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Laudatio for E. C. G. SUDARSHAN

On his 75th BirthDay. Jaca, (HU), Spain, September 18, 2006

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Abstract.

The scientific career of E. C. G. Sudarshan is reported, with some biographical notes to frame the results. His research and teaching achievements span more than fifty years, and he has been Professor of Physics at the University of Texas at Austin since 1969, where he is still quite active and taking up students.

Symmetry, in its multiple aspects, is perhaps the feature more persistent in his whole work; also the complex relations between classical and quantum realities permeates most of his mature-period papers.

1. Outlook

Professor Sudarshan is one the greatest scientists India has ever produced. He joins Ramanujan, Raman, Bose or Chandrasekhar as outstanding Indian scientists of our century.

Sudarshan reached the edge of winning the Nobel Prize for physics, as he was nominated no less than six times. Last time was in 2005, and he was merely cited in the Nobel Prize for his work on coherent states and Quantum Optics and the reconstruction of the diagonal coherent state formula for any quantum state, though the prize was awarded to Roy Glauber.

His work combines western logic and precision with eastern imagination; greek-type philosophy with ancient indian way of thought.

His major contributions to physics are the discovery of the V-A form of weak interactions, the use of coherent state representation in optics, and the study of dynamical maps of density matrices through the concept of positive maps. Symmetry, in its multiple aspects, has been a constant in his research work.

Sudarshan is author of several books, the first of which with Robert Marshak on *Elementary Particles*, and among the others two standard TextBooks: *Classical Dynamics* with N. Mukunda and *Fundamentals of Quantum Optics*, with J. Klauder.

As Professor, George has been an outstanding one. As research advisor, he usually takes up four or five students simultaneously, and has been doing that for the last 40 years ...

2. Family, and First Education

Ennackal Chandy George SUDARSHAN was born in Pallam, Pakkil, Kottayam District, State of Kerala, India, on 16 September, 1931. His mother, Achamma, was a School Teacher; his

father, E. I. Chandy, was a Revenue Supervisor for the Kerala Goverment Service. He has two brothers, Joseph and Thomas Alexander.

Today his wife is the Physicist Gopalakrishnan Bhamathi. Formerly she was Professor and Head of Physics Department in the University of Madras. George has three sons

- Pradip Alexander, MD 1959, Eye Surgeon,
- Arvind Jewett, JD 1962-2004, Lawyer
- Ashok John, MBA 1966, Business Executive

George attended the C.M.S. College at Kottayam, 1946-48, and graduated B. Sc. (Honors) at Madras (= Chennai) Christian College, 1948-51 in Tamil Nadu. He got a Master of Arts degree from Madras University in 1952.

He is United States Citizen since 1991

3. Professional Career

Sudarshan started his research career in 1951 at the Tata Institute for Fundamental Research (TIFR) at Bombay (=Mumbai), whose Director was the famous Professor Homi J. Bhabha; there was a strong group in Mathematics in TIFR, and George became acquainted with modern algebra, theory of spinors, topology and functional analysis, and this was later very useful for his own career. At TIFR Sudarshan collaborated with Professor B. Peters in cosmic rays research, only to discover very soon he could be a better theoretician inspired by experimental research rather than being an experimentalist himself.

Many illustrious visitors came to TIFR during that time, among them Harish-Chandra, Dirac, Pauli, Tomonaga and in particular Robert E. Marshak, on his way to the important Kyoto conference on High Energy Physics (1953; the first in Japan after the war); Marshak was already a renowed physicst, disciple of Hans A. Bethe, and co-author with him of the important work on "the two-meson hypothesis". He invited George to join him at Rochester; the plan did not materialize at once, for reasons of bureaucratic hurdles, human frailty included.

In September 1955 George Sudarshan started graduate studies at Rochester University under Marshak. The big new discovery at the time was the antiproton, just found in Berkeley. Marshak asked George to compute multiple meson production in antiproton annihilation. Later work with Marshak and S. Okubo (1956) turned out to be the first calculation on group theoretical grounds on semistrong interactions, the precursor of the later Gell-Mann & Okubo mass formula.

In 1956, parity violation was suspected not to be an exact symmetry of nature; it was first publicly suggested by T.D. Lee and C.N. Yang, and was soon confirmed experimentally by C.S. Wu; that was a big revolution in particle physics. At the time of Sudarshan´s qualifier exam the dominant terms in weak interactions were believed to be scalar (S) and Tensor (T). Marshak assigned this problem to George as Ph. D. Thesis topic, while he himself was more engaged in the internucleon potential (the later Marshak-Signell potential). It was not only in beta decay processes, (i.e. weak interaction in nuclei), but also muon decay and absorption, charged pion decay, etc., what was to be called Universal Fermi Interaction. Of course, ST dominance was at variance with pion decay, which could go only by axial (A) or pseudoscalar P (negligible at the low energy regime). By a detailed analysis of the available data George was soon convinced that experimental data on weak interactions were inconsistent with each other; the blame was put mainly on the ^6He decay (soon to be rectified). At the time of the Rochester Conference in 1957, Marshak and Sudarshan were certain the interaction had to be V-A, as we know today it is correct, but George did not get even five minutes to present this. Later that summer Marshak was consultant for the Rand Corporation in Los Angeles, California. At Marshak´s behest George presented the details of his analysis and his conclusion of the V-A choice for the weak interaction (UFI) to Murray Gell-Mann, at a luncheon meeting in June, 1957. This was the source of the later famous paper (by Gell-Mann and Feynman (1958)); in full fairness, George

is happy to recognize that the idea of Conserved Vector Current, CVC, which was to play an important role in subsequent developments by Gell-Mann in Current Algebras in the 60s, was developed in this G-M & F paper. For the record, however, it is also important to remark that the comments of Gell-Mann on the Marshak-Sudarshan-Gell-Mann conversations in California in the summer, 1957, were unaccurately reported in the latter contribution to the Sant-Feliu (Catalunya, Spain) 1983 Conference on the History of Scientific Ideas.

There is no historical doubt to-day that George Sudarshan was the first person to understand and write (but not immediately publish) the correct expression for the universal form of weak interaction as the V-A theory, which includes uniqueness, chirality, action of left-spinors only, maximal parity violation, and the necessity of re-doing at least four beta decay and particle decay experiments, including the infamous ^6He experiment. Even the Proceedings of the Padova-Venezia conference (fall 1957), with a full account of the theory by Marshak and George, were delayed more than a year ... Not much later, back at Rochester, Sudarshan submitted his Ph. D. Thesis.

In 1957 George proceeded to join Harvard University as Julian Schwinger´s Research Fellow. With hindsight, one can tell of some inspiration by Schwinger on George´s later work, including the Action Principle (enunciated first by Weiss in 1938 at the classical level), which, starting from a lagrangian, gives you both the equations of motion and the symmetries of the system (e.g., Noether´s Theorem). Schwinger was a lonely bird, but George managed to come to very good terms with Shelly Glashow, who became a lifelong friend. During the two years at Harvard, George used to visit Rochester regularly (the two cities are close) to collaborate with S. Okubo and Marshak. Later, Steve Weinberg joined them too, mainly in works on weak interaction topics like nonleptonic weak processes, the $\Delta I = 1/2$ rule, etc. Steve and George became later (since 1981) colleagues at Austin.

In 1959 George Sudarshan was appointed Assistant Professor of Physics at University of Rochester, to become there full Professor in 1961. After a year of absence as invited Professor at the Institute for Exact Sciences in Bern, Switzerland, he became a (full) Professor at Syracuse University in 1964. It was in Syracuse that George fell in love with group theory, as the supreme tool to account for symmetries. With N. Mukunda and the late L. O´Raifeartaigh they developed the idea of Spectrum Generating Groups (called at first noninvariance groups). This powerful idea looks for noncompact groups, some of whose irreducible unitary representations, necessarily infinite-dimensional, could account for the full discrete spectrum of systems like the Hydrogen atom or the n-dimensional harmonic oscillator. Today we understand this phenomenon as a case of superintegrable systems. Out of the collaboration with Marshak during the Rochester period came the book by both authors on Elementary Particles, one of the very first and still one of the best in the field.

The work on infinite dimensional representations led George soon to study analytic functions, and in special to develop methods of analytic continuation to describe decay of metastable particles and resonances. As applications, many results were obtained by George and his students on unitary representations of higher order pseudo-orthogonal groups. Work on approximate symmetries of strong interactions continued, as Gell-Mann developed the SU(3) (flavour) model; with Alan Macfarlane, George published papers on electromagnetic mass differences of hyperons, etc. More work with O´Raifeartaigh culminated with the later´s no go theorem, about (no) mixing of internal and Poincaré symmetries. Coleman-Mandula and Weinberg sharpened the theorem a little later. George´s contributions to Quantum Optics, starting in this period, were fundamental, and people refer often to Sudarshan´s diagonal coherent state representation, or P-representation.

In 1969 George Sudarhan moved to The University of Texas at Austin, where he has been ever since, except for temporary leaves of absence (at Brandeis, at Harvard again, at Chennai, etc.). A Center for Particle Theory (CPT) was founded at Austin, with George and Yuval Ne'eman as

Co-Directors, which atracted young physicists like Arno Böhm, Austin Gleeson, Charles Chiu, etc. It was supposed to be the counterpoint to the Relativity Group started also at Austin by A. Schild, with J. A. Wheeler as frequent visitor (from Princeton). The late Yuval Ne'eman was also commuting from Tel-Aviv and CPT for many years. The name CPT was changed later to Center for Particle Physics, with the inclusion of High Energy experimentalists.

George commuted between Austin and Chennai, where he was Director of the Institute of Mathematical Sciencies. He was a frequent contributor to Indian journals, philosophical as well as scientific.

Earlier George wrote with T. Jordan and D.G. Currie several papers on No Interaction theorems which occur in Relativistic Dynamics (work later continued e.g. by Lluis Bel in Paris, around 1970); a paper by George alone had to struggle with the referees because his (ECG) unconventional approach to superselection rules.

Around 1980 George started a long and fruitful collaboration with the italian school centered around Giussepe Marmo in Napoli. Frequent visits to Italy followed, with some excursions also to Sweden (J. Nilsson) and other places.

The number of Ph D students, colleagues and collaborators of George in his nearly 40 years at Austin is countless, and we shall mention some of them. We were happy to meet his actual and recent Ph D students, like M. Byrd, Todd Tilma, Eric Chisolm, Chikako Uchiyama, Anil Shaji and Cesar Rodriguez, etc.. at the celebrations.

But no one present then can forget the talk by Robert Marshak as after-dinner speech on 16 september, 1991, commemorating George´s 60th birthday, reivindicating George´s role. The title of the talk was "*The Pain and Joy of a Major Scientific Discovery*", but the subtittle was even more illuminating, as I recall it: "*Setting the Record Straight for the V-A theory*"; there is no substitute for reading Marshak´s words.

4. Honors and Awards

We quoted already the six mentions for the Nobel Prize. Here we just include, somewhat telegraphically, the main Honors and Awards bestowed on George along his distinguished career.

A Honorary degrees

1969: D. Sc., Honoris Causa, University of Wisconsin
1973: D. Sc., Honoris Causa, Delhi University
1984: D. Sc., (Engineering), Gotheburg University
1987: D. Sc., Honoris Causa, University of Madras
1989: D. Sc., Honoris Causa, Burdwan University
1993: D. Sc., Honoris Causa, Cochin University (India)
2003: D. Sc., Honoris Causa, Kerala University, Trivandrum

B Visiting Professor

1966: Brandeis University
1968: University of Bern, Switzerland
1976: Jubilee professor at Chalmers University Gothenborg, Sweeden
1978: Viswa Bharati, India
1992: Visitor, Zaragoza University, Spain

C Awards

1965: American Physical Society Fellow
1968: Fellow of the Indian Academy of Sciencies
1970: C.V. Raman distinguished Professor University of Madras, India
1974: Padma Bhusan (order of the Lotus) awarded by the President of India
1976: Honors Award, Association of Indians in America

1977: S. N. Bose Medal
1980: Kerala State Government Award
1986: The First Prize in Physics, Third World Academy Award in Physics
1988: Fellow of the Indian National Science Academy
Distinguished Scientist. Andhra Pradesh Academy of Science. Hyderabad
1989: Elected member of the Society for the Philosophy of Science
Distinguished Visitor, Central University of Hyderabad
1998: Desikottama (Distinguished Scholar) Award Visva-Bharati University
1999: Honorary Fellow, Central Insititute of English and Foreign Languages, Langnayas, Hyderabad.
2001: President, World Malayalee Council,
Honorary Fellow, Indian Institute for Advanced Studies, Shinja
2002: Fellow, European Academy of Arts Science and Letters.
2003: Distinguished Visitor, Barcelona Conference on Philosphy of Science
2006: Presidential Citation, University of Texas at Austin.
2007: Padma Vibhusan, awarded by the Indian Government.

5. Main research topics

It is nearly impossible to describe all the research line in which Sudarshan has been engaged, although one can pursue a certain systematics: description of the Physical world through mathematical models, symmetry and groups, quantization vs. classical description, coherent states of light, quantum description via density matrices: positive maps, quantum coherence, spin and statistics, quantum entanglement, stochastic processes in quantum systems, decoherence, etc.

Peculiarities of Relativity and Quantum Theory: tachyons (or superluminal particles), the work on the quantum Zeno effect with B. Misra ("the tea pot never boils if you look at it closely enough ..."). Also exotic states of the 2- dim harmonic oscillator, simple proof of the spin and statistics relation, etc.

In Quantum Field Theory, there is a remakable work on the inconsistency of spin 3/2 lagrangians, and some important results in solvable models.

His work on Statistical Mechanics including irreversibility was most influenced by his contacts with the later Ilya Prigogine at Austin during several years.

Recent work of George in Austin and Italy is related to Density Matrices and Positive Maps, Quantum Information and Quantum Computing, Theorem on Spin and Statistics in arbitrary dimensions.

George´s research output reaches 300+ papers, besides Conference contributions and several unpublished gems.

6. Selected bibliography

Of the manifold George´s papers, we select just three:

(i) Semiclassical and Quantum-Mechanical equivalence description of Light Beams. Physical Review Letters 1963 : 503 quotations
(ii) Zeno Paradox, with B. Misra. Journal of Mathematical Physics 1977: 455 quotations
(iii) Stochastic Dynamics of Quantum Systems. Phys. Rev. 1961: more than 300 quotations.

Books:

1 Introduction to Elementary Particle Physics; with R. Marshak. Wiley Interscience, 1962
2 Introduction to Quantum Optics; with John Klauder. W. A. Benjamin 1968

3 Classical Dynamics; with N. Mukunda. J. Wiley 1974

4 A Gift of Prophecy (Robert E. Marshak FestSchrift); Editor. World Scientific, 1994

5 100 years of Planck's Quantum; with Ian M. Duck. World Scientific 1996

6 W. Pauli and the Spin-Statisics Theorem; with Ian M. Duck. World Scientific 1997

7 Doubt and Certainty; conversations with Tony Rothman. Perseus Books, 2000. Reissued by Scientia Press, 2004.
Translated into spanish, Zaragoza Univ., 2003

8 From Classical to Quantum Mechanics; with G. Esposito and G. Marmo. Cambridge UP 2004

The books with N. Mukunda and with John Klauder have more than 400 quotations each ...

His Complete Works are being prepared at Austin.

In the mean time, the following book has been published, containing 57 research papers of Sudarshan covering from 1956 to 2000:

> ECG Sudarshan, Selected Scientific Papers, Ranjit NAIR Editor, Principia Publishing, New Delhi 2006