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K. Srinivasa Rao and his work

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1. Who is K. Srinivasa Rao?

Killampalli Srinivasa Rao is known for his research work in theoretical and mathematical physics. For more than three decades, he was a faculty member of the Institute of Mathematical Sciences (IMSc, also known as Matscience). IMSc started in 1962 in Madras (now known as Chennai), India, with Professor Alladi Ramakrishnan as its Founder Director.

Srinivasa Rao is the author of three and the editor of eight books. He published 57 articles in international journals, and 43 papers in conference proceedings and Indian journals. The bibliography of his books and international journal articles is presented at the end of this article [1–68].

Srinivasa Rao joined IMSc soon after his M.Sc. in Physics from Presidency College, Chennai, in 1964. His Ph.D. thesis, *Studies in Pion Photo-production from Nuclei*, was under the supervision of Professor Alladi Ramakrishnan, and he obtained his degree from the University of Madras in 1972. The same year he was appointed as a Temporary Member and served the Institute until his superannuation, after 30 years service, as a Senior Professor, in November 2002. During this period, he was an Alexander von Humboldt Foundation Fellow at the Institut für Theoretische Kernphysik of the University of Bonn, Germany, for two years (between 1977 and 1982); a Visiting Associate Professor for the academic year 1978–1979 at the Department of Physics of the Rensselaer Polytechnic Institute (RPI), Troy, New York; and for shorter periods of 4 months he held visiting positions at the Departments of Physics of the Catholic University of America, Washington D.C., University of Texas at Austin and Duke University. In the 1990s, he started a research collaboration between IMSc and two of us (GVB and JVdJ) at Ghent University, Belgium. A 4 year project funded by the European Economic Commission, on quantum theory of angular momentum and hypergeometric series was a part of this collaboration.

He and his wife, Geetha Srinivasa Rao—a mathematician and Professor at the Ramanujan Institute for Advanced Study in Mathematics of the University of Madras—have two sons, Aravind and

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Anand. Their first son is at present a Ph.D. student at Cornell University's Department of Chemical Engineering. Their second son has completed his final year exams for the B.E. degree in Computer Science of the University of Madras, at the S.S.N. College of Engineering, Chennai.

Srinivasa Rao's father, Mr. K. Vallabheswar Rao (1899–1983) was an advocate who came to the city of Madras for his postgraduate studies from his native place, Rajahmundry. He settled down there after his law degree and practiced in the High Court and other Courts of Madras. His mother, Lakshmikanthamma (1907–) had only elementary school education but is a well-read scholar in Telugu literature, especially the epics of India, and a diligent story teller. Srinivasa Rao is the youngest of four brothers and two sisters.

2. Srinivasa Rao's work

Srinivasa Rao spent most of his time at research institutes, teaching occasionally. His research work in mathematical sciences has three parts: theoretical nuclear physics, quantum theory of angular momentum and its applications and computational physics.

2.1. Theoretical nuclear physics

Srinivasa Rao's first paper [12] was with Dr. K. Ananthanarayanan, then a Senior Research Fellow at IMSc, who inducted him into the work on neutral pion photo-production from the deuteron using the impulse approximation, Chew–Goldberger–Low–Nambu (CGLN) amplitudes for single-nucleon photo-pion production and the analytic wave functions of Hulthén and Sugawara which included the D-state of the deuteron and a hard core radius for the nucleon–nucleon interaction. The senior researchers at the Institute, Dr. G. Ramachandran and Dr. V. Devanathan had developed the theoretical framework for pion photo-production from complex nuclei, through a series of papers in Nuclear Physics. A couple of Ph.D. students at IMSc used this work for theoretically calculating the differential and total cross sections for light nuclei. The study of $\gamma d \to d\pi^0$ [12] required numerical integration and the two authors of this paper did this on the first computer in the city of Madras at the Fundamental Engineering Research Establishment, an IBM 1620 computer. Around that time Dr. S.C.K. Nair joined the small group of theoretical nuclear physicists at IMSc, after obtaining his Ph.D. from the University of Sussex. Dr. Nair introduced Srinivasa Rao to the particle–hole (p–h) formalism for closed shell nuclei and to the thesis of Dr. V. Gillet which gave the wave functions for magic, doubly closed shell nuclei—^{12}C, ^{16}O, ^{40}Ca and ^{208}Pb. The correspondence that Srinivasa Rao had with his senior, Dr. V. Devanathan (then a postdoc with Prof. M.E. Rose at the University of Virginia) resulted in a collaborative effort for the extended numerical computations for $^{16}\mathrm{O}(\gamma,\pi^+)^{16}\mathrm{N}$, and a comparison with the experimental data from Illinois. In this effort, M. Rho joined with his wave functions from Migdal's theory and the resultant four author paper [14] was the first significant theoretical study of charged pion photo-production from a closed-shell nucleus.

Srinivasa Rao got the impetus now to carry on with his research and spotted problems of interest on his own. The work of G.E. Brown and A.M. Green on muon capture from ^{16}O, using 2p–2h ground state correlations, triggered the idea of studying the effect of the same on positive pion photo-production from ^{16}O [17]. Charged pion photo-production form ^{11}B [13], and from ^{27}Al and ^{51}V [21] were studied using the phenomenological surface production model to simulate the effect of the final state interactions (FSI) of the outgoing pion with the residual nucleus. The chief problem of the photonuclear people had been how to get the giant dipole resonance state theoretically at the required high experimental energy. Taking the cue from the work of G.E. Brown and M. Bolsterli of constructing the state from single-particle excitations, Srinivasa Rao studied the cross sections for positive pion photo-production from ^{16}O to analogues of giant resonance states in [18]. He also made use of the realistic deuteron wave functions of Reid to redo his work on the deuteron [19]. All these and the study of the effect of short-range correlations on positive pion photo-production from ^{16}O, required extensive computations not possible in Madras at that time and Srinivasa Rao did the final numerical work for his Ph.D. thesis during 1969–1970 on the then powerful CDC3600-160A National Computer Facility at the Tata Institute of Fundamental Research in Bombay. His thesis work was completed in the middle of 1970 and he was awarded the Ph.D. degree of the University of Madras in early 1972.

Srinivasa Rao was directed by Professor Alladi Ramakrishnan to go abroad in 1972 to present his work on pion photo-production at an International Conference at Aix-en-Provence, France, in 1972. Soon after his first lecture tour to Saclay, Orsay, Freiburg, CERN—European Organization for Nuclear Research (Genève), Sussex and International Centre for Theoretical Physics (ICTP), Trieste, he was inducted as a Temporary Member into IMSc. The prestigious Alexander von Humboldt Foundation Fellowship enabled him to work at the Institute for Theoretical Nuclear Physics of the University of Bonn, in the group of Prof. K. Bleuler, for 2 years (during 1977–1983). A Visiting Associate Professorship at the RPI, for the academic year 1978–79, gave him an opportunity to teach and to guide a student of Prof. J.S. Levinger, S. Malecki, to study the FSI in photo-production of π^+ from ^9B. He participated, on invitation, in the first (and only) Photo-pion Nuclear Physics Conference at RPI, in a Gordon Photonuclear Conference, at Meriden, New Hampshire, and in a couple of few-body problems in physics conferences, at Quebec and New Delhi, during 1974–1985, besides visiting McGill University, McMaster University (collaboration with Prof. D.W.L. Sprung [24]), the Catholic University of America and Lund Institute of Technology (collaboration in an experiment [31]) for shorter periods.

2.2. Quantum theory of angular momentum (QTAM) and special functions

Srinivasa Rao's interest in QTAM was kindled by a half-a-page article of E. Yakimiw in Journal of Mathematical Physics (J. Math. Phys. 12 (1971) 1134) pointing out that the article of B.M. Minton (J. Math. Phys. 11 (1970) 3061) on a claim of having found a new symmetry for the Racah coefficient was simply wrong due to the violation of triangle inequalities in the published result. Asking for himself and finding the answer [25] as to why the use of the Bailey transformation for a ${}_4F_3(1)$ yielded a dubious result, was the beginning of his research in this area.

In 1984, Prof. E.C.G. Sudarshan took charge as the second Director of IMSc. This coincided with the trend of the shift in interest of many theoretical nuclear physicists in India. Srinivasa Rao too made his transition to the study of QTAM and related hypergeometric series. New results were obtained [28] in which the theory of hypergeometric functions was used to study the intimate connection between the angular momentum coupling (3-j) and re-coupling (6-j) coefficients and sets of hypergeometric functions of unit argument. He realized that *nontrivial* zeros of angular momentum coefficients—recognized by L.C. Biedenharn and J.D. Louck (Encycl. Math. Appl. 8, 9 (1981))—were indeed *polynomial zeros* and went on to classify the zeros of 3-j and 6-j coefficients [38–40,48]. The identification of the 9-j or ℓs-jj transformation coefficient with the highly asymmetric triple sum series and hence the triple hypergeometric function of unit arguments [49] led to the definition and classification of the polynomial zeros of this coefficient [45,60].

The problem of multiplicative Diophantine equations was related to the idea of reciprocal arrays by E.T. Bell (Amer. J. Math. 55 (1933) 50). This intertwining hampered Bell from providing a general induction proof for the main theorem of his regarding the number of parameters obeying certain greatest common divisor conditions for obtaining the complete set of solutions for the homogeneous multiplicative Diophantine equation of degree n, namely, $x_1x_2,\ldots,x_n = u_1u_2,\ldots,u_n$ for $n > 2$. This problem was solved by Srinivasa Rao et al. who reformulated the main theorem of Bell and provided a general induction proof for it by avoiding the use of reciprocal arrays [55]. This fundamental number theoretic result was then used to provide a complete solution to the problem of polynomial zeros of degree 1 of the $3n$-j coefficients of QTAM (see [2], Chapter 6). Srinivasa Rao guided a couple of Ph.D. students (K. Venkatesh and V. Rajeswari) in these topics and he wrote a research monograph with his student collaborator V. Rajeswari [2].

The collaboration between Ghent University and IMSc was due to the overlapping interests in the study of the aforesaid zeros of 6-j coefficients. A visit to Gent by Srinivasa Rao (with his family) in 1991 heralded the beginning of a continuing long, fruitful collaboration. Together they studied the algebra of spherical tensor operators and showed [54] that the structure constants involve 9-j coefficients. In the 1990s, the collaboration was sustained by a 4-year European Commission Project in which an Indian student (Sangita N. Pitre) was guided for her Ph.D. degree of Ghent University by Srinivasa Rao and one of us (JVdJ). In the last decade, the work on QTAM and hypergeometric series was continued to obtain many more new results. In this collaborative effort, it has been shown that from the theory of angular momentum it is possible to derive new results in the theory of summations and transformations of generalized or multiple hypergeometric functions. This has opened up new vistas for research. For instance, a recursive use of a Whipple transformation for a terminating ${}_3F_2(1)$ series was shown to result in a 72-element group associated with the 18 terminating series [53], thus initiating the group theory of hypergeometric series transformations. This work was later extended [64] to a systematic study of invariance groups related to transformation formulas for basic hypergeometric series. More recently, in the same spirit, the 24 Kummer solutions of the Gauss differential equation were related to the symmetries of the cube [65]. Apart from such group theoretical approaches, a number of new transformation and summation formulas for double hypergeometric series were obtained by a judicious study [58,59,61] of the properties of the so-called *stretched* 9-j coefficient and its symmetry properties starting with its triple hypergeometric series representation. One of these new results was independently proved by P.W. Karlsson (J. Phys. A 27 (1994) 6943), and the q-extension of a summation formula for a Kampé de Fériet series was established by G. Gasper (Contemp. Math. 254 (2000) 187).

2.3. *Computational methods*

Srinivasa Rao's interest in computer programming using Fortran in the early part of his career was responsible for writing his first book [1] in 1974. It served as a text book for teaching in colleges in those early years of computers in India. The first computer at IMSc was indeed an IBM-PC/AT, given as a gift by the Alexander von Humboldt Foundation, at the instance of Srinivasa Rao, in 1985.

His realization that the terminating hypergeometric series has the Horner scheme for polynomial evaluation built-in enabled him to write new computer programs for the accurate computation of angular momentum coefficients [29,34,50]. This comprehensive work of Srinivasa Rao in numerical computation has been extensively cited in the text book *Angular Momentum* by W.J. Thompson (John Wiley, 1994). The first parallel algorithm for the numerical computation of angular momentum coefficients has been proposed in [56]. Teaming with Dr. C. Krattenthaler he derived [66] new hypergeometric identities from old ones by the beta integration method, using the computer algebra package HYP and HYP-q, and conducted workshops in Chennai on computer algebra.

3. Some other highlights

Srinivasa Rao's interest in Ramanujan commenced just before the birth centenary of Ramanujan in December 1987. Encouraged by Prof. Sudarshan, the Director of IMSc, he organized at the Institute for Fundamental Studies, Kandy, Sri Lanka, an International Conference on Number Theory in December 1987, as a part of the Ramanujan centenary celebrations. A delegation of seven members including Professors Atle Selberg, Don Zagier, Bruce Berndt, Robert Rankin and Sudarshan took part in this meeting and he spoke for the first time on the Life and Work of Ramanujan. Later, this became one of his favorite seminar topics, culminating in a book *Srinivasa Ramanujan: a Mathematical Genius* [3]. He has lectured on the Life and Work of Ramanujan at many institutions in India and abroad, including the Flemish Royal Academy for Science and the Arts of Belgium, in October 2001. Recently, he started his study [67,68] of the Entries in the Notebooks of Ramanujan, in collaboration with one of us (GVB).

During his stays abroad, he has visited and lectured at several research centers in Austria, Belgium, Canada, England, France, Germany, Iran, Italy, Japan, Mexico, The Netherlands, Sri Lanka, Sweden, Switzerland, USA and Russia, participated and presented his work at more than 25 International Conferences and more than 40 Indian conferences. He convened and conducted an International Conference on Number Theory at Kandy, Sri Lanka, in December 1987; an International Workshop on Special Functions and Differential Equations at IMSc, in January 1997; an International Conference on Special Functions and their Applications, in Lucknow, in February 2001; and an International Conference in Special Functions and their Applications, at IMSc, in September 2002; besides conducting a dozen of conferences in India. For his creation of the so-called *πie Pavilion and the Ramanujan Gallery*, for the Indian Science Congress Exhibition in January 1998, Srinivasa Rao was awarded the *Science Popularization Award* by the Tamil Nadu State Council for Science and Technology for the year 2000. These have been improved upon and installed as the *Ramanujan Gallery* and *Ramanujan Photo Gallery* at the Periyar Science and Technology Center, in Chennai. The same Council also awarded to him the *Mathematical Physics Award*, in February 2001, for the year 2000. He is an elected Fellow of the National Academy of Sciences of India and an elected Fellow of the Tamil Nadu Academy of Sciences.

Srinivasa Rao has been very active in setting up the *Society for Special Functions and their Applications* (SSFA) in India. In 1995, Prof. R.P. Agarwal expressed the view that the time was ripe for such a special functions group for promoting basic research in the field of special functions and their applications in mathematics, science and industry and to encourage and support the dissemination and exchange of information, ideas and techniques between researchers in the field and other mathematicians and scientists. Srinivasa Rao is at present the editor of the newsletter and the librarian of the society. Two numbers of the newsletter have been brought out by now, in close collaboration with the newsletter of the SIAM activity group on orthogonal polynomials and special functions.

Srinivasa Rao is an enthusiastic research worker who presents his work, be it on QTAM or the Life and Work of Ramanujan, with passion and infectious enthusiasm. Attending his lectures is like going to a well-organized performance. His pride for India is shown in all his powerpoint presentations, where he uses as background the colours of the Indian flag. He is a lively conversationalist, loves good classical Carnatic and Western music and is a movie buff. He is a promotor of the vegetarian Indian cuisine and the cultural heritage of his country. The participants of every conference he organizes can expect, apart from a strong scientific program, also a cultural evening or weekend program: events such as a traditional dance performance, a concert of Carnatic music or modern Indian pop music, a trip to a typical Tamil movie and visits to ancient Hindu temples are part of these activities.

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