics become operative in place of the classical rules. The Pauli exclusion principle precludes the packing of electrons in any given volume beyond a set limit, When that limit is reached the electron matter is said to become degenerate. Thus a tendency for continued contraction by the star is halted by the pressures which arise from degenerate matter.

This was Fowler's result and it allowed the existence of white dwarfs of *any* mass. But what Chandrasekhar discovered was a major loophole in the argument. As one starts packing electrons up to the limit allowed, their energy levels also rise; and at sufficiently high energy the electrons have speeds comparable to that of light. In other words, the electrons become relativistic and the rule for close-packing them gets modified. This is known as *relativistic degeneracy*.

Now if we consider stars of low enough mass, the state of degeneracy is reached in them even in the new situation. But for massive stars the central temperature is so high that the degeneracy limit is never reached even if they contract to higher and higher densities. Chandrasekhar found that a critical mass threshold came into the picture. A star of mass less than the critical value can be sustained as an equilibrium structure while for larger mass stars equilibrium is not possible. Now well established and known as the *Chandrasekhar mass limit*, this critical value is approximately 1.44 times the mass of the Sun.

It took many years, however, for the result to get established and accepted. For, a profound scepticism of this work was expressed by no less an authority then Eddington himself who believed that relativistic degeneracy was an absurd concept and that whatever its mass, the star would encounter no problem of equilibrium as originally deduced by Fowler. Otherwise, what would happen to the stars that continued to shrink? It was partly the resistance encountered at Cambridge that Chandra felt like making a change not only in the field of his research but also in the place of his work.

Research Interests of Later Years

In mid-thirties Chandra made an attempt to settle in India but the gap between India and the West proved too wide to bridge, and he moved to the University of Chicago in 1937 where he had a brilliant academic career with an ascending series of positions which he held with distinction till the end.

His research interests included radiative transfer, hydrodynamic and hydromagnetic instability, equilibrium configurations of rotating fluids, stellar dynamics, general relatively including black holes and colliding gravitational wavefronts. The following example will illustrate his characteristic style of functioning.

I first met him near Warsaw in 1962 when I was a research student attending an international conference on relativity and gravitation. He was attending the meeting not as an expert but as a novice wishing to learn the general relativity theory and to know what were the interesting problems for research. That he was more than fifty years in age when most scientists begin pulling down the shutters on their original work, did not matter. And his subsequent work demonstrated the effect of his hard work and originality in that new area of research. In the eighties he wrote the massive volume entitled *The Mathematical Theory of Black Holes*. Ironically one of Eddington's objections to Chandra's work had been to its implication that a star more massive than the Chandrasekhar limit would continue shrinking until its gravity become so strong as to hold in all its radiation. Had Eddington taken this implication seriously he would have deduced the existence of black holes!

Anyhow, this is the way Chandra operated: learn a new subject, make original contributions to it at a high level and then write an authoritative monograph on it..., and then repeat the process with a new field of research! His latest work was a book explaining some of the results derived in Newton's *Principia* to the common man. When Chandra visited IUCAA (of which he was an honorary Fellow) in 1992 he had lectured on this topic explaining how he found Newton's geometrical derivations more satisfying than his own alternative derivations with modern techniques.

Chandra was interested in the role of beauty, creativity and excellence in arts as well as sciences. His Dedication Day Lecture at IUCAA sought to draw a comparison between the series paintings of Claude Monet and the landscape of general relativity. Earlier, in 1975, he had talked about Shakespeare and Beethoven along with Newton while discussing the role of creativity.

Awards and Distinctions

Chandra's numerous distinctions included the Nobel Prize for Physics in 1983, Fellowship of the Royal Society, Padma Vibhushan from India, the Vainu Bappu Memorial Award of the Indian National Science Academy, the Gold Medal of the Royal Astronomical Society, the Copley Medal of the Royal Society, etc., the list being too long to be exhaustive. The Nobel Award had been long overdue — in the opinion of many scientists it should have been given at least two decades earlier in recognition of his work on white dwarfs.

This account would not be complete without reference to the seminal contributions Chandra made to the *Astrophysical Journal* as its Editor from 1952 to 1971. During this period he brought the journal to the forefront of research journals in astrophysics. His single-minded and often single-handed approach in establishing this journal is legendary.

Chandra is survived by his wife Lalitha whom he married in 1936, and who had been his constant companion and a source of strength all along.

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