E C G Sudarshan: quantum catalyst

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Abstract. A survey of Sudarshan’s works is presented to show that his brilliant role in advancing science on many fronts has been like a catalytic agent which, by definition, plays a singular role in increasing the rate of a process, but remains hidden, and is unchanged at the process end. As might be necessary to remain catalytically active for a lifetime, his broad and seminal contributions to science have often gone unappreciated, and rarely given due honor – unfortunately at a great cost to scientific progress.

Help rendered another cannot be measured by the extent of assistance imparted. Its real measure is the recipient's worthiness. (Kural 105, Thirukkural, Thiruvalluvar, First Century BCE)

The idea for the “Sudarshan: Seven Science Quests Symposium” was born in 2005 shortly following the announcement, on October 4 by the Royal Swedish Academy of Sciences, that a part of the 2005 Nobel Prize in Physics was awarded to Professor Roy J. Glauber of Harvard University “for his contribution to the quantum theory of optical coherence”. Many of George Sudarshan’s colleagues around the world, well aware that he was the first to formulate this theory, were stunned by the failure of the Academy to neither recognize his seminal and singular role in the development of this theory, nor to include him in the award. They were also quite familiar with an earlier injustice in which George and Bob Marshak’s formulation [1,2] of the V-A theory for the weak nuclear interactions was erroneously assigned to Richard Feynman and Murray Gell-Mann [3]. I will return to these incorrect attributions later.
The Symposium organizers puzzled over the question of why none of the singular contributions of one of the greatest scientists the world has ever known, has been recognized, or honored with a major international award. Could it be, they asked, because his many seminal papers are on a variety of subjects, and he may appear to be the great originator, rather than the best follower or expositor, of new ideas? George initiates new ideas with one or at most a few papers (although he has published more than 400) in which he manages to give by far its most elegant formulation and also the complete, basic, and generally the most succinct solution of the key problem. In other words, he finds the core kernel of the problem and brings it out for everyone to see. After that, to others, he may seem to be generally disinterested in exploring all the manifold effects of his own key discovery. He moves to another new problem. His colleagues understand, however, that all of his work has a common theme; how can irreversible processes and transformations (including decay, measurement, etc) be understood in terms of strictly reversible dynamical quantum systems.

George has dedicated his scientific life to the pursuit of this “Holy Grail” problem but, along the way, found his progress blocked by a number of important, unresolved enigmas of physics; the most significant of these have been identified in the diagram on the first page as his Seven Quests.

He addressed these problems, not for their closure, but because of their relationship to his main concern. If George had continued to make contributions to further advances in these areas they would, combined with his seminal resolution of the principal enigmas, have earned him prestigious honors for each.

The composite picture of George is therefore one of a scientist: (1) whose work initiates a field of inquiry and accelerates the rate at which it develops, (2) whose vital contributions seem to resist acknowledgement, and (3) whose primary goal is unchanged by the profound consequences of the results of his individual quests. By analogy, this is a fair description of a catalytic agent that, by definition, plays a singular role in increasing the rate of a process, but remains hidden, and is unchanged at the process end. In every field of human endeavor, the catalytic “agent” is a genius, best defined as someone who sees what everyone else sees - but thinks what nobody else thinks. Metaphorically speaking, it could be said that a genius is the agent catalyzing an enormous acceleration in the transition of humankind from a state of ignorance to one of enlightenment.

**1) Initiation and Acceleration of Field of Inquiry:** To exemplify, note the exponential rise in the number of papers published annually by the AIP on the quantum Zeno effect (QZE), that cite Misra and Sudarshan’s seminal 1977 paper [4].

This transition followed George Sudarshan’s catalytic role in initiating an understanding of the non-decay of quantum states (quantum non-collapse). Also note the other tell tale of a seminal contribution; a continued increase in citations over a long period (30 years in this case) indicating that this work continues to set the agenda for progress. In his Symposium paper [5], Wayne Itano observes that “interest in the QZE continues to be high, partially due to the possibility of practical applications in quantum information processing”.

Rajiah Simon has also addressed this theme in his masterful review [6] of George’s role in formulating the theory of Quantum Optical Coherence:

“Commenting on the information theory which came into being, in one stroke, through the remarkable 1948 work of Shannon, A.I. Kinchin writes .....”rarely does it happen in mathematics
that a new discipline achieves the character of a mature and developed scientific theory in the first investigation devoted to it.” Shannon’s work set the agenda for the classical information theory community. The agenda has not changed in spite of the enormous progress. …… A similar description seems to fit perfectly Sudarshan’s seminal work of 1963 which founded the field of Quantum Theory of Optical Coherence.”

The discontinuity in papers on Quantum Optical Coherence that followed the publication of Sudarshan’s seminal 1963 paper \cite{7} is seen in this table. The acceleration in the rate of research contributions that followed these breakthrough publications can be understood in analogy with the transition state theory of catalysis. As shown in the following diagrams, prior to the breakthrough, only a very small fraction of the population would be able to overcome the conceptual barrier.

\begin{table}
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{PERIOD} & \textbf{\# Papers Citing QUANTUM OPTICAL COHERENCE} \\
\hline
1898 - 1962 & 0 \\
1963** & 93 \\
1964 - 2006 (After GS paper**) & 30,800 (average = 715/year) \\
\hline
\end{tabular}
\caption{Number of papers citing Quantum Optical Coherence.}
\end{table}

The role of the genius (catalytic agent) is to lower this barrier and make it possible for many more to contribute to further progress as depicted in the modified diagrams.

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{conceptual_barrier}
\caption{Conceptual Barrier}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{normal_curve}
\caption{Normal Curve}
\end{figure}

**(2) Vital contributions are hidden and unacknowledged.** It is readily established that George has catalyzed profound changes in the understanding of a number of scientific issues. But has his vital role in producing these changes remained hidden? Let me examine two spectacular, hard-to-believe examples (formulation of the theories of Quantum Optical Coherence and Weak Nuclear Interactions). In both cases, George’s seminal role has been mis-attributed.

George’s 1963 paper \cite{7} was the first formulation of Quantum Optical Coherence, and is believed to still set the agenda for this field, now largely concentrated on practical quantum information systems. Some might argue that this transition was generated by R. J. Glauber’s earlier publication \cite{8} that is very frequently cited as the first theory of Quantum Optical Coherence. This is clearly erroneous, since this paper did not address quantum optical coherence, and his later 1963 paper \cite{9} actually cites Sudarshan’s 1963 paper \cite{7}.
On November 3, 2005, several of the Symposium organizers sent a letter to the Nobel Committee on Physics of the Royal Swedish Academy, appealing “the incorrect attribution of the discovery of the “quantum-mechanical theory of optical coherence” in the citation for the 2005 Nobel Prize in Physics”. The following is an excerpt from it:

In a communication dated 4 October 2005 posted on its website entitled “Advanced information on Nobel Prize in Physics 2005”, the Royal Swedish Academy of Sciences announced the award of half the Nobel prize to Prof. Roy J. Glauber for the discovery of the “quantum-mechanical theory of optical coherence”. We, the undersigned, point out that:

1. The actual first formulation of the “quantum-mechanical theory of optical coherence” was given solely by Prof. E.C.G. Sudarshan in his 1963 paper [7].
2. Sudarshan’s paper formulates the quantum theory in a manner that allowed its comparison with classical coherence theory. This facilitates the differentiation of specifically quantum effects from classical effects.
3. Quantum effects are manifested only through the non-positivity of the weight function \( f(z) \) in the Sudarshan diagonal coherent state representation.
4. All of the subsequently discovered inherently quantum effects, such as anti-bunching and anti-correlation of intensities, can only be understood with Sudarshan’s representation.
5. In contrast, in Glauber’s original paper [8] the “probability” \( p(a_i) \) in eq.4 did not contain any non-positivity. Therefore, it is not the same as Sudarshan’s weight function \( f(z) \), and cannot represent any strictly quantum phenomena that require non-positivity.
6. Hence, Glauber did not formulate the “quantum-mechanical theory of optical coherence”. In fact, in a subsequent paper, Glauber cites Sudarshan’s earlier work, criticizes it as being in error (in Sec X), but also adopts it as his own – calling it the “P-representation” (in Sec VII).
7. Accordingly, Sudarshan is the sole discoverer of the “quantum-mechanical theory of optical coherence.” The only original, true quantum representation is the Sudarshan representation - not the “P-representation” or “Glauber-Sudarshan representation” or the “Glauber representation”.

Professor Jeff Kimble, who was the first to experimentally verify Sudarshan’s theory of quantum optical coherence [10], provides further support in his historical account [11] in the session on Quantum Optical Coherence.
“Two very important papers (were) published in 1963 by George and by Glauber, .... one had a language and formulas to understand things which had only been discussed in more qualitative terms before....one had the full quantum description ... and in the lab one had the tools to describe what earlier could be described with classical theories of optical coherence - and that’s the Optical Equivalence Theorem which George introduced in his paper.”

In his Symposium paper [11], Professor Kimble uses the above figure to further make it clear that Glauber’s 1963 paper describes classical optical states, whereas Sudarshan’s 1963 paper describes manifestly quantum optical states.

In their deliberations, the Symposium organizers were not concerned with Prof. Glauber’s selection for this award, for his contributions to the theory of quantum optical coherence are substantial, meritorious, and worthy. Instead, they focused on trying to understand why a singular contribution of one of the greatest scientists the world has ever known, was being attributed to another scientist.

To Sudarshan, this had to be a cruel repeat of a previous injustice surrounding the attribution of the theory of the Weak Nuclear Interactions. The V-A theory of the weak interactions was first formulated by George and his Ph.D. professor, Bob Marshak, but erroneously attributed to Richard Feynman and Murray Gell-Mann. This egregious error has been acknowledged by both Richard Feynmann [12]:

The Sudarshan-Marshak paper on the theory and prediction of the (V-A) universal Fermi interaction (UFI), although submitted at the same time as Feynman and Gell-Mann submitted theirs to Physical Review, was published with considerable delay in the Proceedings of the Padua-Venice International Conference (1958) ....... their principal work was overshadowed by the publication of the Feynman – Gell-Mann paper..... and no mention of the work of Sudarshan and Marshak had been made at the April 1957 Rochester Conference, by which time – several months before the Feynman – Gell-Mann paper was ready – Sudarshan and Marshak had arrived at their principal conclusions. Richard Feynman, when he became aware of this complex situation tried to make amends to Sudarshan and Marshak by making the following remarks at the conclusion of a conference on weak interactions: ‘So I would like to say that we have a conventional theory of weak interactions invented by Marshak and Sudarshan, published by Feynmann and Gell-Mann…….’

and by Murray Gell-Mann [13]:

“...But for years everyone cited Gell-Mann and Feynman … and ignored Sudarshan and Marshak. As late as 1955, Marshak had to publicly remind Feynman at an American Physical Society conference that V-A was not the Feynman - Gell-Mann theory. And he was hurt that it was not until 1970 that Murray approached him to apologize for the widespread misunderstanding.”

Their exposition of the Weak Nuclear Force, should have propelled the names of Sudarshan and Marshak alongside those of Newton and Maxwell as suggested in this. This chart not only dramatizes the spectacular recognition they were denied, but shows that this Symposium was important because all of the living members (names underlined) who first contributed to our understanding of the fundamental forces participated in it, were afforded an opportunity to clarify this story and set the record straight, and that they did.

In his Symposium talk [14], Steven Weinberg observed:

At that time I did not understand how important that breakthrough (the Sudarshan-Marshak V-A theory) would prove to be. It opened up the door to a line of theoretical work, which in less
than a decade led to a thorough understanding of things that had earlier, when I was a graduate student, seemed like a mélange of miscellaneous facts that had no coherence and certainly no beautiful theoretical interpretations.

Professor Weinberg makes the case that Sudarshan and Marshak were the first to formulate the V-A theory when in his paper he writes:

“perhaps because Feynman and Gell-Mann were already justly famous for other work, and George, after all, was just beginning his career, people tended to refer to this as the Feynman and Gell-Mann Theory. They don’t now. I think that with the passage of time, the history has gotten sorted out and it’s now generally realized that the earliest statement of the V – A theory was due to Marshak and Sudarshan”. He further states; “weak interactions are produced by both vector and axial vector currents, as with great courage and physical insight and élan, Marshak and Sudarshan were the first to propose in 1957.”

The only other living member of this exclusive club is Sheldon Glashow who shared the 1979 Nobel Prize in Physics with Steven Weinberg and Abdus Salam for their theory unifying the weak and electromagnetic forces. Professor Glashow was scheduled to participate in the symposium, but a medical issue preventing him from attending. In the message he sent to the Symposium [15] he categorically stated for the record that:

“The Sudarshan-Marshak paper (SM) [2] was submitted practically at the same time as the Feynman--Gell-Mann (FG) [3], ‘Theory of the Fermi Interaction.’ The two papers cover much of the same ground. They offer somewhat different arguments leading to the same V-A theory, and both identify the same conflicting experiments. However, several reasons underlie my belief that Sudarshan and Marshak deserve priority in this matter.

(1) The FG paper includes the footnote: ‘A universal VA interaction has also proposed by Sudarshan and Marshak (to be published).’ This surely suggests that FG had access to the SM work. In contrast, the SM paper, submitted on the very same day, includes merely the polite acknowledgment, ‘We are grateful to Prof. Gell-Mann….for valuable discussions.’ These facts are consonant with Sudarshan’s later claim ‘that Gell-Mann was informed of our work on the V-A theory [by] the first week of July, 1957, at which time our paper (SM) was completed.’

(2) Richard Feynman, himself a protagonist in the priority issue, made the following public and unpublished remark much later, in 1974: ‘We have a conventional theory of weak interactions (the V-A theory) invented by Marshak and Sudarshan (sic), published by Feynman and Gell-Mann and completed by Cabibbo.’ So much, I would say, for the issue of priority.”

Professor Glashow’s final statement sends chills up my spine each and every time I re-read it:

“Their (Marshak’s and Sudarshan’s) daring hypothesis was accompanied by a list of four experimental results….all of these experiments should be redone…if any stand….it will be necessary to abandon our hypothesis.” This is theoretical physics at its zenith! The experiments were redone and the results confirmed their hypothesis. It was a stunning accomplishment, yet one never recognized with a prize.”

Dr. Prashant Valanju, a Symposium organizer, and the first to demonstrate the QZE from an analysis of the experimental data on hadron-nucleus collisions [16], believes that George’s work is not given the attention it deserves because “the breadth of his work, and the way he mostly starts new tracks, is probably why only a very few cognoscenti - those whose souls are really troubled at that moment by the specific problem he solves with such clarity, grace, and perfection - can possibly recognize the greatness of his work. Each of us sees only a small part of this giant elephant. The rest do not see him sweating long in the field, so often do not even know that he has worked in the area. His seminal papers are quoted but often unread. In modern times, when much “work” in science is done by huge groups, and valued more by the quantity and glitz of the wrapper than the quality of its core content, someone like George is sure to go unrecognized.”

(3) Goals are unchanged by the profound consequences of his accomplishments.

The unifying theme of George Sudarshan’s work is that of resolving the fundamental dilemma of how irreversible processes and transformations (including decay, measurement, etc) could be
understood as strictly reversible dynamical quantum systems. In each of his 7 Science Quests, George Sudarshan has brilliantly used his deep understanding of quantum mechanics to catalyze the resolution of physics enigmas related to this goal. Like any catalyst, his role has been masked, which has allowed him to emerge unchanged by each of his quests, to focus his catalytic potency on other important enigmas of physics.

George writes [17]:

"In most of my work I have to recognize that discoveries do not confer credit on their discoverers; and that great and not-so-great scientists can be small men. But most of all I have learned to value those gifts of insight, irrespective of what is the official position. Not with pride but with awe since the insight came to me, they were not my doing; that I was a channel for the vision. This is part of my tradition, to be a seer, to be a rishi."

The “rishi” is a "seer" or one to whom wisdom is revealed through states of higher consciousness. Awareness begins in an unbounded state with pure consciousness and then cascades until it reaches the physical world. It has been long suspected that two of the greatest mysteries of modern science, quantum mechanics, and consciousness are somehow related. The very statement of this mystery suggests that one must necessarily be a rishi to be an observer of it.

I believe that the sum of all of George’s Quests are leading him to address this enigma and that he is destined to play a seminal role in resolving the physics of consciousness. But mentioning “consciousness” is controversial and only scientists who have received the highest peer recognition could safely venture into this arena. If he were younger, to do so would surely jeopardize his effectiveness; but he is now very experienced and battle tested, so the risk is likely small. I hope that science will bestow on George the necessary recognition that encourages him to apply his brilliance to this problem because, if he does not, it may be a very long time before someone with his capacity to attack such issues comes along.

As mentioned, this Symposium - Sudarshan: Seven Science Quests was designed to focus attention on his numerous singular contributions, so George would be recognized as a genius creator, distinct from other prolific and important builders. Some of his colleagues have suggested that George had more than 7 significant Quests. Stanley Deser, for example, asked if George’s work in Quantum Field Theory (particularly the work George did with him and Walter Gilbert (Nobel Prize in Medicine) [18]) might be included as an 8th Quest. Others mentioned George’s Quest into Axiomatic Field Theory (e.g. see Johnson & Sudarshan’s important paper on " Inconsistencies of Quantizing the Spin 3/2 Field” [19]) and another of his Quests into Indefinite Metric Quantization [20,21]. Faced with the daunting chore to select a limited number of his Quests for the Symposium, logistical constraints forced the Organizers to choose 7 of George’s most prodigious scientific contributions.

All of the participants in the Symposium are distinguished scientists who have collaborated with George and contributed to his 7 Science Quests. I will leave it to them to tell the rest of the story, and for the reader to decide on George Sudarshan’s rightful place in the history of science.

It has been more than 50 years since Sudarshan and Marshak formulated the first theory of the weak interaction. It is evident from the remarks of both Professors Weinberg and Glashow, that it is important to note and respect such seminal efforts, since they lead the way for all further progress. The failure to sort out and honor Sudarshan’s and Marshak’s achievement has undoubtedly impacted progress in understanding the forces of nature and will continue to do so until it is corrected. The same might be said about George’s paradigm-shifting theory of quantum optical coherence, and any of his other 7 Science Quests.

George has paid dearly for this neglect, but what has been the cost to science? Alas, as might be necessary to remain catalytically active for a lifetime, his brilliant works have frequently gone undetected or unnoticed, and rarely given the honor they deserve. In this symposium Sudarshan: Seven Science Quests, the participants reviewed and examined 7 of George's principal seminal contributions to science, with the goals of illuminating them, and understanding their common
thread, without jeopardizing the continuation of his quest. They have succeeded admirably and, in honoring George Sudarshan, brought great distinction to themselves.

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