Guruswamy Rajasekaran (1936–2023)

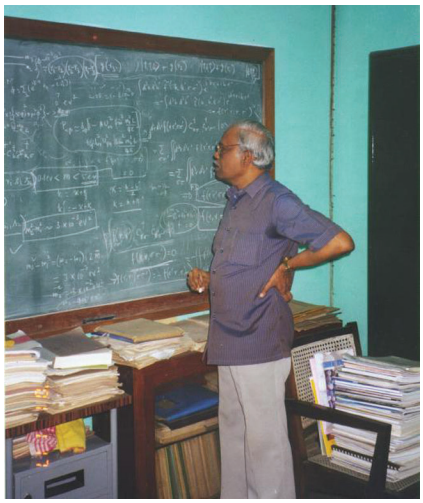
Professor Guruswamy Rajasekaran, doyen of particle physics in India, passed away on 29 May 2023. The end was swift and painless. He was active till the last day. One of us (MVN) met him just a few days earlier when he discussed in detail the issue of the nature of the neutrino – whether it is its own anti-particle or not. The location was his newly rebuilt home which stood where the old one was. He enthusiastically gave a tour around the house, explaining its salient features. He planned to invite all his colleagues from the Institute of Mathematical Sciences for a get-together in his new home. He was many things – a researcher, mentor, teacher and science popularizer. With his passing, India's community of scientists, especially particle physicists, have lost their most respected voice.

Education

Rajaji, as he was affectionately called, was the first of 10 children born in 1936 in a small town, Kamuthi, near Madurai in Tamil Nadu. His parents had modest means (his father owned a brass vessel shop). He went to Kshatriya Nadar school in Kamuthi up to fourth standard and then to Board High School till eleventh standard. Throughout, he had many excellent and inspiring teachers, but his high school years were marked by an absence of teachers for science. Rajaji was self-taught in Mathematics (only Arithmetic was taught in school). Nevertheless, he was at the top of the class throughout his schooling. He went on to higher education with encouragement from his father, though the family wanted him to continue in business.

Higher education was a problem due to a lack of finances. Rajaji got a loan scholarship from the Nadar Mahajana Sangam and also the merit-cum-means scholarship of the Madras state government to pursue intermediate at The American College in Madurai in 1952. Here he experienced watching the night sky through the telescope. He read Eddington's *Expanding Universe* and Gamow's *Life and Death of the Sun* in the well-equipped library in the college. He wrote his first article, *Mysterious Universe*, for the college magazine. By the end of intermediate in 1954, he had decided to pursue physics, having done very well in the exams.

Rajaji moved to Madras to pursue his undergraduate education at the Madras Christian College (MCC). Initially, he was admitted to mathematics honours, which he did not like, but by sheer luck, a seat opened in Physics honours, which Rajaji took gladly. He was taught by an excellent faculty; he especially mentions M. A. Thangaraj, the only Ph.D. among his teachers, fondly. While at the MCC, he had the opportunity to meet many scientists from the Tata Institute of Fundamental Research (TIFR) who were conducting cosmic ray balloon



experiments on the campus. Many of them – M. G. K. Menon, Bernard Peters, etc. – also gave lectures to students. Rajaji was inspired to apply for the Atomic Energy Establishment Training School (which later became the BARC training school).

Training School

The training school was Homi Bhabha's great idea to develop the human resources needed for the Atomic Energy programme. The one-year programme started in 1957 with about 150 students. Rajaji topped the first batch by a wide margin in 1958. Much later, he received a gold medal from Prime Minister Manmohan Singh during the golden jubilee of the training school in 2007. This allowed him to choose between TIFR or AEET (later called BARC). He chose to join TIFR to pursue his research in Theoretical Physics. The first three years, 1958–1961, in TIFR were spent diving deep into quantum mechanics, the physics of hypernuclei, and the quantum theory of radiation. An event that impacted his learning was the Bangalore Summer School in 1961, where Murray Gellmann and Richard Dalitz were the lecturers. The former talked about the 'Eight-fold way', where proton, neutron and other baryons span an octet representation of the group SU(3). Rajaji remembers the persistent question from Dalitz about the fundamental representation of SU(3), which should have only three states. There was no answer from Gellmann. Rajaji felt that if he had answered, the idea of quarks would have originated in Bangalore. Furthermore, if he or other participants had pondered over the question, it would have been a major Indian discovery, and hence he considered it a missed opportunity.

As was the custom in TIFR in those days, and on the suggestion of Menon, Rajaji was packed off in 1961 to do his Ph.D. in the University of Chicago. He did his thesis work with Richard Dalitz at the University of Chicago while attending lectures by many department luminaries, including Fermi, Telegdi and Chandrasekhar. He spent a year at Oxford University before returning to TIFR in 1964. When he returned to Bombay, he had not yet got his Ph.D. – his defense was conducted by post, after which the University of Chicago awarded him the degree!

Immediately after his return, he married Suthandra Devi in 1965. His daughters Poongodhai and Uma were born in 1966 and 1972 respectively.

University of Madras

Rajaji moved to the University of Madras in 1976, primarily to be in a place with a large number of students as well as to be closer home to his roots though the immediate provocation was the anti-Madrasi sentiment growing in Bombay at that time. The university made every effort to match his emoluments at TIFR. The Department of Theoretical Physics was already a well-established department with active faculty headed by P. M. Mathews. With the addition of Rajaji, the Department of Theoretical Physics at Madras University became one of the best places to do theoretical physics in India. This was despite the fact that there was no additional funding for faculty beyond the bare salary, unlike in TIFR, where every conceivable facility was available. The department, which was a pure research department, also started an M.Sc. course around this time. Rajaji brought a project called 'Gauge Theory', funded by the University Grants Commission (UGC), using which he created an active research

group including many post-docs and students along with other faculty.

The Institute of Mathematical Sciences

In 1983, the Founder Director of the Institute of Mathematical Sciences (IMSc), Alladi Ramakrishnan, retired. The Institute was small at that time when the Department of Atomic Energy stepped in to expand the activities of IMSc. In 1984, Rajaji was appointed as the Joint Director of the Institute, vested with the full powers of the Director when the newly appointed Director, E. C. G. Sudarshan, was not in station. He was initially reluctant to accept the offer but was persuaded by Raja Ramanna, who was then the Minister for Science and Technology. In the first five years, Rajaji built a strong physics group, hiring a young group of researchers from institutions worldwide. To attract good faculty, he also needed to improve the infrastructure. Through his efforts, the institute was granted the land across the street where the hostel and guest house now stands. The salary structure was not competitive. Rajaji worked to bring this on par with other research institutes in India. However, the power structure was not ideal, leading to serious misunderstandings and problems with the Director. The resulting turbulence left a permanent scar in Rajaji's mind as he faced the brunt of the problems in the late 80s. Things soon normalized after R. Ramachandran took over as the Director in 1990. Rajaji continued his research work in peace until his retirement in 2001 and beyond. He remained Professor Emeritus till his last day at IMSc.

The turbulent period of the late 80s at IMSc also saw many faculty leaving the Institute. The distinguished mathematician, C. S. Seshadri, who had helped grow the Mathematics and Computer Science groups at IMSc along with Rajaji, also left along with some of his proteges to found the new Institute for Mathematics, which later became Chennai Mathematical Institute (CMI). In the first decade of the millennium, Rajaji helped Seshadri create a physics school at CMI. Along with R. Balasubramanian, he initially encouraged many IMSc faculty to teach at CMI. The synergy created by Rajaji, Seshadri, and others between IMSc and CMI continues to this day.

Neutrino Observatory (INO)

The closure of KGF underground laboratory was a setback for the pioneering cosmic-ray experiments deep underground. Rajaji was one of those who strongly believed that this pioneering effort should be continued and revitalized. He strongly supported the proposal in 2000 to set up the India-based Neutrino Observatory (INO), which would house the world's most massive magnetized iron detector. Rajaji contributed to defining the physics goals of such a detector, mainly by studying naturally occurring atmospheric neutrinos. This would become his life's mission in the last 25 years. Despite his age and condition of health, Rajaji travelled widely, canvassing for the project with people from the scientific community, politicians, administrators and the general public. Rajaji was involved with the site selection and worked vigorously for this very ambitious project, although, unfortunately, it has still not seen the light of day.

Teaching and outreach

Throughout his life, Rajaji has been an exemplary teacher who did not hesitate to teach at any level – from school students to advanced researchers and teachers. His move from TIFR to the University of Madras reflected this attitude. The absence of graduate training programmes in high energy physics (HEP) was felt by all researchers and students in the 70s and 80s. To overcome this lacuna, the Department of Science and Technology started a two-week long programme of intense teaching of basics as well as recent advances in HEP beginning in the 80s. These schools came to be known as SERC schools.

N. Mukunda took charge of these schools in the first five years, followed by Rajaji in the next five years. He gave a course in almost all of these highly successful schools. These SERC-HEP schools continue to operate successfully to this day.

Rajaji lectured extensively about science, particularly INO, in English and Tamil. He started writing regularly in Tamil about science for a monthly magazine edited by Jeyapragasam from Madurai. Two volumes of his collected articles in Tamil have also been brought out. He was also the inspiration behind the 'Sunday School', started by S. V. M. Satyanarayana, in which any student of physics could come and learn physics from stalwart teachers. Students came from all over Tamil Nadu, many of whom have become excellent researchers in their own right. This school celebrated twenty-five years recently and still continues. Encouraged by the success of a similar effort in Mathematics, Rajaji encouraged the setting up 'Physics Training and Talent Search' (PTTS) to identify exceptionally talented physics students and train them towards research. Both these programmes have achieved success in recent years.

Research work

Rajaji was active in research for over six decades. He has significant contributions in a wide range of areas – hypernuclear physics, flavour physics, current algebra, neutral current weak interactions, integer quark model, string theory, new forms of quantum statistics, neutrino physics, dark matter, etc. He has published more than 200 research papers. He was always keen to enlarge his sphere of activity and influence over the development of HEP in the country – a true scholar. We highlight some of his important contributions.

In the 60s, Rajaji and Dalitz showed that a multi-channel resonance pole is followed by a retinue of poles on the complex Riemann sheets on the complex energy plane. This answered one of the serious objections of Oakes and Yang against SU(3) flavour symmetry, paving the way for the eventual success of SU(3) flavour symmetry. The core of his thesis was this discovery of what is now known as 'Shadow Poles'. Following this, he worked on the structure of Lambda Λ (1405 MeV), which is an odd-parity excitation of the Lambda Λ (1115 MeV) baryon. The excitation energy is nearly 30% less than in the case of the nucleon odd-parity excitation, and hence it was anomalous. Rajaji pointed out that it could not be a 3-quark bound state and proposed that it should be a molecular bound state of hadrons – a nucleon and kaon. After nearly fifty years, this fact is getting confirmation from QCD lattice gauge theory calculations.

He was among the first to see the tremendous potential of the Weinberg–Salam (W–S) model soon after it was proposed. The model, a precursor to the Standard Model, described the weak and electromagnetic interactions of particles in a unified way. He gave a course of lectures on this electro-weak unified theory at many places. His lectures at the Saha Institute of Nuclear Physics in 1971 were turned into lecture notes, forming the basis for many young researchers to learn the W–S model. This was the first such course in the country, but probably also in the world. Many young physicists benefitted tremendously from these lectures. He was among the

first to get on the Gauge Theory bandwagon, but he could not contribute substantially in the initial stages. One of Rajaji's regrets was that even though he had a 'seat on the front row', he missed out on the 'big stage'. But not for long!

As soon as the neutral current weak interaction, a prediction of the W–S model was discovered at CERN, Rajaji and K. V. L. Sarma presented in 1975 the first model-independent analysis of the data analysing all the constraints. The 'Master Equations', as Sakurai called them, were central to determining neutral current coupling constants when combined with the work of Sakurai and L. M. Sehgal.

Around the same time, Rajaji and Probir Roy constructed a colour gauge theory with integrally charged quarks. They showed that quarks, even if integrally charged, can manifest as fractionally charged particles (which is what we now know them to be) in deep inelastic scattering experiments, a result that was also obtained by Jogesh Pati and Abdus Salam. He worked on the integrally charged quark model well into the 80s with his students T. Jayaraman, Lakshmi Bala and colleague Saurabh Rindani. At that time, the data seemed to indicate that it could be a possibility, but over time it became clear that was not the correct theory. While at the university, he also attempted an ambitious programme of proving the quark confinement with his colleague V. Srinivasan.

The decade of the 80s was somewhat dull by Rajaji's standards since he was fully immersed in rebuilding IMSc. But he encouraged and directed some of us by pointing out important directions in HEP, especially neutrino physics, where extraordinary results were being found, and neutrino mixing and oscillations were discovered. This became a big programme in the 90s when Rajaji, along with Uma Sankar, Mohan Narayan and one of us (MVN), embarked on a complete analysis of all data on neutrino oscillations in a realistic three neutrino-flavour framework. Along with Uma Sankar and Mohan Narayan, he was the first to analyse the null result on neutrino oscillation for the CHOOZ reactor neutrino experiment using the three-flavour framework. The analysis gave an upper bound on one of the neutrino mixing angles. In the first preprint by CHOOZ, they had wrongly concluded that their result contradicted the atmospheric neutrino data since they had used only a two-flavour toy model. This was communicated to the experimenters, who subsequently corrected their preprint without any acknowledgement or reference to the IMSc work! The three-flavour analysis of all phenomena continued into the new millennium, including the day–night effect with solar neutrinos in collaboration with Rahul Sinha. The neutrino production from supernovae and its possible signatures were analysed in collaboration with Indumathi and Murthy. As soon as the idea of INO came up, the sensitivity of the ICAL detector for its physics goals was analysed in collaboration with Indumathi, Murthy and Nita Sinha. With Earnest Ma of the University of California, he constructed the A_4 model of neutrino masses and mixing, which became quite popular due to its simplicity. In collaboration with M. K. Parida and R. Mohapatra, he worked on understanding the differences between neutrino mixing angles and quark mixing angles using the renormalization group evolution.

While the neutrino work was going on in full steam, Rajaji was also involved in a completely different field – new forms of quantum statistics – with A. K. Misra, when there was a renewed interest in these digressions due to fractional statistics playing a role in understanding the Quantum Hall Effect. More recently, he got involved in discussions on Laser Plasma Acceleration (LPA) as he believed that the future of high-energy accelerators lies with LPA.

Rajaji was also quite daring and did not hesitate to speculate or take risks on important issues when required. Since he had already worked on the so-called anomalous Kolar events, when one of us (MVN) asked him if it could be due to dark matter decay, he immediately jumped at the possibility. He knew about these anomalous events since the late 80s and had even tried to explain them unsuccessfully. The details were worked out within a few hours, and the paper was written in a matter of days. Even though it was later realized that the idea could cause problems elsewhere or may even be wrong, it remains a tantalizing possibility. But it highlights his ability and keenness to work on unconventional ideas.

Rajaji

Rajaji did his research, public outreach, institute building in a refreshingly lively, honest way. He was a generous, loving and kind-hearted person who would never say no when help was needed. In the passing away of Rajaji we have lost a colossus who touched the lives of a huge number of people – students, collaborators, friends and family. We will miss him, his boundless enthusiasm and his infinite optimism.

'Yathum Ooray, Yavarum Kelir' (All places are mine and all are my relatives)

– Kaniyan Poongunranar,
around 6 BCE Sangam poetry

Notes

1. The Tamil quotations at the end of the article is taken from the autobiography of Rajaji: Rajasekaran, G., *My Inward Bound Journey*; https://play.google.com/store/books/details?-id=9h-CEAAAQBAJ. It is an extremely readable and delightful narration of Rajaji's life.
2. This article is an expanded version of the tribute to Rajaji that appeared in *The Hindu*; https://www.thehindu.com/sci-tech/science/g-rajasekaran-imsc-physics-teacher-neutrino-observatory/article66940575.ece

D. INDUMATHI
M. V. N. MURTHY*

The Institute of Mathematical Sciences,
CIT Campus,
Chennai 600 113, India
**e-mail: murthymundur@gmail.com*