Chandra's Influence on Indian Astronomy

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Prof. Narlikar
(Photo courtesy:
Suhas B. Naik-Satam,
Nehru Planetarium,
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Professor Jayant Vishnu Narlikar is arguably the most well-known Indian astrophysicist. A Ph.D. and an Sc.D. from the University of Cambridge, he joined TIFR in 1972. During his Cambridge period he laid the foundations of his research work in cosmology and astrophysics in collaboration with his mentor Fred Hoyle. In 1989 he took over as the Founder Director of the Inter-University Centre for Astronomy and Astrophysics (IUCAA).He is now Emeritus Professor at IUCAA. Professor Narlikar is internationally known for his work in cosmology, in championing models alternative to the popularly believed big bang model. His work has been on the frontiers of gravity and Mach's Principle, quantum cosmology and action at a distance physics. He is Fellow of the three national science academies as well as of the Third World Academy of Sciences. Also well-known for his popular science writings and lectures, he was honoured by the UNESCO in 1996 with the Kalinga Award. He was decorated Padmabhushan in 1965 and Padmavibhushan in 2004.

The extraordinary achievements of Subrahmanyan Chandrasekhar (Chandra) have guided and inspired many younger astrophysicists. The brief survey seeks to highlight a few specific cases in India where, through his writings, lectures and discussions, Chandra made a lasting impact. It will be argued that although at a general, somewhat superficial level, Chandra is a light beacon to be followed, very few Indian astrophysicists reached a level where they could engage Chandra in a scientific discussion on a topic that interested him.

1. Introduction

A centenary provides an admirable opportunity to review the impact of the concerned scientist on his recognized field of research. Subrahmanyan Chandrasekhar (`Chandra' henceforth) had a very successful career in theoretical astrophysics, topped with many awards and distinctions including the 1983 Physics Nobel Prize, which he shared with William A. Fowler. He died on August 21, 1995 at the age of 85 years. So this centenary gives us the opportunity of evaluating Chandra's impact in his native land of India, some 15 years after his passing away.

To begin such an evaluation I can do no better than reproduce extracts from Chandra's own assessment of his work[1]: "...After the early preparatory years, my scientific work has followed a certain pattern motivated, principally, by a quest after perspectives. In practice, this quest has consisted in my choosing (after some trials and tribulations) a certain area which appears amenable to cultivation and compatible with my taste, abilities, and temperament. And when after some years of study, I feel that I have accumulated a sufficient body of knowledge and achieved a view of my own, I have the urge to present my point of view, ab initio, in a coherent account with order, form and structure.

There have been seven such periods in my life: stellar structure, including the theory of white dwarfs (1929-1939); stellar dynamics, including the theory of Brownian motion (1938-1943); the theory of radiative transfer, including the theory of stellar atmospheres and the quantum theory of the negative ion of hydrogen and the theory of planetary atmospheres, including the theory of the illumination and the polarization of the sunlit sky (1943-1950); hydrodynamic and hydromagnetic stability, including the theory of the Rayleigh-Bénard convection (1952-1961); the equilibrium and the stability of ellipsoidal figures of equilibrium, partly in collaboration with Norman R. Lebovitz (1961-1968); the general theory of relativity and relativistic astrophysics (1962-1971); and the mathematical theory of black holes (1974-1983). The monographs which

resulted from these several periods are:

1. *An Introduction to the Study of Stellar Structure* (1939, University of Chicago Press; reprinted by Dover Publications, Inc., 1967).
2. (a) *Principles of Stellar Dynamics* (1943, University of Chicago Press; reprinted by Dover Publications, Inc., 1960).
   (b) *Stochastic Problems in Physics and Astronomy'*, Reviews of Modern Physics, **15**, 1-89 (1943) reprinted in Selected Papers on Noise and Stochastic Processes by Nelson Wax, Dover Publications, Inc., 1954.
3. *Radiative Transfer* (1950, Clarendon Press, Oxford; reprinted by Dover Publications, Inc., 1960).
4. *Hydrodynamic and Hydromagnetic Stability* (1961, Clarendon Press, Oxford; reprinted by Dover Publications, Inc., 1981).
5. *Ellipsoidal Figures of Equilibrium* (1968; Yale University Press).
6. The Mathematical Theory of Black Holes (1983,Clarendon Press, Oxford)."

This pattern is, I believe, unique in the sense that I know of no other scientist who had systematically compartmentalized his interests so precisely that he never revisited any of the earlier fields of interest. We will encounter in Section 6 an example of this trait. But it follows that given the diversity of interests in the above list, two scientists following the lead given by Chandra may not share a common interest.

Before coming to the topic of my presentation, I should briefly outline the evolution of Indian astronomy and astrophysics over the period of Chandra's work. The theoretical work was mostly done in physics departments, except for general relativity, which was mostly done in mathematics departments. Amongst the former, during the 1930s and 1940s, Delhi and Allhabad universities stood out, with D.S. Kothari in Delhi and M.N. Saha in Allahabad. Amongst the latter, Calcutta University and Banaras Hindu University were prominent in hosting schools of general relativity.

This pre-eminence of universities declined, however, in the post-independence, post-1947 era. The emphasis on research dwindled, and instead found another outlet in the so called autonomous research institutes. These, including the CSIR laboratories and the prestigious Tata Institute of Fundamental Research (TIFR), proliferated in the post-independence era. Their impact on the growth of astronomy and astrophysics (A&A) was predictable and has continued till today. The major Indian research in A&A today comes from the TIFR, the Raman Research Institute (RRI), the Indian Institute of Astrophysics (IIA), the Physical Research Laboratory (PRL), the Institute of Mathematical Sciences (IMSc), the Harish-Chandra Research Institute (HRI) and the Aryabhatta Research Institute of Observational Sciences (ARIES). The heavy tilt away from the universities was to some extent counterbalanced by the creation of the Inter-University Centre for Astronomy and Astrophysics (IUCAA), an institution within the university sector, providing guidance and facilities to university academics working in A&A, besides very successfully conducting its own research. With this background we may now try to assess Chandra's impact.

2. The 1930s and 1940s

In his biography of Chandra, Kameshwar Wali[2] has described how Chandra as a student in 1930 attended a get-together in the house of Meghnad Saha in Allahabad, following a major scientific meet in the city. That the talk at Saha's house was related to issues in A&A sets a contrast to a modern meeting of a similar kind where the talk would be largely on local or national politics. As it turned out a few years later Saha himself took part in national politics, took up positions in important committees, became an M.P. and so on.



Professor D.S. Kothari (1905-1993) (Credit: AIP Emilio Segre Visual Archives, Physics Today Collection)

Nevertheless Chandra's work on white dwarfs did have impact on a young Indian trained by Saha at Allahabad who left for Cambridge for his Ph.D. in astrophysics. Daulat Singh Kothari got his degree in 1933 and after his return to India he set up

the Physics Department at the University of Delhi. Significantly, the new department was named as Department of Physics and Astrophysics. Kothari, following Chandra, was interested in astronomical objects made of dense matter. Normally one considers the ionized state of matter as arising at high enough temperature. Kothari showed that under high pressure also, ionization could be achieved [3]. Sir A.S. Eddington wrote: "*I mentioned that we only gradually came to realize that ionization could be produced by high pressure as well as high temperature. I think the first man to state this explicitly was D.S. Kothari. Stimulated by some work of H. N. Russell, Kothari has made what I think is an extremely interesting application.*" Further commenting on Kothari's work, Arnold Sommerfeld wrote: "*During the times of Galileo and Kepler the planets were at the focus of astronomical interest but in view of the developments of the last few decades the interest has shifted to stellar physics and spiral nebula. It is noteworthy that the Indian D.S. Kothari has developed an audacious relationship between the old fashioned planets and the now discovered newest heavenly bodies, the white dwarfs*"[4].

Indeed by keeping temperatures low and pressures high, Kothari could simulate conditions inside a planet through pressure ionization. One important conclusion he arrived at was that a "cold body" cannot have radius exceeding that of planet Jupiter[3,5].

Kothari's tenure at the University of Delhi, unfortunately came to an end when, in 1948, he became scientific advisor to the Defence Minister. Like other scientists of repute such as Saha, Bhabha, Bhatnagar, etc., Kothari too left the academic world in favour of an important government appointment. As after achieving independence, the nation needed brains of demonstrated ability to come forward to create the national infrastructure, many intellectuals were so lost by the academia.

Nevertheless, not *all* brains were lost this way. Some continued to work in the universities, and later, in the autonomous research institutes. As mentioned earlier, the emergence of a school of general relativity and gravitation (GRG) came up at the Banaras Hindu University (BHU). Its mentor was my father Vishnu Vasudeva Narlikar (VVN) who had worked in Cambridge under the guidance of A.S. Eddington. VVN was more or less contemporary of Chandra at Cambridge and the two continued to exchange correspondence in the subsequent years.

In the 1940s, Prahlad Chunilal Vaidya, a student of VVN came up with an important exact solution in general relativity. Whereas the classic Schwarzschild solution of 1916 describes the gravitational field of a spherically symmetric, non-radiating mass distribution, the Vaidya solution describes the gravitational field of a radiating mass[6].

At that time VVN sensed that GRG might play a more decisive role in astrophysics than expected hitherto. Nevertheless, to get an expert's assessment he wrote to Chandra to ask if relativists like him should engage themselves in research in relativistic astrophysics. Chandra replied, expressing his view that he did not expect general relativity to be crucial in any part of astrophysics. As a result of this negative assessment VVN as well as Vaidya stayed away from further work in relativistic astrophysics. One can see the logic behind Chandra's assessment through this simple calculation. The dimensionless quantity

$$\alpha = \frac{2GM}{c^2 R} \qquad \ldots(1)$$

describes the gravitational effect of mass M, radius R on the ambient spacetime geometry. For a significant impact of general relativity α needs to approach 1. For white dwarf stars this ratio is $\alpha \sim 10^{-5}$. As believed by most astronomers including Chandra, in the 1940s (–and even a decade later –) more dense objects with higher α lay in the realm of speculation.

We may look upon α in (1) as made up of two quantities: the mass (M) and the average density (ρ) of the stellar size object. Then the condition for general relativity to be important is that

$$\alpha = \left(\frac{32\pi}{3}\right)^{1/3} \frac{GM^{2/3}\rho^{1/3}}{c^2} \sim 1 \qquad \ldots(2)$$

As mentioned earlier, for white dwarfs, $\alpha \sim 10^{-5} - 10^{-4} << 1$. However, in the 1960s two important discoveries led to the raising of α. Neutron stars with densities approaching 10^{15} times that of water became known. These raised α to within the range $10^{-2} - 10^{-1}$. The second discovery was that of quasars which were suspected to have masses as high as 10^{9} solar masses. This possibility also raised α to a value close to unity at comparatively modest densities, thus making the system of significance so general relativity. We

may recall that in his historic controversy with Chandra, Eddington himself had expressed his lack of belief in the existence of what are today known as 'black holes'[7].

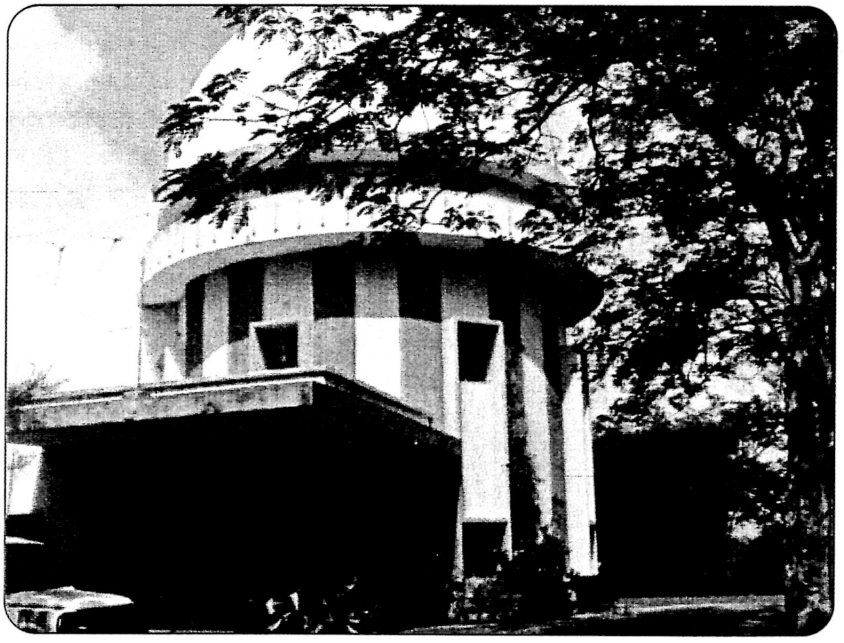
These discoveries showed that two decades earlier Chandra also had erred in grossly under-estimating the impact of general relativity on astrophysics. In 1963 a symposium on the new subject 'Relativistic Astrophysics' had been held in Dallas, Texas and it launched several investigations in general relativity of relevance to astrophysics. Chandra did not attend the meeting since, because of racial problems still existing in the South he avoided travelling to the southern states. Ironically, however, later he made significant contributions to this interdisciplinary field.

3. Alumni of Osmania University

In a personal recollection to this author, VVN had mentioned the offer sent through him to Chandra by Professor S. Radhakrishnan, Vice-Chancellor of BHU in the 1940s. The offer was an invitation to head an observatory, and the associated astronomical research, at a handsome salary. The telescope itself was promised by the industrialist Birla family. Chandra declined the offer with thanks. His reservations, as expressed to VVN were largely to do with the lack of an assurance that the autonomy promised by Dr. Radhakrishnan would continue after he left the position of the V.C. This was a valid fear, since India has seen several instances of individuals after attaining important positions like that of a V. C., disowning the promises made by their predecessors. Chandra was also afraid of the disruption in his own research brought upon by the administrative and infrastructural issues of running an observatory.

Nevertheless in his capacity as a distinguished visitor, Chandra played a constructive role in India. In my correspondence with Professor Saleh Mohammed Alladin, who retired from the Astronomy Department of Osmania University, Hyderabad, Dr Alladin recalled attending a graduate course on general relativity given by Chandra in 1959 in the Physics Department of the University of Chicago. While stating that Chandrasekhar's lectures were lucid and provided a good background of the subject, Alladin mentions *'Professor Chandrasekhar used to emphasize that mathematical work should not only be correct but should also be elegantly expressed'*. Those of us who have read Chandra's book reassessing Newton's Principia, will have seen echoes of this sentiment there too.

Alladin recalls that he was due to be interviewed for a post at Osmania University in 1964 on the same day that Chandra was to visit the University. Between lunch and tea arranged by the University in honour of Chandra, Alladin's interview for the post had been scheduled. However, no interview took place and when the tea party began, the Vice-Chancellor called Alladin and asked him to join the party. He was introduced to the experts invited to interview him. However, at the end of the party the V.C. congratulated him for his selection, without an interview! Alladin feels that Chandra may have been consulted and spoken in his favour.



Rangapur Observatory of Osmania University (Photo courtesy Dr. S. N. Hasan)

This episode tells of the flexibility still existing in the university system which enabled a Vice-Chancellor to make an appointment based on recommendation but no interview. Flexibility can be used both ways: to corrupt a system or to invigorate it. Alladin's work on merging galaxies, which he started as a graduate student of D. Nelson Limber - himself a former student of Chandra - later fructified in a lot of very interesting work on

dynamics of galaxies at Osmania University[8]. In today's highly regulated system the Vice-Chancellor is powerless in terms of what he can do to recruit highly qualified staff. The present decline of Osmania University is a classic example of this situation, and presents a sad contrast to the situation described by Alladin in 1964.

While visiting Hyderabad in 1962, Alladin recalls, Chandra also helped another astronomer from Osmania University, K.D. Abhyankar, in selecting the site for the proposed Rangapur Observatory. Abhyankar's own work on radiative transfer was considerably influenced by the discussions he had with Chandra during this visit[9].

4. Indian Graduate Students

Chandra had two graduate students from India who later returned home and continued their research there. They were (the late) S.K. Trehan and Bimla Buti, both working in the area of plasma oscillations, two stream instability, etc. Trehan worked in the Applied Mathematics Department of Punjab University, Chandigarh whereas Buti joined the Physical Research Laboratory, Ahmedabad. At the time of writing Trehan is no more. (*A photograph of Late Prof. S.K. Trehan appears here, Prof. Buti's article and photo appear elsewhere in this issue. Ed.*)

Buti mentions that at the time of her tenure as graduate student at Chicago University the research publications belonging to the Ph.D. thesis had to be single authored, written by the student, only. So all her thesis publications are under her name only[10-12].

As the only surviving member from India who worked under Chandra's



Prof. S. K. Trehan (1931-2004)

guidance, I asked Bimla her impressions of Chandra as a human being. She wrote:

"I was impressed and influenced, directly or indirectly, by some of his following habits and actions:

He was a man of very simple habits.

He himself was an extremely disciplined person and expected discipline around him e.g., from all the students in his class. But he was never harsh.

Without fail, he would visit the library and glance through the latest journals.

He was extremely hard working and thorough not only in scientific work but in all respects. However, he would find time for some other activities like gardening, musical concerts, reading classic novels.

While preparing his manuscripts, he was very particular about the English grammar and even punctuations. He would tell his students to follow this pattern.

He had a terrific memory. At a social gathering, he would narrate stories about his pleasant interactions (scientific and social) with other great scientists like Einstein etc. He would keep everyone busy, for hours, with anecdotes.

I personaly found him a very friendly and affectionate person."

5. From White Dwarfs to Neutron Stars and the Sun

Coming now to a later era, 1960-70, my former colleague at the Tata Institute of Fundamental Research (TIFR), Kumar Chitre has provided useful inputs. His own work was influenced by two of Chandra's interests : stellar structure and hydrodynamic and hydromagnetic stability.

In the 1960s, the problem of determining the limiting mass of a neutron star, like the Chandrasekhar mass limit for white dwarfs posed a challenge to theoreticians. The answer lies in finding the correct equation of state for matter with density approaching ~10^{15} g cm^{-3}, the density expected to be present within the core of a neutron star. S.M. Chitre at TIFR and V. Canuto at CCNY went through the exercise with the solution that the limiting mass is around $2M_{\odot}$[13]. A somewhat different line leading to the same answer was followed by Pandhari Pande in the University of Illinois at Urbana.

Chitre was also guided by Chandra's work on hydrodynamic and hydromagnetic stability to look at the stability of solar models. The spectrum of eigenfrequencies derived numerically by perturbing the solar model could then be compared with the accurately observed acoustic mode oscillation frequencies. This technique helps in arriving at an accurate model of the Sun with a confident prediction of solar neutrino flux emerging from it. The value so obtained agrees very well with that obtained from the standard model of the Sun. So one was led to the conclusion that the observed deficit of solar neutrino

flux had to come from neutrino physics, e.g., from neutrino oscillations[14,15].

Both these works demonstrate practical applications of ideas Chandra had propagated decades ago.

6. Antonov Instability

Chandra's name and achievement have become textbook material. Even secondary school children in India will have encountered his life story sometime during their school studies. The younger generation therefore views him more in awe as a scientist who had scaled high peaks of excellence than really understanding what exactly he did achieve. His academic interaction with a young working scientist has thus been somewhat rare. The episode described by T. Padmanabhan is therefore of some interest. I quote him almost verbatim in what follows.

"My main academic encounter with Professor S. Chandrasekhar was related to the question of Antonov instability. During my postdoctoral years (1986-87) at Institute of Astronomy, Cambridge, Donald Lynden-Bell got me interested in the study of statistical mechanics of gravitating systems and, in particular, in Antonov instability, first described by Antonov in 1962. His original derivation was quite complicated[16] *and I was trying to understand its physical origin from a simpler point of view from the structure of the equations describing an isothermal sphere.*

Chandrasekhar, in his work [17] in 1939, has discussed how the equations of stellar structure (including the ones describing the isothermal sphere) can be reduced to a first order differential equation by using two variables u, v. The solutions to isothermal sphere equation in these variables is represented as a spiral in the uv plane. I realized the key dimensionless parameter $q = RE/GM^2$ - where R is the radius, M is the mass and E is the energy - which describes the Antonov instability can also be expressed in terms of these variables. In fact, I found that q = constant curves are straight lines in the uv plane! Any solution with a fixed value of q is given by the intersection of two curves (one spiral and one straight line) in the uv plane. The condition that these lines have to intersect immediately leads to the condition for Antonov instability. This is shown in figure 4.2 page 316 of my review [18]. I was surprised that Chandrasekhar, in his ref., did not bother to plot lines of constant RE/GM^2 in a corresponding figure. If he had done that he would have discovered Antonov instability nearly 25 years before Antonov!

I was happy to get this simpler derivation but wanted to know whether Chandra had some thoughts on this matter. I wrote him a letter around 1990 when I was working on my review and asked him about it. He sent me a polite reply saying that as the matter refers to something which he did nearly 50 years back he cannot quite recollect what his thoughts were when he performed this analysis. Later on, when I met him at IUCAA, I had attempted to discuss this problem with him. He told me that he likes to work in an area for some time and then move on but almost never re-visits that topic. In fact, he was not very keen to know the details of my derivation. It was an interesting approach to physics in the sense that he almost showed certain amount of reluctance to discuss/revisit the problem he has pioneered, once he has moved on."

This is the aspect of Chandra that I had hinted at earlier in this presentation: that once he made a transition from one major topic to another and written a monograph on the work just completed, the topic became a `closed book' for him.



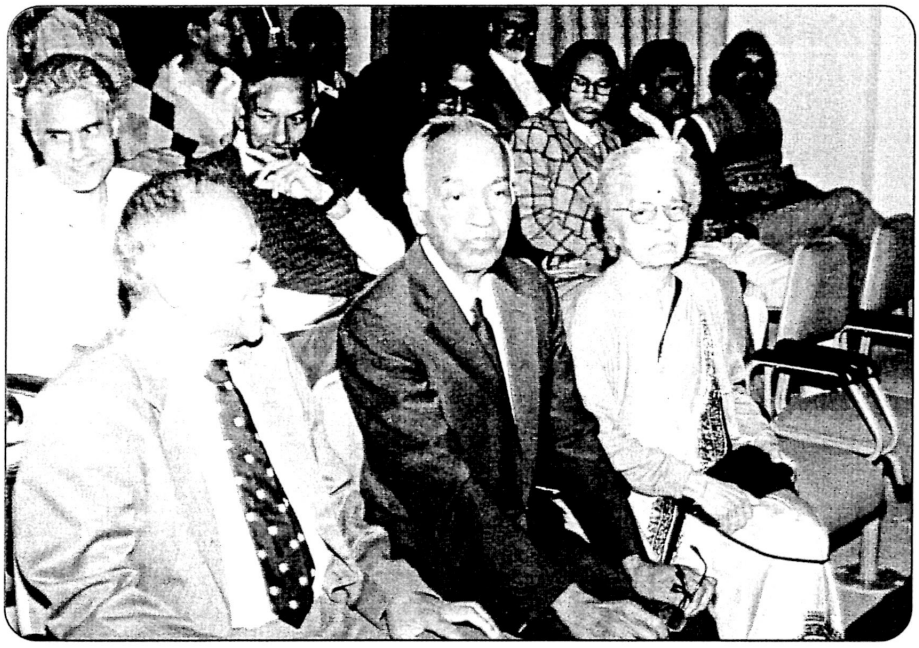
Chandra with the author and Prof. Cowsik (2nd from L)
(courtesy TIFR archives)

7. Concluding Remarks

In a moving account sent as a letter to me, Ramnath Cowsik has narrated his various encounters with Chandra. It becomes interesting in the present context because it throws light on Chandra's attitude to science and other intellectual pursuits as expressed before Indian students. I mention a few instances next.

At a radio interview in Mumbai Cowsik asked him a question, that he said, had been prompted by many students : "How does a student prepare for a career in Physics? Should he first have a serious study of theoretical physics or should he learn experimental techniques?.." Chandra answered this question in his inimitable way: "Different students depending upon their temperament and preparation approach physics in their own unique ways. Each of these is as valid as any other. But what is important is they dedicate themselves to academic life. It does not matter through which gate that one enters a garden. Once you are in, you may wander enjoying a bloom here or a bough there".

The dedication ceremony of my centre IUCAA (Inter-University Centre for Astronomy and Astrophysics) was highlighted by Chandra's talk entitled *The Series Paintings of Claude Monet and the Landscape of General Relativity*. That was in 1992 December. Cowsik recalls a seminar Chandra gave at the Indian Institute of Astrophysics, entitled "On the oscillations of a star as a problem in the scattering of gravitational waves". In both lectures he showed how to map one problem into another and thereby from the second obtain an elegant solution to the first problem.



Professor & Mrs. Chandrasekhar with the author at the Dedication ceremony of IUCAA (courtesy IUCAA)

Finally, I end with an account of my first meeting with Chandra. In 1960 when I was in the final stages of completing the Mathematical Tripos Examination at Cambridge, my father wrote to Chandra to explore the possibility of my becoming his research student. Chandra replied that he was in the process of changing his field of research and in this transitional phase he did not intend taking a new research scholar. So I missed the chance of being Chandra's pupil. But I continued at Cambridge as student of Fred Hoyle.

In 1962 I attended the International Conference on General Relativity and Gravitation held near Warsaw. On the first morning I took a stroll before breakfast in the vast well laid gardens of the Polish country house where I was staying. There I met a senior gentleman in a dark suit, evidently from the Indian subcontinent. He smiled and introduced himself. I reciprocated, although my face may have shown some surprise as to what a mathematical astrophysicist was doing at a relativity conference. For Chandra volunteered the information: "I have decided to work in the field of general relativity. What better place than an international conference, to get to know the areas where intellectual challenges exist? So I have come as a student to learn."

At early fifties, as I estimated Chandra's age to be, most scientists begin to taper down their research. Here was someone entering a new field with the enthusiasm of a twenty-odd year old. It is this attitude that I, as a twenty-four year old, felt the need to copy.

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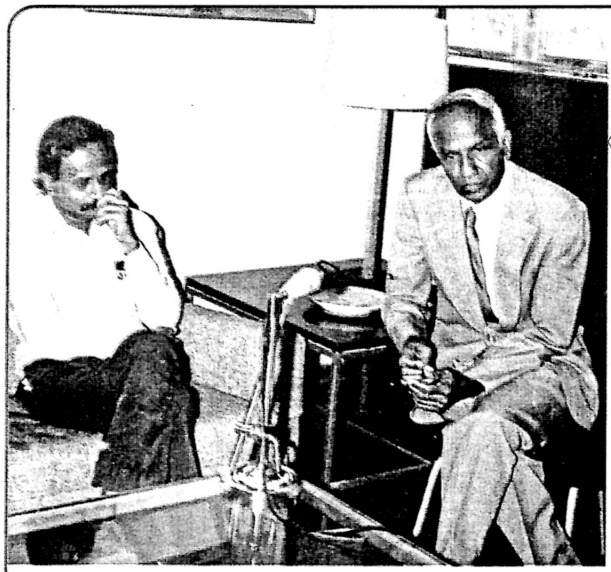

Chandra with Dr. V.S. Venkata Vardhan, former Director, during his visit to Nehru Planetarium (courtesy Suhas Naik-Satam, Nehru Planetarium)



Chandra with wife Lalitha at TIFR Lawn, Courtesy : TIFR Archives



Chandra with Prof. Narlikar and Prof. Ajit Kembhavi at IUCAA (courtesy : IUCAA)