B. V. Sreekantan (1925–2019)

The new face of India after independence could be seen not only in dams and industries, but it was also apparent in the experiments in fundamental research undertaken with zeal by its youngsters. One of those youngsters was B. V. Sreekantan who passed away on 27 October 2019 at the ripe age of 95 years. He pioneered experiments in three fields: (1) Cosmic ray interactions and extensive air showers; (2) Underground muon and neutrino experiments; and (3) High energy astrophysics experiments. His experiments of those times are interesting for several reasons: (a) These are pioneering efforts of an individual as also of a new institution looking for new ways and means in research. (b) These would set up the roads to be travelled by the next generation of researchers. (c) The ingenuity in the face of scarcity of science instruments was very important in a newly independent and not an affluent country.

Badanaval Venkatasubba Sreekantan was born into an erudite family in Nanjanagudu, a temple town 20 km from the historic city of Mysore (Badanaval, near Nanjanagudu, is famous for Khadi and Gramodyog Centre established in 1927 by Gandhiji). Sreekantan's father B. V. Pundit (1887–1975) was the legendary Ayurvedic physician and entrepreneur of indigenous Indian medicine. He started Sadvaidyashala, a pharmacy and a research centre; one of its products – the tooth powder – was so famous throughout the state that the train from Mysore to Nanjanagudu was known as the Toothpowder express. Sri Pundit was also well known for his philanthropy and was looked up to as an elder statesman of the town. Pundit and Smt Lakshmidevamma had eleven children: eight boys and three girls. Sreekantan was the fifth child and was born on 30 June 1925. Sreekantan's remarkable equitable temperament as we will see is probably a legacy of life in a joint family. All the boys in the Pundit family were well educated and pursued interesting careers later on in life. Thus the young Sreekantan was exposed to an atmosphere of learning from an early age: 'it was those books, which raised these fundamental questions about philosophy, about matter, what is life.' All the brothers would get together and discuss everything under the sun. Since they indeed had a round table around which these discussions were held, these were termed as Round table conferences of the Pundit household.

Sreekantan's initial schooling was done in Nanjanagudu and later left for the nearby Mysore to continue his studies. Sreekantan did his intermediate in the Yuvaraja's college in 1942–1944 where '...we got very good training in many things – in handling instruments

and all the types of chemicals. Laboratory practices were very good in those days.' Later he went to Bangalore to continue his studies in the Central College which had illustrious alumni and had developed good departments and where C. V. Raman had given a detailed lecture on his Nobel winning work in March 1928. Sreekantan was in Bangalore as a student for 4 years starting from 1944 and took electronics as the special subject in M Sc. Immediately after his M Sc Sreekantan joined the Communication Engineering Department of IISc in August 1947 where he learnt considerable amount of electronics under Chatterjee, the head of the department. However, his interest was still in physics and a new chapter opened up in Sreekantan's life when Homi Bhabha beckoned him away from Bangalore to the shores of the Arabian Sea.

It is well known how Homi Jahangir Bhabha, who studied in England in 1920s and wrote seminal papers on several aspects of Cosmic ray and particle physics, came back to India and started Tata Institute of Fundamental Research (TIFR) in 1945 on the lines of the best institutions of the West. In the initial years he recruited several bright young men who went on to eventually lead activities in their respective disciplines in the country. One of those was this young man from Mysore who did well in the interviews and took up experimental work based on Bhabha's suggestion. One of the premier areas of research at that time was experimental particle physics and Cosmic Rays provided various types of particles in plenty. Among all the particles at that time (~1950), the most interesting was the muon, which was part of the hard component of secondary cosmic rays and which could penetrate large amounts of matter, but had seemingly no role in the scheme of particles.

Sreekantan's first experiment was to find the lifetime of muons and he decided to use GM counters for their detection. It also required building of pulse electronics, triggered cathode ray tube, coincidence circuits, etc. with better than microsecond capability. There was a picaresque element in locating these war surplus components – valves, resistors, condensers, oscilloscope tubes, etc. – since they were available only in the dangerous areas of the city. And once they got them 'we could play with the electronics and that is how we learnt electronics ourselves'. The GM counter production also started in parallel. The experiment was considered as one of the most sophisticated cosmic ray experiments of that time. Sreekantan from this experiment derived the life-time of positive muons to be 2.24 ± 0.15 microsecond which can be compared with modern value of 2.197083 ± 0.000015 microseconds.

The famous underground experiments of TIFR in the field of muons and neutrinos were started when Bhabha suggested working in the mines to see whether there are any new type of particles. In 1951 Sreekantan and S. Naranan (and later P. V. Ramanamurthy) did measurements of intensity of particles at different depths and different angles using GM counter trays. Sreekantan analysed this data by 1953 and submitted his Ph D thesis to Mumbai University on the intensity and angular distribution of muons at different depths in KGF. Bhabha was his guide and the renowned Cosmic Ray physicist Bruno Rossi of MIT was the external examiner. The recommendation of the examiners said '...the experiments appear to be well conceived, carefully executed and intelligently analyzed…'.

A new series of TIFR experiments in 1961 by Miyake, V. S. Narasimham and P. V. Ramanamurthy (MNR) showed that the muon intensity declined rapidly with increasing depth and at 2760 m deep there were no counts at all even with an exposure of nearly two months. Thus it was realized that the deep mines in KGF with very minimal background was the right place to search for atmospheric neutrinos. The atmospheric neutrino experiment at KGF was conducted by groups from TIFR, Durham University (UK) and Osaka City University (Japan). The first atmospheric neutrino event was recorded in the first month (April 1965) itself and at the end of the experiment 18 events were identified as products of neutrino interactions. The results of this path-breaking experiment were received very well by the community.

KGF mines was used again in the 1980s for another important experiment: to look for the proton decay. The Grand Unified Theory (GUT) proposed at that time implied the decay of protons. Therefore, search for proton decay started in the mines at KGF where the decay mode looked for was into a positron and a pie zero meson. The TIFR group, along with the Osaka City University group, set up a two-phase experiment with many layers of proportional counters at depths of 2.3 and 2.0 km. However, after many years of operation, this experiment, as some other experiments elsewhere, did not record any proton decays.

It is interesting to listen to Sreekantan about the importance of instruments: 'Without instrumentation it is impossible to do any fundamental research and this has become obvious in the last century or so. The more sophisticated instrument that you have, the higher the quality of research that you can do. In fact, compared to other institutions in India the reason TIFR stood out in the earlier days was essentially because it was able to develop these instruments in all the fields.'

Sreekantan visited USA twice for extended periods. The first was when Bhabha asked him to spend some time in various other laboratories. On both occasions he visited Bruno Rossi's group at MIT. First time it was to work on particle physics like the properties of *K* mesons. During that visit he also saw the Air Shower experiments being conducted there. It is important to note that his first visit was of great significance in Sreekantan's life in that it gave him enormous confidence. Apart from being proud of the experimental activities in India, this stay instilled in him the courage to conduct front line experiments at par with the West. Thus this visit was important from the view of Indian science as it spurred Sreekantan to start various experimental activities like studies of extensive air showers, X-ray astronomy, etc.

While particles like pions, muons, kaons etc were discovered at first in cosmic ray experiments, the detailed study of particles shifted to accelerators in the 1950s. However, cosmic ray interactions also were of much higher energy which gave rise to the possibility of finding higher mass particles and other interesting phenomena. These were termed High Energy interaction studies. In the 1930s it had also been observed by Rossi and others that a extensive group of particles arrived simultaneously upon detectors. These were studied in detail later by British and French physicists and this phenomenon came to be known as Extensive Air Showers (EAS). The beautiful hill station of Ooty (~2.3 km asl) in Tamil Nadu was chosen by Bhabha and Sreekantan for the studies of both High Energy Interactions and Extensive Air Showers.

Work on High Energy Physics had started in TIFR from the early days itself with emulsion stacks by R. R. Daniel, Yash Pal, Bernard Peters, M. G. K. Menon, D. Lal and others. The highlight of the work at Ooty was innovative instrumentation. TASS, a total absorption spectrometer, was built with alternate layers of iron and scintillators, to determine the energy of the cosmic ray particle impinging on the instrument. It should be noted that this was the forerunner of the ubiquitous calorimeter present in all HEP experiments today. A Cerenkov counter was also built to differentiate between different types of hadrons. Added to all this was the big multiplate cloud chamber, the largest of its kind in the world at that time. Sreekantan himself had worked on a spark chamber for some time. A combination of all these instruments was used to study the characteristics of hadrons.

Sreekantan had seen EAS arrays by MIT when he was in USA and similar arrays of plastic scintillators (made at BARC) were set up in both Ooty and KGF. New electronic circuits (chronotron) for nanosecond phenomena were built to determine the arrival direction of the EAS. Another novelty was the use of Monte Carlo calculations. TIFR group was one of the first to set up the code for these calculations which were to be repeated later in many Cosmic Ray experiments. Apart from the many plastic scintillators, muon detectors were also set up. Important results were obtained at Ooty on the characteristics of hadrons at much higher energies than was available those days at accelerators. Similar EAS experiments at KGF with detectors underground showed that the primary Cosmic rays were probably getting lighter at >10**(15) eV.

Early 1960s saw the birth of two major activities in astronomy, both connected with high energy phenomena; the discovery of quasars and of X-ray astronomy. Bruno Rossi, who had worked mostly on particle aspects, started looking up at the sky for his future research. Rossi and others set up a simple payload consisting of GM counters in a rocket to look at possible X-rays from the moon but accidentally found the strongest X-ray source Sco X-1. This marked the birth of X-ray astronomy and the field was perceived as the next step for cosmic ray physicists. Sreekantan who had gone to MIT around that time also played a major role in identifying the source. So when he returned he realized that studies of hard X rays (>30 KeV) could be done in India with balloons and the observations would be of longer duration compared to rockets. Balloon activity was already a big effort in TIFR with contributions from Gokhale, M. G. K. Menon, R. R. Daniel, S. V. Damle and others. Balloons for X-ray astronomy were imported and youngsters like G. S. Agrawal and Manchanda joined these efforts in the initial stages itself. In a very short time they were able to launch experiments in hard X-ray astronomy and were also very successful; first successful balloon-borne experiment was conducted in April 1968 followed by another in December 1968. X-rays of >20 KeV were clearly seen from Sco X-1. Later Sreekantan and Naranan started rocket X-ray astronomy programme in 1970 and got interesting results from the payload on the first satellite (*Aryabhata*) itself.

Cerenkov radiation produced in the Earth's atmosphere by Cosmic Ray particles was discovered in 1953 using a simple mirror and a photo multiplier by Jelley and Galbraith. The possibility of

Gamma ray emission from celestial sources was proposed by Philip Morrison in 1958 and Giuseppe Cocconi in 1959 suggested the use of the Atmospheric Cerenkov Technique (ACT) for detecting these gamma rays. While Gamma ray astronomy started out at that time as a method to study the problem of cosmic ray origin, today it has been recognized as an extension of traditional astronomy to high energies.

The TIFR group used two parabolic (searchlight) mirrors at a place outside Ooty in 1968 and looked for emission from several pulsars. While this was naive, the amount of enthusiasm with which this work was done continued and future studies were done with a eighteen mirror array. In 1982, the first international workshop on Very High Energy Gamma ray astronomy was held in Ooty and there were only four or five groups in the field. Later there were several efforts to increase the *S*/*N* ratio in the Ooty efforts and varied types of analyses showed significant transient emission from Crab pulsar and possible Gamma ray emission from the Geminga pulsar. The TIFR group had to move away from Ooty because of a large increase in the amount of ambient light and continuous cloudy weather. I accompanied Sreekantan and Ramanamurthy when the group was invited by the MP government to check out Pachmarhi where we eventually got a 10 acre plot with a big ground and living space. It is interesting to note that Sreekantan was involved when all these hill stations – Ooty, Pachmarhi, Gulmarg, Hanle – were selected for Cosmic Ray/Gamma Ray research.

At energies higher than 10**(14) eV, Ultra High Energy (UHE) Gamma rays are studied using the EAS technique where the arrival direction of the shower can be determined. TIFR had two EAS arrays, one at Ooty and the other at KGF. Reports of possible detection of UHE gamma rays from Cygnus X-3, a celestial source always in news at that time, triggered this field in early 1980s. Sreekantan urged that the array at KGF be rejigged for purposes of UHE gamma ray astronomy. Both arrays collected lot of data for years but did not find any gamma ray source, a similar result obtained by several experiments elsewhere. However, the KGF array did detect an interesting burst from the direction of the Crab nebula.

It is interesting to note that most of the programmes started by Sreekantan became larger with time and some have indeed received Nobel Prizes. The neutrino experiment of KGF was the forerunner for later experiments in Kamiokande (Japan), Homestake mines (USA), SNO (Canada), etc. which saw oscillations in atmospheric neutrinos and solar neutrinos. The number of X-ray sources, from a handful in the 1970s, increased to more than a lakh and importantly have given seminal information of high energy astrophysical processes. Further, India has its own X-ray satellite, ASTROSAT, since 4 years which has observed several sources and given interesting information. The TeV (VHE) Gamma ray programme of TIFR was shifted to Hanle in Ladakh thereby achieving low threshold energy and a new array was built which eventually recorded steady emission from Crab at high significance and also several flares from AGNs. From a lone significant source in the late 1980s, the total number of TeV gamma rays sources today is more than 200. The EAS array at Ooty with 400 + detectors has also given interesting information on solar flares. The high points of high energy physics studies were the discovery of the Top Quark and the Higgs Boson where there was significant Indian participation in both these ventures in instrumentation and analysis. The composition of EAS at

I first met Prof. Sreekantan when I joined National Institute of Advanced Studies (NIAS), Bangalore in 1994. I had been interviewed by him and Ramanna, and was quite surprised to find two well-known scientists who were keen to start a programme in philosophy of science. Although this discipline at NIAS has had a difficult time, Sreekantan continued his incessant attempt to understand philosophy of science from his own unique perspective. The impact of his interest in this field has to be understood in a milieu which had little awareness of the discipline of philosophy of science. There was no programme such as a specialized postgraduate degree in philosophy of science anywhere in India. I remember our first attempts with Sreekantan and some scholars like P. K. Mukhopadhyaya to come up with coursework for a full philosophy of science course. The fact that we failed then and have failed even now to establish a professional degree in philosophy of science today in India is a testament to the struggles that this discipline has had to face in India. Sreekantan's interest in philosophy was largely driven by his fascination with the study of consciousness. He was conversant with traditions of Indian philosophy, particularly Vedanta. His early interest was to find ways of bridging the growing study of consciousness with Indian philosophy since consciousness was a core theme for many of these philosophical traditions. Around this time, the study of consciousness began to grow around the world and the first major journal in consciousness studies was started. This led to a deeper interest in scientific modelling, including using quantum theories, of consciousness from scientists such as Penrose. Much before it became fashionable or politically expedient, Sreekantan and Ramanna had already emphasized the importance of engaging with philosophical traditions such as Vedanta and Buddhist philosophy to understand some aspects of modern science.

In the face of scepticism about such approaches, particularly from the Indian scientific community, what distinguished Sreekantan's approach to his study was his deeply held, unshakeable, belief in the virtues of science and its practices. Whenever I met him, he would talk about some developments in physics which had some bearing on consciousness studies. Till the end, he was the one who, every day, would come to the office first and stay till the evening. Even when he was past ninety, he gave lectures and sat through lectures when students could not be bothered to do so. The spirit of science that was so important to him was this constant openness to learning something new. He was one of the gentlest persons that I have met. I met him for the last time on the last day of my stay at NIAS. It was the only time in 25 years that I heard him speak with a sense of despondence about the state of affairs and how his vision for the study of consciousness had not fructified. But by the time I left his office, he was enthusiastically telling me about new ways of approaching the problem!

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both medium and very high energies is also better understood today. Apart from these individual programmes, increase of interest in experimental research in the country is Sreekantan's lasting legacy. (The Indian physicists who worked in various projects with Sreekantan at different times were S. Naranan, M. G. K. Menon, P. V. Ramanmurthy, A. Subramanian, S. Lal, S. D. Verma, G. T. Murthy, B. K. Chatterjee, M. V. S. Rao, V. S. Narasimham, T. N. Rangasamy, S. V. Damle, R. Cowsik, P. C. Agrawal, S. C. Tonwar, R. H. Vatcha, K. Sivaprasad, P. R. Vishwanath, M. R. Krishnaswamy, R. K. Manchanda, P. N. Bhat, N. K. Mondal, B. S. Acharya, Srikantarao, S. K. Gupta, S. Sinha, H. Adarkar, S. Dugad, P. K. Kunte, K. P. Singh, A. R. Rao and others.)

After Homi Bhabha and M. G. K. Menon, Sreekantan became the director of TIFR in 1975 and held this position for the next 12 years. He was responsible for starting new activities like the Giant Meter Wave Radio Telescope (GMRT) in Pune, National Centre for Biological Sciences (NCBS) in Bangalore, Homi Bhabha Centre for Science Education (HBCSE) in Mumbai, etc. The pelletron facility also started during his directorship. At that time, Sreekantan had expressed his thanks to Sri J. R. D. Tata and M. G. K. Menon for their cooperation in completing many of these projects. He was known to give a patient hearing to innovative research proposals. He had very good rapport with the employees. He was well respected for his leadership and liked for the fact that he could be approached at all times. His kindness was legendary. He was also the Chairman of the Governing Council of Indian Institute of Astrophysics (IIA) for several years where he initiated several new programmes.

He was Srinivasa Ramanujan Professor during 1987–92. He received a number of professional awards including the R. D. Birla Award of the Indian Physics Association and the *Padma Bhushan*. After moving to Bangalore in 1992, he joined the National Institute of Advanced Studies (NIAS,) where he started scientific and philosophical studies on consciousness and exploration of commonalities and similarities in holistic approaches in modern science and ancient philosophies.

Sreekantan was married to Ratna, a gracious lady and a connoisseur of Karnatak music; she predeceased her husband by 13 years. Sreekantan leaves behind two sons – Venkatesh, a physicist and Ramesh, a mathematician.

The first time I saw Sreekantan I was a wide eyed teenager interested in physics and he told me about the books I should read; The last time I saw him was two months before his death when he could not speak at all. However, he did talk to me a lot in the last few years when I was writing his biography. Till the last few days in his life, he used to go every day at 9 in the morning to NIAS and would return by 5 in the evening. I would meet him at his house in the evening and we discussed physics but his life too. Both his long term and short term memories were superb and he was always up to date about the latest happenings in science. He told me of his early life when he used to play tennis and represented the college in Mysore and later in Bangalore and his interests ranged from Shankara to Marx. During the Quit India movement, he took part in political activity and even flirted with communism. It was very natural that he was drawn to a subject like consciousness when he started working in NIAS after his stint in TIFR. Here was, of course, a pioneering experimenter; but he was also an interesting and a very kind human being.

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